Lect. 10
Introduction of wind energy and its application

Introduction to Wind

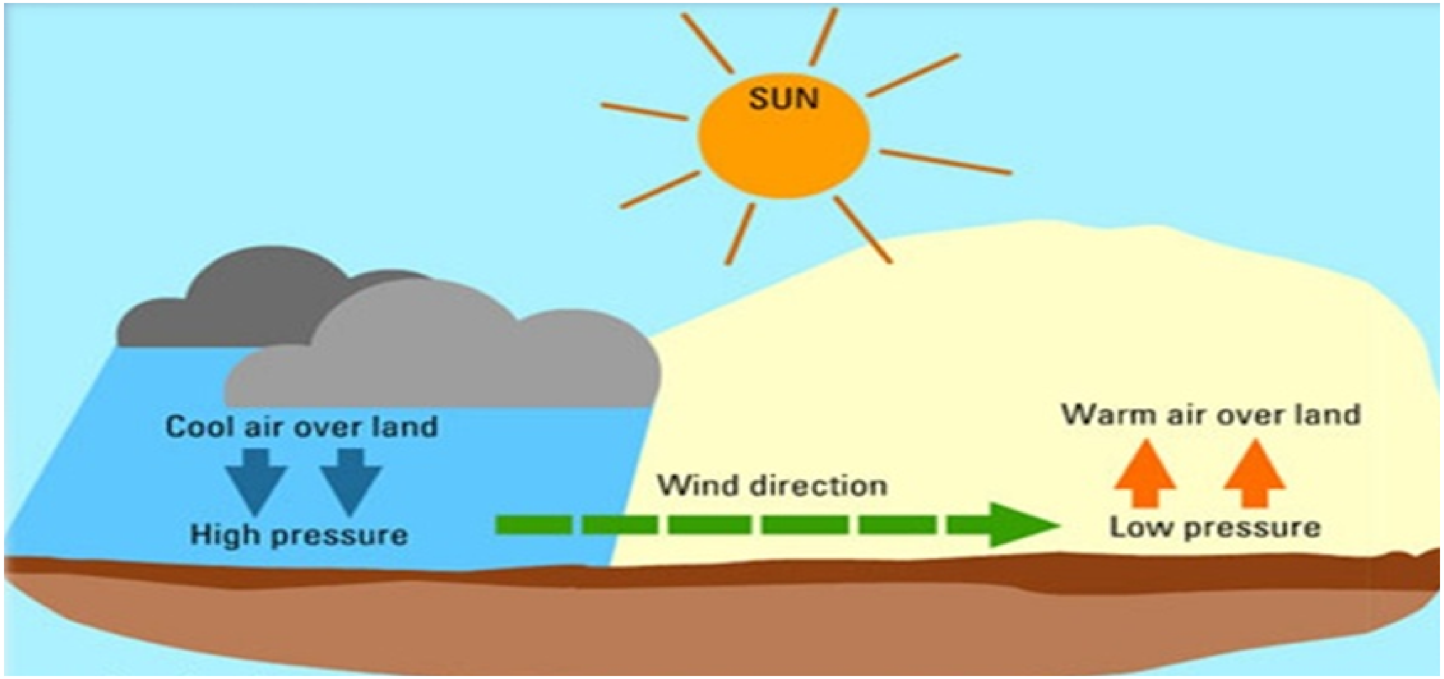
- Wind – Atmospheric air in motion.

- It has become an energy source.

- Sun produces 4×10^{26} joules of electromagnetic radiation every second that is radiated into space.

- About 2% of the sunlight that falls on the earth is transformed to wind energy.

- Air in motion is called wind. i.e. A moving mass of air.
- The winds on earth surface are caused primarily by the unequal heating of the land and water by the sun.
- The differences in temperature gradients induce the circulation of air from one place to another place. The hot air being lighter, rises upwards. The cooler air starts flowing towards the space vacated by the rising air.
- Energy derived from wind velocity is wind energy.



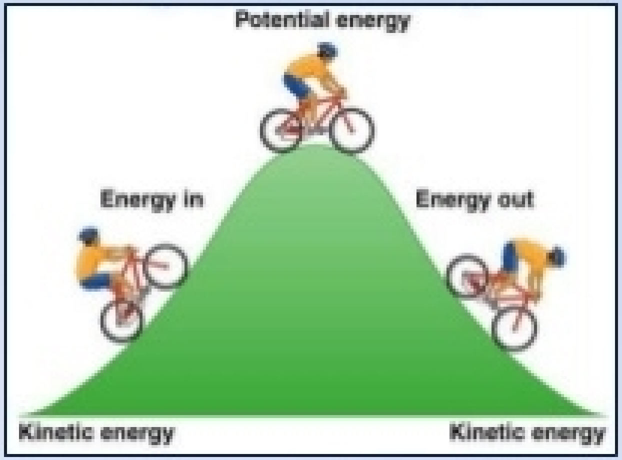
This behaviour of warm gases or liquids moving upward and being replaced by cooler particles is called Convection. The energy moving during convection is called convectional current.

The wind energy is kinetic energy from the wind.

Wind speed generally increases with height above ground. This is because the roughness of ground features such as vegetation and houses cause the wind to be slowed.

Wind energy

- Wind Energy is kinetic energy from the wind that can be directly converted to electrical or mechanical energy by reacting to the atmospheres pressure slope.
- The windmill was invented in 200 BC in China and was used to pump water and grind grain
- In modern days, wind energy has doubled through the years



$$E_k = \frac{1}{2} m v^2$$

Causes of wind blow (driving forces)

- Absorption of solar energy by the surface of earth.
- Absorption of solar energy by the atmosphere.
- Motion of the earth about its axis.
- Motion of the earth around the sun.

Uses:

- It is used to propel sail boats.
- It is used to drive wind mills for water lifting and flour mills.
- Used for generation of electricity.
- The aeroplanes make use of wind energy.
- Gliders depend totally on the wind energy.

- As on 31 March 2019 the total installed wind power capacity was 36.625 GW, the fourth largest installed wind power capacity in the world.
- Wind power capacity is mainly spread across the South, West, North and East regions.
- Wind power accounts for nearly 10% of India's total installed power generation capacity and is nearly 4% of total electricity generation.

Wind Turbines

- Rotating machines that can be used to generate electricity from the kinetic power of the wind.

- Alike aircraft propeller, turn in moving air, power the electric generator, supply electric current.

- For fan Electricity → Wind
- For turbines Wind → Electricity

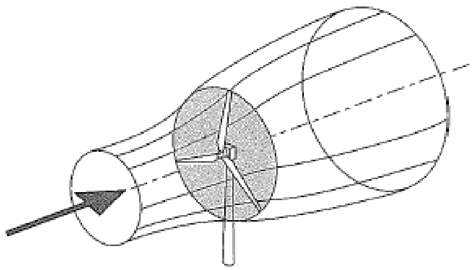
- Wind rotates the turbine blades
    - spins a shaft connected to a generator
    - The spinning of the shaft in the generator makes electricity

- Efficiency depends on number of blades in windmill.

  Efficiency $\uparrow$ as Blades $\uparrow$.

Wind Turbine Principles

Converting one form of energy to another

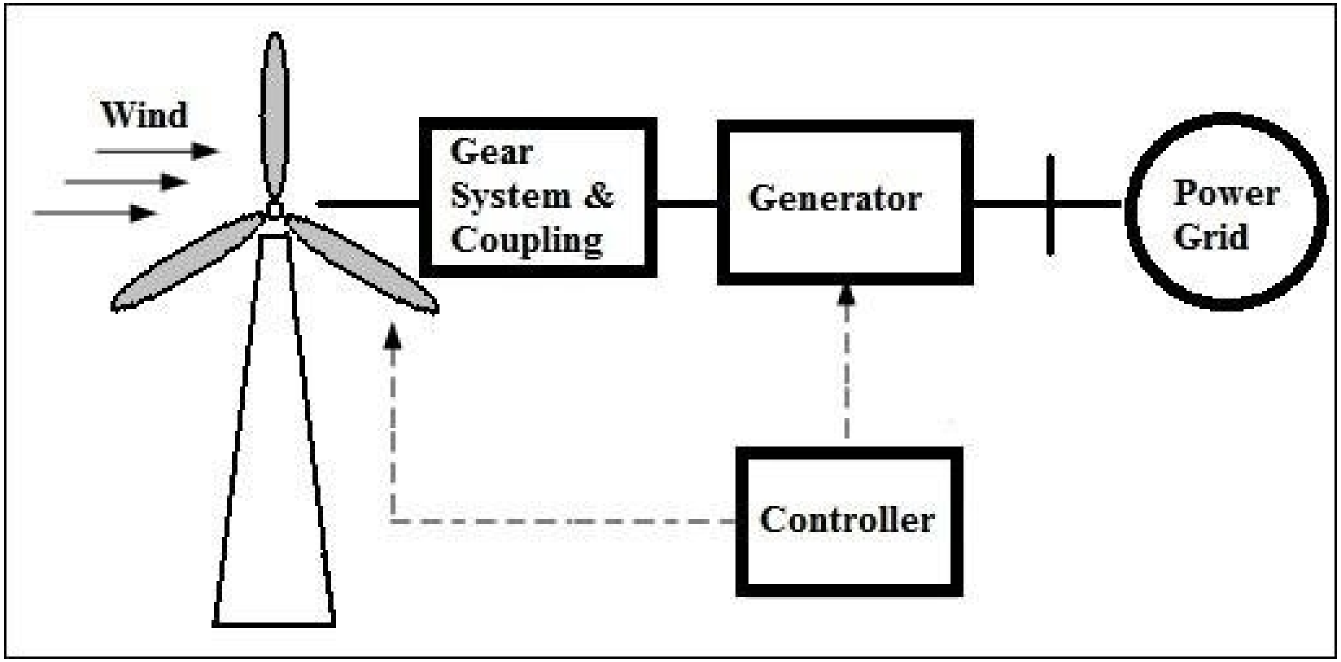


Kinetic Energy → Mechanical Energy → Electrical Energy

Component	Rotor	Gearbox	Generator	Converter
Efficiency	45-52%	95-97%	97-98%	96-99%

Overall: 42 – 50% Efficient Today… Theoretical Maximum is 59.3% (no losses)

Flow Diagram of a Wind Turbine System



Why 3 Blades?

-**4 blades cost more than 3 – provide marginal performance benefit.**

-**2 blades provides loads balancing issue - requires teetered hub/downwind rotor.**

-**3 blades (tripod) provides solution to loads resolution**

Turbines: Sizes & Application

Small Turbines (<1kW)

- Homes(grid-connected)

-Farms

-Remote applications

Intermediate wind turbines(10-500kW)

-Village power

-Hybrid systems

-Distributed power

Large wind turbines (500kW -5MW)

-Central station wind farms

-Distributed power

-Off-shore wind

Power in the Wind

- The power in the wind is:

$$Power = \frac{1}{2} \rho A V^3$$

$$= 1/2 \text{ x air density x swept rotor area x (wind speed)}^3$$

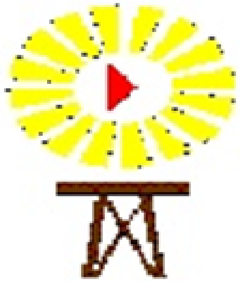
ρ

Density = P/(RxT)

P – pressure (Pa)
R – specific gas constant (287 J/kgK)
T – air temperature (K)

kg/m^3

A



Area = πr^2

m^2

V^3

Instantaneous Speed
(not mean speed)

m/s

- Using the density of air at sea level:

$$Power = 0.6125 AV^3 \quad \text{(metric)}$$

Power in Wind

$P = ½.\rho.A.V^3$

where, P is power in watts (W)

ρ is the air density in kilograms per cubic metre (kg/m^3)

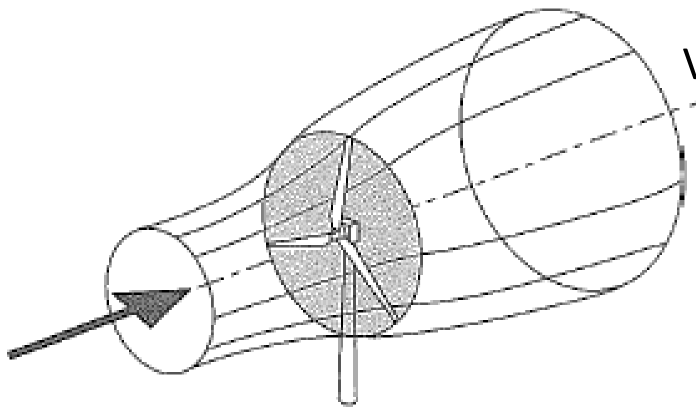
A is the swept rotor area in square metres (m^2)

V is the wind speed in metres per second (m/s)

The power in the wind is proportional to:

- Area of windmill being swept by the wind.
- Cube of the wind speed.
- Air density - which varies with altitude.

Wind Turbine Energy Capture



Ideal (Betz limit)

$$P = \tfrac{1}{2}\rho A V_1^3 C_p$$

where:

(wind velocity slows by 2/3)

C_p = rotor power coefficient

ρ = air density

A = rotor swept area

The actual power will depend on several factors, such as the type of machine and rotor used, the sophistication of blade design, friction losses, and the losses in the pump or other equipment connected to the wind machine.

Theoretically, any windmill can only possibly extract a maximum of 59.3% of the power from the wind (this is known as the Betz limit).

In reality, this figure is usually around 45% (maximum) for a large electricity producing turbine and around 30% to 40% for a wind pump.

So, modifying the formula for ‘Power in the wind’

The power which is produced by the wind machine can be given by:

$P_M = ½.Cp.ρ.A.V^3$ Where Cp is the coefficient of performance of the wind machine (Rotor power coefficient)

A wind machine will only operate at its maximum efficiency for a fraction of the time it is running, due to variations in wind speed. A rough estimate of the output from a wind machine can be obtained using the following equation;

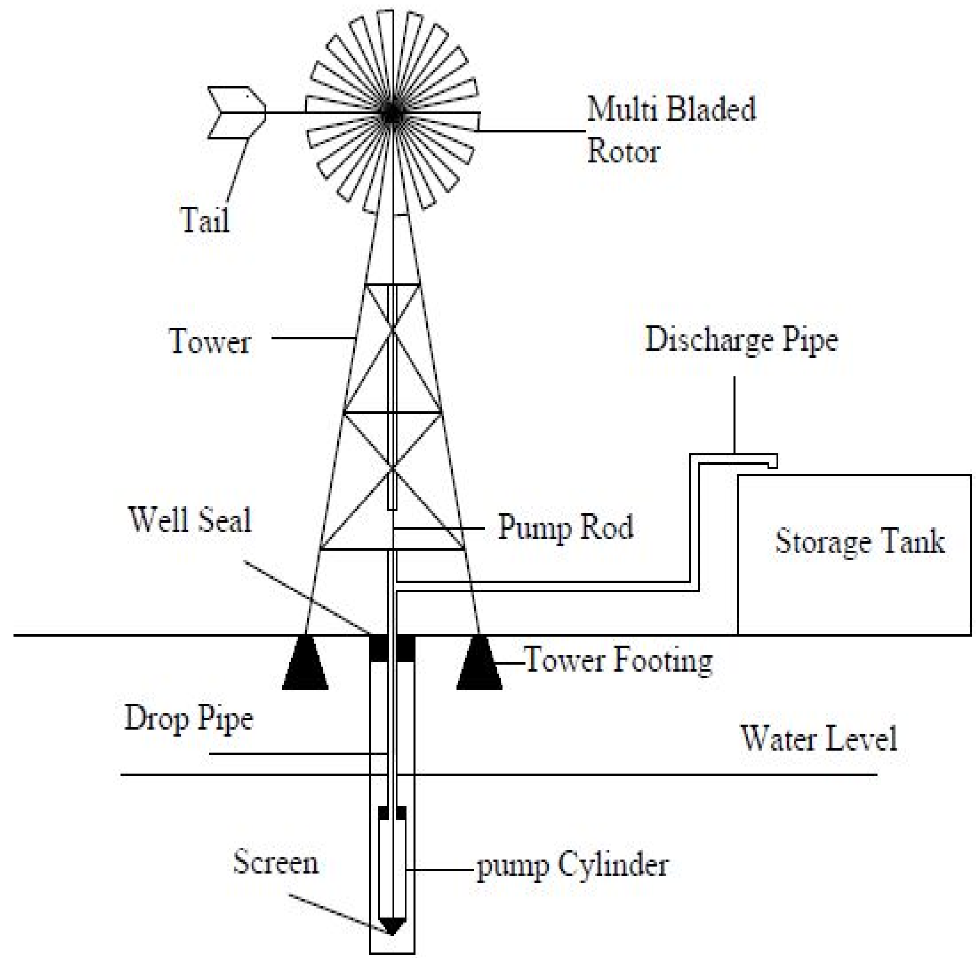
$P_A = 0.2\ A\ V^3$

where, P_A is the average power output in watts over the year. V is the mean annual wind speed in m/s.

Wind mill

A wind mill is a machine which works with the energy of blowing wind.

It can be used for water lifting, grain grinding and electricity generation.



How does a windmill work?

- The blades of the windmill are mounted on a rod which has a U shaped bend. The rod is called crank.
- A piston of water pump with piston rod is connected to U shaped onto the crank.
- When wind falls on the blades, they rotate, which causes the crank to rotate, this causes the piston rod to move and piston moves up and down, which lifts water during its upward movement.

Terminology

- Coefficient of performance: The proportion of the power in the wind that the rotor can extract is termed the coefficient of performance (or power coefficient or efficiency; symbol (Cp).

  There is an upper limit of Cp = 59.3%, although in practice real wind rotors have maximum C values in the range of 25%-45%.
- Tip speed ratio: It is the ratio of the speed of tip of the rotor to the wind velocity.
- Wind shear: The rate of change of wind speed with height is called wing shear.
- Gradient height: The height at which shear forces of wind becomes zero. Its height is about 2000 m.
- Wind turbines: It convert the kinetic energy in the wind into mechanical power.

Solidity

Solidity is usually defined as the percentage of the area of the rotor, which contains material rather than air.

Low-solidity machines run at higher speed and tend to be used for electricity generation.

High-solidity machines carry a lot of material and have coarse blade angles.

They generate much higher starting torque (torque is the twisting or rotary force produced by the rotor) than low-solidity machines.

High-solidity machines inherently less efficient than low -solidity machines. The wind pump is generally of this type. High solidity machines will have a low tip-speed ratio and vice versa.

π

Q.1 A horizontal axis windmill of 5 m diameter rotor is installed for water lifting in a farm. If av. Wind velocity available is 14.4 km/hr, calculate theoretical power generated by the wind rotor. Assume air density as 1.29 kg/m^3.

Solution:

d= 5m

v= 14.4 km/hr = 4 m/sec

ρ_{a} = 1. 29 kg/m^3

So theoretical power generated = (1/2) ρ_{a}. A. V^3

$= (1/2) \times 1.29 \times (\pi/4)d^2 \times V^3$

So power generated = 810.12 W

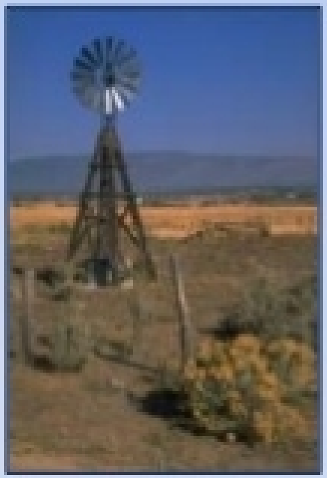
Q.2 A horizontal axis windmill of 4 m diameter rotor is installed for water lifting in a farm. If av. Wind velocity available is 7.2 km/hr, calculate theoretical power generated by the wind rotor. Assume air density as 1.00 kg/m^3.

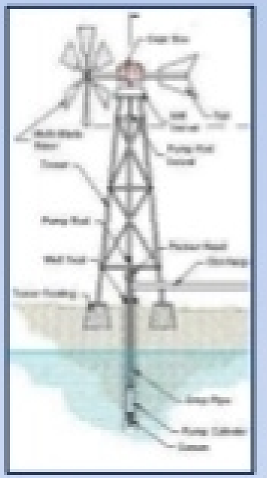
50.24 W

(to be solved by the students)

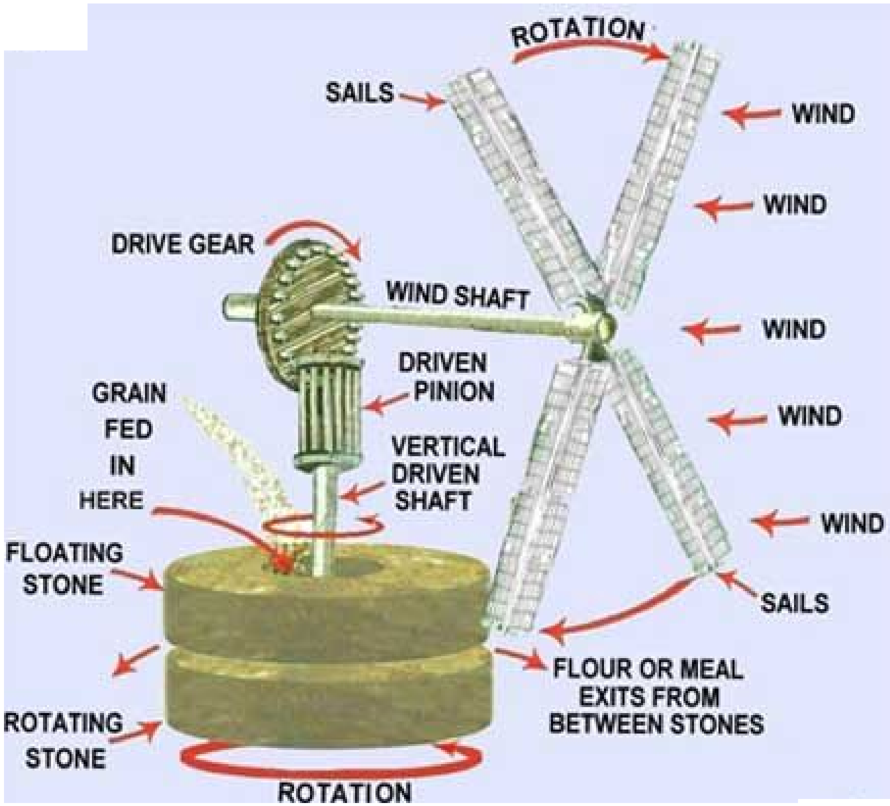
Wind turbines: how do they work? (1)

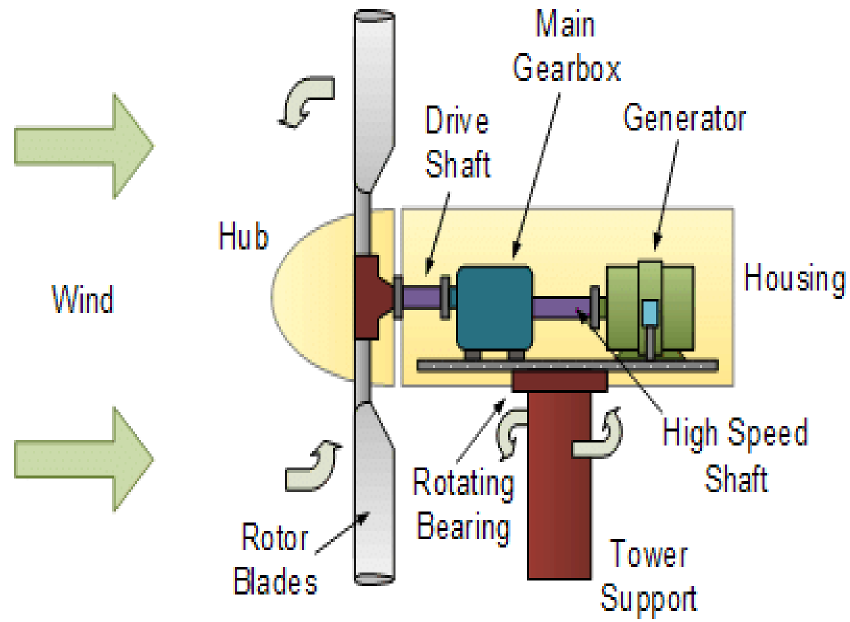
- Wind turbines convert the **kinetic energy** in the wind into mechanical power.
- This **mechanical power** can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into **electricity**.
- A wind turbine works the opposite of a fan.
- Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity.





Gristmills





The other use of wind mills is for grinding grains into flour. These are called gristmills, corn mills or flour mills.

Various important wind speeds to consider:

Start-up wind speed - the minimum wind speed needed for the rotor and the blades to begin spinning. It will not provide any usable electric power.

Cut-in wind speed – the wind speed at which the blades start to turn and a tirckle of electricity start to be produced. It is typically 7- 9 mph.

Rated wind speed – the wind speed at which the machine is designed to run (this is at optimum tip-speed ratio).The rated speed is usually in the rang of 25 to 35 mph.

Furling wind speed – the wind speed at which the machine will be turned out of the wind to prevent damage.

Maximum design wind speed – the wind speed above which damage could occur to the machine.

Anatomy and characteristics of the wind generator

- Wind electric generator converts kinetic energy available in wind to electrical energy by using rotor, gear box and generator.
- A typical small wind generator has rotor that is directly coupled to the generator, which produces electricity either at 120/240 volt alternating current for direct domestic use or at 12/24 volt direct current for battery charging.
- Larger machines generate 3 phase electricity.
- There is often a tail vane which keeps the rotor orientated into the wind.
- Some wind machines have a tail vane, which is designed for automatic furling (turning the machine out of the wind) at high wind speeds to prevent damage.

- Larger machines have pitch controlled blades (the angle at which the blades meet the wind is controlled).
- The tower is of low solidity to prevent wind interference and is often guyed to give support to the tower.
- The system may be grid connected or battery charging type.
- When wind is used for supplying electricity to a grid, a diesel generator set is often used as a backup for the periods when wind speeds are low.

Considerations related to use of wind generators:

Electromagnetic interference - some television frequency bands are susceptible to interference from wind generators.

Noise - wind rotors, gearboxes and generators create acoustic noise when functioning; this needs to be considered.

Components of wind electric generator

Basic components of a Wind Electric Systems are:

1. Tower
2. Nacelle
3. Rotor
4. Gearbox
5. Generator
6. Braking System
7. Yaw System
8. Controllers and
9. Sensors

Four types of supporting towers deserve consideration, these are:

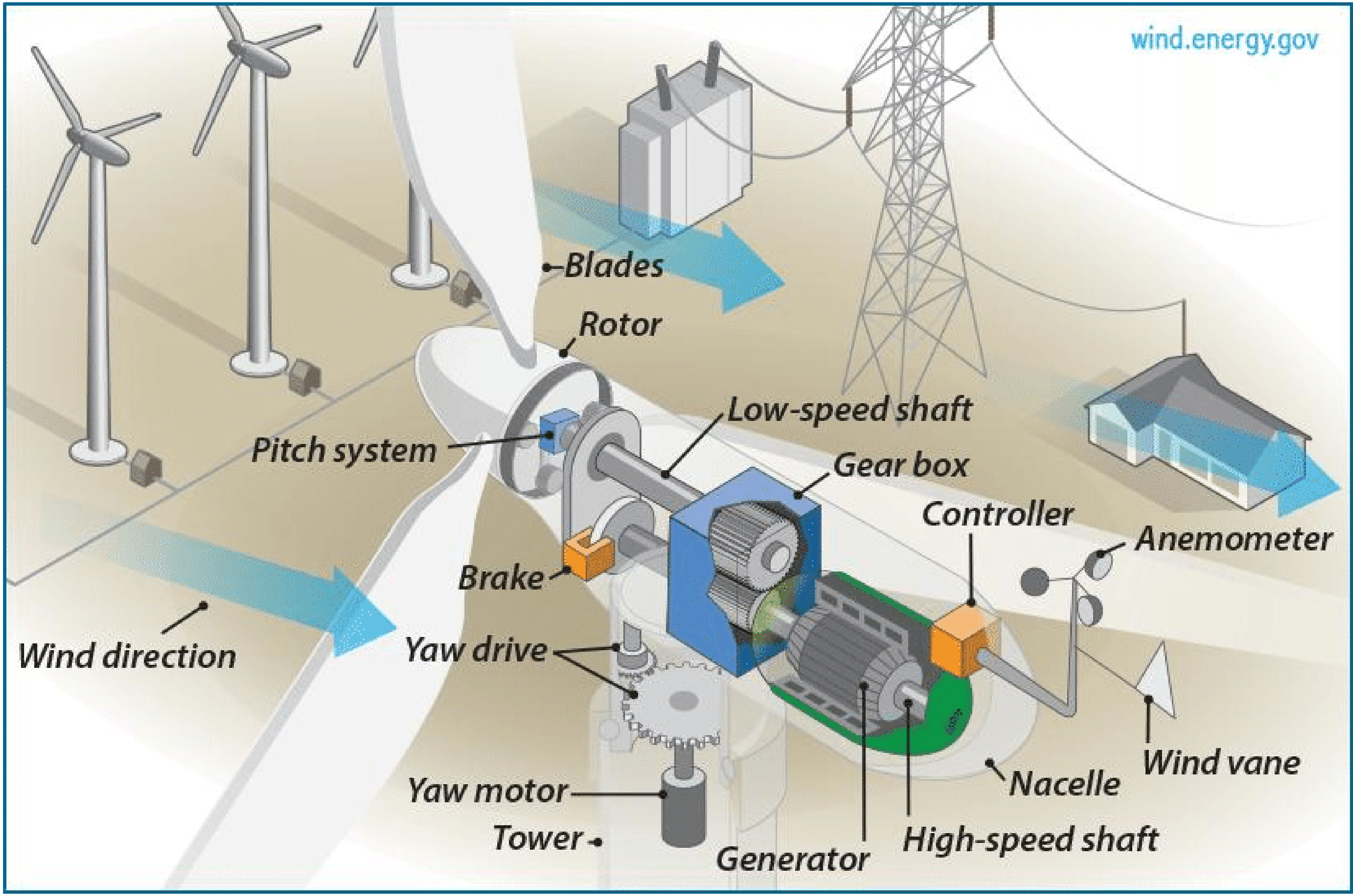
- the reinforced concrete tower
- the pole tower
- the built up shell-tube tower, and
- the truss tower

Among these, the truss tower is favoured because it is proved and widely adaptable, cost is low and the parts are readily available.

The minimum tower height for a small WECS is about 10m, and the maximum practical height is estimated to be roughly 60 m.

The turbine may be located either upwind or downwind of the tower. In the upwind location

Downwind rotors (i.e. the wind encounters the turbine before reaching the tower), are generally preferred especially for the large aero generators.


wind.energy.gov
Blades
Rotor
Low-speed shaft
Pitch system
Gear box
Controller
Anemometer
Brake
Wind direction
Yaw drive
Wind vane
Nacelle
Yaw motor
Tower
High-speed shaft
Generator

Yaw control

For localities with the prevailing wind in one direction, the design of a turbine can be greatly simplified. The rotor can be in a fixed orientation with the swept area perpendicular to the predominant wind direction. Such a machine is said to be yaw fixed.

Most wind turbines, however, are yaw active, that is to say, as the wind direction changes, a motor rotates the turbine slowly about the vertical (or yaw) axis so as to face the blades into the wind.

In the small turbines, yaw action is controlled by tail vane.

In larger machines, a servomechanism operated by a wind- direction sensor controls the yaw motor that keeps the turbine properly oriented.

Principles of wind energy conversion

Two important aerodynamic principles are utilized in windmill operation, i.e., lift and drag. The wind can rotate the rotor of a wind mill either by lifting (lift) the blades or by simply pushing against it (drag). (or through a combination of the two).

The basic features that characterise lift and drag are:

- Drag is in the direction of air flow.
- Lift is perpendicular to the direction of air flow.
- Generation of lift always causes a certain amount of drag to be developed.

- With a good aerofoil, the lift produced can be thirty times greater than the drag.
- Lift devices are generally more efficient than drag devices.
- Drag devices always have tip-speed ratios less than one and hence turn slowly, whereas lift devices can have high tip-speed ratios (up to 13:1) and hence turn quickly relative to the wind.

Horizontal and vertical axis rotors

- Windmills rotate about either a vertical or a horizontal axis.
- Windmills most in practical use today, are horizontal axis type.
- Vertical axis mills do not need to be orientated to face the wind, since they present the same cross section to the wind from any direction.

There are three main types of vertical axis windmill.

- Panamone differential drag devices
- Savonius rotor or "S" rotor and
- Darrieus wind turbine.

Horizontal axis windmill

Horizontal –axis wind machine where the rotating axis is parallel to the direction of wind flow and parallel to the ground.

There are two or more aerodynamic blades mounted on the horizontal shaft.

The blade tips can travel at several times the wind speed which results in high efficiency.

The blade shape is designed by using the same aero-dynamic theory as for aircraft. The low-speed horizontal axis wind mills are used mainly for mechanical purposes, like in water pumps.

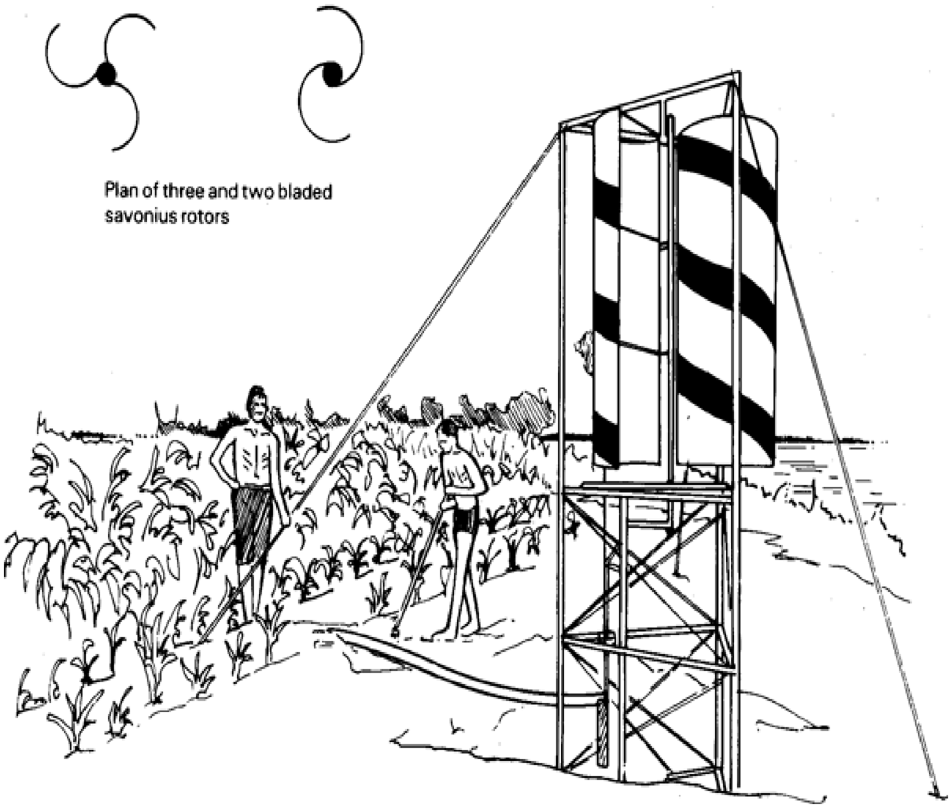
Vertical axis windmill

Vertical – axis wind machines are those where the rotating axis is perpendicular to the wind stream and to the ground.

The French engineer, Davieus designed another type of vertical – axis rotor called Davious type wind mill. Flexible metal strips in the shape of a catenary form the rotor blades. For a given wind speed, the unit rotates more rapidly and is more efficient that the savionious rotor. Unfortunately, the Darreieus rotor is not self-starting even in high winds.

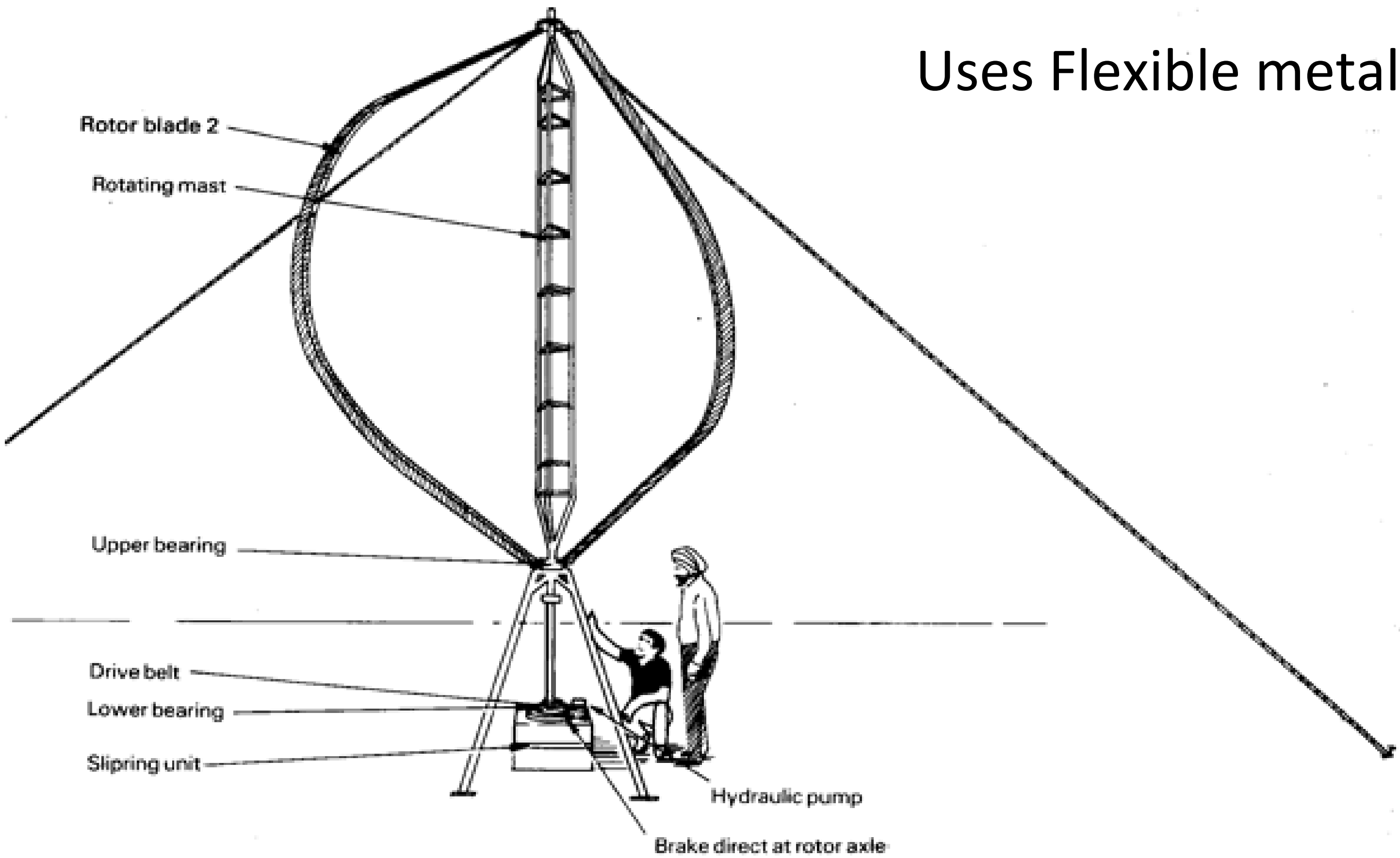
The **Savonius rotor** consists of two or sometimes three curved interlocking plates grouped around a central shaft between two end caps; it works *by a* mixture of differential drag and lift.

This was developed by the Finnish engineer, Savonious (1931), and is being used increasingly for small wind – energy installations.



Darrieus vertical axis wind turbine

Uses Flexible metal strips

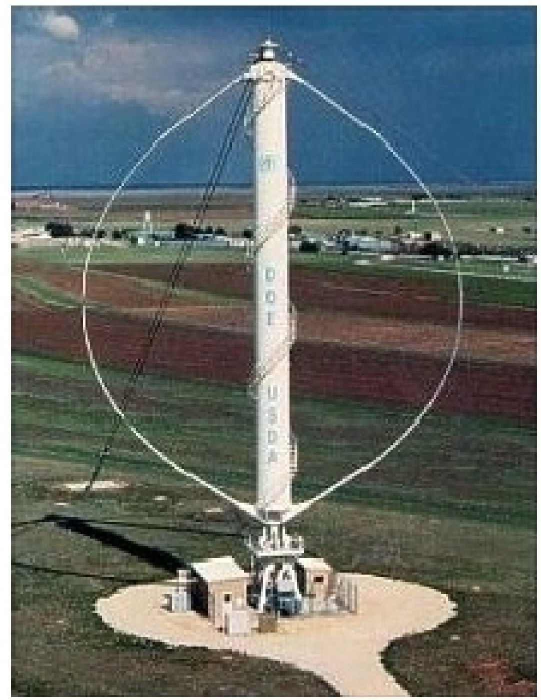


Rated at 15 Kilowatts

The Darrieus wind turbine has airfoil cross-section blades (streamlined lifting surfaces like the wings of an aircraft). Most machines have the curved "egg-beater“ profile .

Types of wind machines

Fan Mill Horizontal Axis



Darrieus Vertical Axis

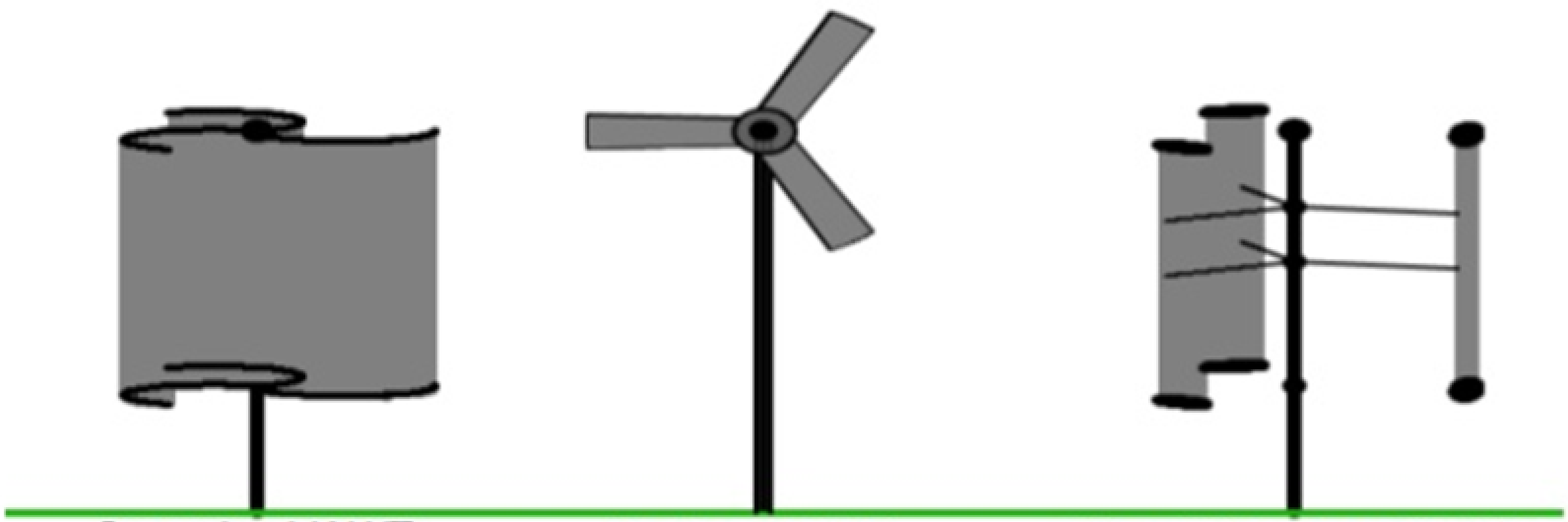
Vertical axis

- Rotating axis of the wind turbine is vertical or perpendicular to the ground
- Primarily used in small wind projects and residential applications
- Powered by wind coming from all 360 degrees, no yaw mechanism
- Ideal for installations where wind conditions are not consistent, or due to public ordinances the turbine cannot be placed high enough to benefit from steady wind

Horizontal axis

- Rotating axis of the wind turbine is horizontal or parallel to the ground
- Primarily used in big wind application
- Able to produce more electricity

  from a given amount of wind
- Disadvantage of horizontal axis however is that it is generally heavier and it does not produce well in turbulent winds



Savonius VAWT   Modern HAWT   Giromill/Darrieus VAWT

Types of wind turbine

2. Vertical axis type

Vertical axis wind turbines(VAWTs) have the main rotor shaft arranged vertically.
VAWTs runs in any wind direction.

Darrieus wind turbine	Savonius wind turbine
Good efficiency Produce large torque and cyclic stress on the tower Require some external power source to start turning 	drag type turbine used in cases of high reliability in many things such as ventilation and anemometers. self starting less efficient 

Comparison

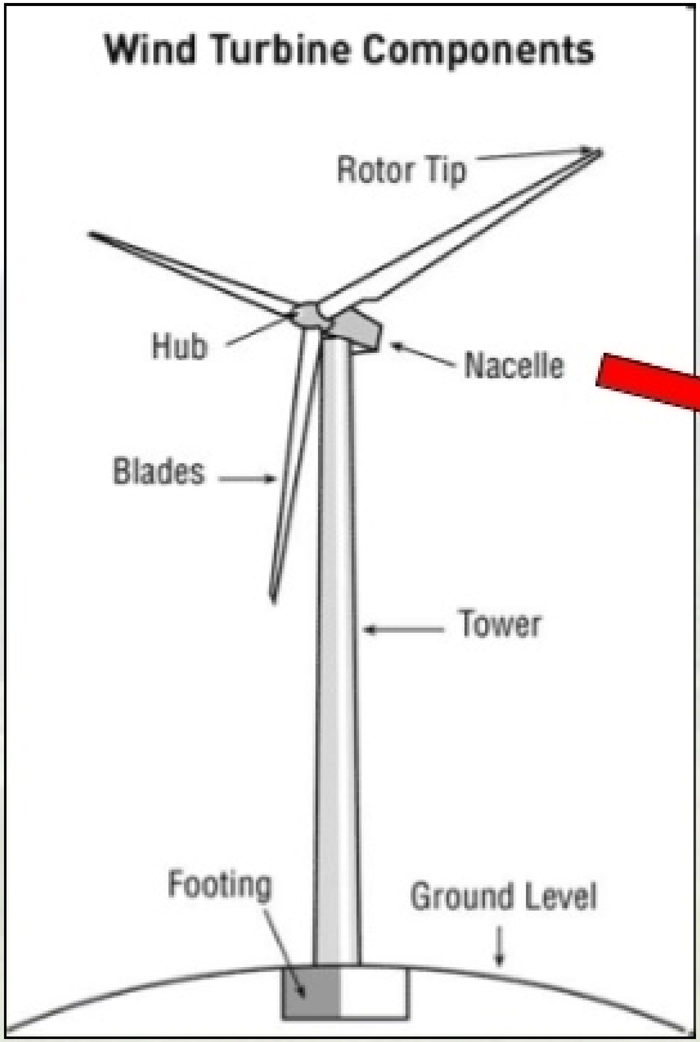
Comparison of HAWT & VAWT

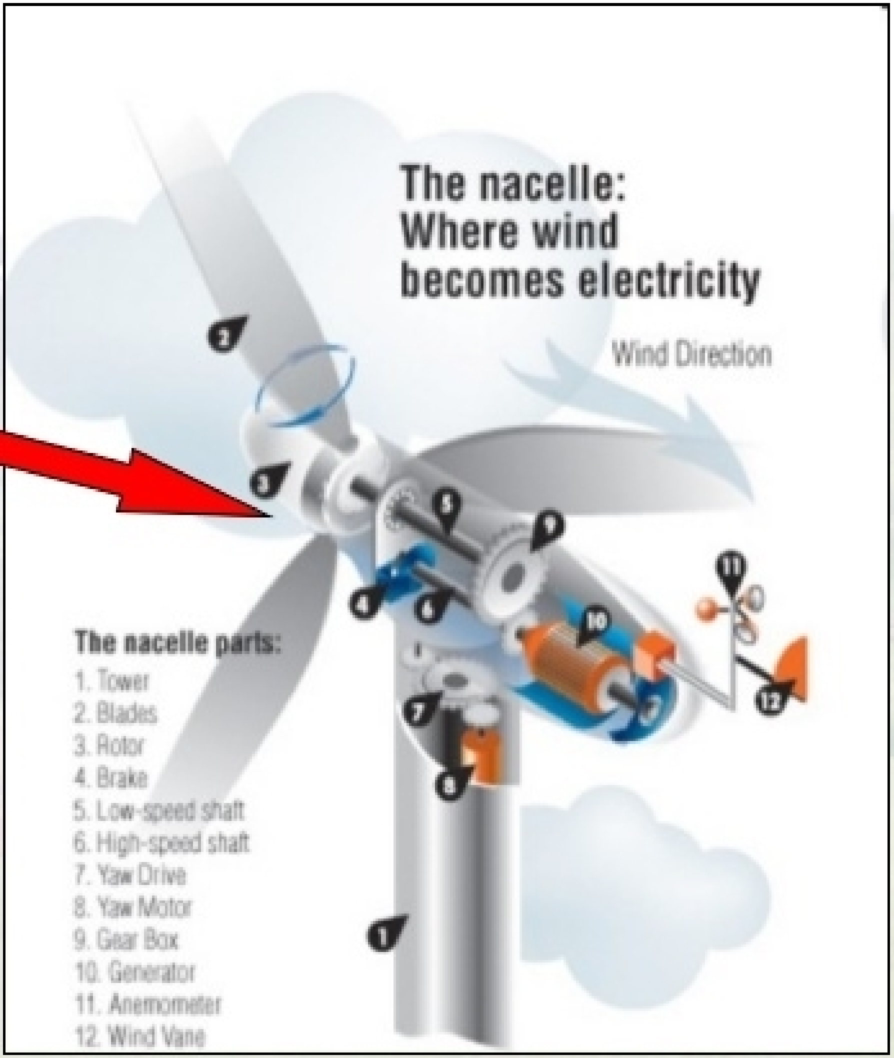
FACTORS	HAWT	VAWT
Power generation efficiency	50-60%	Above 70%
Steering mechanism of wind	Y	N
Blade rotation speed	Quite large	Quite small
Wind-resistance capability	Weak	Strong
Noise	5-60db	0-10db
Starting wind speed	High	Low
Failure rate	High	Low
Maintenance	Complicated	Convenient
Rotating speed	High	Low
Effect on birds	Great	Small
Cable stranding problem	Y	N


Jaisalmer wind farm
[The 2 largest off shore wind farm in the world]

Wind Energy - Technology

- **Major Components of Wind Turbine**





- ***Anemometer***: Measures the wind speed and transmits wind speed data to the controller.
- ***Blades***: Lifts and rotates when wind is blown over them, causing the rotor to spin.
- ***Brake***: Stops the rotor mechanically, electrically, or hydraulically, in emergencies.
- ***Controller***: Starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 55 kmph

Pitch: Turns blades out of the wind to control the rotor speed, and to keep the rotor from turning in winds that are too high or too low to produce electricity.

Rotor: Blades and hub together form the rotor.

Tower: Made from tubular steel (shown here), concrete, or steel lattice. Supports the structure of the turbine.

- ***Gear box***: Connects the low-speed shaft to the high-speed shaft and increases the rotational speeds from about 30-60 rotations per minute (rpm), to about 1,000-1,800 rpm; this is the rotational speed required by most generators to produce electricity.

- ***Generator***: Produces 60-cycle AC electricity; it is usually an off-the-shelf induction generator.

High-speed shaft: Drives the generator.

Low-speed shaft: Turns the low-speed shaft at about 30-60 rpm.

Nacelle: Sits atop the tower and contains the gear box, low- and high-speed shafts, generator, controller, and brake.

- ***Wind vane***: Measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.
- ***Yaw drive***: Orients upwind turbines to keep them facing the wind when the direction changes. Downwind turbines don't require a yaw drive because the wind manually blows the rotor away from it.
- ***Yaw motor***: Powers the yaw drive.