UNIT V – OCEAN AND GEOTHERMAL ENERGY

Introduction

Tidal power or tidal energy is the form of hydropower that converts the energy obtained from tides into useful forms of power, mainly electricity. The barrage method of extracting tidal energy involves building a barrage across a bay or river that is subject to tidal flow. Turbines installed in the barrage wall generate power as water flows in and out of the estuary basin, bay, or river. Wave energy (or wave power) is the transport and capture of energy by ocean surface waves. The energy captured is then used for all different kinds of useful work, including electricity generation, water desalination, and pumping of water. Ocean Thermal Energy Conversion (OTEC) is a process that can produce electricity by using the temperature difference between deep cold ocean water and warm tropical surface waters. A fuel cell works by passing hydrogen through the anode of a fuel cell and oxygen through the cathode. At the anode site, the hydrogen molecules are split into electrons and protons. A hybrid energy system, or hybrid power, usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply.

Tidal Energy: Energy from the tides

Tidal power, also called tidal energy is any form of renewable energy in which tidal action in the oceans is converted to electric power. There are three main types of energy that can be captured from the oceans: wave, tidal stream, and tidal range.

Using the power of the tides, energy is produced from the gravitational pull from both the moon and the sun, which pulls water upwards, while the Earth"s rotational and gravitational power pulls water down, thus creating high and low tides. This movement of water from the changing tides is a natural form of kinetic energy. The tidal stream devices which utilise these currents are broadly similar to submerged wind turbines and are used to exploit the kinetic energy in tidal currents. Due to the higher density of water the blades can be smaller and turn more slowly, but they still deliver a significant amount of power. To increase the flow and power output from the turbine, concentrators (or shrouds) may be used around the blades to streamline and concentrate the flow towards the rotors.

It can only be installed along coastlines. Coastlines often experience two high tides and two low tides on a daily basis. The difference in water levels must be at least 5 meters high to produce electricity. The various components include, steam generator, tidal turbine or the more innovative dynamic tidal power (DTP) technology to turn kinetic energy into electricity.

The world's first tidal power station was constructed in 2007 at Strangford Lough in Northern

Barrage and Non Barrage Tidal power systems

Tidal electricity can be created from several technologies, the main ones being tidal barrages, tidal turbines and tidal lagoons.

Tidal Barrages

The Tidal Barrage uses long walls, dams, sluice gates or tidal locks to capture and store the potential energy of the ocean. A Tidal Barrage is a type of tidal power generation scheme that involves the construction of a fairly low walled dam, known as a “tidal barrage”. It spans across the entrance of a tidal inlet, basin or estuary creating a single enclosed tidal reservoir, similar in many respects to a hydroelectric impoundment reservoir. The bottom of this barrage dam is located on the sea floor with the top of the tidal barrage being just above the highest level that the water can get too at the highest annual tide. The barrage has a number of underwater tunnels cut into its width allowing the sea water to flow through them in a controlled way by using “sluice gates” on their entrance and exit points. Fixed within these tunnels are huge tidal turbine generators that spin as the sea water rushes past them either to fill or empty the tidal reservoir thereby generating electricity.

The water which flows into and out of these underwater tunnels carries enormous amounts of kinetic energy and the job of the tidal barrage is to extract as much of this energy as possible which it uses to produce electricity. Tidal barrage generation using the tides is very similar to hydroelectric generation, except that the water flows in two directions rather than in just one. On incoming high tides, the water flows in one direction and fills up the tidal reservoir with sea water. On outgoing ebbing tides, the sea water flows in the opposite direction emptying it. As a tide is the vertical movement of water, the tidal barrage generator exploits this natural rise and fall of tidal waters caused by the gravitational pull of the sun and the moon.

The tidal energy extracted from tides is a potential energy as the tide moves in a vertical up-down direction between a low and a high tide and back to a low creating a height or head differential. A tidal barrage generation scheme exploits this head differential to generate electricity by creating a difference in the water levels at the side of a dam and then passing this water difference through the turbines. The three main tidal energy barrage schemes that use this water differential to their advantage are:

1. **Flood Generation:** The tidal power is generated as the water enters a tidal reservoir on the incoming Flood tide.
2. **Ebb Generation:** The tidal power is generated as the water leaves a tidal reservoir on the Ebb flow tide.
3. **Two-way Generation:** The tidal power is generated as the water flows in both directions in and out of the reservoir during both the Flood and the Ebb tides.

Tidal Barrage Flood Generation

A Tidal Barrage Flood Generation uses the energy of an incoming rising tide as it moves towards the land. The tidal basin is emptied through sluice gates or lock gates located along the section of the barrage and at low tide the basin is affectively empty. As the tide turns and starts to comes in, the sluice gates are closed and the barrage holds back the rising sea level, creating a difference in height between the levels of water on either side of the barrage dam.

The sluice gates at the entrances to the dam tunnels can either be closed as the sea water rises to allow for a sufficient head of water to develop between the sea level and the basin level before being opened, generating more kinetic energy as the water rushes through, turning the turbines as it passes. Or may remain fully open, filling up the basin more slowly and maintaining the same water level inside the basin as out in the sea.

The tidal reservoir is therefore filled up through the turbine tunnels which spin the turbines generating tidal electricity on the flood tide and is then emptied through the opened sluice or lock gates on the ebb tide. Then a flood tidal barrage scheme is a one-way tidal generation scheme on the incoming tide with tidal generation restricted to about 6 hours per tidal cycle as the basin fills up.

The movement of the water through the tunnels as the tidal basin fills up can be a slow process, so low speed turbines are used to generate the electrical power. This slow filling cycle allows fish or other sea life to enter the enclosed basin without danger from the fast rotating turbine blades. Once the tidal basin is full of water at high tide, all the sluice gates are opened allowing all the trapped water behind the dam to return back to the ocean or sea as it ebbs away.

Flood generator tidal power generates electricity on incoming or flood tide, but this form of tidal energy generation is generally much less efficient than generating electricity as the tidal basin empties, called "Ebb Generation". This is because the amount of kinetic energy contained in the lower half of the basin in which flood generation operates is much less the kinetic energy present in the upper half of the basin in which ebb generation operates due to the effects of gravity and the secondary filling of the basin from inland rivers and streams connected to it via the land.

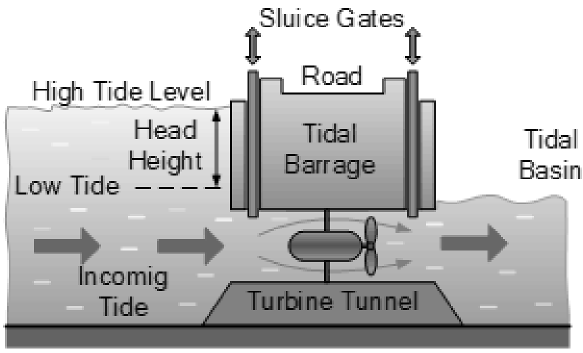

Fig. 1. Tidal Barrage Flood Generation

Tidal Barrage Ebb Generation

A Tidal Barrage Ebb Generation uses the energy of an outgoing or falling tide, referred to as the "ebb tide", as it returns back to the sea making it the opposite of the previous flood tidal barrage scheme. At low tide, all the sluice and lock gates along the barrage are fully opened allowing the tidal basin to fill up slowly at a rate determined by the incoming flood tide. When the ocean or sea level feeding the basin reaches its highest point at high tide, all the sluices and lock gates are then closed entrapping the water inside the tidal basin (reservoir). This reservoir of water may continue to fill-up due to inland rivers and streams connected to it from the land.

As the level of the ocean outside the reservoir drops on the outgoing tide towards its low tide mark, a difference between the higher level of the entrapped water inside the tidal reservoir and the actual sea level outside now exists. This difference in vertical height between the high level mark and the low mark is known as the "head height".

At some time after the beginning of the ebb tide, the difference in the head height across the tidal barrage between the water inside the tidal reservoir and the falling tide level outside becomes sufficiently large enough to start the electrical generation process and the sluice gates connected to the turbine tunnels are opened allowing the water to flow.

When the closed sluice gates are opened, the trapped potential energy of the water inside flows back out to the sea under the enormous force of both the gravity and the weight of the water in the reservoir basin behind it. This rapid exit of the water through the tunnels on the outgoing tide causes the turbines to spin at a fast speed generating electrical power.

The turbines continue to generate this renewable tidal electricity until the head height between the external sea level and the internal basin is too low to drive the turbines at which point the turbines are disconnected and the sluice gates are closed again to prevent the tidal basin from over draining and affecting local wildlife. At some point the incoming flood tide level will again be at a sufficient level to open all the lock gates filling-up the basin and repeating the whole generation cycle over again as shown.

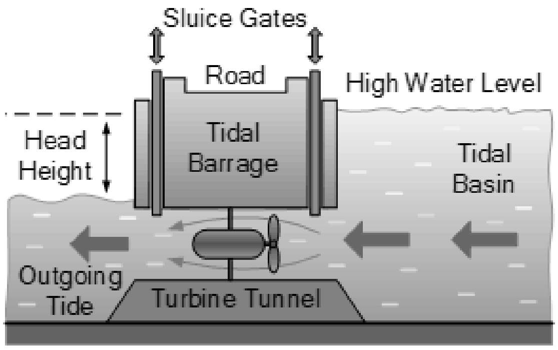

Fig. 2. Tidal Barrage Ebb Generation

According to the estimates of the Indian government, the country has a potential of 8,000 MW of tidal energy. This includes about 7,000 MW in the Gulf of Cambay in Gujarat, 1,200 MW in the Gulf of Kutch and 100 MW in the Gangetic delta in the Sunderbans region of West Bengal.

Two-way Tidal Barrage Generation Scheme

Both Flood Tidal Barrage and Ebb Tidal Barrage installations are "one-way" tidal generation schemes, but in order to increase the power generation time and therefore improve efficiency, we can use special double effect turbines that generate power in both directions. A Two-way Tidal Barrage Scheme uses the energy over parts of both the rising tide and the falling tide to generate electricity.

Two-way electrical generation requires a more accurate control of the sluice gates, keeping them closed until the differential head height sufficient in either direction before being opened. As the tide ebbs and flows, sea water flows in or out of the tidal reservoir through the same gate system. This flow of tidal water back and forth causes the turbine generators located within the tunnel to rotate in both directions producing electricity.

However, this two-way generation is in general less efficient than one-way flood or ebb generation as the required head height is much smaller which reduces the period over which normal one-way generation might have otherwise occurred. Also, bi-directional tidal turbine generators designed to operate in both directions are generally more expensive and less efficient than dedicated uni-directional tidal generators.

Non Barrage Tidal power systems

Tidal turbines

Tidal stream generators are underwater tidal turbines which produce mechanical power by converting the kinetic energy from water currents (the kinetic power component), in a similar way to wind turbines which draw energy from air currents. A tidal stream is a fast-flowing body of water created by tides. A turbine is a machine that takes energy from a flow of fluid. That fluid can be air (wind) or liquid (water). Because water is much more dense than air, tidal energy is more powerful than wind energy. Unlike wind, tides are predictable and stable. Where tidal generators are used, they produce a steady, reliable stream of electricity.

Placing turbines in tidal streams is complex, because the machines are large and disrupt the tide they are trying to harness. The environmental impact could be severe, depending on the size of the turbine and the site of the tidal stream. Turbines are most effective in shallow water. This produces more energy and allows ships to navigate around the turbines. A tidal generator's turbine blades also turn slowly, which helps marine life avoid getting caught in the system.

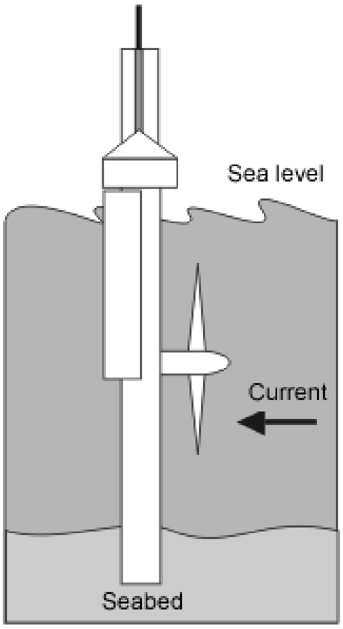

Fig. 3. Tidal turbine

The Bay of Fundy in Canada has the highest tidal ranges in the world, where the height difference between low and high tide water levels can reach 16.3 meters, taller than a three storey building, and therefore brimming with potential for tidal energy production.

Tidal lagoon

A tidal lagoon is a power station that generates electricity from the natural rise and fall of the tides. Tidal lagoons work in a similar way to tidal barrages by capturing a large volume of water behind a man-made structure which is then released to drive turbines and generate electricity. Unlike a barrage, where the structure spans an entire river estuary in a straight line, a tidal lagoon encloses an area of coastline with a high tidal range behind a breakwater, with a footprint carefully designed for the local environment.

As the tide comes in (floods) the water is held back by the turbine wicket gates, which are used to control the flow through the turbine and can be completely closed to stop the water from entering the lagoon. This creates a difference in water level height (head) between the inside of the lagoon and the sea. Once the difference between water levels is optimised, the wicket gates are opened and water rushes into the lagoon through the bulb turbines mounted inside concrete turbine housings in a section of the breakwater wall. As the water turns the turbines, electricity is generated.

The water in the lagoon then returns to closely match the same level as the sea outside. This process also happens in reverse as the tide flows out (ebbs) because the turbines are „bi-directional" and so electricity can be generated from the incoming and outgoing tides. We can hold the tide within the lagoon for approximately 2.5 hours as the sea outside ebbs and the head builds.

The height and time of the tides can be predicted years in advance to a high degree of accuracy, allowing the precise operation of the lagoon on each tidal cycle to be optimised well in advance.

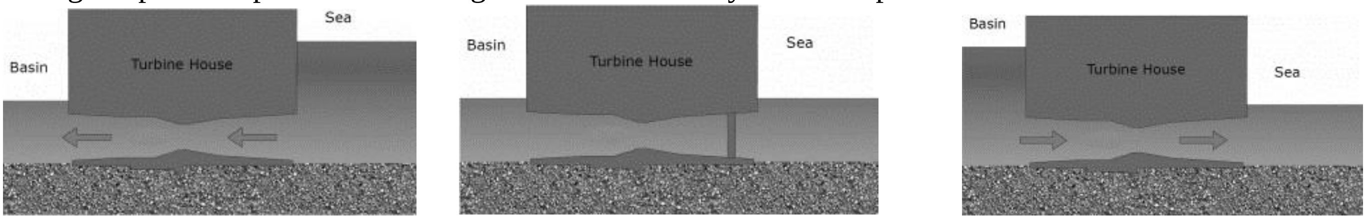

Fig. 4. a. Generating on the flood tide b. Holding period at high or low water c. Generating on the ebb tide

Advantages of Tidal Energy

- **Renewable:** Compared to fossil fuels or nuclear reserves, the gravitational fields from the sun and the moon, as well as the earth‟s rotation around its axis won‟t cease to exist any time soon.
- **Green:** Tidal power is an environmentally friendly energy source. In addition to being a renewable energy, it does not emit any climate gases and does not take up a lot of space.
- **Predictable:** Tidal currents are highly predictable. High and low tide develop with well-known cycles, making it easier to construct the system with right dimensions, since we already know what kind of powers the equipment will be exposed to.
- **Effective at Low Speeds:** Water has 1000 times higher density than air, which makes it possible to generate electricity at low speeds. Calculations show that power can be generated even at 1m/s (equivalent to a little over 3ft/s).
- **Long Lifespans:** We have no reason to believe that tidal power plants are not long lived. This ultimately reduces the cost these power plants can sell their electricity, making tidal energy more cost-competitive.

Disadvantages of Tidal Energy

- **Environmental Effects:** Tidal barrages relies on manipulation on ocean levels and therefore potentially have the environmental effects on the environment similar to those of hydroelectric dams.
- **Close to Land:** Tidal power plants needs to be constructed close to land.
- **Expensive:** It is important to realize that the methods for generating electricity from tidal energy is a relatively new technology.

The IEA believes tidal energy could start playing a significant part in the global energy mix by 2030. Tidal energy may produce up to 748 GW of power by 2050, according to Ocean Energy Systems. Although, compared to solar, the predictions are conservative. (Solar power could hit 4,600 GW by

Wave Energy: Energy from waves

Waves form as wind blows over the surface of open water in oceans and lakes. Ocean waves contain tremendous energy. Wave power is produced by the up and down motion of floating devices placed on the surface of the ocean. As the waves travel across the ocean, high-tech devices capture the natural movements of ocean currents and the flow of swells to generate power.

Wave energy or wave power is essentially the power drawn from waves. When wind blows across the sea surface, it transfers the energy to the waves. They are powerful source of energy and the energy output is measured by wave speed, wave height, wavelength and water density. The more strong the waves, the more capable it is to produce power. The captured energy can then be used for electricity generation, powering plants or pumping of water. For example when you look out at a beach and see waves crashing against the shore, you are witnessing wave energy. Wave energy is often mixed with tidal power, which is quite different. When wind blows across the surface of the water strongly enough, it creates waves. This occurs most often and most powerfully on the ocean because of the lack of land to resist the power of the wind. The kinds of waves that are formed, depend on from where they are being influenced.

Long, steady waves that flow endlessly against the beach are likely formed from storms and extreme weather conditions far away. The power of storms and their influence on the surface of the water is so powerful that it can cause waves on the shores of another hemisphere. When you see high, choppy waves that rise and fall very quickly, you are likely seeing waves that were created by a nearby weather system. These waves are usually newly formed occurrences. The power from these waves can then be harnessed through wave energy converter (WEC).

Wave power devices

As an ocean wave passes a stationary position, the surface of the sea changes in height, water near the surface moves as it losses its kinetic and potential energy, which affects the pressure under the surface. The periodic or oscillatory nature of ocean waves means that we can use a variety of different Wave Energy Devices to harness the energy produced by the oceans waves.

The problem lies is that the oscillatory frequency of an ocean wave is relatively slow and is much less than the hundreds of revolutions per minute required for electric power generation. Then a great variety of wave energy devices and designs are available to convert these slow-acting, reversing wave forces into the high speed, unidirectional rotation of a generator shaft.

There are three fundamental but very different wave energy devices used in converting wave power into electric power, and these are:

1. **Wave Profile Devices:** These are wave energy devices which turn the oscillating height of the oceans surface into mechanical energy.
2. **Oscillating Water Columns:** These are wave energy devices which convert the energy of the waves into air pressure.
3. **Wave Capture Devices:** These are wave energy devices which convert the energy of the waves into potential energy.

Tidal turbines are more expensive to build and maintain than wind turbines, but produce more energy. They also produce energy more consistently as the tide is continuous while the wind doesn't always

Wave Profile Devices

Wave profile devices are a class of wave energy device which floats on or near to the sea surface and moves in response to the shape of the incident wave or, for submersible devices, it moves up and down under the influence of the variations in underwater pressure as a wave moves by. Most types of wave profile devices float on the surface absorbing the wave energy in all directions by following the movements of waves at or near the sea surface, just like a float.

If the physical size of the wave profile device is very small compared to the periodic length of the wave, this type of wave energy device is called a “point absorber”. If the size of the device is larger or longer than the typical periodic wavelength, it is called a “linear absorber”, but more commonly they are collectively known as “wave attenuators”. The main difference between the two wave energy devices is how the oscillating system converts the wave energy between the absorber and a reaction point. This energy absorption can be achieved either by a floating body, an oscillating solid member or oscillating water within a buoys structure itself.

The waves energy is absorbed using vertical motion (heave), horizontal motion in the direction of wave travel (surge), angular motion about a central axis parallel to the wave crests (pitch) or angular motion about a vertical axis (yaw) or a combination of all four with the energy being generated by reacting these different movements against some kind of fixed resistance called a reaction point.

To make efficient use of the force generated by the wave, we need some kind of force reaction. In other words, we want the waves force on the float to react against another rigid or semi-rigid body. Reaction points can be inertial masses such as heavy suspended ballast plates, sea-floor anchors or a fixed dead-weight or pile as shown. The pitching and heaving of the waves causes a relative motion between an absorber and reaction point.

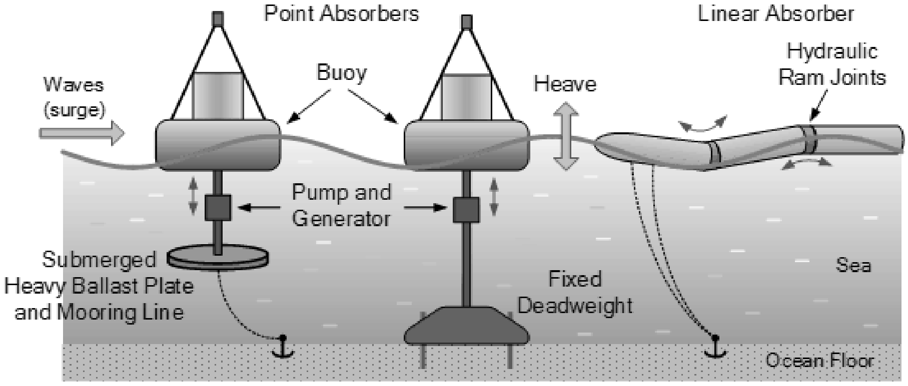

Fig. 5. Wave Profile Devices

The left hand wave energy device above, uses a heavy ballast plate suspended below the floating buoy. The buoy is prevented from floating away by a mooring line attached to a sea-floor anchor. This mooring line allows the point absorber to operate offshore in deeper waters. As the buoy bobs up-and-down in the waves, a oscillatory mutual force reaction is generated between the freely moving absorber and the heavy plate causing a hydraulic pump in between to rotate a generator producing electricity.

The middle wave energy device operates in a similar manner to the previous floating buoy device. The difference this time is that the freely heaving buoy reacts against a fixed reaction point such as a fixed dead-weight on the ocean floor. As this type of point absorber is bottom mounted, it is operated in shallower near shore locations.

The third device is an example of a linear absorber (wave attenuator) which floats on the surface of the water. It to is tethered to the ocean floor so that it can swing perpendicularly towards the incoming waves. As the waves pass along the length of this snake like wave energy device, they cause the long cylindrical body to sag downwards into the troughs of the waves and arch upwards when the waves crest is passing.

Oscillating Water Column

The Oscillating Water Column, (OWC) is a popular shoreline wave energy device normally positioned onto or near to rocks or cliffs which are next to a deep sea bottom. They consist of a partly submerged hollow chamber fixed directly at the shoreline which converts wave energy into air pressure.

The structure used to capture the waves energy could be a natural cave with a blow hole or a man made chamber or duct with a wind turbine generator located at the top well above the waters surface. Either way, the structure is built perpendicular to the waves with part of the ocean surface trapped inside the chamber which itself is open to the sea below the water line. The constant ebbing and flowing motion of the waves forces the trapped water inside the chamber to oscillate in the vertical up-down direction.

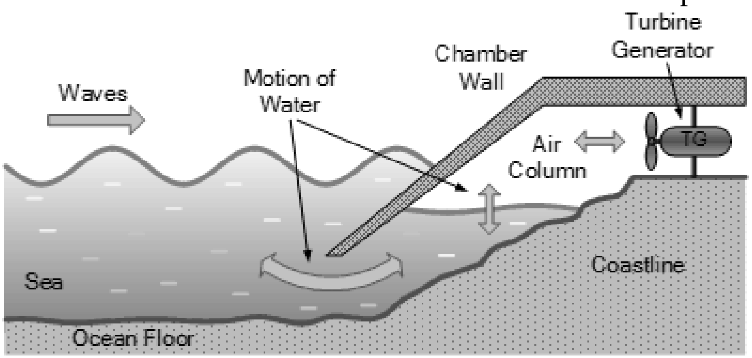

Fig. 6. Oscillating Water Column

As the incident waves outside enter and exit the chamber, changes in wave movement on the opening cause the water level within the enclosure to oscillate up and down acting like a giant piston on the air above the surface of the water, pushing it back and forth. This air is compressed and decompressed by this movement every cycle. The air is channelled through a wind turbine generator to produce electricity as shown.

The type of wind turbine generator used in an oscillating water column design is the key element to its conversion efficiency. The air inside the chamber is constantly reversing direction with every up-and-down movement of the sea water producing a sucking and blowing effect through the turbine. If a conventional turbine was used to drive the attached generator, this too would be constantly changing direction in unison with the air flow. To overcome this problem the type of wind turbine used in oscillating water column schemes is called a Wells Turbine. The Wells turbine has the remarkable property of rotating in the same direction regardless of the direction of air flow in the column. The kinetic energy is extracted from the reversing air flow by the Wells turbine and is used to drive an electrical induction generator. The speed of the air flow through the wells turbine can be enhanced by making the cross-sectional area of the wave turbines duct much less than that of the sea column.

As with other wave energy converters, oscillating wave column technology produces no greenhouse gas emissions making it a non-polluting and renewable source of energy, created by natural transfer of wind energy through a wells turbine. The advantage of this shoreline scheme is that the main moving part, the turbine can be easily removed for repair or maintenance because it is on land. The disadvantage though is that, as with the previous wave energy devices, the oscillating wave columns output is dependent on the level of wave energy, which varies day by day according to the season.

Wave Capture Device

A Wave Capture Device also known as a Overtopping Wave Power Device, is a shoreline to near shore wave energy device that captures the movements of the tides and waves and converts it into potential energy. Wave energy is converted into potential energy by lifting the water up onto a higher level. The wave capture device, or more commonly an overtopping device, elevates ocean waves to a holding reservoir above sea level.

The overtopping wave energy converter works in much the same way as an impoundment type hydroelectric dam works. Sea water is captured and impounded at a height above sea level creating a low head situation which is then drained out through a reaction turbine, usually a Kaplan Turbine generating electricity as shown.

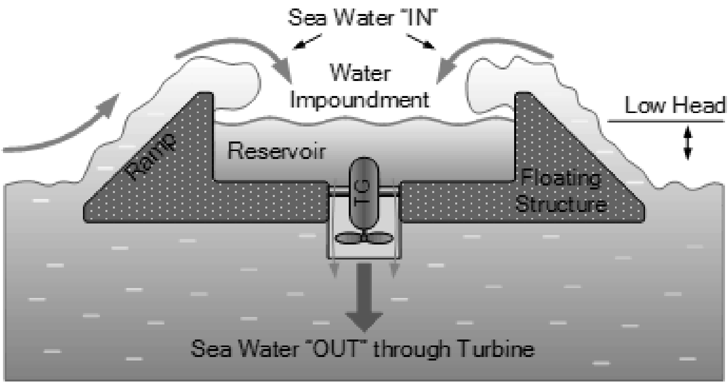

Fig. 7. Wave Capture Device

The basic impoundment structure can be either fixed or a floating structure tethered to the sea bed. The wave overtopping device uses a ramp design on the device to elevate part of the incoming waves above their natural height. As the waves hit the structure they flow up a ramp and over the top (hence the name "overtopping"), into a raised water impoundment reservoir on the device in order to fill it. Once captured, the potential energy of the trapped water in the reservoir is extracted using gravity as the water returns to the sea via a low-head Kaplan turbine generator located at the bottom of the wave capture device.

Ocean Thermal Energy Conversion (OTEC)

Ocean Thermal Energy also called as Ocean Thermal Energy Conversion (OTEC) refers to a method of using the temperature difference between the deep parts of the sea which are cold and the shallow parts of the sea which are cold to run a heat engine and produce useful work. Basically, Ocean thermal energy conversion is an electricity generation system. The deeper parts of the ocean are cooler due to the fact that the heat of sunlight cannot penetrate very deep into the water. Here the efficiency of the system depends on the temperature difference. Greater the temperature difference, greater the efficiency. The temperature difference in the oceans between the deep and shallow parts is maximum in the tropics, 20 to 25^{0} C. Tropics receive a lot of sunlight which warms the surface of the oceans, increasing the temperature gradient.

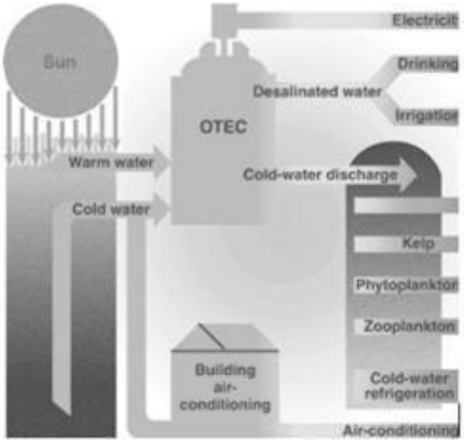

Fig. 8. Ocean Thermal Energy Conversion

The energy source of OTEC is abundantly available, free and will be so, for as long as the sun shines and ocean currents exist. Estimates suggest that ocean thermal energy could contain more than twice the world‟s electricity demand. This makes it necessary for us to give it a closer look.

Types of Ocean Thermal Energy Conversion Systems

The two types of Ocean Thermal Energy Conversion Systems are closed cycle and open cycle.

Closed Cycle: Closed cycle Ocean Thermal Energy Conversion systems use a working fluid with a low boiling point, Ammonia for example, and use it to power a turbine to generate electricity. Warm seawater is taken in from the surface of the oceans and cold water from the deep at 5^{0} . The warm seawater vaporizes the fluid in the heat exchanger which then turns the turbines of the generator. The fluid now in the vapour state is brought in contact with cold water which turns it back into a liquid. The fluid is recycled in the system so it is called a closed system.

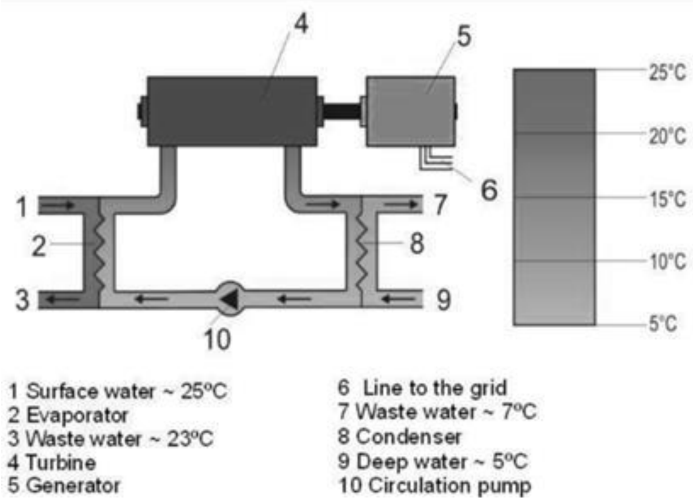

Fig. 9. Closed cycle Ocean Thermal Energy Conversion Systems

Open Cycle: Open cycle OTEC directly uses the warm water from the surface to make electricity. The warm seawater is first pumped in a low-pressure chamber where due to the drop in pressure, it undergoes a drop in boiling point as well. This causes the water to boil. This steam drives a low-pressure turbine which is attached to an electrical generator. The advantage of this system over a closed system is that, in open cycle, desalinated water in the form of steam is obtained. Since it is steam, it is free from all impurities. This water can be used for domestic, industrial or agricultural purposes.

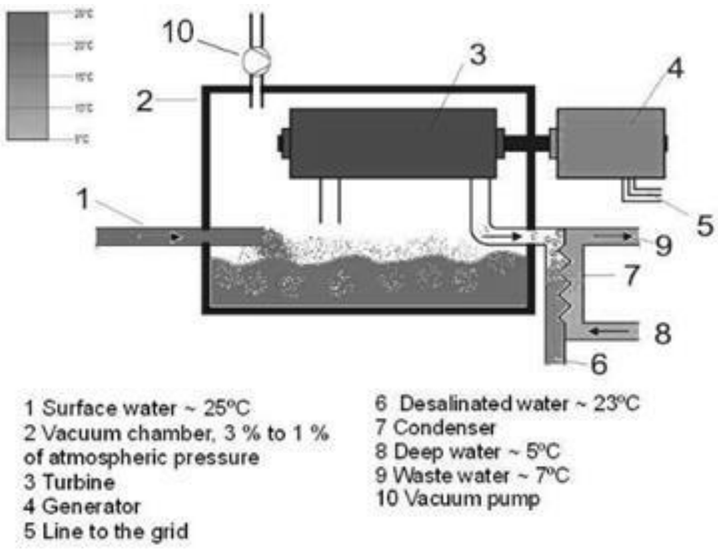

Fig. 10. Open cycle Ocean Thermal Energy Conversion Systems

Land- and sea-based OTEC

Open- and closed-cycle OTEC can operate either on the shore (land-based) or out at sea (sometimes known as floating or grazing). Land-based OTEC plants are constructed on the shoreline with four large hot and cold pipelines dipping down into the sea: a hot water input, a hot water output, a cold-water input, and a cold-water output. Unfortunately, shoreline construction makes them more susceptible to problems like coastal erosion and damage from hurricanes and other storms.

Sea-based OTEC plants are essentially the same but have to be constructed on some sort of tethered, floating platform, not unlike a floating oil platform, with the four pipes running down into the sea; early prototypes were run from converted oil tankers and barges. They also need a cable running back to land to send the electrical power they generate ashore. Hybrid forms of OTEC are also possible.

Advantages:

- Power from OTEC is continuous, renewable and pollution free.
- Unlike other forms of solar energy, output of OTEC shows very little daily or seasonal variation.
- Drawing of warm and cold sea water and returning of the sea water, close to the thermocline, could be accomplished with minimum environment impact.
- Electric power generated by OTEC could be used to produce hydrogen.

Disadvantages:

- Capital investment is very high.
- Due to small temperature difference in between the surface water and deep water, conversion efficiency is very low about 3-4%.
- Low efficiency of these plants coupled with high capital cost and maintenance cost makes them uneconomical for small plants.

Geothermal Energy: Basics

The word geothermal comes from the Greek words geo (earth) and therme (heat). So, geothermal energy is heat from within the Earth. We can recover this heat as steam or hot water and use it to heat buildings or generate electricity. Geothermal energy is a renewable energy source because the heat is continuously produced inside the Earth.

Volcanoes, hot springs, and geysers, are all examples of concentrated geothermal energy that has made its way to the surface. In general, however, it is not obvious where pockets of concentrated geothermal energy are located because most sources occur unevenly and deep underground. To find and access a geothermal reservoir, water or steam wells are generally drilled to test temperatures. Beyond concentrated geothermal pockets, there is some degree of geothermal potential almost everywhere because temperatures just several feet below the earth's surface tend to remain a relatively constant 50 to 60 °F.

Worldwide geothermal power capacity is around 12.8 gigawatts, and it is expected to rise to about 18 gigawatts by 2020

Geothermal Energy Generated Deep Inside the Earth

Geothermal energy is generated in the Earth's core. Temperatures hotter than the sun's surface are continuously produced inside the Earth by the slow decay of radioactive particles, a process that happens in all rocks. The Earth has a number of different layers:

- The core itself has two layers: a solid iron core and an outer core made of very hot melted rock, called magma.
- The mantle surrounds the core and is about 1,800 miles thick. It is made up of magma and rock.
- The crust is the outermost layer of the Earth, the land that forms the continents and ocean floors. It can be 3 to 5 miles thick under the oceans and 15 to 35 miles thick on the continents.

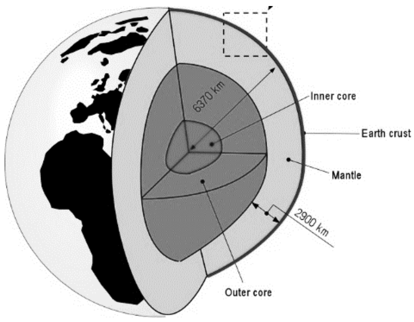

Fig. 12. Earth core

Use of Geothermal Energy

Some applications of geothermal energy use the Earth's temperatures near the surface, while others require drilling miles into the Earth. The three main uses of geothermal energy are:

- **Direct use** and district heating systems use hot water from springs or reservoirs near the surface.
- **Electricity generation power plants** require water or steam at very high temperature (300° to 700°F)
- **Geothermal heat pumps** use stable ground or water temperatures near the Earth's surface to control building temperatures above ground.

Geothermal energy is generated in the earth's core, almost 4,000 miles beneath the earth's surface.

Direct Use

Direct or non-electric use of geothermal energy refers to the immediate use of the energy for both heating and cooling applications. The primary forms of direct use include heating swimming pools and baths or therapeutic use (i.e., balneology), space heating and cooling (including district heating), agriculture (mainly greenhouse heating, crop drying, and some animal husbandry), aquaculture (heating mainly fish ponds and raceways), and providing heat for industrial processes and heat pumps (for both heating and cooling).

Heat exchangers

The principle heat exchangers used in geothermal systems are the plate, shell-and-tube, and downhole types. The plate heat exchanger consists of a series of plates with gaskets held in a frame by clamping rods. The counter-current flow and high turbulence achieved in plate heat exchangers provide for efficient thermal exchange in a small volume. In addition, compared to shell-and-tube exchangers, they have the advantage of occupying less space, they can easily be expanded when additional load is added, and are typically 40% cheaper. The plates are usually made of stainless steel, but titanium can be used when the fluids are especially corrosive.

- Shell-and-tube heat exchangers may be used for geothermal applications, but are less popular due to problems with fouling, greater approach temperature (the difference between incoming and outgoing fluid temperature), and the larger size as compared to the plate type.
- Downhole heat exchangers eliminate the problem of disposal of geothermal fluid, since only heat is taken from the well. However, their use is limited to small heating loads, such as the heating of individual homes, a small apartment, house, or business.

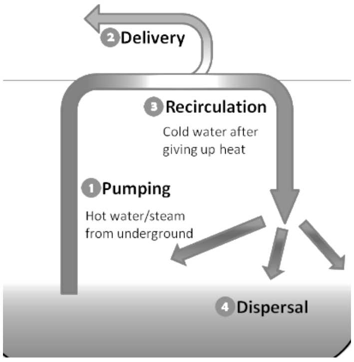

Fig.13. Deep hole geothermal

Refrigeration systems

Cooling can be accomplished from geothermal energy using lithium bromide and ammonia absorption refrigeration systems.

- The lithium bromide system is the most common because it uses water as the refrigerant. However, it is limited to cooling above the freezing point of water. The major application of lithium bromide units is for the supply of chilled water for space and process cooling in either one- or two-stage units. The two-stage units require higher temperatures (about 320°F), but they also have high efficiency. The single-stage units can be driven with hot water at temperatures as low as 180°F. Lower geothermal water temperatures result in lower efficiency and require a higher flow rate.
- For geothermally driven refrigeration below the freezing point of water, the ammonia absorption system must be considered. However, these systems are normally applied in very large capacities and have seen limited use. For the lower temperature refrigeration, the driving temperature must be at or above 250°F for a reasonable performance.

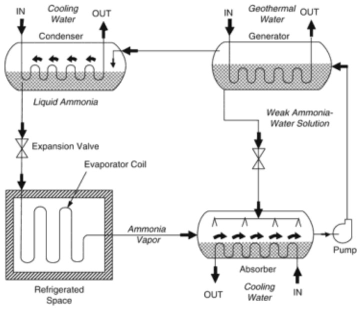

Fig.14. Refrigeration system

Distribution networks

Supply and distribution networks can consist of either a single-pipe or a two-pipe system. The single-pipe system is a once-through system where the fluid is disposed of after use. This distribution system is generally preferred when the geothermal energy is abundant and the water is pure enough to be circulated through the distribution system. In a two-pipe system, the fluid is re-circulated so the fluid and residual heat are conserved.

A two-pipe system must be used when mixing of spent fluids is called for, and when the spent cold fluids need to be injected into the reservoir. Two-pipe distribution systems cost typically 20% to 30% more than single-pipe systems.

Heating mode

- **Circulation:** The above-ground heat pump moves water or another fluid through a series of buried pipes or ground loops.
- **Heat absorption:** As the fluid passes through the ground loop, it absorbs heat from the warmer soil, rock, or ground water around it.
- **Heat exchange and use:** The heated fluid returns to the building where it is used for useful purposes, such as space or water heating. The system uses a heat exchanger to transfer heat into the building's existing air handling, distribution, and ventilation system, or with the addition of a desuperheater it can also heat domestic water.
- **Recirculation:** Once the fluid transfers its heat to the building, it returns at a lower temperature to the ground loop to be heated again. This process is repeated, moving heat from one point to another for the user's benefit and comfort.

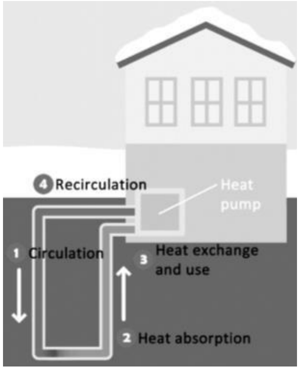

Fig. 15. Heating mode

Cooling mode

- **Heat exchange and absorption:** Water or another fluid absorbs heat from the air inside the building through a heat exchanger, which is the way a typical air conditioner works.
- **Circulation:** The above-ground heat pump moves the heated fluid through a series of buried pipes or ground loops.
- **Heat discharge:** As the heated fluid passes through the ground loop, it gives off heat to the relatively colder soil, rock, or ground water around it.
- **Recirculation:** Once the fluid transfers its heat to the ground, the fluid returns at a lower temperature to the building, where it absorbs heat again. This process is repeated, moving heat from one point to another for the user's benefit and comfort.

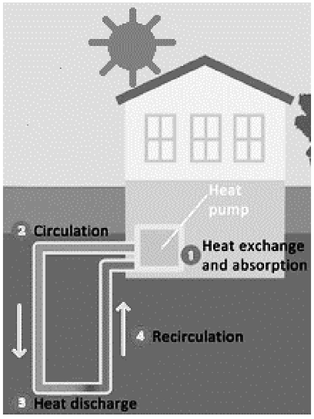

Fig. 16. Cooling mode

Geothermal Electricity

All geothermal energy plants literally uses super hot steam to run large turbines, coupled with generators to produce electricity. In the Geysers geothermal area, dry steam from the below ground is used directly in the steam turbine. Where as in some areas, super hot water is flashed in to steam within the power plant and that steam turns the turbine. There are another type of geothermal energy plants, which uses

The largest hot spring in the world is Frying Pan Lake in New Zealand. It's spans around nine acres and its average temperature is 131 degrees Fahrenheit.

different type of fluid instead of hydro thermal fluids to drive the turbine by using a heat exchanger to transfer heat from the water to special fluid.

Direct Dry Steam

Steam plants use hydrothermal fluids that are primarily steam. The steam goes directly to a turbine, which drives a generator that produces electricity. The steam eliminates the need to burn fossil fuels to run the turbine. (Also eliminating the need to transport and store fuels) This is the oldest type of geothermal power plant. It was first used at Lardarello in Italy in 1904. These plants emit excess steam and very minor amounts of gases.

They work by piping hot steam from underground reservoirs directly into turbines from geothermal reservoirs, which power the generators to provide electricity. After powering the turbines, the steam condenses into water and is piped back into the earth via the injection well.

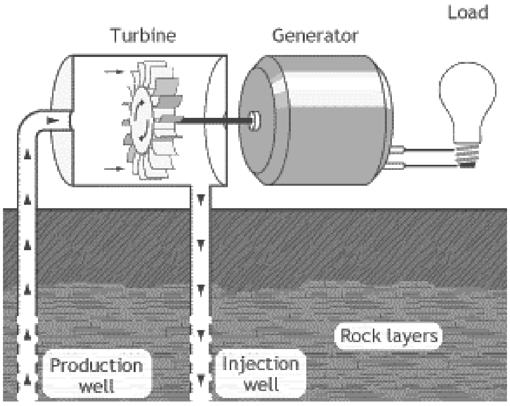

Fig. 17. Direct Dry Steam

Flash and Double Flash Cycle

Hydrothermal fluids above 360°F (182°C) can be used in flash plants to make electricity. Fluid is sprayed into a tank held at a much lower pressure than the fluid, causing some of the fluid to rapidly vaporize, or "flash." The vapor then drives a turbine, which drives a generator. If any liquid remains in the tank, it can be flashed again in a second tank (double flash) to extract even more energy. Flash steam plants differ from dry steam because they pump hot water, rather than steam, directly to the surface. These flash steam plants pump hot water at a high pressure from below the earth into a ―flash tank‖ on the surface.

The flash tank is at a much lower temperature, causing the fluid to quickly ―flash‖ into steam. The steam produced powers the turbines. The steam is cooled and condensed into water, where it is pumped back into the ground through the injection well.

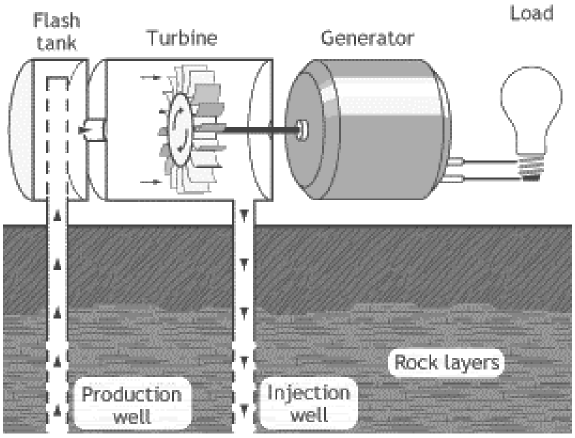

Fig. 18. Flash and Double Flash Cycle

Geothermal energy produces 0.03% of the emissions that coal produces and .05% of the emissions that natural gas produces.

Binary Cycle

Most geothermal areas contain moderate-temperature water (below 400°F). Energy is extracted from these fluids in binary-cycle power plants. Hot geothermal fluid and a secondary (hence, "binary") fluid with a much lower boiling point than water pass through a heat exchanger. Heat from the geothermal fluid causes the secondary fluid to flash to vapour, which then drives the turbines. Because this is a closed-loop system, virtually nothing is emitted to the atmosphere. Moderate-temperature water is by far the more common geothermal resource, and most geothermal power plants in the future will be binary-cycle plants.

In these binary cycle plants, the main difference is that the water or steam from below the earth never comes in direct contact with the turbines. Instead, water from geothermal reservoirs is pumped through a heat exchanger where it heats a second liquid—like isobutene (which boils at a lower temperature than water.) This second liquid is heated into steam, which powers the turbines that drives a generator. The hot water from the earth is recycled into the earth through the injection well, and the second liquid is recycled through the turbine and back into the heat exchanger where it can be used again.

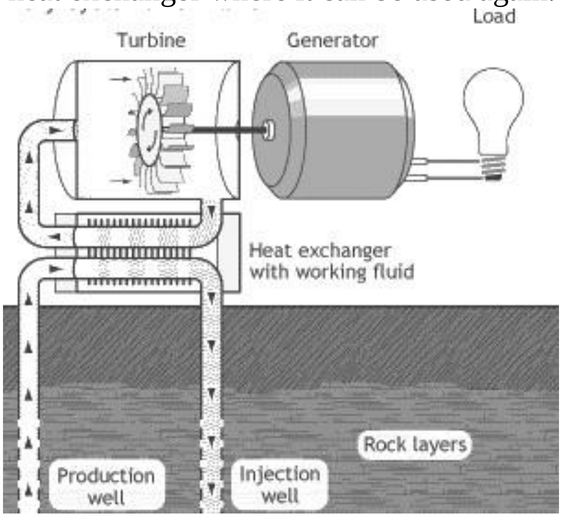

Fig. 19. Binary Cycle

Mini/micro hydro power: Classification of hydropower schemes

The hydroelectric power plants may be classified according to:-

A. Classification According to the Extent of Water Flow Regulation Available
   i. Run off river power plants without pondage
   ii. Run off river power plants with pondage
   iii. Reservoir power plants
B. Classification According to Availability of Water Head
   i. Low Head
   ii. Medium Head
   iii. High Head
C. Classification According to Type of Load Supplied
   i. Base Load
   ii. Peak Load
   iii. Pumped storage plants for the peak load
D. Classification of Hydroelectric Power Plants Based on Installed Capacity.
   i. Large hydro
   ii. Medium hydro
   iii. Small hydro
   iv. Mini hydro
   v. Micro hydro
   vi. Pico hydro

A. Classification According to the Extent of Water Flow Regulation Available

As of 31 March 2020, India's installed utility-scale hydroelectric capacity was 45,699 MW, or 12.35% of its total utility power generation capacity.

i. **Run off river power plants without pondage:** In this type of hydroelectric power plant, water is not available all the time. So this type of power station is not suitable for constant steady load. There is no pondage or storage facility available in such type of power plant. Plant is placed in such a area, where water is coming directly from the river or pond. This type of hydroelectric power plant is called run off power plant without pondage. Plant produces hydro electricity only when water is available. This type of plant cannot be used all the time. During high flow and low load period, water is wasted and the lean flow periods the plant capacity is very low. Power development capacity of this type of plant is very low and it produces power incidentally. The development cost of such a plant is relatively cheaper than full-time power development hydro electric power plant. Though it is not used for constant steady load supply, it's objective is to generate electricity by using excessive flow of water during flood or rainy season or whatever flow is available to save some sort of our natural resource of energy such as coal etc., diesel etc.

ii. **Run off river power plants with pondage:** This type of plant is used to increase the capacity of pond. The pond is used as a storage water of hydro electric power plant. Increased pond size means more water is available in the plant, so such type of hydro electric power plant is used during fluctuating load period depending on the size of pondage. On a certain limitation, this type of power plant can be a part of load curve and it is more reliable than a hydro plant without pondage. Such type of plant is suitable for both base load or peak load period. During high flow period, this plant is suitable for base load and during lean flow period it is used to supply peak loads only. During high flood period, the flood should not raise tail-race water level. Such types of power plant save conservation of coal.

iii. **Reservoir power plants:** Most hydroelectric power plant in the world is reservoir power plant. In this type of plant, water is stored behind the dam and water is available throughout the year even in dry season. This type of power plant is very efficient and it is used during both base and peak load period as per requirement. It can also take a part of load curve in grid system.

B. Classification According to Availability of Water Head

Though there is no rule regarding water head height but below 30 meters is considered as low head, above 30 meters to 300 meters is called medium head and above 300 meters is known as high head hydro electric power plant.

i. **Low head hydro electric power plant:** Francis, Kaplan or propeller turbines are used for this type of hydro electric power plant. To create a low head, dam construction is essential. Water resource level i.e. river or pond is placed just behind the dam to create a necessary water head level. Water is led to the turbine through the penstock. This type of hydro plant is located just below the dam and it creates useful water level as well. No surge tank is required for this plant, dam itself discharges the surplus water from the river. Science head is low, huge amount of water is required for desire output. That's why large diameter and low length pipe is used for this plant. Such types of power plant use low speed and large diameter type generators.

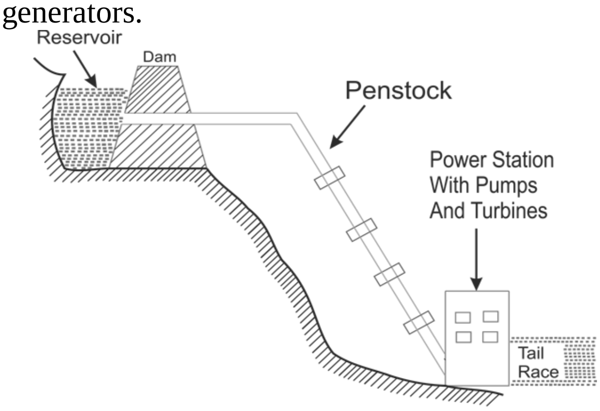

Fig. 20. Low head hydro electric power plant

ii. **Medium head hydro electric power plant:** In these power plants, the river water is usually tapped off to a forebay on one bank of the river as in case of a low head plant. From forebay the water is led to the turbines through penstocks. The forebay provided at the beginning of penstock serves as a water reservoir for such power plants. In these plants, water is usually carried in open channel from main reservoir to the forebay and then to the turbines through the penstock. The forebay itself serves as the surge tank in this case. In these plants horizontal shaft Francis, propeller or Kaplan turbines are used.

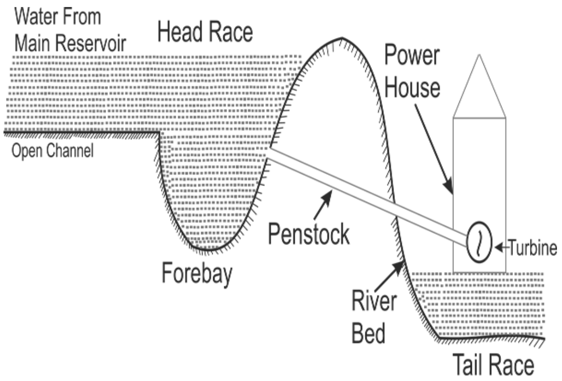

Fig. 21. Medium head hydro electric power plant

As of 31 January 2020, Tamilnadu's installed capacity of Hydro power is 2,178 MW

iii. **High head hydro electric power plant:** The head of this power plant is more than 300 meters. A dam is constructed in such a level that maximum reserve water level is formed. A pressure tunnel is constructed which is connected to the valve house. Water is coming from reservoir to valve house via this pressure tunnel and it is the starting of penstock. A surge tank is also constructed before valve house which reduces water hammering to the penstock in case of sudden closing of fixed gates of water turbine. Surge tank also store some extra water which is useful for picking load demand because it will serve extra water to the turbine. Valve house consists of a main valve sluice valves and automatic isolating valves, which operate on bursting of penstock and cut off further supply of water to penstock. The penstock is a connecting pipe which supplies water from valve house to turbine. For high head more than 500 meters, Pelton wheel turbine is used for lower head Francis turbine.

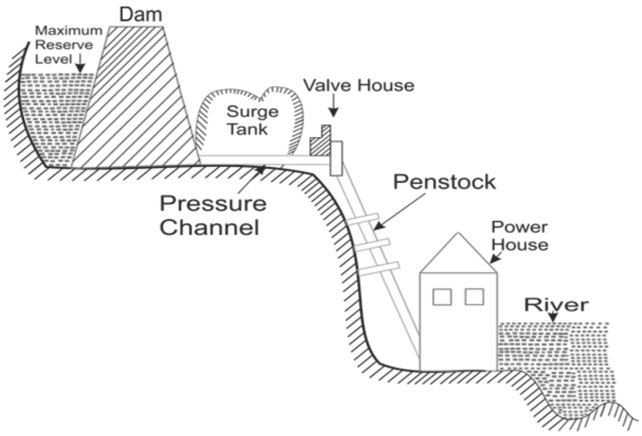

Fig. 22. High head hydro electric power plant

C. **According to the types of load supply**

i. **Base load hydro electric power plant:** This is a large capacity power plant. This plant work as a base portion of load curve of power system, that's why it is called base load plants. Base load plant is suitable for constant load. load factor of this plant is high and it is performed as a block load. Run off river plants without pondage and reservoir plants are used as base load plants.

ii. **Peak load hydro electric power plant:** This plant is suitable for peak load curve of power system. when demand is high, this type of plant do their job very well. Run off river plants with pondage can be employed as peak load plants. If water supply is available, it generates large portion of load at a peak load period. It needs huge storage area. Reservoir plants can be used as peak load plants. This type of plant can serve power throughout the year.

iii. **Pumped storage hydro electric power plant for the peak load:** This is unique design of peak load plants. Here two types of water pond is used, called upper head water pond and tail water pond. Two water ponds are connected each other by a penstock. Main generating pumping plant is lower end. During the off load period, surplus energy of this plant is utilized to pumping the lower head pond water to upper head pond water. This extra water is used to generate energy at pick load periods. By doing this arrangement, same water is used again and again. Extra water is required only to take care of evaporation and seepage.

D. Classification of Hydroelectric Power Plants Based on Installed Capacity.

i. Large hydro	Exceeding 100 MW and usually feeding into a large grid.
ii. Medium hydro	15 – 100 MW and usually feeding into a grid
iii. Small hydro	1-15 MW and usually feeding into the grid
iv. Mini hydro	100 kW – 1 MW either isolated or feeding into the grid
v. Micro hydro	100 kW – 1 MW usually provides power for a small community or rural industry in remote areas away from the grid
vi. Pico hydro	From few hundred watts upto 5 kW

Classification of water turbine

Water turbines or hydraulic turbines are rotary prime movers which convert the potential or kinetic energy of water into mechanical energy in the form of rotational energy. A water turbine when coupled with an electrical generator produces electrical energy. It is one of the most suitable means of electric power generation system. It is estimated that about 20% of the total electric power in the world comes from hydro power plants. The only limitation is that it can be operated through the turbine, if there is a continuous flow of water.

In the areas which are surrounded by hills and mountains known as catchment area, water turbine systems can be installed. The small rivers form a big river to flow. By constructing a machinery dam across flowing rivers, a water reservoir can be formed. The water is carried from the reservoir to water turbine by a long pipe known as penstock and the hydraulic energy possessed by water is converted into mechanical energy and then to electrical energy.

The main classification of water turbines depend upon the type of action of the water on the turbine. These are mainly categorized into two categories.

i. **Impulse turbine:** In this case, the total potential energy of water is converted to kinetic energy in the nozzles. The impulse due to the high velocity jet coming out of the nozzles is used to turn the turbine wheel. The pressure inside the turbine is atmospheric. It is found suitable when the available potential energy is high and flow available is comparatively low. E.g. Pelton wheel

ii. **Reaction Turbines:** In these turbines, water enters the runner under pressure having some velocity head. While the water passes over the runner, its pressure is gradually converted into velocity head until its pressure is reduced to atmospheric pressure along with the change in K.E based on its absolute velocity.

Water turbines are classified on various parameters:

A. Based on Direction of Flow of Water Through the Runner:

i. Radial flow:
- Inward radial flow: E.g. Old francis turbine, Girard radial flow turbine, etc.
- Outward radial flow: E.g Fourneyron turbine

ii. Axial Flow Turbines:
These are also called as parallel flow turbines. E.g Kaplan and propeller turbines

iii. Mixed Flow Turbines:
E.g Modern francis turbine

B. Based on Available Head and Discharge

Reaction turbines are used for low and medium heads.

i. Medium Head Turbines:
- 60m-250m- Medium flow rate E.g. Modern Francis

ii. Low Head Turbines:
- Head<60m- Large flow rates E.g. Axial flow Kaplan and propeller turbines.

C. Based on Specific Speed, Ns:
- Pelton turbine, Ns=9 to 35
- Francis turbine, Ns=50 to 250
- Kaplan turbine, Ns=250 to 850

D. Based on position of Shaft
- Horizontal shaft type
- Vertical shaft type

Tehri Dam Hudro Electric project is the highest Hydal project in India which generates 2400MW capacity of power and 575m in length

a) Impulse Turbine: In an impulse turbine, the total potential energy available with water is fully converted into kinetic energy by means of nozzle. The turbine is quite suitable for high head and low discharge available with it. In this type of turbine, there is a water nozzle which converts the total potential energy available with water into kinetic energy. Water is discharged from the nozzle in the form of water jet and high kinetic energy.

The high kinetic energy jet is made to strike on a series of curved buckets or blades mounted on the periphery of a wheel which is placed on the turbine shaft. This is the type of impulse turbine which requires high head and less water availability.

Pelton wheel is one of the most commonly used impulse turbines. A Pelton turbine or Pelton wheel is a type of hydro turbine (specifically an impulse turbine) used frequently in hydroelectric plants. These turbines are generally used for sites with heads greater than 300 meters.

The operation of a Pelton turbine is fairly simple. In this type of turbine, high speed jets of water emerge from the nozzles that surround the turbine. These nozzles are arranged so the water jet will hit the buckets at splitters, the center of the bucket where the water jet is divided into two streams. The two separate streams then flow along the inner curve of the bucket and leave in the opposite direction that it came in. This change in momentum of the water creates an impulse on the blades of the turbine, generating torque and rotation in the turbine.

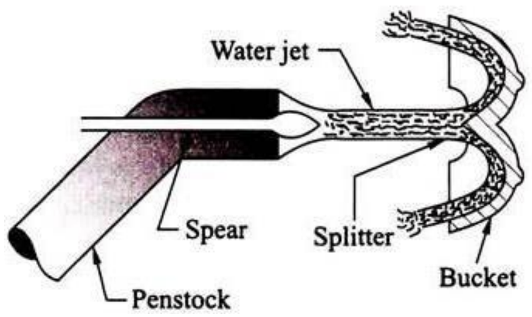

Fig.23. Discharge of water from nozzle

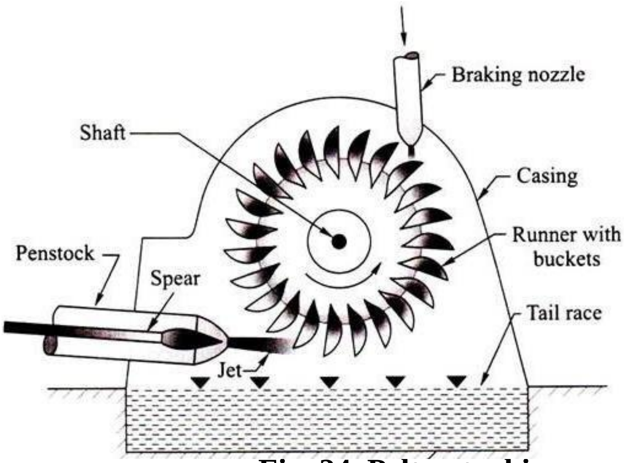

Fig. 24. Pelton turbine

b) Reaction Turbine:

Reaction turbine is quite suitable for low head and high discharge. The water supplied to the reaction turbine possesses both pressure as well as kinetic energy. The total pressure energy is not fully converted to kinetic energy initially, as it happens in impulse turbine. The water flows first of all to guide blades which supply water in a proper direction and then it is passed through moving blades which are mounted on the wheel. A part of the pressure energy of water, when flowing through the moving blades, is converted into kinetic energy which is absorbed by the turbine wheel. The water leaving the moving blades is at low pressure. Thus, there is a difference in pressure between the entrance and exit of the moving blades.

Due to this difference in pressure, there is an increase in kinetic energy and hence a reaction is developed in opposite direction which acts on the moving blades. The rotation of the wheel is set up in opposite direction. In case of reaction turbine, the water is discharged at the tail race through draft tube.

i. Francis Turbine:

Francis turbine is also called medium head turbine. In this turbine, water flows radially and finally discharges axially. Hence, this turbine is also called mixed flow turbine. It consists of a spiral casing, inside which there are large numbers of stationary guide blades/guide vanes. They are fixed all around the circumference of an inner ring of moving vanes called runner. The runner is fixed on the turbine shaft.

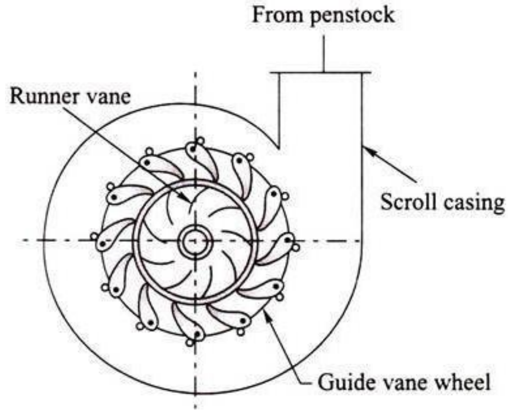

Fig. 25. Components of Franics Turbine

The runner consists of a series of curved blades numbering 16-24. The runner vanes are so well-designed in shape that water enters the runner radially and leaves the runner axially. Water with pressure energy enters through the passage into the casing radially through the guide vanes. It flows from the outer periphery of the runner in the radial direction over the moving vanes and finally it is discharged at the centre axially at low pressure. The kinetic energy is imparted to the runner when it flows over the moving vanes which produce rotation to the shaft. Water is then discharged at lower pressure through a diverging conical tube known as draft tube, which is fitted at the centre of the runner.

The draft tube converts kinetic energy into pressure energy and hence the pressure available at the exit of draft tube is the atmospheric pressure. The other end of the tube is immersed in water known as tail race.

ii. Kaplan Turbine:

Kaplan turbine is also called as low head reaction turbine which is suitable for comparatively low discharge and is known as axial flow reaction turbine. It is similar to Francis turbine. It consists of a spiral casing in which there are large numbers of stationery guide vanes. They are fixed all around the circumference of an inner ring of moving vanes called runner.

High-pressure water enters the turbine casing and enters into the guide vanes. The water strikes the runner and flows axially through guide vanes and imparts kinetic energy to the runner which produces rotation. The water is then discharged at the centre of the runner in axial direction into the draft tube. The outlet of the draft tube is immersed in water. The construction of Kaplan turbine is just similar to Francis turbine except the shape of runner. The runner of Kaplan turbine has only 3, 4, or 6 blades, either fixed or adjustable on hub The latter is known as propeller turbine.

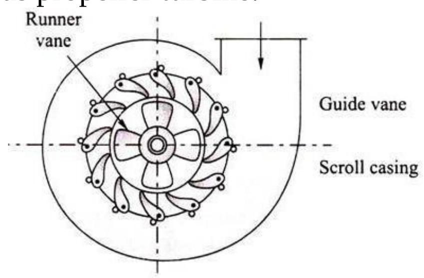

Fig. 26. Components of Kaplan turbine

Turbine theory

Like steam turbines, water turbines may depend on the impulse of the working fluid on the turbine blades or the reaction between the working fluid and the blades to turn the turbine shaft which in turn drives the generator. Several different families of turbines have been developed to optimise the performance for particular water supply conditions.

Turbine Power Output

The turbine converts the kinetic energy of the working fluid, in this case water, into rotational motion of the turbine shaft. Swiss mathematician Leonhard Euler showed in 1754 that the torque on the shaft is equal to the change in angular momentum of the water flow as it is deflected by the turbine blades and the power generated is equal to the torque on the shaft multiplied by the rotational speed of the shaft.

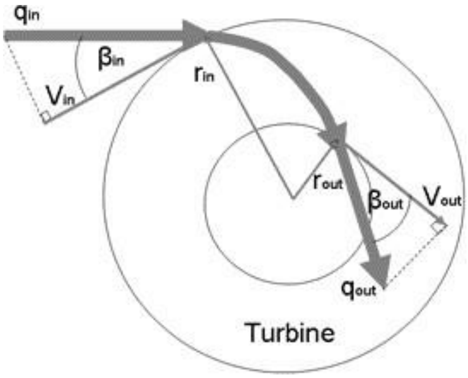

Fig.27. Turbine power

Torque $T = \rho Q(r_{in}V_{in} - r_{out}V_{out})$

Power $P = \omega T = \omega\rho Q(r_{in}q_{in}\cos\beta_{in} – r_{out}q_{out}\cos\beta_{out})$

Q = Fluid flow rate
P = Fluid density
q = Fluid velocity
β = incident angle
V = Tangential fluid velocity
V = qcosβ
r = turbine radius
ω = turbine rotation speed
T = torque
P = Power output

In most types of power generation the kinetic energy of a moving fluid is converted by a turbine into the rotational motion of a shaft. The turbine blades deflect the fluid and the rate of change of angular momentum of the fluid is equal to the net torque on the shaft.

A fluid of density ρ flowing through the turbine with a volume flow rate Q has a mass flow per second given by ρQ. Suppose that the fluid enters at a radius r_1 with a circumferential velocity v_{t1} and exists at a radius r_2 with a circumferential v_{t2}.

The torque exerted on the turbine is equal to the rate of change of angular momentum. Thus

$$T = \rho Q(r_1Vt_1 – r_2V_{t2}) \quad (1)$$

The power delivered to a turbine rotating with angular velocity ω is given by

$$P = \omega T \quad (2)$$

Substituting for T from eqn 1 in eqn 2 yields the power as

$$P = \omega\rho Q(r_1v_{t1} – r_2v_{t2}) \quad (3)$$

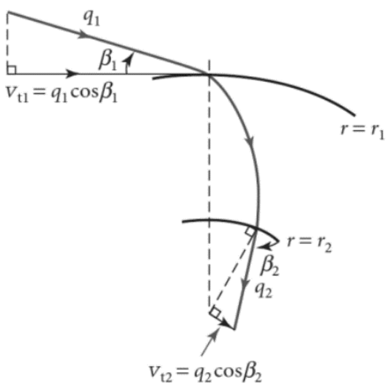

Fig. 28. Triangle diagram

Writing the tangential velocity in the form $v_t = q\cos\beta$, where q is the total quality of the fluid and β is the angle between the direction of motion of the fluid and the tangent to the wheel,

$$P = \omega\rho Q(r_1q_1\cos\beta_1 – r2q2\cos\beta_2) \quad (4)$$

Eqn 4 is known as the Euler's turbine equation. The importance of Euler's turbine equation is that the details of the flow inside the turbine are irrelevant. All that matters is the total change in the angular momentum of the fluid between the inlet and the outlet. The maximum torque is achieved when the fluid flows out in the radial direction, i.e when cos $\beta_2 = 0$ Eqn 4 reduces to

$$P = \omega\rho Q r_1 q_1 \cos\beta_1 \qquad (5)$$

Essential components of hydroelectric system

The main components of a Hydro electric power plant are given below.

1. Power House
2. Penstock
3. Water Reservoir
4. Water Turbine or Hydraulic Turbine (Prime mover)
5. Spillway
6. Dam
7. Surge Tank
8. Draft Tube
9. Tail Race Level
10. Gate
11. Pressure Tunnel

1. **Power House:** Power house contains generator, water turbine, with transformer and control room. When the water rushes through the turbine, it turns the turbine shaft, which is attached to electric generator. Generator has a rotary electromagnet called as rotor with a stationary element called as stator. Rotors generates magnetic fields that create an electric charge in stator. Charge is transmitted as electricity. Step up transformer increase the voltage coming from the stator. Electricity is than dispersed through power lines.
2. **Penstock:** Penstock pipe is use to convey water from the dam to hydraulic turbine. Penstock pipes are made of steel or reinforced material. Turbine is installed at a lesser level from the dam. Penstock is connected by a gate valve at inlet to totally close the water supply. It has a control valve to control water flow rate into turbine.
3. **Water Reservoir:** In reservoir, water is collected at the catchment area during raining period and is stored at the dam. Catchment area obtains its water from rains and streams. Permanent accessibility of water is a essential necessity for hydroelectric power plant. The stage of water surface in reservoir is call Head water level. Eater head presented for power generation depends on reservoir height.
4. **Water Turbine or Hydraulic Turbine (Prime mover):** Hydraulic turbines change energy of water into mechanical energy. Mechanical energy (revolution) accessible on turbine shaft is attached to shaft of an electric generator were electricity is created. Water after performing work on turbine blade is discharge through draft tube. Prime movers which are in regular use are Francis turbine, Pelton wheel, Kaplan turbine.
5. **Spillway:** Overload addition of water endanger the strength of dam construction. Also in order to avoid the overflow of water out of dam mainly during raining seasons spillways are provided. This prevents the increase of water level in dam. Spillways are passage which allows excess water to flow to a dissimilar storage area away from the dam.
6. **Dam:** The function of dam is to store water and control the outgoing flow of water. Dam helps to store all incoming water. It also helps to raise the head of water. In order to make a necessary quantity of power, it is needed that an enough head is available.
7. **Surge Tank:** Surge tank is a little tank or reservoir in which water level rise or fall due to unexpected changes in pressure. There might be rapid enhancement of pressure in penstock pipe due to rapid backflow of water, as load on turbine is condensed. This rapid rise of pressure in penstock pipe is identified as water hammer.
   Surge tank is initiated from the dam with the turbine and serves the follow reason:
   - To decrease the distance among the free water surface in dam and turbine, thus dropping the water hammer cause. Otherwise, penstock will damage the water effect.

- To provide as a supply tank to turbine while the water in pipe accelerates during amplified load situation and as a storage tank while the water is decelerating during reduced load situation.

8. **Draft Tube:** Draft tube is joined to outlet of turbine. It changes the kinetic energy available in water in pressure energy in diverge section. Therefore, it retains a pressure of just above the atmospheric level at the end of draft tube to travel the water into a tail race. Water from the tail race is free for irrigation.
9. **Tail Race Level:** Tail race is a water path to guide the water discharged from the turbine to river or canal. Water held in the tail race is call Tail race water level.
10. **Gate:** Gate is use to adjust or control the flow of water from the dam.
11. **Pressure Tunnel:** It carries the water from the reservoir to surge tank.

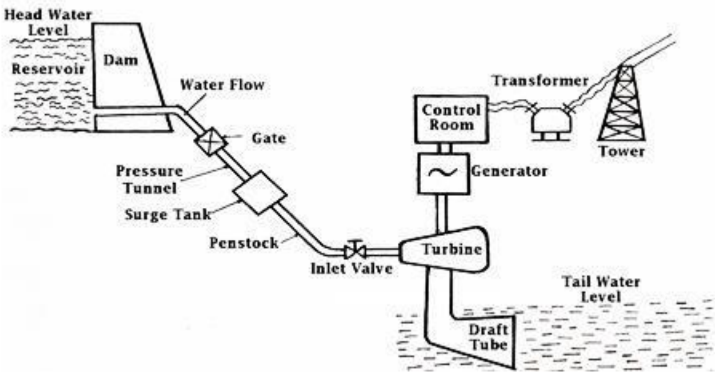

Fig. 29. Components of Hydro power plant