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D.R.G.Government Degree College

Tadepalligudem-534166,
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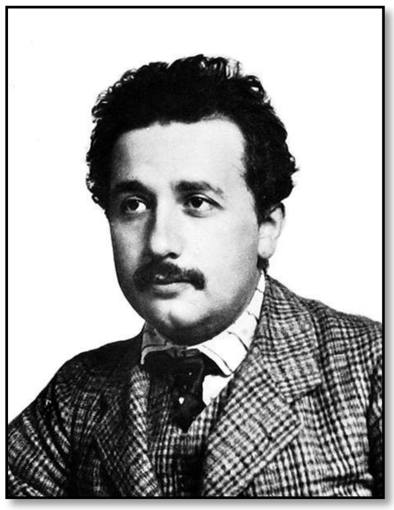
Department of Physics



VI Semester

Physics Cluster-Paper-VIII C-2

Wind, Hydro & Ocean Energies

STUDY MATERIAL

(English Medium)

Prepared by

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III B. Sc. Physics : Semester-VI

Cluster Paper-VIII C2 - Wind, Hydro and Ocean Energies

No. of Credits: 03
3 Hour/Week
Total Hours: 45

UNIT-I(9hrs)

1. Introduction: Wind generation, meteorology of wind, world distribution of wind, wind speed variation with height, wind speed statistics, Wind energy conversion principles; General introduction; Types and classification of WECS; Power, torque and speed characteristics.

UNIT-II(9hrs)

2. Wind Energy Conversion System: Aerodynamic design principles; Aerodynamic theories; Axial momentum, blade element; Rotor characteristics; Maximum power coefficient.

UNIT-III(9hrs)

3. Wind Energy Application: Wind pumps: Performance analysis, design concept and testing; Principle of wind energy generation; Wind energy in India; Environmental Impacts of Wind farms.

UNIT-IV(9hrs)

4. Small Hydropower Systems: Overview of micro, mini and small hydro systems; Hydrology; Elements of pumps and turbine; Selection and design criteria of pumps and turbines; Site selection; Speed and voltage regulation.

UNIT-V(9hrs)

5. Ocean Thermal, Tidal and Wave Energy Systems:Ocean Thermal - Introduction, Technology process, Working principle, Electricity generation methods from OCET, Advantages and disadvantages, Applications of OTEC.

6. Tidal Energy - Introduction, Origin and nature of tidal energy, Wave Energy – Introduction, Basics of wave motion, Power in waves, Wave energy conversion devices, Advantages and disadvantages, Applications of wave energy.

VI Semester-Physics Cluster-Paper-VIII-C-2-Study Material
Wind, Hydro & Ocean Energies
1.1 Principle of wind energy conversion

Wind means "Air in motion". We know that a moving object has kinetic energy. Hence wind has kinetic energy. The kinetic energy of the wind can be converted in to electrical energy by using wind turbines.

Wind energy is an important renewable energy resource. Winds are formed due to pressure differences which are created due to the uneven heating of the earth's surface by the sun. Hence wind energy is an indirect form of solar energy. Approximately, 2% of the solar energy is converted to wind energy.

Advantages and disadvantages of Wind energy:

Advantages:

- ✓ Wind energy is a renewable energy.
- ✓ Wind energy is a clean energy. It does not cause environmental pollution.
- ✓ Wind energy can be produced even in remote areas where other forms of energy may not be available.

Disadvantages:

- Wind turbine design is complex.
- Since the speed of wind is not always constant, Wind energy is irregular and unsteady.

Principle of wind energy conversion:

Wind energy is the kinetic energy of the moving air. The basic principle of wind energy conversion is

"Converting the kinetic energy of the wind to mechanical energy using a wind turbine. This mechanical energy is converted to Electrical energy using an aero-generator".

Let V be the velocity of the wind, ρ be the density of air and A be the area through which the air flows per unit time. Then the mass of the air passing through the wind turbine per unit time is given by

$$m = \rho AV$$

$$\text{Kinetic energy} = \frac{1}{2}mV^2 = \frac{1}{2}\rho AV.V^2 = \frac{1}{2}\rho AV^3$$

$$\text{Total power} = \frac{1}{2}\rho AV^3$$

Let D be the diameter of the wind turbine, then

$$A = \pi\frac{D^2}{4}$$

$$\text{Total power} = \frac{1}{2}\rho AV^3 = \frac{1}{2}\rho\left(\pi\frac{D^2}{4}\right)V^3 = \frac{1}{8}\rho\pi D^2V^3$$

$$\textbf{Wind power } \boldsymbol{P = \frac{1}{8}\rho\pi D^2V^3}$$

The above equation gives the maximum theoretical power that can be obtained from wind. But experimentally, all this power cannot be extracted. Approximately a fraction $\frac{16}{27} = 59.3$ % of the power in the wind can be extracted. This limit is called Gilbert's limit or Betz coefficient.

It is clear from the above equation that wind power depends on the following factors

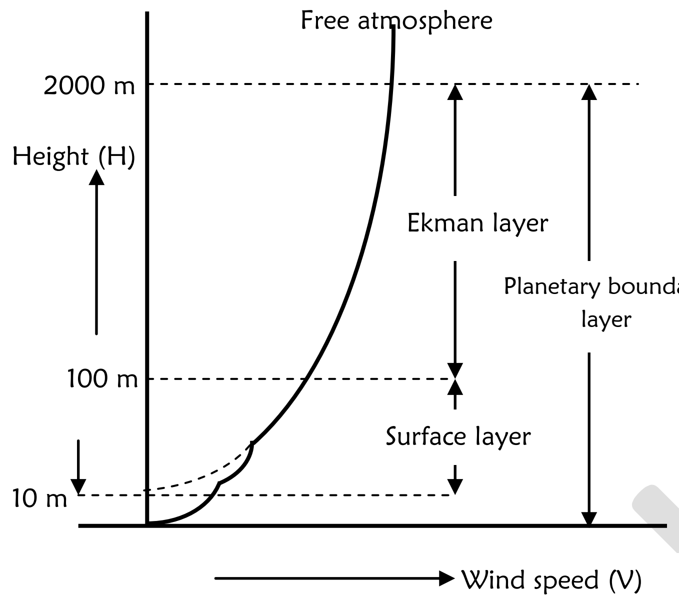
1. **Air density (ρ):**
   Wind power is directly proportional to the air density (ρ).
2. **Wind speed (V):**
   Wind power is directly proportional to the cube of wind speed (V). Hence wind turbine should be established in areas where wind speed is high. Optimal wind speed range is 5 m/s to 25 m/s.
3. **Diameter of the rotor (D):**
   Wind power is directly proportional to the square of the diameter of the wind turbine rotor. Hence wind turbine should have large rotors.

Hence principles of wind energy conversion are

- ✓ Wind should be high
- ✓ The rotors of the wind turbine should be large.

1.2 Wind speed variation with height

We know that wind power is directly proportional to the cube of wind speed. Hence wind speed is an important factor in the construction of a wind turbine.



Wind speed is always zero at the ground level due to the surface roughness. It increases gradually with height due to temperature differences and frictional forces between different layers of air. The rate of change of wind speed with height is called wind shear. The wind speed increases up to a certain height known as gradient height which is approximately 2000 m. Above the gradient height, the wind speed is not effected by ground conditions. The layer of air from ground to gradient height is known as planetary boundary layer. The planetary boundary layer is divided in to two parts.

1. **Surface layer:** The layer of air from ground to a height of 100 m is known as surface layer.
2. **Ekman layer**: The layer of air from 100 m to gradient height is known as Ekman layer.

Change in wind speed with height is given by the following equation

$$\frac{V_2}{V_1} = \left(\frac{H_2}{H_1}\right)^{\propto} \longrightarrow (1)$$

Here V_1, V_2 are wind speeds at levels H_1, H_2 respectively. $\propto$ is known as power law index. The value of $\propto$ depends on the surface roughness. Its value is 1/7 for open land and 0.10 for calm sea area. The value of $\propto$ can be calculated using the following formula.

$$\propto = \frac{\log V_2 - \log V_1}{\log H_2 - \log H_1}$$

Ideal wind energy locations have low value of $\propto$ .Generally wind measurements are carried out at an elevation of 10 m. But modern wind turbines are installed at a height of 25 m to 50 m. Wind speed at this height is calculated using equation (1)

Power density at a particular height can be calculated using the following equation using a set of values.

$$\frac{P_{H_2}}{P_{H_1}} = \left(\frac{H_2}{H_1}\right)^{3\propto}$$

Types and classification of Wind Energy Conversion Systems

Wind energy conversion systems are classified basing on their axis of rotation and the type of rotor.

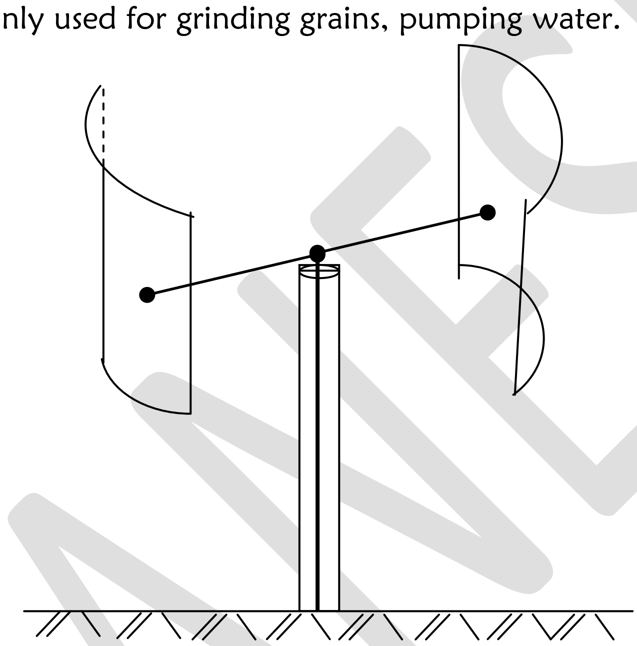
Based on the type of rotor:

1. **Propeller type wind mill:**
   - These are the most commonly used wind mills.
   - They have two or three blades.
   - Even though the two blade design is most efficient, it has the disadvantage of vibrations during Yaw control.
   - The capacity of these wind mills ranges from 1 to 3 MW.

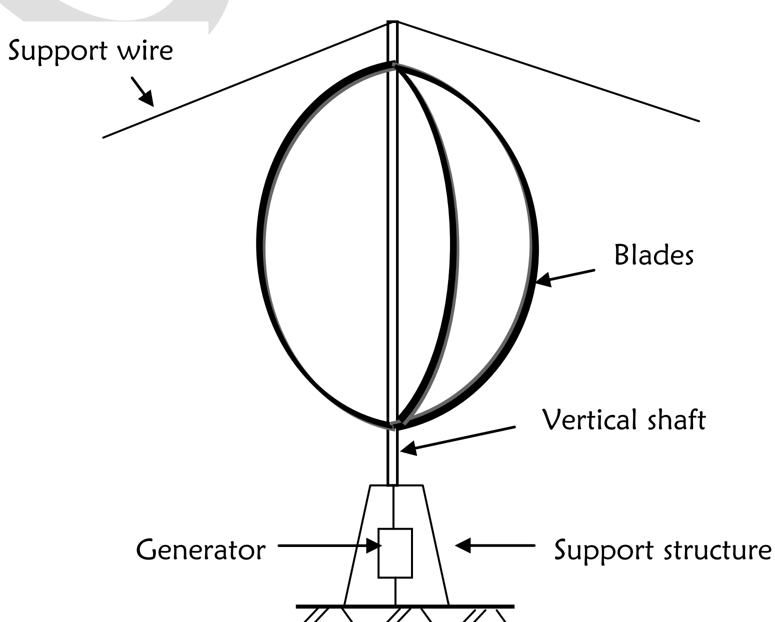
- Axis of rotation is horizontal

2. Multiblade type wind mill:
    - These wind mills have large number of blades.
    - These are mainly used for pumping water due to high staring torque.
    - They have less efficiency.
    - They are less noisy.
    - Axis of rotation is horizontal

3. Savonius type wind mills:
    - It has hollow circular cylinder sliced in half and the two halves are mounted on a vertical shaft with a gap in between.
    - Axis of rotation is vertical
    - Yaw and pitch control are not needed.
    - Very efficient but needs a large surface area.
    - Torque is produced due to pressure difference.
    - Operates at low wind speeds.
    - It is mainly used for grinding grains, pumping water.



4. Darrieus type wind mills:
    - It is shaped like an egg beater and has two or three blades shaped like airfoils.
    - Axis of rotation is vertical
    - Yaw and pitch control are not needed.
    - Very efficient but needs a small surface area.
    - Operates at high wind speeds.



Based on the axis of rotation:

1. Horizontal axis wind turbines:

- If the axis of rotation of a wind turbine is horizontal and parallel to the wind direction, then it is known as horizontal axis wind turbine.
- This type of winds turbine are most successful and hence used widely around the world.
- Heavy components of the wind turbine like gearbox, generator etc are placed at a great height. Hence the installation and maintenance of this type of wind turbines is difficult.
- Since the rotation of this turbine depends on the wind direction, the turbine must also be rotated in accordance with change in wind direction using yaw control.

2. **Vertical axis wind turbines:**
   - If the axis of rotation of a wind turbine is vertical and perpendicular to the wind direction, then it is known as vertical axis wind turbine.
   - This type of wind turbines are not subjected to continuous cyclic gravity loads. Hence the metal fatigue is very less compared to horizontal axis wind turbines.
   - Heavy components of the wind turbine like gear box, generator etc can be located at the ground. Hence installation and maintenance of this type of wind turbine is easy.
   - Since the rotation of this turbine is independent of the wind direction, the turbine need not be rotated in accordance with the wind direction.

2.Aerodynamic design principles of WECS- Axial momentum theory- Maximum Power coefficient

The basic principle of wind energy conversion is

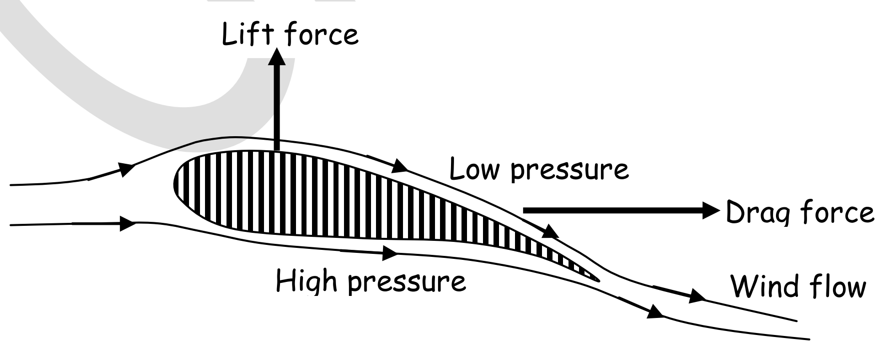
"Converting the kinetic energy of the wind into rotational energy (Mechanical Energy) using a wind turbine. This rotational energy is then converted into Electrical energy using an aero-generator".

It is important to note that, rotation of the turbine blades is the key for extracting wind power. This rotation of turbine blades is possible only because of the principles of aerodynamics involved in the design of the turbine blades.

When the moving air passes through the wind turbine, two forces act on its blades.

1. **Drag force (F_D):** The force which acts in the direction of the wind is known as drag force (F_D). This drag force does not produce rotation of the turbine blades and dissipated energy.
2. **Lift force (F_L):** The force which perpendicular to the direction of the wind is known as Lift force (F_L). This lift force is responsible for the rotation of turbine blades.

The basic design of the wind turbine blade's air foil is shown in figure.



The bottom surface of the blade is flat while the top surface is curved. As a result, when wind passes through the blades, the velocity of wind passing over the top surface of the blade is greater than the velocity of wind passing over the bottom surface. According to Bernoulli's principle, when the velocity of airflow increases, pressure decreases. Hence pressure on the top surface of the blade is less than the pressure on the bottom surface. This pressure difference produces a Lift force from high pressure side to low pressure side causing the blade to rotate. The Lift force can be maximized by adjusting the angle of the blades depending on the wind direction. Hence the blades of the wind turbine are always designed such that lift force is maximum and drag force is minimum.

Let P, P_u, P_d be the atmospheric wind pressure, upstream pressure and downstream pressure respectively. Let V_u, V_d, V_b be the velocity of wind upstream and velocity of wind downstream and velocity of wind at blades. Let ρ be the air density and m be the mass flow rate of wind.

Kinetic energy of the wind passing through the turbine is given by

$$K.E = \frac{1}{2}mV_b^2$$

Mass flow rate of wind

$$m = \rho A V_b$$

$$K.E = \frac{1}{2}\rho A V_b . V_b^2 = \frac{1}{2}\rho A V_b^3$$

$$K.E = \frac{1}{2}\rho A V_b^3$$

Force acting on the rotor is given by

$$F = (P_u - P_d)A \quad \text{--- (1)}$$

Force acting on the rotor can also be expressed as the change of momentum per unit time

$$F = m(V_u - V_d)$$

$$F = \rho A V_b (V_u - V_d) \quad \text{--- (2)}$$

From equations 1 and 2

$$(P_u - P_d)A = \rho A V_b (V_u - V_d)$$

$$(P_u - P_d) = \rho V_b (V_u - V_d) \quad \text{--- (3)}$$

Applying Bernoulli's equation to upstream and downstream sides,

$$P + \frac{1}{2}\rho V_u^2 = P_u + \frac{1}{2}\rho V_b^2$$

$$P_d + \frac{1}{2}\rho V_b^2 = P + \frac{1}{2}\rho V_d^2$$

$$P_u - P_d = \frac{1}{2}\rho\left(V_u^2 - V_d^2\right) \quad \text{--- (4)}$$

From equations 3 and 4

$$\frac{1}{2}\rho\left(V_u^2 - V_d^2\right) = \rho V_b (V_u - V_d)$$

$$\frac{V_u^2 - V_d^2}{2} = V_b (V_u - V_d)$$

$$\frac{(V_u + V_d)(V_u - V_d)}{2} = V_b (V_u - V_d)$$

$$\boldsymbol{V_b = \frac{(V_u + V_d)}{2}}$$

Work done

$$W = (K.E)_u - (K.E)_d = \frac{1}{2}mV_u^2 - \frac{1}{2}mV_d^2 = \frac{1}{2}m\left(V_u^2 - V_d^2\right) = \frac{1}{2}\rho A V_b\left(V_u^2 - V_d^2\right) = \frac{1}{2}\rho A \frac{(V_u + V_d)}{2}\left(V_u^2 - V_d^2\right)$$

$$= \frac{1}{4}\rho A (V_u + V_d)\left(V_u^2 - V_d^2\right)$$

Power output of wind turbine is given by

$$P = \frac{1}{4}\rho A (V_u + V_d)\left(V_u^2 - V_d^2\right)$$

For maximum turbine output, $\frac{dP}{dV_d} = 0$

$$\frac{dP}{dV_d} = 3{V_d}^2 + 2V_u V_d - V_u^2 = 0$$

Solutions of the above equations are,

$$V_d = \frac{1}{3}V_u \text{ and } V_d = V_u$$

For power generation, $V_d < V_u$, hence $V_d = \frac{1}{3}V_u$

$$\therefore P_{max} = \frac{1}{4}\rho A\left(V_u + \frac{1}{3}V_u\right)\left(V_u^2 - \frac{V_u^2}{9}\right) = \frac{8}{27}\rho A V_u^3 = \frac{16}{27}\left(\frac{1}{2}\rho A V_u^3\right) = 0.593\left(\frac{1}{2}\rho A V_u^3\right)$$

Total power in the wind stream

$$P_{max} = 0.593\left(\frac{1}{2}\rho A V_u^3\right)$$

$$P_{total} = \frac{1}{2}\rho A V_u^3$$

$$P_{max} = 0.593\, P_{total}$$

$$C_p = \frac{P_{max}}{P_{total}} = 0.593$$

C_p is known as Maximum power coefficient or Blitz limit.

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Let D be the diameter of the wind turbine, then

$$A = \pi\frac{D^2}{4}$$

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Hence principles of wind energy conversion are

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3.2 Wind energy in India

- ✓ In India, wind energy programme started in 1983. It is implemented by Ministry of New and Renewable Energy Sources, Government of India.

- ✓ Approximately 10 % of power generation in India is from wind energy.
- ✓ The total installed wind power capacity in India is 32720 MW till December 2017.
- ✓ The total estimated wind power potential in India is 49,130 MW at 50m height and 1,02,788 MW at 80m height.
- ✓ India is the fifth largest producer of wind energy in the world after China, USA, Germany and Spain.
- ✓ Tamilnadu State is the largest producer of wind energy in India.
- ✓ In Andhra Pradesh the estimated wind power potential is 5394 MW.

Wind turbines with capacity between 225 kW and 2.50 MW are installed across the country

3.3 Impact of wind farms on environment

We know that wind energy does not cause environmental pollution unlike fossil fuels. Hence wind energy is a green energy. But use of energy in any form affects the environment. Hence wind farms also affect the environment slightly. Some of the environmental concerns of wind farms are given below.

1. **Indirect energy use and emissions:**
   Energy is used in the production of materials required for construction of wind turbine. This is known as indirect energy use. Since the size of the wind turbine is large, indirect energy use is very high. Moreover, CO_2 is also emitted in the process of production of materials required for wind turbine which causes environmental pollution.
2. **Bird life:**
   Wind farms pose a threat to bird life as the turbine blades are located at a height where most of the birds fly. Many birds accidentally die when they hit the turbine blades. Resting and feeding patterns of birds are also affected by wind farms.
3. **Noise:**
   Noise is an environmental concern of wind turbines. Owing to noise, Wind farms are established away from residential places. Noise produced by wind turbines is of two types.
   - ➢ Mechanical noise: Noise produced due to the movement of the parts inside nacelle is known as mechanical noise. It can be reduced by good design.
   - ➢ Aerodynamic noise: Noise produced due to movement of air through the wind turbine is known as aerodynamic noise. It cannot be reduced since it depends on the wind speed.
4. **Telecommunication interference**:
   Wind farms obstruct the propagation of electromagnetic waves of TV and radio. Hence the quality of radio and TV signals are badly affected since the electromagnetic waves are scattered due to the wind farms. This effect can be minimized by using cable system or by installing powerful antennas.
5. **Safety:**
   If the parts of a wind turbine are damaged then the detached blade or fragment can harm people and property. Since most of the wind turbines are located away from residential places, accidents of wind turbines will not harm people.
6. **Effect on eco system**:
   Since the wind speed decreases due to wind farms, the eco system is affected. Lakes that are near the wind farms might become warmer because of reduced evaporation from their surface.

4.1 Overview of Micro, Mini and Small Hydro Systems

We know that falling water has both kinetic energy and potential energy. This energy of water can be converted in to mechanical energy using water turbines. This mechanical energy is then converted into electrical energy using a generator. This system is known as a Hydro power system.

- ➢ Hydropower is the most established conventional renewable energy resource for electricity generation.
- ➢ Hydro power does not cause environmental pollution. Hence it is a green energy.

Hydropower systems are broadly classified as large scale and small hydropower systems depending on their capacity. In India, Hydropower systems with a capacity of more than 25 MW are called large hydropower systems while those with capacity less than 25 MW are called small hydropower systems. Large hydropower systems are well established and are used widely around the world for electricity generation. On the other hand, small hydropower systems have not been used for a long time due to techno-economic reasons.

But recently, use of small hydro power systems is increasing rapidly due to the following reasons.

- Advancements in the design of low head hydraulic turbines
- Advancements in construction technology
- Better control techniques

Many countries including India are now establishing small hydro power systems due to these advancements in technology. The small hydropower systems are considered as non conventional energy resources as they were developed recently.

Small hydropower systems are again classified into Micro, Mini and Small basing on their capacity.

Category	Capacity
Micro	Up to 100 kW
Mini	100 kW to 1 MW
Small	1 MW to 25 MW

These small hydropower systems are further classified as Storage and run-of-river schemes.

- <u>Storage Scheme</u>: In the storage scheme, a dam is used to stop a river flow and store the water in a reservoir behind the dam. The water is then released through the turbines to produce electricity. The advantage of this scheme is that the rainfall accumulated in wet season of the year can be used to produce power during summer.
- <u>Run-of-the-river scheme</u>: In the run-of-the river scheme, river flow is not stopped, but a part of the flow is diverted into a channel and pipe and then through the turbine. Micro hydropower systems always use the run-of-the-river scheme. The advantages of this scheme are
  - Can be built at low cost
  - Environmental damage is negligible

<u>Advantages of Micro, Mini and Small hydropower systems:</u>

- ✓ Installation and maintenance of small hydropower systems is easy compared to large hydropower systems.
- ✓ Small hydro plants can be established in remote areas which doesn't have access to electricity.
- ✓ They have small gestation period.
- ✓ There is no need of long transmission lines as the electricity produced is used locally.
- ✓ They can be operated by less number of personnel. Some small hydro plants are operated by remote control.

<u>Disadvantages of Micro, Mini and Small hydropower systems:</u>

- Since most of the small hydropower systems are located in remote places, they cannot be connected with grid.
- Dams used in small hydropower systems affect the environment of fishes and their reproduction cycle. But these effects are minor compared to that of large hydro plants.
- The rotation of turbines can kill fishes.

4.2 Selection of site for Hydro-Electric plant

We know that falling water has both kinetic energy and potential energy. This energy of water can be converted in to mechanical energy using water turbines. This mechanical energy is then converted into electrical energy using a generator. This system is known as a Hydro power system.

- Hydropower is the most established conventional renewable energy resource for electricity generation.
- Hydro power does not cause environmental pollution. Hence it is a green energy.

The following factors are taken into account for selecting the site for a hydro-electric plant.

- ✓ Availability of water
- ✓ Water storage
- ✓ Water head
- ✓ Accessibility of the site
- ✓ Distance from load centre
- ✓ Type of the land at site

1. <u>Availability of water:</u>

   Availability of water is the most important factor for selecting the site for a hydro-electric plant. Hence run-off data at the proposed site is collected to estimate the availability of water. If the run-off data at the proposed site is not available, data of rainfall over the area is collected.

This data is used to estimate the average quantity of water available and the maximum and minimum quantity of water available during the year. These details are used to

- Decide the capacity hydro-electric plant
- To provide spillways during the flood period

2. **Water Storage:**

Water Storage is an important factor for a hydro-electric plant since the rainfall is not consistent during the year. Hence water must be stored to produce power throughout the year. The storage capacity of a plant can be calculated with the help of mass curve. There are two types of storages.

- Storage may be such that water is available for power generation for one year only. In this case, storage becomes full in the beginning of the year and becomes empty at the end of the year.
- Storage may be such that water is available in sufficient quantity even during the worst dry periods.

3. **Water head:**

A hydro-electric plant can produce a large quantity of power if a large quantity of water is available at a sufficient head. If the water is at a higher level, then the quantity of water required to produce a given amount of power is less.

4. **Accessibility of the site:**

The site selected for hydro-electric plant should be easily accessible. That means the site should have transportation facilities of rail and road. This is necessary for utilization of the power produced by the plant near the plant site.

5. **Distance from the load centre:**

It is important that the hydro-electric plant must be located near the load centre. This will reduce the cost of erection and maintenance of transmission line.

6. **Type of the land of site:**

The land selected for the site should be cheap and rocky. The site should have large catchment area and store water at high head.

- ✓ The rock should be strong enough to withstand the stress from the dam structure and the thrust of the water.
- ✓ The rock should remain stable under all conditions.

4.3 Speed and voltage regulation of a hydro-electric plant

We know that falling water has both kinetic energy and potential energy. This energy of water can be converted in to mechanical energy using water turbines. This mechanical energy is then converted into electrical energy using a generator. This system is known as a Hydro power system.

- Hydropower is the most established conventional renewable energy resource for electricity generation.
- Hydro power does not cause environmental pollution. Hence it is a green energy.

The frequency and voltage of the power produced from a hydro-electric plant depends on the speed of the hydraulic turbine. It is observed that voltage fluctuations up to 7 percent and frequency fluctuations up to 5 percent are acceptable. But in a small hydro system, fluctuations in voltage and frequency may exceed these limits during switching operation for a short time. Hence speed governors are used to regulate the speed of the turbines. The speed regulation of the turbine is an important and complicated problem. It depends on the size, type of machine whether it is grid-tied or not. Traditional speed governors used in large hydro systems are highly efficient but they are too expensive to be used in small hydro systems. Hence the quality of speed and voltage control is poor in small hydro systems. However, the following measures are taken to control voltage fluctuations.

- The flow through the turbine is set at a constant value to keep the input power constant. Hence the mechanical input to the generator remains constant.
- The load imposed on the generator is also kept constant. This is done by using a ballast load across the generator which can be increased or decreased in accordance with the user load. Hence the excess power generated is wasted in the ballast load. For this purpose an Electronic Load Controller (ELC) is used. The electronic load controller ensures that the generator always supplies a constant electrical load.

Hence by adopting these two measures, both the mechanical input and the electrical output remain constant. Hence the speed remains constant. In this approach, a part of the energy produced is wasted in the ballast load. Bu this is not important for run-of-the river schemes since water is not stored for power generation.

5.1 Ocean thermal energy conversion (or) Electricity generation methods from OTEC

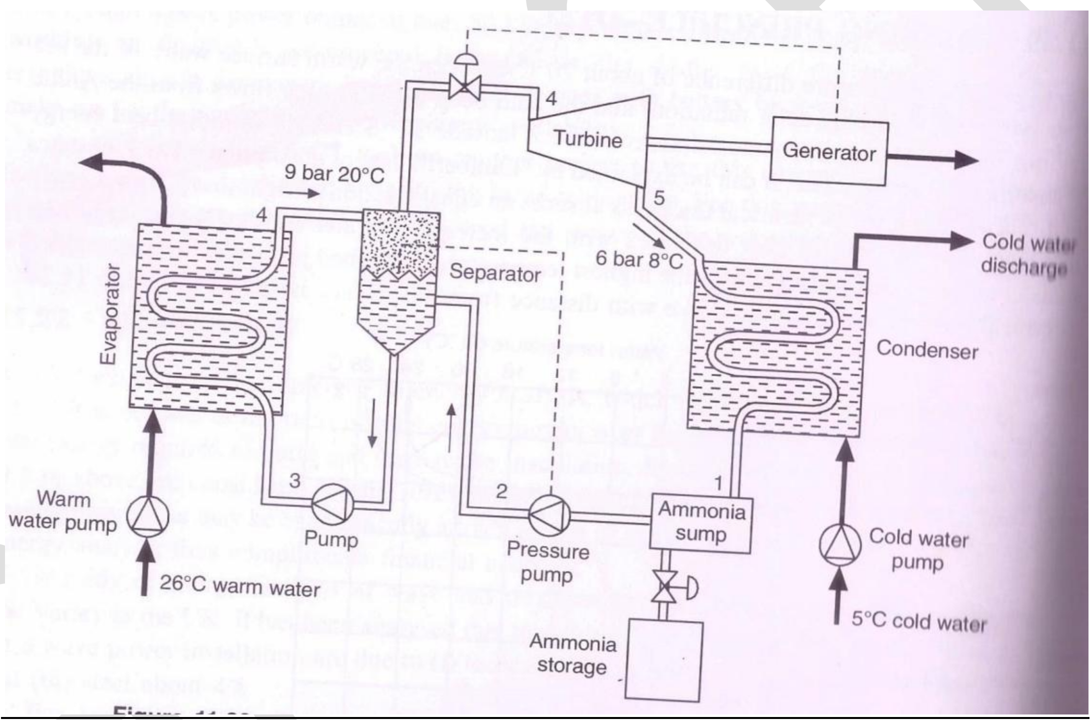
We know that 70 percent of the Earth's surface is covered by oceans. Hence oceans receive enormous amount of thermal energy from Sun which can be converted in to electrical energy. This is known Ocean Thermal Energy Conversion (OTEC).

- Ocean thermal energy is a form of solar energy.
- Since the oceans receive enormous amount of thermal energy from the Sun continuously, ocean thermal energy is a renewable energy.
- Ocean thermal energy does not cause environmental pollution. Hence it is a green energy.

Working principle of Ocean Thermal Energy Conversion (OTEC)

Ocean thermal energy exists in the form of temperature difference between the warm surface water and cold deep water of oceans. Temperature at the surface of oceans remains constant at a depth of 200m and decreases to a value of 4⁰C at a depth of 1000 m. The temperature difference is approximately 20⁰C in the equatorial regions. Ocean thermal energy conversion is based on the working of heat engine which converts heat energy into mechanical energy. In OTEC, the warm surface water acts as heat source and the cold deep water acts as heat sink to convert the heat energy into mechanical energy. The mechanical energy is in turn converted into electrical energy using a generator.

Closed cycle OTEC system



A closed cycle OTEC system is shown in figure. It contains the following parts.

- ✓ Warm water pump
- ✓ Cold water pump
- ✓ Evaporator
- ✓ Condenser
- ✓ Turbine
- ✓ Generator

Working of closed cycle OTEC system is explained below.

- The warm surface water which is at a temperature of about 26⁰C is brought in one pipe and cold deep water at a temperature of 5⁰C is brought in another pipe from a depth of about of 1000m.
- A low boiling point working fluid like ammonia or propane absorbs heat from the warm water and becomes vapor. This takes place in a chamber called evaporator.
- The liquid ammonia which is not evaporated collects in a chamber known as separator.
- The evaporated ammonia vapour under high pressure is passed through a turbine.
- The turbine rotates due to the temperature and pressure of the ammonia vapour. Hence the thermal energy of the vapour is converted into mechanical energy.
- The mechanical energy of the turbine is converted into electrical energy using a generator.

- The ammonia vapour coming out of the turbine which is at a low pressure is condensed back into liquid form by the cold deep water coming from the sea.
- The liquefied ammonia collects in a chamber called ammonia sump. After some time, some quantity of ammonia is added from the ammonia storage to make up for the operational loss.
- The liquefied ammonia is then pumped back to the evaporator and the cycle continues.

5.2 Applications of OTEC

- ✓ OTEC power generation is a multipurpose project which produces several useful products apart from electrical energy.
- ✓ Energy from OTEC can be converted into either electrical, chemical or protein form.
- ✓ OTEC plants can be combined with several industries for production of ammonia, hydrogen and aluminum.
- ✓ Fresh water can be produced from sea water using open cycle OTEC plants. In this process, the vapour produced from sea water condenses to produce fresh water after rotating the turbine.
- ✓ OTEC plants can be combined with aquaculture to produce marine food and pearls. The cold water from deep sea which is rich in nutrients can be placed in a lake where the nutrients can help to raise fish, oysters or other biological life.

5.3 Advantages and disadvantages of OTEC

We know that 70 percent of the Earth's surface is covered by oceans. Hence oceans receive enormous amount of thermal energy from Sun which can be converted in to electrical energy. This is known Ocean Thermal Energy Conversion (OTEC).

Advantages:

- ✓ Since the oceans receive enormous amount of thermal energy from the Sun continuously, ocean thermal energy is a renewable energy.
- ✓ Ocean thermal energy does not cause environmental pollution. Hence it is a green energy.
- ✓ OTEC power generation is a multipurpose project which produces several useful products apart from electrical energy.
- ✓ OTEC produce steady power without fluctuations and independent of weather conditions and seasons.
- ✓ Fresh water can be produced from sea water using open cycle OTEC plants. In this process, the vapour produced from sea water condenses to produce fresh water after rotating the turbine.

Disadvantages:

- Efficiency of OTEC plants is low.
- Installation cost of OTEC plant high.
- Changes in local temperature and salinity in sea water due to OTEC plants affects the local eco system and climate.
- In open cycle OTEC system, CO_2 dissolved in warm water is released to atmosphere.

5.4 Advantages and disadvantages of wave energy

Advantages:

- ✓ Wave energy is a free and renewable energy source.
- ✓ Wave energy does not cause environmental pollution. Hence it is a green energy.
- ✓ Wave energy devices do not use large land masses unlike solar and wind energies.
- ✓ After extracting energy from eaves, the waves are in placid state.
- ✓ Wave energy devices not only produce electricity, but also protect the coast lines from large waves, minimizes erosion and create artificial harbor.

Disadvantages:

- Since wave energy is available in oceans, construction and maintenance of wave energy devices is difficult.
- Construction of wave energy conversion devices is relatively complicated.
- Lack of dependability
- Wave energy devices have to withstand enormous power of storms.
- Scarcity of accessible sites of large wave activity.