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Department of PHYSICS

III B.Sc. Physics Cluster2 STUDY Material

Paper PHY C2: Wind, Hydro and Ocean Energies

Name of the Student : ______________________________

Roll Number : ______________________________

Group : ______________________________

Academic Year : ______________________________

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UNIT-1

WIND GENERATION

Wind is air in motion. It is produced by the uneven heating of the earth's surface by the sun. Since the earth's surface is made of various land and water formations, it absorbs the sun's radiation unevenly. Two factors are necessary to specify wind: speed and direction.

The horizontal wind speed is usually much greater than the vertical wind speed. The total energy in the atmosphere is the result of conversion of potential energy of the atmosphere into kinetic energy. The ultimate energy source is of course the Sun. It is estimated that 1 per cent of all solar radiation falling on the face of the earth is converted into kinetic energy of the atmosphere, 30 per cent of which occur in the lowest 1000 m of elevation.

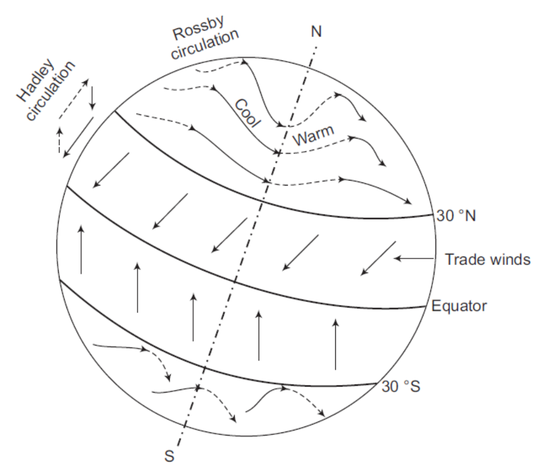
As the sun warms the Earth's surface, the atmosphere warms too. Some parts of the Earth receive direct rays from the sun all year and are always warm. Other places receive indirect rays, so the climate is colder. Examples: clouds, mountains, volcanoes, valleys, rivers, lakes, seas, forests, other vegetation and deserts. Warm air, which weighs less than cold air, rises. Then cool air moves in and replaces the rising warm air. This movement of air is what makes the wind blow.

ORIGIN OF WINDS

The origin of winds may be traced basically to uneven heating of earth surface due to sun. This may lead to circulation of widespread winds on global basis, producing planetary winds or may have a limited influence in a smaller area to cause local winds.

Global Winds

(i) Primary force for global winds is developed due to differential heating of earth at equator and Polar Regions. In the tropical regions there is net gain of heat due to solar radiation, whereas in the Polar Regions there is net loss of heat. This means that the earth's atmosphere has to circulate to transport heat from tropics towards the poles. On a global scale, these atmospheric currents work as an immense energy transfer medium. Ocean currents act similarly, and are responsible for about 30 per cent of this global heat transfer.



Global circulation of wind

Spinning of earth about its axis produces Coriolis force, which is responsible for deviation of air currents towards west.

Between 30°N and 30°S, heated air at the equator rises and is replaced by cooler air coming from north and south. This is known as Hadley circulation. Due to Coriolis force these winds deviate towards west. These air currents are also known as trade winds.

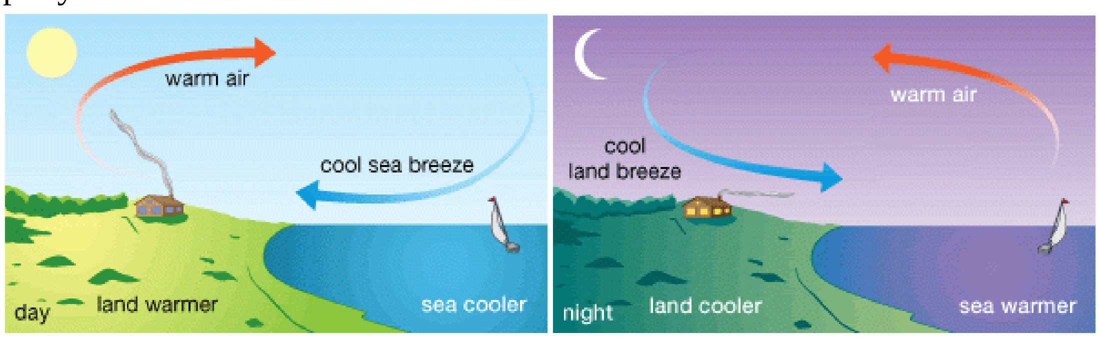
There is little wind near the equator (±5° around it), as the air slowly rises upwards rather than moving westward.

Between 30°N (/S) and 70°N (/S) predominantly western winds are found. These winds form a wavelike circulation, transferring cold air southward and warm air northward (in northern hemisphere and vice versa in southern hemisphere). This pattern is called Rossby circulation.

Local Winds

Localized uneven heating is responsible for local winds. Local winds are produced due to two mechanisms:

(i) The first is differential heating of land surface and water bodies due to solar radiation. During the day, solar energy is readily converted to sensible thermal energy on the land surface and thus quickly increases its temperature. Whereas, on water bodies it is partly consumed in evaporating water and only partly absorbed to cause an increase in temperature. The land mass thus becomes hotter than water, which causes differential heating of air above them. As a result, cool and heavier air blow from water towards land. At night, the direction of wind is reversed as the land mass cools to sky more rapidly than the water. This is the mechanism of shore breeze.



(ii) The second mechanism of local winds is differential heating of slope on the hillsides and that of low lands. The slope heats up during the day and cools down during night more rapidly than the low land. This causes the heated air to rise along the slope during the day and relatively cool air to flow down at night.

WORLD DISTRIBUTION OF WIND

We know that some areas of the earth's surface have higher wind speeds than others. These variations are due primarily to the irregular heating of the earth's surface in both time and position. According to the position and pressure, Earth divided into some pressure bands. Those are

Equatorial Calms or Doldrums:

These occur at a belt of low pressure surrounded by the earth's equatorial zone as there is an average overheating of the earth in this region. The warm air here rises in a strong convection flow and showers are common due to adiabatic cooling. So humidity is very high without providing much surface cooling. The regions near the equator will not be very good for wind power applications.

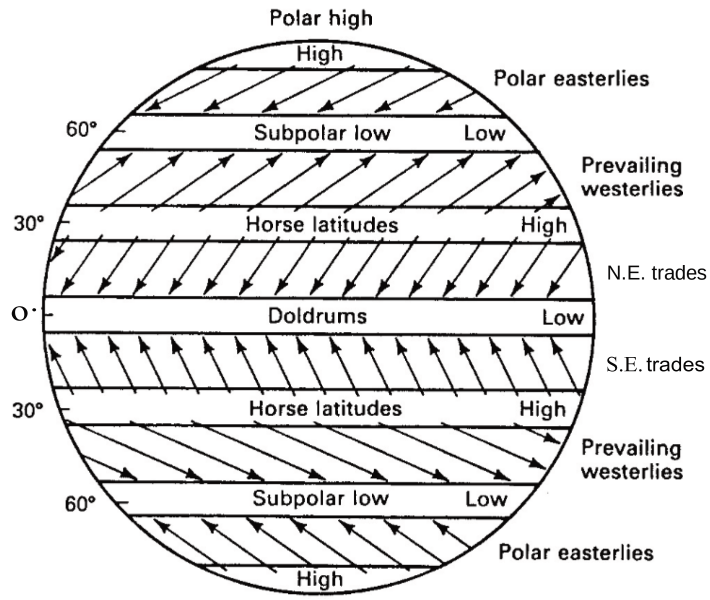


Figure: Ideal terrestrial pressure and wind systems

Subtropical Highs or Horse Latitudes:

Ideally, there are two belts of high pressure and relatively light winds around the equator at 30° N and 30° S latitude. These are called the *subtropical calms* or *subtropical highs* or *horse latitudes.* The high pressure pattern is maintained by vertically downward air inside the pattern. This air is warmed adiabatically and therefore develops a low relative humidity with clear skies. The dryness of this descending air is responsible for the bulk of the world's great deserts which lie in the horse latitudes.

Subpolar Lows:

There are then two more belts of low pressure which occur at perhaps 60° S latitude and 60° N latitude, the subpolar lows. In the Southern Hemisphere, this low is stable and does not change much from summer to winter. In the Northern Hemisphere, however, there are large land masses and strong temperature differences between land and water. These cause the lows to reverse and become highs over land in the winter (the *Canadian* and *Siberian highs).*

Polar Regions:

Finally, the Polar Regions are high pressure areas more than low pressure. The intensities and locations of these highs may vary widely, with the center of the high only rarely located at the geographic pole.

The combination of these high and low pressure areas with the Coriolis force produces the prevailing winds shown in Fig. The *northeast* and *southeast trade winds* are among the most constant winds on earth, at least over the oceans. This causes some islands, such as Hawaii (20° N. Latitude) and Puerto Rico (18° N. Latitude), to have excellent wind resources. The westerlies are well defined over the Southern Hemisphere because of lack of land masses. Wind speeds are quite steady and strong during the year, with an average speed of 8 to 14 m/s. This means that islands in these latitudes, such as New Zealand, should be prime candidates for wind power sites.

In the Northern Hemisphere, the westerlies are quite variable and may be masked or completely reversed by more prominent circulation about moving low and high pressure areas. This is particularly true over the large land masses.

WIND SPEED VARIATION WITH HEIGHT:

- Wind speed near the ground changes with height. This requires an equation that predicts the wind speed at one height in terms of the measured speed at another.
- The most common expression for the variation of wind speed with height is the power law having the following form,

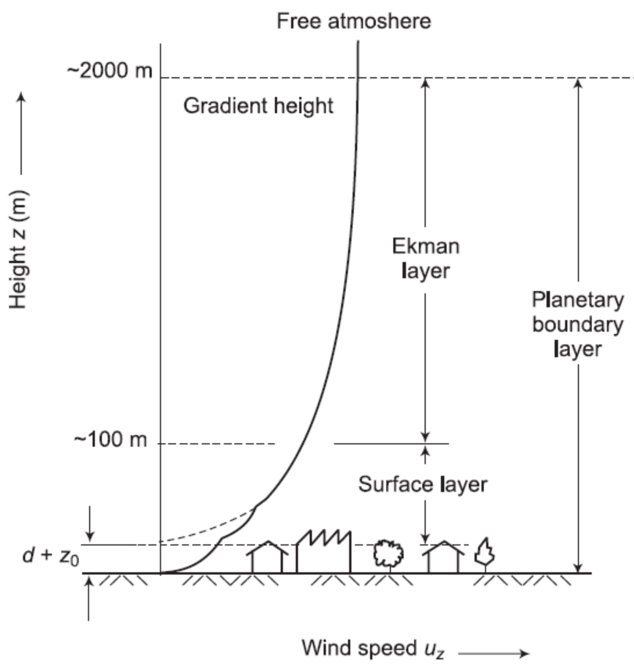
$$\frac{v_2}{v_1} = \left(\frac{h_2}{h_1} \right)^{\alpha}$$

  where v_1 and v_2 are the mean wind speeds at heights h_1 and h_2 respectively. The exponent α depends on factors such as surface roughness and atmospheric stability.
- Numerically, it lies in the range 0.05–0.5, with the most frequently adopted value being (1/7 = 0.14) which is widely applicable to low surfaces and well exposed sites. So, Eq approximates $v \propto h^{\frac{1}{7}}$
- Wind speed increases with height above the ground. The rate of change of wind speed with height is called wind shear. The lower layers of the air delay those above them, resulting in change in mean wind speed with height.
- The height at which shear forces are reduced to zero are called the gradient height and is typically of about 2000 m. above the gradient height, known as free atmosphere. Here changes in wind speed are not affected by ground conditions.

- The layer of air from ground to gradient height is known as planetary boundary layer. The planetary boundary layer mainly consists of (i) surface layer, which extends from the height of local obstructions to a height of approximately 100 m and (ii) Ekman layer, which starts from 100 m and extends up to gradient height as shown in Fig.
- In the surface layer the variation of shear stress can be neglected and mean wind speed with height can be represented by Prandtl logarithmic law model:

$$u_z = V \ln\left(\frac{z-d}{z_o}\right)$$

where, V is characteristic speed, d is zero plane displacement, its magnitude is a little less than the height of local obstructions, zo is roughness length, (z_o + d) is the height of local obstructions.



- As stated earlier, the standard wind speed measurements are often taken at a height of 10 m from ground but wind turbines often operate at a height above this. A simple empirical power law model can be used to estimate wind speed u_z at a height z relative to that available at standard reference height H.

$$u_z = u_H \left(\frac{z}{H}\right)^{\alpha}$$

where u_H is mean wind speed at reference height H (usually 10 m), a depends on surface roughness and the range of height being covered. Great care should be taken in using this formula, especially for z > 50 m.

MATEOROLOGY

Wind, in climatology, the movement of air relative to the surface of the Earth. Winds play a significant role in determining and controlling climate and weather. Wind occurs because of horizontal and vertical differences (gradients) in atmospheric pressure. Accordingly, the distribution of winds is closely related to that of pressure. Near the Earth's surface, winds generally flow around regions of relatively low and high pressure—

cyclones and anticyclones, respectively. They rotate counterclockwise around lows in the Northern Hemisphere and clockwise around those in the Southern Hemisphere. Similarly, wind systems rotate around the centers of highs in the opposite direction.

The list below provides some common applications of meteorology (it's far from exhaustive, but it will give you an idea of the types of things meteorologists are involved in):

- weather observation and forecasting
- computer modeling of the atmosphere
- analyzing, monitoring, and predicting air pollution
- Earth science education
- helping industries (agriculture, energy, aviation, insurance, etc.) manage the risks posed by weather
- assisting emergency managers and disaster planners
- studying Earth's climate and climate change

Meteorologists work in these areas in academia, public-sector (government), and private sector (business) settings. Some of the companies and organizations that have meteorologists on staff or use various meteorological services.

BASIC PRINCIPLE OF WIND ENERGY CONVERSION

1. The Nature of Wind

The circulation of air in the atmosphere is caused by the non-uniform heating of the earth's surface by the sun. The nature of the terrain, the degree of cloud and the angle of the sun in the sky are all factors which influences this process.

In general, during the day the air above the land mass tends to heat up more rapidly than the air over water. At night the process is reversed because the air cools down more rapidly over the land and the breeze therefore blows off shore.

2. The Power in Wind

Wind possesses energy by virtue of its motion. Any device capable of slowing down the mass of moving air, like a propeller, can extract part of the energy and convert is into useful work.

There are three factors determine the output power generated from the wind mill, they are

(1) The wind speed
(2) The cross section of wind swept by rotor, and
(3) The overall conversion efficiency of rotor, transmission system and generator or pump.

No device, however well-designed, can extract all of the wind's energy because the wind has a halt at rotor and this would prevent the passage of more air through the rotor. A 100%

efficient aero generator would therefore only be able to convert up to a maximum of around 60% of the available energy in wind into mechanical energy.

Kinetic Energy = ½ mv^2

mass 'm' is equal to its volume V multiplied by its density 'ρ' of air.

m = ρ V= ρ Av

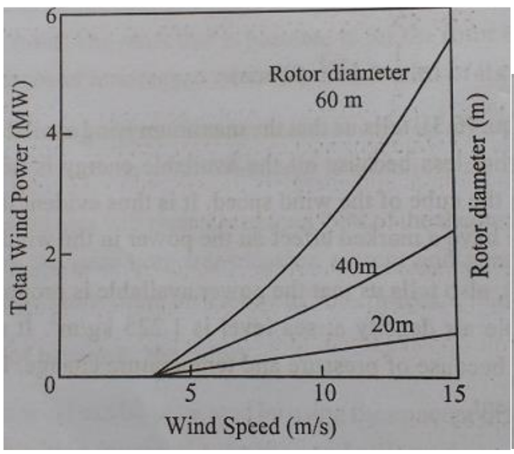
where m is the mass of air, A is the cross sectional area of rotor, v is the velocity of the air particles.

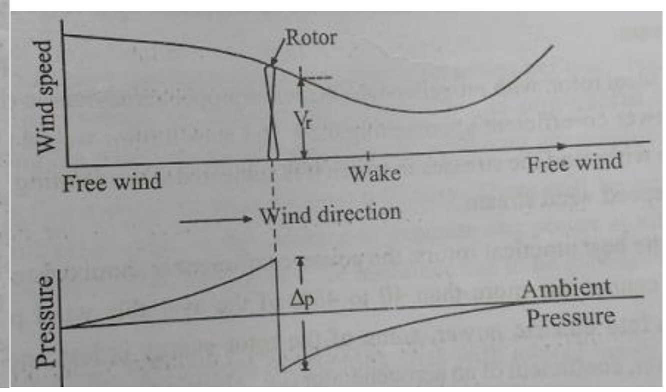
Kinetic Energy = ½ ρ Av.v^2 = ½ ρ Av^3

The power is nothing but energy per unit time

So, P = ½ ρ Av^3

Power variation corresponds to combined effect of rotor diameter and wind speed.





Power Coefficient

The fraction of the free-flow wind power that can be extracted by the rotor is called the power co-efficient; Thus,

Power Coefficient = Power of wind rotor / Power available in the wind

Where, power available is calculated from the air density, rotor diameter and free wind speed. The maximum theoretical power coefficient is equal to 16/27 or 0.593. This value cannot be exceeded by a rotor in free-flow wind-stream.

An ideal rotor, with propeller-type blades of proper aerodynamic design, would have a power co-efficient approaching 0.59.

Instantaneous Wind Power P_w (t) = ½ ρ Av^3 (t)

Average power $\overline{P_w(t)}$ = ½ ρ A $\overline{v^3(t)}$

Average wind power density $\frac{\overline{P_w(t)}}{A}$ = ½ ρ $\overline{v^3(t)}$

CLASSIFICATION OF WECS

The systems which convert the energy from wind to other suitable form are called Wind Energy Conversion Systems (WECS). Mainly wind energy converted into electrical energy for most of the requirements.

(1) Based on axis

(a) Horizontal axis machines

(b) Vertical axis machines

(2) According to size

(a) Small size machines (upto 2kW)

(b) Medium size machines (2 to 100kW)

(c) Large size machines (100kW and above)

(3) No. of generators

(a) Single generator at single site

(b) Multiple generators

(4) Types of output

(a) DC output

i. DC generator

ii. Alternator rectifier

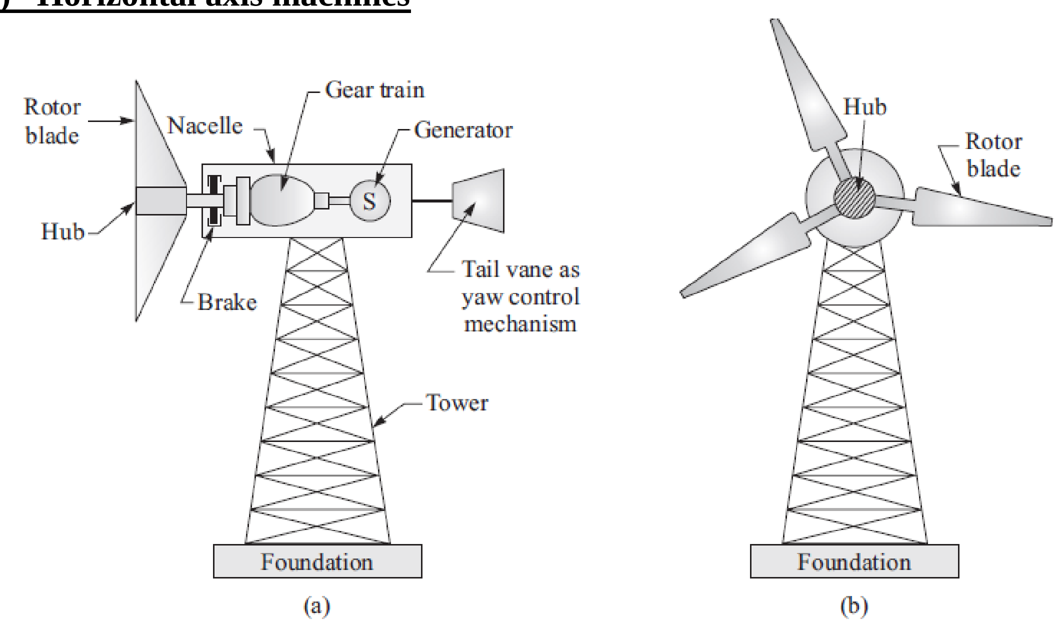
(b) AC output

i. Variable frequency, variable or constant voltage AC.

ii. Constant frequency, variable or constant voltage AC

(1) Based on axis

<u>(a) Horizontal axis machines</u>



Horizontal axis wind turbines, also shortened to HAWT, are the common style of a wind turbine. A HAWT has a similar design to a windmill, it has blades that look like a propeller that spin on the horizontal axis as shown in figure.

The components or main subsystems include turbine blades, hub, nacelle, yaw control mechanism, generator and tower.

Turbine blades

Turbine blades have aerofoil type cross section to extract energy from wind. These blades are made of high-density materials such as wood, glass fibre and epoxy composites. The blades are twisted from tip to root to maintain pitch angle. Most of wind turbines have two- or three- blades similar to the propeller of an old aeroplane, but blades of a wind turbine rotates very slowly compared to that of an aeroplane. A two-bladed rotors give much smoother power output compared to three-bladed rotors. A three-bladed rotor generates little more power output (more than 5%), but additional blade incorporation adds to substantial additional weight to the windmill (about 50% extra). A two-bladed rotor is also simpler to be constructed and erected on the ground.

Hub

The central solid portion of a rotor is called hub. It helps in the attachment of all blades and the incorporation of pitch angle control mechanism.

Nacelle

The rotor is attached to nacelle which is mounted at the top of a tower. It houses gearbox, generator, controls and brakes. The purpose of gearbox is to regulate the output rotation from the rotor with the speed of the generator. Electromagnetic brakes are provided for automatic application of brakes if the wind speeds exceed the designed speed.

Yaw control system

The yaw control system is provided to adjust the nacelle around the vertical axis so that rotor blades are always facing the wind stream. In small wind turbine, a tail vane is used as passive yaw control.

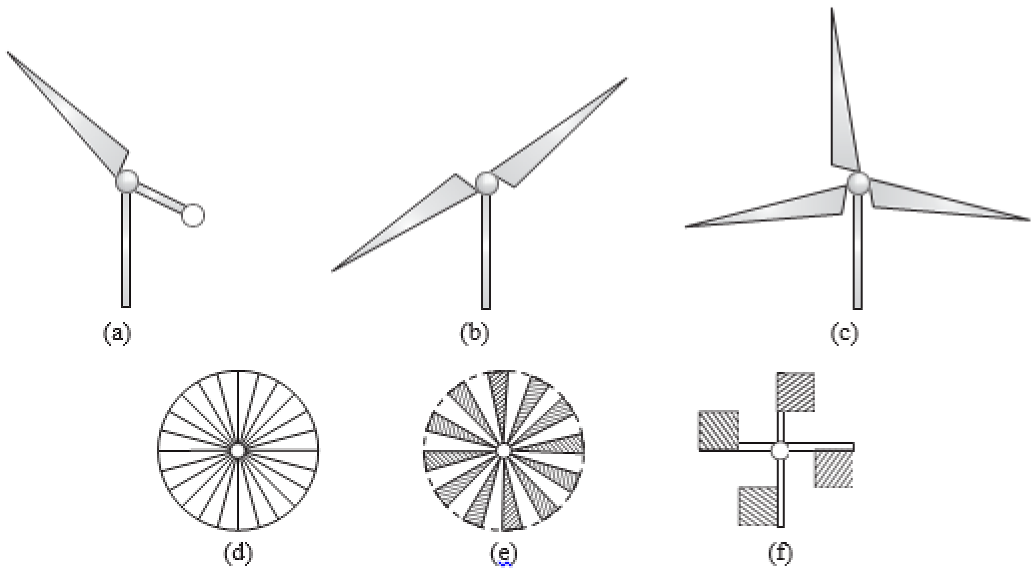
Tower

Tower is provided to support nacelle and rotor. The tower height should be sufficient so that enough wind speed can be intercepted by the rotor. For medium- and large-sized wind turbines, the tower is slightly taller than the rotor diameter, while in small sized wind turbines, the tower is much larger than the rotor diameter. There should not be any obstruction in the way of wind stream in its approach to the rotor. Tower can be made of materials such as steel or concrete.

Electrical systems

The wind turbines are provided with induction generators to convert mechanical energy into electrical energy. Induction generation has brushless and rugged construction. It is also available at economical cost.

The rotors of HAWT can be (a) single blade rotor, (b) two blades rotors, (c) three blades rotors, (d) Chalk multiblades rotor, (e) multibladed rotor and (f) Dutch-type rotor

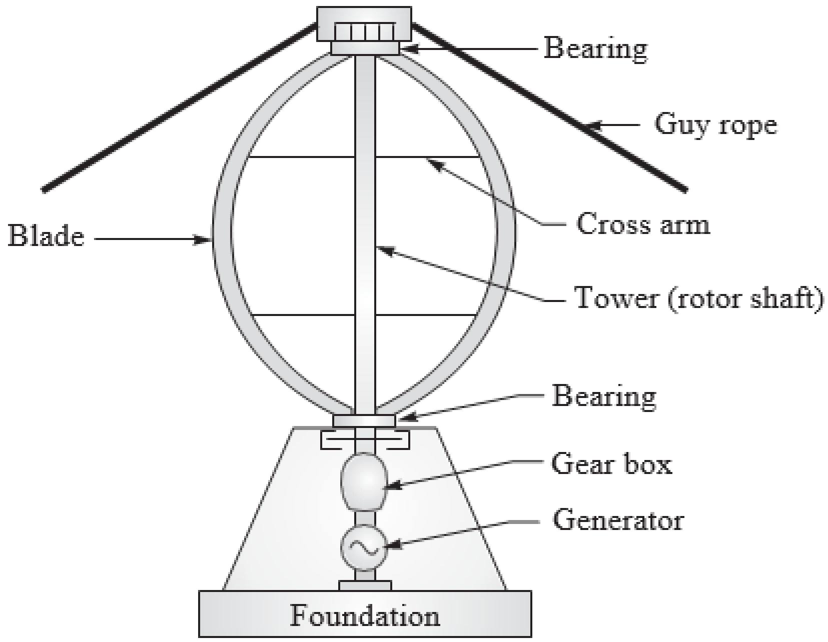


- HAWTs are commonly produced with two- and three-bladed rotors.
- A single-bladed rotor with balancing counterweight has simple construction and less cost, but it makes more noise during operation. It is used where small power is required.
- The multi-bladed and Dutch-type rotors are used where low speeds are required. Hence, these rotors are suitable for applications such as piston pumps where high starting torque is needed. As these rotors have high solidity, these can operate even when slow winds are present.

<u>Vertical Axis Wind Turbine</u>

Vertical axis wind turbine has the axis of rotation of its rotor perpendicular to the wind stream. Vertical axis wind turbine is advantageous as (i) it can accept wind from any direction, thereby eliminating the necessity of any yaw control system and (ii) it can have its gearbox and generator system (nacelle) at the ground level, thereby eliminating the necessity of mounting the heavy nacelle (with gearbox and generator) at the top of the tower. These features of VAWT also help in the simpler design and installation of the wind turbine, the easier inspection and maintenance of the wind turbine and reducing the overall cost of the wind turbine.

A VAWT (Darrieus) with all its components is shown in Figure. The components and subsystems include tower blades and support structure.



Tower (rotor shaft)

The tower consists of a hollow vertical shaft which can rotate about its vertical axis between its bearings at top and bottom. It is provided with a support structure at the bottom and at the upper end, it is supported by guy ropes. The height of the tower is about l00 m.

Blades

The wind turbine has two or three blades which are thin and curved shaped similar to an “eggbeater”. The blades are curved in such a way that minimum bending stresses are produced on rotation due to the centrifugal forces. The blades are designed in such a way that they offer aerofoil type cross section to wind stream. The height of blade is kept 94 m, diameter about 65 m and chord length about 2.4 m.

Support structure

It is provided with blades, gearbox and generator to support the weight of tower

<u>Rotor of VAWT</u>

Depending on the design of rotor, these are classified as

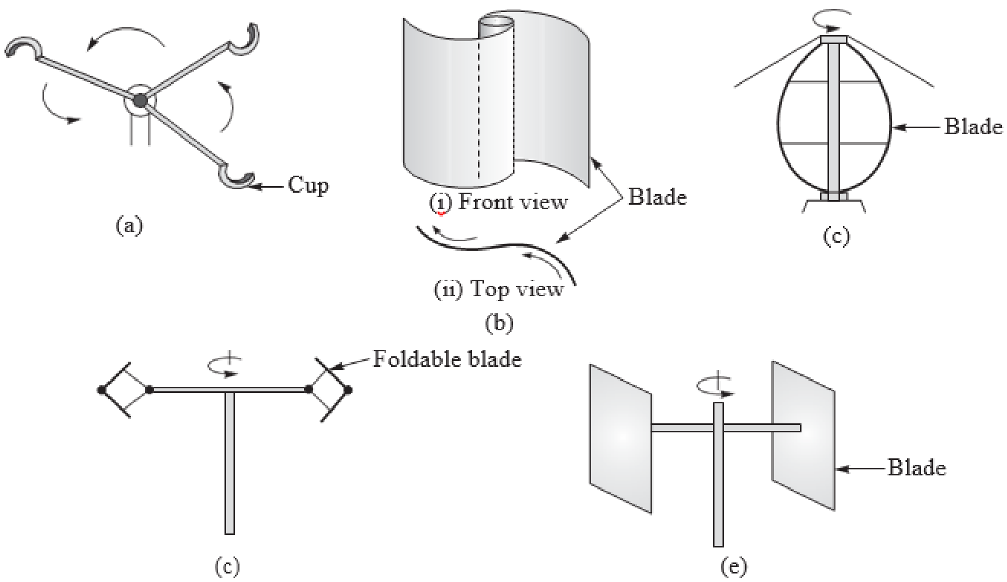
(a) Cup type rotor,

(b) Savonious rotor,

(c) Darrieus rotor,

(d) Musgrove (H-shaped) rotor,

(e) Evans rotor (gryromill)



WIND POWER

Kinetic motion of air is called wind disturb so when has kinetic energy will stop if you is a speed of wind through an area A per unit time then the volume of the wind is given by area A if ρ is the density of the air mass through area

$m = \rho A v$

Kinetic energy $KE = \frac{1}{2} mv^2$

$KE = \frac{1}{2} (\rho A v)v^2$

$KE = \frac{1}{2} \rho Av^3$

Power is nothing but energy per unit time, ie. $P = \frac{1}{2} \rho Av^3$

Power available per unit area $P/A = \frac{1}{2} \rho v^3$

TORQUE:

- Talk is nothing but force cross product of force and perpendicular distance

  τ = Force × perpendicular distance

  $= F \times r$

  $= rF \sin\theta$
- Torque causing rotation of the body.
- When the distance is equal to zero or theta equal to zero then torque become zero.
- Torque is maximum when θ equal to 90 degrees and force applied at extreme point.
- If Very low wind speed there is insufficient torque on the turbine to make them rotate
- If the wind speed increases a certain value, turbine will begin rotates and generates electrical power.
- Generally the motors are designed to deliver a maximum 50 W power at 4000 rpm.

APPLICATION and ADVANTAGES OF WIND ENERGY:

Wind energy may be considered as the world's fastest growing energy source. By the development of technology, wind power may become most economical and environmental friendly source of electricity in many countries in the coming 10 to 20 years.

The following are the important applications of wind energy.

- The wind energy is used to propel the sailboats in river and seas to transport men and materials from one place to another.
- Wind energy is used to run pumps to draw water from the grounds through wind mills.
- Wind energy has also been used to run flourmills to grind the grains like wheat and corn into flour.
- Now-a-days wind energy is being used to generate electricity.
- It is a renewable source of energy.
- Like solar energy, the wind energy conversion systems does not emit any pollutants. It is a pure form of energy.

WIND CHARACTERSTICS

- Wind has two important characteristics – direction and speed.
- The direction of wind can be gauged using an instrument called the wind vane. It is also called winter vane. A very common shape for wind vane is the shape of an arrow.
- When wind blows, the arrow align itself such that its tip point in direction from which the wind is blowing will be marked on the wind vane.
- Speed of wind is measure by anemometer.
- As the wind power is proportional to the cubic wind speed, it is crucial to have detailed knowledge of the site-specific wind characteristics
- Site-specific wind characteristics relevant to wind turbines include:
  1. Mean wind speed: The average value of wind speed for the specific years of duration, but does not tell how often high wind speeds occur.
  2. Wind speed distribution: diurnal, seasonal, annual patterns
  3. Turbulence: short-term fluctuations
  4. Long-term fluctuations
  5. Distribution of wind direction
  6. Wind shear (profile)

WIND MEASUREMENTS

Measurement of wind speed is very important to people such as pilots, sailors, and farmers. Wind speeds are measured in a wide variety of ways, ranging from simple tests to the most sophisticated electronic systems. Winds from east and west are less frequent and also have lower average speeds than the winds from north and south. There are several methods for measuring both wind speed and direction.

EOLIAN FEATURES

To know the wind behavior, we cannot always depend on sophisticated instruments, but sometimes approximate things are needed. The surface of the earth itself will be shaped by persistent strong winds, with the results called *eolian features* or *eolian landforms.*

(a) These eolian landforms are present over much of the world. They form on any land surface where the climate is windy and strongest. An important use of eolian features will be to pinpoint the very best wind energy sites, as based on very long term data.

(b) Sand dunes are the best known eolian feature. Dunes tend to be elongated parallel to the dominant wind flow. The size distribution of sand at a given site gives an indication of average wind speed, with the rougher sands indicating higher wind speeds.

(c) Another eolian feature is the *playa lake.* The wind scours out a depression in the ground which fills with water after a rain. When the water evaporates, the wind will scour out any sediment in the bottom. These lakes go through a development process and their stage of maturity gives a relative measure of the strength of the wind.

(d) Other eolian features include *sediment plumes* from dry lakes and streams, and *wind scour,* where airborne materials scratch out strips in exposed rock surfaces.

Eolian features do not give precise estimates for the average wind speed at a given site, but can identify the best site in a given region for further study.

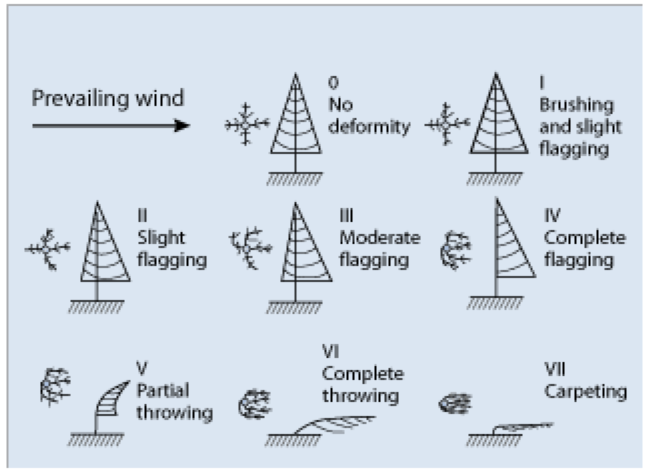
BIOLOGICAL INDICATORS

Living plants will indicate the effects of strong winds as well as eolian features on the earth itself. Strong winds deform trees so that they indicate an integrated record of the local wind speeds during their lives.

Basically there are five types of deformation in trees: *brushing, flagging, throwing, wind clipping,* and *tree carpets.*

Brushing: the branches are bent to *leeward* (downwind) like the hair in an animal skin i.e., brushed one way. It will occur with light prevailing winds, and is therefore of little use as a wind mining tool.

Flagging: The wind has caused branches of the tree to stretch out to leeward, perhaps leaving the windward side bare, so the tree appears like a flagpole carrying a banner in the breeze. This effect occurs over a range of wind speeds important to wind power applications.



Throwing: The main trunk, as well as the branches, is deformed so as to lean away from the prevailing wind. This effect is produced by the same mechanism which causes flagging. The wind is now strong enough for generating power.

Wind clipping: The wind has been sufficiently severe to suppress the leaders and hold the tree tops to a common, abnormally low level. Every twig which rises above that level is promptly killed, so that the upper surface is as smooth as a well-kept hedge.

Tree carpets: This is the extreme case of clipping in that a tree may grow only a few centimeters tall before being clipped. The branches will grow out along the surface of the ground, appearing like carpet because of the clipping action. Here this indicate the dangerous level of wind speeds.

ANEMOMETERS

The meteorological device that is used to measure the speed of the wind and its pressure is known as an anemometer. There are different type of Anemometers based on their design and working. Some of the types include the *propeller*, *cup*, *pressure plate*, *pressure tube*, *hot wire*, *Doppler acoustic radar*, and *laser*. The propeller and cup anemometers depend on rotation of a small turbine for their output, while the others basically have no moving parts.

ROTATIONAL ANEMOMETERS

Cup Anemometer

These are the oldest form of anemometers and are using around for centuries. These are the simplest type and among the most accurate. This kind of anemometer includes three or four hemispherical cups. These are arranged on the horizontal arms at one side at equivalent angles over the vertically positioned shaft. As wind levels pick up, the cups spin faster, with the instrument capturing the speed of the wind. So that it is comparative to the wind speed. By measuring the rotations of the cups over a certain period, the normal wind speed can be found on digital or analogue wind meter. They’re mostly designed to be mounted on structures such as buildings, sailboats, etc. This type of anemometer doesn’t need to point towards the wind direction to sense the wind speed. These devices are utilized by meteorologists, educational institutions, researchers, for commercial and research purposes.

The visual indication of wind speed is obtained by connecting this dc generator to a dc voltmeter with an appropriately calibrated scale. The scale needs to be arranged such that the pointer indicates a speed of 1 m/s when the generator outputs the voltage is zero. Then any wind speeds above 1 m/s will be correctly displayed.

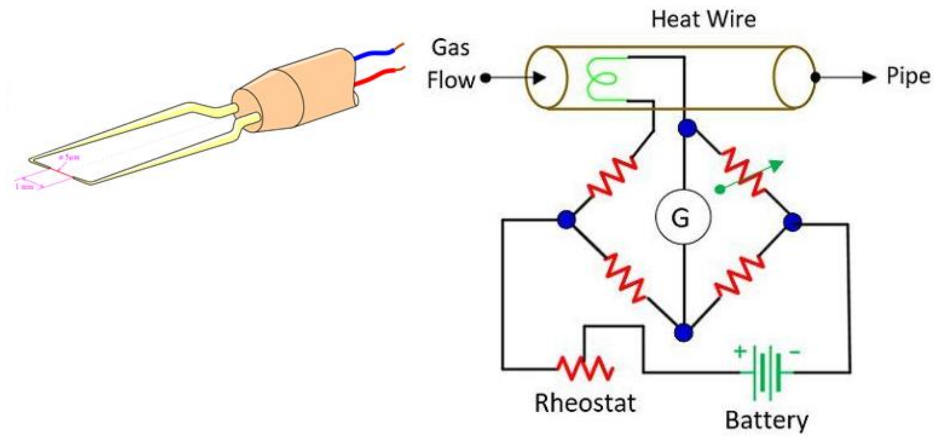
<u>Vane/Propeller Anemometers</u>

After cup anemometers, there have been several new types of anemometers and the vane/propeller anemometer is one of them. These are also referred to as propeller or windmill anemometers and are similar to the cup design but instead of cups, they have wind blades that spin. Unlike cup anemometers, this anemometer has to be parallel to the wind and rotate about a horizontal axis to obtain accurate data. Vane anemometer counts the number of spins per second to measure wind speed, with the results displayed on a digital display. They can handle the harshest and dirtiest environment and are more rugged and durable than other anemometers like a hot wire. They can be used outdoors and indoors and also can be compact and used in handheld devices, and measure other atmospheric parameters besides wind speed.

Anemometers may have an output voltage, either dc or ac, or a string of pulses and their frequency is proportional to anemometer speed. The dc generator is coupled to a simple dc voltmeter for readouts or to an analog-to-digital converter for digital use. It is difficult to accomplish accurately at the low voltages and frequencies associated with low wind speeds. This type of anemometer would not be used, therefore, where wind speeds of below 5 m/s are of primary interest.

OTHER ANEMOMETERS

Hotwire Anemometer



This kind of anemometer have a thin wire that is heated up to a fixed temperature which is above the atmospheric temperature. Basically a metal wire have a definite resistance at a particular temperature. When the air flows fast, then the wire gets cool. Now the resistance of the wire also decreases. The relation between the wire’s resistance as well as wind velocity must be obtained to estimate the velocity. If the hot wire is placed in one leg of a bridge circuit and the bridge balance is maintained by increasing the current so the temperature remains constant, the current will be related to the wind speed by

$$i^2 = i_o^2 + K\sqrt{u} \qquad \mathrm{A}^2$$

where i_o is the current flow with no wind and K is an experimentally determined constant.

The wire, made of fine platinum, is usually heated to about 1000^{o}C to make the anemometer output reasonably independent of air temperature. This anemometer is especially useful in measuring very low wind speeds, from about 0.05 to 10 m/s. Hot-wire devices can be further classified as CCA (constant current anemometer), CVA (constant voltage anemometer) and CTA (constant-temperature anemometer). The voltage output from these anemometers is thus the result of some sort of circuit within the device trying to maintain the specific variable (current, voltage or temperature) constant, following Ohm's law. This type is applied in areas with relatively constant temperature such as indoor environments checking flow hoods, HVAC systems, and exhaust monitoring.

Pressure Plate Anemometers:

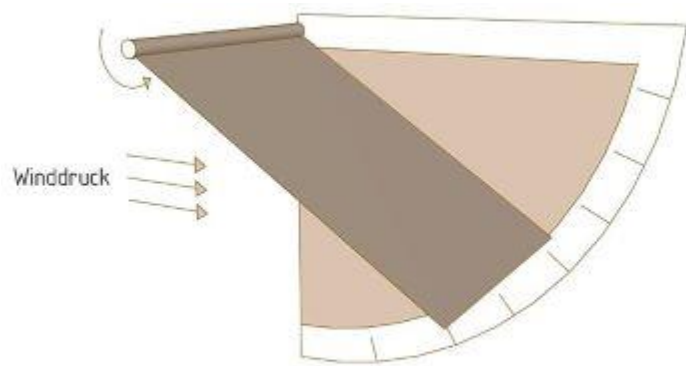
These are the first modern anemometers. The pressure of the wind on its face is balanced by a spring. The compression of the spring determines the actual force which the wind is exerting on the plate, and this is either read off on a suitable gauge or a recorder. These anemometers are intended for gusty winds. Instruments of this kind do not respond

$$F_w = cA\rho\frac{u^2}{2} \qquad \mathrm{N}$$

to light winds, are inaccurate for high wind readings, and are slow at responding to variable winds. Plate anemometers have been used to trigger high wind alarms on bridges. It uses the fact that the force of moving air on a plate held normal to the wind is

where *A* is the area of the plate, *ρ* is the density of air, *u* is the wind speed, and *c* is a constant depending on the size and shape of the plate but not greatly different from unity.

This force can be used to drive a recording device directly or as input to a mechanical to electrical transducer. The main application of this type of anemometer has been in gust studies because of its very short response time. Gusts of duration 0.01 s can be examined with this anemometer.



Tube Anemometers:

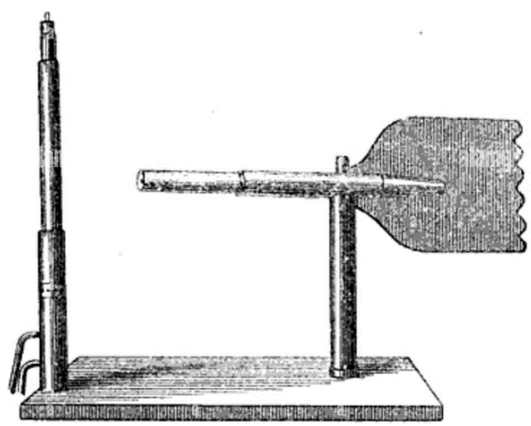
A pressure tube anemometer is called a windsock. These devices are found around airports. Material is made into a tube shape and is connected to wires. As the wind blows, it catches the larger end of the tube. This anemometer provides wind direction because the larger end of the sock will move into the wind. The faster the wind blows, the higher the tube raises off the ground. Pressure tubes do not provide readouts but are relative measurements of wind speed.

$$p_1 = p_s + \frac{1}{2}\rho u^2 \qquad \text{Pa}$$

The wind blowing into the mouth of a tube causes an increase of pressure in the tube, and that an air flow across the mouth causes a suction. The pressure in a thin tube facing the wind is

where p_s is the atmosphere pressure. The pressure in a tube perpendicular to the wind is

where c_1 is a constant less than unity. The total



$$p_2 = p_s - \frac{1}{2}c_1\rho u^2 \qquad \text{Pa}$$

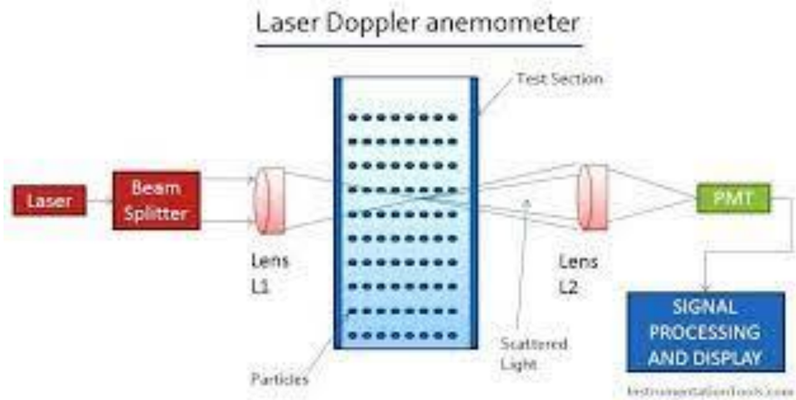
difference of pressure will then be

$$\Delta p = p_1 - p_2 = \frac{1}{2}\rho u^2(1 + c_1) \qquad \text{Pa}$$

The pressure difference can be measured with a *manometer* or with a solid state pressure-to-voltage transducer. It is not used much in the field because of difficulties with ice, snow, rain, moisture, dirt, insects and the sealing of rotating joints.

Laser Doppler Anemometer

Laser Anemometer is the one of the most effective anemometers. The device utilizes the Doppler shift effect, which is an excellent and reliable method of determining the speed of the wind. It contain more machinery setups. In this anemometer, a light ray can be used and that is further divided into two rays. The velocity can be decided by measuring amount of light that has been reflected off by the moving air particles when one of the two beams is made to enter the anemometer. Laser Doppler anemometers are advantageous because they don't disturb the fluid's path and they don't need to be calibrated. They can even work and measure in contaminated or reversed flow environments. This device can measure even the slightest changes in airflow. This type of anemometers commonly finds use for high-tech applications such as in jet engines and also in river hydrology.



Sonic Anemometer

The wind speed can be obtained by using sound waves that are made to flow throughout the transducer. These devices are used in scientific wind turbines and aircraft. An ultrasonic anemometer (or sonic anemometer) is the most advanced type. In this type, the speed of the wind is obtained by sending sound waves between a pair of transducers and calculating the way their speed is affected. These anemometers have the advantage of a very short time constant. They typically feature four sensors arranged in a square. They are Weather resistant and very less likely to fail due to the icing effect.

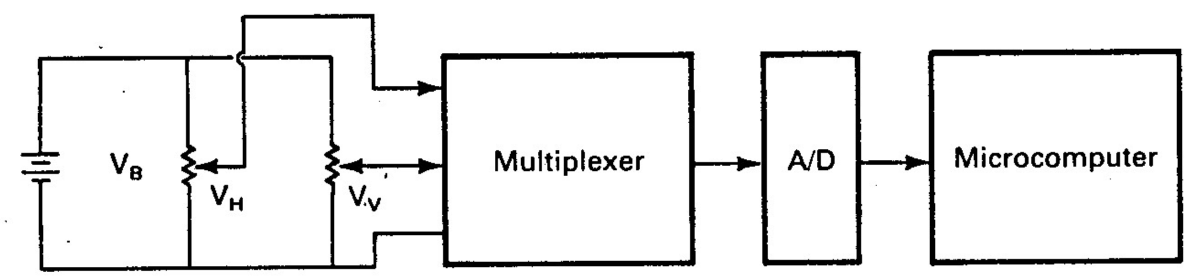
Ultrasonic anemometers can be either two-dimensional or three-dimensional. The two-dimensional ones are used in navigation and aviation, while the three-dimensional ones are used in measuring emissions, like in the industry power plants.

WIND MEASUREMENTS WITH BALLOONS

For installation of large wind turbines, we require knowledge of wind speed and direction at least the first 100 m above the earth's surface. As *night-time jets* moves at even greater heights, up to several hundred meters, so proper wind data is desirable. For the estimation of the wind data, wind balloons are widely used known as *meteorological balloons.* This method is relatively fast and inexpensive in screening of a number of sites which are useful for installing meteorological towers or wind turbines. About 600,000 meteorological balloons are released annually at various National Weather Service stations throughout the United States.

Larger balloons carry payloads of electronic instrumentation (Sonde instruments) which telemeter information back to earth. These can be used in extreme weather where visual tracking is impossible, and also can provide data from much greater heights. Whereas smaller balloons are quite adequate for the lower level wind measurements. In two hours, a weather balloon can rise above the clouds, higher than the paths of jet planes, passing through the ozone layer in the stratosphere. Reaching altitudes of 35 km (22 miles) or higher. The sonde instruments measure temperature, air pressure, humidity, and wind speed and wind direction. A radio signal sends these data back to scientists on the ground. To obtain wind data, they can be tracked by radar, radio direction finding, or navigation systems (such as the satellite-based Global Positioning System, GPS).

The following is the schematic diagram used for wind measurement using wind balloons containing sophisticated instruments.



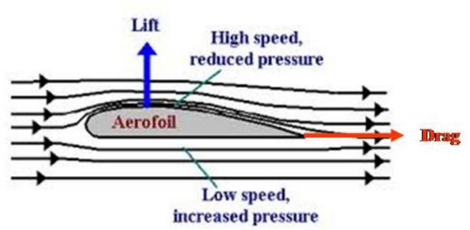
UNIT-2

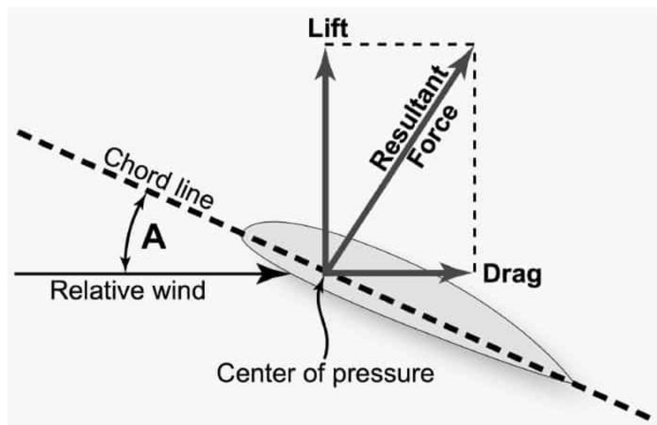
AERODYNAMIC PRINCIPLE

Aerodynamics is the study of dynamics associating with the motion of air over a moving object. When an aircraft moves, there is a relative motion between air and wings of aircraft. There is a rush of air over and below the wings. There are two primary physical principles by which energy can be extracted from the wind. Those are

i. Aerodynamic lift force
ii. Aerodynamic drag force

Drag forces provide the most obvious means of propulsion, these forces can feel by a person (or object) exposed to the wind. Drag force acts on the surface of the moving object in the opposite direction of the air. Lift forces are those created in vertically upward direction. When a body moving in air, air flows over the surface with greater velocity than below the surface. This create vertical pressure difference above and below the moving surface. So Lift force generated vertically upwards. The combination of these two forces creating the rotation of the body in air. This is the fundamental principle of motion of aero turbines. For better lift drag ratio, the object must be of aerofoil shape as shown in figure.





The basic features that characterize 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 aero foil, the lift produced can be more than thirty times greater than the drag
- Lift devices are generally more efficient than drag devices

Aerodynamic theories

Different theories are proposed to analyze the aerodynamics of wind turbines.

These theories give an insight to the behavior of the rotor under varying operating conditions. Let us discuss some of the fundamenta theories among them, applicable to HAWT.

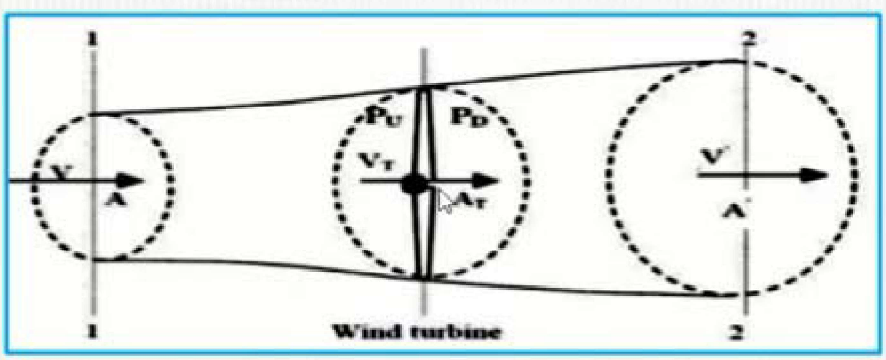
Axial momentum theory:

The conventional analysis of HAWT originates from the axial momentum concept

Assumption :-

- The flow is assumed to be incompressible and homogeneous.
- The rotor is considered to be made up of infinite number of blades.

Consider a wind turbine with rotor of area A_T, placed in a wind stream. Let A and A' be the areas of the sections 1-1, and 2-2 and V and V' are the respective wind velocities at these sections.



V_T is the velocity at the turbine section. According to the law of conservation of mass, the mass of air flowing through these sections is equal. Thus:

$$\boxed{\rho_a AV = \rho_a A_T V_T = \rho_a A'V'} \quad \text{---}(1)$$

Here P_U The Pressure at the top up stream side of the rotor
P_D The Pressure at the down stream side of the rotor

The thrust force experienced by the rotor is due to the difference in momentum of the incoming and out going wind, which is given by $F = m\,v_{incoming} - m\,v_{outgoing}$

Here $m = \rho_a A V$

$$F = \rho_a A V^2 - \rho_a A' V'^2 \quad -(2)$$

as $AV = A_T V_T = A'V'$ From equation (1) the thrust can be expressed as

$$F = \rho_a\, AV(V) - \rho_a\, A'V'(V')$$

$$F = \rho_a\, A_T\, V_T(V) - \rho_a\, A_T V_T(V')$$

$$F = \rho_a A_T V_T (V - V') \quad \text{--- (3)}$$

The thrust can also be represented as the pressure differences in the upstream and down stream sides of the rotor. P_U and P_D respectively. hence $F = (P_U - P_D) A_T$ --- (4)

Applying the Bernoulli's equation $P + \rho_a g h + \frac{1}{2}\rho_a V^2 = \text{Constant}$

at the sections and considering the assumption that the static pressure at sections 1-1 and 2-2 are equal to the atmospheric pressure p, we get

$$P + \frac{\rho_a V^2}{2} = P_U + \frac{\rho_a V_T^2}{2} \quad \text{--- (5)}$$

and

$$P + \frac{\rho_a V'^2}{2} = P_D + \frac{\rho_a V_T^2}{2} \quad \text{--- (6)}$$

From subtract equation's (5) - (6)

$$\boxed{P_U - P_D = \frac{\rho_a (V^2 - V'^2)}{2}} \quad \text{--- (7)}$$

Substitute equation (7) in equation (4)

$$\boxed{F = \frac{\rho_a A_T (V^2 - V'^2)}{2}} \quad \text{--- (8)}$$

Comparing equations (3) &(8)

$$(V - V')\cancel{\rho_a A_T} V_T = \frac{\cancel{\rho_a A_T}(V^2 - V'^2)}{2}$$

$$(V - V')V_T = \frac{(V^2 - V'^2)}{2}$$

$$\cancel{(V - V')}V_T = \frac{\cancel{(V - V')}(V + V')}{2}$$

$$\boxed{V_T = \frac{(V + V')}{2}} \quad \text{--- (9)}$$

Thus, the velocity of the wind stream at the rotor section is the average of the velocities as it's up-stream and down- Stream sides,

At this stage, we introduce a parameter, termed as the "axial induction" factor into our analysis.

The axial induction factor (a) :- indicates the degree with which the wind velocity at the upstream of the rotor in slowed down by the turbine , thus

$$\boxed{a = \frac{V - V_T}{V}}$$

$$aV = V - V_T$$

$$aV - V = -V_T$$

$$V_T = V - aV$$

$$\boxed{V_T = V(1 - a)} \quad \text{--- (10)}$$

From equations (9) & (10)

$$\frac{V+V'}{2} = (V - aV)$$

$$V + V' = 2(V - aV)$$

$$V + V' = 2V - 2aV$$

$$V' = 2V - 2aV - V$$

$$V' = V - 2aV$$

$$\boxed{V' = V(1 - 2a)} \quad \text{--- (11)}$$

The power imparted to the wind turbine is due to the transfer of kinetic energy from the air to the rotor
the mass flow through the rotor over a unit time is

$$\boxed{m = \rho_a A_T V_T} \quad \text{--- (12)}$$

hence the power developed by the turbine due to this transfer of kinetic energy is

$$\boxed{P_T = \frac{1}{2}\rho_a A_T V_T (V^2 - V'^2)} \quad \text{--- (13)}$$

Substitute V_T & V' values of equations (10) & (11) substitute in equation (13), we get,

$$P_T = \frac{1}{2}\rho_a A_T (V - aV)[V^2 - V^2(1-2a)^2]$$

$$P_T = \frac{1}{2}\rho_a A_T (V - aV)[\,V^2 - \,V^2(1 + 4a^2 - 4a)]$$

$$P_T = \frac{1}{2}\rho_a A_T \{V(1-a)\left[-4a^2V^2 + 4aV^2\right]\}$$

$$P_T = \frac{1}{2}\rho_a A_T \{V(1-a)\left[\,4aV^2(1-a)\right]\}$$

$$P_T = \frac{1}{2}\rho_a A_T \left[\,4aV^3(1-a)^2\right] \quad \text{--- (14)}$$

We know that $\boxed{P_T = \frac{\rho_a A_T V^3}{2} C_P}$

From power coefficient $C_P = \frac{2P_T}{\rho_a A_T V^3}$

Substitute equation (14) in equation C_P

$$C_P = \frac{2\frac{1}{2}\rho_a A_T \left[4aV^3(1-a)^2\,\right]}{\rho_a A_T V^3}$$

$$\boxed{C_P = 4a(1-a)^2} \quad \text{--- (15)}$$

For C_P is maximum $\frac{dC_P}{da} = 0$

The differentiating equation (15) and solving we get , $a = \frac{1}{3}$

Substitute $a = \frac{1}{3}$ in equation (15)

$$C_P = 4\left(\frac{1}{3}\right)\left[1 - \frac{1}{3}\right]^2$$

$$C_P = \frac{4}{3}\left[\frac{3-1}{3}\right]^2$$

$$C_P = \frac{4}{3}\left[\frac{2}{3}\right]^2 \rightarrow C_P = \frac{4}{3}\left[\frac{4}{9}\right]$$

$$\boxed{C_P = \frac{16}{27}}$$

The maximum theoretical power co-efficient of a horizontal axis wind turbine is 16/27 and maximum power produced is

$$\boxed{P_{T_{max}} = \frac{1}{2}\rho_a A_T V^3 \frac{16}{27}}$$

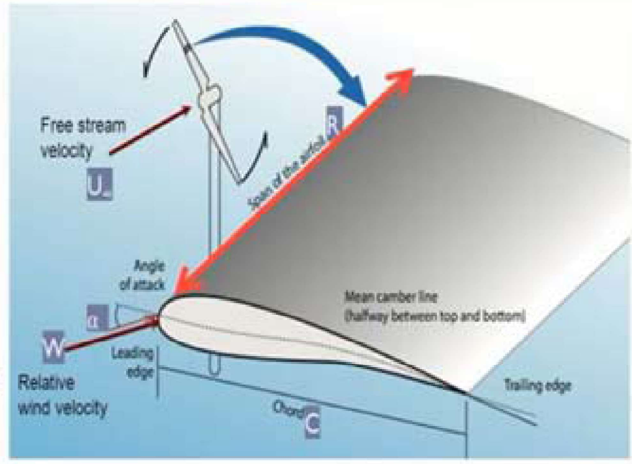
This limit for the power coefficient is Betz limit

Blade element theory

It is considered :-

- The blades are made up of a number of strips arranged in the span wise direction.

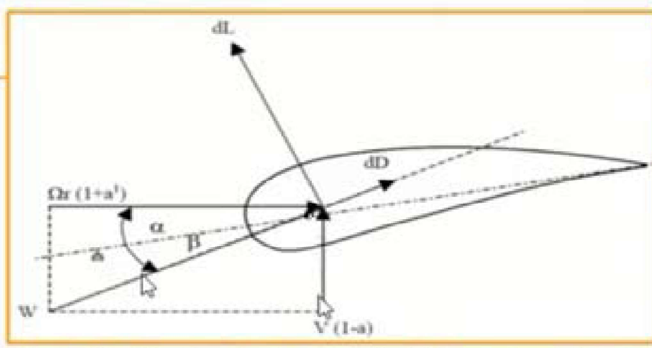
Span = length of airfoil normal to the cross-section



- The strips have infinitesimal thickness.
- These strips are aerodynamically independent and do not have any interference between them.

- Under this analysis, the lift and drag forces acting over the strip are estimated and integrated over. The total blade span incorporating the velocity terms, to obtain the torque and power developed by the blade.
- This is further multiplied by the number of blades to get the total rotor torque and power.
- The blade element theory give us more understanding on the relation between the airfoil properties, thrust experienced by the rotor and the power produced by it.

- The velocities and forces acting on an infinitesimal blade element.
- The understand wind velocity V is slowed down to $(1\text{-}a)V$ as it reaches the rotor.
- A velocity of $\Omega r(1 + a')$ is experienced by the element due to rotation of the blades and the wake behind the rotor, where a' is the tangential induction factor.
- W represents the resultant of these two velocities α is the angle of attack, Φ is the flow angle and β is the blade setting angle.



An infinitesimal element of the rotor blade

Lift forces acting on the infinitesimal airfoil section is given by:

$$dL = \frac{1}{2}\rho_a C dr W^2 C_L \qquad \text{---(1)}$$

where C is the airfoil chord, dr is the thickness of the section considered and C_L is the lift coefficient. Similarly, the elemental drag is given by where C_D is the drag coefficient

$$dD = \frac{1}{2}\rho_a C dr W^2 C_D \qquad \text{---(2)}$$

the thrust (dF) and torque (dT) acting on the blade element are

$$dF = dL\cos\phi + dD\sin\phi \qquad \text{---(3)}$$

$$dT = r[dL\sin\phi - dD\cos\phi] \qquad \text{---(4)}$$

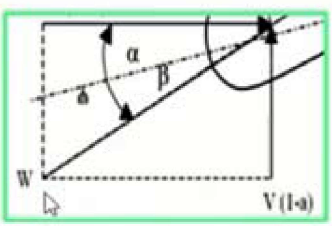
Substitute (1) & (2) equations in (3) & (4) equations, and considering the total number of blades B

$$dF = \frac{1}{2}\rho_a B\, C\, dr\, W^2[C_L\cos\phi + C_D\sin\phi] \qquad \text{---(5)}$$

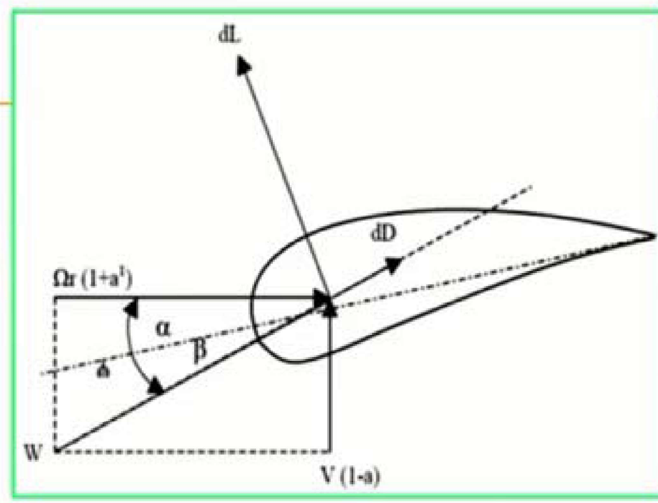
and

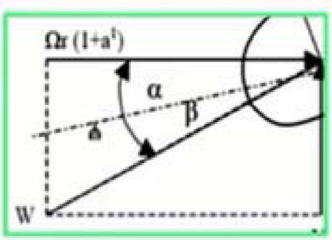
$$dT = \frac{1}{2}\rho_a B\, C\, r\, dr\, W^2[C_L\sin\phi - C_D\cos\phi] \qquad \text{---(6)}$$

From the geometry of the figure



$$\sin\phi = \frac{V(1-a)}{W}$$





$$\cos\phi = \frac{\Omega r(1+a')}{W}$$

$$\sin^2\phi + \cos^2\phi = \frac{V^2(1-a)^2}{W^2} + \frac{\Omega^2 r^2(1+a')^2}{W^2}$$

$$W^2(\sin^2\phi + \cos^2\phi) = V^2(1-a)^2 + \Omega^2 r^2(1+a')^2$$

$$W^2 = V^2(1-a)^2 + \Omega^2 r^2(1+a')^2$$

$$\boxed{W = \sqrt{V^2(1-a)^2 + \Omega^2 r^2(1+a')^2}}$$

Here, **W** can be represented as the resultant of the velocities

The total torque developed by the rotor can be computed by integrating the elemental torque from the root to the tip of the blade.

Rotor power is estimated by multiplying this torque by its angular velocity.

Maximum power Coefficient (C_p)

Power Coefficient (C_p) is a measure of wind turbine efficiency often used by the wind power industry.

C_p is the ratio of actual electric power produced by a wind turbine divided by the total wind power flowing into the turbine blades at specific wind speed.

$$\boxed{C_P = \frac{\text{Actual electrical power produced}}{\text{Wind power into Turbine}} = \frac{P_{out}}{P_{in}}}$$

The term C_p is called a power coefficient, which has a theoretical maximum of 0.593 (or 59.3%) this is called Betz's Law and the power coefficient is called the Betz limit.

In practice, the Betz limit is about 0.4–0.5 (40–50%).

The Cp of a particular wind turbine varies with operating conditions such as wind speed, turbine blade angle, turbine rotation speed, and other parameters. It is a measure of a particular wind turbine's overall system efficiency.

WIND TURBINE DESIGN CONSIDERATION

The efficiency of any wind turbine obviously due to the specific design of the turbine. Wind turbines are designed based on certain conditions like blade design, height of the tower, supported area and wind speed.

Blade design;

The moment of turbine blade in air due to lift drag ratio. Basically the ratio 3:1. For maintaining such ratio the shape of the blade must be in aerofoil structure. The no. of blades may be 2 or 3. Number of blades is also important, as the blade number beyond 3, decrease the power efficiency of the turbine. The design and size of the blades are depending on the local wind speeds and area.

Height of the tower:

Most of the wind turbines are constructed at high hill regions as the wing speed is maximum at high altitudes. So maximum wind energy can be produced at greater heights. Fundamentally design of the turbine depends on the height of the tower supported from the base. The low height turbine cannot produce much energy as there are several obstacles near the ground like trees, buildings, other towers, etc.

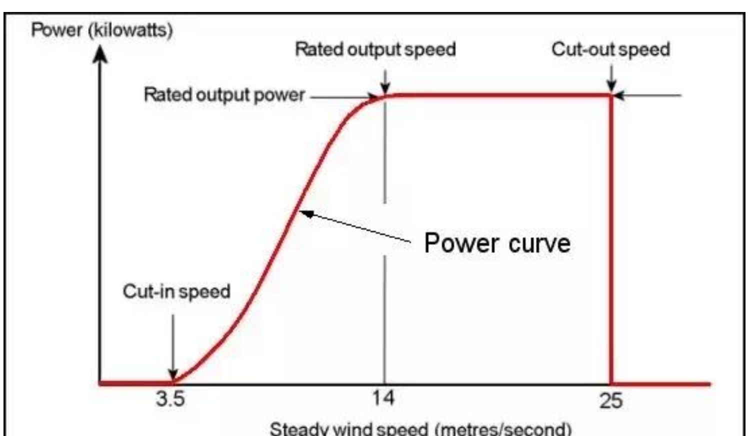
Supported area:

Wind turbines are constructed on strong supported surface area because the thrust force acting on the blades of the turbine may affect the base of the tower. So the base of the tower must be well supported with concrete on the hard surface. It cannot be constructed on loose soil types. The base of the turbine depends on the turbine size and wind speed.

Wind Speed:

Wind speed have the much significance in the design of the any wind turbine. Wind turbines are designed in such a way that maximum energy can be obtained from winds. The efficiency of the wind turbine depends on the local wind speeds. So the turbines are constructed where the location have constant high wind speeds.

THEORETICAL SIMULATIONS OF TURBINE CHARACTERISTICS



Typical wind turbine power output with steady wind speed.

For the large-scale development of wind turbines, it is important to analyze the aerodynamic performance of the turbines. There are many experimental and numerical simulation methods are available to study the aerodynamic performance of wind turbines. There are certain wind related theoretical simulations to check the performance of the wind turbine. The actual performance can be identified using theoretical wind power-speed curve. From the theoretical simulation curve, the important parameters like cut-in speed, rated output speed, cut-off speed are identified. Further, performance of wind turbine is estimated.

Turbines are designed to operate within a specific range of wind speeds. The limits of the range are known as the cut-in speed and cut-out speed.

Cut-in speed

At very low wind speeds, the rotation of blades of the turbine not possible. At a certain possible wind speed, the blades of the turbine starts rotating and can generated power. This speed is called cut-in speed. The cut-in speed is the point at which the wind turbine is able to generate power. Typically the value of cut-in speed around 3-5 m/sec.

Rated output speed

When the speed raises above cut-in speed, the power generation increased rapidly as in the figure. At a certain speed the power become maximum. This speed is called rated output speed. Between the cut-in speed and the rated speed, the maximum output is reached. Here the power output will increase cubically with wind speed. For example, if wind speed doubles, the power output will increase 8 times. This cubic relationship is an important factor for wind power. This cubic dependence does cut out at the rated wind speed limit. Generally it occurs between 12 to 17 m/sec.

Cutout speed

As the wind speed increase furthermore, the force on the wind turbine increases rapidly. Now there is a risk of damage of rotor. This is called cut-out speed. The cut-out speed is the point at which the turbine must be shut down to avoid damage to the equipment. The typical cut-out speed value is above 25 m/sec.

The cut-in and cut-out speeds are related to the turbine design and size and are decided on prior to construction.

Wind turbine efficiency or power coefficient: The available power in a stream of wind of the same cross-sectional area as the wind turbine can easily be shown to be

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

where the wind speed U is in metres per second, the density ρ is in kilograms per cubic metre and the A is the cross-sectional area in square meters then the available power is in watts. The efficiency, μ, or, as it is more commonly called, the power coefficient, cp, of the wind turbine is simply defined as the actual power delivered divided by the available power:

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

TEST METHODS FOR DESIGN OF WIND TURBINES

When design a wind turbine, many considerations kept in mind both general and technical. The design process involve a large no. of electrical and mechanical things that we used to convert wind power into electrical power. The key design steps are

1. Determine applications

The first step when design a wind turbine is to determine the applications. Wind turbines that are being used for large scale power generation have a different design and they are used in remote areas.

2. Review previous experiences

Older turbines give useful information in how they were built and constructed. Previous experiences show that the maintenance and services through the turbine must be safe. It helps designer to construct a desired wind turbine.

3. Select a layout

Selecting a layout is another important point for the designing. The layout should well connected by the transport and better be at high altitude.

4. Preliminary loads and estimates

It is very crucial to estimate the loads of the turbine and must be able to withstand which is done in the early design process.

5. Develop the design

A preliminary design can be developed after the layout has been chosen and the load has been estimated.

6. Predict the performance

It is also important to predict the performance of the wind turbine by using the power curve.

7. Elevate the design

The turbine must be able to withstand any expected loading that can be taken place normal operation and abnormal circumstances.

8. Estimate cost and cost of energy

How much the turbine can produce power and the cost of the turbine itself is the key factor of the energy.

9. Build a prototype

A prototype should be build be after the design is completed. The prototype verifies the assumptions in the design. By testing the factors one can make sure the turbine can operate as expected.

10. Test a prototype

After the prototype build, several tests done to verify the performance whether the power is on the power curve is developed or not.

11. Design production machine

The production of machine is the final step in the design process. The final design should be as close to the prototype as possible.

ROTORS CHARACTERISTICS

- There are several technical parameters that are used to characterize windmill rotors. The tip speed ratio is defined as the ratio of the speed of the extremities of a windmill rotor to the speed of the free wind.
- 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.
- 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 C_p) and its variation as a function of tip-speed ratio is commonly used to characterize different types of rotor. As mentioned earlier there is an upper limit of C_p = 59.3%, although in practice real wind rotors have maximum C values in the range of 25%-45%.

- 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 but are 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.

There are various important wind speeds to consider:

- Start-up wind speed - the wind speed that will turn an unloaded rotor
- Cut-in wind speed – the wind speed at which the rotor can be loaded
- Rated wind speed – the wind speed at which the machine is designed to run (this is at optimum tip-speed ratio)
- 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.

UNIT-3

WIND PUMPS

Wind pumps are devices for moving water, powered solely by the wind.

There are 3 main types:

Direct drive: a crank on the axle of the turbine rotor raises and lowers a pump plunger via a rod

Geared drive: does the same, but the crank is geared to run more slowly than the turbine; smaller turbines benefit from being geared, to enable a slower pump, but with more volume

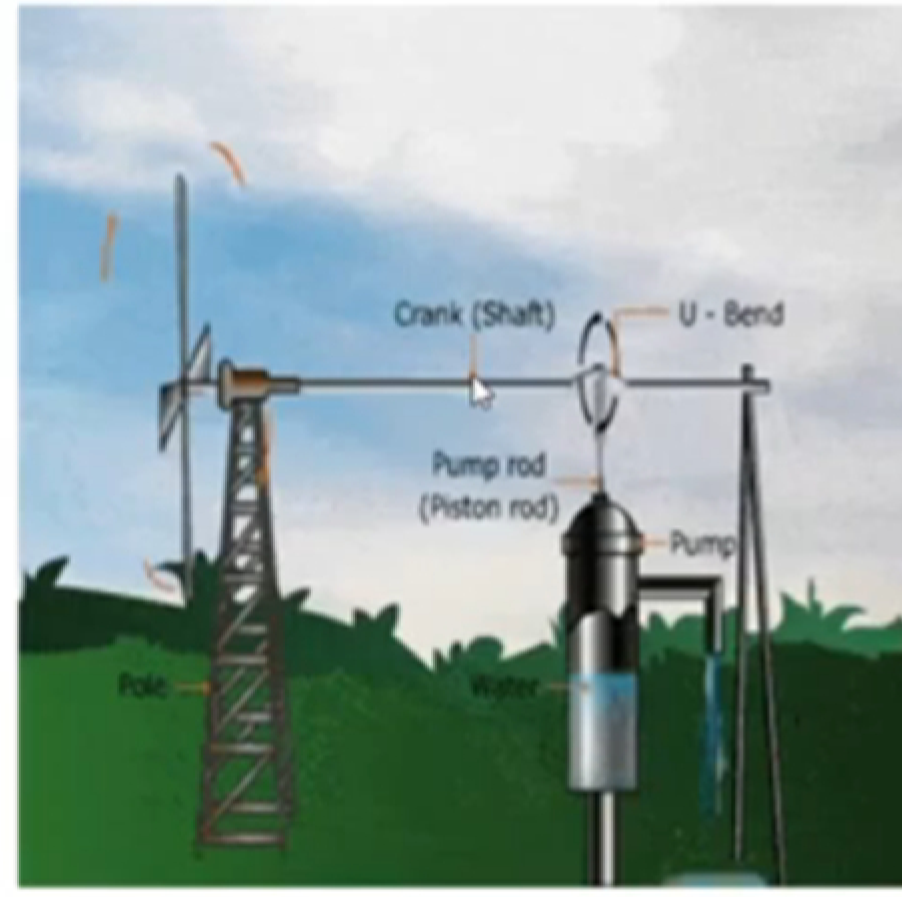
Electric generator on the turbine: the turbine generates electricity which drives the pump; you can then have the pump some distance from the turbine

- A water-pumping windmill pumps water from wells, ponds, and bore wells for drinking, minor irrigation, salt farming, fish farming, etc.
- Available windmills are of two types, namely direct drive and gear type.
- The most commonly used windmill has a horizontal axis rotor of 3–5.5 m diameter, with 12–24 blades mounted on the top of a 10–20 m high mild steel tower.
- The rotor is coupled with a reciprocating pump of 50–150 mm diameter through a connecting rod.
- Such windmills start lifting water when wind speed approaches 8–10 kilometres (km) per hour.
- Normally, a windmill is capable of pumping water in the range of 1000 to 8000 litres per hour, depending on the wind speed, the depth of water table, and the type of windmill.
- Windmills are capable of pumping water from depths of 60 m. Water-pumping windmills have an advantage in that no fuel is required for their operation, and thus they can be installed in remote windy areas where other conventional water pumpings are not possible.
- However, water-pumping windmills have limitations too. They can be operated satisfactorily only in medium wind regimes (12–18 km per hour).
- Further, special care is needed at the time of site selection as the sites should be free from obstacles such as buildings and trees in the surrounding areas.
- The cost of the system being high, many individual users do not find them affordable.

A wind pump is a type of windmill which is used for pumping water.

Windmill water pump is advice use wind energy to lift water by using translation motion of wind to rotate the blades which connect by rotor with gear that transfer that rotation motion of windmill to reciprocating motion on crank shaft that act on reciprocating pump to lift water by its motion.

reciprocating motion



COMPONENTS OF THE WINDMILL WATER PUMP

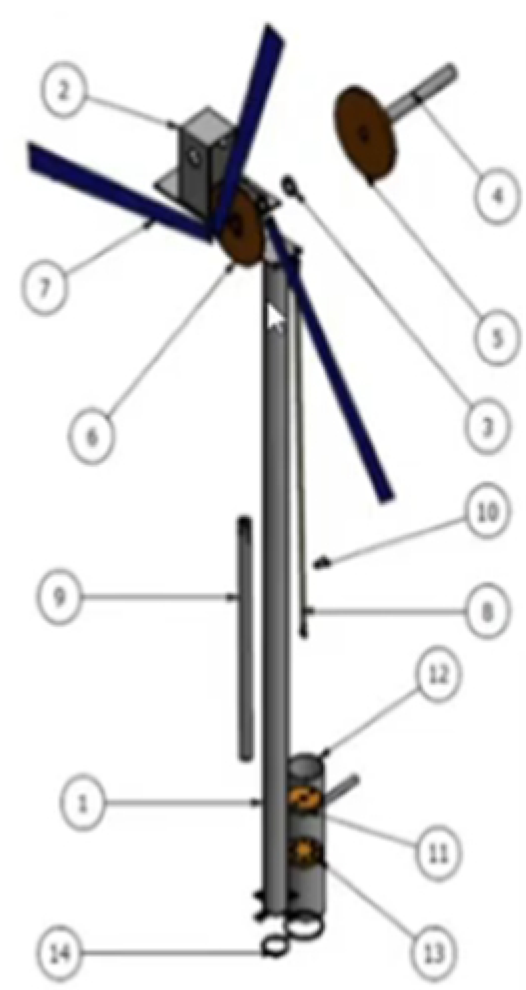
1. Rotor Blade

Rotor blades are the most important in a windmill powered water pump assembly as it captures wind. A cup shaped PVC septic pipe material which proved to be helpful for generation of mechanical work leading to the generation of water pump.

2. Blade Hub

The material of the blade hub is wood disc. It is used to transfer motion from the shaft to the slider crank disc.

Part Number	Part Name
1	Support Tower
2	Casing
3	Ball bearing
4	Shaft windmill
5	Rotating disc
6	Blade hub
7	Fan Blade
8	Shaft link
9	Plunger shaft
10	Connecting rod
11	Displacement pump
12	Plunger
13	Plunger hanger



3. Slider Crank Disc

The slider crank disc is made up by a cyclic wood which is connected to the shaft at one end and the other end of the slider crank disc is connected to the hand pump by means of a connecting rod. The slider crank disc converts rotary motion of the windmill to reciprocating motion.

4. Shaft

The shaft is a component which is connected between the blade hub and the slider crank disc.

Gear Box contain a Gear system used to increase the rotational speed from rotor to crank, bearing system used to reduce the frictional losses and vibration

5. Ball Bearing

These are machine components designed to provide support for rotating elements by taking pure radial loads, pure thrust loads or a combination of the two.

6. Connecting Rod

The connecting rod connects between slider crank disc and the plunger. It has length of 2.1 m and pinned at radius of 0.15m to the slider crank and plunger.

7. Tower

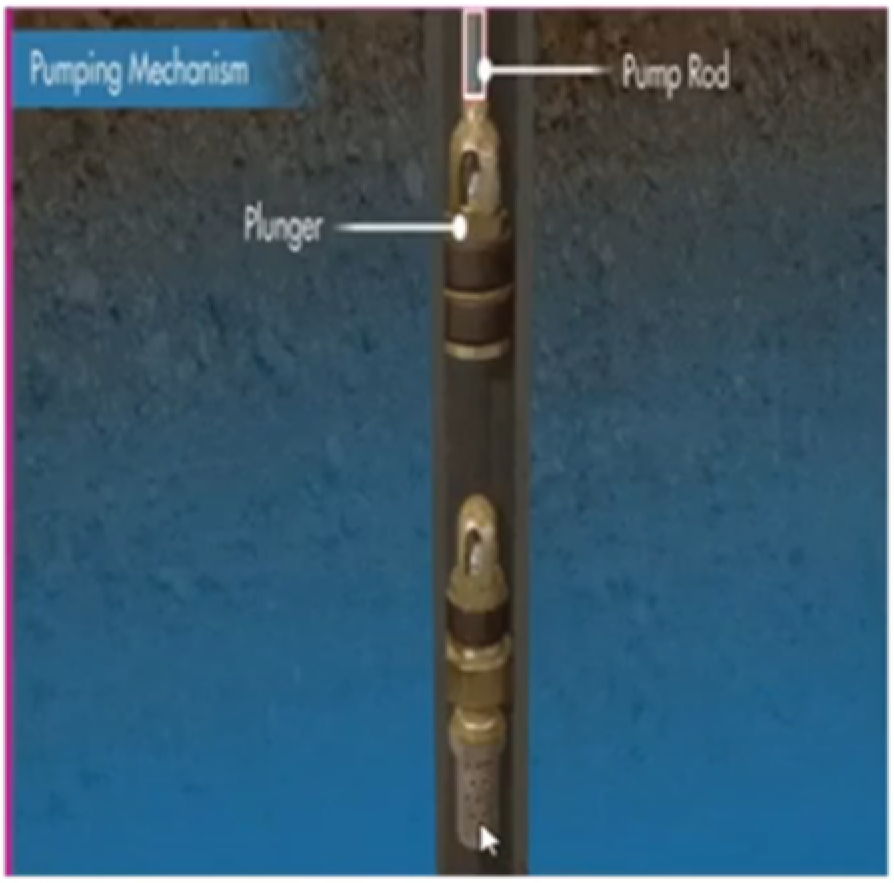
The tower raises the turbines assembly well above the turbulent air current close to the ground and captures higher wind speeds

8. Displacement Pump

This consists of cylinder with an inlets pipes and valves at the base. A rubber sealed piston with a one way valve and water outlets at the top.

Water passes through the top only on the lifting stroke of the piston. These rely on a piston, which is close fitting within a cylinder containing water.

By lifting the piston a vacuum is created which displaces the water up the pipe. A one way foot valve is needed to stop water from flowing back into the well or tank.



PERFORMANCE EVALUATION TESTS OF THE WINDMILL WATER PUMP

A wind powered water pump with rotor diameter of 2.14m giving a total surface area of $3.733m^2$ and average wind speed of 2.5m/s at 16m above the ground level .

The design head pump is 0.3m and flow rate per day 120.179 L/min.

The pumping performance test consists of continuous sets of measurements taken every twenty minutes time intervals.

Measurements of wind speed, flow rate, time and volume of water discharge were taken in the same order every time.

ECONOMICS OF WIND ENERGY

- The growth of wind energy in India is enormous and proves to be an option to moderate the challenges to meet electricity demands, environmental pollution, greenhouse gas emission and depleting fossil fuel etc. India has the second largest wind market in Asia after China and fourth amongst the global cumulative installed countries of the world after USA and Germany.
- Economics of wind energy utilization is a very important thing. Onshore wind is an inexpensive source of electric power, cheaper than coal plants and new gas plants. According to the survey the wind turbines reached grid parity (the point at which the cost of wind power matches traditional sources) in some areas of India.
- In 2021 the CEO of Siemens Gamesa warned that increased demand for low-cost wind turbines caused by high input costs and high costs of steel. This increased pressure on the manufacturers and decreasing profit margins.
- In worldwide, Northern Eurasia, Canada, some parts of the United States, and Patagonia in Argentina are the best areas for onshore wind: whereas in other parts of the world solar power, or a combination of wind and solar, tend to be cheaper.
- Wind power is initially capital intensive but has no fuel costs. The price of wind power is therefore much more stable than the volatile prices of fossil fuel sources. However, the estimated average cost per unit of electric power must include the cost of construction of the turbine and transmission facilities, borrowed funds, return to investors (including the cost of risk), estimated annual production, and other components averaged over life of the equipment (more than 20 years). Energy cost estimates are highly dependent on these assumptions.
- The cost will be decreased when wind turbine technology improved.
- The government must provide subsidies and incentives for encouraging alternative energy resources.

WIND ENERGY IN INDIA

- The growth of wind energy in India is enormous and proves to be an option to moderate the challenges to meet electricity demands, environmental pollution, greenhouse gas emission and depleting fossil fuel etc. India has the second largest wind market in Asia after China and fourth amongst the global cumulative installed countries of the world after USA and Germany.
- In the early 1980's, the Department of Non-conventional Energy Sources (DNES) came into existence with the aim to reduce the dependence of primary energy sources like coal, oil etc. in view of the Country's energy security.

- The DNES became Ministry of Non-conventional Energy Sources (MNES) in the year 1992 and now from 2006, the Ministry was renamed as Ministry of New & Renewable Energy (MNRE).
- The growth of Renewable Energy in India is enormous and Wind Energy proves to be the most effective solution to the problem of exhausting fossil fuels, importing of coal, greenhouse gas emission, environmental pollution etc. Wind energy as a renewable, non-polluting and affordable source directly avoids dependency of fuel and transport, can lead to green and clean electricity.
- Wind energy and other Renewable Energy Sources (excluding large Hydro) have installed capacity 39248 MW (March 2021), accounts for 24.7% of India's overall installed power capacity of 382151 MW.
- Wind Energy holds the major portion of 41.5% of total RE capacity (94434 MW) among renewable and continued as the largest supplier of clean energy.
- The Government of India has announced a creditable Renewable Energy target of 175GW by 2022 out of which 60GW will be coming from wind power.
- According to National Institute of Wind Energy (NIWE), the Wind Potential in India have 49 GW for 50 m hub-height but the potential grows to 102 GW for 80m hub height, and can be extended to 302GW at 100 Meter hub height.
- Further a new study by NIWE at 120m height has estimated a potential of 695GW power.
- One of the major advantages of wind energy is its integral strength to support rural employment and uplift of rural economy. Further, unlike all other sources of power, wind energy does not consume any water-which in itself will become a scarce commodity.
- Overall the future of Wind Energy in India is bright as energy security and self-sufficiency. The biggest advantage with wind energy is that the fuel is free, and also it doesn't produce CO_2 emission.
- Wind farm can be built quickly and the wind farm land can be used for farming also. So it serving dual purpose, and it is cost-effective as compare to other forms of renewable energy. The following are the top 10 wind potential states in India.

S. No.	State	Wind Potential (MW)
1	Gujarat	84431.33
2	Rajasthan	18770.49
3	Maharashtra	45394.34
4	Tamil Nadu	33799.65
5	Madhya Pradesh	10483.88

6	Karnataka	55857.36
7	Andhra Pradesh	44228.60
8	Kerala	1699.56
9	Telangana	4244.29
10	Odisha	3093.47

Principle of wind energy Generation

Wind is defined as moving air when the earth heats up from sun rays it releases wind. It is a balanced reaction to cool earth. The sun heat is more on dry land than on sea. The air expands and easily reaches maximum high altitudes, then cool air drops downwards and moves as wind.

STAND-ALONE WIND ENERGY CONVERSION SYSTEM APPLICATIONS

In many places wind power is a less cost option for proving power to homes and businesses that are remote from a grid. Wind energy generated by WECS. If the wind speed is above 4m/sec then it is utilized as electricity in household range from operating small house hold applications to refrigeration, freezing, heating, cooling and lighting.

A large system can provide power to the centralized community centers, health clinic or school. A power system for a school can provide electricity for computers and educationl television, video and radio. The waste energy can be used to changing the devices. The energy requirement and equipment size calculations are similar on a large scale to those for a stand-alone system.

GRID-CONNECTED WECS APPLICATIONS:

Today in good wind regions, wind power can be the least cost resources. Wind power has been the fastest growing energy source in the world for the past few years. Wind power can help the diversity of the country energy resources and can bring construction and maintenance jobs to the local community. In large scale wind power applications, there are two keys to develop the cost effective wind speed and project size. Since the power output is depends on the wind speed differences in 1m/sec can mean difference of a cent or more per kWh in the cost of the electricity productions. Wind projects are subjected to small scale economics.

HYBRID APPLICATIONS OF WECS:

The system was sized to supply an average of 36.5 kWh/day enough to provide electricity for lighting and appliance use in 72 households, a school, street lights and the village playground.

Supply of electricity to a dryer supports the lively hood of the village formers.

Since the system was developed specifically for remote areas. It has automatic start-stop controls and easy operation and maintenance procedure.

ENVIRONMENTAL IMPACT ON WIND TURBINES

(i) **Emission.** There is no pollution or emission of carbon dioxide during operation of wind turbine. Carbon dioxide emission only takes place during manufacturing and installation of wind turbine, which is also very low. Even energy used to construct and install wind turbine is low, which is also paid back by generating same amount of energy in a period of few months.

(ii) **Bird's life.** The rotating rotors give a threat to bird's life. As per the reports, a large number of birds are killed every year when they fly into the fast rotating blades unknowingly.

(iii) **Noise.** The rotating blades create noise of high sound level due to movement of blades and churning of air (aerodynamic noise). The noise disturbances caused by a wind turbine are very high and unbearable. This is the reason why the wind turbine is not located close to any inhabited areas.

(iv) **Interference to transmission.** Wind turbine with high tower can interfere with the microwave signals of TV and communication, thereby adversely affecting the quality of radio and TV reception at nearby areas.

(v) **Visual intrusion.** Wind turbines with their high towers are visible over a wide area, thereby disturbing the natural beauty of a site.

(vi) **Safety.** The rotating blades may cause harm and injury when any of these blades may break or get damaged, especially during high wind conditions.

(vii) **Impact on ecosystem.** The wind is produced due to differential heating of the earth surface so that ecosystem is maintained. Hence, large-scale interception and use of wind energy can cause adverse impact on ecosystem.

UNIT-4

HYDROLOGY

Hydrology is the study of the distribution and movement of water both on and below the Earth's surface, as well as the impact of human activity on water availability and conditions.

Hydrology is an extremely important field of study, dealing with one of the most valuable resources on Earth: water. All aspects of the Earth's available water are studied by experts from many disciplines, from geologists to engineers, to obtain the information needed to manage this vital resource. Hydrologists rely on their understanding of how water interacts with its environment, including how it moves from the Earth's surface, to the atmosphere, and then back to Earth. This never-ending movement is called the hydrologic cycle, or the water cycle.

Hydrology is the science that encompasses the occurrence, distribution, movement and properties of the waters of the earth and their relationship with the environment within each phase of the hydrologic cycle. The water cycle, or hydrologic cycle, is a continuous process by which water is purified by **evaporation** and transported from the earth's surface (including the oceans) to the **atmosphere** and back to the land and oceans. All of the physical, chemical and biological processes involving water as it travels its various paths in the atmosphere, over and beneath the earth's surface and through growing plants, are of interest to those who study the hydrologic cycle.

OVER VIEW OF HYDRO POWER PLANTS

Small hydropower resources are considered as non-conventional and these resources have attracted favorable attention after the oil crisis of 1973. The small hydropower projects are extremely suitable for hilly, underdeveloped and remote areas as these resources eliminate the need of long transmission system.

Hydro power projects are classified as large and small hydro projects based on their sizes. Different countries have different size criteria to classify small hydro power project capacity ranging from 10MW to 50 MW. In India, hydro power plants of 25MW or below capacity are classified as small hydro, which have further been classified into micro (100kW or below), mini (101kW-2MW) and small hydro (2-25MW) segments. Hydro

Power was being looked after by Ministry of Power prior to 1989 mainly with the help of State Electricity Boards. In 1989, plant capacity up to 3MW and below was transferred to the Ministry of New and Renewable Energy (MNRE) and as such 63 MW aggregate installed capacity of 3MW and below hydro projects came within the jurisdiction of MNRE. Many initiatives were taken by the Ministry since then for the promotion of small hydro which included implementation of a UNDP-GEF assisted Technical Assistance project entitled “Optimizing Development of Small Hydro Resources in Hilly Regions of India” and India-Renewable Resources Development Project with IDA credit line having interalia small hydro development component with target of 100MW canal based small hydro power projects through private sector participation. Subsequently plant capacity up to 25MW and below was entrusted with the MNRE in November 1999.

PRINCIPLE OF Hydroelectric power plants

Electric power is generated when water from height is made to flow through hydraulic turbine. The hydraulic turbine converts the potential energy of water or kinetic energy of flowing stream into mechanical energy on its rotating shaft. The old-style water wheels used the impulse generated by the weight of falling water for their rotation, but modem hydraulic turbines operated on the principle of impulse and reaction to convert kinetic energy and potential energy respectively into mechanical energy.

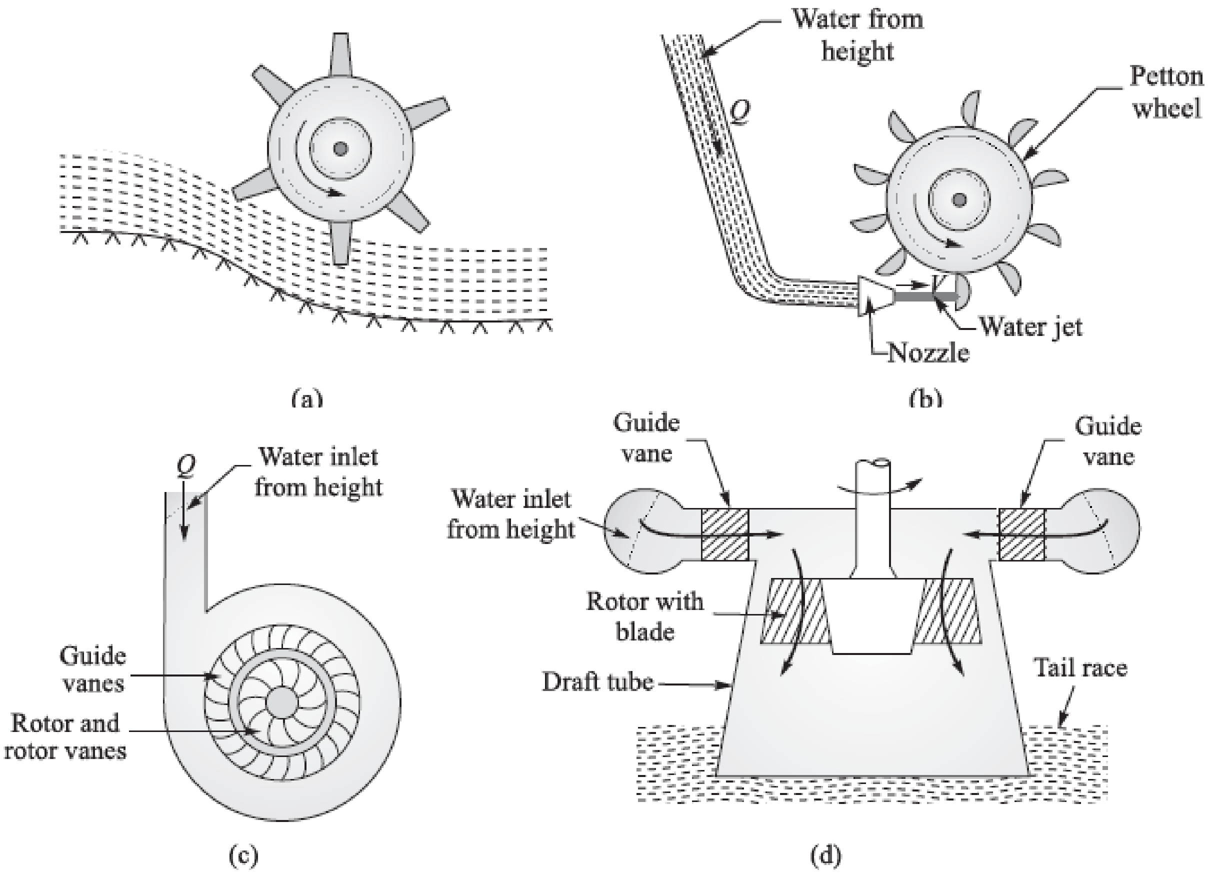
TYPES of TURBINES:

The turbines can work on the principles of impulse and reaction. In impulse turbine, the complete potential energy or head of water is firstly converted into kinetic energy using a nozzle outside the turbine. The fast jet of water emerging from the nozzle is used to strike the vanes of the turbine to impart motion. In reaction turbine, nozzle is not used and vanes (guide or stationary vanes and movable vanes on the rotor) are shaped in the form of nozzles to convert potential energy of water into kinetic energy when water flows from the inlet to the outlet of the turbine.

Turbines are more commonly used today to power small hydropower systems. The moving water strikes the turbine blades, much like a waterwheel, to spin a shaft. But turbines are more compact in relation to their energy output than waterwheels. They also have fewer gears and require less material for construction. There are two general classes of turbines: impulse and reaction.

Impulse

Impulse turbines, which have the least complex design, are most commonly used for high head microhydro systems. They rely on the velocity of water to move the turbine wheel, which is called the *runner*. The most common types of impulse turbines include the *Pelton* wheel and the *Turgo* wheel.



Types of hydraulic turbines. (a) Water wheel, (b) Impulse turbine, (c) Reaction turbine (Francis) and (d) Reaction turbine (Kaplan).

The Pelton wheel uses the concept of jet force to create energy. Water is funneled into a pressurized pipeline with a narrow nozzle at one end. The water sprays out of the nozzle in a jet, striking the double- cupped buckets attached to the wheel. The impact of the jet spray on the curved buckets creates a force that rotates the percent. Pelton wheel turbines are avail- able in various sizes and operate best under low-flow and high-head conditions.

The Turgo impulse wheel is an upgraded version of the Pelton. It uses the same jet spray concept, but the Turgo jet, which is half the size of the Pelton, is angled so that the spray hits three buckets at once. As a result, the Turgo wheel moves twice as fast. It's also less bulky, needs few or no gears, and has a good reputation for trouble-free operations. The Turgo can operate under low-flow conditions but requires a medium or high head.

Reaction

Reaction turbines, which are highly efficient, depend on pressure rather than velocity to produce energy. All blades of the reaction turbine maintain constant contact with the water. These turbines are often used in large-scale hydropower sites. Because of their complexity and high cost, they aren't usually used for microhydro projects. An exception is the propeller turbine, which comes in many different designs and works much like a boat's propeller. Propeller turbines have three to six usually fixed blades set at different angles aligned on the runner. The bulb, tubular, and Kaplan tubular are variations of the propeller turbine. The Kaplan turbine, which is a highly adaptable propeller system, can be used for micro hydro sites.

Pumps as substitutes for turbines

Conventional pumps can be used as substitutes for hydraulic turbines. When the action of a pump is reversed, it operates like a turbine. Since pumps are mass produced, you'll find them more readily available and less expensive than turbines.

SITE SELECTION OF TURBINES:

The Turbines are classified according to their specific speeds. The selection of turbine on the basis of specific speed is made in the following ways:

(i) Low specific speed. Impulse turbines have a low value of specific speeds and these turbines are suitable to work under high head and large discharge conditions. The specific speeds of these turbines vary from 8 to 50.

(ii) Medium specific speeds. Reaction turbines such as Francis turbines have specific speeds varying from 51 to 225. These turbines are suitable to work under moderate head and discharge conditions.

(iii) High specific speeds. Reaction turbines such as Kaplan turbines have high specific speeds varying from 250 to 850. These turbines are suitable to work under low head and large discharge conditions.

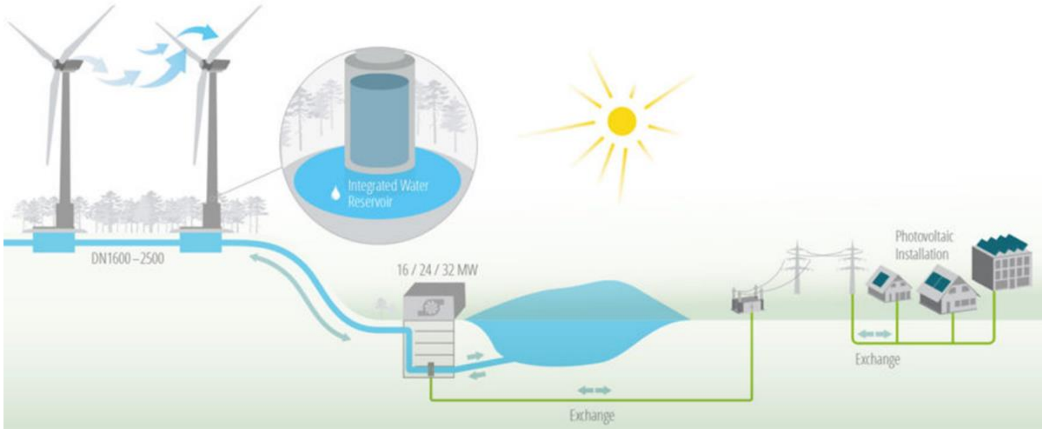
POTENTIAL OF SMALL HYDRO POWER PLANTS IN INDIA

- Hydro power projects are classified as large and small hydro projects based on their sizes.
- Different countries have different size criteria to classify small hydro power project capacity ranging from 10MW to 50 MW.
- In India, hydro power plants of 25MW or below capacity are classified as small hydro, which have further been classified into micro (100kW or below), mini (101kW-2MW) and small hydro (2-25MW) segments.

- Hydro Power was being looked after by Ministry of Power prior to 1989 mainly with the help of State Electricity Boards.
- In 1989, plant capacity up to 3MW and below was transferred to the Ministry of New and Renewable Energy (MNRE) and as such 63 MW aggregate installed capacity of 3MW and below hydro projects came within the jurisdiction of MNRE.
- The estimated potential of 21135.37 MW from 7135 sites for power generation in the country from small / mini hydel projects is assessed by the Alternate Hydro Energy Centre (AHEC) of IIT Roorkee in its Small Hydro Database of July 2016.
- The hilly States of India mainly Arunachal Pradesh, Himachal Pradesh, Jammu & Kashmir and Uttarakhand, and constitute around half of this potential. Other potential States are Maharashtra, Chhattisgarh, Karnataka and Kerala.
- The Ministry has taken a series of steps to promote development of SHP in a planned manner and improve reliability & quality of the projects.
- By giving various physical and financial incentives, investments have been attracted in commercial SHP projects apart from subsidizing State Governments to set up small hydro projects.
- The Ministry is also giving special emphasis to promote micro hydel projects up to 100 KW for remote village electrification.
- These projects are taken up with the involvement of local organizations such as the Water Mills Associations, cooperative societies, registered NGOs, village energy cooperatives, and State Nodal Agencies.

WIND HYDRO BASED STAND-ALONE SYSTEMS

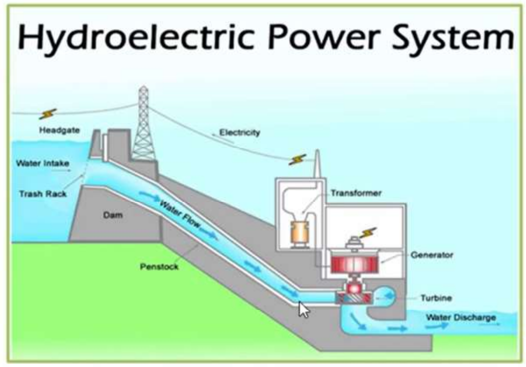
- Hybrid power are combinations between different technologies to produce power. In power engineering, the term 'hybrid' describes a combined power and energy storage system. Hybrid power plants often contain a renewable energy component (such as PV).
- A wind-hydro system generates electric energy combining wind turbines and pumped storage.



- The combination has been the subject of long-term discussion, and an experimental plant, which also tested wind turbines, was first implemented in Wreck Cove hydroelectric power site, Canada in the late 1970s.
- Wind-hydro stations dedicate all, or a significant portion, of their wind power resources to pumping water into pumped storage reservoirs.
- These reservoirs are an implementation of grid energy storage.
- Wind and its generation potential is inherently variable. However, when this energy source is used to pump water into reservoirs at an elevation (the principle behind pumped storage), the potential energy of the water is relatively stable and can be used to generate electrical power by releasing it into a hydropower plant when needed.
- The combination has been described as particularly suited to islands that are not connected to larger grids.
- During the 1980s, an installation was proposed in the Netherlands. The IJsselmeer would be used as the reservoir, with wind turbines located on its barrage.
- Feasibility studies have been conducted for installations on the different islands.
- However, some expectations were not realized in practice, probably due to inadequate reservoir volume and persistent problems with grid stability.
- 100% renewable energy systems require an over-capacity of wind or solar power

Small Hydro Power System

- A small hydro project (SHP) generates electricity of up to 25 MW from the energy of moving water which is used to run a turbine.
- The mechanical energy from the movement of the turbine is then converted to electrical energy using magnetic fields.
- Water flowing through a stream enters the fore bay through a canal. After this, the water flows through the penstock to the turbine and the generator unit, where electricity is generated.



➢ **The electricity is then transmitted to the point of use via the transmission system.**

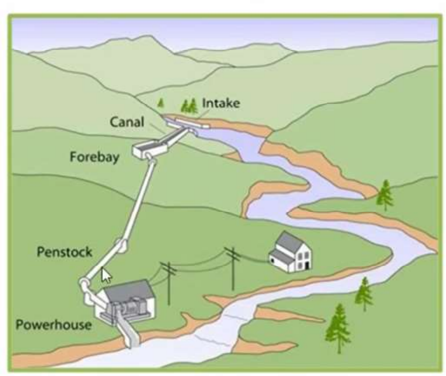
Micro hydropower System

- Micro hydropower can be one of the most simple renewable energy.
- Micro hydropower systems usually generate up to 100 kilowatts of electricity. Most of the hydropower systems used by small business owners, including farmers
- But a 10-kilowatt micro hydropower system generally can provide enough power for a large home, a small resort or a small farm.
- A micro hydropower system needs a turbine, pump, or waterwheel to transform the energy of flowing water into rotational energy, which is converted into electricity.

Micro hydropower System Components

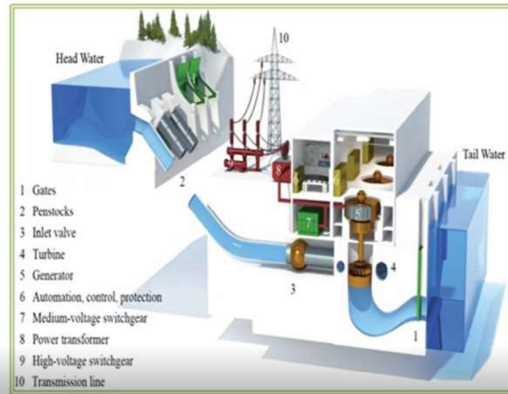
Micro hydropower systems consist of these basic components:

- Water conveyance - channel, pipeline, or pressurized pipeline (penstock)that delivers the water
- Turbine, pump or waterwheel - transforms the energy of flowing water into rotational energy
- Alternator or generator - transforms the rotational energy into electricity
- Regulator - controls the generator
- Wiring - delivers the electricity.



Mini Hydro Power System

- Mini and micro hydropower installations are very similar to the small-scale hydropower.
- They also low cost of installations and maintenance and very little, only that their power is much lower than the small scale hydro.
- The mini hydropower has a capacity between 100 and 500KW while the micro hydropower installation has a capacity less than 100KW



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Hydropower Generation

Advantages

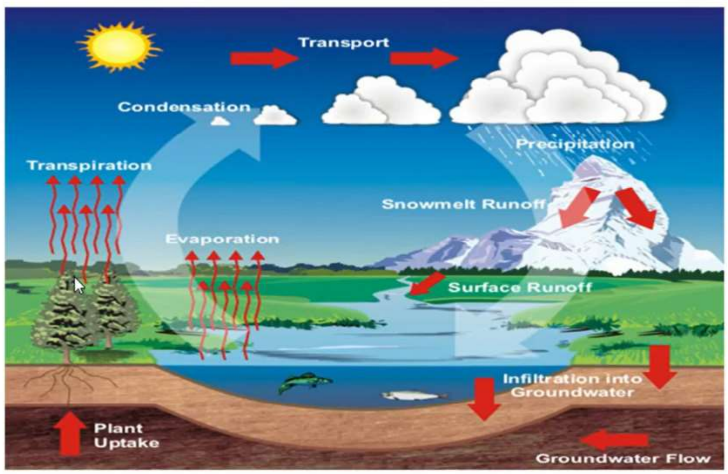
- No fuel charge
- Less supervising charge is required
- Plant is highly reliable
- Maintenance charge is less
- Low running cost
- Plant efficiency doesn't change with age
- No fuel transportation is required
- No ash or flue gas problem
- Flood control
- Irrigation

Disadvantages

- High initial cost of plant
- Take a long time for construction
- Large area is required
- It affects aquatic organism
- Relocation
- Transmission Losses: Plant is located at hilly area & its far away from load centre, reason for transmission line losses.
- Hydro power station depends on rain & it is difficulty to operate the hydro power station during summer

Hydrology:

- A science dealing with the properties, distribution, and circulation of water on and below the earth's surface and in the atmosphere.
- Hydrology provides guidance for undergoing proper planning and management of water resources.
- Calculates rainfall, surface runoff, and precipitation.
- It determines the water balance for a particular region.
- It mitigates and predicts flood, landslide and drought risk in the region.



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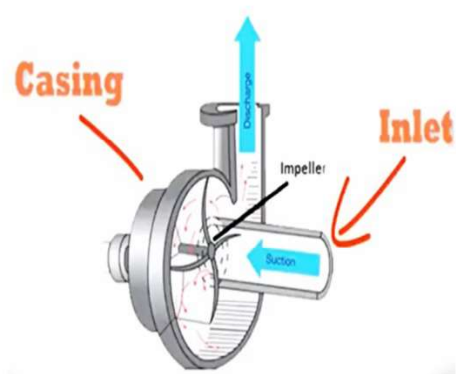
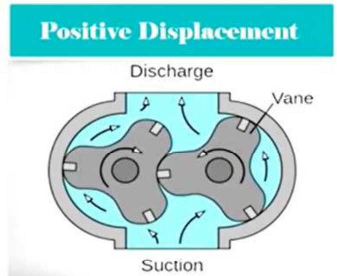
- A pump is a device that moves liquids or gases, by mechanical action.
- All pumps have an inlet, a casing, and an outlet.
- During operation liquid enters the pump through the inlet located here, this side of the pump is also called the suction side.
- The pressure of the liquid is lowest at this point.



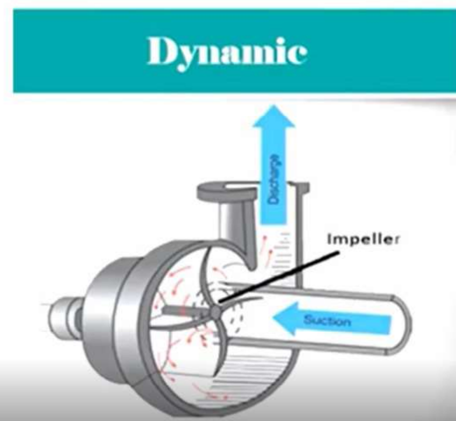
TYPES OF PUMP

- Basically pumps can be grouped into two general categories,
- **Positive Displacement Pump and Dynamic Pump.**

A **positive displacement pump** makes a fluid move by trapping a fixed amount of the fluid and forcing or displacing that trapped volume into a discharge pipe or discharge system.
Some positive displacement pumps use an expanding cavity on the suction side and a decreasing cavity on the discharge side.



Dynamic pumps impart velocity and pressure to the fluid as it moves past or through the pump impeller and, subsequently, convert some of that velocity into additional pressure.
It is also called Kinetic pumps.
These pumps operate by developing a high liquid velocity and converting the velocity to pressure in a diffusing flow passage.



A positive displacement pump can be further classified according to the mechanism used to move the fluid.

TYPES OF POSITIVE DISPLACEMENT PUMP

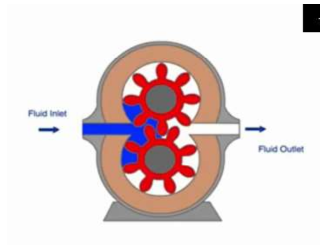
1).Rotary Types Positive Displacement
2).Reciprocating Types Positive Displacement

Rotary Types Positive Displacement

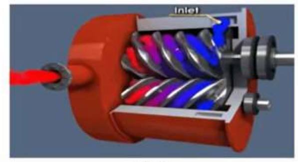
The nature of Rotary pump requires very close clearances between the rotating pump and the outer edge, making it rotate at a slow, steady speed. If rotary pumps are operated at high speeds, the fluids cause erosion, which eventually causes enlarged clearances that liquid can pass through, which reduces efficiency.

Rotary positive displacement pumps fall into three main types:

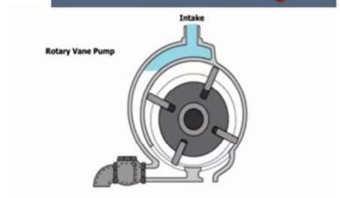
Gear pumps: A gear pumps are simple type of rotary pump where the liquid is pushed between two gears.



Screw pumps: Screw pumps are the shape of the internals of this pump is usually two screws turning against each other to pump the liquid.



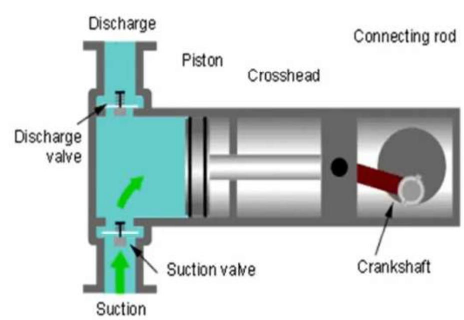
Rotary vane pumps: This pumps are similar to scroll compressors; these have a cylindrical rotor encased in a similarly shaped housing. As the rotor orbits, the vanes trap fluid between the the rotor and the casing, drawing the fluid through the pump.



Reciprocating-type positive displacement Pump

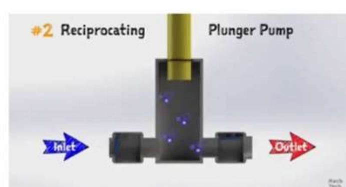
Reciprocating pumps move the fluid using one or more oscillating pistons, plungers, or membranes (diaphragms), while valves restrict fluid motion to the desired direction.

- In order for suction to take place, the pump must first pull the plunger in an outward motion to decrease pressure in the chamber.
- Once the plunger pushes back, it will increase the pressure chamber and the inward pressure of the plunger will then open the discharge valve and release the fluid into the delivery pipe at a high velocity

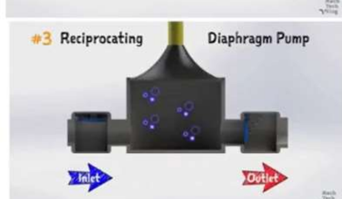


Reciprocating pumps are

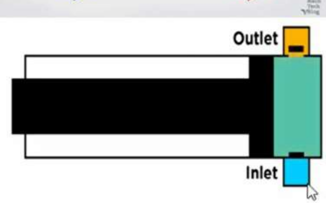
Plunger pumps: A reciprocating plunger pushes the fluid through one or two open valves, closed by suction on the way back.



Diaphragm pumps: Similar to plunger pumps, where the plunger pressurizes hydraulic oil which is used to flex a diaphragm in the pumping cylinder. Diaphragm valves are used to push liquids like volatile solvents, viscous, pharma product and gels etc.

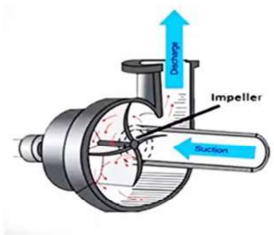


Piston pumps: Displacement pumps usually simple devices for pumping small amounts of liquid or gel manually.



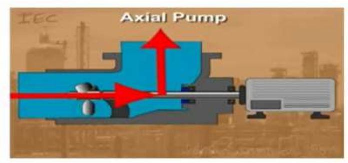
Dynamic pumps are centrifugal pumps

Centrifugal Pumps: A centrifugal pump is a rotating machine in which flow and pressure are generated dynamically.
The energy changes occur by virtue of two main parts of the pump, the impeller and the volute or casing.
The function of the casing is to collect the liquid discharged by the impeller and to convert some of the kinetic (velocity) energy into pressure energy.

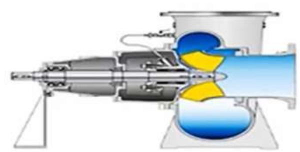


Centrifugal pumps are subdivided into several categories:

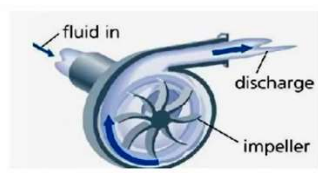
Axial Flow Pumps: Axial Flow Pumps are high flow, low pressure pumps which lift fluid in a direction parallel to the impeller shaft.



Mixed Flow Pumps: Mixed Flow Pumps are medium flow, medium pressure pumps which push fluid out away from the pump shaft at an angle greater than 90°.



Radial Flow Pumps: Radial Flow Pumps are high pressure, low flow pumps which accelerate fluid along the impeller blades perpendicular to the shaft.



Turbine

The turbine is a device which converts the hydraulic power from the water to rotating mechanical energy.
There are several turbines that have been developed for specific purposes.

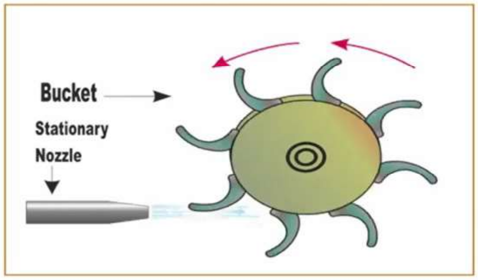
Hydro electric Turbines are classified into

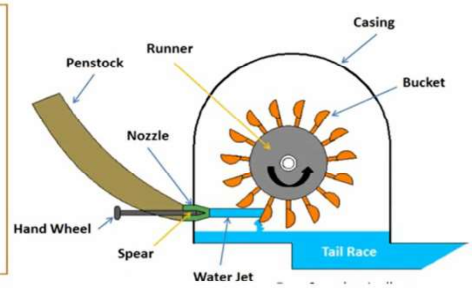
a) Impulse turbines for high heads
Example: Pelton

b) Reaction turbines for low heads.
Example: Francis, Kaplan

Impulse turbine (Pelton)

A Pelton turbine is a type of impulse turbine in which the flow enters the wheel tangentially.



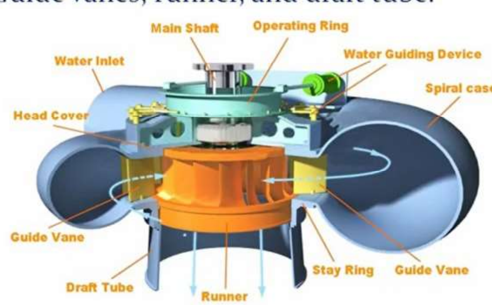


- The whole set is at atmospheric pressure, the flow with potential energy and high pressure flows in the Penstock and reaches the nozzle.

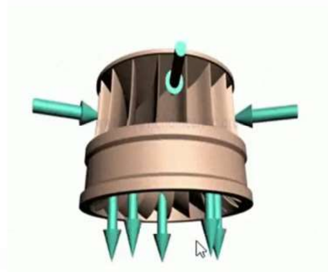
- The nozzle is responsible for converting high-pressure flow to high-speed flow.
- Therefore, the water flow hits the blades of this turbine, which are in the shape of a bucket, at high speed and causes the runner to rotate.
- These turbines are suitable for high heads (up to 2000 meters) and low flow rates (4-15 m^3/s).
- They are classified as low specific speed turbines.
- They are produced in various sizes and have been used up even to a capacity of 200 MW.
- In the figure, the main components of the Pelton turbine, including nozzle, deflector plate (to prevent water jets in case of load stop), runner, and bucket-shaped blades.

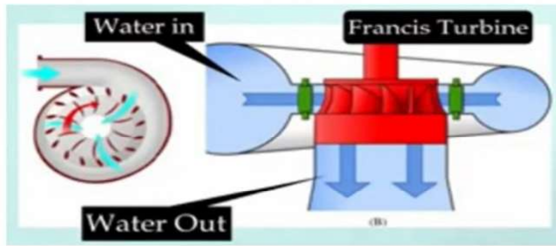
Reaction turbine (Francis)

- **Francis Turbine is a reaction turbine** used for **medium heads (10-650 meters) and medium flows**.
- Output power can be from **10 MW to 750 MW.** These turbines are in the range of **medium specific speed turbines**. The main components of these turbines include spiral case, stay vanes, Guide vanes, runner, and draft tube.
- The spiral case distributes the water around the wheel, and because its cross-sectional area gradually decreases, it does not allow the water velocity to decrease.
- The flow is directed to the wheel by stay vanes.



Francis Turbine

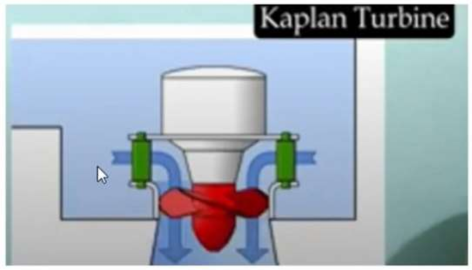




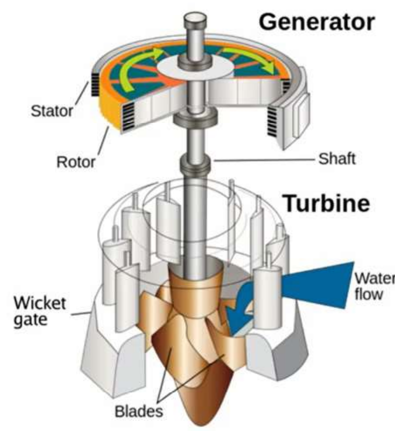
- Guide vanes are responsible for changes in the direction and velocity of water during changes in flow rate.
- Finally, the energy exchange takes place in the runner section.
- The draft tube also acts as an outlet which increases the net head by moving the exiting water level upwards.
- The wheels of these turbines are inward radial or mixed.
- The higher the specific speed, the closer the wheel gets to the mixed flow.
- The axis of these turbines is made vertically or horizontally.
- The horizontal type is used for less power and smaller power plants.

Kaplan

- **Kaplan is a propeller-type of reaction turbine.**
- **Kaplan turbines are used for low heads and high flow rates.**
- The main components of these turbines include spiral case, stay vanes, wicket gates, runner, and draft tube.
- The water flows radially into the guiding regulator.
- The spire, blade, and movable vanes act similarly to the Francis turbine.
  Unlike propellers, blades are adjustable in Kaplan.
- Therefore, by adjusting the guide vanes and blades, the flow rate can be changed in order to maintain efficiency.
- The Kaplan turbine, whose wheel is axial, is mounted vertically for high power and horizontally for low power and low heads.



- The specific speed of these turbines is 2 to 3 times that of Francis and they are classified in the category of **high specific speed turbines.**
- The efficiency of these turbines is flat and can maintain its efficiency in a wider range of flow, unlike Francis.
- The number of blades is 3 to 6, which is much less than Francis being 11 to 17.



Site Selection

Factors considered for selecting the site for hydroelectric power plant

1. Availability of water
2. Water storage capacity
3. **Availability of Water head**
4. Accessibility of the site
5. Distance from the load centre
6. Types of the land of site

Availability of water : primary requirement of a hydro-electric power station is the availability of huge quantity of water, such plants should be built at a place (*e.g., river,* canal) where adequate water is available at a good head.

Storage of water : site selected for a hydro-electric plant should provide adequate facilities for erecting a dam and storage of water.

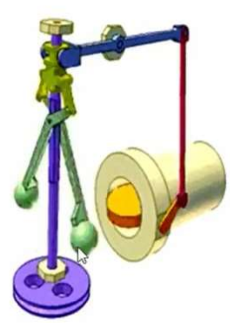
Cost and type of land : The land for the construction of the plant should be available at a reasonable price.

Transportation facilities : *The site selected for a hydro-electric plant should be accessible* by rail and road so that necessary equipment and machinery could be easily transported.

Speed and Voltage regulation

- The hydropower plant generators are conventional synchronous machines.
- The synchronous generators which are driven by the water turbines are called as hydro-generators.
- The hydro-generators are driven at a speed of 100-1000 rpm.
- Governing system or governor is the main controller of the hydraulic turbine.
- The governor varies the water flow through the turbine to control its speed or power output.
- Governor is a device to control the speed variation caused by the varying load.

- A governor, or speed limiter or controller, is a device used to measure and regulate the speed of a machine, such as an engine.
- Generating units speed and system frequency may be adjusted by the governor.
- These generators use a conventional brushless excitation system and an automatic voltage regulator (AVR) to regulate voltage.
- This hydropower plant has several one water jet Pelton turbines.
- These generators can operate as a synchronous condenser.
- In this operation mode, they can generate reactive power to contribute to the voltage regulation of the power system.



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- This hydropower plant has several one water jet Pelton turbines.
- These generators can operate as a synchronous condenser.
- In this operation mode, they can generate reactive power to contribute to the voltage regulation of the power system.
- Furthermore, in this operation mode they can generate active power, if required.