Module 4

Wind Energy: *Properties of wind, availability of wind energy in India, wind velocity and power from wind; major problems associated with wind power, wind machines; Types of wind machines and their characteristics, horizontal and vertical axis wind mills, elementary design principles; coefficient of performance of a wind mill rotor, aerodynamic considerations of wind mill design, numerical examples.*

Tidal Power: *Tides and waves as energy suppliers and their mechanics; fundamental characteristics of tidal power, harnessing tidal energy, limitations.*

Ocean Thermal Energy Conversion: *Principle of working, Rankine cycle, OTEC power stations in the world, problems associated with OTEC.*

Contents

1 Wind Energy

1.1 Introduction, Properties of wind

Wind results from air in motion. Air in motion arises from a pressure gradient. On a global basis one primary forcing function causing surface winds from the poles toward the equator is convective circulation. Solar radiation heats the air near the equator, and this low-density heated air is buoyed up. At the surface it is displaced by cooler denser higher-pressure air flowing from the poles. In the upper atmosphere near the equator the air thus tend to flow back toward the poles and away from the equator. The net results is a global convective circulation with surface winds from north to south in the northern hemisphere.

It is clear from the above over simplified model that the wind is basically caused by the solar energy irradiating the earth. This is why wind utilization is considered a part of solar technology.

In actuality the wind is much more complex. The above model ignores the earth's rotation which causes a Coriolis force resulting in an easterly wind velocity component in the northern hemisphere.

There is the further complication of boundary layer frictional effects between the moving air and the earth's rough surface. Mountains, trees, buildings, and similar obstructions impair stream line air flow. Turbulence results, and the wind velocity in a horizontal direction markedly increases with altitude near the surface.

Then there is the obvious fact of land and water with their unequal solar absorptivity’s and thermal time constants. During day light the land heats up rapidly compared to nearby sea or water bodies, and there tends to be a surface wind flow from the water to the land. At night the wind reverses, because the land surface cools faster than the water.

Local winds are caused by two mechanisms. The first is differential heating of land and water. Solar isolation during the day is readily converted to sensible energy of the land surface but is partly absorbed in layers below the water surface and partly consumed in evaporating some of that water. The land mass becomes hotter than the water, which causes the air above the land to heat up and become warmer than the air above water. The warmer lighter air above the land rises, and the cooler heavier air above the water moves into replace it. This is the mechanism of shore breezes. At night, the direction of the breezes is reversed because the land mass cools to the sky more rapidly than the water, assuming a clear sky. The second mechanism of local winds is caused by hills and mountain sides. The air above the slopes heats up during the day and cools down at night, more rapidly than the air above the low lands. This causes heated air the day to rise along the slopes and relatively cool heavy air to flow down at night.

It has been estimated that 2 per cent of all solar radiation falling on the face of the earth is converted to kinetic energy in the atmosphere and that 30 per cent of this kinetic energy occurs in the lowest 1000 m of elevation. It is thus said that the total kinetic energy of the wind in this lowest kilometer, if harnessed, can satisfy several times the energy demand of a country. It is also claimed that the wind power is pollution free and that its source of energy is free. Such are the seemingly compelling arguments for wind power, not unlike those for solar power. Although solar energy is cyclic and predictable, and even dependable in some parts of the globe, wind energy, however, is erratic, unsteady, and often not reliable, except in very few areas. It does, however, have a place in the total energy picture, particularly for those areas with more, or less steady winds, especially those that are far removed from central power grids, and for small, remote domestic- and farm needs.

Conversion of the kinetic energy (i.e., energy of motion) of the wind into mechanical energy that can be utilized to perform useful work, or to generate electricity. Most machines for converting wind energy into mechanical energy consist basically of a number of sails, vanes, or blades radiating from a hub or central axis. The axis may be horizontal, as in the more familiar windmills, or vertical, as it is in some cases. When the wind blows against the vanes or sails they rotate about the axis and the rotational motion can be made to perform useful work. Wind energy conversion devices are commonly known as Wind turbines because they convert the energy of the wind stream into energy of rotation: the component which rotates is called the rotor. The terms turbine and rotor are, however, often regarded as being synonymous.

Because wind turbines produce rotational motion, wind energy is readily converted into electrical energy by connecting the turbine to an electric generator. The combination of wind turbine and generator is sometimes referred to as an aero generator. A step-up transmission is usually required to match the relatively slow speed of the wind rotor to the higher speed of an electric generator.

1.2 Availability of wind energy in India

In India the interest in the windmills was shown in the last fifties and early sixties. Apart from importing a few from outside, new designs were also developed, but it was not sustained. It is only in the last few years that development work is going on in many institutions. An important reason for this lack of interest in wind energy must be that wind, in India are relatively low and vary appreciably with the seasons. Data quoted by some scientists that for India wind speed value lies between 5 km/hr to 15-20 km/hr. These low and seasonal winds imply a high cost of exploitation of wind energy. Calculations based on the performance of a typical windmill have indicated that a unit of energy derived from a windmill will be at least several times more expensive than energy derivable from electric distribution lines at the standard rates, provided such electrical energy is at all available at the windmill site.

The above argument is not fully applicable in rural areas for several reasons. First electric power is not and will not be available in many such areas due to the high cost of generation and distribution to small dispersed users. Secondly there is possibility of reducing the cost of the windmills by suitable design. Lastly, on small scales, the total first cost for serving a felt need and low maintenance cost are more important than the unit cost of energy. The last point is illustrated easily: dry cells provide energy at the astronomical coat of about

Rs. 300 per kWh and yet they are in common use in both rural and urban areas. This raises the question of that the felt needs are that a windmill might satisfy while large scale energy production at some favorable sites in India is a possibility that needs to be explored, there appears to be a definite need for small sources of mechanical energy in rural areas. For example, even casual polls among villagers quickly reveal that their first concern is invariably water for drinking, washing and irrigation; and lifting water is a task which a windmill can perform. For such a task, a windmill should produce about 100 W, considering that a pair of bullocks, often used for lifting water in villages, typically provides about 250 W power. Many projects on windmill systems for water pumping and for production of small amount of electrical power have been taken up by various organizations, such as National aeronautical laboratory Banglore, central salt and Marine Chemicals Research Institute Bhavnagar, Central Arid Zone Research Institute (CAZRI)Jodhpur etc.

Wind energy offers another source for pumping as well as electric power generation. India has potential of over 20,000 MW for power generation and ranks as one of the promising countries for tapping this source. The cost of power generation from wind farms has now become lower than diesel power and comparable to thermal power in several areas of our country especially near the coasts. Wind power projects of aggregate capacity of 8 MW including 7 wind farms projects of capacity 6.85 MW have been established in different parts of the country of which 3 MW capacity has been completed in 1989 by NES. Wind farms are operating successfully and have already fed over 150 lakh units of electricity to the respective state grids. Over 25 MW of additional power capacity from wind is under implementation. Under demonstration Programme 271 wind pumps have been installed up to February 1989. Sixty small wind battery chargers of capacities 300 watts to 4 kW are under installation. Like wise to stand-alone wind electric generators of 10 to 25 kW are under installation.

1.3 Basic Principles of Wind Energy Conversion

1.3.1 The Nature of the Wind

The circulation of air in the atmosphere is caused by the non-uniform heating of the earth's surface by the sun. The air immediately above a warm area expands, it is forced upwards by cool, denser air which flows in from surrounding areas causing a wind. The nature of the terrain, the degree of cloud cover and the angle of the sun in the sky are all factors. which influence this process. In general, during the day the air above the land mass tends to heat up more rapidly than the air over water. In coastal regions this manifests itself in a strong onshore wind. At night the process is reversed because the air cools down more rapidly over the land and the breeze therefore blows off shore. The main planetary winds are caused in much the same way Cool surface air sweeps down from the poles forcing the warm air over the tropics to rise. But the direction of these massive air movements is affected by the rotation of the earth and the net effect is a large countries-clockwise circulation of air around low-pressure areas in the northern hemisphere, and clockwise circulation in the southern hemisphere. The strength and direction of these planetary winds change with the seasons as the solar input varies.

Despite the wind's intermittent nature, wind patterns at any particular site remain remarkably constant year by year. Average wind speeds are greater in hilly and coastal areas than they are well inland the winds also tend to blow more consistently and with greater strength over the surface of the water where there is a less surface drag.

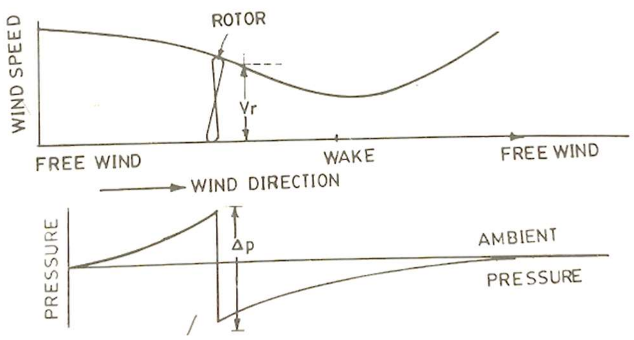
Wind speeds increase with height. They have traditionally been measured at a standard height of ten meters where they are found to be 20--25% greater than close to the surface. At a height of 60 m they may be 30-60% higher because of the reduction in the drag effect of the earth's surface.

1.3.2 The Power in the Wind

Wind possesses energy by virtue of its motion. Any device capable of slowing down the mass of moving air, like a sail or propeller, can extract part of the energy and convert is into useful work. Three factors determine the output from a wind energy converter:

i. the wind speeds.
ii. the cross-section of wind swept by rotor; and
iii. the overall conversion efficiency of the rotor, transmission system and generator or pump.

No device, however well-designed, can extract all of the wind's energy because the wind would have to be brought to a halt and this would prevent the passage of more air through the rotor. The most that is possible is for the rotor to decelerate the whole horizontal column of intercepted air to about one-third of its free velocity. A 100% efficient aerogenerator would therefore only be able to convert up to a maximum of around 60% of the available energy in wind into mechanical energy. Well-designed blades will typically extract 70% of the theoretical maximum, but losses incurred in the gearbox, transmission system and generator or pump could decrease overall wind turbine efficiency to 35% or loss.



The power in the wind can be computed by using the concept of kinetics. The wind mill works on the principle of converting kinetic energy of the wind to mechanical energy. We know that power is equal to energy per unit time. The energy available is the kinetic energy of the wind. The kinetic energy of any particle is equal to one half its mass times the square of its velocity, or $\frac{1}{2}$ mV^2. The amount of air passing in unit time, through an area A, with velocity V, is A.V, and its mass m is equal to its volume multiplied by its density ρ of air, or

$$m = \rho AV$$

(m is the mass of air transversing the area A swept by the rotating blades of a wind mill type generator).

Substituting this value of the mass in the expression for the kinetic energy, we obtain

$Kinetic\ energy = \frac{1}{2}\rho A\, V^2 V$ watts

$Kinetic\ energy = \frac{1}{2}\rho A\, V^3$ watts

Above equation tells us that the maximum wind available the actual amount will be somewhat less because all the available energy is not extractable-is proportional to the cube of the wind speed. It is thus evident that small increase in wind speed can have a marked effect on the power in the wind.

Equation also tell us that the power available is proportional to air density (1.225 kg/m^3 at sea level). It may vary 10-15 percent during the year because of pressure and temperature change. It changes negligibly with water content. Equation also tells us that the wind power is proportional to the intercept area. Thus an aero turbine with a large swept area has higher power than a smaller area machine but there are added implications. Since the area is normally circular of diameter D in horizontal axis aero turbines, then $A = \frac{\pi D^2}{4}$

Available wind power $P_a = \frac{1}{2}\rho \frac{\pi}{4} D^2 V^3$

$$P_a = \frac{1}{8}\rho\pi D^2 V^3$$

1.4 Major problems associated with wind power

The two major disadvantages of wind power include initial cost and technology immaturity. Firstly, constructing turbines and wind facilities is extremely expensive. The second disadvantage is technology immaturity. High cost of energy can, in part, be addressed directly with technology innovations that increase reliability and energy output and lower system capital expenses. Offshore wind energy produces more energy than onshore wind energy, but costs much more to establish. The primary costs of wind turbines include construction and maintenance. New technology is needed to lower costs, increase reliability and energy production, solve regional deployment issues, expand the resource area, develop infrastructure and manufacturing facilities, and mitigate known environmental impacts. Therefore, one may argue that implementation of wind energy must be delayed until technological advancements are made. Other Problems include:

1. Aesthetic impact: Many people are concerned with the visual effects that wind turbines have on the beautiful scenery of nature. They believe that giant wind turbines distract viewers from the beautiful surroundings.

2. Wildlife: Wind turbines may be dangerous to flying animals. Many birds and bats have been killed by flying into the rotors. Experts are now conducting research to learn more about the effects that wind turbines have on marine habitats.
3. Remoteness of location: Although this may be an advantage (placing wind turbines in desolate areas, far away from people), it may also be a disadvantage. The cost of travel and maintenance on the turbines increases and is time consuming. Offshore wind turbines require boats and can be dangerous to manage.
4. Noise: Some wind turbines tend to generate a lot of noise which can be unpleasant
5. Safety at Sea: In the darkness/at night it may be difficult for incoming boats to see wind turbines thus leading to collisions.

1.5 Aerodynamic consideration in wind turbine

The basic requirement in the design of a wind turbine, it must utilize maximum energy available with the wind. This totally depends upon the blade shape which is fully responsible for extracting maximum energy from the wind. Therefore, it is necessary to understand the basic principle of aerodynamic theory when the wind is flowing over the blade surface area.

1.5.1 Terms Associated with Aerofoil

It is necessary to be familiar with the terms associated with aerofoil section as shown in Fig. before going to analysis of the system

1. Aerofoil. It is a streamlined curved surface designed for the air to flow over it in order to produce high lift force and low drag force.
2. Angle of Attack. It is the angle between the chord of the aerofoil and relative air flow direction.
3. Leading and trailing edges of the aerofoil. It is the front edge of the blade towards the wind flow direction and trailing edge is the rear edge of the blade.
4. Chord-line. It is a straight line joining leading edge and trailing edge of the blade
5. Mean-line. It is line which is at equidistance between upper and lower surfaces of the blade at all points.
6. Chamber. It is the maximum distance between the mean line and chord.
7. Tip speed ratio (λ). It is the ratio of the blade tip velocity to the undisturbed wind velocity (V)
8. Pitch angle. It is the angle made by the chord to the plane of blade rotation. A system used to change the pitch angle according to the wind speed is known as pitch control system. It is necessary for the efficient operation of the system.

9. Swept Area. It is the area covered by the rotating rotor.
10. Solidity (σ). It is the ratio of the blades area to the swept area.
11. Drag and Lift Forces. Drag force is the component of the force along the velocity of the wind and lift force is the component perpendicular to drag force.
12. Cut-in and cut-out speeds. Cut-in is the wind speed at which wind-turbine starts operation and cut-out wind speed at which the turbine stops operating for the safety. Rated speed of the wind mill is that speed at which the turbine provides maximum power.

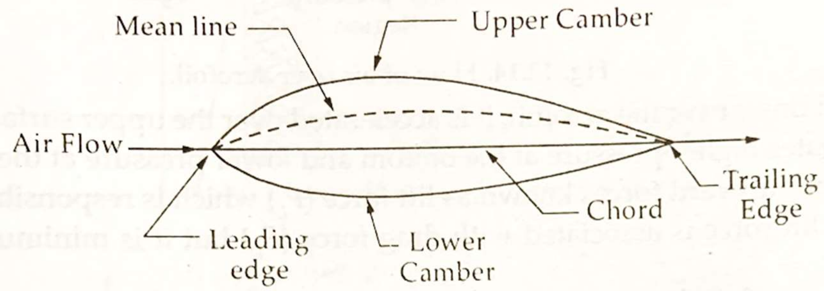


Fig. 12.12 (*a*) Configuration of an aerofoil

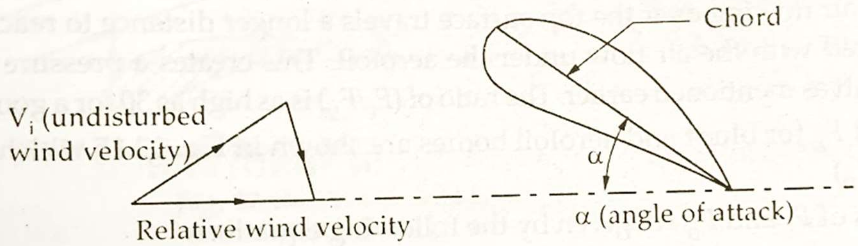


Fig. 12.12 (*b*)

1.5.2 Aerodynamic forces on aerofoil blades

Presently, wind turbines designed for electric generation are built with a properller type rotor on a horizontal axis with two or three blades. When the air-flows over the blades, it creates two forces known as lift (responsible for blade rotation) and drag which creates friction over the blade surface. For efficient blade, lift force must be highest possible and drag force must be minimum possible.

As the wind flows over the aerofoil, it is accelerated over the upper surface and deaccelerated below it. This creates higher pressure at the bottom and lower pressure at the top and the effect is to create a resultant upward force known as lift force (F_L) which is responsible for the rotation of the blade. Every lift force is associated with drag force (F_D) but it is minimum with streamlined bodies.

In case of wind-turbines, the top surface of the aerofoil is made curved and bottom surface nearly flat. The air flowing over the top surface travels a longer distance to reach the top end of the aerofoil compared with the air flow under the aerofoil. This creates a pressure difference which is responsible for lift as mentioned earlier. The ratio of (F_L/F_D) is as high as 30 for a good designed aerofoil.

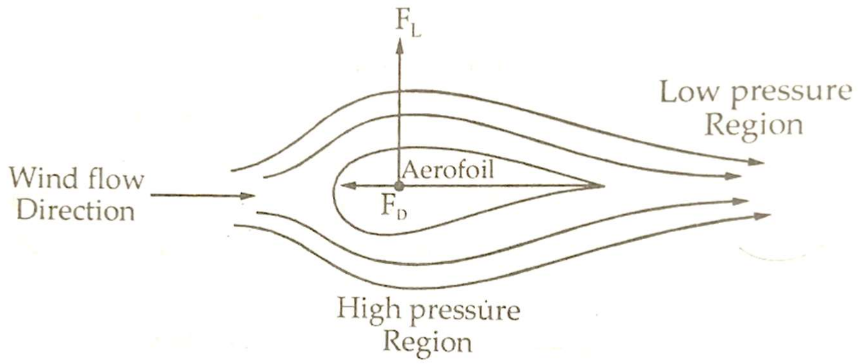


Fig. 12.14. Flow of air over aerofoil.

The values of F_L and F_D are

$$F_L = C_L \rho A \frac{V^2}{2}$$

$$F_D = C_D \rho A \frac{V^2}{2}$$

C_L, and C_D are known as lift and crag coefficients for a given blades.

1.6 Types of wind machines and their characteristics

1.6.1 Horizontal Axis Turbines

These are very commonly used for converting wind energy into electrical energy. These a further classified as 2-blades, 3-blades and multiblade machines.

1.6.1.1 Two blade-Rotor.

These are used for electric power generation and used in the range 1 MW to 3 MW. They are subjected to large vibrations during running. A teething-cont is provided to this machine to reduce the fatigue to the main shaft. This is because the bla in upper position experiences greater force than blade at lower position. The tip speed ratio of this rotor is 33% higher than 3-blade machines.

1.6.1.2 3-Blade Rotor.

This rotor is commonly used as its efficiency is higher than two-blade rotor but the cost is 30 - 40% high. It is used from 15 kW to 5 MW capacity range. A small scale machine of this type is roof top mounted for generating the power to run all electrical equipments in the house. Small size rotor of 2 m diameter is generally used to produce 800-1000 watts power. These units are provided with wind-vane at tail which makes the rotor to come inline with wind direction.

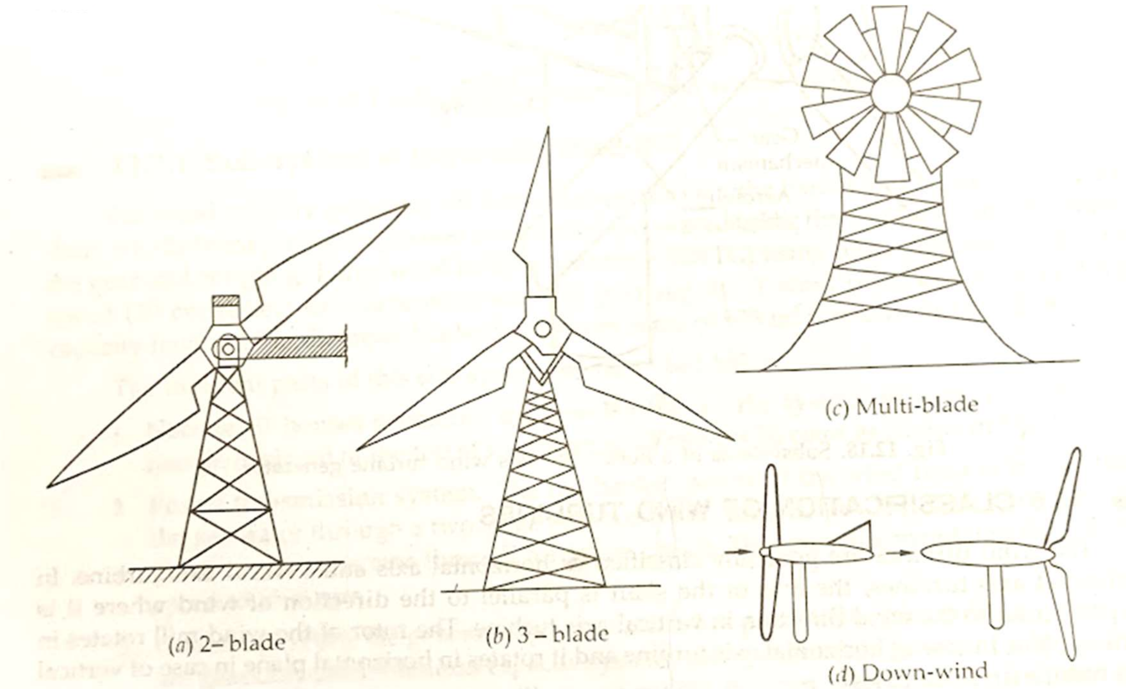
1.6.1.3 Multiblade Rotor.

This rotor has high solidity factor and generally used for water pumping purposes. This is because of high starting torque-characters which is needed for water pumping. This rotor has low tip speed ratio and therefore less noisy. The main disadvantage is less efficient.

1.6.1.4 Up-ward and Down-ward rotors.

The rotor is also classified as upward and downward machine.

In upward machine the rotor is located in front of towar whereas it is located behind the tower



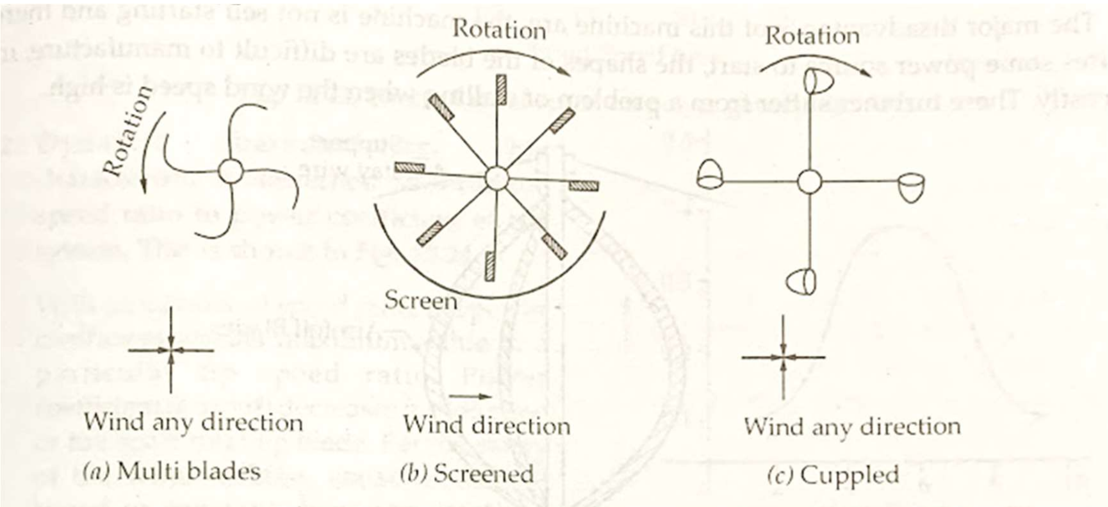
Downward machine allows the use of free yaw-system and also allows the blades to deflect away from the tower when loaded. But, it suffers from wind-shadow-effect of tower on the blades (in region of separated flow).

On the other hand, upward machine produces higher power as it eliminates the effect of tower shadow on the blades. This also results in lower noise, lower fatigue on the blades and smoother power output.

1.6.2 Vertical Axis Wind-Mill

In this system, the rotor is mounted on the vertical shaft. The types of the blades mounted are of different configurations as shown in Fig. Among all, two configurations described beloware commonly used.

(a) Primary Drag type



1.6.2.1 Savonious wind mill.

The rotors of these turbines are S-type in shape and supported at top and bottom by two circular plates as shown in Fig. The two curved blades are fixed on central pipe and free to rotate. The air strikes on concave side of the blade, rotate through centre of rotor and glides over the convex surface of the other blade. This turbine suffers from the disadvantage that when the convex surface faces the wind, the speed of the turbine slows down. This effect is eliminated by providing 4-blades so that one concave surface will always be there to allow the air-flow irrespective of wind direction.

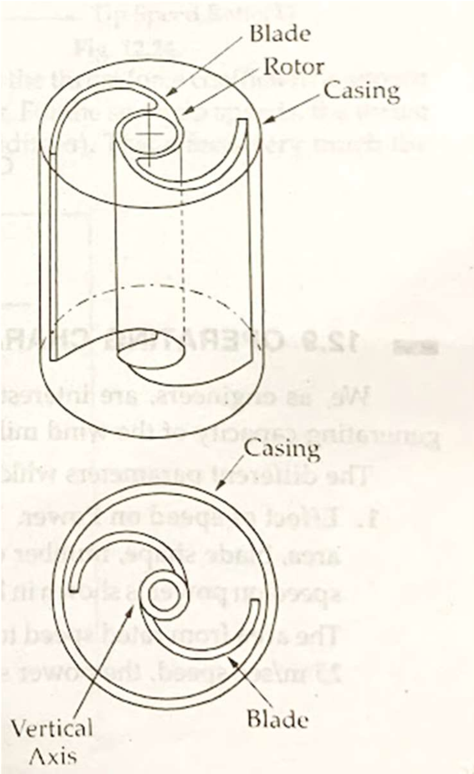


Fig. 12.21. Savonious wind turbine.

These machines are used for pumping water and grinding mills because of low speed (100 RPM). They are not preferred for electric power generating purposes because of low speed.

The advantages of this machine are:

1. Low speed wind is successfully used.
2. Pitch and yaw-controls are not required.
3. Generator can be mounted on the ground which further simplifies the tower design.

The noise is more as well as its power density is lower compared with horizontal axis and mills.

1.6.2.2 Darrieus wind-mill.

This is the only vartical axis machine used successfully on commercial basis. It is named in the honor of French engineer Georges Darrieus. This type of turbine is shown in Fig. It consists of 2 or 3 thin curved aerofoil section, C shaped blades. Both the ends of the blades are fixed to the vertical shaft. The rotor rotates on two bearings placed at top and bottom of the pipe.

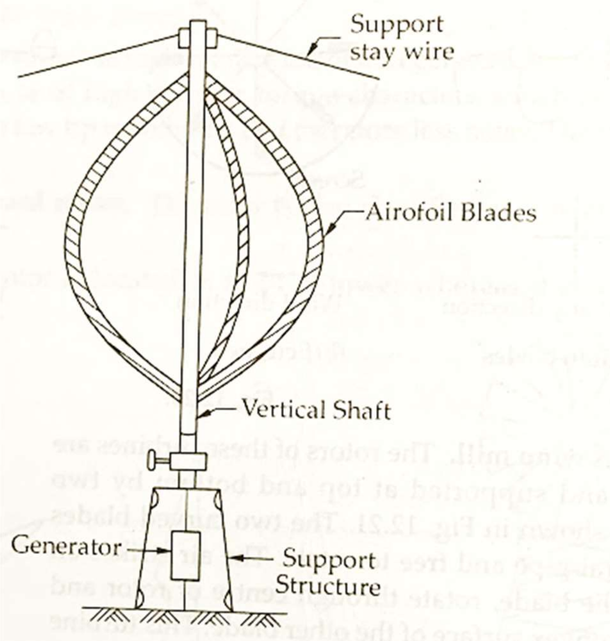


Fig. 12.22. Darrieus rotor.

It looks like an egg-beater and operates with the wind coming from any direction. This type of wind mills are available in the range of 4 to 14 MW capacity and with an efficiency of 35 - 40%.

The major advantages of this machine are, the generator can be mounted on the ground and it does not require yaw mechanism to turn the rotor as per wind direction. The major disadvantages of this machine are, the machine is not self starting and therefore requires some power source to start, the shapes of the blades are difficult to manufacture, install and costly. These turbines suffer from a problem of stalling when the wind speed is high.

1.7 Advantages and disadvantages of wind energy

1.7.1 Advantages

1. The electrical energy generation is totally pollution free.
2. It is renewable form of energy and available free of cost.
3. It is more suitable in rural, offshore and onshore areas.
4. It is reliable and cost effective for large capacity units.
5. Wind does not require any transportation.
6. It does not require any water like thermal and nuclear power plants.
7. The operating cost is considerably low.
8. This plant does not require any regular man power.
9. It is economically competitive with other energy sources.

1.7.2 Disadvantages:

1. The power output is not uniform and some back-up is required. This system requires storage batteries. They are very far away from the cities and load centers.
2. Wind power density (W/m^2) is very low.
3. The wind-rotor efficiency is low (10-40%).
4. Capital cost (Rs/kW) for small unit is considerably high.
5. The weight of this system (kg/kW) is high compared with conventional system.
6. Wind energy generates noise pollution.
7. It requires large open area.
8. As it is located far away from the point of utilization, therefore transmission losses are large if connected to main grid.
9. It is observed that big wind farms change the rainfall pattern which is not desirable for crops.
10. The windmill creates interference when placed between radio and television stations as it reflects electromagnetic radiation. It is also hazardous for civil aviation.

1.8 Problems in operating large wind power generators

1. **Location of site:** The most important factor is locating a site big enough which has a reasonable average high wind velocity. Sourashtra and Coastal Regions in India are promising areas.
2. **Constant angular velocity:** A constant angular velocity is a must for generating A.C power and this means very sensitive governing.
3. **Variation in wind velocity:** The wind velocity varies with time and varies in direction and also varies from the bottom to top of a large rotor. This causes fatigue in blades.
4. **Need of storage system:** At zero velocity conditions, the power generated will be zero and this means some storage system will have incorporated along with the wind mill.
5. **Strong supporting structure:** Since the wind mill generator will have to be located at a height, the supporting structure will have to be designed to withstand high wind velocity and impacts. This will add to the initial costs of the wind mill.
6. **Occupation of large areas of land:** large areas of land will become unavailable due to wind mill gardens. The whole area will have to be protected to avoid accidents.

Inspite of all these difficulties, interest to develop wind mills is there since this is a clean source of energy.

2 Tidal Energy

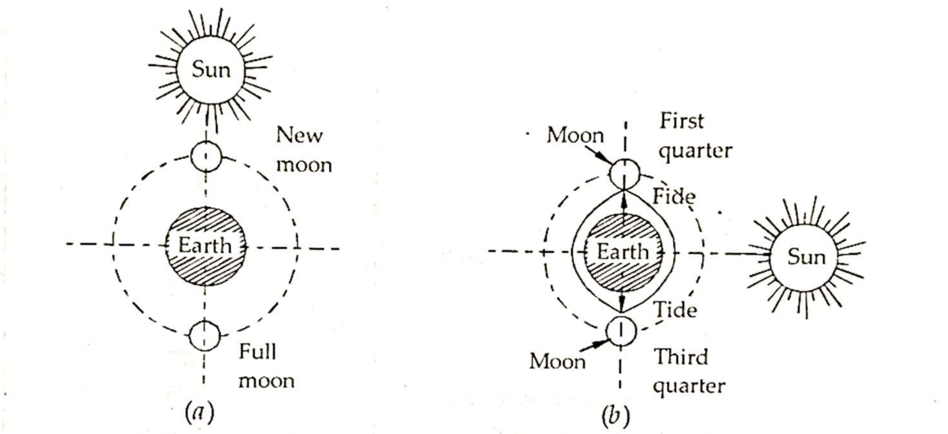
2.1 Principle of Tide Formation and its Characteristics

The generation of energy using tides is not new. Various poets have described the tides in various forms. One such interesting thought is like this. Due to the love for earth, heart of sea becomes full of emotions and these emotions can be seen in the form of flood-tides, but being of afraid of Agarti Muni, ebb tides starts occurring in the sea.

Now-a-days, scientists have found the reason of tidal generation. They have found that the tides in the sea occur due to both the sun and the moon, i.e., attraction effect of sun and moon on every water particle on the earth.

The tides are caused by the combined attraction force of sun and moon on the water surface of the revolving earth. The attraction force of moon is 2.6 times higher than that of sun. Therefore, moon influences more for creating the tides in the ocean.

The tide is a periodic rise and fall of the water level of the ocean. The water in the oceans rises and falls twice during a lunar day (24 hours and 50 minutes). The extra 50 minutes over the solar day results in the maximum water levels occurring at different times, on different days. The magnitude of water level variations at different sites on the earth depends upon latitude of the place. The earth's rotation causes two high tides and two low tides at any place daily.



The time interval between the two successive high tides increases from 12 hours to 12 hours and 25 minutes because of the revolution of the moon around the earth. The three bodies, the sun, earth and moon come in alignment after every two weeks at new moon and full moon as moon takes 28 days to complete one revolution around the earth. At these positions, the sun and moon act simultaneously to produce tides of maximum amplitude as shown in Fig. The solar pull and moon pull act along a line at new moon and full moon causing greater flow and known as spring tides and ebb tides. On the other hand, we get low tides, called neap tide when the pulls act at right angles when the sun and moon are considered in first and third quarter as shown in Fig,

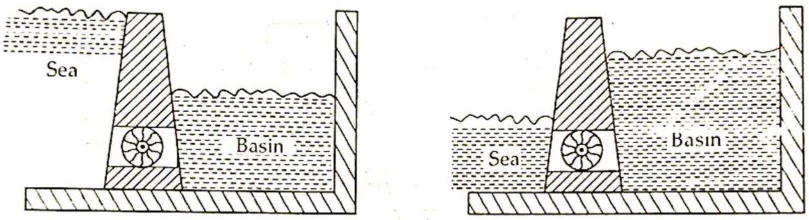
The spring tide is high when the moon is at new and full position because it is the closest point of its orbit to the earth. The simultaneous rotation of moon and earth around the sun creates further variations in the tide amplitude. Because of this combined effect, the spring tide occurs at the quinones in March and September during the year as shown in Fig. The above phenomenon has an important bearing on the location and design of the tidal power plant. A high tide occurs at a point, which is directly under the moon and at the same time, there is also a high tide at diametrically opposite point due to dynamic balancing of the ocean water over the earth. The water over the earth surface bulges during the earth's rotation as shown in Fig(a). The bulging depends upon the position of moon and sun with respect to the position considered on the earth as the forces by moon and sun act *simultaneously.

2.2 Working of the Tidal Plant

The simplest scheme for developing tidal power is the single basin arrangement, in which a single basin of constant area is provided with inlet sluices large enough to admit the tide with only very small loss of head, the level of the water in the basin being the same as that of the tide outside. At high tide, when the basin is full, the sluices are closed, and as the tide falls, the water flows out through the turbines to generate power. A head of water must obviously be provided for the turbines to generate energy, and they will continue to operate until a point after low water at which the falling water level in the tidal basin coincides with the level of the rising tide.

We, therefore, have to reconcile three variables in order to generate maximum power, namely, the capacity of the turbine; the minimum head under which these turbines will operate efficiently; and the period of delay in beginning the operation. In the older designs of water turbines, high efficiency was maintained over a relatively small variation of water pressure in the turbine, but modern turbines can be designed to operate at high efficiency over a much wider range of pressure. The Kaplan-type of water turbine operates in the manner of a variable pitch propeller as used in ships and aircraft. Between the fully open and the closed positions of the blades, there is a range of angles at which they can be set to give maximum efficiency at definite heads. Fig. shows the working of tidal plant. During flood tide water enters through the turbine located in the dam and produces the power.

During the ebb tide, the water in the basin flows through the turbine and again produces the power.



(a) Filling of basin (Flood tide) (b) Emptying of basin (Ebb - tide)

The design and construction of tidal plant are similar to hydroelectric power plants. Th turbine speed is (1/10)th of speed of turbine used in hydroelectric plant (50 rpm - 100 rpm). It requires large number of turbines as huge amount of water has to pass during a small time period. The average power output is limited by twice daily ebb and flood tides and therefore, average output of tidal plant is hardly 40% of the installed generating capacity. Tidal plant works like hydel plant except the dam is much larger in size (length). The time periods can be explained with respect to sea level and basin level when flood tide occurs as shown in Fig. below

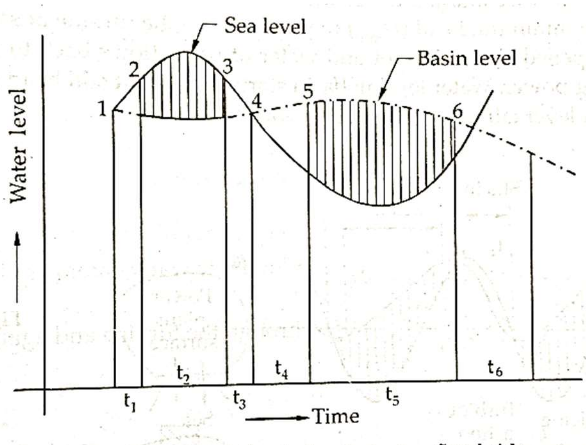


Fig. 16.7. Sea and basin levels during flood tide

In a single basin tidal system, power is generated only at high and low levels of basin only Therefore, power generation is non-uniform.

1. Period t_1 During this period, the head is too low. Both sea and basin are at low tide level (1). Therefore, all gates are closed.
2. Period t_2. When the head is sufficient (2), the gates are opened and water from the sea flows through the reversible turbine to the basin and power is generated during the period.

3. Period t_3: The sea level reaches its peak and then begins to decrease. The basin level increases up to point 3. The head is too low for power generation. Therefore, the gates to the turbine are closed and bypass gates are opened so that the basin is allowed to fill during the period t_3.
4. Period t_4. At point 4, all the gates are closed and basin level more or less remains constant. The sea level decreases during the period t_4
5. Period t_5. At point 5, the head is again sufficient to pass the water through the turbine in opposite direction. The power generation takes place during the period t_5
6. Period t_6: At point 6, power generation stops as the head is not sufficient to rotate the turbine but basin is allowed to empty during the period. The percentage of power generation period is $\frac{(t_2+t_5)}{(t_1+t_2+t_3+t_4+t_5+t_6)} X\ 100$, which is hardly 35 % to 40 %

2.3 Tidal Energy Conversion Systems

The tidal power plants are mainly classified in two groups as :

(A) Tidal plant using one basin.

(1) Single ebb cycle system.

(2) Single tide cycle system.

(3) Double cycle system.

(B) Tidal power plant employing two basins.

(1) System of alternating operating basins.

(2) System of co-operating basins.

2.3.1 Tidal plant using one basin

2.3.1.1 Single Ebb Cycle System

In this system, power is generated only during emptying of basin. When there is ebb at some instants, water level in sea and basin will be same. After this, sea level falls and will cause water of basin to flow back to sea.

During ebb at time t_1 water level in basin and sea are same. The sluice gate is closed. The water level in sea continues to fall and level difference goes on increasing at time t_2. The difference reaches the minimum head (H_{min}) required to run the turbine at satisfactory efficiency. The turbine gate is opened at this instant and water of basin flows back to sea through turbine which starts generating power. Water level in basin starts falling but still head reaches a maximum value because the sea level falls faster than basin water level.

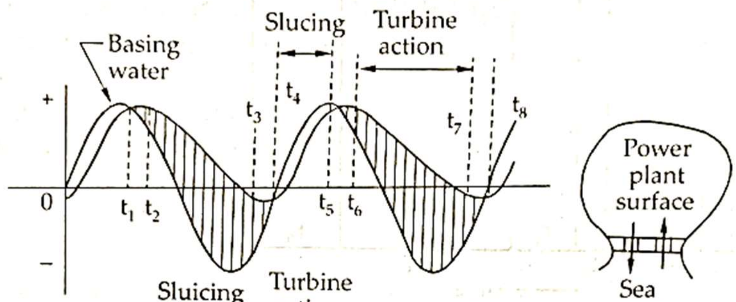


Fig Single ebb cycle system

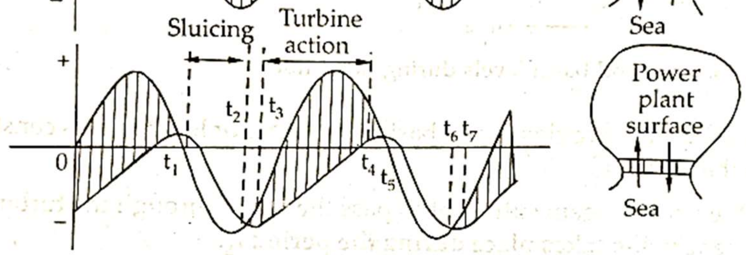


Fig. Single tide cycle system

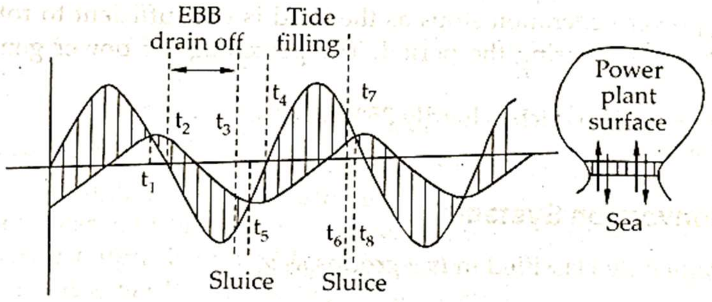


Fig. Double cycle system

When tide starts, head starts reducing and becomes H_{min} at ty then turbine is stopped. At t_l levels are once again the same. Sluice gate 1 starts to fill the basin and at t_5, it is once again same. The gate is closed as before. Thus, turbine works in the period t_2 to t_3, t_6 to t_7 and so on and sluice gate is opened during t_4 to t_5

In this, turbine action is intermittent and takes place only during ebb.

2.3.1.2 Single Tide Cycle System

In this, system, power is generated only during the filling of the basin as shown in Fig. When ebb is going on at time t_l water levels are equalized and the sluice gate is opened. At t_2 water level is once again equalized and the sluice gate is closed at this moment. The sea level starts rising at t_3 and H_{min} is attained for economic and efficient working of turbine. Sea water is allowed to enter the basin through turbine for power generation.

The head increases because sea level increases faster. Then ebb starts and head start decreasing. At t_4, the minimum head is again reached, so the turbine is shut off at this moment. At t_5, water level is equalized again and sluice gate is opened.

Thus, in this, sluicing takes place during intervals t_1 to t_2, and t_5 to t_6 and the turbine operates during intervals t_3 to t_4 during the tide. In this case, too, the power generation is intermittent and occurs only when there is tide.

2.3.1.3 Double Cycle System

In this, both tide and ebb cycle are employed alternatively as shown in Fig.

At time t_1, water levels are equal and sluice gate is closed. At t_2, difference in water level reaches the H_{min} essential for running the turbine efficiently. The turbine gate is opened and water in the basin is allowed to flow back to sea. After some time, sea reaches minimum level and tide starts. At t_3, when again H_{min} is reached, the turbine is stopped. Sluice gate is opened for short time until the water level equalizes. At t_4, sluice gate is closed. Sea continues high tide when H_{min} is again reached and the turbine gate is opened and sea water is admitted in the basin through the turbine. Again, at t_6 during ebb H_{min} is reached and turbine is stopped. The sluice gate is opened for short period to equalize the level. At t_7, levels are equal and sluice gate is closed. At t_8 H_{min} is again attained and cycle is repeated.

In this, turbine is shut off for short period, only during t_0 to t_2, t_3 to t_5, t_6 to t_8 and so on but duration of shut down is very less as compared to other two cases.

Main difficulty in this is that the same turbine is to be operated in two different cases i.e., ebb tide that too in opposite direction. Therefore, appropriate arrangement of chambers before turbine makes one directional operation of turbine, both during emptying and filling. Otherwise, it becomes uneconomical to have two sets of turbine i.e., one for tide and one for ebb.

2.3.2 Tidal power plants with two basins

2.3.2.1 Alternating Operating Basins

In this, two adjacent basins are operated on a normal single cycle. Basin 1 produces power on the ebb cycle and basin 2 produces power on the tide cycle as shown in Fig.

By this, continuous power generation is made possible avoiding excessive power fluctuation. There will be fluctuation only between t_1 to t_2, t_3 to t_4 t_5 to t_6 and so on but this is for a very short period. This is because of changes in power supply from one basin to another basin.

2.3.2.2 Co-operating Basins

In this case, there is a upper basin adjacent to a lower basin. The water level in the upper basin is always higher than mean sea level and that of lower basin is always lower than mean sea level. During high tide, upper basin is filled up by sluice 'l' as shown in Fig.

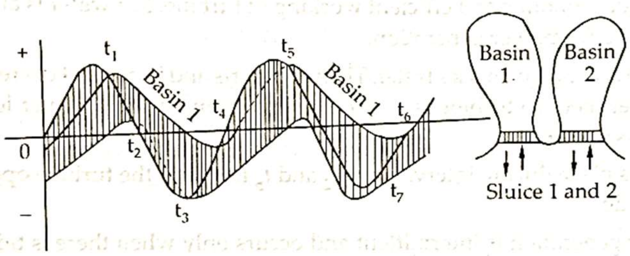


Fig System of alternating operating basin

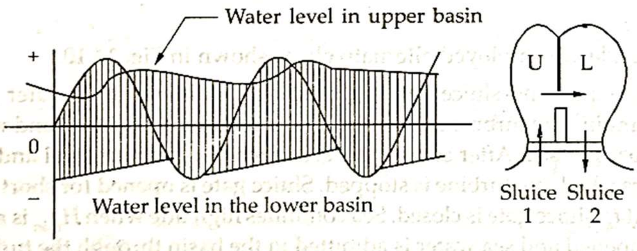


Fig. System of co-operative basin

Tide takes place from t_1 to t_2, and at this time, sluice '1' is kept open and upper basin is filled up. During t_2 to t_5 water of upper basin is allowed to flow to lower basin through power plant. Thus, cycle is repeated.

For lower basin, from t_0 to t_3, the level of the lower basin goes on increasing due to flow of

water from upper basin. At t_3, the level of sea and basin are equal, so sluice '2' is opened and level of sea further goes down, therefore, the basin water flows back to the sea. This is continued up to t_4, when again both levels are equal.

During t_4 to t_7, again water goes from the upper to lower basin. This way cycle is repeated. In this, there is a continuous flow of water from the upper basin the to lower basin the through turbine, thus, power generation is continuous, in this case.

2.4 Details of Tidal Plant Components

The major components of tidal power plants are the dam or barrage to form a basin for collecting water, the power house and sluice gates from the basin to the sea and vice versa.

Dam or barrage: Barrage is commonly used instead of dam, in case of tidal power plant as forces acting on it and structural strength are not the main considerations as in conventional hydel plants. Tidal barrage has to resist wave shock and where pressure changes as continuously.

Short barrages are preferred instead of long barrage upto height of 20 m cost per unit length remains same as it is not necessary to build dam wall to withstand high hydrostatic pressure.

Most tidal plants do not have heads above 20 m. The barrage provides channels for the turbines in reinforced concrete. Construction of barrage usually influences the tidal amplitude. The construction influences the resonance of the bay and most bays are less than the resonant length of the tidal wave. If resonance is reduced, the range will decrease, and if measures are taken to augment the resonance, tidal amplitude may increase. The design of barrage and its mode of operation mostly depend on the requirements of power. The simplest and cheapest scheme is single basin designed to trap water in a basin during high tide and to generate on the ebb. More complex system can involve generation on both ebb and flood tides or the construction of the secondary basin which will store the water and discharge wherever required. Such arrangement provides more power. The location of the barrage is important because the energy available is directly related to the basin size (water quantity) and the square of the tidal range (R^2). The nearer it is built to the month of an estuary or bay, the larger is the basin but the smaller is the tidal range. Therefore, a balance must be maintained between increased output and increased material requirements and construction costs.

Power House: Another important component of the plant is power house. As the maximum head available in a plant is 12 m, large size turbines are required and power house structure is also huge. If the water head is more than 8 meters, a propeller-type turbine is more suitable because the blade angels can be changed to obtain maximum efficiency. The main aim of the designer for the tidal power plant is to achieve as long a period of operation as possible. The turbines beginning and finishing work at the minimum head provides maximum efficiency and this is the main advantage of working a turbine with variable pitch blades (Kaplan).

The common turbines which are used in tidal plants are bulb turbine, tube turbine and rim turbine. The selection should be made according to the suitability.

(a) Bulb Turbine: It is a set of Kaplan turbine and generator whose shape looks like a small submarine. It is placed in a horizontal duct and entirely surrounded by water. The complete set works like a turbine-generator in direct sense basin to sea and provides power in reverse, sea to basin functioning as pump in direct sense.

(b) Tube Turbine: It is a combined set of turbine and generator but the shaft can be arranged horizontally or inclined. The generator is located outside the water. A power house with tube turbine is shown in Fig.

(c) Rim-type Turbine: In this system, generator is attached peripherally on the turbine blades. The main problem in this turbine, in which the rotor surrounds the turbine runner as rim is carried by the runner blades, is the seal between the stationary parts and rotating rim. This is considered more compact than the earlier two systems.

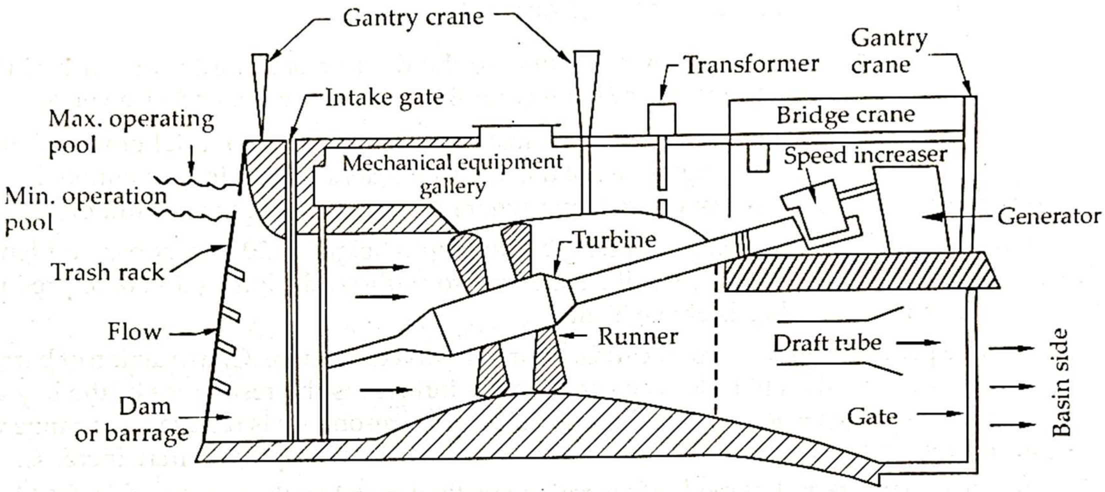


Fig. Layout of a typical tidal power house

Gats and Locks: In tidal power plants, the basins are filled and emptied regularly as per the cycle periods. Gates are opened regularly and frequently but heads vary in height and on the side where they occur. This is not the case in conventional hydro-electric plants. The gates must be opened and closed rapidly with minimum power. The corrosion problem is quite acute as the sea water is highly corrosive. It is prevented by cathodic protection.

The vertical lift gates are successfully used in existing plants. But presently, the technology is able to substitute a series of flaps that operate by water pressure. Flap gates are positioned so as to allow water to flow in the basin and does not require mechanical effort to operate. The flap gates open only in the direction of sea to basin. Hence, the basin level rises well above the sea level as ebb flow area is far less than flood flow area.

2.5 Major Problem Associated with Tidal Plants

The greatest and most obvious problem about tidal power is its intermittent nature, and a single basin scheme will give an intermittent supply of power varying considerably over the period of operation. Since high tide occurs about 50 minutes later each day and power will be available by this amount later each day, which is a great inconvenience. Tidal range or the head of water provided by a tide, shows wide variation; at spring tides it is nearly twice that at neaps, therefore energy output at springs being nearly three times that at neaps. In the case of the proposed Severn Barrage, this ratio is 3.5 : 1. It is quite clear that so far a public power system can not conveniently make use of such a variable and intermittent supply, and this is perhaps the chief reason why tidal power has not been developed on a large scale. Therefore much study has been devoted to various methods of regulating output from a tidal power scheme; one is the two-basin system as suggested for Menai Straits. The sluices of both basins are in direct communication with the tideway; as the tide rises, the upper basin is filled through the inlet sluices. The lower basin, previously emptied on the falling tide, will remain empty; at the turn of the tide, water will pass from the upper basin through the turbines to the lower basin and power will, thus, be generated. In the double-basin system, constant and continuous output is maintained by suitable adjustment of the turbine valves to suit the head, under which the turbines are operating.

Although, a two-basin system will regulate power output on an individual tide, it still leave unsolved problem of the great difference in output between spring and neap tides. This system is, therefore, only a partial solution to the problem of getting a steady output of power from a tidal scheme.

2.6 Advantages and Limitations of Tidal Power Plants

2.6.1 Advantages

1. The barrage provides protection to coast-line against damage by storms.
2. It does not produce green-house effect or other waste.
3. Tidal power does not require any fuel and produces electricity reliably.
4. The tides are predictable and correct design of the plant is possible.
5. The maintenance cost of the plant is less.
6. The tidal plant life is 100 years, which is much higher than thermal plant life (25 years)
7. It is more economical and provides clean energy
8. It is completely independent of the uncertainty of rains which is a common danger of conventional hydel plant.

2.6.2 Disadvantages

1. It does not produce power continuously as tides are available only for 10 hours a day.
2. There are huge effects on ecosystem by the currents in estuary.
3. The construction cost of barrage across an estuary is very high.

4. This energy is available only at selected sites in the world as minimum tide range required to produce power economically is greater than 4 m.
5. Sedimentation and filtration of basin are the common problems.
6. The effect on ecosystem at the bay site is the biggest drawback of tidal plant.
7. The capital cost is very high, period for construction is longer and payback period is 20 years to 25 years.
8. The tidal ranges are highly variable and the turbine has to work on a wide range of head variations. This affects the efficiency of the plant largely.
9. The tidal power generating capacity depends upon the level difference in the sea and basin. It has to be an intermittent operation feasible only at a certain stage of tidal cycle. This pattern can be improved to some extent by using double cycle and multiple basins systems.
10. The duration of power cycle is reasonably constant but its time of occurrence keeps changing. This produces difficulties in every day planning of the load sharing in the grid.
11. Sea water is highly corrosive, therefore, all machine parts should be made of very special stainless steel which increases the capital cost of the plant.

2.7 Environmental Effects

The large tidal barrages create many environmental effects as listed below:

1. The big barrages block ventilation.
2. Barriges make it difficult for wildlife and fish to migrate as they are very large in sizes.
3. The barrages change the size and location of the area that is alternatively exposed to wet and dry during the tide so the wildlife has to move to new places.
4. The barrages change the tidal regime downstream and affect the hydrology and salinity of these areas.

3 Wave Energy

Waves in the water is another large source of energy and is constantly available more or less throughout the year. The useful power potential of tides and wave sources are different kinds of periodic motion that has been eyed by the engineers from a long time.

Movement of ocean water (up and down), huge in height and quantity as one goes further from the coast can be considered as a big source of energy. The up and down movement of the water can be converted into useful energy by some mechanical source.

Waves are generated by the force of wind. Oceans are efficient collectors of wind energy. Wide waves are a source of energy steadier than the wind, becomes once wind generates a wave, the latter conveys the energy (derived from the wind over large distance (5 km to 50 km) with small dissipation of energy.

The ocean is a large collector of energy transferred by wind over a large surface area, which stores energy in the form of wave energy. Wave energy is more concentrated compared with wind energy, which is thinly distributed. Wave energy is available in coastal areas and in island locations and its potential depends upon its geographic location. The wave energy if harnessed with improved technology, can prove to be competitive renewable energy source in future. The nation such as India, with Arbian sea on one side and Bay of Bengal on other side the idea of extracting power from sea waves is very attractive. For all the countries, which have sea fronts, wave power probably offers a greater potential than any other natural a renewable energy source.

Japan being on island, the utilization of wave power is an attractive possibility of future energy source. In Japan, 400 units of wave-powered light houses are already in operation. Although, it has been shown that the wave power generating machine has quite long life, all existing machines are small in capacity (70 watts-120 watts) and this only restricts the possible use. The recent estimate suggests that nearly 30% of world energy demand could be fulfilled by energy from ocean waves.

3.1 Wave and Wave Generation

The periodic motion of water over the sea surface is known as wave. The basis of all energy resources of the ocean is the solar radiation falling on earth surfaces. The amount of solar energy received in low latitude is much higher than that received in the temperature regions. The differential heating of land and sea creates world's wind systems and wind moving over the ocean transfers kinetic energy to upper layers of ocean water and thus the waves are formed. The energy contained in the waves, is an indirect manifestation of immense amount of solar energy intercepted by the earth. We thus, see that the wave energy is simply a derived form of solar power which is constantly renewed by the sun and the engine of the atmosphere. Once the waves are formed in the ocean, they can travel great distances with minimum loss of energy until they break on some distant shore.

3.2 Advantages and Disadvantages of Wave Energy

3.2.1 Advantages:

1. It is superior to wind and solar energy as it is naturally concentrated by accumulation over time and space.
2. The power density of wave (kW/m^2) is 100 times greater than power density in wind.
3. Wave power devices do not use large land masses like solar and wind.
4. The wave conversion devices remove a large amount energy from the waves and stops destruction of the sea shore as the water coming out remains in calm state.
5. It is free and renewable energy as well as the devices used are relatively pollution free.
6. It is more superior than solar and tidal energy as the waves are continuous (period is hardly 5 sec to S sec). Solar energy is not available at nights, cloudy weather, rainy seasons and winter. The period of tidal energy is large as it is 12 hours and 25 minutes.
7. The energy storage is not required whereas energy storage for 12 hours to 16 hours is required for solar (in night) and tidal requires storage for a few hours.
8. The power density in wave system is 800 W/m against 250 W/m for solar energy, therefore, the wave energy conversion machine is comparatively smaller (25% only).
9. Wave plants reduce the erosion and corrosion of coastal land.
10. Coastal regions which lack other energy sources can develop wave power.
11. The ocean wave energy can be usefully converted and used in remote islands, ships, light houses, drilling platforms where other alternatives are difficult and costly.

3.2.2 Disadvantages:

1. The energy is available far away from the land, therefore, the transportation is difficult and costly.
2. The wave energy converting machines have to work in a marine environment (like storm and corrosion) and this is to be taken into account during design and construction.
3. Wave machines must be able to withstand severe stresses in storms.
4. The sites of large energy availability are very less in the world.
5. The wave energy converters are relatively complicated and costly.
6. Economic factors such as capital cost, maintenance, repair and replacement are large in nature and are relatively unknown.
7. The corrosion of materials used for plant is one main problem.

4 Ocean Thermal Energy Conversion System (OTEC)

4.1 Introduction

Nearly 82% of the world is commercial primary energy is supplied by fossil fuels, nuclear provide 4%, conventional hydro 10% and non-conventional energy sources provide remaining 3 to 4%. The rate of consumption of fossil fuels is increasing rapidly because of population growth and increase in living standard. Therefore, the conventional fossil fuels are going to be exhausted soon and long-term security cannot be assured by these fuels. We need to switch-on to nonconventional energy sources that are available in nature.

It is also estimated that about 10' MW of solar energy falls on the earth. The 75% of the ear surface is covered with water and average depth of the water in the sea is 3800 m. There are mainly four Oceans on the earth (Pacific, Atlantic, Hindi and Arctic) and they contain approximately 2.3 x 10^{15} m^3 of water. On an average, 60 million kilometers of sea area absorbs solar radiation which is equivalent to 170 billion barrels of oil per day (1 billion = 10^9). Therefore, this makes the world's largest solar energy collector and energy storage system.

Thus, the ocean has enormous potential to generate power. The heat energy available with sea water can be used for generating power using closed cycle system (Rankine cycle), which is known as OTEC. This system has a good future and potential. It is estimated that the absorbed heat energy in ocean can generate 10^6 MW constantly, if utilized properly and effectively.

This source of non - conventional energy is already used in England, Japan and USA.

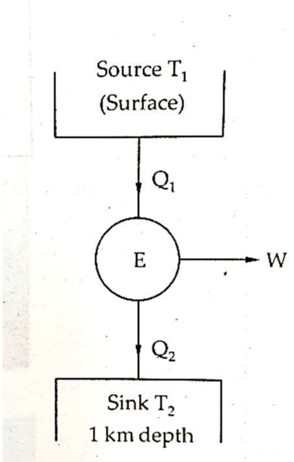
4.2 Principle of OTEC system

In OTEC system, the temperature gradient existing in ocean is used for power generation. In OTEC system, the surface of the water acts as the collector of solar heat. The temperature of water decreases as the depth of water increases. The bottom layer (nearly 1 km from the water surface) consists of colder water. Therefore, the upper water layer works as a source of heat and lower layer acts as a sink. The temperature difference between the upper warm and bottom cold layers ranges from 10°C to 25°C with higher values found in equatorial waters. The higher is the temperature

$$\eta = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = \frac{T_1 - T_2}{T_1}$$

In general, high temperature remains at the surface (T, = 25°C) and 1 km below, the temperature remains in the range of 4°C to 5°C, creating a temperature difference of 20°C.

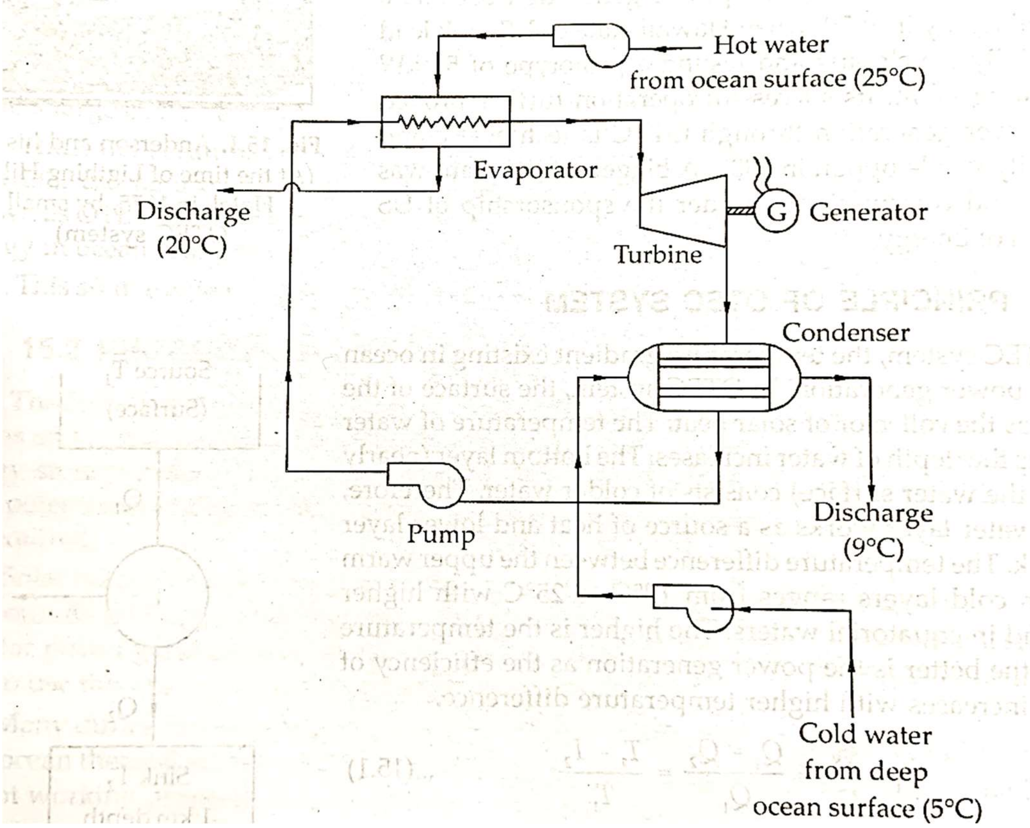
The water density at the surface is lower (being hot) than the water density at lower surface (being cold). Therefore, there is no thermal convection current from the warmer towards the depth.



To an engineer, this implies that there are two enormous reservoirs providing heat source and heat sink required to operate an heat engine. In this system, some low boiling organic fluid (NH, Propane, R-12) is used to absorb the heat at higher temperature (T_1 =25°C) and rejects the heat at lower temperature (T_2 =5°C) after developing the work. Such system works on closed Rankine cycle. The major difficult experienced in operating OTEC plant is its efficiency which is extremely low as 4% to 5% only because of low temperature difference between source and sink. With 25°C and 5°C temperatures of source and sink, the Carnot efficiency is hardly 6.7% only. Therefore, the OTEC plant is extremely huge in size and requires enormous quantities of warm and cold water.

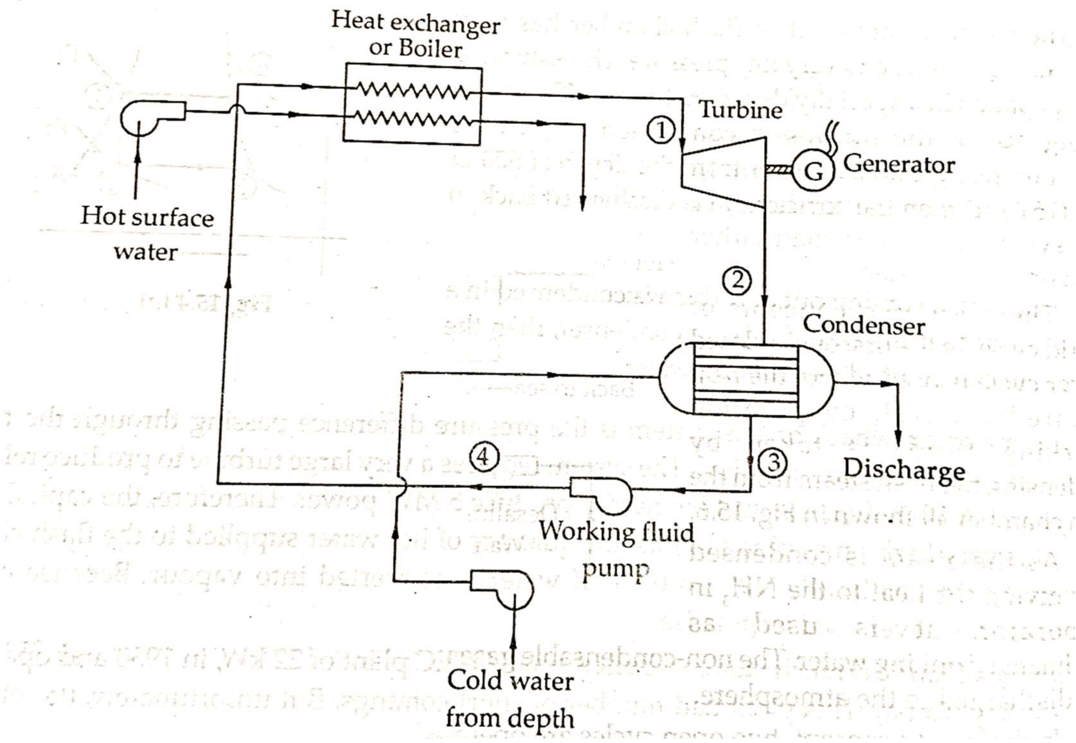
Presently, the largest plant of 7.5 MW capacity is in operation in France, using temperature difference of 22°C. The oceans are thus, considered, as a vast reservoir of source of energy, with a potential to produce billions of watts. This potential is estimated to be about 1013 watts.

The components required for the operation of an OTEC system are shown in Fig. The working fluid (say R-12) is evaporated in the evaporator using hot water from the ocean surface and high-pressure vapour expands passing through a turbine and develops power. The vapour coming out of turbine at lower pressure and temperature is condensed in the condenser using low-temperature ocean water from depth. Then the condensed liquid is pumped back with the help of the pump and the cycle is completed.

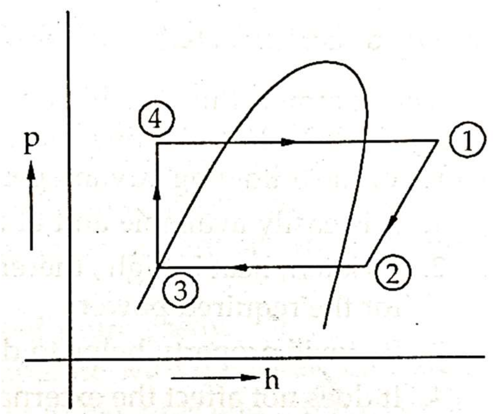


4.3 Closed Cycle System (Rankine or Anderson cycle)

In this system, the working fluid is separated from the heat transfer fluid (surface hot water and bottom cold water). The arrangement of the system is shown in the fig below



The working fluid is generally some refrigerant which boils at lower temperature and higher pressure. High pressure refrigerant vapour is generated in the boiler using heat from surface hot water.



The generated refrigerant vapour expands in turbine and generates the power. The low-pressure refrigerant vapour coming out of turbine is condensed in the condenser using cold sea water

The condensed refrigerant coming out of condenser is further fed to the refrigerant boiler and the cycle is completed. If the power developed by the turbine is say P kW, then the amount of refrigerant required to be circulated in the cycle is given by $P = m_r(h_1 - h_2)$

Then the amount of hot water required to be circulated in the refrigerant boiler is given by

$$m_{wh}C_{pw}(\Delta T)_h = m_r(h_1 - h_4)$$

where $(\Delta T)_h$ is the drop in temperature of the hot water coming out of the refrigerant boiler. The amount of cold water from the depth required to be circulated in the condenser is given by

$$m_{wh}C_{pw}(\Delta T)_c = m_r(h_2 - h_3)$$

where $(\Delta T)_c$ is the increase in temperature of the cold water passing through the condenser. The efficiency of the cycle is given by

$$\eta_c = \frac{h_1 - h_2}{h_1 - h_4} = \frac{h_1 - h_2}{h_1 - h_3}$$

As $h_4 = h_3$, if the pump work is neglected.

4.4 Advantages and disadvantages of OTC system

4.4.1 Advantages:

1. Warm surface water and cold water from the ocean depth are used for power generation so it is considered as a clean abundant and renewable natural source. This source is available day or night.
2. The OTEC plant does not produce CO, so these is no danger of Green-House effect like conventional thermal plants. These is hardly any adverse environmental effect from discharging the used OTEC water back to the ocean. It is environmental friendly.

3. OTEC system can produce power as well as fresh drinking water. It is a significant advantage in island areas where fresh water is a problem.
4. It is considered as unlimited source of energy as the energy is received from the sun on daily basis. In future, this source, if properly developed, will remove complete dependence on fossil fuels.
5. In addition to all above, the cold water drawn from the depth has many other uses like air-conditioning of buildings, assisting agriculture and growing fishes and other sea plants.
6. OTEC can also be used to produce methanol, ammonia, chlorine and many other chemicals.
7. Sea water from the depth is rich in nutrients and it is discharged on surface around the OTEC plant. It offers the possibility of fish farming.

4.4.2 Disadvantages:

1. The cost of power produced by OTEC system is considerably high because of its very poor generating efficiency (5%) and huge capital costs.
2. OTEC plants must be located only where the difference in temperature must be 20°C and above around the year for its economic and practical operation. Ocean depths must be available fairly close to shore-based facilities for economic operation. Floating plantships can provide such flexibility.
3. Construction of OTEC plant and lying of pipes in coastal water are difficult and may cause localized damage to reefs and marine ecosystems.
4. Although successful testing of OTEC is experimentally established, this technology is not yet established on commercial basis.
5. Some additional developments of key components is essential as deep sea water pipe lines, low pressure turbines and condensers for the further development of OTEC system.

4.5 Environmental impact of OTEC systems

OTC plant poses different environmental impacts compared with other power generating systems. Some of these impacts are listed below:

1. The marine life is very much affected.
2. Release of toxic chemicals and entrainment of small sea organisms in intake pipe is very common.

3. The atmosphere surrounding the OTEC system gets disturbed because of high water discharges (4 m^3/MW).
4. The marine environment is affected because of change in salinity, dissolved gases and carbonates.
5. The large discharge of mixed water below the sea surface for a long time affects the production rate of fishes as pH value of mixed water also changes.
6. Toxic chemicals from the plant (say NH,) may leak to the environment and may kill the marine organisms.

4.6 Some notable OTEC power plants

1. **Naura plant (Japan).** The world first land-based OTEC plant of 100 kW capacity was opened in 1981 on the Japanese island of Nauru. The civil work was completed by shimizh construction, Toshiba completed mechanical and electrical components and Tokyo Electric Power Services operated the plant. Nauru lies on the perfect position sitting almost on equator. This plant operates on closed cycle like Mini OTEC (50 kW in US) except F-22 was used as working fluid instead of NH_3 which was used at Mini. The Nauru plant takes in 1400 tones, each of hot and cold water per hour. It uses 30°C hot water and 8°C cold water from a depth of 500 m and 1000 m offshore using a pump motor of 27 kW capacity. The intake pipe of 70 cm diameter and 954 m long made of polyethylene was used. The capital cost of the plant was $40 million (1981).
2. **Lockhead plant (USA).** Lockhead OTEC plant in US is working on closed cycle, using ammonia as a working fluid, using water temperature difference of 20°C. It is a 100 MW plant in shape of 110 m diameter concrete cylinder whose platform extends above the water line. The structure houses 4-power modules and central cold water intake pipe of 16 m diameter made of glass fiber and extends 1210 m down the water level and brings up the cold water on the upper layer of the ocean. Lockhead plant features the use of 4-power modules attached to a semi-submersible spar-buoy, which provides buoyancy for the entire system. Each of the power modules is self contained and has its own heat exchangers, turbines, generators, working fluid pumps, ocean water circulating pumps, buoyancy control system and all other essential auxiliary equipment's Lockhead uses a single point mooring in which the OTEC structure is connected by a series of steel links to an anchor planted on the sea floor. The mooring is used at 760 m depth in the Gulf stream of Florida. The next leap forward in American OTEC is the construction of 40 MW floating plant. The next target was 100 MW power

by 1986, 500 MW by 1998 and 10.000 MW by 1999. The power from such generators could be used " on board" to make energy-intensive products such as ammonia, methanol, hydrogen, oxygen and fresh water, using the sea and air as raw materials. In the basic OTEC concept, which the Andersons (centre) demonstrated with their model simulating the different thermal levels of the ocean, surface water of about 27°C is pumped through tubes in an evaporator. Outside these tubes flows a "working fluid" with a low boiling point, such as propane (R-11 in the model). The working fluid is vaporized by the heat from the water and the vapour expands through the turbine.

4.6.1 Status of OTEC in India

India is fortunate to have long costal line. It also has large ocean thermal energy potential with water temperature difference of (29 - 7) 22°C with a depth of 1200 m. The OTEC potential is estimated at around 180 × 10^3 MW. The National Institute of Ocean Technology (NIT) proposed 1 MW OTEC plant and signed memorandum of understanding with Saga University (Japan) for the joint development of the plant near the port of Tuticorin (TN). It is also planned to set-up 25 MW OTEC plant as proposed by Tamil Nadu State Electricity Board. The generated power will be conveyed to the shore via undersea cables. Four possible sites have been chosen for the project.

It is also estimated that the Bay of Bengal can sustain 10,000 MW OTEs plants. A pilot plant is proposed to be set-up in collaboration with GE of USA.