EE8703 RENEWABLE ENERGY SYSTEMS L T P C 3 0 0 3

OBJECTIVES:

To impart knowledge on the following Topic

Awareness about renewable Energy Sources and technologies

Adequate inputs on a variety of issues in harnessing renewable Energy.

Recognize current and possible future role of renewable energy sources.

UNIT I RENEWABLE ENERGY (RE) SOURCES 9

Environmental consequences of fossil fuel use, Importance of renewable sources of energy, Sustainable Design and development, Types of RE sources, Limitations of RE sources, Present Indian and international energy scenario of conventional and RE sources.

UNIT II WIND ENERGY 9

Power In the Wind – Types of Wind Power Plants (WPPs)-Components of WPPs – Working of WPPs – Sitting Of WPPs-Grid integration issues of WPPs.

UNIT III SOLAR PV AND THERMAL SYSTEMS 9

Solar Radiation, Radiation Measurement, Solar Thermal Power Plant, Central Receiver Power Plants, Solar Ponds.- Thermal Energy storage system with PCM- Solar Photovoltaic systems : Basic Principle of SPV conversion – Types of PV Systems- Types of Solar Cells, Photovoltaic cell concepts: Cell, module, array ,PV Module I-V Characteristics, Efficiency & Quality of the Cell, series and parallel connections, maximum power point tracking, Applications.

NIT IV BIOMASS ENERGY g

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Introduction- Bio mass resources –Energy from Bio mass: conversion processes-Biomass Cogeneration-Environmental Benefits. Geothermal Energy: Basics, Direct Use, Geothermal Electricity. Mini/micro hydro power: Classification of hydropower schemes, Classification of water turbine, Turbine theory, Essential components of hydroelectric system.

UNIT V OTHER ENERGY SOURCES 9

Tidal Energy: Energy from the tides, Barrage and Non Barrage Tidal power systems. Wave Energy: Energy from waves, wave power devices. Ocean Thermal Energy Conversion (OTEC)- Hydrogen Production and Storage- Fuel cell : Principle of working- various types - construction and applications. Energy Storage System- Hybrid Energy Systems.

UNIT-I

Renewable Energy (RE) Sources.

Environmental consequences of fossil fuel use :-

→ A pollutant is a substance usually a harmful one.

The following air pollutants resulting from fossil fuel combustion are :

(a) carbon monoxide.

(b) oxides of sulfur (SO_2 & SO_3)

(c) oxides of nitrogen (NO & NO_2).

(d) Particulates - very fine soot & ash particles.

Major air pollutants and their sources are listed below :

(1) **carbon monoxide (CO) :**

→ This is a colorless, odorless gas that is produced by the incomplete burning of carbon based fuels including petrol, diesel and wood.

→ Also produced from combustion of natural and synthetic products such as cigarettes.

Effects :

1) Lowers the amount of oxygen that enters our blood. It can slow our reflexes and make us confused and sleepy.

(2) **Carbon dioxide (CO_2) :**

This gas is emitted due to human activities such as burning of coal, oil, natural gases.

(3) Chlorofluoro carbons (CFC) :-

There gases are released mainly from air conditioning systems and refrigeration. when released into the air, CFCs rise to the stratosphere, where they come in contact with other gases, which lead to a reduction of the ozone layer.

Ozone layer that protects the earth from the harmful UV rays of the sun.

(4) Lead :-

This is present in petrol, diesel, Lead batteries, paints, hair dye products etc.

Effects :

It affects children in particular. It can cause nervonse system damage and digestive problems and cancer.

(5) Ozone (O_3) :-

This is the naturally upper layers of atmosphere. This important gas shields the earth from the harmful UV rays of the sun.

But at the ground level, it is a pollutant with highly toxic effects. Vehicles and industries are the major source of ground level ozone emissions.

Effects :

Ozone makes our eyes itch, burn and water. It lowers our resistance to colds and pneumonia.

(6) Nitrogen oxide (NOx):

This causes smog and acid rain. It is produced from burning fuels including petrol, diesel and coal. Nitrogen oxides can make children susceptible to respiratory diseases in winter.

(7) Suspended particulate matter (SPM):-

This consists of solids in the air in the form of smoke, dust and vapour and that can remain suspended for extended periods.

Effects:-

Reduce visibility, when breathed it can lodge in our lungs and cause lung damage and respiratory problems.

(8) Sulfur dioxide (SO_2)

This is a gas produced from burning coal, production of paper, smelting of metals, produce SO_2.

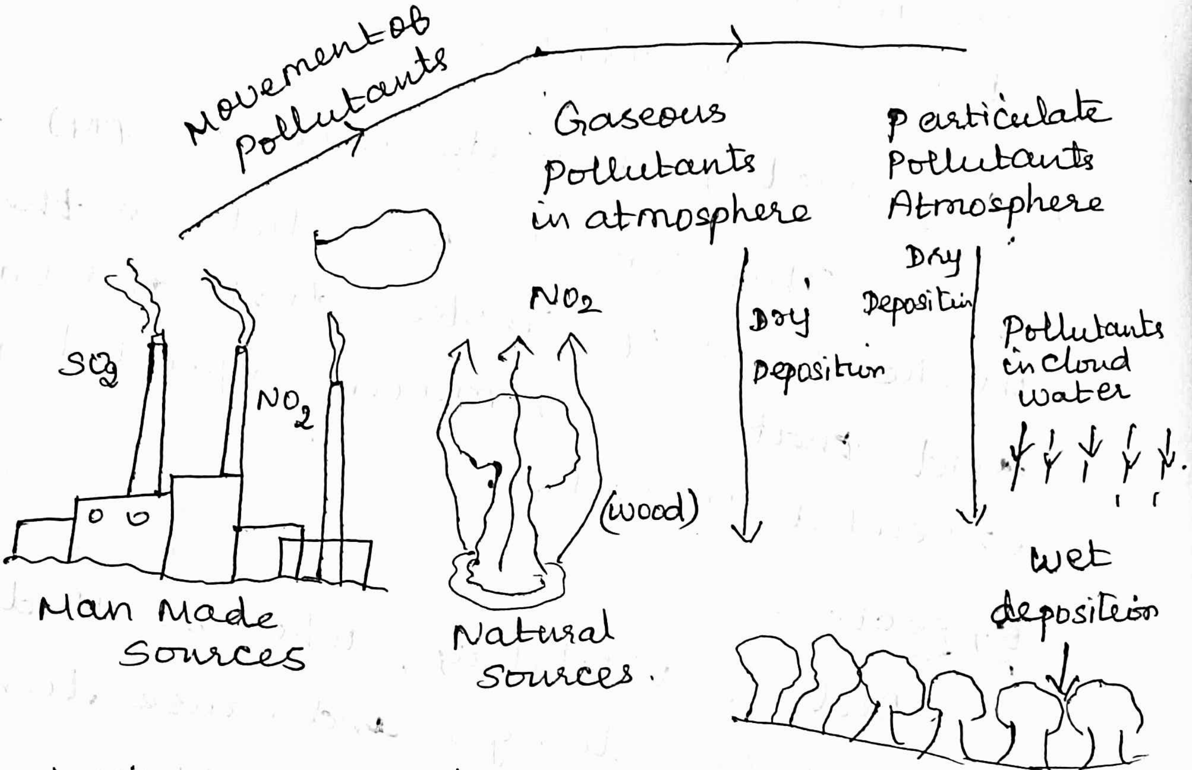
Effects:

Major contributor to smog and acid rain, lung diseases.

Acid Rain:

The power plant which uses high sulfur coal pollutes many lakes and rivers in industrial areas that become too acidic for fish to grow.

Forests in different regions of the earth also experience a slow death due to absorption of acids from acid rain through the leaves, needles and roots of the trees.



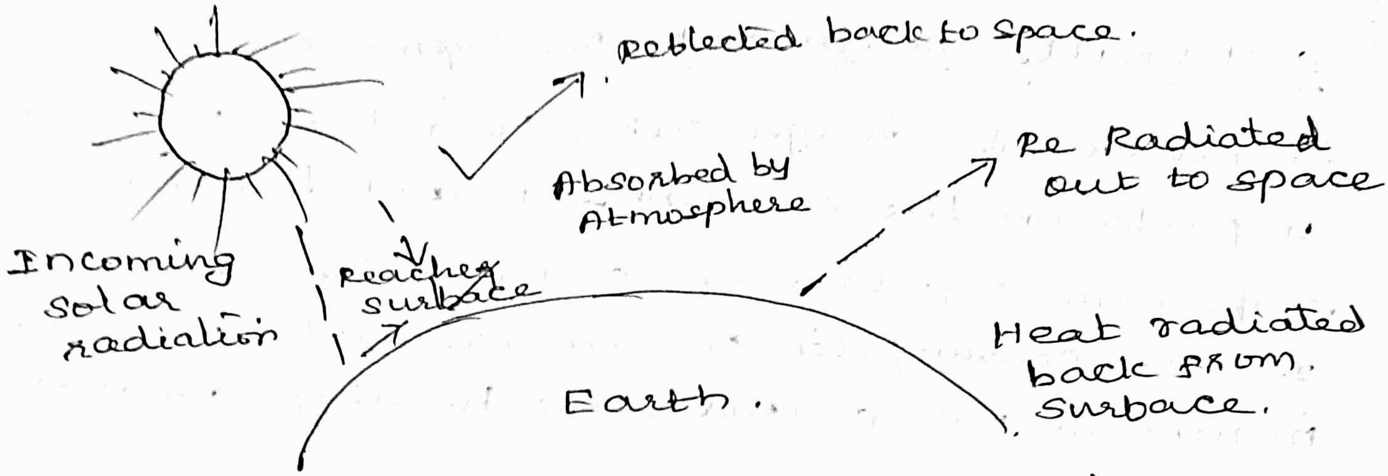
(9) Depletion of ozone layers :-

⇒ A global environmental problem is the distortion and regional depletion of the stratospheric ozone layer. This effect due to the emissions of NOx & CFCs etc.

⇒ Leads to increased levels of UV rays reaching the ground.

⇒ This increases to skin cancer, eye damage and harm to many biological ~~spices~~ species.

(10) Global warming and climate change :-



Global warming and the greenhouse effect.

Importance of renewable sources of energy :-

=) Renewable energy emits no or low greenhouse gases. → good for climate

=) Renewable energy emits no or low air pollutants. So, it is good for health.

=) Renewable energy comes with low costs. It is good for keeping energy prices at affordable levels.

=) Renewable energy makes the energy system resilient. It is to prevent power shortages.

=) Renewable energy is secure. Good for stability.

=) Renewable energy is democratic.

=) Renewable energy technologies cover the electricity demand and reduce emissions.

=) Renewable energy is less harmful and often cheaper.

Sustainable Design and Development :-

⇒ Sustainable design seeks to reduce negative impacts on the environment and health.

⇒ The basic objectives of sustainability are to reduce consumption of non-renewable resources, minimize waste and create healthy, productive environments.

⇒ The global energy system, which is 85% based on fossil fuels is responsible for over 70% of the greenhouse gas emissions.

⇒ Sustainable design include
- Knowledge Transfer
- Improved environmental Quality
- Reduced health risks from pollutants

⇒ According to World Resource Institute Report 2017, India is responsible for nearly 6.65% of Global carbon emissions, ranked fourth next to China (26.83%), the USA (14.36%) EU (9.66%)

⇒ Awareness of saving energy has been promoted among citizens to increase the use of solar, wind, biomass, waste & hydropower energies.

⇒ Advancement in technology, proper regulatory policies, tax deduction and attempts in efficiency enhancement due to research and development.

are some of the pathways to conservation of energy.

=> To facilitate R&D in renewable power technology, a national Lab policy on testing, standardization and certification was announced by MNRE.

=> The Surya Mitra Program was conducted to train college graduates in the installation, commissioning, operations and management of solar panels.

=> The International Solar Alliance (ISA) headquarters in India (Gurgaon) will be a new commencement for solar energy improvement in India.

=> To recognize and encourage innovative ideas in renewable energy sector, the Government provides prizes and awards.

=> Awarness of saving energy has been promoted among citizens to increase the use of solar, wind, biomass, waste & hydropower energies.

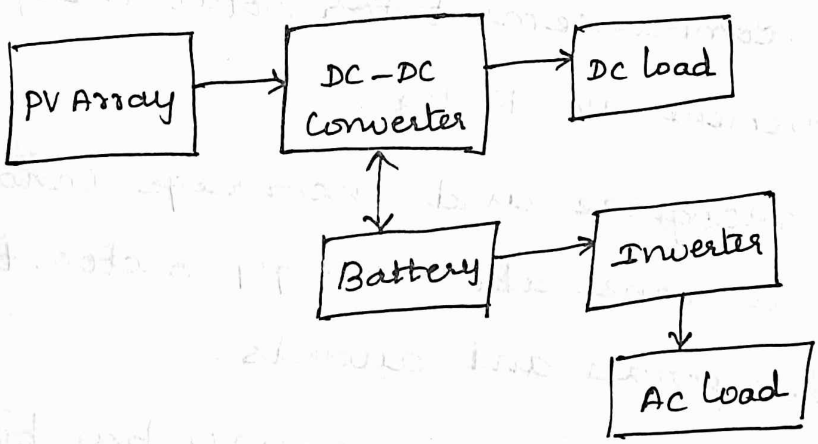
Types of RE sources, Limitations of RE sources :-

Renewable energy is energy generated from natural resources - such as sunlight, wind, rain, tides & geothermal heat which are renewable.

Renewable Resources :-

1) Solar energy
2) wind energy
3) Hydro Power
4) Heat energy
5) Biomass.

1) Solar energy :-



⇒ Solar power is the technology of obtaining usable energy from the light of the sun.

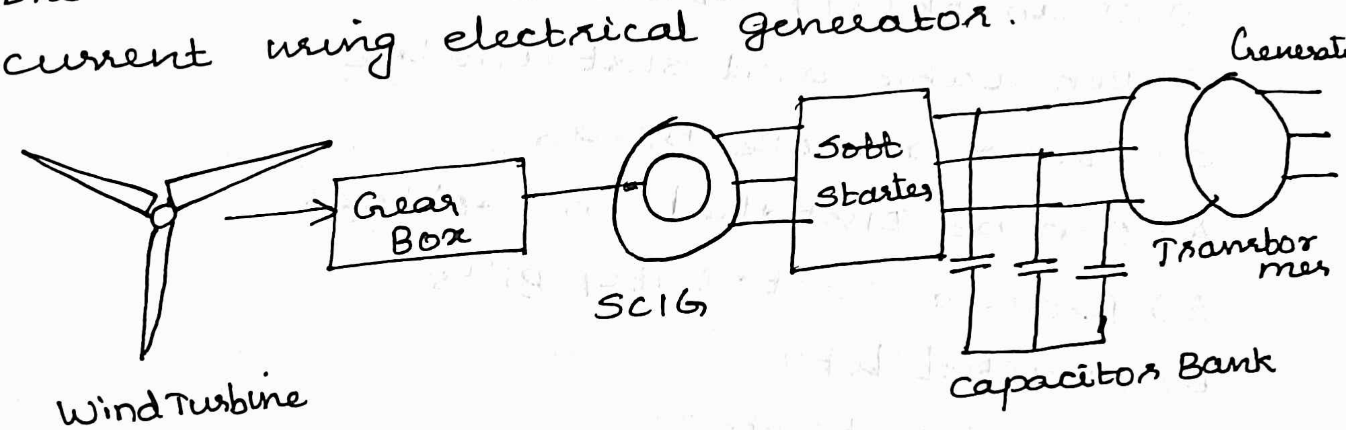
⇒ Solar power energy has come into use where other power supplies are absent, e.x : places off from the electrical grid.

Wind Energy :-

Wind power is using the energy of wind and usually changed into electricity using wind turbines.

=> At the end of March 2017, total installed wind power capacity was 32.17 GW.

=> wind power is generated by converting the rotation of a turbine blades into electrical current using electrical generator.



PROS

1) clean and Renewable source
2) cost effective, use of Modern Technology
3) Rapid Growth, Huge potential.
4) Build on Existing farms.

CONS

1) wind Reliability
2) Threat to wildlife
3) Noise and visual Pollution
4) Expensive to setup.
5) suitable to certain Locations.

Applications :

=) Heat (hot water, building heat, solar cooking)

=) Electricity generation (photovoltaics, solar thermal, heat engines).

=) Desalination of sea water.

=) Lightning.

PROS

1) clean Energy resource
2) Renewable and sustainable
3) Power remote Areas
4) can be Installed on Rooftops.
5) Reduce electricity Bills
6) Availability.
7) Low Maintenance
8) silent.

CONS

1) Produce power During Day.
2) low solar cell Effectiveness (14 % - 17 %)
3) Initial Cost high (Rs 90 - 120 /watt).
4) Required Large Area for setup (10 sq m/kw).
5) Required Expensive Storage (batteries).

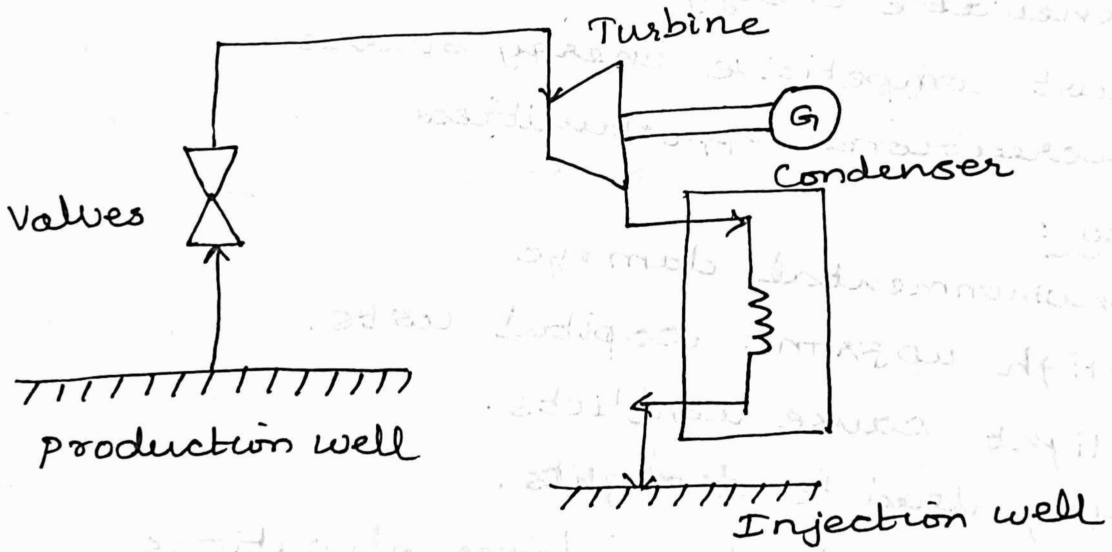
which then drives turbines to generate electricity.

PROS :

1) Renewable source
2) Environment Friendly
3) No fuel Needed
4) Abundant supply

CONS :

1) suitable to particular region
2) High initial costs
3) cost of powering the pump
4) surface instability
5) High temperature needed

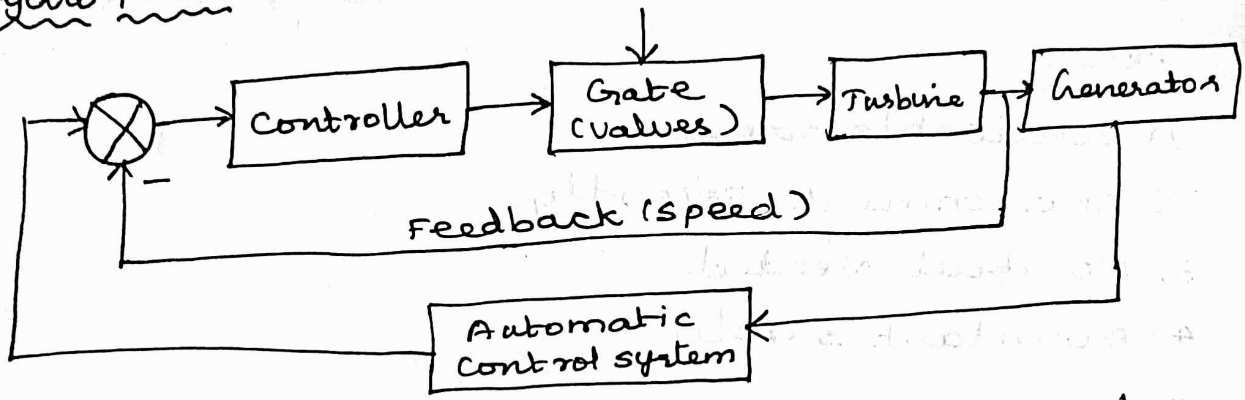


Blomass Energy

Biomass Energy is the energy that is derived from organic matter of plants and animals.

Some of this is burned to make electricity, some is made into biogas, biofuel like ethanol as a replacement for gasoline.

Hydro Power :-



=) Flowing water creates energy that can be captured and turned into electricity. This is called hydro power.

PROS :

1) clean source of power.
2) Renewable energy source
3) cost competitive energy source
4) Recreational opportunities.

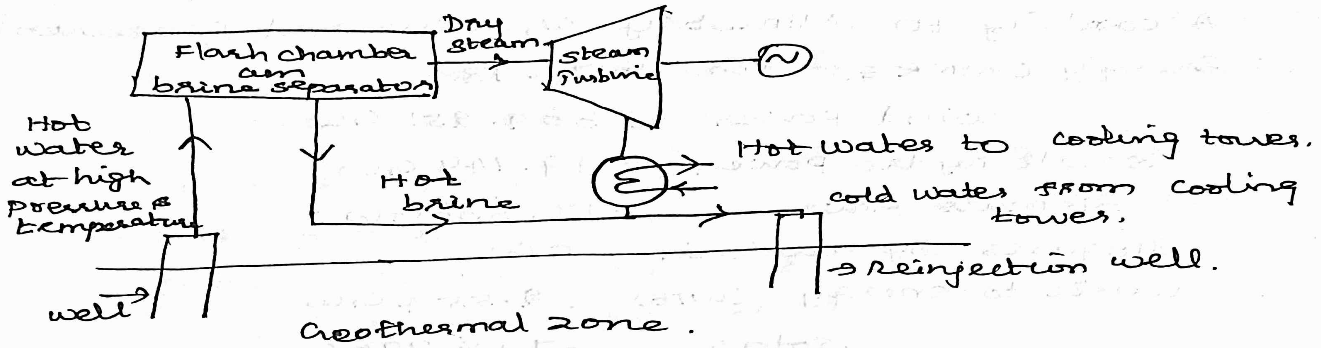
CONS :

1) Environmental damage
2) High upfront capital costs.
3) Might cause conflicts.
4) May lead to droughts.
5) Risk of floods in lower elevations.
6) Carbon dioxide and methane emissions.

Geothermal Energy :-

=) This type of energy is obtained by tapping the heat of the earth, which is mostly in the form of hot water and steam.

=) Another technology uses deep wells in hot rock in which fluid is heated to produce steam



PROS :

1) Renewable source
2) Dependency on fossil fuels is reduced
3) widely Available
4) Helps to reduce waste .

CONS :

1) Not totally clean when burned
2) can lead to Deforestation
3) In-efficient
4) Requires lot of space
5) Expensive.

Present Indian Energy Scenario of RE sources :

The estimated potential of wind power in 1995, was 20,000 MW (20 GW),

Solar energy - 5×10^{15} kwh/pa.

Bio energy - 17,000 MW.

biogases cogeneration - 8000 MW

small hydro power - 10,000 MW.

In 2006, RE potential - 85,000 MW.

wind - 4,500 MW

Solar - 35 MW

Bio mass / Bio energy - 25,000 MW.

Small hydropower - 15,000 MW.

According to Ministry of New and Renewable Energy (MNRE) for 2017 – 18,

wind power – 302.251 GW

small hydro power – 19.749 GW

Biomass power – 17.536 GW

Biogases cogeneration – 5 GW

waste to energy (WTE) – 2.554 GW

Solar – 748.990 GW.

Total RE Potential – 1096.080 GW.

Gross installed capacity of renewable energy – statewise

Karnataka – 12,953.24 MW (17.485%, I[st] rank)

Tamilnadu – 11,934.38 MW (16%, II[nd] rank)

Maharashtra – 9,283.78 MW (12.532%, III[rd] rank)

Gujarat – 8,641 MW (10.641%, IV[th])

Rajasthan – 7,573.86 MW (10.224%, V[th]).

These 5 states cover almost 66.991% of the installed capacity of total renewable.

Solar Energy:

⇒ under the National solar Mission, the MNRE updated the objective of grid connected solar power projects from 20 GW by 2021–2022 to 100 GW by 2021 – 2022.

⇒ India has 5[th] highest solar installed capacity worldwide. 2022 → 25,212.26 MW achieved. 22.8 GW capacity has been tendered out or current implementation.

Wind Energy :

As on 31st Dec 2018, Total installed capacity of India = 35,138.15 MW.

By, 2022 Target of 60 GW to achieve.

India stands 4th position in the world for installed capacity of wind power.

9.4 GW has been tendered out.

Hydro Power :-

Hydro projects classified

→ large hydro

→ small hydro (2 - 25 MW)

→ Micro hydro (upto 100 kw).

→ Mini hydro (100 kw - 2 MW).

Estimated potential of SHP → 20 GW.

2022 target for India → SHP → 5 GW.

1) India stands 4th & 6th position - cumulative installed capacity in the wind & solar sector.

2) MNRE doubled the target for solar parks (projects of 500 MW or more) from 20 to 40 GW.

3) From 2014 - 2018, more than 2.5 lakh biogas Plants were setup for cooking → in rural homes.

4) 682 MW small hydropower projects installed during last 4 years, along with watermills.

Total energy consumption in India

No. of solar street lighting systems	- 55,795.
No. of home lighting systems	- 342607.
Solar lanterns	- 560295
solar photovoltaic power plant	- 1566 kw.
solar photovoltaic pumps	- 6,818.

World Energy Scenario : RE sources :

1) renewables made up 29 % of electricity generation in 2020, much of it from hydropower (16.8 %).

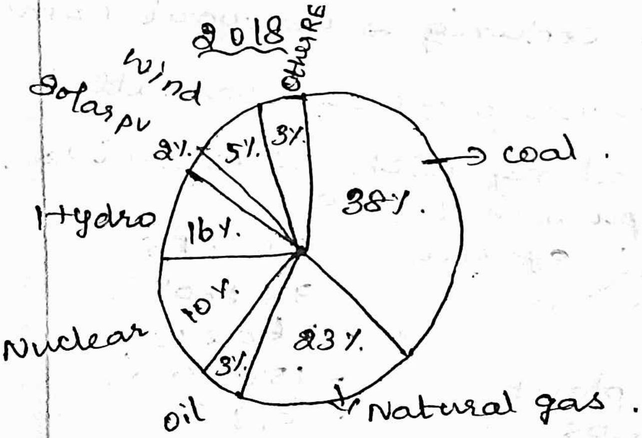
2) A record amount of over 256 GW of renewable power capacity was added globally during 2020.

3) Renewable energy is the fastest growing energy source in the united states increasing 42% from 2010 to 2020.

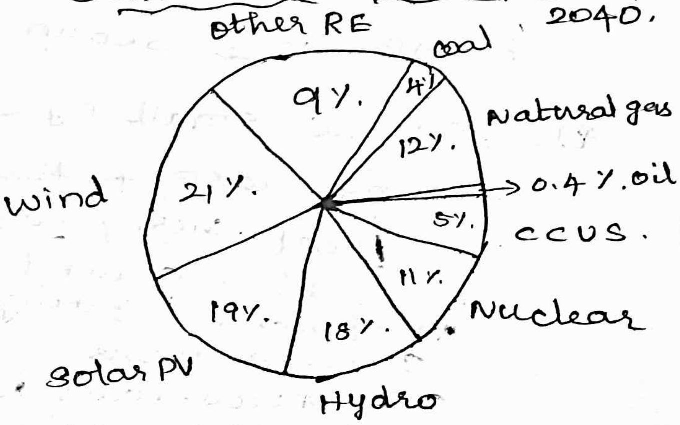
4) About 11.2 % of the energy consumed globally for heating, power and transportation came from modern renewables in 2019.

5) renewables made up 29 %. of global electricity generation by the end of 2020.

6) Led by wind power and solar PV, more than 256 GW of capacity was added in 2020, increase of nearly 10%- in total installed Renewable power capacity.



Sustainable development 2040.



CCUS → Carbon capture, Utilization and Storage.

Present India - Conventional Energy status :

Oil :

=) India produced roughly 880 thousands barrels / day (bbl/d) of total oil in 2009 from 3,600 operating oil wells. Approximately 680 thousand bbl/d was crude oil and the remainder was other liquids and refinery gain.

=) The EIA (Energy Information Administration) expects India to become the 4th largest net importer of oil in the world by 2025, behind the US, China & Japan.

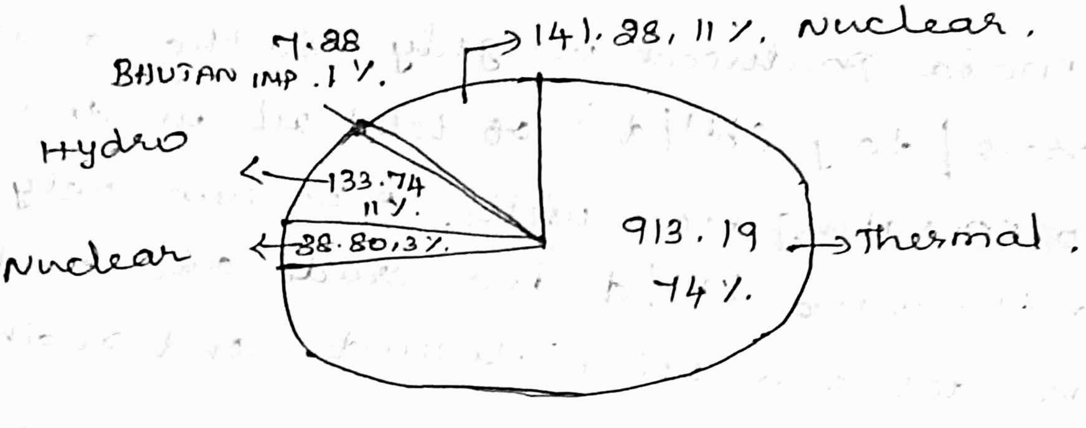
Coal :-

Coal based power generation during 2021-22 → 850.845 BU. During 2021-22, the contribution of Thermal Generation was 74%. out of total ~~genera~~ Electricity generation 1234.3 BU, thermal power contributed 913.19 BU.

Generation :

→ The electricity generation from Fossil fuel sources in the country during 2021-22 is 913.193 BU.

Electricity generation during FY 2021-22 in Billion units : (upto Jan 2022).



Total : 1234.3 BU.

International conventional Energy Resources :-

Coal :

→ Fossil fuels accounted for 82% of primary energy use last year, down from 83% in 2019 and 85% five years ago.

→ China & India accounted for 70% of the growth in coal demand in 2021, increasing by 3.7 & 2.7 EJ respectively.

→ ~~China an~~ Europe and North America showed in increase in coal consumption in 2021.

Oil :

→ oil consumption increased by 5.3 million barrels / day in 2021.

→ Gasoline → 1.5 million b/d, China 1.3 million/ b/d. EU 570,000 b/d.

(b/d - barrels / day).

=> Global oil production increased by 1.4 million barrel/day in 2021.
Libya (840,000 b/d), Iran (540,000 b/d)
Canada (300,000 b/d).

Natural Gas :-

=> Global natural gas demand grew 5.3% in 2021.

=> LNG supply grew to 516 Bcm in 2021.

Two marks :

(1) Define Energy Efficiency ?

Energy efficiency is the use of less energy to perform the same task or produce the same result. Energy efficiency is one of the easiest and most cost effective ways to combat climate change, reduce energy cost for consumers.

(2) Define stalling :-

A lot of turbulence ensues the lift decreases and the drag increases quite substantially. This phenomenon is known as stalling. A wind turbine blade needs to function with as much lift and as little drag because drag dissipates energy.

UNIT-VI.

WIND ENERGY.

Introduction :-

Wind results from air in motion. Air in motion arises from the pressure gradient. The wind is basically caused by solar energy radiating the earth.

The useful work done for the conversion of kinetic energy of the wind into mechanical energy can be utilized to generate the electricity.

Wind energy conversion devices are known as wind turbines, they convert wind stream into energy of rotation.

Basic principle of wind energy conversion :-

Any energy conversion device can extract the motion and convert it into useful work depending on :

i) The wind speed.

ii) The cross section of wind swept by the rotor.

iii) The over all efficiency of the rotor and generator efficiency.

The power in the extracted wind can be found out by kinetics concept.

The amount of air passing in unit time through an Area A, with velocity V is A X V.

Mass is given by,

$M = \rho A V.$

$\rho \rightarrow$ density of the air. kinetic energy of the particle is given by,

$\rho = 1.225\ kg/m^3$ at sea level.

vary 10-15 %. → due to pressure & Temp.

$E = \frac{1}{2} M V^2.$

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

Eqn shows the maximum wind energy available, and is proportional to the cube of the wind speed. since power available is proportional to density, it may vary 10-15%.

As power available is directly proportional to the cross sectional area, it decides the diameter of the vanes for the required power.

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

Available wind power

$Pa = \frac{1}{2} \times \rho \times \frac{\pi}{4} D^2 \times V^3.$

$= \frac{1}{8} \rho D^2 V^3$ watts.

⇒ It is not possible to convert all the wind energy into any other form of energy because the load would reduce the wind speed to zero.

$P = \frac{1}{2} \rho A V^3 C_p.$

$C_p \rightarrow$ power co-efficient

$C_p = \frac{\text{Energy available}}{\text{Energy input}}.$

$P = KAV^3..$

$P = \eta_m K A V^3.$

$P = 0.37 \times \left(\frac{V}{10}\right)^3.$

Aero dynamics forces of Blades :-

Two forces are

1. Lift - which acts perpendicular to the flow.

2. Drag - which operates in the direction of the flow.

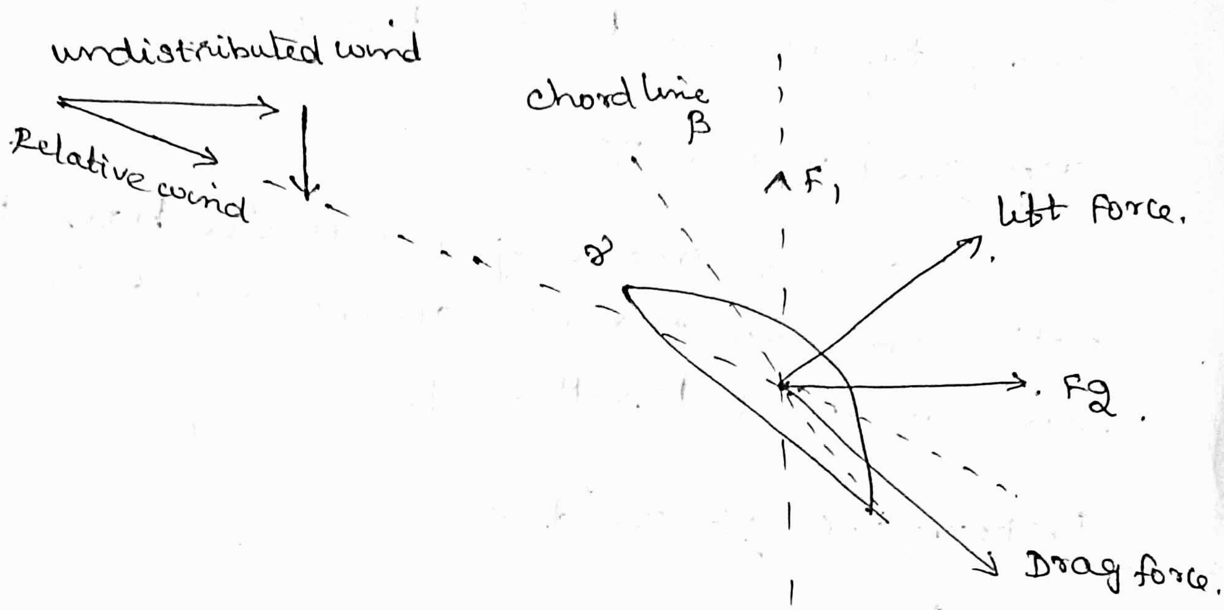


Fig : Aero dynamics of wind Energy.

Lift and drag forces are perpendicular and parallel to the wind velocity.

It is resolved into forces F_1 in the direction of air foil F_2 in direction of the undisturbed wind.

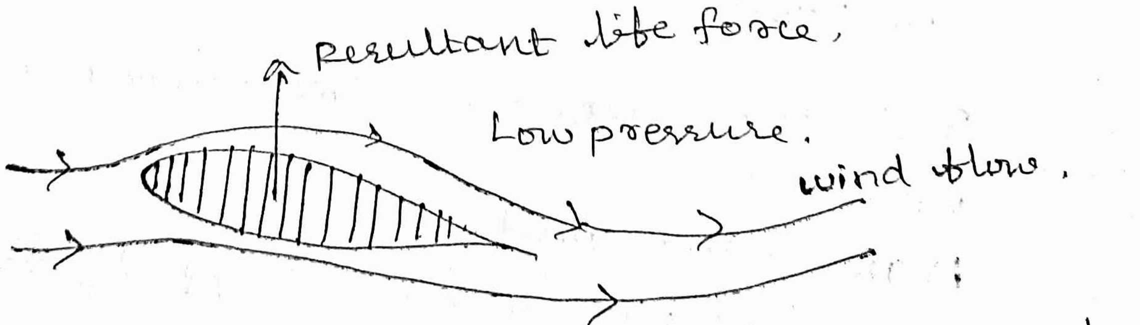


Fig : Aerodynamic lift force on blade cross section of wind turbines.

Pitch :-

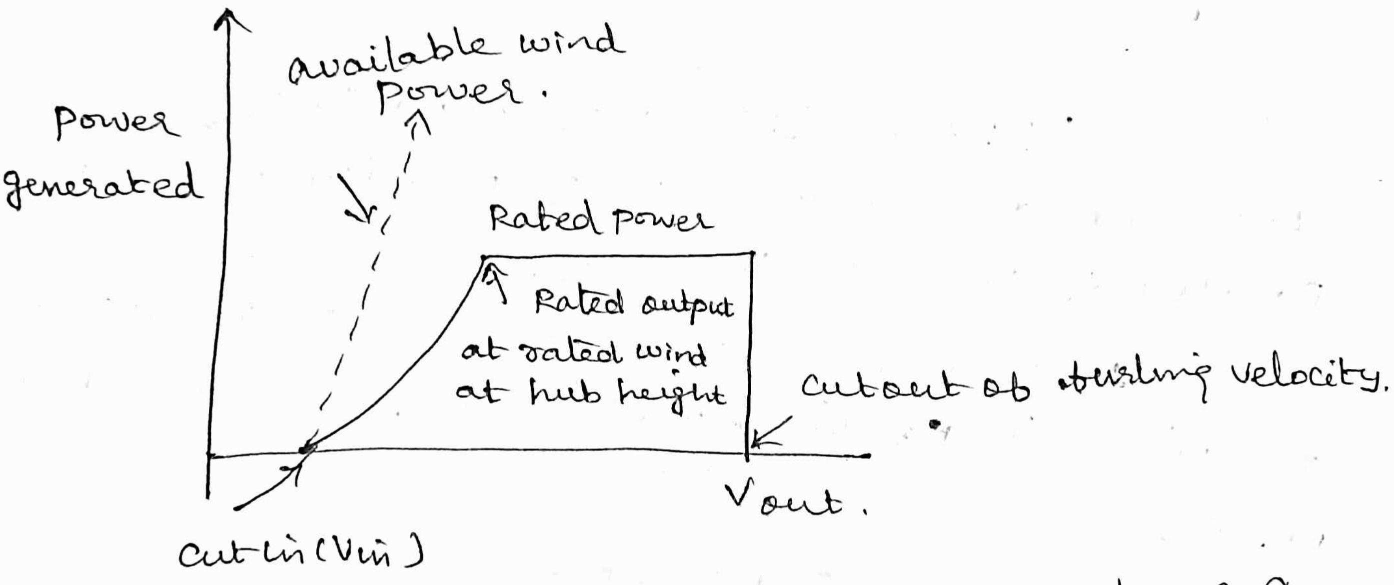
To generate the maximum amount of lift, the blades are to be set at an appropriate angle to the wind direction, called pitch. Pitch angle (γ) varies along the length of blade.

=> To make the pitch angle large, all the way along the blade to be twisted.

Tip speed ratio (λ) :-

Faster rotating windmills have tip speed ratios of more than 1, slower rotating windmills have tip speed less than 1.

Performance of wind :-



3 factors determine the output from a WECS :

1) The wind speed.
2) Cross section of wind swept by rotor.
3) Overall conversion efficiency of the rotor.

The power of wind :-

wind is made up of moving air molecules which have mass. Any moving object with mass carries kinetic energy in an amount given by,

$$\text{kinetic energy} = \frac{1}{2} m v^2 \text{ J.}$$

$$\text{Mass/sec (kg/s)} = \text{velocity (m/s)} \times \text{Area } (m^2) \times \text{Density } (kg/m^3).$$

$$\text{Power} = \frac{1}{2} \times \text{swept area} \times \text{Air Density} \times \text{velocity}^3.$$

$$\text{watts} = \left(\frac{1}{2} \times m^2 \times kg/m^3 \times \text{..} \ m/s\right)$$

P → Mechanical power.

ρ → Air density kg/m^3.

A → Area swept by the rotor blades m^2.

V → velocity of the air m/s.

Volumetric flow rate $= A.V.$

Mass flow rate $= \rho . A . V.$

Power in the wind $P = \frac{1}{2} (\rho A V) . V^2.$

$$P = \frac{1}{2} \rho A V^3 \text{ watts.}$$

~~specific power~~ $= \frac{1}{2} \rho V^3.$

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

$$P = \frac{1}{2} \rho \left(\frac{\pi}{4} D^2\right) V^3$$

$$\boxed{P = \frac{1}{8} \rho \pi D^2 V^3 \text{ watts}}$$

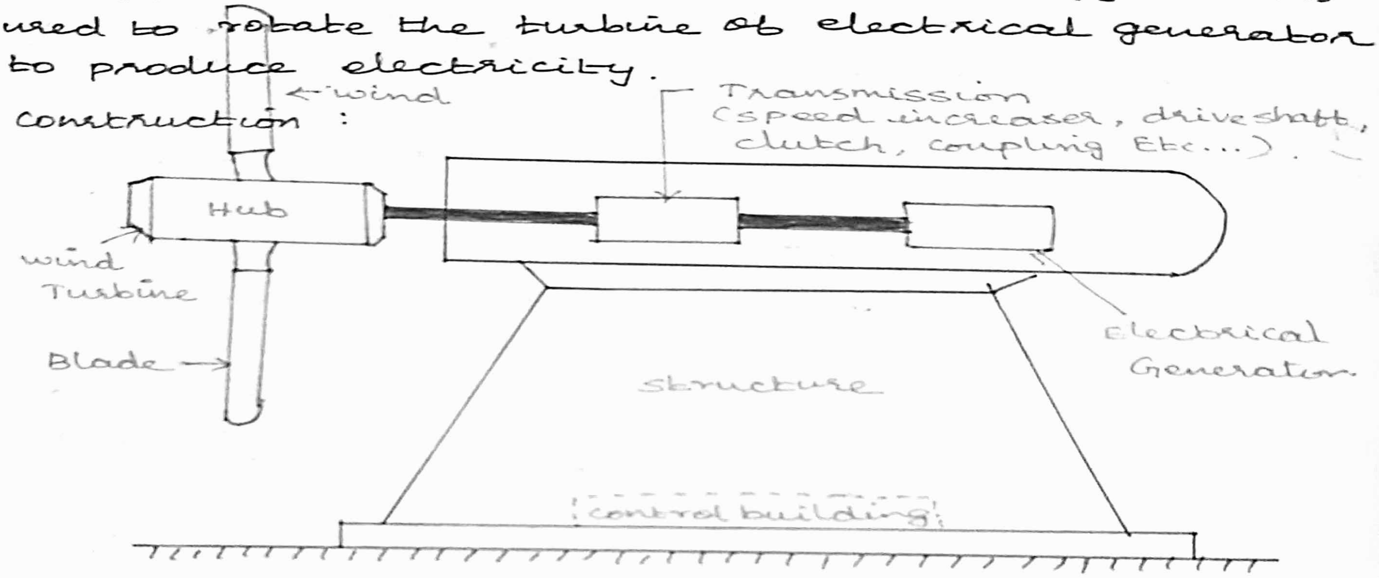
(2) Explain the working principle, construction and working of wind Power Generation :

(12)

✓ Principle :

A windmill converts wind energy into rotational energy by means of its blades. The basic principle of every windmill is to convert kinetic energy of wind into mechanical energy which is used to rotate the turbine of electrical generator to produce electricity.

Construction :



wind - Electric Generating Power Plant

1) wind mill :

The main component of a wind energy conversion system is the windmill alone. A system of blades fixed on a tower is rotated by the wind to either produce mechanical work or electrical energy.

2) wind Turbines :

wind turbines are available in various sizes according to the potential to generate electricity in ideal wind conditions. It is called "rated capacity" wind turbines capacity rating ranges from 250W to 1.65MW. Electricity production and consumption are referred in kilowatt-hours (kwh).

3) Towers :-

Wind mills and wind turbines are kept on high towers due to light in weight. In addition, wind turbines use light-weight towers than conventional mechanical windmills. There are two types of towers such as guyed towers and free-standing self supporting towers. Usually the range of tower is from 18m to 37m for small wind applications and it is from 30m to 75m or higher for moderate wind turbines.

4) Hybrid system combinations :-

A photovoltaic (solar) array, elements of passive solar heating and a back-up diesel generator are combined with wind turbines. During the peak period power demand, the hybrid system is mainly used in order to meet the demand.

5) Pump/ Motor :-

The type of pump is selected on the basis of head, wind turbine electrical output, site conditions and flow requirement for pumping water by using wind power.

6) Storage :-

The most common storage device is the lead-acid battery. If the wind energy conversion system is to pump water and the pumped storage system of water is followed.

7) Energy converters :-

Usually, the electricity produced from wind energy is direct current (DC). So, it should be into alternating current (AC) using an alternator before supplying it to transmission grid for industrial and household appliances.

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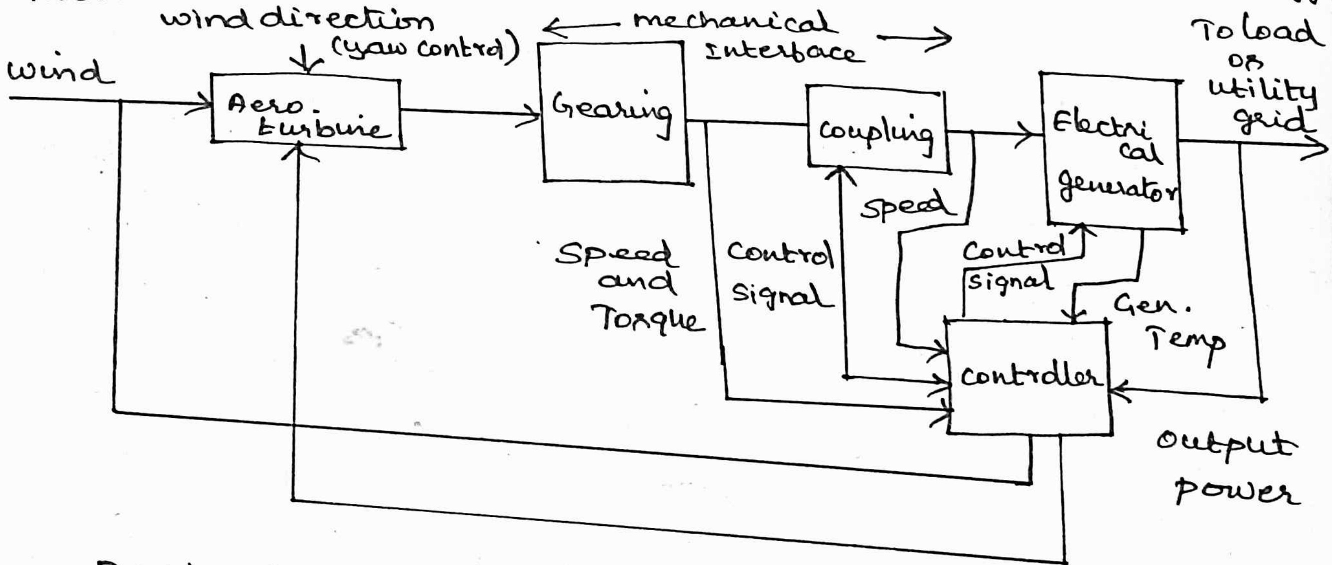
8) Balance of System:

The other components of the system are included in the wind system are monitoring equipment, wiring and the hardware required to complete the system.

Working :-

A wind turbine works on a simple principle. The rotor is connected to the main shaft, which spins a generator to create electricity. Wind turbines are mounted on a tower to capture the most energy.

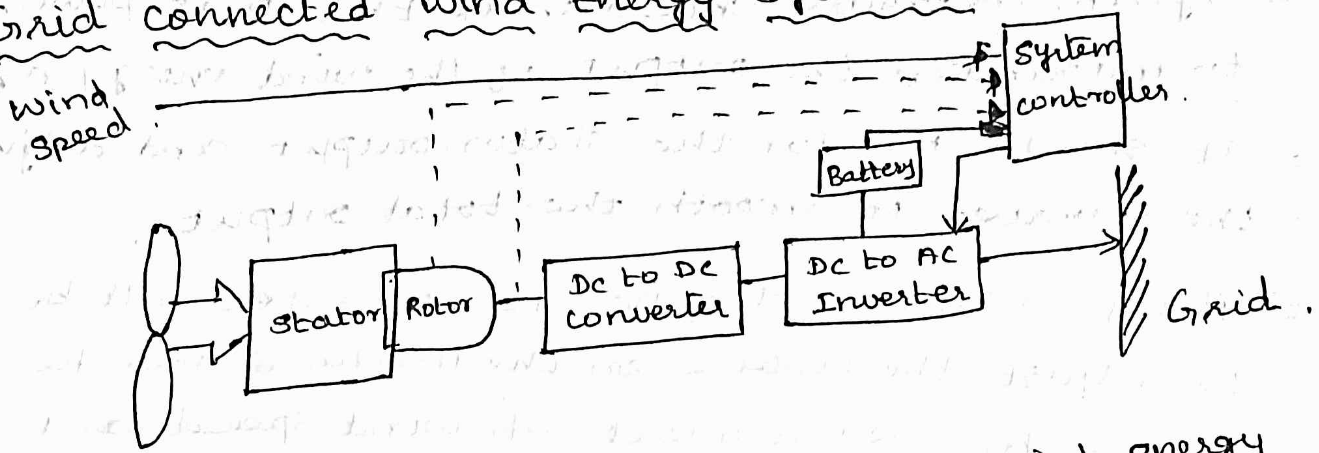


Basic components of a wind-Electric system.

Aeroturbines convert energy in moving air to rotary mechanical energy. In general, they require Pitch control and yaw control for proper operation. A mechanical interface consisting of a step-up gear and a suitable coupling transmits the rotary mechanical energy to an electrical generator. The output of this generator is connected to the load or power grid.

✓ The purpose of the controller is to sense wind speed, wind direction, shafts speeds and torques at one or more points, output power and generator temperature as necessary and appropriate control signals for matching the electrical output to the wind energy input and protect the system from extreme conditions by strong winds, electrical faults.

Grid connected wind Energy systems :-



Block diagram of grid connected wind energy systems.

Small scale wind turbines connected to the Grid :-

=) Remote area power supplies are characterized by low inertia, low damping, poor reactive power support.

=) In this weak grid situation, power fluctuations in the grid would lead to reduced quality of supply to users. This may leads to voltage and frequency variations or spikes in the power supply.

=) These systems have two storage elements. First is the inertia of the rotating mechanical parts includes the blades, gearbox and rotor of the generators.

=) second energy storage element is the small battery storage between the DC-DC converter and the inverter.

Large scale wind turbines connected to the grid

=) It includes the inverter control which reduces fluctuation and increase the total output power.

⇒ system controller should track the peak power to maximize the output of the wind energy system.

⇒ It should monitor the stator output and adjust the inverter to smooth the total output.

⇒ The function of the DC - DC converter will be to adjust the torque on the machine and hence ensure by measurement of wind speed and shaft speed.

Voltage Dip Ride - through capability of wind Turbines :

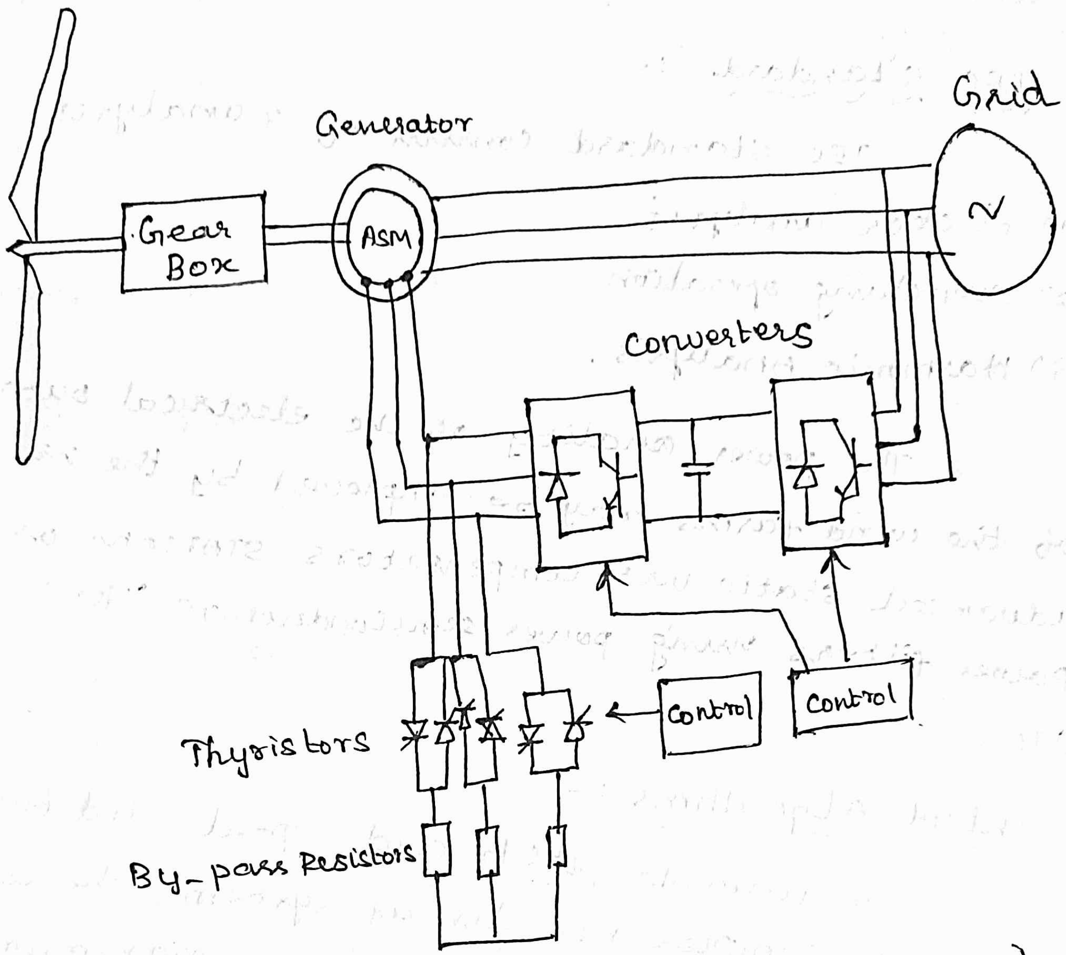
⇒ A major drawback occured in variable speed wind turbines with Doubly fed Induction generators (DFIG) in their opperation when grid faults.

⇒ If a fault occurs in the power system, far away from the location of the turbine, can cause a voltage dip at the connection point of the wind turbine.

⇒ The dip in the grid voltage will result in an increase of the current in the stator windings of the DFIG. This leads to permanent damage of the converter. High voltage at the converter terminals which lead to the destruction of the converter.

Protection Techniques :-

To limit the high currents and to provide a bypass for it in the rotor circuit via a set of resistors that are connected to the rotor windings. Thyristors can be used to connect the resistors to the rotor circuit.



DFIG Bypass resistors in the rotor circuit.

Power Quality Requirements for Grid Connected wind Turbines :-

=> Modern forced commutated inverters used in variable speed wind turbines produce not only harmonics but also inter-harmonics.

=> In 1998, IEC issued IEC-61400-21 standard for "power Quality Requirements for Grid connected wind turbines.

=> wind turbines not only produce harmonics but also produce inter harmonics. i.e., harmonics which are not a multiple of 50 Hz. This whole range of harmonics and inter harmonics represents variations in the switching frequency of wind turbine.

IEC standard :-

IEC standard consists of 3 analyses.

1) Flicker analysis
2) switching operation
3) Harmonic Analysis.

The power quality of the electrical output of the wind farms may be improved by the use of advanced static var compensators STATCOM or active power filters using power semiconductors like IGBT, GTO.

Control Algorithms :-

A variable pitch and speed wind turbine is a very complex non-linear system. The control problem is more difficult such as maximum power captured, constant speed, minimum mechanical stress. To solve this a fuzzy logic control has recently been proposed.

Impact of wind power on system security :-

Security of a power system is regarded as the ability of the system to withstand disturbances without causing a breakdown of the power system.

Power Imbalance :-

wind speed cannot be predicted. wind often fluctuates from minute to minute & hour to hour. The variability and the unpredictability of wind power causes power imbalance of the grid.

challenges on Power system stability :

Stability that considers, large disturbances, transient stability, small signal stability, frequency stability.

Types of wind turbines :-

A wind turbine converts the kinetic energy of the wind's motion to mechanical energy transmitted by the shaft. A generator further converts it to electrical energy, to produce electricity.

classification are

1) Horizontal axis type.

2) Vertical axis type.

Horizontal axis type wind mills :-

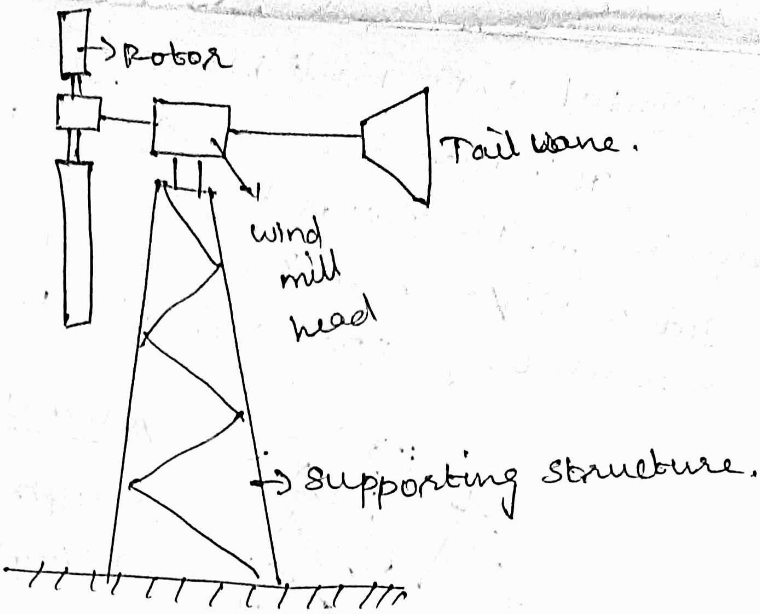
The blade of the wind mill may have the thin cross section or the more efficient thick cross section of an aerofoil.

Horizontal axis using two aerodynamic blades :-

In this type rotor drives a generator through a stepup gear box. The blade rotor is usually designed to be oriented down wind of the tower.

The components are mounted on a bed plate which is attached on a pintle at the top of the tower.

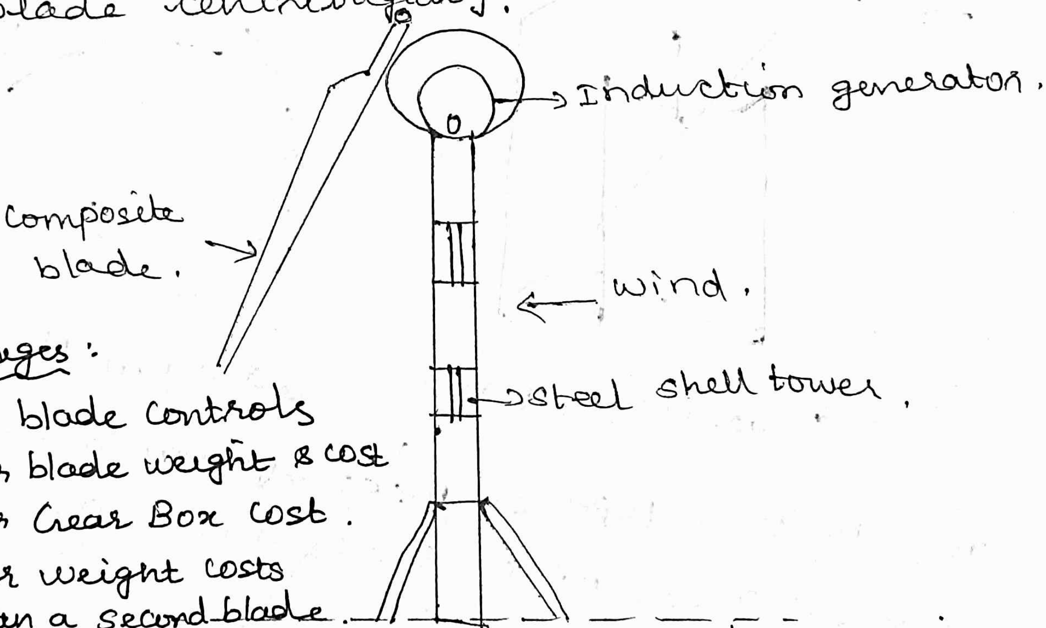
If the blades are made of metal, flexing reduces their fatigue life. with rotor the tower is also subjected to above loads, which may cause serious damage.



Horizontal axis type wind mills

Horizontal axis propeller type using Single blade :-

A long tube is mounted on a rigid hub. Induction generator and gear box are used. To reduce rotor cost, use of low cost counter weight is recommended which balances long blade centrifugally.



Advantages :

1) Simple blade controls
   - lower blade weight & cost
   - lower Gear Box cost.
2) counter weight costs less than a second blade.
3) counter weight can be inclined to reduce blade coning

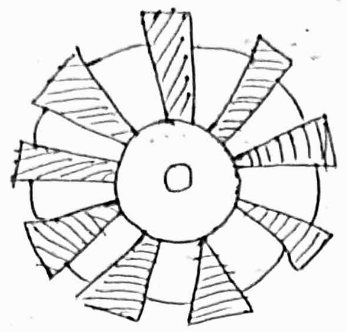
Fig: Horizontal axis single blade wind mill.

4) Blade root spar can be large diameter i.e., more rugged.

Disadvantages : ① Vibrational produced. ② unconventional appearance ③ starting torque reduced.

✓ Horizontal axis multiblade type :-

This type is made from sheet metal or aluminium. The rotors have high strength to weight ratios and known as to ~~survive~~ service hours of free wheeling operation in . 60 km/hr winds.



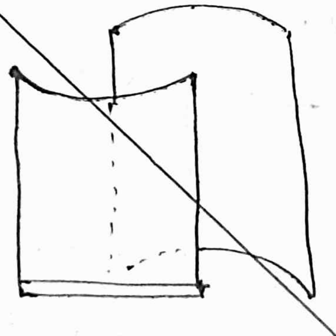
Advantages

1) High starting torque.
2) Simplicity
3) Low cost .

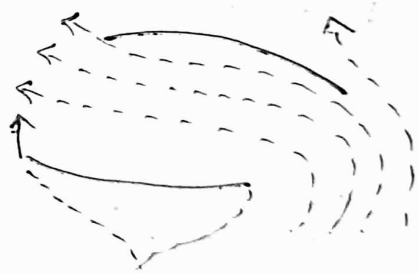
fig: Multi blade propeller.

Vertical Axis type wind mills :-

The Savonions Rotor :-



Savonions rotor



stream flow.

The modern types of WECS system is the savonius rotor which works like a cup anemometer

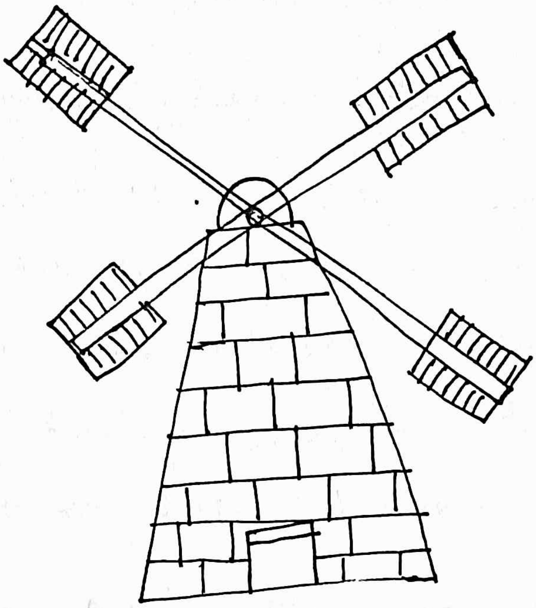
Construction :-

It consists of two half cycles facing opposite directions in such a way as to have almost an S-shaped cross section.

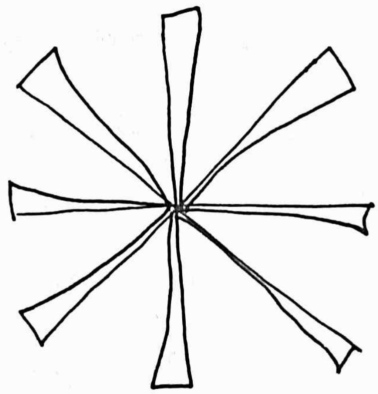
Horizontal axis wind mill Dutch type :-

=) It is one of the oldest designs.

=) The blade surfaces are made from an array of wooden slats which feather in high wind speed.



Sail type :-



=) It is of recent origin. The blade surface is made from cloth, nylon or plastics arranged as mast and pol or sailwing's.

There is also variation in the no. of sails used.

=) There is also variation in the no. of sails used

(F) wind at 1 standard

Vertical Axis Machines :-

Vertical axis Machines use drag forces to turn rotors of different shapes. It use cups, plates or turbines as the drag devices.

Savonius - S shaped rotor :-

It provides some lift force but pre-dominantly use drag devices. drag devices have relatively high starting torques compared to lift devices, but low tip to wind speed and lower power outputs / rotor size, weight & cost.

=> Vertical Axis rotor, can be either drag or lift based. The cup-anemometer is an example of a drag based.

=> Concave side of savonius rotor faces the wind, the drag on a cup is greater. when convex surfaces faces the wind, a small lift is experienced. Thus causes a pressure reduction.

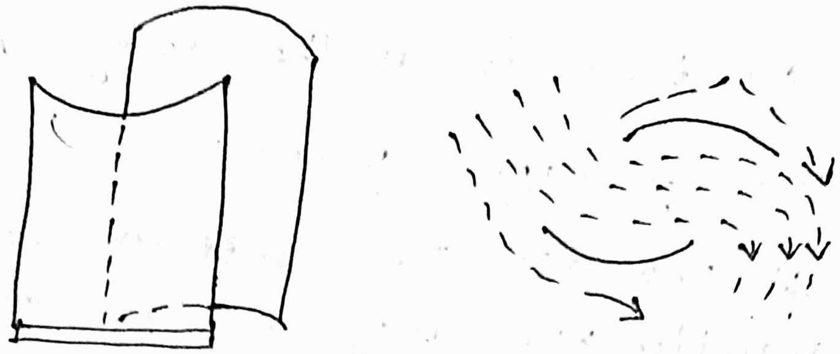
=> Main virtue of cup anemometer is that it tends to rotate within a narrow range of TSRS. Rotational speed is closely proportional to wind speed.

=> Not used for large scale operation.

=> There are pure drag devices. one side of rotor carries blades, while the other side produces reduced drag by shielding or furling the blades.

=) Drag devices run at TSR below unity.

=) Savonius Rotor requires low velocity winds for operation.



Savonius rotor and its stream flow.

Construction :-

It consists of two half cylinders facing opposite directions to have almost S-shaped cross section.

These two semi circular drums are mounted on a vertical axis with a gap between the two drums.

Irrespective of the wind direction, the rotor rotates to make the convex side of the buckets head into the wind. From the rotor shaft we take power for use like water-pumping, battery charging.

Two edges are overlap to leave a wide space between the two inner edges. Each edge is near the central axis of the opposite cylinder.

Advantages:

1) Continue to work effectively even if the wind changes direction. 2) It works well even at low wind speeds. 3) No need for a tower. 4) The device is quiet, easy to build. 5) Maintenance is easy.

Disadvantages :-

1) large metal or other material surface required for the amount of wind intercepted. So, it is difficult to protect during severe storm.

2) Not useful for a very tall installation.

(b) Darries type Machines :-

(High velocity wind).

→ invented by G. J. M. Darrieus in 1925, French Engineer.

⇒ It has two or three, thin curved (egg beater) blades with airfoil cross section. Both ends of blades attached to a vertical shaft.

⇒ Force on the blade due to rotation is pure tension.

⇒ This provides stiffness to withstand heavy wind forces. Blades materials are lighter than in propeller type.

⇒ These airfoil blades provide a torque about the central shaft. This shaft torque transmitted to a generator at the base.

Types

1) ϕ - Darriens → one blade

2) Δ - Darriens → Two blades

3) Y - Darriens → Three blades

4) □ - Darriens. → More blades.

=) Drag devices ...

working :

The force of the wind is greater on the cupped face than on the rounded face. The wind curving around the back side of the cupped face exerts a reduced pressure ~~much~~ much as the wind over the top of an air-foil. This help to rotation. Power co-efficient of S is low.

characteristics :-

i) self starting
ii) Low speed.
iii) Low Efficiency.

Advantages :-

1) It does not depends the wind direction. Machines performs even at low wind velocity ranges

2) low cut in speed. [wind speed required for switching electric power into the line].

3) Produces power effectly in wind 8 km/hr, where as propeller type machines requires 16 km/hr for large effective operation.

4) Electric Generators may be carried at ground level.

5) cost is low.
6) simple structure, easy to manufacture.
7) Yaw control & pitch control not needed.
8) Reduced maintenance, & tower cost.
9) overall weight of the turbine is less.

Characteristics of Darrieus Rotor :-

1) self starting

2) High speed

3) High efficiency.

4) low capital cost.

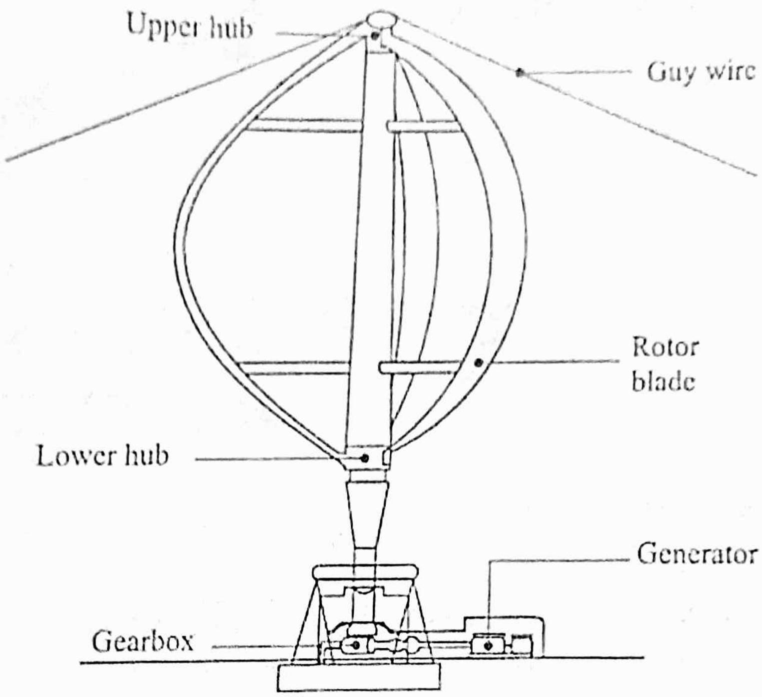
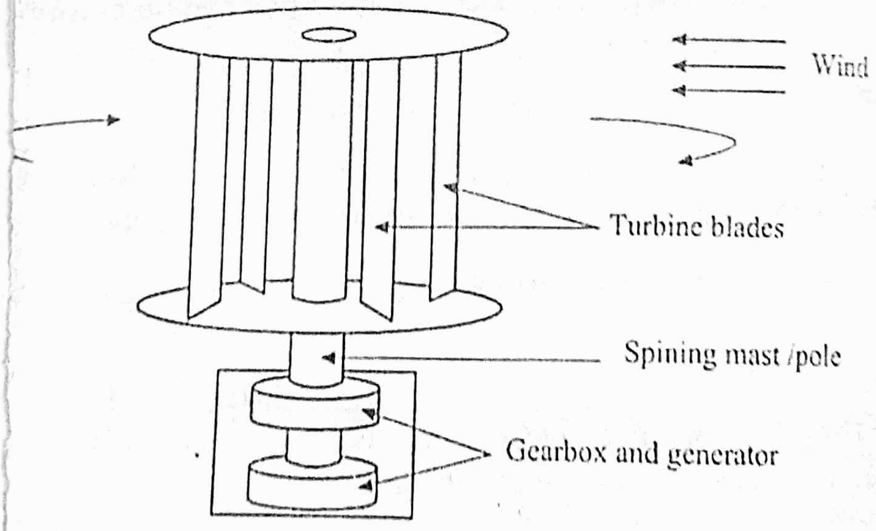


Fig. 5.9 Schematic Structure of Vertical Axis Wind Turbines (Darrieus wind turbine)



9 Schematic Structure of Vertical Axis Wind Turbines (Savonius wind turbine)

=> Drag design ...

Explain the various classification of WECS :-

(1) Based on axis

(a) Horizontal axis machines.

(b) Vertical axis machines.

(2) According to size.

1) Small size machines (upto 2kw).

2) Medium size machines (2 to 100 kw).

3) Large size machines (100 kw and above).

(3) Types of output

(a) DC output

1) DC generator 2) Alternator rectifier.

(b) AC output.

(1) Variable frequency, variable or constant voltage AC.

2) Constant frequency, variable or constant voltage AC.

(4) According to the rotational speed of the area turbine

(1) Constant speed & variable pitch blades.

(2) Nearly constant speed with fixed pitch blades.

(3) Variable speed with fixed pitch blades.

(4) Variable speed constant frequency generating system.

(5) As per utilization of output

(1) Battery storage.

(2) Direct conversion to an electro magnetic energy converter.

Explain site selection consideration for wind Energy conversion system (WECS) :

1) High annual average wind speed :

The speed generated by the wind mill depends on cubic values of velocity of wind, the small increase in velocity affect the power in the wind.

For e-x : Doubling the velocity, increases power by a factor of 8.

It is desirable to select a site for WECS with high wind velocity.

2) Availability of anemometry Data :-

The anemometry data should be available over some time period at the spot where any proposed WECS is to be built.

3) Availability of wind V(t) curve :-

Average wind speed V such that V >= 12-16 km/hr (3.5-4.5 m/sec) which is about the lower limit.

V(t) curve → Reliability of the delivered WECS generated power.

If V(t) curve → 0, power → 0.

4) wind structure at the proposed site :-

V(t) curve was flat i.e., a smooth steady wind that blows all the time.

5) Altitude of the proposed site :

→ It affects the air density, the power in the wind is useful to generate electric power.

→ higher velocities at higher altitudes.

=) Drag devices run at ...

6) Terrain and its aerodynamic :

=) To make use of hills or mountains which channel the prevailing wind into a pass region, obtaining higher wind power.

7) Local Ecology :

=) If the surface is base rock, it may mean lower hub height, lower structure cost.

=) If trees, grass or vegetation are present, tend to destructure the wind, the higher hub height results in large system costs.

8) Distance to road or railways :-

The site should be nearer to road or railways for heavy / machinery, structure, materials, blades and other apparatus will have to be moved into any choosen WECS site.

9) Nearness of site to local centre/users :

The site should be nearer to local centre/ users to minimezes transmission line length and hence losses and cost.

10) Nature of ground :

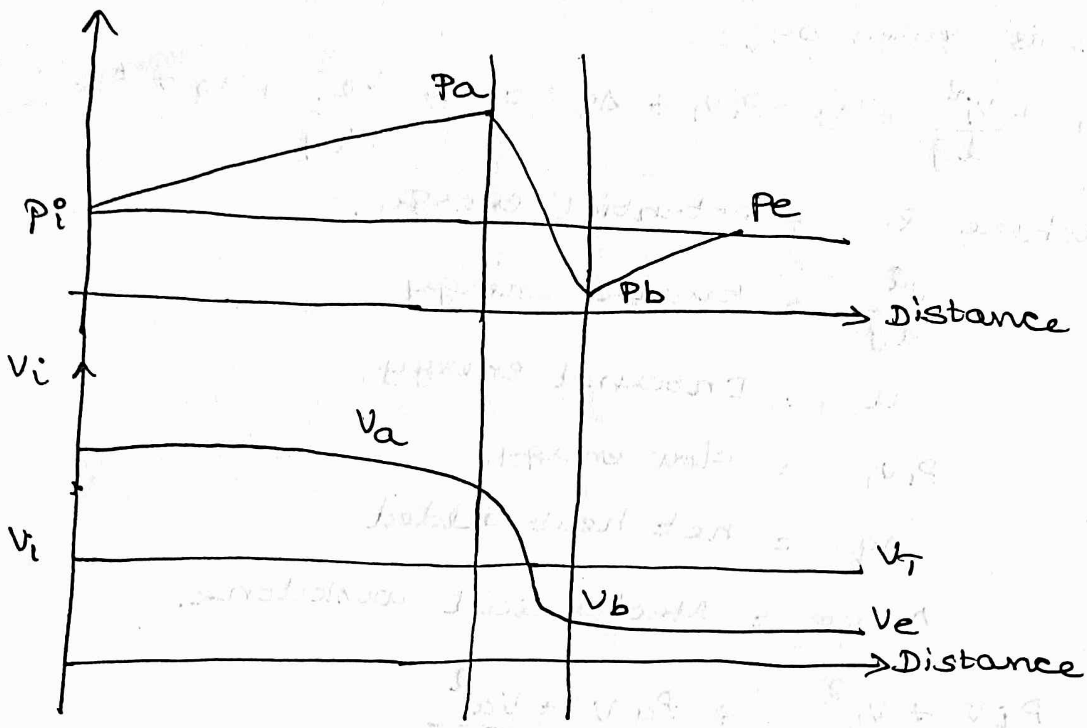
Ground surface should be stable. Erosion problem should not be there. If it is erosion destroying the whole system.

11) Favourable land cost :

Land cost should be favourable. The total WECS system cost reduced.

12) Other conditions such as icing problem, salt spray or blowing dust should not present at the site. They may affect the aeroturbine blades or

Maximum Power in wind



⇒ The total power cannot be converted into mechanical Power.

⇒ Turbine wheel thickness is a, b.

Let Vi, Pi are the wind velocity and pressure at the upstream of the turbine.

Ve, Pe are the wind velocity and pressure at the downstream of the turbine.

$V_e < V_i$ → due to kinetic energy is extracted by the turbine.

⇒ Incoming air between 'i' and 'a', the air density remains constant. (changes in pressure & temperature are very small).

⇒ No heat or work are added or removed between 'i' and 'a'.

General equation for steady state flow for unit mass is given by,

$$z_1 + \frac{v_i^2}{2g} + u_1 + P_1 v_1 + \Delta q = z_2 + \frac{V_{2e}^2}{2g} + u_2 + P_2 v_2 + \Delta W_{SF}.$$

where z_1 = potential energy.

$\frac{v^2}{2g}$ = kinetic energy

u = Internal energy

$P_1 v_1$ = Flow energy.

Δq = net heat added

ΔW_{SF} = Mechanical workdone.

$$P_i v + \frac{v_i^2}{2g} = P_a v + \frac{V_a^2}{2g}.$$

$\div v$,

$$\boxed{P_i + \frac{v_i^2}{2gv} = P_a + \frac{V_a^2}{2gv}}$$

$v \rightarrow$ specific volume.

$$\rho = \frac{1}{v}.$$

$$\boxed{P_i + \frac{\rho v_i^2}{2g} = P_a + \frac{\rho V_a^2}{2g}} \quad \text{——— (1)}$$

$$P_a = P_i + \frac{\rho v_i^2}{2g} - \frac{\rho v_a^2}{2g}.$$

|||ly for the exit region 'b'

$$\boxed{P_b = P_e + \frac{\rho V_e^2}{2g} - \frac{\rho V_b^2}{2g}} \quad \text{——— (2).}$$

From the equation,

$V_i > V_a$, $V_b > V_e$, $P_a > P_i$, $P_b > P_e$.

Combining these equations :

$$P_a - P_b = P_i + \rho\left(\frac{V_i^2 - V_a^2}{2g}\right) - \left\{P_e + \rho\left(\frac{V_e^2 - V_b^2}{2g}\right)\right\} \quad (3)$$

Assume that wind pressure at e assumed to ambients,

$$\boxed{P_e = P_i} \quad (4)$$

Blade width a, b very thin. velocity does not change much.

$$V_a = V_b = V_t \quad (5).$$

Combine (3) to (5) yields,

$$P_a - P_b = P_i + \frac{\rho V_i^2}{2g} - \frac{\rho V_t^2}{2g} - P_i - \frac{\rho V_e^2}{2g} + \frac{\rho V_t^2}{2g}$$

$$= \frac{\rho V_i^2}{2g} - \frac{\rho V_e^2}{2g}.$$

$$= \rho\left(\frac{V_i^2 - V_e^2}{2g}\right) \quad (6).$$

Axial force $= P \times A$.

$F(x) = \frac{\Delta (mv)}{g}$ → rate of change of momentum.

m → mass flow rate,

$$m = \rho A V_t.$$

(Newton's second law $F = m.A$).

$$F(x) = \frac{\rho A V_t \times V}{g} = \frac{\rho A V_t}{g}(V_i - V_e) \quad (7)$$

$$F(x) = P \times A.$$

Axial force $F_x = (P_a - P_b) A$.

$$F_x = \rho A\left[\frac{V_i^2 - V_e^2}{2g}\right] \quad (8).$$

Equating (7) & (8) :

$$\rho A\left[\frac{V_i^2 - V_e^2}{2g}\right] = \frac{\rho A V_t (V_i - V_e)}{g}$$

$$V_t = \frac{V_i^2 - V_e^2}{V_i - V_e} \times \frac{1}{2}.$$

$$V_t = \frac{(V_i + V_e)(V_i - V_e)}{(V_i - V_e)} \times \frac{1}{2}.$$

$$\boxed{V_t = \frac{V_i + V_e}{2}} \quad \text{——— (9)}.$$

Work done $w = KE_i - KE_e$

$$= \frac{V_i^2 - V_e^2}{2g} \quad \text{——— (10)}$$

The power P is defined as, rate of work from mass flow rate equation.

$$P = m \cdot \frac{V_i^2 - V_e^2}{2g}$$

$$= \frac{1}{2g} \rho A V_t (V_i^2 - V_e^2) \quad \text{——— (11)}.$$

Combine this eqn (11) with (9).

$$P = \frac{1}{2g} \rho A \left(\frac{V_i + V_e}{2}\right)(V_i^2 - V_e^2).$$

$$= \frac{1}{4g} \rho A (V_i + V_e)(V_i^2 - V_e^2) \quad \text{—— (12)}.$$

$$= \frac{1}{4g} \rho A \left[V_i^3 - V_i V_e^2 + V_i^2 V_e - V_e^3\right].$$

Maximum Power obtained by differentiating P and equating to zero.

$$\frac{dP}{dV_e} = 0.$$

$$\frac{dP}{dV_e} = -3V_e^2 - 2V_eV_i + V_i^2 = 0.$$

$$\Rightarrow 3V_e^2 + 2V_eV_i - V_i^2 = 0.$$

Two solutions are $V_e = V_i$, $V_e = \frac{V_i}{3}$

choose $V_e = \frac{V_i}{3}$.

Sub V_e value in (D).

$$P = \frac{1}{4g}\rho A\left(V_i + \frac{V_i}{3}\right)\left(V_i^2 - \left(\frac{V_i}{3}\right)^2\right).$$

$$P = \frac{\rho A}{4g}\left(\frac{3V_i + V_i}{3}\right)\left(\frac{9V_i^2 - V_i^2}{9}\right).$$

$$P = \frac{\rho A}{4g}\left(\frac{4V_i}{3}\right)\left(\frac{8V_i^2}{9}\right).$$

$$P = \frac{8V_i^3\rho A}{27g}$$

$$P_{max} = \frac{8\rho AV_i^3}{27g}.$$

(×) & (÷) by 2 in num & deno

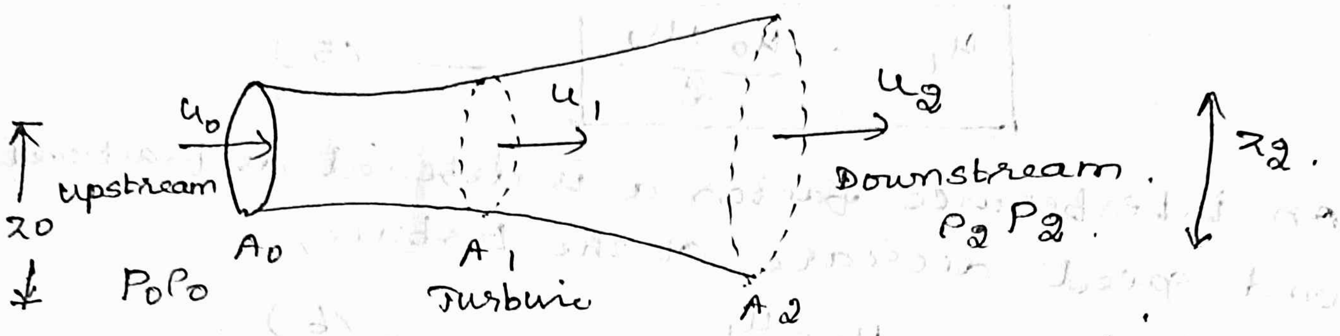
$$P_{max} = \frac{2}{2} \times \frac{8\rho AV_i^3}{27g}$$

$$\boxed{P_{max} = \frac{0.593\,\rho AV_i^3}{2g}}$$

0.593 → Betz - coefficient.

Power extraction from wind.

The stream tube model, also known as Betz model is shown in fig. Air mass flow rate must be same everywhere within the stream tube, the speed must decrease and air expands.



wind stream tube in presence of turbine.

The stream tube area of constant air mass is A_0 upstream, which expands to A_1 passing through the rotor and becomes A_2 downstream.

The wind speed is u_0 upstream, which reduces to u_1 while passing through the rotor and becomes u_2 downstream. Air mass flow rate remains same through out the stream tube.

$$\dot{m} = \rho A_0 u_0 = \rho A_1 u_1 = \rho A_2 u_2 \quad \text{--- (1)}$$

Force on the rotor is equal to the reduction in momentum / unit time,

$$F = \dot{m} u_0 - \dot{m} u_2 \quad \text{--- (2)}$$

Power extracted by the turbine is,

$$P_T = F u_1 = \dot{m}(u_0 - u_2) u_1 \quad \text{--- (3)}$$

Power extracted from wind is also equal to loss in KE / unit time.

$$P_w = \frac{1}{2}\dot{m}(u_0^2 - u_2^2) \quad \text{—— (4)}$$

Equating (3) & (4)

$$\dot{m}(u_0 - u_2)\,u_1 = \frac{1}{2}\dot{m}(u_0^2 - u_2^2)$$

$$(u_0 - u_2)\,u_1 = \frac{(u_0 + u_2)(u_0 - u_2)}{2}$$

$$\boxed{u_1 = \frac{u_0 + u_2}{2}} \quad \text{—— (5)}$$

An interference factor a is defined as fractional wind speed decrease at the turbine,

$$a = \frac{u_0 - u_1}{u_0} \quad \text{—— (6)}$$

$$u_0 - u_1 = a u_0$$

$$u_1 = u_0 - a u_0 \Rightarrow (1 - a)\,u_0 \quad \text{—— (7).}$$

Sub eqn (5) in (7). $a = \dfrac{u_0 - \frac{(u_0 + u_2)}{2}}{u_0}$

$$\frac{u_0 + u_2}{2} = (1 - a)\,u_0$$

$$\frac{u_0 + u_2}{2u_0} = 1 - a$$

$$a = 1 - \frac{u_0 + u_2}{2u_0} = \frac{2u_0 - u_0 - u_2}{2u_0}$$

$$\boxed{a = \frac{u_0 - u_2}{2u_0}} \quad \text{—— (8).}$$

With no energy Extraction, Bernoulli's equation for upstream and downstream may be written as

$$z_0 + \frac{u_0^2}{2} + P_0 V_0 = z_2 + \frac{u_2^2}{2} + P_2 V_2 .$$

$v \rightarrow$ specific volume.

$$\rho = \frac{1}{v} .$$

$$z_0 + \frac{u_0^2}{2} + \frac{P_0}{\rho_0} = z_2 + \frac{u_2^2}{2} + \frac{P_2}{\rho_2} .$$

~~Spa.~~ $z_0 = z_2 \Rightarrow \frac{u_0^2}{2} + \frac{P_0}{\rho_0} - \frac{u_2^2}{2} - \frac{P_2}{\rho_2} = 0 .$

Static pressure difference across the turbine,

$$\Delta P = P_0 - P_2 = (u_0^2 - u_2^2)\,\rho/2 .$$

$$\frac{P_0}{\rho_0} - \frac{P_2}{\rho_2} = \frac{u_2^2 - u_0^2}{2} .$$

$$P_0 - P_2 = \frac{(u_2^2 - u_0^2) \times \rho}{2} .$$

$$\frac{u_0^2}{2} + \frac{P_0}{\rho_0} = \frac{u_2^2}{2} + \frac{P_2}{\rho_2} .$$

$$\frac{\rho_0 u_0^2}{2} + P_0 = \frac{\rho_2 u_2^2}{2} + P_2 .$$

$$P_0 - P_2 = \rho\left(\frac{u_0^2 - u_2^2}{2}\right) .$$

~~Axial force $F_A = P \times A$.~~

~~$F_A =$~~

Maximum value of static pressure difference occurs when $u_2 = 0$,

$F = P \times A .$

$$\Delta P_{max} = \frac{\rho u_0^2}{2}$$

Maximum thrust on the disk is,

$$F_{A\,max} = A_1 \times \frac{\rho u_0^2}{2} .$$

The axial thrust must be equal to loss of momentum of the air stream.

Using the equations,

$$P_0 = \frac{1}{2} \rho A u_0^3$$

$$u_1 = \frac{u_0 + u_2}{2}$$

$$a = \frac{u_0 - u_1}{u_0}$$

$$F_A = \dot{m} u_0 - \dot{m} u_2$$

$$m = \rho A_1 u_1$$

$$= \rho A_1 u_1 u_0 - \rho A_1 u_1 u_2$$

$$= \rho A_1 \left(\frac{u_0 + u_2}{2}\right) u_0 - \rho A_1 \left(\frac{u_0 + u_2}{2}\right) u_2$$

$$\boxed{F_A = 4a(1-a) A_1 \frac{\rho u_0^2}{2}}$$

Torque developed by the turbine, T

Maximum conceivable torque T_M on ideal turbine rotor occurs if maximum circumferential force acts at the tip of the blade with Readius R.

$$T_M = F_{cirMax} \times R$$

$$T_M = \frac{P_0}{u_0} \times R$$

At maximum efficiency, $\eta_{max} = \frac{16}{27}$, the torque has maximum value T_{max}.

$$T_{max} = \frac{16}{27} \times \frac{1}{8} \frac{\rho D V_i^3}{N}$$

$$= \frac{2}{27} \frac{\rho D V_i^3}{N}$$

The axial force or thrust is,

$$F_x = \frac{1}{2} \rho A (V_i^2 - V_e^2)$$

$$= \frac{\rho \pi D^2}{2 \times 4} (V_i^2 - V_e^2)$$

$$= \frac{\pi \rho D^2}{8} (V_i^2 - V_e^2)$$

The axial force on a turbine wheel operating at maximum efficiency at $V_e = \frac{1}{3} V_i$.

$$F_{x\,max} = \frac{1}{2} \rho A \left(\left(\frac{V_i}{3}\right)^2 - V_e^2 \right)$$

$$= \rho \pi D^2$$

$$= \frac{\pi \rho D^2}{8} \left(V_i^2 - \frac{V_i^2}{9} \right)$$

$$= \frac{\pi \rho D^2}{8} \times \frac{8 V_i^2}{9}$$

$$\boxed{F_{x\,max} = \frac{\pi}{9} \rho D^2 V_i^2}$$

Two types of forces :-

1) circumferential force → acting in the direction of wheel rotation.

2) Axial force → direction of the wind stream.
↓
axial thrust.

circumferencial force or torque T

$$T = \frac{P}{\omega} = \frac{P}{\pi D N}$$

T → ~~torque~~ Newton.

ω → angular velocity of turbine wheel m/s.

D → Diameter of turbine wheel.

N → wheel revolutions / unit time.

$$\text{efficiency } \eta = \frac{P}{P_{total}}$$

$$A = \pi r^2 = \pi (D/2)^2$$

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

$$P = \eta \times P_{total}$$

$$= \eta \times \frac{1}{2} \rho A V_i^3$$

$$T = \frac{P}{\omega} = \frac{P}{\pi D N} = \frac{\eta \rho A V_i^3}{2 \pi D N}$$

$$= \eta \cdot \frac{1}{2} \rho \frac{\pi}{4} \frac{D^2 V_i^3}{\pi D N}$$

$$\boxed{T = \eta \frac{1}{8} \frac{\rho D V_i^3}{N}}$$

Velocity = 12 m/s.

H = 10 m.

ρ = 1.226 kg/m^3.

α = 0.14.

D = 80 m.

A_1 =

u_1 = 0.8 u_0.

η_{Gen} = 0.85.

① A propeller type wind turbine has the following data:

speed of free wind at a height of 10 m = 12 m/s.

Air density = 1.226 kg/m^3.

α = 0.14.

Height of tower = 100 m.

Diameter of rotor = 80 m.

wind velocity at the turbine reduced by 20%.

Generator efficiency = 85%.

(i) total power available in wind.

(ii) Power extracted by the turbine.

(iii) electrical power generated.

(iv) axial force on the turbine.

v) maximum axial thrust on the turbine.

u_H = 12 m/s, H = 10 m, z = 100 m.

ρ = 1.226 kg/m^3, α = 0.14.

D = 80 m, $A_1 = \pi\left(\frac{D^2}{4}\right) = \frac{\pi \times 80 \times 80}{4} = 1600\pi$

$= 5024\,m^2$.

u_1 = 0.8 u_0, η_{Gen} = 0.85.

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

$$= 12 \times \left(\frac{100}{10}\right)^{\alpha} = 12 \times (10)^{0.14}$$

$$= 16.565 \text{ m/s} = u_0.$$

$$u_1 = 0.8 \times 16.565 = 13.252 \text{ m/s}.$$

(i) $P_0 = \frac{1}{2} \rho A u_0^3.$

$$= \frac{1}{2} \times 1.226 \times 16.565$$

$$= 14 \text{ MW}.$$

(ii) $P_T = C_p P_0.$

$$C_p = 4a(1-a)^2.$$

$$a = \frac{u_0 - u_1}{u_0} = \frac{16.565 - 13.252}{16.565}$$

$$\boxed{a = 0.2}$$

$$C_p = 4 \times 0.2 (1 - 0.2)^2$$

$$= 0.512.$$

$$P_T = 0.512 \times 14 = 7.168 \text{ MW}.$$

(iii) $\eta = \frac{\text{output power}}{\text{Input power}}$

output power $= \eta \times$ Input power.

$$= 0.85 \times 7.168 = 6.09 \text{ MW}.$$

iv) Axial thrust on the turbine

$$F_A = 4a(1-a) A_1 \frac{\rho u_0^2}{2}$$

$$= 5.4 \times 10^5 \text{ N}.$$

v) Maximum axial thrust occurs when

$a = 0.5$, $C_p = 1$.

$$F_{Amax} = A_1 \times \frac{\rho u_0^2}{2}$$

$$= 8.455 \times 10^5 \, N.$$

$$F_A = 4a(1-a) A_1 \frac{\rho u_0^2}{2}.$$

$$= C_F \times F_{Amax}$$

$$C_F = 4a(1-a).$$

$$F_A = A_1 \times \frac{\rho u_0^2}{2}.$$

UNIT - III

Solar PV and Thermal systems

Radiation Measurement :-

Measurement of solar radiation are important because of the increasing numbers of solar heating and cooling applications.

Two basic types of instruments are employed for solar radiation measurement :

i) a pyrheliometer : used to determine the beam intensity as a function of incident angle.

ii) a pyranometer : which measures the total hemispherical solar radiation.

Pyrheliometer :-

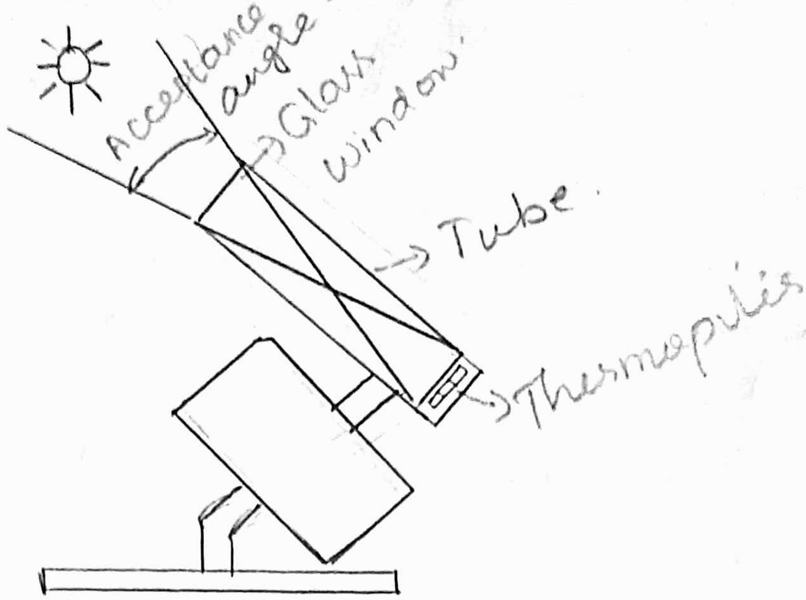
→ A pyrheliometer is an instrument which measures beam radiation.

→ Most pyrheliometer operate on the thermopile effect. It used thermopile. to measure emb difference.

→ The pyrheliometer looks like a telescope.

→ It's outer structure look like a long tube and we have to point the lens to the sun to measure the radiance. It can measure the radiation having wavelength between 280nm to 3000nm.

→ It is used for climatological and weather monitoring research purpose.



Pyrheliometer construction :-

Acceptance Angle :

To set the pyrheliometer at specific angle which will measure the radiation coming from the sun. The acceptance angle of the instrument should be close to 5°, so that the lens can bend and focus the light into black body.

Long collimator tube :-

In this tube we will set the solar radiation which is lengthy tube.

Alignment Indicator :-

This will be used for setting the angle. It will align the instrument.

Black absorber plate :

when the rays will come inside the tube there will be black plate which will absorb the radiation

Thermopile Junction :-

Thermopile junction is located below the black absorber plate which will used to measure the emf.

It will measure the heat from the black body.

Pivot for 2-axis rotation:

The whole system is mounted on it with the help of this. It will be able to follow the sun throughout the day. we can also change the direction of the instrument according to the direct radiation.

Working:

The sunlight will enter in the long collimator tube and incident on black absorber plate. The thermopile is in contact with the black absorber plate. The black plate will absorb the heat, the emf will be generated between the hot and colder surface due to temperature difference. This emf used to measure the value of beam radiation.

Advantages:

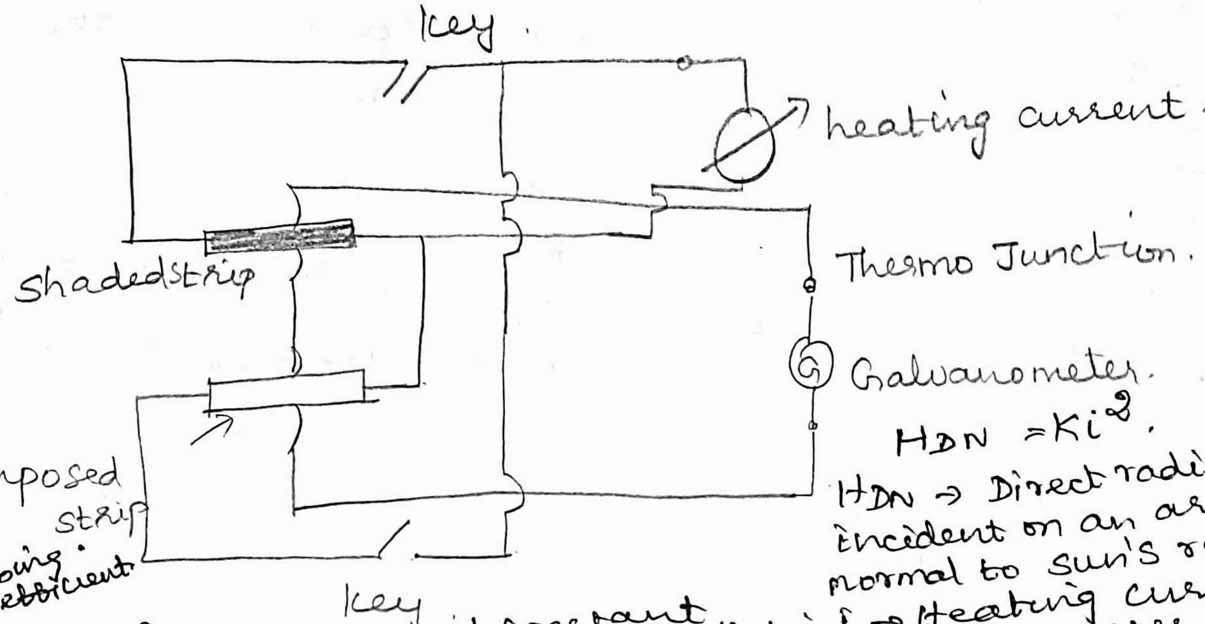
1) It has very less power consumption.
2) wide range of voltage can be operated with it.
3) It is stable and Rigid.
4) usually used in solar tracking system. when the sun will moving the tracking system will follow the sun.

Three pyrheliometers are used

1) Angstrom pyrheliometer
2) Abbot silver disc pyrheliometer.
3) Eppley pyrheliometer.

1) Angstrom compensation pyrheliometer :-

In this pyrheliometer, a thin blackened shaded manganin strip (size 20 × 2 × 0.1 mm) is heated electrically. The similar strip which is exposed to solar radiation.



$H_{DN} = Ki^2$.

H_{DN} → Direct radiation incident on an area normal to sun's rays.

α → absorbing coefficient.

K → Dimension & Instrument constant

i → Heating current in Amperes.

$K = \frac{R}{w\alpha}$

R → resistance/unit length of absorbing strip

w → Mean width of the absorbing strip

under both strips at identical temperature the energy used for heating is equal to the absorbed solar energy.

The thermopiles on the back of each strip, connected in opposition through a sensitive galvanometer are used to test the temperature.

2) Abbot silver disk pyrheliometer :-

It consists of a blackened silver disk positioned at the lower end of a tube. The aperture to be 5.7°.

A mercury in glass thermometer is used to measure the temperature at the disk.

=) A shutter made of 3 polished metal leaves is provided at the upper end of the tube to allow solar radiation to fall on the disk. The corresponding changes in temperature of the disk are measured.

Eppley pyrheliometer :-

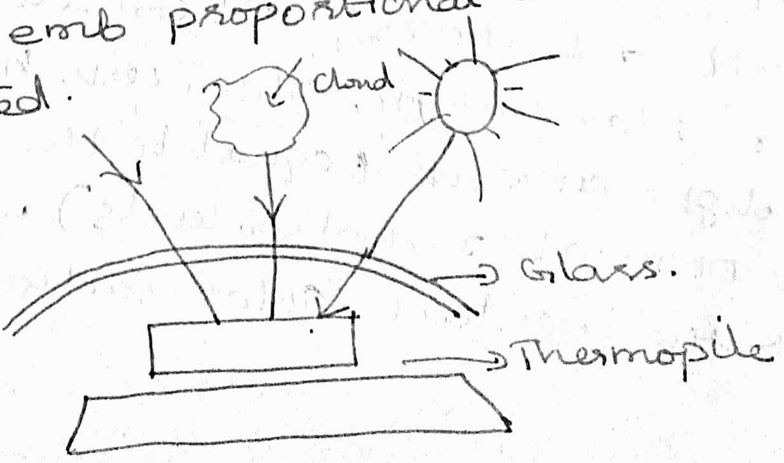
15 Junction bismuth silver thermopile is mounted at the base of a brass tube. The tube is filled with dry air and is sealed with a crystal quartz window.

Pyranometers :-

A pyranometer is a type of actinometer used for measuring solar irradiance on a planer surface.

Pyranometer which is a radio meter with a glass dome that has hemispherical view of the whole sky. used for measuring diffused radiation. The sun's radiation is allowed to fall on a black surface to which the hot junctions of a thermopile are attached. The cold junctions of the thermopile are located in a such a way that they do not receive the radiation.

An emf proportional to the solar radiation is generated.



This emb range is 0 to 10mV can be read, recorded or integrated over a period of time.

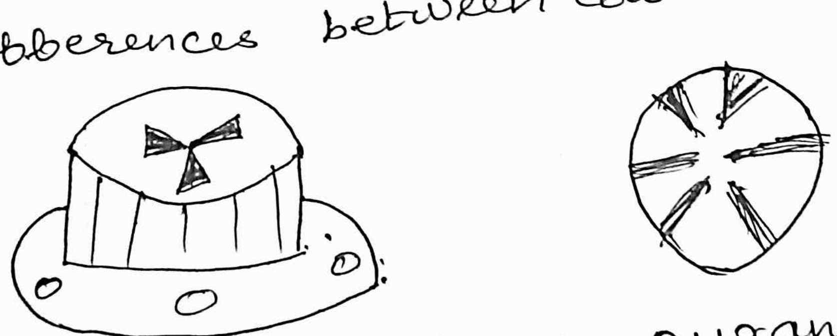
There are following types of Pyranometers:

i) Eppley pyranometer.
ii) Yellot solarimeter.
iii) Moll Gorczyheski solarimeter
iv) Bimetallic Actionographs.
v) Velochme Pyranometer.
vi) Thermo electric pyranometer etc..

Eppley pyranometer :-

=) There is a difference between the temperature of black surfaces (absorb most solar radiation) & white surfaces (reflect most solar radiation).

=) Detection of temperature difference achieved by thermopile. It uses concentric silver rings 0.25mm thick, coated black & white, 10 or 50 thermocouple junctions to detect temperature differences between coated rings.



Yellot Solarimeter :- pyranometers also used in solar cell detectors. Silicon cells are the most common for solar energy. Silicon cells have the property that their light current (equal to the short circuit current at normal radiation levels) in a linear function of the incident solar radiation.

Solar Thermal Electric Conversion

The conversion of solar energy into electricity by the way of thermal (or heat) energy. Heat can be converted directly into electrical energy by solar cell or thermionic or thermo electric methods. But these techniques may not be suitable for use with the sun-generated heat.

The most practical thermal electric procedure for solar energy is to utilize the energy to heat a working fluid. The heat energy is then converted into mechanical energy in a turbine and finally into electrical energy by generator. This is called solar thermal power production system.

Thermal Electric Conversion systems :-

In a solar thermal power production system the energy is first collected by using a solar pond, a flat plant collector or a focussing collector. This energy is used to increase the temperature of a fluid.

This fluid using any of the common cycles such as Rankine, Brayton or passes through a heat exchanger to heat a secondary fluid (working fluid) to produce mechanical power and electrical power is easily produced.

Following four systems are used :

i) Low temperature cycle using flat plate collector or solar pond.

(ii) Concentrating collectors for medium and high temperature cycle.

iii) Power tower concept (or) central receiver system.

iv) Distributed collector system.

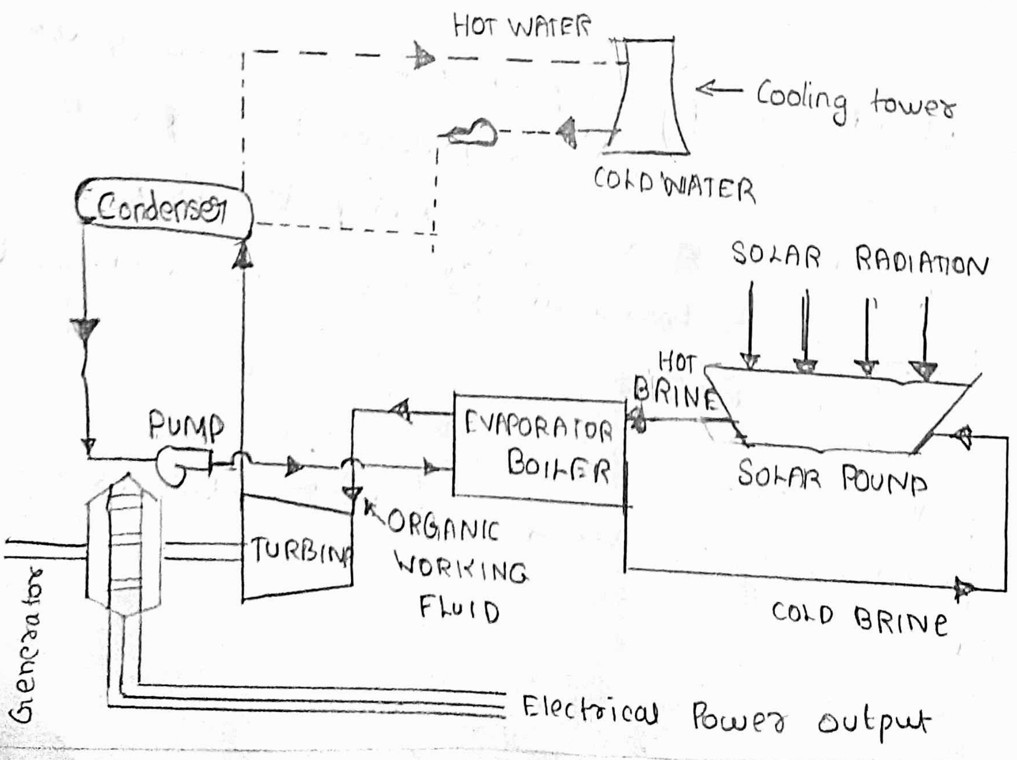
(i) Low temperature systems :-

The temperature achieved is of the order of 60°C to 100°C, efficiency 30 to 50 %. Thermal energy from a solar pond is used to derive a Rankine cycle heat engine.

Hot water from the bottom level of the pond is pumped to the evaporator where the organic working fluid is vaporized.

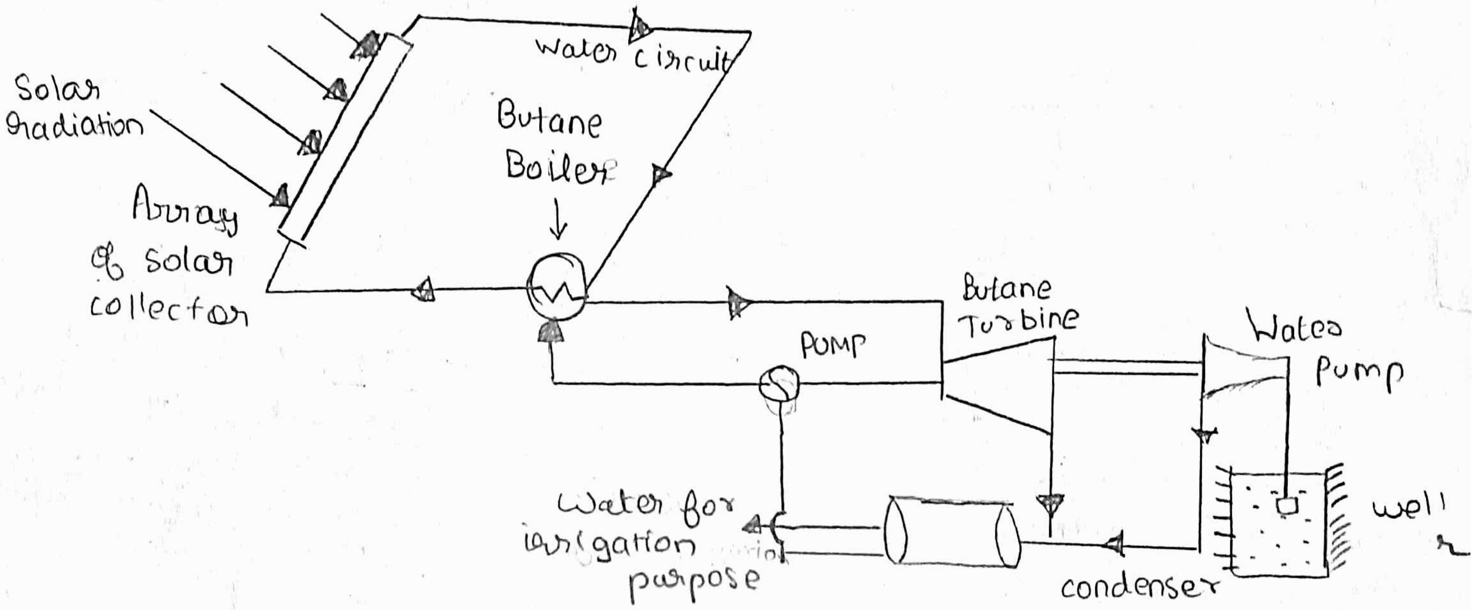
The vapour flows under high pressure to the turbine and thereby expanding through the turbine wheel and the electric generator linked to it.

The vapour then travels to the condenser where cold water from the cooling tower condenses the vapour back to a liquid.



Another low temperature solar engine, using heated water from flat plate collector and butane as the working fluid.

The system has array of flat-plate collectors to heat water upto nearly 70°C and in the heat exchanger, heat of water is used for boiling butane. The high pressure butane vapour runs a butane turbine which operates a hydraulic pump which pumps the water from well and used for irrigation.



Medium Temperature systems with concentrating Collectors :-

It consists of a parabolic cylindrical reflector to concentrate sunlight on to a collecting pipe within a pyrex or glass envelop. A selective coating of suitable material is applied to pipe to minimise infrared emission. Proper sun tracking arrangement is made so that maximum sunlight is focused on the absorber. These systems generally employ an array of parabolic trough concentrating collectors, which give temperature above 100°c. General range of temperature is of the order of 250 - 500°C.

High temperature system :-

For the efficient Conversion of heat energy into mechanical energy and hence into electricity, the working fluid should be supplied to the turbine at high temperature.

To obtain such temperatures above about 175°c, from Solar energy requires the use of focusing or concentrating collectors.

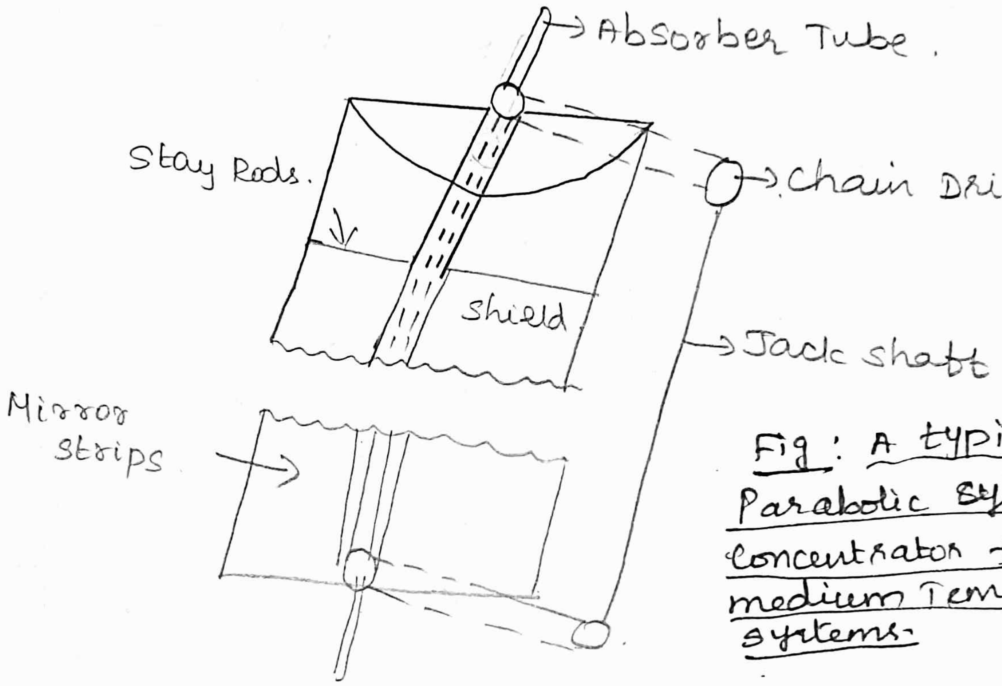


Fig : A typical Parabolic Cylindrical concentrator for medium Temperature systems.

Central Receiver systems :- (Tower Power Plant)

The incoming Solar radiation is focused to a central receiver or a boiler mounted on a tall tower using thousands of plane reflectors, which are steerable and are called heliostats.

The mirrors are installed on the ground and are oriented so as to reflect the direct beam radiation into an absorber or receiver (boiler) to produce high temperature. This make is possible to position the boiler in the field of view of all mirrors at all hours of the day.

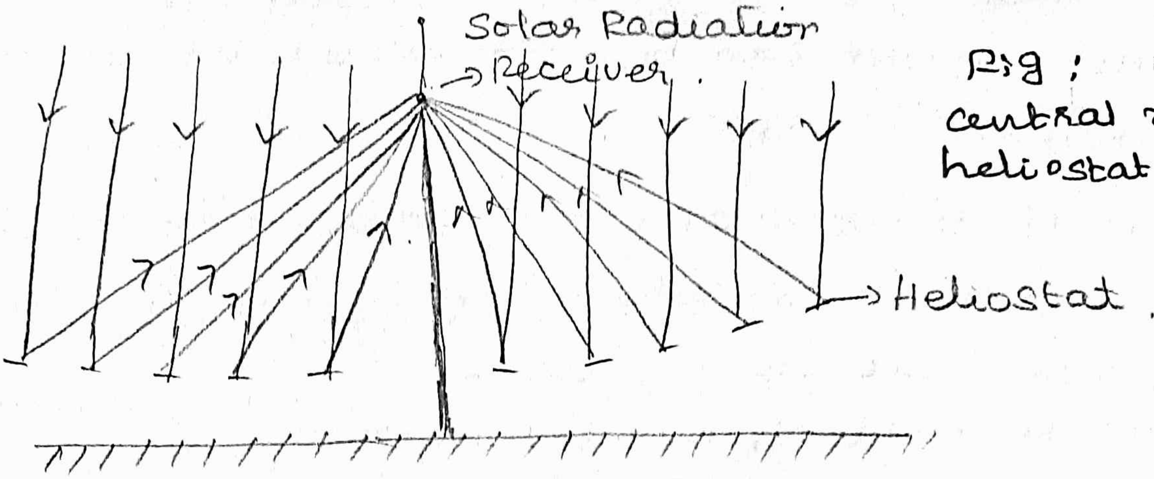
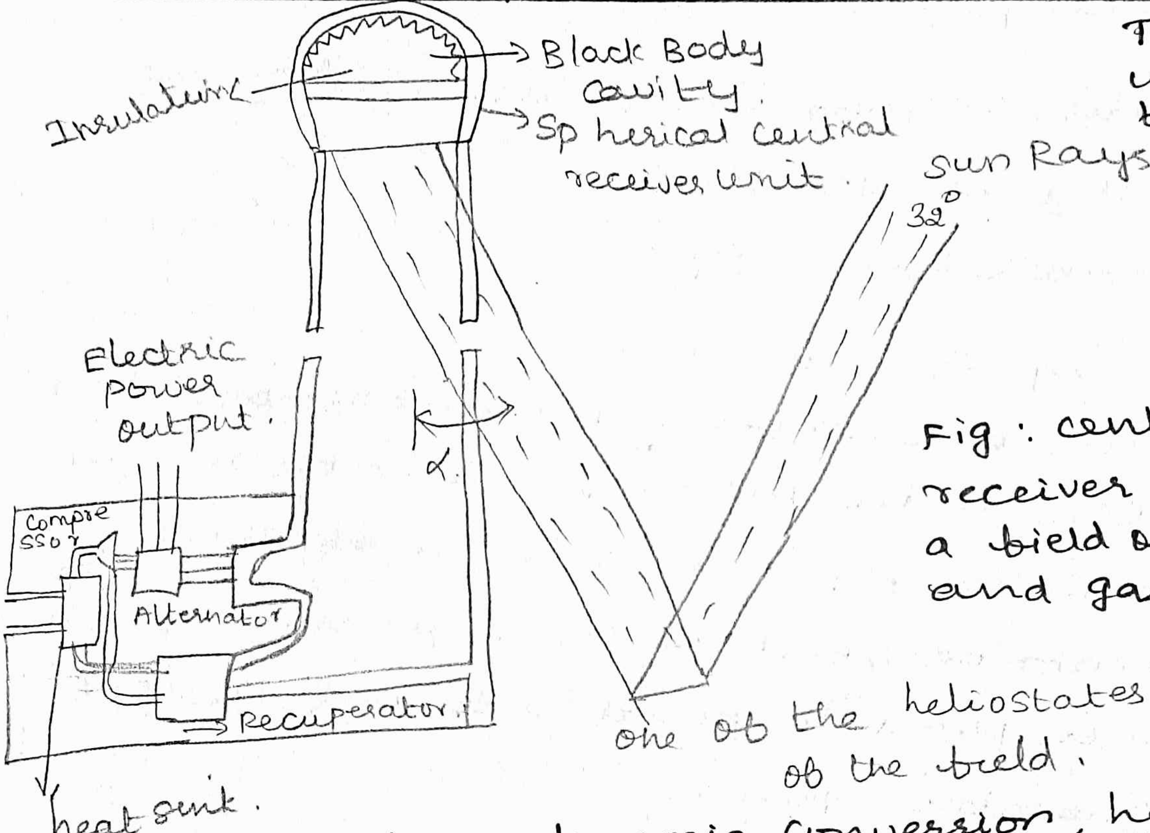


Fig : central receiver heliostat array

Beam radiation incident on Boiler absorbed by black pipes in which working fluid circulates and is heated. The working fluid is allowed to drive a turbine and produce mechanical energy.



The turbine which is coupled to an alternator produces electrical energy.

Fig : central tower receiver associated with a field of flat mirrors and gas turbine.

As in many thermodynamic conversion, heat sink is provided. A suitable heat storage is also provided to supply the heat energy during the period of cloudiness.

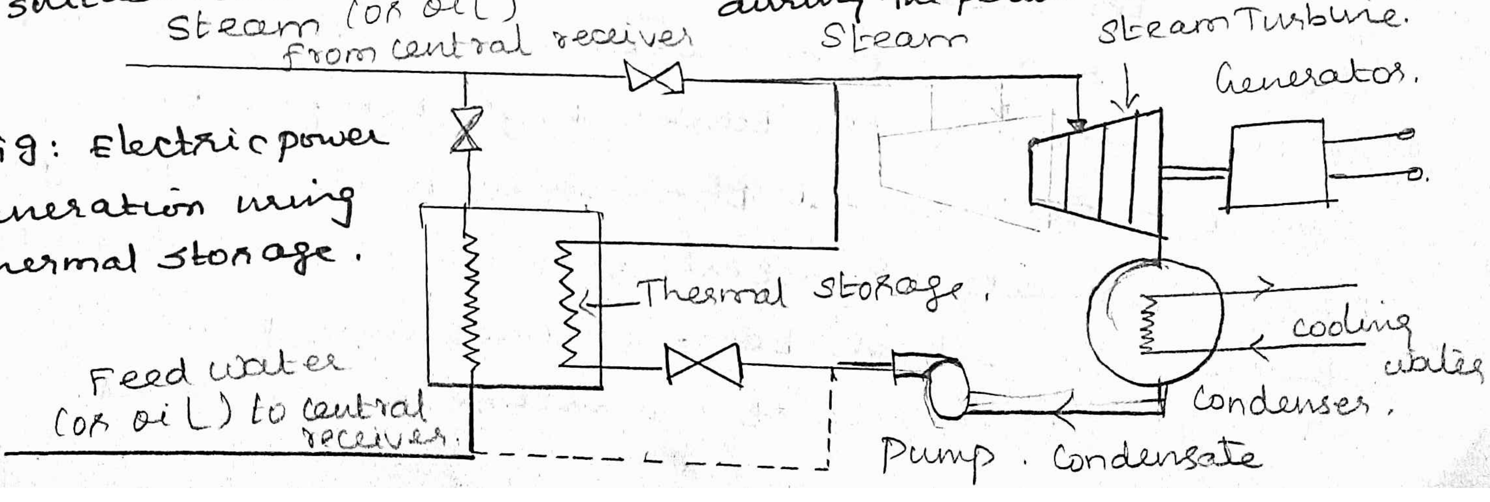


Fig: Electric power generation using thermal storage.

This system can be subdivided into the following subsystems, namely :

a) The tower with the central receiver on top of it

b) The heat conversion subsystem.

c) The heat storage device

d) The field of oriented mirrors.

a) Receiver subsystem :-

The central receiver at the top of the tower has a heat absorbing surface (e.g. panels coated with a heat absorbing material) by which the heat transport fluid is heated.

Two basic receiver configurations

i) Cavity Receiver pipe

ii) External Receiver pipe.

b) Heat Transport subsystem :

Water is a convenient heat transport fluid. Liquid water under pressure enters the receiver absorbs heat energy and leaves as superheated steam. steam temperature 500°c, pressure 100 atm. The steam is piped to ground level and drives a turbine generator system.

In advanced central receiver system, liquid Sodium or a molten mixture of salts are used. At the bottom of the tower high temperature liquid is circulated through a heat exchanger where the heat transferred to water to generate steam at a high temperature and pressure. So, high efficiency of conversion is achieved.

Energy storage :

Short term storage of heat can be provided by fire bricks, ceramic oxides, fused salts (NaNO$_3$ melts at 260°c, sulphur (liquid between 113°C & 444°C), lithium metal (liquid between 180°C & 1400°C), sodium metal (liquid between 98°C & 880°C).

Mirrors !

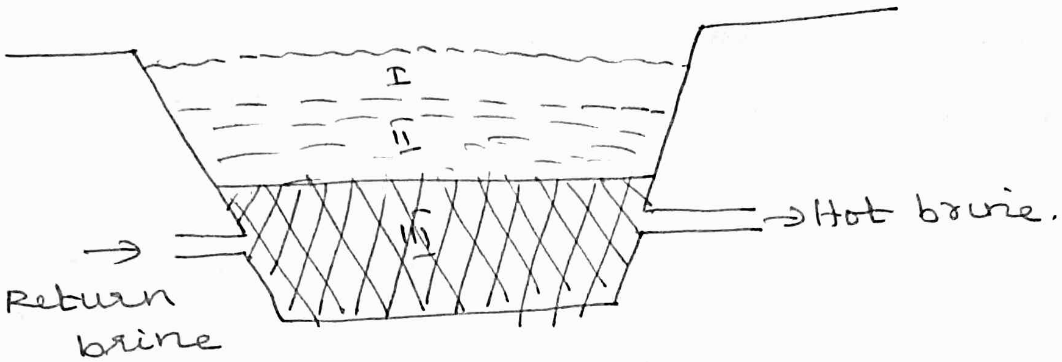
Float glass, metallized with silver or aluminium Provides reflectivness of 93%, 82% & 86% respectively

Solar Pond :-

A natural or artificial body of water for collecting and absorbing solar radiation energy and storing it as heat. The simplest type of solar pond is very shallow, about 5 to 10 cm deep with a radiation absorbing (black plastic) bottom. A bed of insulating material under the pond minimizes loss of heat to the ground. A curved cover made of transparent fibre glass, over the pond permits entry of solar radiation but reduces losses by radiation and convection. It contains dissolved salts to generate a stable density gradient.

Salts like magnesium chloride, sodium chloride or sodium nitrate are dissolved in the water. Dissolved salt is used to create layer of water with different densities.

⇒ The more salt, the denser water. The concentration of the salt at the surface is low, usually less than 5 % by weight and thus the water is relatively light.



I → Surface convective zone
(0.3 – 0.5 m), salinity < 5 %.

II → Non convective zone
(1 – 1.5 m), salinity increases with depth.

III → Storage zone or lower convective zone
(1.5 – 2 m), salinity = 20 %.

→ Surface convective zone has small thickness around 10 to 20 cm. Non-convective zone is much thicker and occupies more than half the depth of the pond. This layer acts as a insulating layer. The storage zone thickness is comparable to the non-convective zone.

→ Depending on location, water clarity and temperature the solar pond can capture 10 to 20 % of the solar energy. Each square meter of pond surface area can supply one half to 2 giga Joules of thermal energy / year temperature from 40°C to 80°C.

Characteristics of salt used in a solar Pond :-

1) It have high value of solubility to allow high solution densities.

2) The solubility not vary with temperature.

3) It should be safe to handle.

4) Available near site, delivered cost low.

Extraction of Thermal Energy :-

→ Energy is stored in low grade thermal form of the lower convective zone.

→ Convection is due to the process of heat extraction accomplished by hot brine withdrawl and cool brine return.

→ Installing the water outer at the same height as the water inlet.

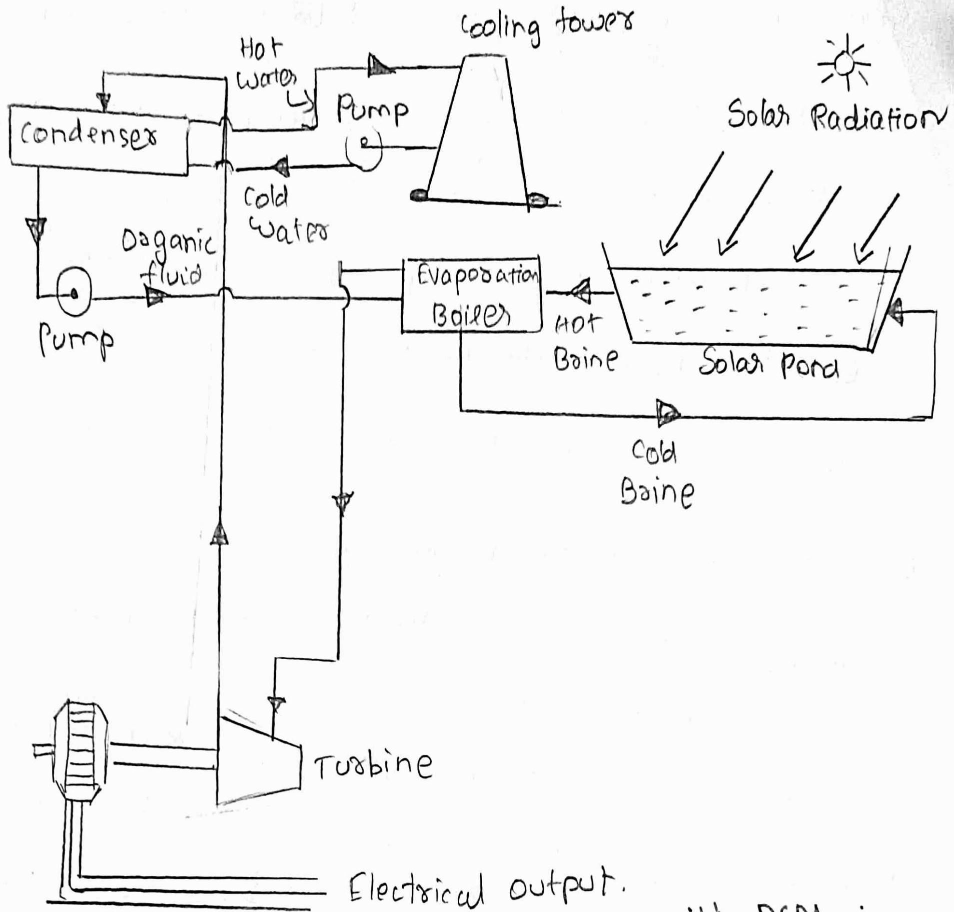
→ Thermal energy from solar pond is used to drive a Rankine cycle heat engine. Hot water from the bottom level of the pond is pumped to the evaporator.

→ Where the organic working fluid to vaporized.

→ The vapour flows under high pressure to the turbine and expanding through the turbine wheel and the electrical generator linked to it.

→ The vapour then travels to the condenser where cold water from the cooling tower condenses the vapour back it to a liquid.

→ The liquid is pumped back to the evaporator where the cycle is repeated.



Thermal Energy storage systems with PCM :-

A phase change material (PCM) is a substance which releases/absorbs sufficient energy at phase transition to provide useful heating/cooling.

Latent heat storage :- (phase change energy storage)

In this system, heat is stored in a material when it melts and extracted from the material when it freezes. Materials that undergo a change of phase in a suitable temperature range may be useful for energy storage.

i) The phase change must be accompanied by high latent heat.

ii) The phase change must occur with limited super cooling.

3) The cost of materials must be reasonable.

4) Phase change must occur close to its actual melting temperature.

5) The material must be harmless.

Materials for phase change energy storage:

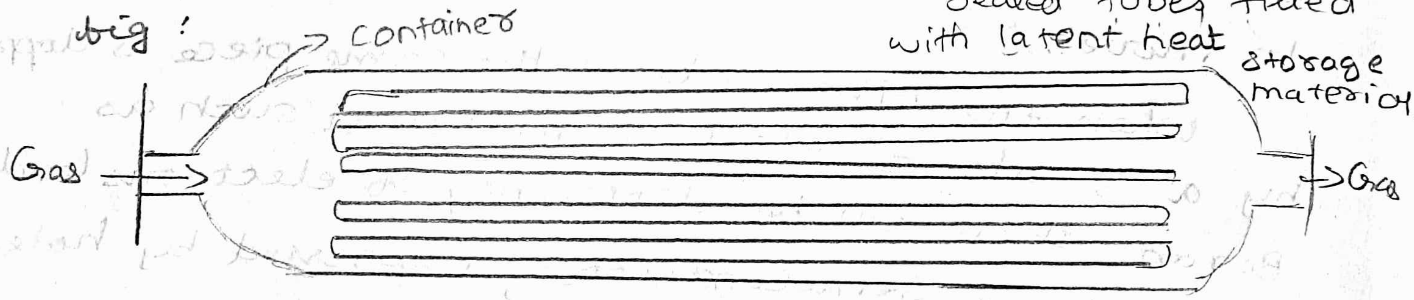
Glauber's salt ($Na_2SO_4 \cdot 10H_2O$), water, $Fe(NO_3)_3 \cdot 6H_2O$

Glauber's: ($Na_2SO_4 \cdot 10H_2O$) (Sodium sulphate decahydrate)

Changes from solid to liquid requires less energy. Phase change materials involving water of dehydration.

$$Na_2SO_4 \cdot 10H_2O + energy \underset{}{\overset{32^\circ C}{\rightleftharpoons}} Na_2SO_4 + 10H_2O.$$

A latent heat storage arrangement is shown in fig:



The storage material is placed in long thin containers e.g; cylinders and the gas is passed through narrow spaces between the tubes.

Refractory materials (MgO, Al_2O_3, SiO_2) are also suitable for high temperature sensible heat storage. $ZnCl_2$, $Na(OH)_3$, $NaOH$, $KOH-ZnCl_2$ $KCl-MgCl_2-NaCl$, $MgCl_2$ $NaCl$ used for temp range $200-450^\circ C$.

Solar photovoltaic Systems : Basic Principle of SPV conversion

When the photons from the sun are absorbed in a semiconductor, they create free electrons with higher energies. once these electrons are created, there must be an electric field to induce these higher energy electrons to flow out of the semi-conductor to do useful work.

In an intrinsic semiconductor such as silicon, each of the four valence electrons of the material atom is tied in a chemical bond, there are no free electrons.

The material is doped on one side by a five valence electron such as arsenic or phosphorus there will be an excess electrons becomes n-type semiconductor. The excess electrons will be free to move.

When the other side of the same piece is dopped by a 3 valence electron material such as Boron, there will be deficiency of electrons leading to p-type semiconductor, expressed by holes free to move.

Such a piece of semiconductor with one side of the p-type and the other of the n-type is called a p-n junction.

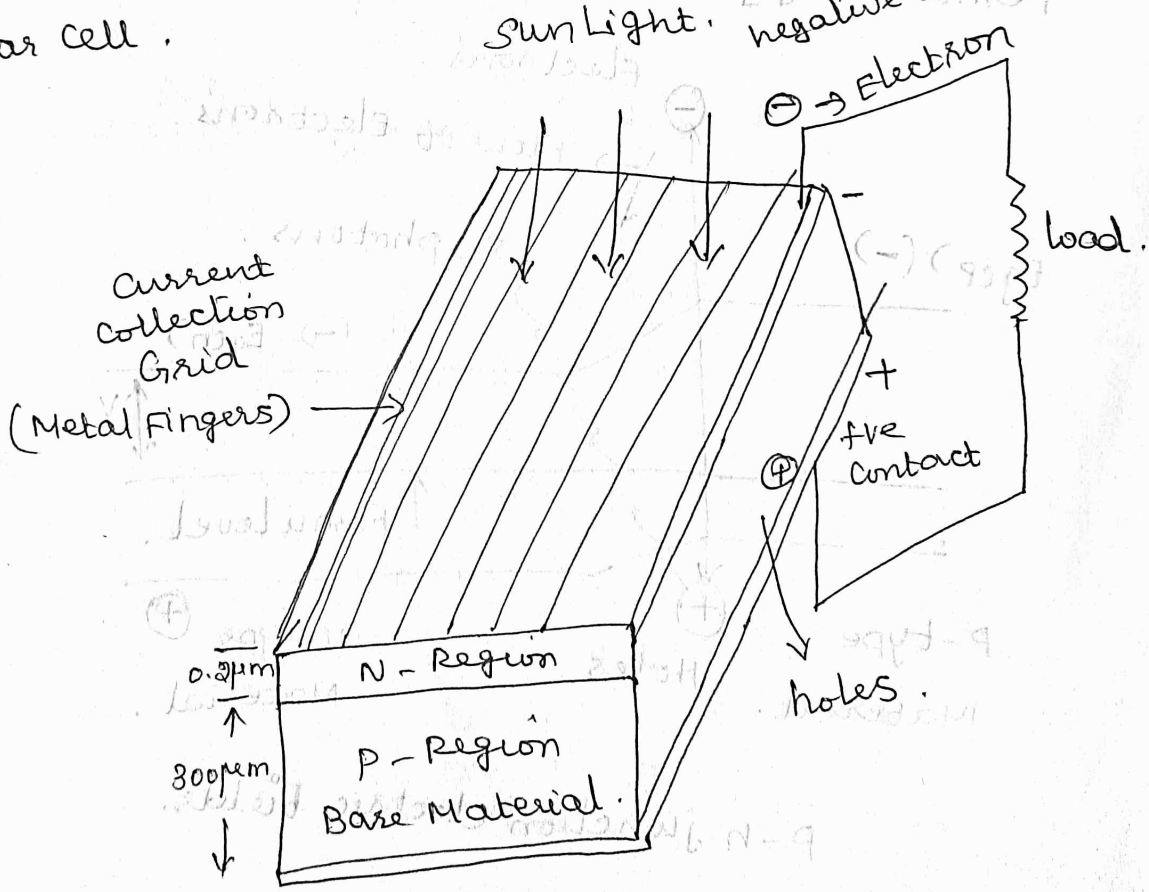
Photons are absorbed, free electrons in n-side will tend to flow to the p-side, and p side holes tend to flow to the n region, to compensate their deficiencies.

This diffusion will create an electric field E_f from the n-region to the p-region. This field will increase until it reaches equilibrium for V_e.

V_e = Diffusion potential for holes + electrons.

The two semiconductor materials are connected through an external electrical conductor, the free electrons will enter the holes and become bound electrons. The flow of electrons through the external conductor constitutes an electric current.

The combination of n-type and p-type semi-conductors constitutes a photovoltaic (PV) cell or solar cell.



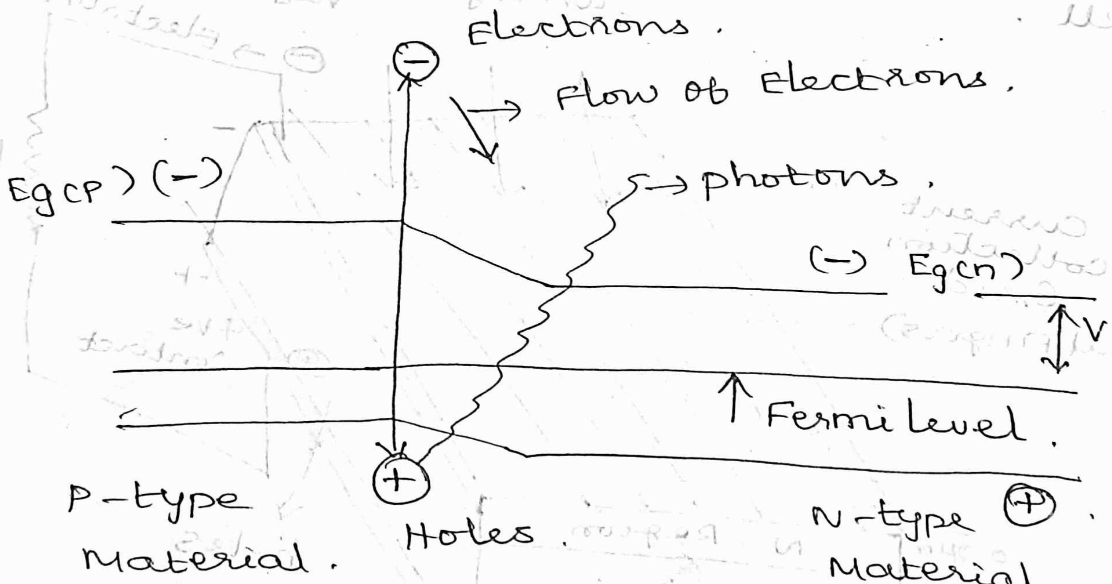
View of a typical solar cell.

This p-n junction is usually obtained by putting a p-type bare material into a diffusion furnace containing gaseous n-type dopant such as phosphorus.

The Junction is thus formed below the planar surface and the light impinges perpendicular to the junction.

The +ve & -ve charges created by the absorption of photons are drift to the front and back of the solar cell.

If the junction is in thermodynamic equilibrium Fermi energy must be uniform.

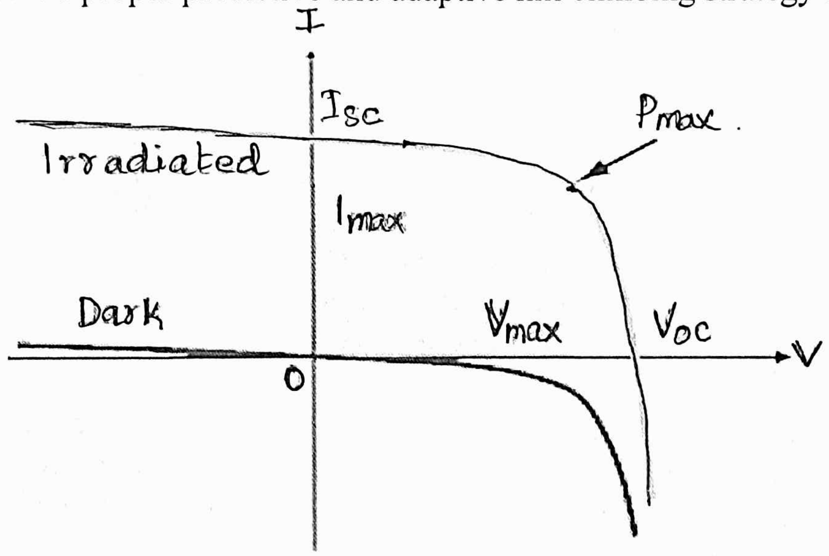


p-n junction electric fields.

Maximum Power Point Tracking (MPPT) Algorithm.

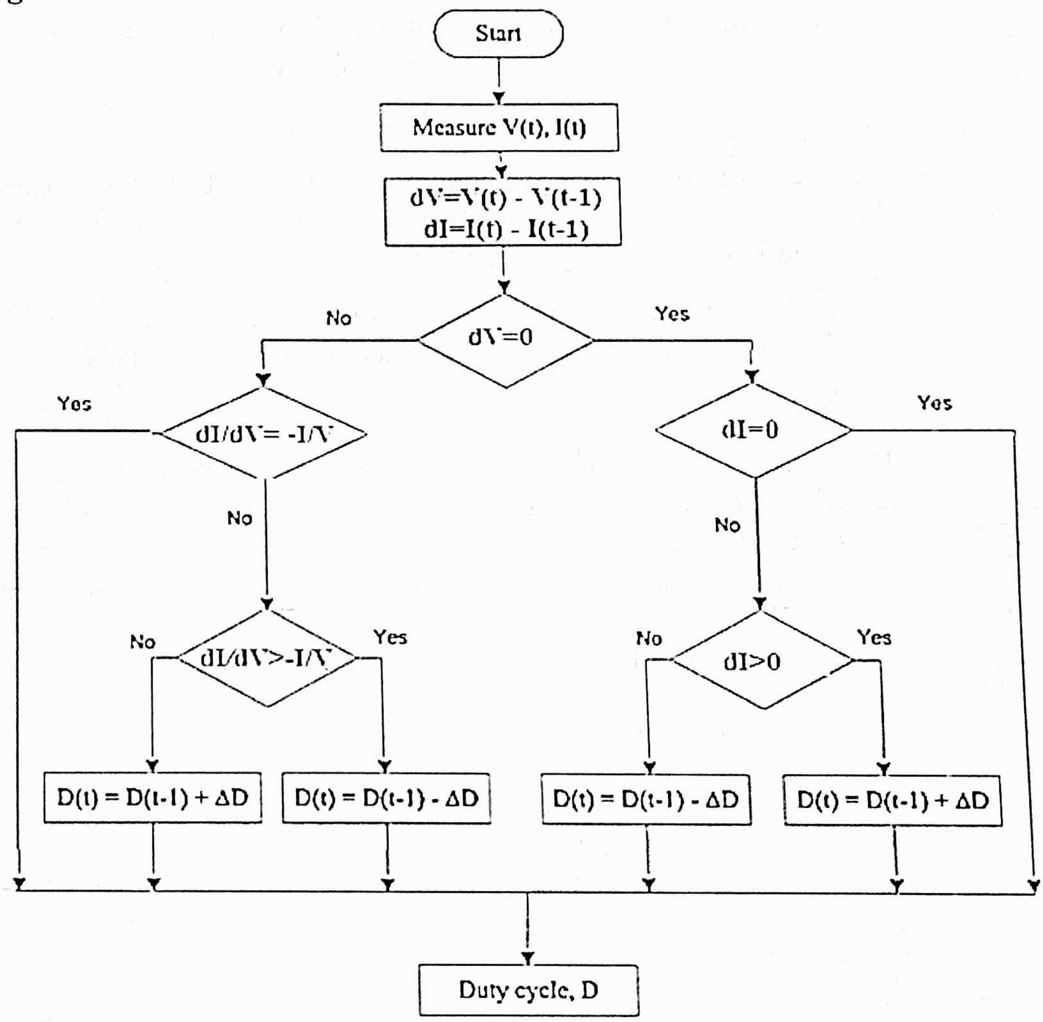
Perturb and Observe (PAO):

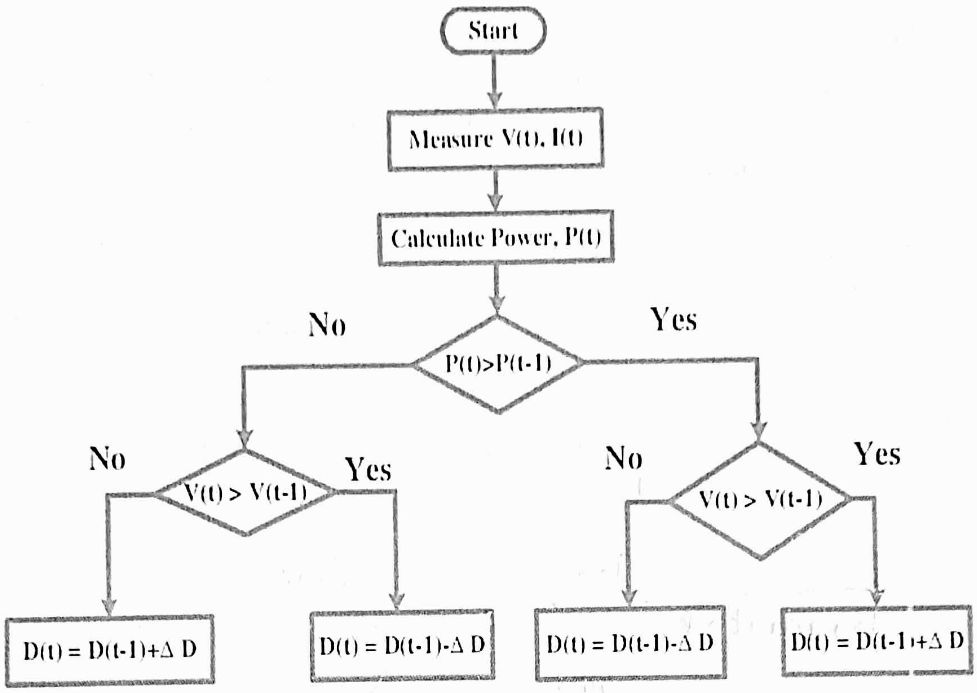
- Perturb-and-observe (P&O) method, also known as **perturbation method** is a type of MPPT algorithm. The concept behind the "perturb and observe" method is to modify the operating voltage or current of the photovoltaic panel until you obtain maximum power from it.
- It is often referred to as **hill climbing method**, because they depend on the fact that on the left side of the MPP, the curve is rising (dP/dV > 0) while on the right side of the MPP the curve is falling (dP/dV < 0). Perturb and observe is the most commonly used MPPT method due to its ease of implementation.
- Perturb and observe method may result in top-level efficiency, provided that a proper predictive and adaptive hill climbing strategy is adopted.



photovoltaic array to compute the sign of the change in power with respect to voltage (dP/dV).

- INC method provides rapid MPP tracking even in rapidly changing irradiation conditions with higher accuracy than the Perturb and observe method.
- **Algorithm:**





Algorithm:

- The voltage to a cell is increased initially. If the output power increases, the voltage is continually increased till the output power starts decreasing. Once the output power starts decreasing, the voltage to the cell is decreased till maximum power is reached.
- This process is continued till the MPP is attained. This results in an oscillation of the output power around the MPP.

Drawback:

- One of the major drawbacks of the perturb and observe method is that under steady state operation, the output power oscillates around the maximum power point.
- This algorithm can track wrongly under rapidly varying irradiation conditions.

Incremental Conductance Technique (ICT):

- Incremental conductance (INC) method is a type of MPPT algorithm. This method utilizes the incremental conductance (dI/dV) of the

- The power-voltage curve's slope is null at the MPP, negative to the right of the MPP and positive to the left of the MPP. INC computes the maximum power point by comparison of the incremental conductance ($\Delta I/\Delta V$) to the instantaneous conductance (I/V). When the incremental conductance is zero, the output voltage is ascertained to be the MPP voltage and fixed at this voltage until the MPP encounters a change due to the change in irradiation conditions. Then the process above is repeated until a new maximum power point is reached.

Advantage:

- This technique has an advantage over the perturb and observe method because it can stop and determine when the Maximum Power Point is reached without having to oscillate around this value.

  It can perform Maximum Power Point Tracking under rapidly varying irradiation conditions with higher accuracy than the perturb and observe method.

Drawback: It can produce oscillations and can perform erratically under rapidly changing atmospheric conditions. The computational time is increased due to slowing down of the sampling frequency resulting from the higher complexity of the agorithm compared to the P&O method.

Types of Solar cell.

Solar cells depending on the type of material used can be classified as:

(1) Single crystal silicon solar cell.

(2) Polycrystalline and amorphous silicon cell.

(3) Cadmium sulphide - cadmium telluride cell.

(4) Copper indium diselenide cell.

(5) Gallium Arsenide cell.

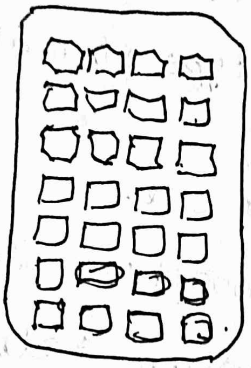
(1) Single crystal silicon :-

=) It is produced from silicon dioxide which is reduced to silica with 1% impurities. It is first purified to polycrystalline form and then further converted into single crystal state.

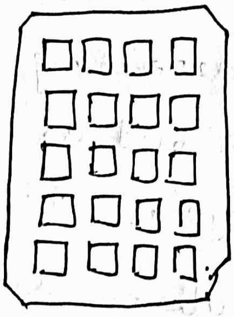
=) The conversion process into single crystal state is very expensive. The single crystal p-type silicon is obtained in the form of a long cylindrical block. (diameter 6 - 15 cm).

=) The p-type silicon wafers are then exposed to phosphorous vapour (doping material) in a furnace so that phosphorous can diffuse into the silicon wafer for a short depth, forming n silicon region over the p-silicon bulk material.

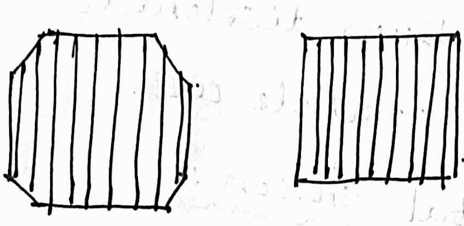
=) Efficiency is about 22%.



Mono crystalline



Poly crystallenis.



(2) Polycrystalline and Amorphons Silicon:

=) cells are made of materials with Lost effective, Lower efficiency compared to a single crystal silicon cell.

=) Process to produce poly crystalline silicon cells is similar to that of single crystal silicon except Costly step of converting polycrystalline to the single crystal is not required.

=) It is directly melted, doped with phosphorons and cooled to derived shape and size. So, economy of materials and energy consumption for the production of cells.

(3) Amorphous Silicon Cells :-

These cells are produced using thin film technology. These cells are a cheaper alternative to single crystal or multicrystalline cells.

Main drawbacks are low efficiency (4-8 %) and degrade easily used in outdoor applications. These cells are useful for indoor lights, pocket calculators, electronic watches & electronic instruments.

(4) Cadmium sulphide cadmium telluride cells :-

=) These cells are produced using thin film Technology.

=) cells require very less material.

=) cadmium telluride (semiconductor) is vaporised and its film (10 μm) is deposited on a thin layer of (12 μm) cadmium sulphide.

=) A barrier layer of copper sulphide is then deposited on top of the cds - cdTe cell.

=) The cell consists of n type cds & p-type cdTe.

=) cell efficiency 10 %.

(5) Copper indium diselenide :-

=) It is a thin film polycrystalline cell made from copper indium diselenide. Efficiency 14 %. It has an easier manufacturing process.

(6) Gallium Arsenide :-

=) The cell has thin film of n-type & p-type gallium arsenide (GaAs) grown on a suitable substrate. Efficiency is 20 %, High cost of Production.

Advantages of PV systems :-

1) It directly converts solar energy to electric power without any use of moving parts.
2) It is more reliable, durable & maintenance free.
3) Works without any noise,
4) Non-polluting.
5) Long life span.
6) Located near the point of load and requires no distribution system.

Disadvantages :-

1) High cost of Installation.
2) Low efficiency.
3) Requires a Large area for installation to produce sufficient power.
4) Output is intermittent, requires some means of store energy during non-sunshine hours.

Efficiency of solar cells :-

Energy conversion efficiency (η) = Power output of cell (watts) at maximum Power Point (P_{max}) / Input light power (E) in W/m^2 × surface area of Solar cell (S) in m^2.

at standard conditions.

$$\eta = \frac{P_{max}}{E \times S}$$

⇒ Current - Voltage (I-V) relationships, which measure the electrical characteristics of Solar cell devices and represented by I-V curves.

⇒ curves obtained by, exposing the cell to a constant level of light, maintaining a constant Cell temperature, varying the resistance of the load and measuring the current that is produced.

⇒ By varying the load resistance from zero (a short circuit) to infinity (an open circuit) we can determine the highest efficiency as the point at which the cell delivers maximum power.

⇒ P_{MAX} occurs where the product of current and voltage is maximum.

⇒ No power produced at the short circuit current with no ~~too~~voltage or at V_{oc}, with no current.

Fill Factor :

$$\text{Fill Factor (FF)} = \frac{\text{Maximum Output Power}}{\text{open circuit voltage} \times \text{short circuit current}}$$

$$FF = \frac{P_{Max}}{V_{oc} \times I_{sc}} = \frac{V_{MP} \times I_{MP}}{V_{oc} \times I_{sc}}$$

$$FF = \frac{h \times S \times E}{V_{oc} \times I_{sc}}$$

5) Position of the cell :-

The cell or panel should be positioned either facing south in the north of equator or facing north in the south of equator for maximum power output and fixed panel applications.

Photovoltaic Panels (series and Parallel Arrays)

=) As single solar cell has a working voltage and current of about 0.5 V & 50mA respectively.

=) They are usually connected together in series (+ve to -ve) to provide larger voltages. Connected together in parallel to provide larger currents.

Photovoltaic panels are made in a wide range of sizes for different purposes.

Three basic categories :

1) Low voltage or low power Panels : Are made by connecting between 3 & 12 small segments of amorphous silicon photovoltaic with a total area of a few square centimetres for voltages between 1.5 & 6 V) outputs → few milliwatts. These panels is very small, total production is large. Applications : used in watches, clocks, calculators, cameras, night lights.

2) small panels : 1–10 w, 3–12 V, areas from $100 cm^2$ to $1000 cm^2$, made by either cutting $100 cm^2$ single or polycrystalline cells into pieces and joining them in series or by using amorphous silicon panels.

Factors Limiting the Efficiency of the cell :-

1) Wavelength of solar spectrum :

Cell response to only a portion of wavelength available in the solar spectrum.

Photon with wavelength >1.1 μm does not have sufficient energy to create electron-hole pair in silicon cell.

2) Temperature:

Normal operating temperature of silicon cells can reach 60°c in peak sunlight and there temperature decreases the efficiency of the cells. It is important to provide heat sinks.

3) Mounting of the cells :-

It should be to a heat sink (aluminium plate) either heat conductive but electrically insulated. This will reduce operating temperature and make the cell more efficient. Heat sink can be water cooled.

4) Arrangement and maintenance of solar cell :-

The negative side of the cells faces the sun and has antireflection coatings. There coatings should be protected from dust, bird dropping, by a clear plastic or glass cover. Dust will reduce the output power by about 10 %.

Uses: radios, toys, small pumps, electric fences.

3) Large Panels: Ranging from 10 to 60W, generally either 6 or 12V, with areas of 1000 cm^2 to 5000 cm^2 are usually made by connecting from 10 to 36 full sized cells in series.

Uses: small pumps, caravan power (lights and refrigeration) or in arrays to provide power for houses, communications, pumping and remote area power supplies. (RAPS).

=) If the load resistance is very low, the cell acts as if it is shortened at the output of light falling on it.

=) If the load resistance is very high, the cell acts as if it is open-circuited & voltage rises very rapidly to maximum voltage.

=) For a charging, 12V battery by a 2cm × 2cm (0.3V - battery charging voltage) silicon cells required = 12/0.3 = 40 cells in series string.

=) A diode is placed in series with the positive terminal of battery to prevent reverse current flow when the cells are not receiving sufficient light to charge battery.

ack

b.

Number of Solar cell required in series :-

Solar cells must be electrically connected in series to provide the Bus voltage (VB) to the space craft load or batteries and any voltage drops in the blocking diodes (VD) and in the wiring (Vw).

Required No. of cells (Ns) in series is

$$N_S = (V_B + V_D + V_W)/V_{MP}.$$

V_{MP} → solar cell voltage at maximum power.

For silicon diode, $V_D = 0.7V$.

No. of. solar cell in parallel strings :

N_P → Number of parallel strings.

I_L → Load current.

I_{MP} → current corresponding to maximum power point on I-V plot.

$$N_P = \frac{I_L}{I_{MP}}$$

Applications of Solar Cell Systems:

1) **Solar Water Pumps:**

There are more than 10,000 solar powered water pumps in use in the world today. They are used to pump water from wells and rivers to villages for domestic consumption and irrigation of crops.

The pump is driven by motor run by solar electricity instead of conventional electricity drawn from utility grid.

It consists of a photovoltaic array mounted on a stand and a motor-pump set compatible with the photovoltaic array.

2) **Solar Vehicle:**

It is an electric vehicle powered completely or significantly by direct solar energy. The term solar vehicle usually implies that solar energy is used to power all or part of a vehicle's propulsion. Solar power used to provide power for communications or controls or other auxiliary functions.

3) **Solar Lanterns:**

when the petromax - type solar lantern is plugged into a solar photovoltaic cell, its rechargeable battery stores the electricity produced, it can be used to light home or power a radio.

4) **Solar Panels on spacecraft:-**

spacecraft operating in the inner solar system usually rely on the use of photovoltaic solar panels to derive electricity from sunlight. In the outer solar system, sunlight is too weak to produce sufficient power, radioisotope Thermal generators (RTGs) are used as a power source.

5) **Grid connected Photovoltaic Power Systems :**

=) These are power systems energized by photovoltaic panels that are connected to the utility Grid.

=) Grid connected Photovoltaic Power systems comprise photovoltaic Panels, battery charging regulators, Solar inverters, Power conditioning units, grid connected equipments.

=) Residential grid connected photovoltaic power systems that have a capacity less than 10 kW can meet the load of most consumers. It can feed excess power to the grid, in this case acts as a battery for the system.

6) **cathodic Protection Systems :-**

=) cathodic Protection is a method of protecting metal structures from corrosion. It is applicable to bridges, pipelines, buildings, tanks, wells & railway lines.

=) To achieve cathodic protection, a small negative voltage is applied to the metal structure and prevents it from oxidizing or rusting.

=) +ve terminal of the source is connected to a sacrificial anode that is a piece of scrap metal which corrodes instead of the structure. Solar cells are used in remote locations to provide this voltage.

7) **Rural Electrification :-**

=) Storage batteries are widely used in remote areas to provide low-voltage electrical power for lighting and communications as well as for vehicles.

=) A photovoltaic-powered battery charging system usually consists of a small solar cell array and a charge controller. These systems are widely used in rural electrification projects in developing countries.

8) Water Treatment systems:

=) Electric power is often used to disinfect or purify drinking water. PV cells are used to power a strong UV light that can be used to kill bacteria in drinking water.

=) This can be combined with a solar powered water pumping system.

=) Desalination of brackish water can be achieved via PV-powered reverse osmosis system.

Types of Solar PV System.

The classification of solar PV systems is shown:

Solar PV systems.

- Central power system
- Distributed PV system
  - Stand alone system
  - Grid interactive system
  - Small consumer system.
- Hybrid solar PV system.

Central Power system:

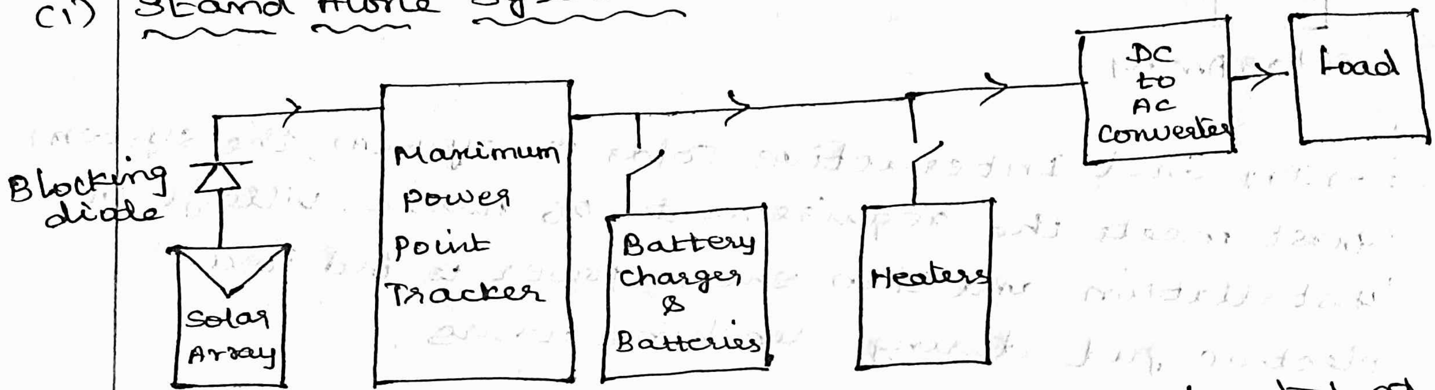
=) This type of solar power station is similar to other conventional power stations which are required to feed generated power into some national grid.

=> These solar power systems are designed to meet high peak daytime load only and have large generation capacity upto 6 MW.

=> capital cost is high.

Distributed PV systems :

(i) Stand Alone system :-



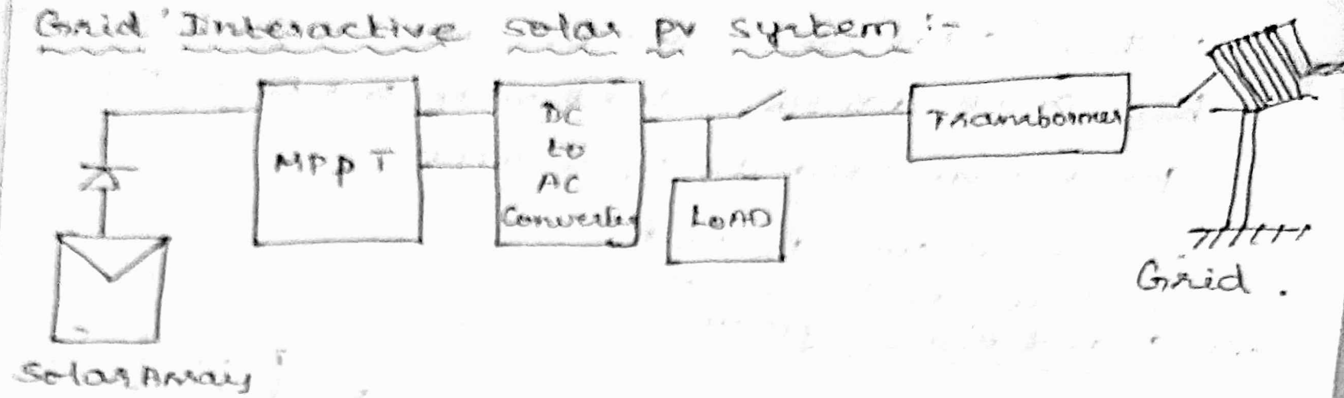
=> Solar PV power station is planned and located at the load centre.

=> Its complete electricity generation is meant to meet the electrical load of any remote area, village or installation.

=> Energy storage is essential to meet the requirement during non-sunshine hours.

=> The maximum power point tracker (MPPT) senses the voltage and current outputs from the solar array and adjusts the operating point to obtain maximum power output from the solar array as possible from the climatic conditions.

(2) Grid Interactive solar pv system :-



=) In Grid Interactive Solar pv system, the system first meets the requirement, of house, village or installation and then excess power is fed to an electric grid during sunshine hours.

=) prevents any dumping of electricity as required in the stand alone Solar PV system.

=) During Absence of insufficient sunshine, the supply of electricity is maintained from the electric grid, by eliminating any need of battery.

=) This system is very popular in the United kingdom, where two-way electric meters provided to record
(i) The electricity generated and supplied by rooftop PV system of various houses to the electric grid system during non-peak sunshine hours
(ii) Electricity supplied to the houses from the electric grid during non-sunshine hours.
The difference of two is paid to consumers or vice versa.

ck

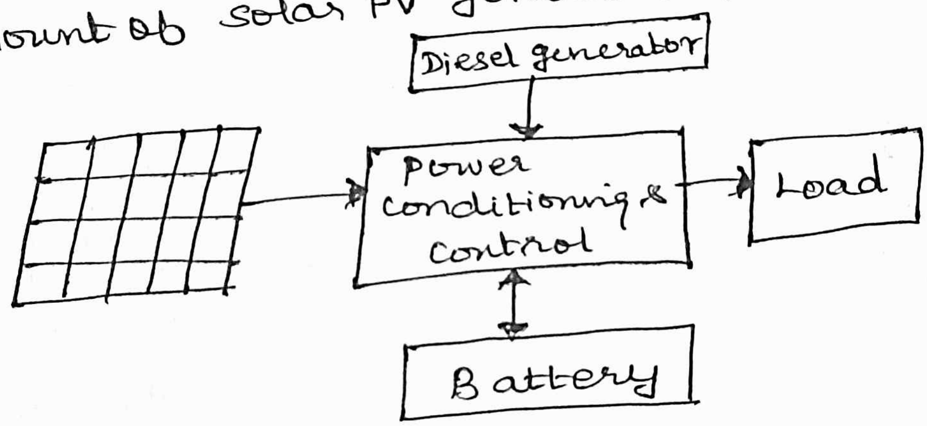
(3) Small consumer systems :

These systems are designed to meet the power requirement of low energy devices which are generally used for indoor applications.

Hybrid solar PV system :

It is dibbicult and uneconomical to provide all of the power from only solar PV system, It is economical to meet the power requirement by some other means, such as windmills, buel cells and diesel or petrol generators.

In best hybrid solar PV system in which no amount of solar PV generated power is wasted.

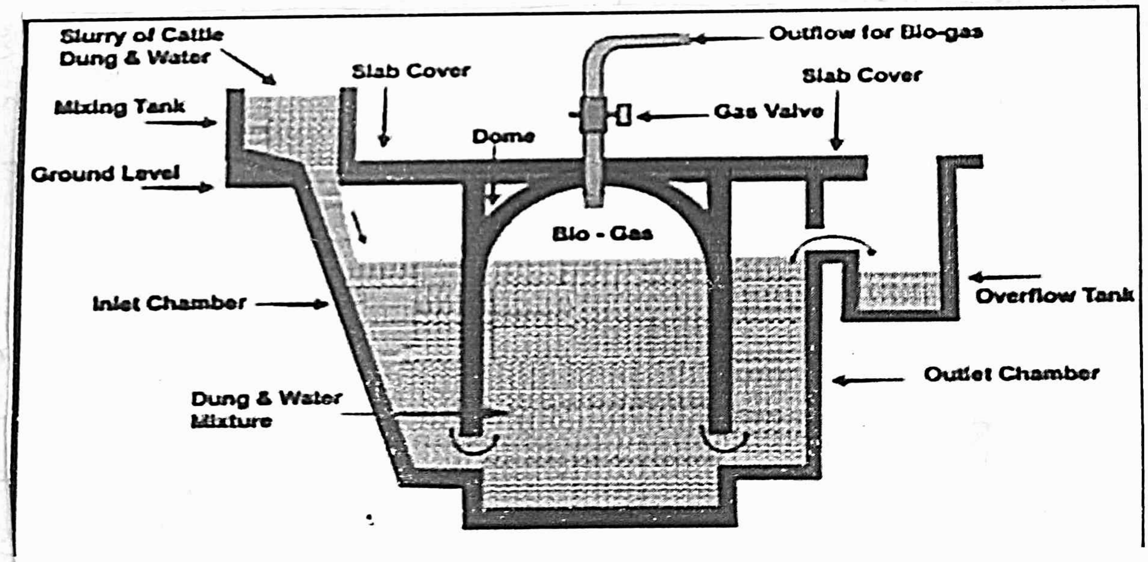


BIO GAS POWER SYSTEMS - UNIT-IV

Principle :

Biomass is an organic matter from plants, animals and micro-organisms grown on land and water and their derivatives. The energy obtained from biomass is called biomass energy. Combustion is the process of burning in presence of oxygen to produce heat, light and by products.

Biomass is decomposed in thermo chemical processes having various combination of temperatures and pressures.



(i) Foundation :

The foundation is the compacted base of the digester made of cement concrete and brick ballast. It provide a stable foundation to the digester walls and full load of slurry filled in the digester.

(ii) Digester :-

It is underground cylindrical wall portion made of bricks, sand and cement. In this place where fermentation of dung takes place. It is also sometimes called fermentation tank.

(iii) Dome :-

It is a hemispherical roof of the digester has a fixed height and forms the critical part in the construction of janata gobar gas plant. The gas gets collected in the space of the dome and exerts pressure on the slurry in the digester.

(iv) Inlet chamber :

An inlet chamber has a bell mouth shape and is made of bricks, cement and sand. It has its top opening at the ground level. Its outlet wall is made inclined to enable the daily cattle dung feed to move easily into the digester.

Biomass Cogeneration

(1) Steam Turbine biomass cogeneration plant :

→ The process of producing electricity and heat from steam includes the following components :

1) Biomass combustion system (combustion chamber)

2) steam system (boiler + distribution system)

3) steam Turbine

4) Electricity generator

5) Heat distribution system (heat from condenser).

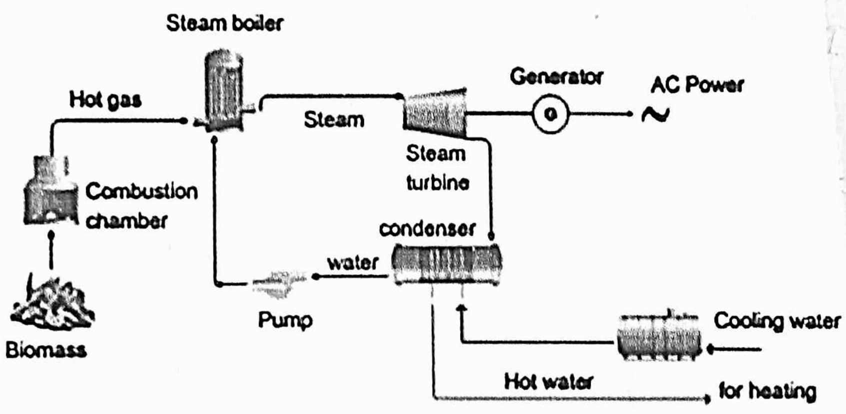


Figure 2. Principle of operation of a steam turbine biomass cogeneration plant.

Advantages of the use of steam cycle :

i) The water is used as a heat transfer fluid has advantages like high availability, non toxic, non-flammable, chemical stability, less friction losses.

ii) Thermal efficiency greater than 30 %.

iii) Low pump consumption.

(V) Outlet chamber:

It is that part of the plant through which digested slurry moves out of the digester at a predetermined height. It has a small rectangular cross section and above this it becomes larger to a defined height.

(Vi) Mixing tank:

It is this tank where gobar and water are mixed properly in the ratio of 1:1 to make slurry which is then poured into the inlet chamber.

Vii) Gas outlet pipe :-

It is a small piece of G.I pipe which is fitted at the top of the dome for conveying the gas to the points of use.

Working :-

→ Biogas is usually fully saturated with water vapour, which leads to condensation. To prevent blocking and corrosion, the accumulated water has to be periodically emptied from the installed water traps.

→ The gas pipelines, fittings and appliances must be regularly monitored by trained personnel.

→ when using biogas for an engine, it is necessary to first reduce the hydrogen sulphide because it forms corrosive acids when combined with condensing water.

(2) Organic Rankine cycle (ORC)

⇒ The ORC has two circuits, one for thermal oil and the other for organic fluid. The heat repleased by the combustion of biomass is transmitted through an oil cycle by an exchanger to the organic fluid, which evaporates at high temperature & high pressure.

⇒ ORC system has four main components :

i) pump
ii) An evaporator
iii) Turbine
iv) Condenser.

⇒ The superheated organic steam is expanded in a turbine and then condensed in a condenser and returned to the circulation pump to start a new cycle.

⇒ The condenser can act as a heat exchanger for sending heat remotely at low temperature. The ~~organic~~ condensed organic liquid is pumped through the regenerator to the evaporator. ORC technology is suitable for medium power applications.

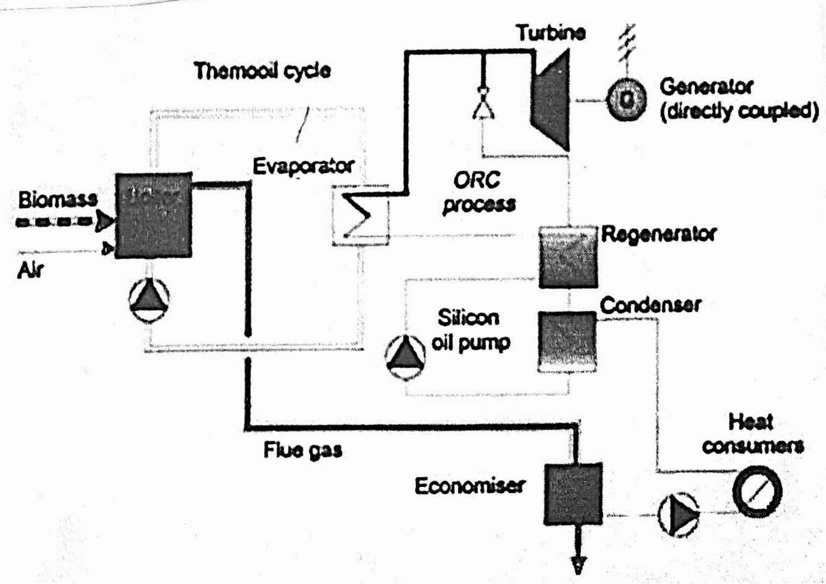


Figure 3. Schematic of Rankine's organic cycle [19].

Advantages :-

(1) Long service life due to the characteristics of the working fluid.

(2) Less complex installation

(3) High efficiency cycle.

(4) More economical than a water steam turbine. in investment & maintenance cost.

(5) No water treatment system is required.

(6) System pressure is low,

(3) Principle of the cogeneration using stirling engine:

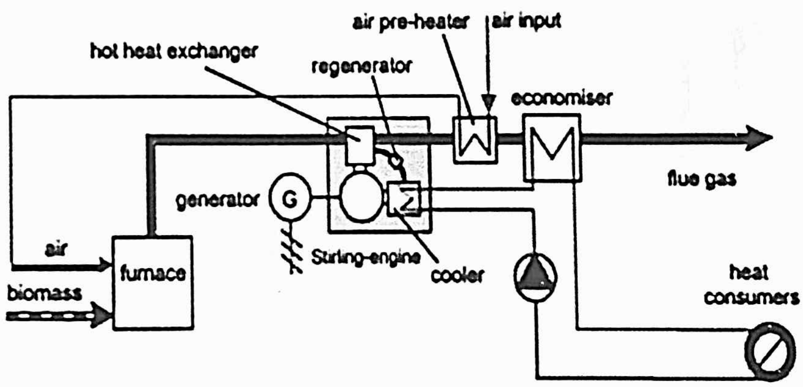


Figure 5. Diagram of the operating principle of the cogeneration using the Stirling engine [63].

=) The stirling engine is based on a closed cycle where the working fluid is usually hydrogen or helium.

=) Hydrogen or helium is compressed in the cold cylinder and expanded in the hot cylinder.

=) Stirling engine regenerator is to provide sufficient heat transfer capacity.

=) The stirling engine design contains a stack of fine metal wire meshes, with low porosity to reduce dead space, wire axes perpendicular to the gas flow to reduce conduction.

Biomass Resources

=) Biomass resources for energy production encompass a wide spectrum of materials ranging from silviculture (forest), agriculture (field), aquaculture (fresh & sea water) and industrial and social activities that produce organic wastes residues.

1) **Forests:**

Forests natural as well as cultivated, serve as a source of fuel wood, charcoal and producer gas. Forest waste and residues from forests processing industries can be utilized at the mill itself.

Forest resource is consumed for sawn timber, papermaking and other Industrial purposes. e.x : ~~ea~~ eucalyptus, poplar, pine are specially cultivated for the purpose of energy.

Some plants produce seeds (or nuts) to yield vegetable oil on pressing. This serves as a liquid bio-fuel (bio-diesel).

Two types of oil producing plants

1) **Wild plants** : e.g Jojoba (a shrub produce nuts). Karanj (a tree used on road sides produce seeds.

2) **Agricultural crops** : e.g : Jatropha Curcas (Ratanjyot produces seeds).

2) **Agricultural Residues** :-

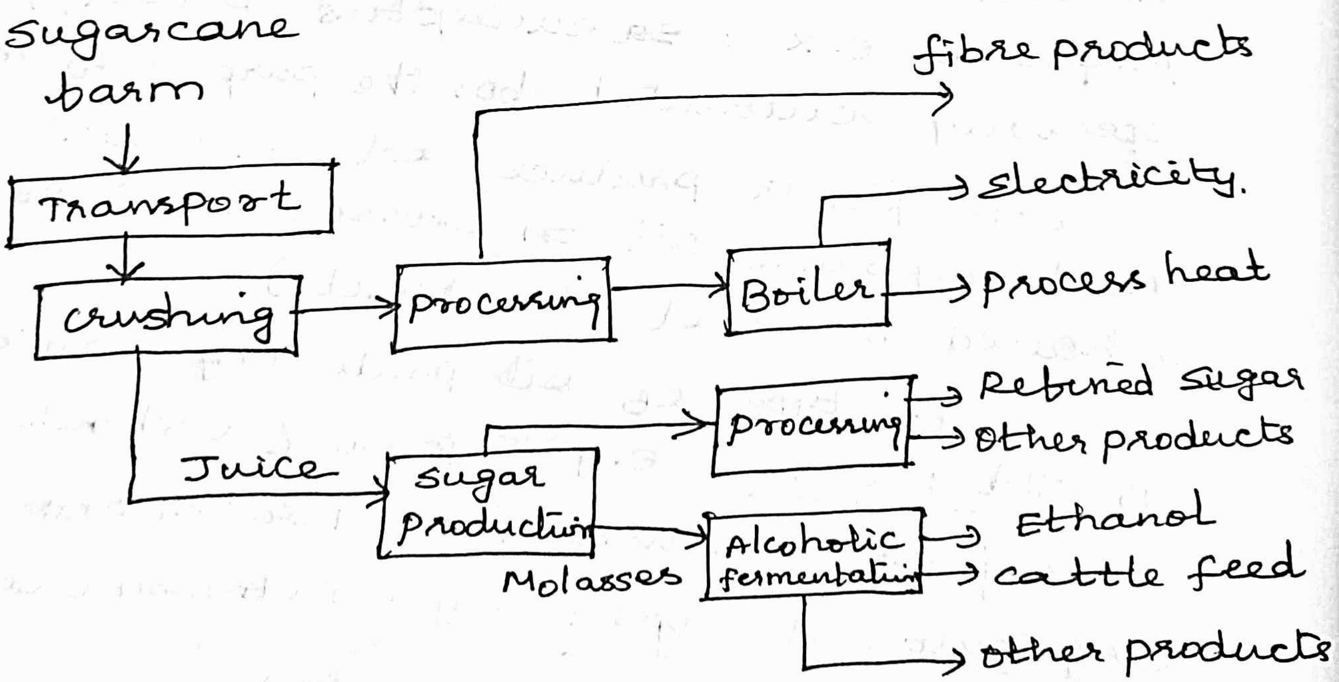
crop residues such as straw, rice husk, coconut shell, groundnut shell, sugarcane bagasse etc...

are garified to obtain producer gas. These are converted to fuel pellets used as solid fuel.

3) Energy crops :

Certain cultivated plants produce raw material for bio-fuels. Sugar cane is a major raw material source for bio-ethanol. Alcohol represents only 30 %. of the total sugar cane energy. 35%. available in bagasse and another 35 %. in leaves and tops of the sugarcane plant. Sweet sorghum also supplies raw material for ethanol production, especially during off-season supply for the sugar mills.

Various products from sugarcane are shown in fig



4) Aquatic Plants :

Some water plants grow faster than land based plants and provide raw materials for

Producing biogas or ethanol. e.g: water hyacinth, kelp, seaweed & algae etc...

5) Urban waste:

Two types

a) Municipal solid waste (MSW or garbage)

b) Sewage (liquid waste).

Energy from MSW can be obtained from direct combustion (incineration) or as fill gas. sewage used to produce biogas after some processing.

Energy From Biomass

There are a variety of ways of obtaining energy from biomass. There may be broadly classified as 1) direct methods 2) Indirect methods.

1) Direct Methods:

Raw materials that can be used to produce biomass energy are available throughout the world in the following forms:

1) Forest wood and wastes.
2) Agricultural crops and residues
3) Residential food wastes
4) Industrial wastes
5) Human and animal wastes
6) Energy crops.

⇒ Raw biomass has a low energy density based on their physical forms and moisture contents and their direct use are burning them to produce heat for cooking.

⇒ Inefficient way of direct cooking applications inconvenient and inefficient methods of raw biomass transportation and storage, high environmental pollution problems made them unsuitable for efficient and effective use.

2) Indirect Methods :

⇒ Biomass can also used indirectly by converting it either into electricity and heat or into a convenient usable fuel in solid, liquid or gaseous form.

The efficient conversion processes are as follows:

(1) Thermo electrical conversion :

The direct combustion of biomass material in the boiler produces steam that is used to either to drive a turbine coupled with an electrical generator to produce electricity or to provide heat for residential and industrial system.

(2) Biomass conversion to fuel :

Biomass conversion processes are fermentation and gasification.

Environmental Benefits :-

1) The environmental benefits of biomass power generation using biomass fuel are clear.

2) By using waste material for fuel, we prevent that waste from burdening our land fills or being left to decay on the forest floor or urban lot.

3) Biomass power is carbon neutral. Any carbon that is released into the atmosphere during combustion of biomass was absorbed from the atmosphere.

4) It doesnot threaten forests.

5) The only fuel for biomass facilities come from waste by products.

Geo Thermal Energy

=> Geothermal energy refers to heat energy stored under the ground for millions of years through the earth formation.

=> It utilizes a rich storage of unutilized thermal energy that exists under the earth's crust.

=> Geothermal energy is very cheap when used for direct heating.

=> It is a challenge to estimate power from this source, it occurs underground at extremly high temperature.

=> The earth's crust has immense heat (thermal) energy stored over millions of years.

=) There exists a huge temperature difference between the earth's crust and the surface. Temperature difference is geothermal gradient.

=) This energy is sufficient to melt rock. The molten rock called magma, at times ~~erup~~ erupts through cracks on earth surface as volcanoes.

=) The presence of geothermal deposits in form of hot geothermal fluid is a sign of a good site.

=) The site should have a shallow aquifier to allow injection of water.

Advantages :

1) No fuel is burnt, since heat is derived from an abundant underground reservoir.

2) It has no emissions and produces 10 %. carbon dioxide which is very little compared to the amount consumed by plants.

3) unlike other sources of renewable energy, it is not affected by weather and will always be available throughout the year.

4) Geothermal energy is less expensive especially when directly used.

Disadvantages :

The only disadvantage of geothermal energy identified is the release of hydrogen sulphide identified by the signature rotten egg smell.

Geothermal Electricity.

=) It provides not just heat and steam, but electricity itself. Geothermal power generation is completely clean and releases no harmful gas emissions.

Conversion Technology for electricity generation:

1) Dry steam Plants: These plants rely on the natural steam that comes from the under ground reservoirs to generate electricity.

2) Flashed steam plants: The water flash boils and the steam is used to turn turbines.

3) Binary power plants: These plants use the water to heat a secondary liquid that vaporizes and turns the turbines. The vaporized liquid is then condensed and reused.

4) Hybrid power plants: In these plants, binary and flash techniques are utilized simultaneously.

(1) Dry steam Power stations:-

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 eliminate the need to transport and store fuels).

Emits only excess steam and very minor amounts of gases.

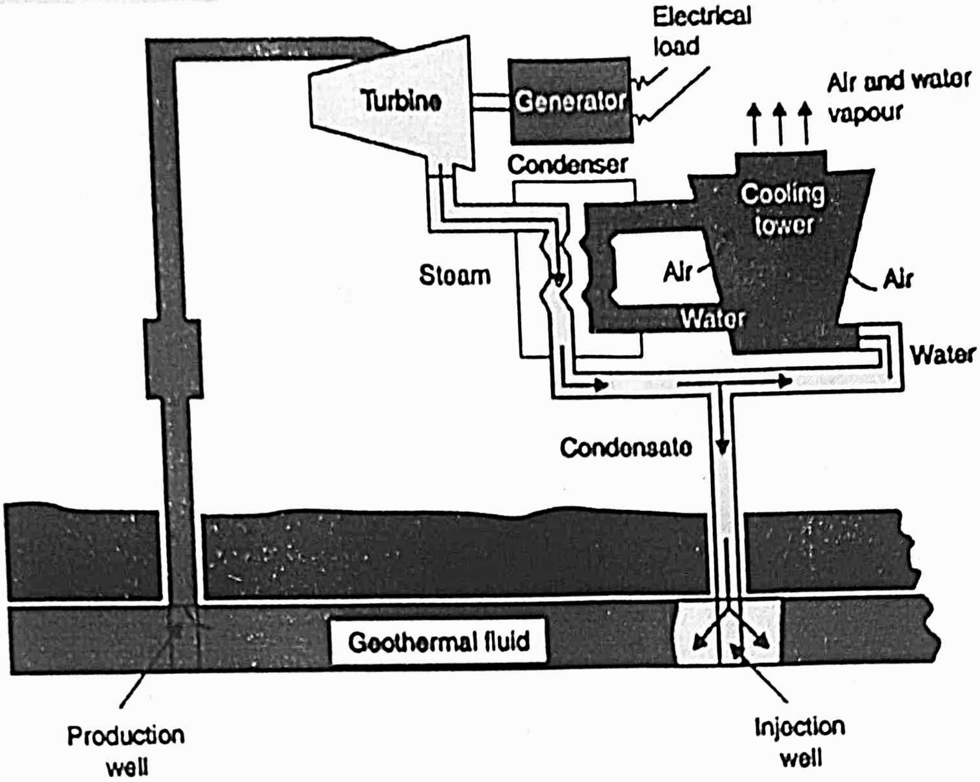


Figure 4.7 Dry-steam power stations

Single 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 vapour drives a turbine, which drives a generator.

Double flash cycle

=) water in wells under high pressure is drawn and the water vaporizes and emitting steam at high temperature. This steam is separated from the water and used to heat up the fluid that turns turbines. At this pressure, the gas is at a very high temperature.

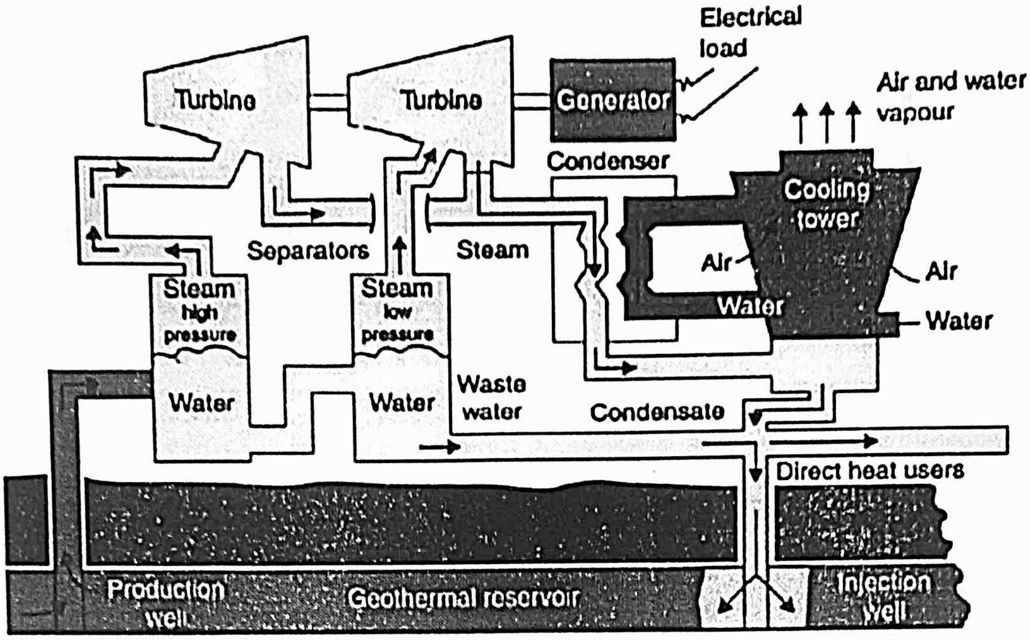


Figure 4.9 Double Flash steam power stations

Binary cycle :-

=> Most geothermal areas contain moderate-temperature water (below 400°F).

=> Hot Geothermal fluid and a secondary (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 drives the turbines.

=> This is a closed-loop system, nothing is emitted to the atmosphere.

=> Most geothermal power plants in the future will be binary cycle plants.

Source: Geo-Heat center

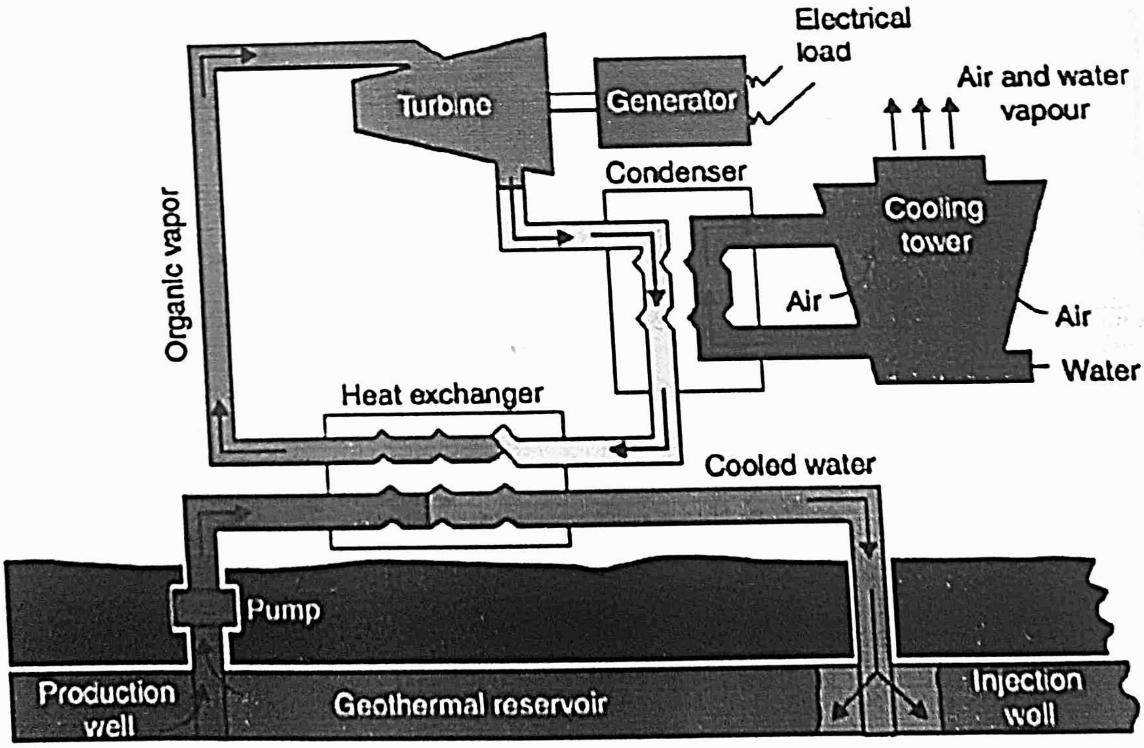


Figure 4.10 Binary cycle power stations

Geo Thermal Energy - Direct use :

Direct use of Low Grade Geothermal Energy :-

1) Aquaculture and horticulture :

→ To raise plants and marine life, require a tropical environment.

→ The steam and heat are all supplied by geothermal energy. Many farmers use geothermal power to heat their greenhouses.

→ In Tuscany, Italy farmers have used water heated by geothermal energy.

→ 80% of the energy demand from vegetable growers is met by using geothermal energy.

→ used in fishing farms.

→ The warm water spurs the growth of animals i.e alligators, shell fish, tropical fish & amphibians.

2) Industry and Agriculture :-

→ Industries are another consumers of geo thermal energy. Their uses vary from drying fruits, vegetables, wood, dying wool to extracting gold and silver from ore.

→ used to heat sidewalks and roads to prevent freezing in the winter.

→ Timber is dried using heat from geothermal energy, paper mills used it for all stages of processing.

(3) Food processing :-

→ Earth naturally contains an endless supply of heat and steam, used to sterilize equipments and rooms.

(4) Providing heat for residential use :-

→ To heat residential districts and businesses.

→ Direct geothermal heating systems contain pumps & compressors, which may consume energy from a polluting source.

→ used in district heating, fisheries, mineral recovery & industrial process heating.

→ About 70 countries made direct use of 270 petajoules (PJ) of geothermal heating.

→ More than half went for space heating, another third for heated pools.

Classification of Hydro Power :- (1) According to Power output

Small hydro can be further divided into mini, micro and pico :

Mini (MH)	<1 MW	grid connected
Micro	<100 kW	Partially grid connected.
Pico (PH)	<10 kW	island grids
Family (FH)	<1 kW	single household/clusters.

(2) According to operation & type of flow :-

(i) Run-of-River (RoR).

(ii) Storage (reservoir)

(iii) Pumped storage hydro power plants.

(iv) In-stream Hydropower schemes.

Water Turbines (Hydraulic Turbines)

=> Water Turbines / 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 coupled with an electrical generator produces electrical energy.

Hydraulic Turbines may be classified as follows.

(i) According to the action of water flowing:

a) Impulse Turbine e.g: Pelton wheel.

b) Reaction Turbine e.g: Francis Turbine, Kaplan Turbine.

(ii) According to the main direction of flow of water

a) Tangential flow turbine e.g: Pelton wheel.

b) Radial flow turbine e.g: Old Francis Turbine

c) Axial flow turbine e.g: Kaplan Turbine

d) Mixed flow turbine e.g: Francis Turbine.

(iii) According to the head & Quantity of water required

a) High head Turbine (>250 m) e.g: Pelton wheel turbine

b) Medium head Turbine (60 m to 250 m) Francis Turbine

c) Low Head Turbine < 60 m Kaplan Turbine.

(iv) According to specific speed:

a) Low specific speed (10 to 35) Pelton wheel

b) Medium specific speed (60 to 400) Francis Turbine

c) High specific speed (300 to 1000) Kaplan Turbine

Turbine Theory.

=) The turbines can work on the principles of impulse and reaction.

=) In impulse turbine, the complete potential energy or head of water is firstly converted into kinetic energy using a nozzle outside the turbine. The fast jet of water emerging from the nozzle is used to strike the vanes of the turbine to impart motion.

=) Reaction Turbines : Nozzle is not used and vanes are shapped in the form of nozzles to convert potential energy of water into kinetic energy when water flows from the inlet to the outlet of the turbine.

Low specific speed :-

Impulse turbines have a low value of specific speeds & these are suitable to work under high head & large discharge conditions. specific speeds of the turbines vary from 8 to 50.

Medium specific speed :

Francis Turbines have specific speeds varying from 51 to 225. suitable to work under moderate head & discharge conditions.

High specific speeds :-

Kaplan turbines have high specific speed varying from 250 to 850. suitable to work under low head & large discharge conditions.

Introduction :-

Hydro electric Power Plants convert the hydraulic potential energy from water into electrical energy. such plants are suitable were water with suitable head are available.

Head :

The kinetic energy of water is its energy in motion and is a function of mass and velocity while the potential energy is a function of the difference in level of water between two points called the head.

The main elements of hydro electric Power Plant are:

i) catchment area and water reservoir.

ii) Dam and the intake.

iii) Inlet water ways.

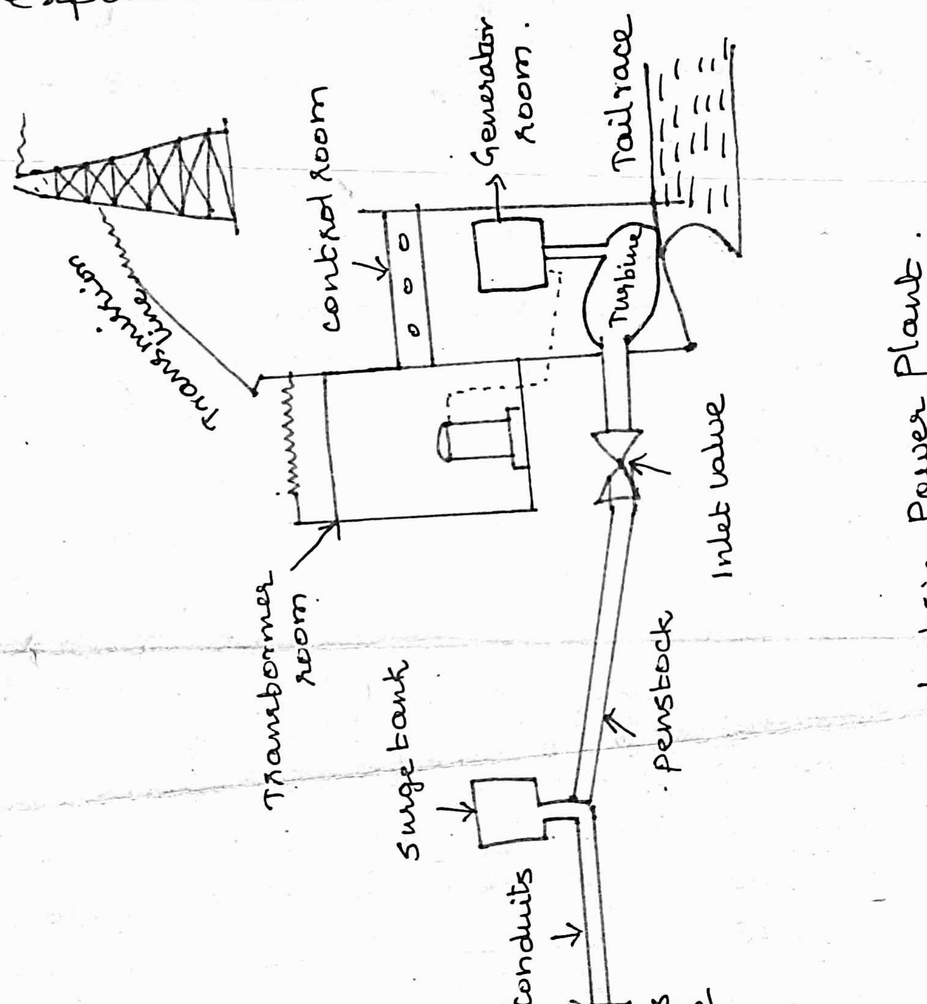
iv) Power house and equipment

v) The tail race.

(i) catchment area and water reservoir :-

The area behind the dam, which collects rain water, drains into a stream or river, is called catchment area. Water collected from catchment area is stored in a reservoir, behind the dam. water surface in the storage reservoir is known as head race level or simply head race. A reservoir can be either natural or artificial. A natural reservoir is a lake in high mountain and an artificial reservoir is made by constructing a dam across the river. water held in upstream reservoir is called storage whereas water behind dam at the plant is called pondage.

① Draw the layout of Hydro Electric Power Plant and explain its associated components :



Layout of Hydro - Electric Power Plant.

ii) Dam and the Intake :-

A dam is a structure of masonry earth and/or rock fill built across a river. It has 2 functions :

a) to provide the head of water,

b) to create storage or pondage

Many times high dams are built only to provide the necessary head to the power plants. Concrete and masonry dams are quite popular and are made as:

i) solid gravity dam

ii) The buttress dam

iii) The arched dam.

The intake house includes the head works, which are the structure at the intake of conduits, tunnels or flumes. Gates and valves control the rate of water flow entering the intake. Gates discharge excess water during flood duration. Gates are of the following types :
Radial gates, sluice gates, wheeled gates, plain sliding gates, crest gates, rolling or drum gates etc.. The various types of valves used are needle valve and butterfly valves.

iii) Inlet water ways :

Inlet water ways are the passages through which water is conveyed from the dam to the power house. It includes canal, penstock (closed pipe) or tunnel, flume boreway and also surge tank.

(a) Tunnel :-

Tunnel is made by cutting the mountains where canal or pipe line can not be used due to topography. Tunneling provides a direct and a short ~~side~~ route for the water passages.

(b) Penstocks :

Water may be conveyed to turbines through open conduits or closed pressure pipes called penstocks made of reinforced concrete or steel. When there is danger from slides of snow, rock, earth etc., covered penstocks are used. The thickness of the penstock increases as working pressure or head of the water increases.

(c) Surge Tanks :

A surge tank is a small reservoir or tank in which the water level rises or falls to reduce the pressure swings so that they are not transmitted in full to a closed circuit.

In general, a surge tank serves the following purposes:

i) To reduce the distance between the free water surface and turbine thereby reducing the water-hammer effect on penstock and also protect upstream tunnel from high pressure rises.

ii) To serve as a supply tank to the turbine when the water in the pipe is accelerating during increased load conditions and as a storage tank when the water is decelerating during reduced load conditions.

Forebay :

The water carried by the power canals is distributed to various penstocks leading to the turbine, through the forebay, also known as the head pond. Water is temporarily stored in the forebay, in the event of a rejection of load by the turbine and there is withdrawl from it when the load is increased.

Spillways :-

These structures provide for discharge of the surplus water from the storage reservoir into the river on the down stream side of the dam. Spillway is considered a safety device for a dam, which acts as a safety valve, which has the capacity to discharge major floods without damage to the dam.

Power House and Equipments :-

The power house is a building in which the turbines, alternators and the auxiliary plant are housed. Here conversion of energy of water to electrical energy takes place. Following are some of the main equipments provided in a power house:

i) Prime movers coupled with generators
ii) Turbine Governors
iii) Relief valve for penstock fittings.
iv) Gate valves
v) Water circulating pumps
vi) Flow measuring Devices
vii) Air ducts
viii) Transformers.
ix) Reactors
x) Oil circuit Breakers.

(a) Tunnel :

xii) Low tension and high tension bus bar

xiii) cranes

xiv) switch board equipment and instruments.

Tail Race and outlet water way :

Tail Race is a passage for discharging the water leaving the turbine into the river and in certain cases, the water from the tail race can be pumped back into the original reservoir. The water held in the tail race is called as tail race water level.

Prime movers :-

In an hydraulic power plant the primemover converts the energy of water into mechanical energy and further into electrical energy.

1. Impulse Turbine :

Here, the pressure energy of water, is converted into kinetic energy when passed through the nozzle and forms the high velocity jet of water. The formed water jet is used for driving the wheel.

2. Reaction Turbine :

The water pressure combined with the velocity works on the runner. The power in this turbine is developed from the combined action of pressure and velocity of water that completely fills the runner and water passage.

Draft Tubes :-

The draft tube serves the following two purposes:

i) It allows the turbine to be set above tail-water level, without loss of head to facilitate inspection and maintenance.

ii) It regains, by diffuser action, the major portion of the kinetic energy delivered to it from the runner.

UNIT - V

OTHER ENERGY SOURCES.

TIDAL ENERGY:

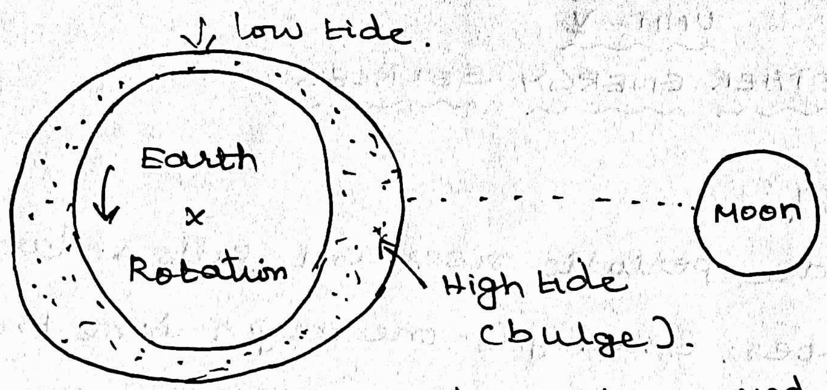
Tides are periodic rises and falls of large bodies of water. Gravity is one major force that creates tides. Ocean tides result from the gravitational attraction of the sun and moon on the oceans of the earth.

Spring tides are especially strong tides that occur when the earth, the sun, and the moon are in a line. The gravitational forces of the moon and the sun both contribute to the tides. Spring tides occur during the full moon and the new moon.

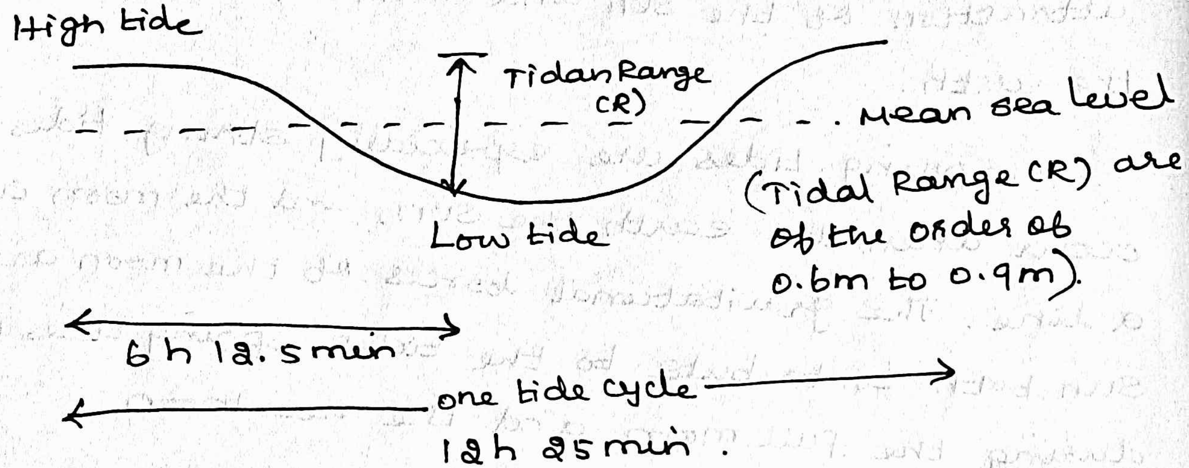
Neap tides are especially weak tides. They occur when the gravitational forces of the moon and the sun are perpendicular to one another with respect to the earth. Neap tides occur during quarter moons.

The moon exerts a larger gravitational force on the earth (about 70 % of the tide producing force) on the earth, as it is closer than the sun.

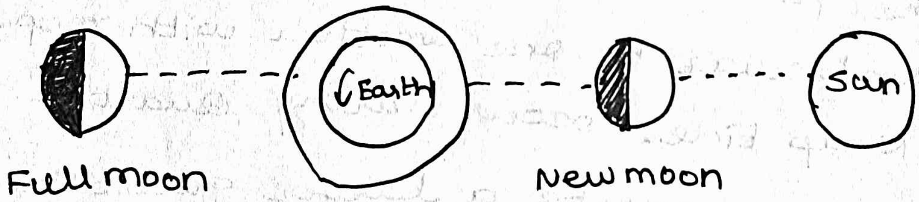
Surface water is pulled away from the earth on the side facing the moon, and at the same time the solid earth is pulled away from the water on the opposite side. Thus the ocean height increases at both the near and far sides of the earth.



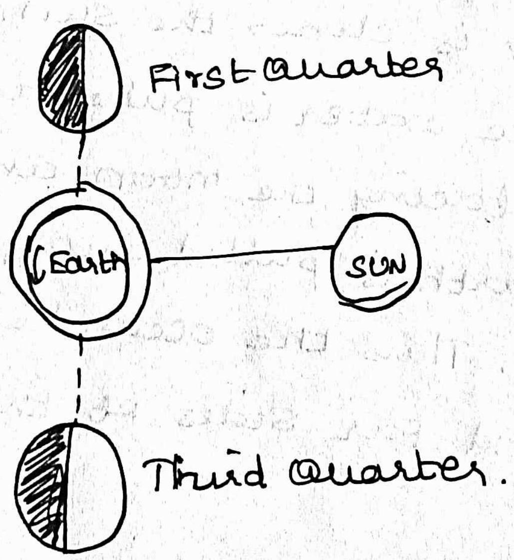
a) Bulge on near and far sides of the earth.



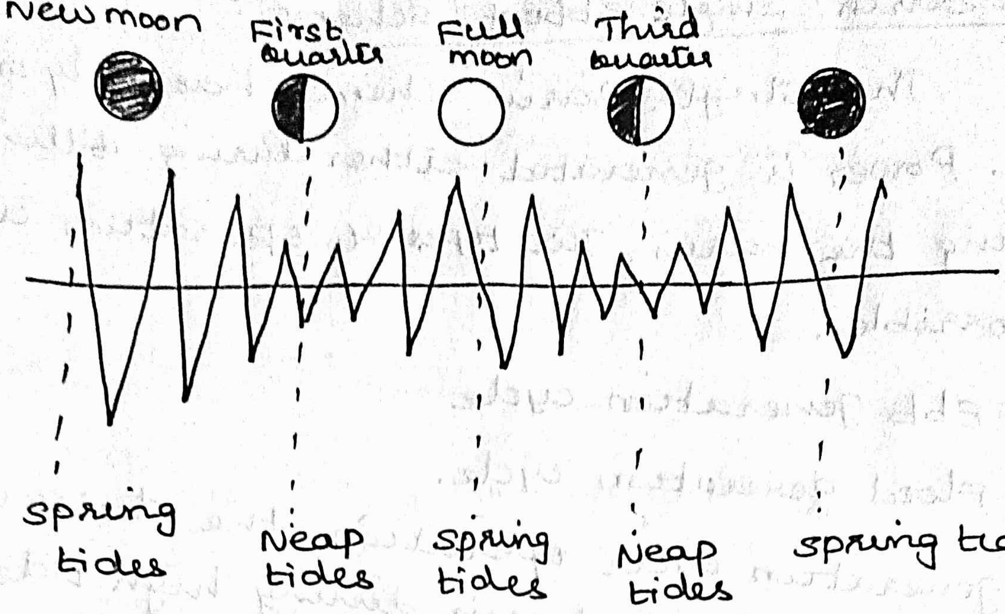
b) Tidal wave.



(a) spring tides.



(b) Neap Tides.



(c) Nature of Tides.

Limitations of Tidal Energy :-

1) Energy is concentrated in the form of tidal Range of about 5m or more and the geography provides a favourable site for economic construction of a Tidal plant.

2) optimum tidal power generation is not in phase with demand.

3) changing tidal range (R) in two-week periods produces changing power.

4) The turbine are required to operate at variable head.

5) Tidal plant disrupts marine life at the location and can cause potential harm to ecology.

Ocean Tidal Energy Conversion Schemes :

The main tidal energy conversion schemes are

(i) single Basin : single effect.

(ii) single Basin : Double effect.

(iii) Two Basin : linked Basin.

iv) Two basin : paired Basin

v) Tidal flow schemes.

(1) Single Basin: single effect scheme:

The single Basin scheme has only one basin. Power is generated either during filling or emptying the basin. Two types of operation cycles are possible.

i) Ebb generation cycle

ii) Flood generation cycle.

Ebb generation cycle operation, the sluice way is opened to fill the basin during high tide. Once filled, the impounded water is held till the receding cycle creates a suitable head. Water is now allowed to flow through the turbine coupled to the generator.

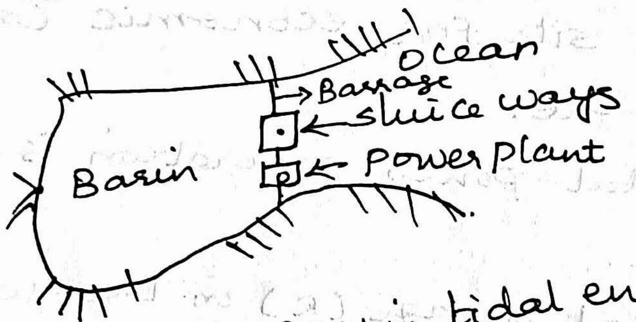
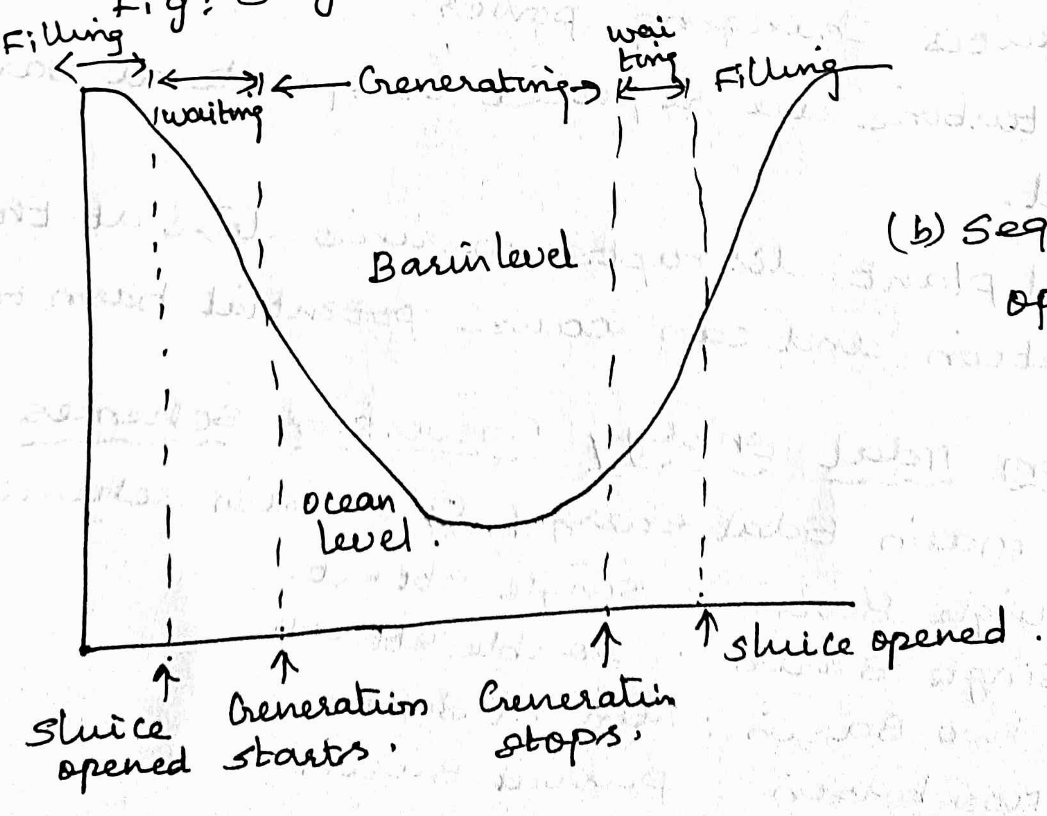


Fig: single Basin tidal energy conversion scheme



(b) Sequence of operation.

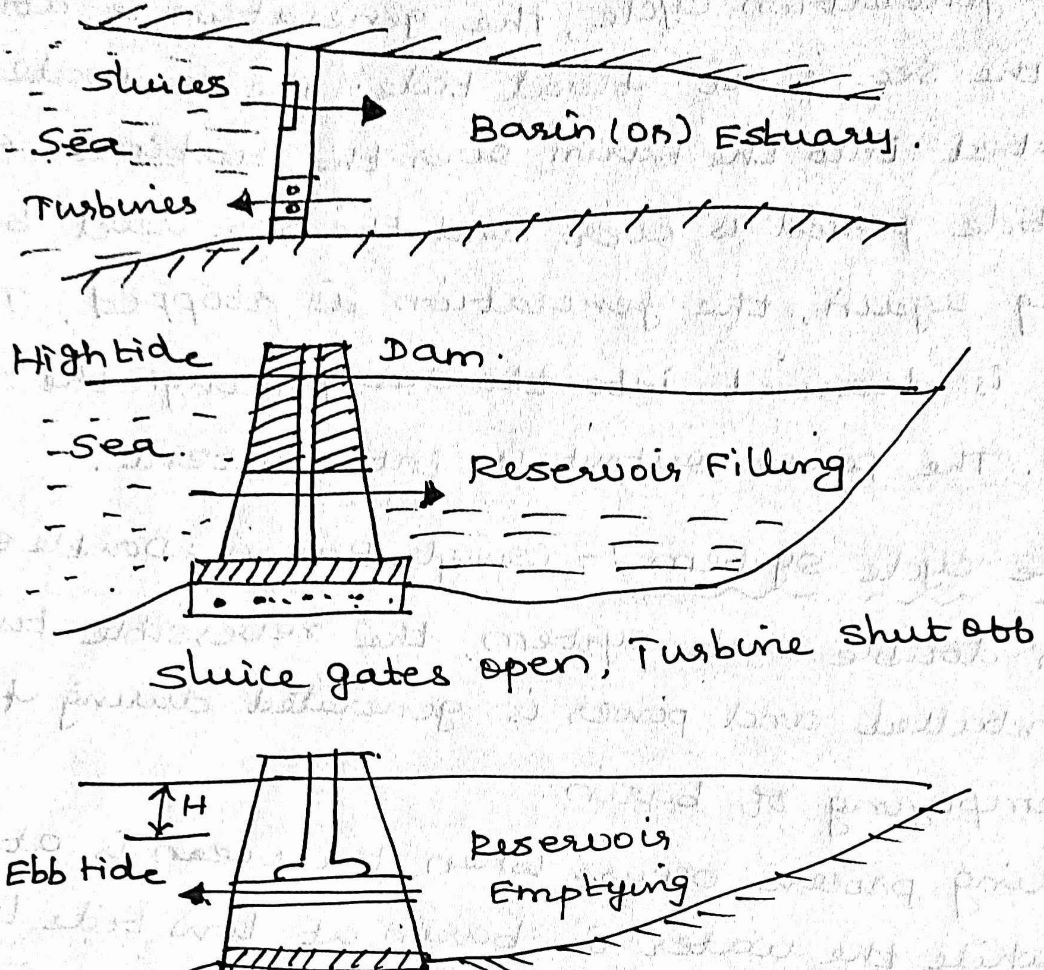


Fig: single Ebb cycle system.

T.G → Turbine Generator set.

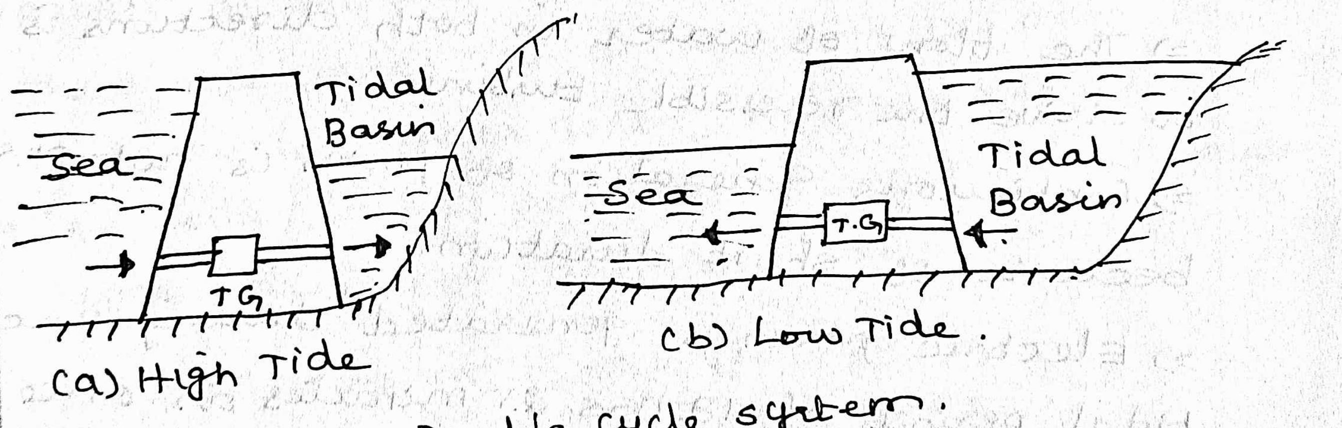


Fig: Double cycle system.

Flood generation cycle, the generation is affected
when the sea is at flood tide. The sea water is
admitted into the basin over the turbines. As the
flood tide period is over and the sea level begins
falling again, the generation is stopped. The
basin is drained into the sea through the sluice
ways. The power output is intermittent.

Double cycle system :- (Single Basin : Double effect).

=> In double cycle system, the reversible turbines
are installed and power is generated during filling
and emptying of basin.

=> Filling process occurs when the ocean is at high
tide while the water in basin at low tide level,
the emptying occurs when the ocean is at low tide
and basin at high tide level.

=> The flow of water in both directions is used
to drive the reversible turbines.

=> Continuous generation of power is not possible
because of short duration.

=> Electric power is generated during each
tidal period of 12 hrs 25 minutes or once every
6 hrs & 12.5 minutes.

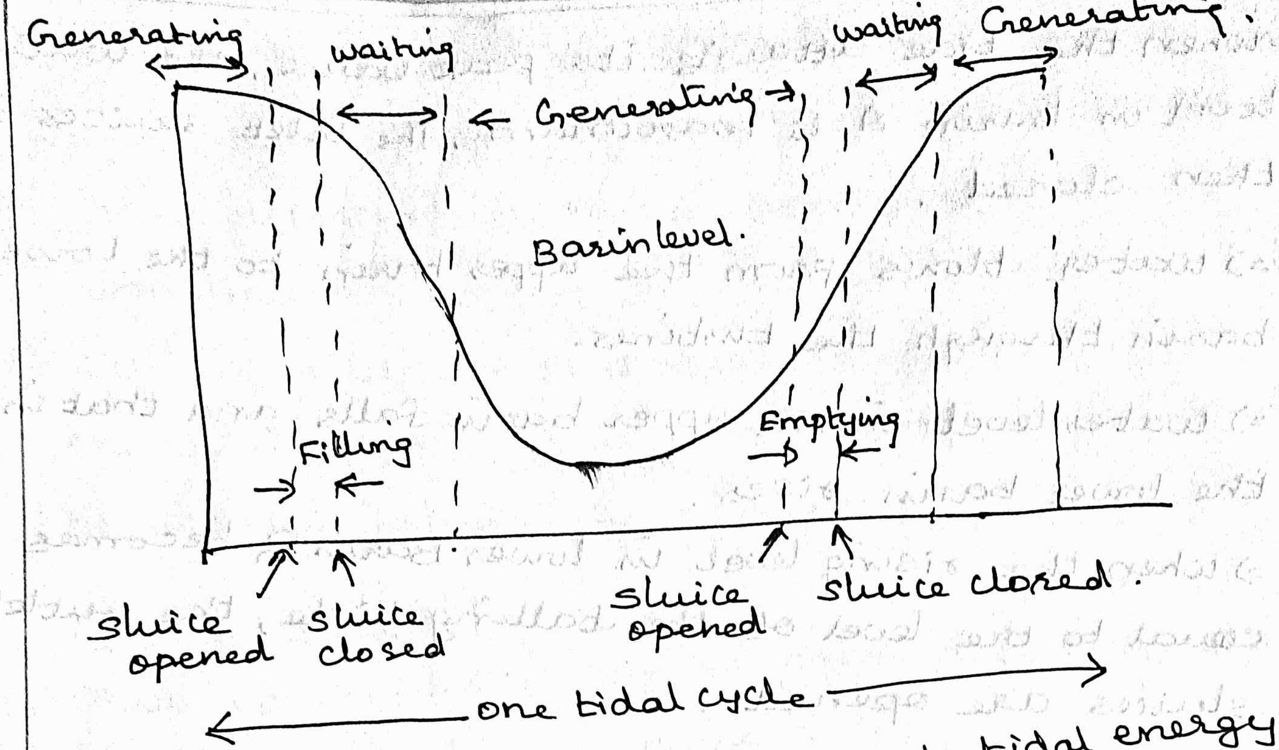


Fig : single basin, Double effect tidal energy conversion scheme.

Double basin system :-

=> There are two basins at dibberent levels. A dam is provided between two basins. The turbines are located in the dam.

=> The sluice gates are provided in the dam. One basin is called upper Basin, Another basin is called Lower Basin. Water level is maintained greater in upper basin compared to Lower basin.

upper basin gates → Inlet Gates.

Lower Basin gates → outlet Gates.

=> When the water level in upper Basin A provides a subbicient dibberence of head between the two basins, the turbines are started.

=> The water blows from Basin A to Basin B through the turbines and the power is generated.

=> when the tide attains its peak value, the level in basin A is maximum. The inlet sluices are then closed.

=> Water flows from the upper basin to the Lower basin through the turbines.

=> water level in the upper basin falls and that in the lower basin rises.

=> when the rising level in lower Basin B becomes equal to the level of the falling tide, the outlet sluices are opened.

=> when the tide reaches its lower most level, the outlet gates are closed. After some time the tide rises.

=> when its level equal to the low level of the upper basin, inlet gates are opened. The level of water in basin A starts rising. The cycle is repeated.

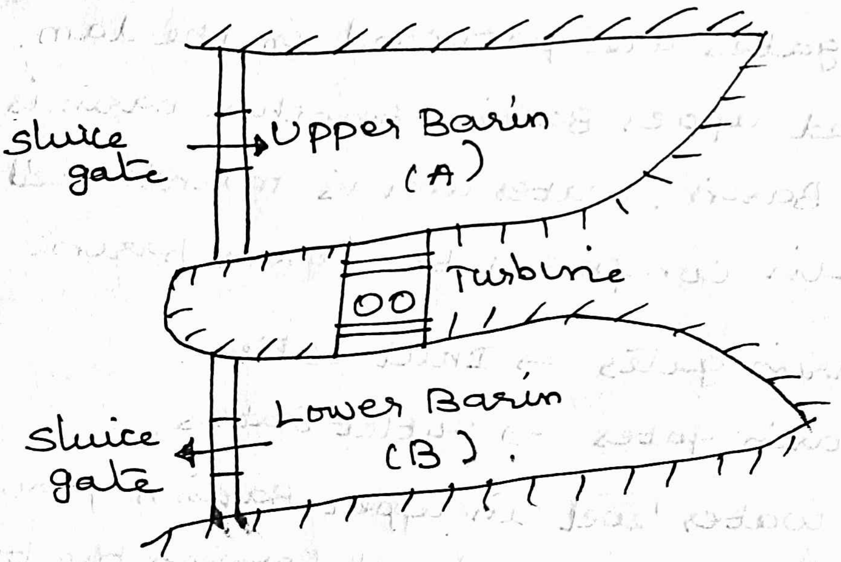


Fig: Double Basin operation.

Advantages of tidal power plants :-

1) It is free from pollution, it does not use any fuels

2) It is superior to hydro-power plant as it is totally independent of rain.

3) It improves the possibility of fish farming in the tidal basins and it can provide recreation to visitors & holiday makers.

Disadvantages :

1) Tidal power plants can be developed only if natural sites are available on the bay.

2) The sites are available on the bays which are always far away from load centres. The power generated has to be transmitted to long distance. This increases the transmission cost & transmission losses.

WAVE ENERGY

Ocean and sea waves are caused indirectly by solar energy like the wind and OTEC. Wave energy derives from wind energy which drives in turn from solar energy. Devices that convert energy from waves can therefore produce much high power densities than solar devices.

Advantages :

1) The energy naturally concentrated by accumulation overtime and space and transported from the point at which it was originally present in the winds

2) It is free and renewable energy source.

3) The wave power devices do not use up large land masses unlike solar or wind.

4) These devices are pollution free.

Disadvantages :-

1) The energy is available on the ocean. The extraction equipment must operated in a marine environment. so, maintenance, construction cost, life time & reliability are increased.

2) wave energy converters must be capable of withstanding very severe peak stresses in storms.

3) wave energy conversion devices are relatively complicated.

4) Energy and Power from the waves

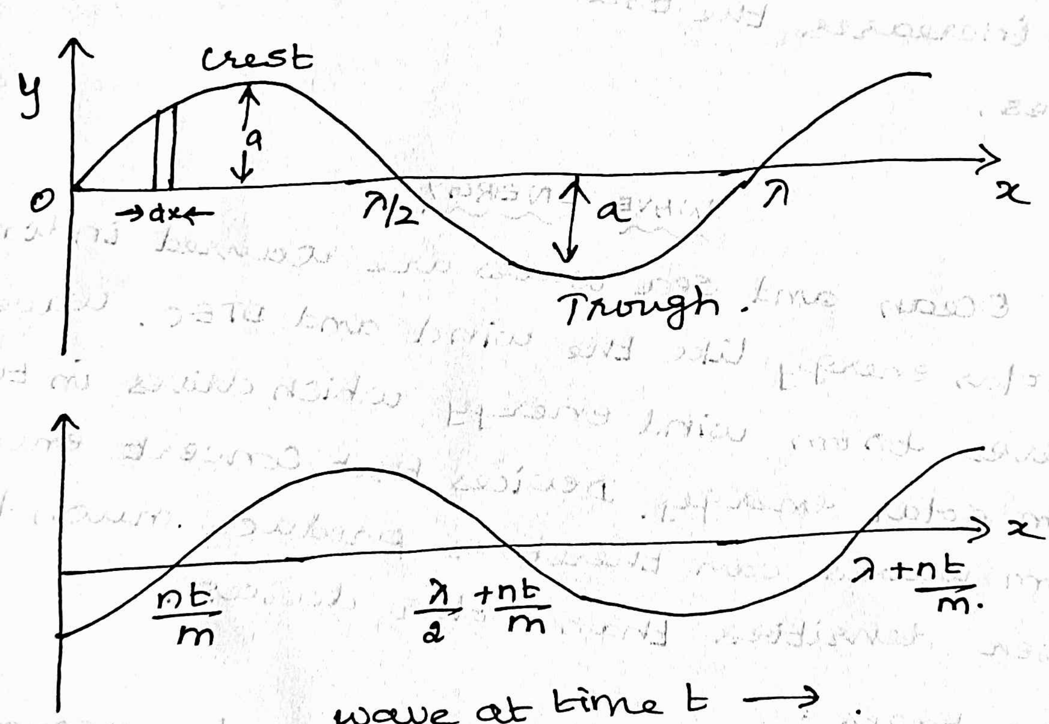


Fig: Progressive wave.

A two dimensional progressive wave is represented by the sinusoidal simple harmonic wave shown at time $t = 0$, and time t.

The wave may be expressed by the following relation involving some parameters :

$$y = a \sin\left[\frac{2\pi}{\lambda}x - \frac{2\pi}{T}t\right]. \quad \text{— (1)}$$

$y \rightarrow$ height above its mean level (m).

$a \rightarrow$ Amplitude (m).

$\lambda \rightarrow$ wavelength (m).

$t \rightarrow$ time (sec).

$T \rightarrow$ period (sec).

$2\pi \left(\frac{x}{\lambda} - \frac{t}{T}\right)$ = phase angle (dimensionless).

The relationship between wavelength and period is approximately,

$$\lambda = 1.56T^2. \quad \text{— 1(a).}$$

$$(1) \Rightarrow \quad y = a\sin(mx - nt). \quad \text{— (2)}$$

where $m = \frac{2\pi}{\lambda}$; $n = \frac{2\pi}{T}$

$2a$ = height (from crest to trough).

Potential Energy :-

The potential energy arises from the elevation of water above mean level (i.e $y = 0$) considering a differential volume $y.dx$, it will have a mean height $y/2$. Thus its potential energy

$$dPE = \frac{mgy}{2} = \frac{(\rho y.dx\,L)\,gy}{2}$$

$$dPE = \frac{g\rho y^2 L.dx}{2} \quad \text{— (3)}$$

m = mass of the liquid (y . dx) kg.

g = gravitational constant.

ρ = water density, kg/m^3.

L = wave propagation, x (m).

Combining eqn (2) & (3),

$$dPE = \frac{g\rho\,(a\sin(mx-nt))^2\,L\cdot dx}{2} \quad \text{— (3).}$$

$$PE = \frac{\rho L a^2 g}{2}\int_0^{\lambda}\sin^2(mx-nt)\cdot dx.$$

$$= \frac{\rho L a^2 g}{2}\left[\int_0^{\lambda}\frac{1-\cos 2(mx-nt)}{2}\right.$$

$$= \frac{\rho L a^2 g}{2}\left[\tfrac{1}{2}mx - \tfrac{1}{4}\sin 2mx\right]_0^{\lambda}.$$

$$= \frac{1}{4}g\rho a^2\lambda L.$$

The Potential energy density per unit area is PE/A,

$A = \lambda L$ (J/m^2).

$$\frac{PE}{A} = \frac{1}{4}g\rho a^2.$$

Kinetic energy : $K.E = \frac{1}{4}g\rho a^2\lambda L$.

$$\frac{K.E}{A} = \frac{1}{4}g\rho a^2.$$

Total energy and power density can be written as,

$$\frac{E}{A} = \frac{1}{2}g\rho a^2.$$

$$P/A = \frac{1}{2}g\rho a^2\times\frac{c}{\lambda}.$$

(Power P = energy x frequency)

$$\boxed{P = \left(\frac{\rho g^2}{8\pi}\right)a^2 T} \rightarrow \text{can also be written.}$$

Estimate of Energy and Power in simple single Basin Tidal system:

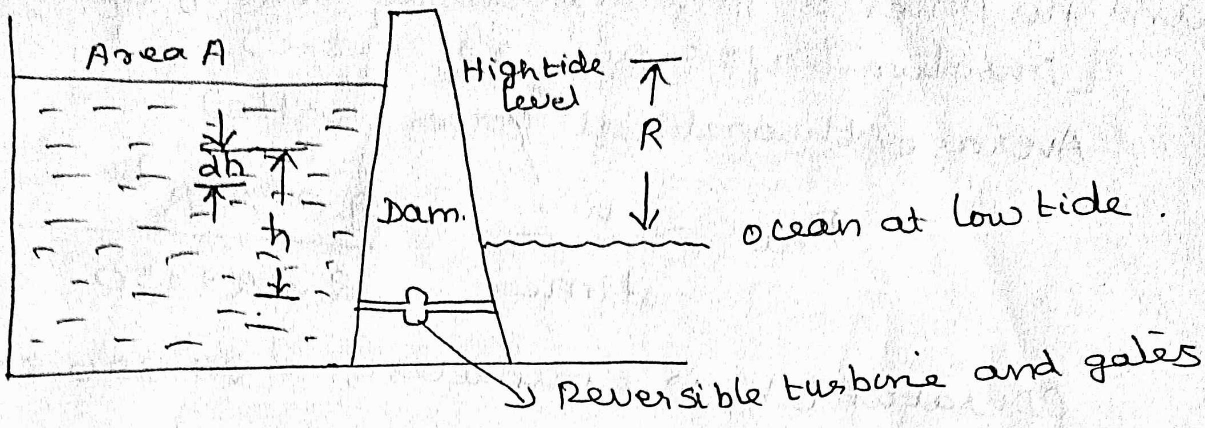


Fig: Single Basin Tidal system.

$$dw = dm \times g \times h. \quad \text{---} (1)$$

$$dm = -\rho . A . dh . \quad \text{---} (2)$$

$$dw = -\rho . A . dh \times g \times h . \quad \text{---} (3)$$

where w = workdone by water (Joule).

g = gravitational constant

m = mass flowing through turbine, kg.

h = head (m).

ρ = water density (kg/m^3).

A = Basin surface area (m^2).

The total theoretical work during a full emptying (or) filling period is obtained by, eqn (3)

$$W = \int_R^0 dw = \int_R^0 -\rho . A . dh \times g \times h .$$

$$= -\rho \times g \times A \int_R^0 h . dh .$$

$$= -\rho . g \times A \left[h^2/2 \right]_R^0 = -\rho \times g \times A \times \left(-\frac{R^2}{2} \right).$$

$$= \frac{1}{2} \rho g A R^2 \quad \text{---} (4)$$

work is proportional to square of the tidal range.

The power is generated during emptying (or filling) and no power is generated during rest of the time.

[Duration 6h 12.5 min = 22,350 sec).

Average theoretical power (watts)

$$P_{av} = \frac{W}{time} = \frac{g \cdot \rho \cdot A \cdot R^2}{2 \times 22350}$$

(Duration 6 h, 12.5 minutes, = 22,350 seconds).

$$= \frac{1}{44,700} g \times \rho \times A R^2.$$

Assuming an average sea water density = 1025 kg/m^3, the average power per unit Basin area is given by,

$$\frac{P_{av}}{A} = \frac{1}{44,700} \times 9.80 \times 1025 R^2.$$

$$= 0.225 R^2 \text{ watts/m}^2. \quad \text{— (5)}$$

The actual power generated by a real tidal system would be less than the average theoretical power obtained by the above expressions.

The actual power may be about 25 to 30 % of the theoretic power.

Estimation of Energy and Power in a double cycle system. (Tidal system).

Power can be calculated by considering the average discharge and available head at any instant.

Total energy obtained by, integrating the value of instantaneous power.

Let V be the volume of the Basin,

$V = Ah_0$. —— (1)

A → average cross sectional Area (m^2).

h_0 → difference b/w maximum & minimum water levels.

Average discharge $Q = \frac{Ah_0}{t}$ —— (2).

t → total duration of generation in one filling/emptying operation.

Power generated at any instant,

$P = \frac{\rho Q h}{75} \times \eta_0$ H.P.

$= \frac{\rho Q h}{75} \times \eta_0 \times 0.736$ kw.

ρ → average density of sea water (1025 kg/m^3).

h → available head.

Total energy $= \int_0^t P \cdot dt = \int_0^t \frac{\rho Q h}{75} dt \times \eta_0 \times 0.736$

Yearly power generation $= \int_0^t \frac{\rho Q h}{75} dt \times \eta_0 \times 0.736 \times 705$ kwh/year.

[There are approximatly 705 full tidal cycle in a year].

WAVE POWER DEVICES.

Energy in the waves is harnessed basically in the form of mechanical energy using wave energy converters, also known as wave devices or wave machines.

Wave device may be placed in the ocean in various possible situations and locations. The fluctuating mechanical energy obtained is modified/smoothed out to drive a generator.

Classifications :

I Depending upon the location

(i) off shore or deep water. (water depth 40m or more).

(ii) shoreline devices.

Availability of wave power at deep ocean sites is 3 to 8 times that of adjacent coastal sites.

II Depending upon the position with respect to sea level.

i) Floating (ii) submerged (iii) Partly submerged

III Depending on the Actuating Motion used :

i) Heaving float type ii) Pitching type

iii) Heaving and pitching float type

iv) oscillating water column type.

v) Surge devices.

(i) Heaving Float Type :-

A float (buoy) placed on the surface of water heaves up and down with waves due to the rise and fall of the water level. The resulting vertical motion is used to operate the piston of an air pump through linkage. Several float operated air pumps are used to store energy in a compressed air storage. The compressed air is used to generate electricity through an air turbine coupled to generator.

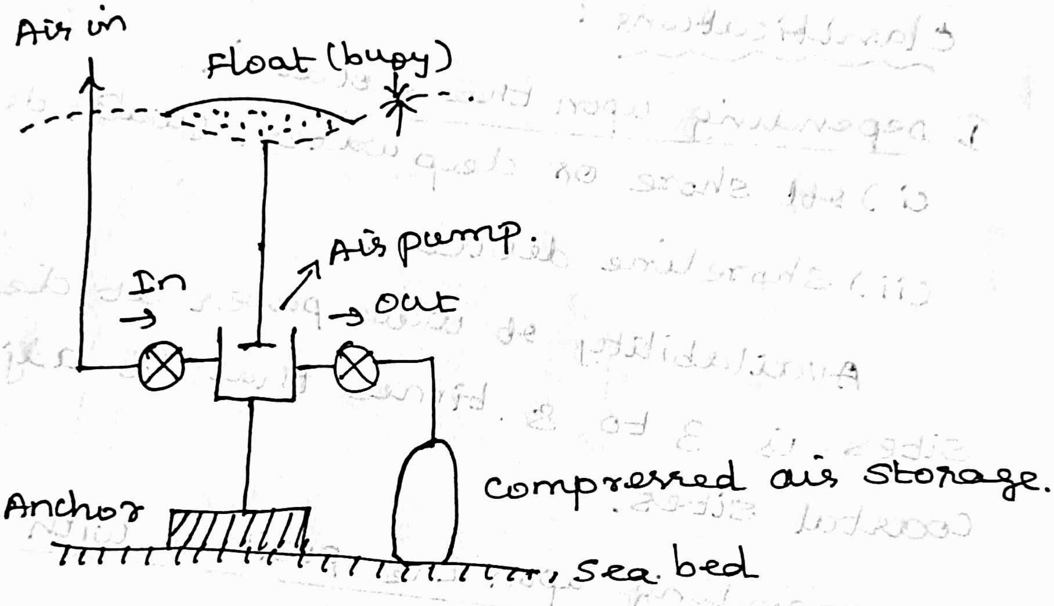


Fig : Float with air pump.

A hydraulic pump is operated by the motion of a buoy to raise water to an onshore reservoir and passed through a turbo-generator to generate electricity.

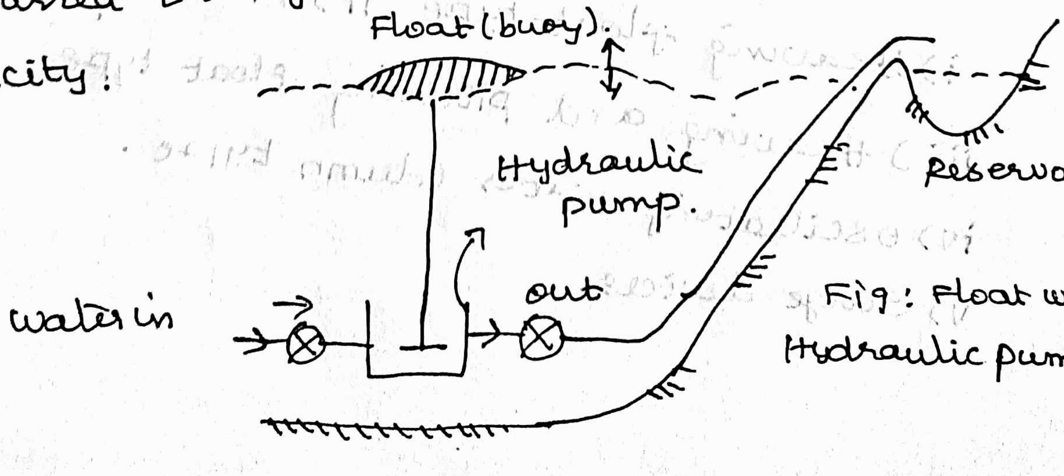
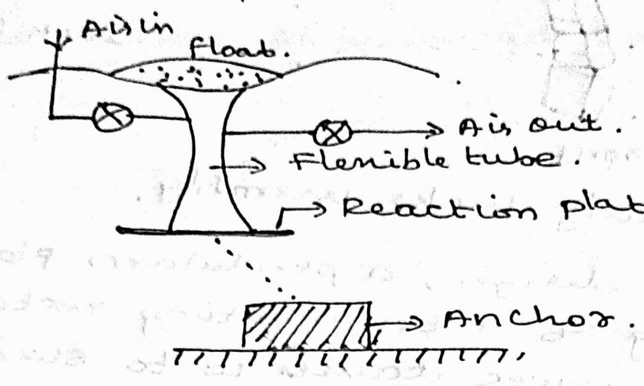


Fig : Float with Hydraulic pump.

In another version, a submerged flexible tube attached to a buoy is used as an air pump. The motion of the buoy stretches the tube, decreasing its volume to provide the pumping action.



Float with flexible tube air pump.

Pitching type :-

In this type, the waves strike horizontally on a floating piece or flap causing it to deflect. Several cam-shaped floating pieces are hinged to a common flexible linkage to form a nodding duck assembly.

A wave entering from the left turns the beak of the duck in the direction of motion. The duck swings backward with the trough of the wave. It then oscillates about its axis. The ratchet and wheel mechanism converts the motion of the ducks to a common shaft. Power collected by an individual duck is thus pooled to drive the generator.

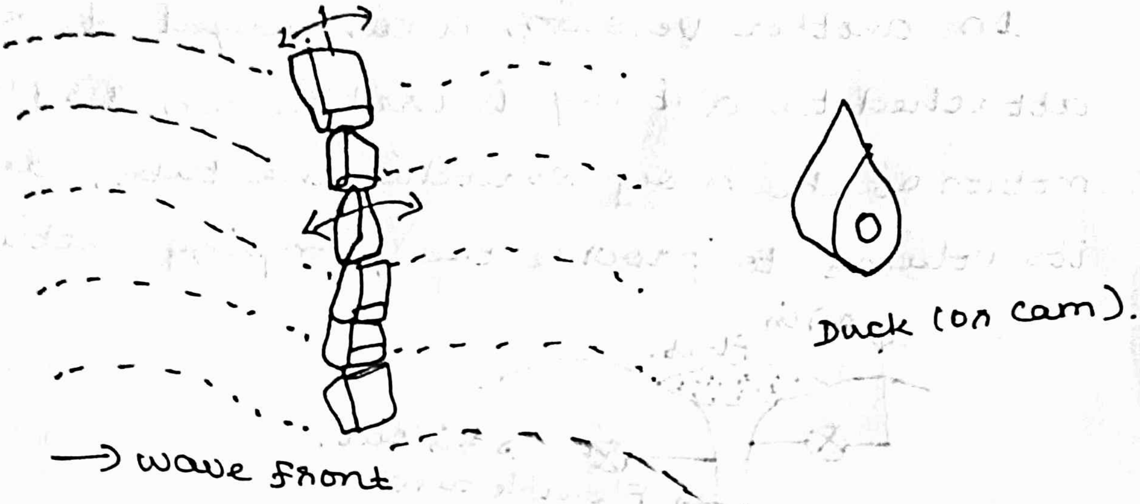


Fig : Nodding ducks assembly.

In another design, a pendulum flap is hinged over the opening of a terminating rectangular box. The action of the waves causes it to swing back and forth. This motion is then used to power a hydraulic pump and generator.

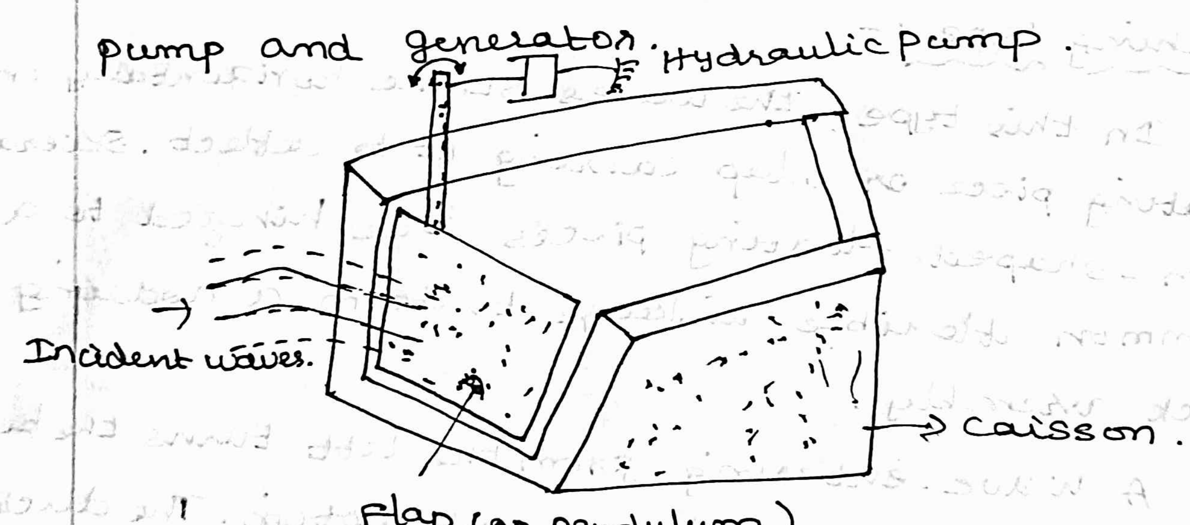
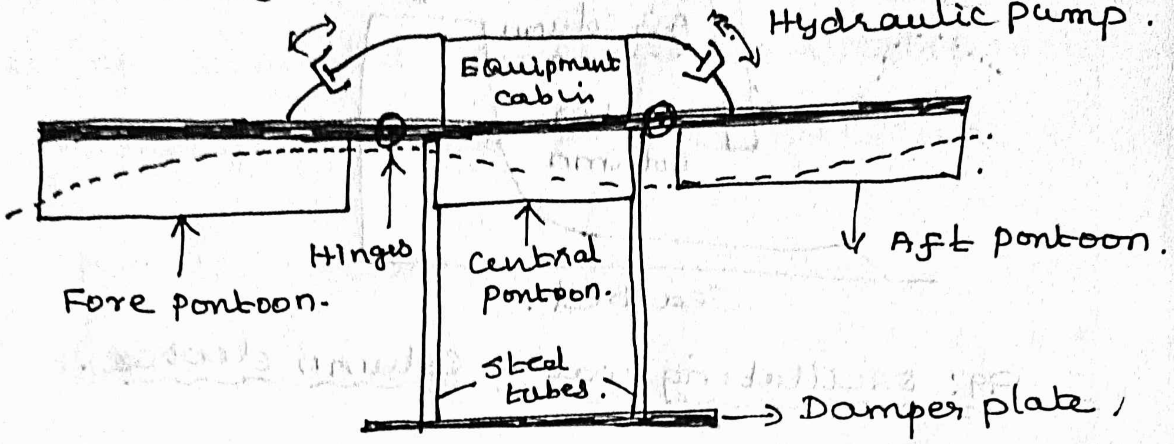


Fig : Pendular device.

Heaving and Pitching - float Type :-

Pitching and heaving motion of a float can also be used to extract wave energy. A system consisting of 3 pontoons, which move relative to each other in the wave. A damper plate is attached to a central pontoon, central pontoon stays still as the fore and aft pontoon move relative to the central pontoon by pitching about the hinges.

Energy is extracted by hydraulic pumps attached to hinges. Electricity can be generated via a hydraulic turbine and generator.



A specially shaped float known as Dolphin rides the wave and rolls as well as heaves as the wave passes. The two motions are converted to unidirectional motion by a ratchet-wheel arrangement and used to operate floating and stationary generators.

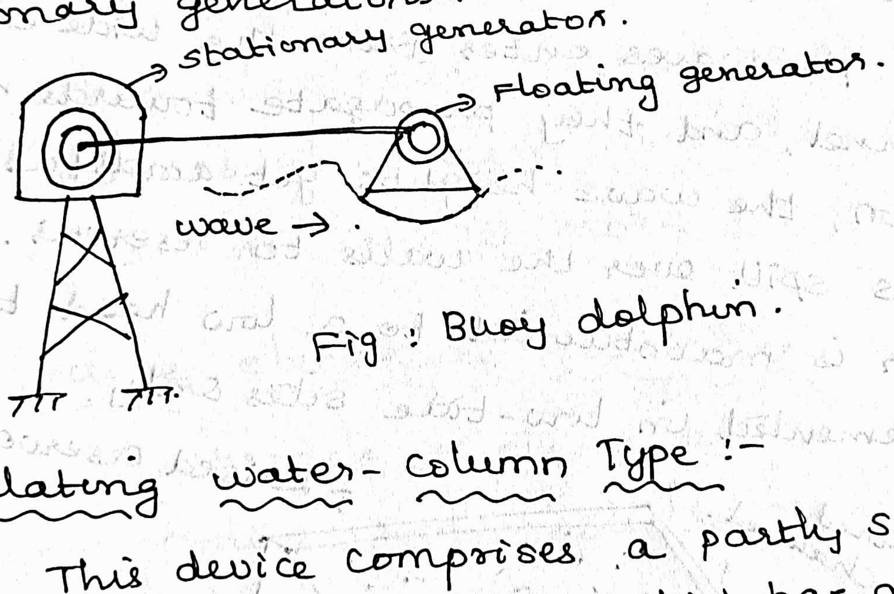


Fig : Buoy dolphin.

Oscillating water-column Type :-

This device comprises a partly submerged concrete or steel structure, which has an opening to the sea below the water line. So, enclosing a column of air above a column of water. The wave impinging on the device causes the water column to rise and fall, which alternately compresses or depressurises the air column. The air is allow to flow through turbine which drives the generator.

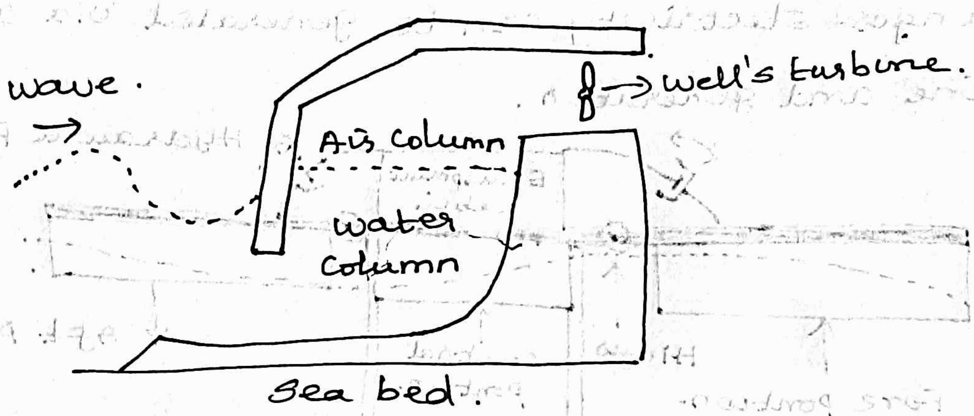


Fig: oscillating water column device.

Surge Devices:

When a moving wave is constricted, a surge is produced raising its amplitude. such a device is known as tapped channel device (TAPCHAN). The TAPCHAN comprises a gradually narrowing channel with wall heights 3 to 5m above sea level.

The waves enter from the wide end of the channel, and they propagate towards narrower region, the wave heights get amplified, until the crests spill over the walls to reservoir. So, stable water is maintained to a low head turbine. Implemented in low-tide sites only.

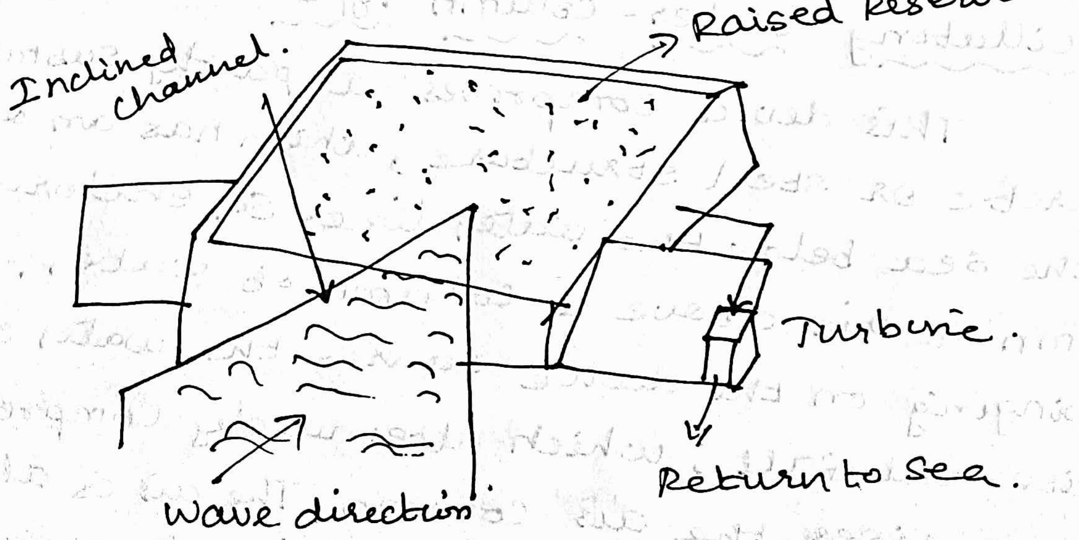


Fig: Tapered channel Device.

Fuel cells :

(19) A fuel cell is an electrochemical device in which the chemical energy of a conventional fuel is converted directly and efficiently into low-voltage, direct current electrical energy.

Possible reactions are :

Hydrogen / oxygen	1.23 V	$2H_2 + O_2 \rightarrow 2H_2O$
Hydrazine	1.56 V	$N_2H_4 + O_2 \rightarrow 2H_2O + N_2$
carbon (coal)	1.02 V	$C + O_2 \rightarrow CO_2$
Methane	1.05 V	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Components of a fuel cell :-

Fuel cell stack which is made of many thin flat cells layered together. Each cell produces electricity and the output of all cells is combined to get more power.

Membrane electrode Assembly :

Electrodes such as anode, cathode, catalyst, polymer electrolyte membrane together form the membrane electrode assembly.

Anode :

It is negative side of the fuel cell. It conducts the electrons. The electrons are used in an external circuit.

cathode :

It is a positive side of the fuel which distribute oxygen to the surface of catalyst

Polymer electrolyte membrane : (PEM)

It is a specially treated material which conducts only +ve charged ions and blocks electrons.

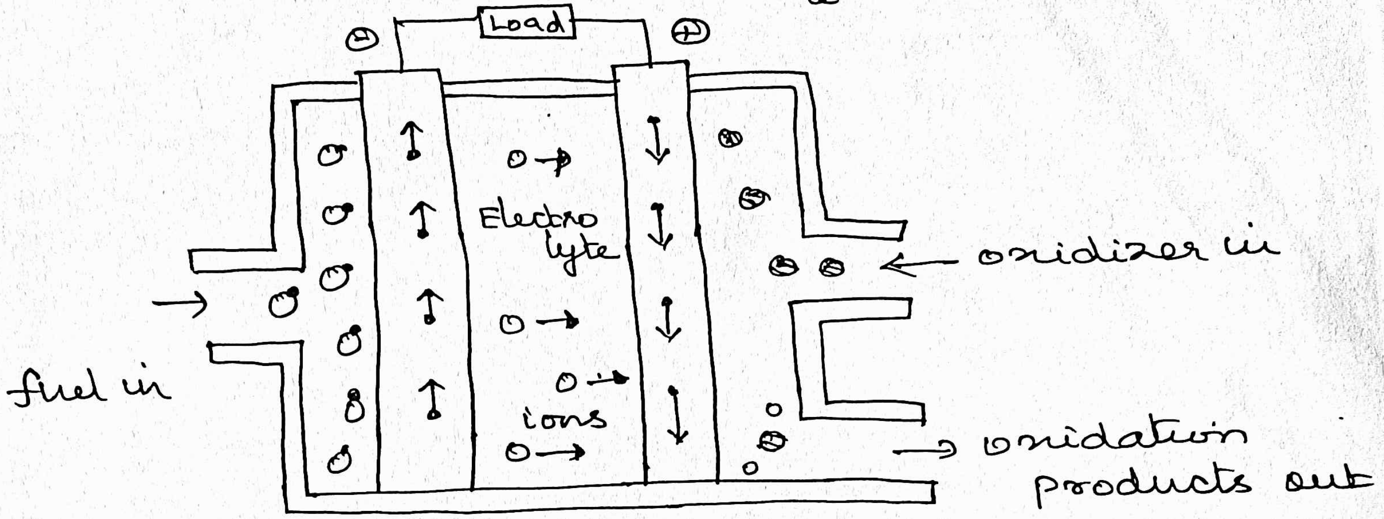
catalyst :-

Each of the electrode is coated at one side with a catalyst layer which speeds up the reaction of oxygen and hydrogen. usually made of platinum powder coated onto carbon paper or cloth.

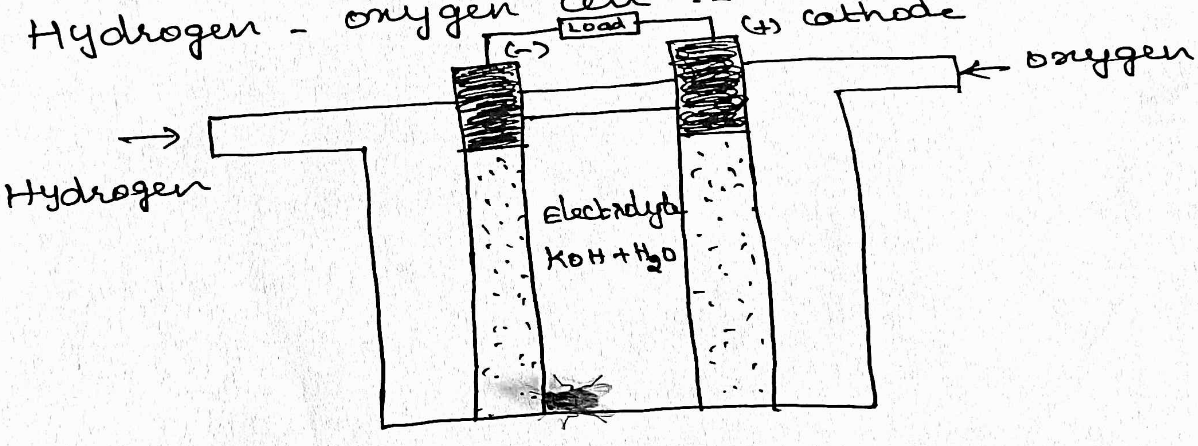
working Principle :-

The pressurized hydrogen gas (H_2) enters the fuel cell at anode side. when a H_2 molecule comes in contact with the platinum on the catalyst, it splits into two H^+ ions and two electrons (e^-). The electrons are conducted through the anode flows in the external circuit and return to the cathode side of fuel cell.

In the cathode side, oxygen gas (O_2) is forced through the catalyst, it forms two oxygen atoms. This negative charge attracts two H^+ ions, combine with an oxygen atom, two of electrons from the external circuit to form a water molecule. (H_2O).



Hydrogen - oxygen cell :-



$$4KOH \rightarrow 4K^+ + 4(OH)^-$$

Anode : $2H_2 + 4(OH)^- \rightarrow 4H_2O + 4e^-$

Cathode : $O_2 + 2H_2O + 4e^- \rightarrow 4(OH)^-$

cell reaction : $2H_2 + O_2 \rightarrow 2H_2O$.

Advantages :-

1) Conversion $\eta \uparrow$, require little attention, less maintenance, space requirement less. does not make noise,

2) Disadvantages :- 1) High initial cost, low service life

Types of fuel cells.

Following fuels are mostly used in fuel cells:
(1) Hydrogen (2) Fossile fuel (3) Hydrocarbon fuel
(4) Alcohol fuel (5) Hydrazine fuel.

Ion Exchange Membrane cell :-

This fuel cell contains a solid electrolyte Ion-exchange membrane, electrocatalysts and gas feed tubes. It uses a solid electrolyte in the form of an ion-exchange membrane.

The membrane is non-permeable to the reactant gases, hydrogen and oxygen and prevents them from coming into contact.

Properties of ideal ion-exchange membrane electrolyte

(i) High ionic conductivity.
(ii) zero electronic conductivity.
(iii) Low permeability of fuel & oxidant.
(iv) High resistance to dehydration.
v) High resistance to its oxidation
vi) Mechanical stability.

=> Electrolyte resistance as low as possible, a thin sheet of (0.076 cm thickness) is used as the electrolyte.

=> The two electrodes, consists of a catalyst, plastic material for water proofing the electrode are in the form of fine metallic wire screens.

=) The wire screen material is titanium or platinum

=) Metallic current collectors are ribbed onto each electrode.

=) The hydrogen compartment of the cell is enclosed, The hydrogen gas enters this compartment through a small inlet and circulates throughout the ribbed current collectors, and distributes over the electrode.

=) On the other side, oxygen or air enter the compartment coolant tubes, run through the ribs of the current collectors.

=) On the oxygen side, the current collectors, also hold wicks which absorb water.

Electrolyte is acidic

$$2H_2 \rightarrow 4H^+ + 4e^-$$

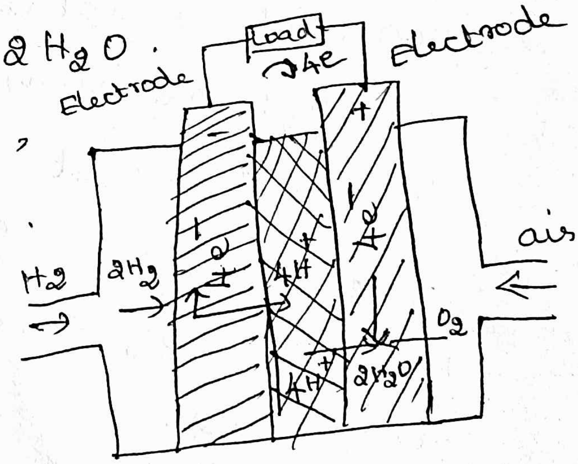
These ions are then transported to the cathode through the electrolyte and the electrons reach the cathode via the external circuit.

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O.$$

overall cell reaction is,

$$2H_2 + O_2 \rightarrow 2H_2O.$$

Cell operates at 40-60°C.



Ion Exchange Membrane cell.

(2) Fossile fuel cells :- (Modified hydrogen-oxygen cells).

Gaseous or liquid hydrocarbon is the source of hydrogen.

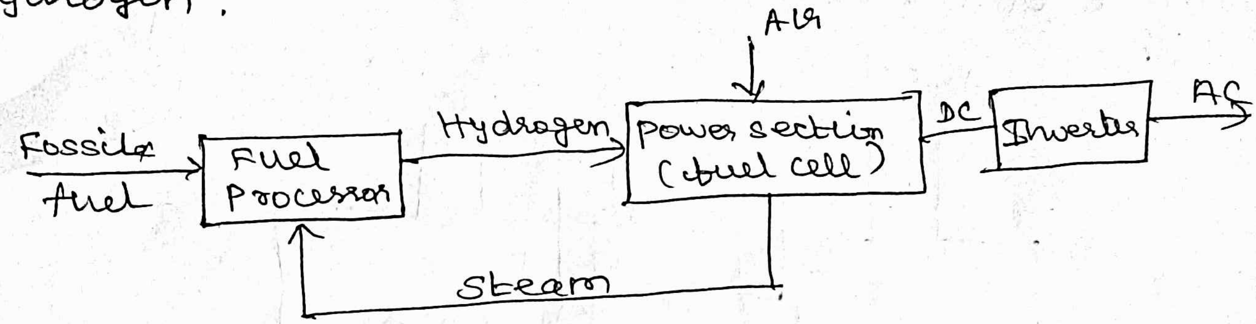


Fig: Main components of fuel cell system.

⇒ The fuel processor convert the fossil fuel into a hydrogen rich gas.

⇒ Power section consisting of actual fuel cell.

⇒ Inverter changing dc generated by the fuel cell to AC.

Primary fuel : light hydrocarbon, natural gas, naphtha.

operating temp : 150 - 200°C.

Discharge voltage : 0.7 - 0.8 V.

(3) Molten carbonate cells :-

→ High temperature fuel cells.

→ Molten carbonate mixture → electrolyte.

Molten mixture → alkali metal (lithium, Sodium and potassium). Temperature : 600-700°C.

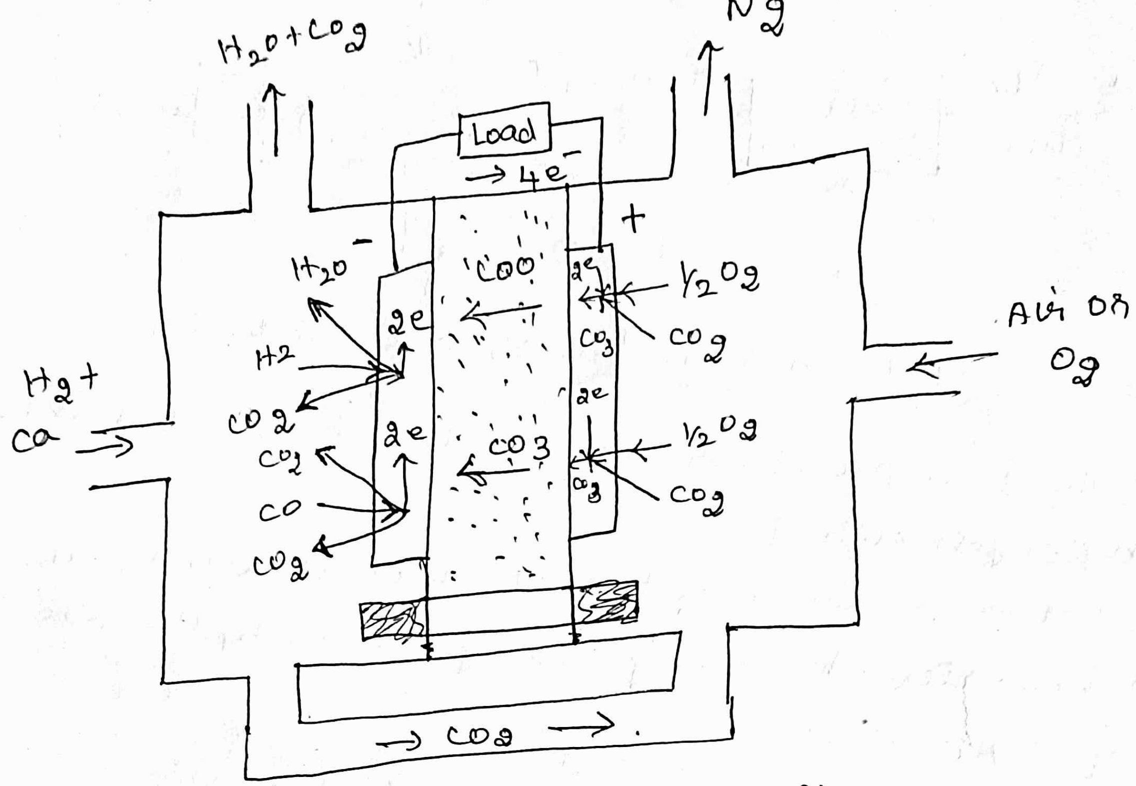
⇒ Due to high temperature, catalysts are not necessary.

Cathode:

Mixture of hydrogen & carbon monoxide → negative electrode.

Oxygen from the air → positive electrode.

e.m.f of the cell → 0.8 V.



Molten carbonate fuel cell.

⇒ Metallic electrodes are placed in direct contact with the solid electrolyte.

⇒ A hydrocarbon fuel such as methane or kerosene is used.

⇒ Fuel is reacted inside the cell to produce H_2 & CO.

⇒ At the fuel electrode, H_2 & CO react with CO_3 ions in the electrolyte releasing electrons to the electrode and forming H_2O & CO_2.

⇒ At the oxygen electrode O_2 reacts with the returning electrons and CO_2 diverted from the fuel electrode to form CO_3 ions.

Fuel electrode :

$$H_2 + CO_3^{--} = H_2O + CO_2 + 2e.$$

$$CO + CO_3^{--} = 2CO_2 + 2e.$$

Oxygen electrode

$$O_2 + 2CO_2 + 4e = 2CO_3^{--}$$

Overall cell reaction

$$H_2 + CO + O_2 = H_2O + CO_2.$$

Solid oxide Electrolyte cell :-

⇒ certain solid, ceramic oxides are able to conduct electricity at high temperatures and acts as a electrolytes for fuel cells.

Electrolyte → zirconium dioxide → This material is able to conduct oxygen ions (O_2^-) at high temperatures.

Electrode → porous nickel

operating temp → 600 – 1000° C.

fuels such as Methanol, ammonia, hydrazine also used.

Ammonia (NH_3) & oxygen (air) fuel cell :-

Ammonia gas obtained from the stored liquid, is decomposed catalytically into hydrogen & nitrogen.

part of hydrogen is burned in air and provide heat for the decomposition. Hydrogen is then supplied to the negative electrode.

Electrolyte : KOH.

Ocean Thermal Energy Conversion (OTEC)

Open cycle OTEC System (Claude Cycle)

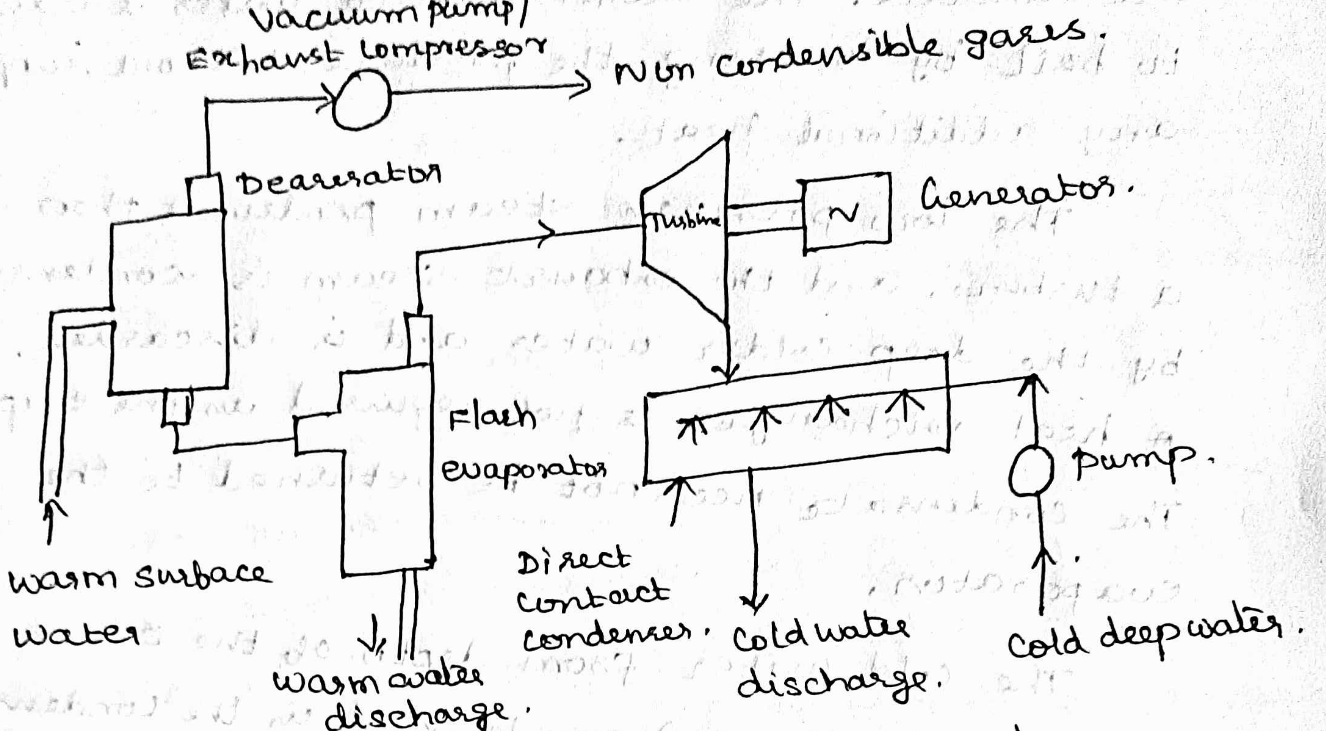


Fig: schematic of the OTEC open cycle.

In the open cycle turbine system, water is the working fluid. Utilization of sea water as the working fluid. The surface of the water acts as the collector for solar heat while the upper layer of the sea constitutes infinite heat storage reservoir.

Solar energy absorption by the water takes place according to Lambert's Law of absorption.

$$-\frac{dI(x)}{dx} = KI$$

$$I(x) = I_0 \cdot e^{-kx}$$

$I_0, I(x) \rightarrow$ Intensities of radiation at the surface ($x = 0$) at a distance x below the surface.

$K \rightarrow$ extinction coefficient ($0.05\,m^{-1}$) for clear water

$0.27 \rightarrow$ turbid fresh water.

Cathode :

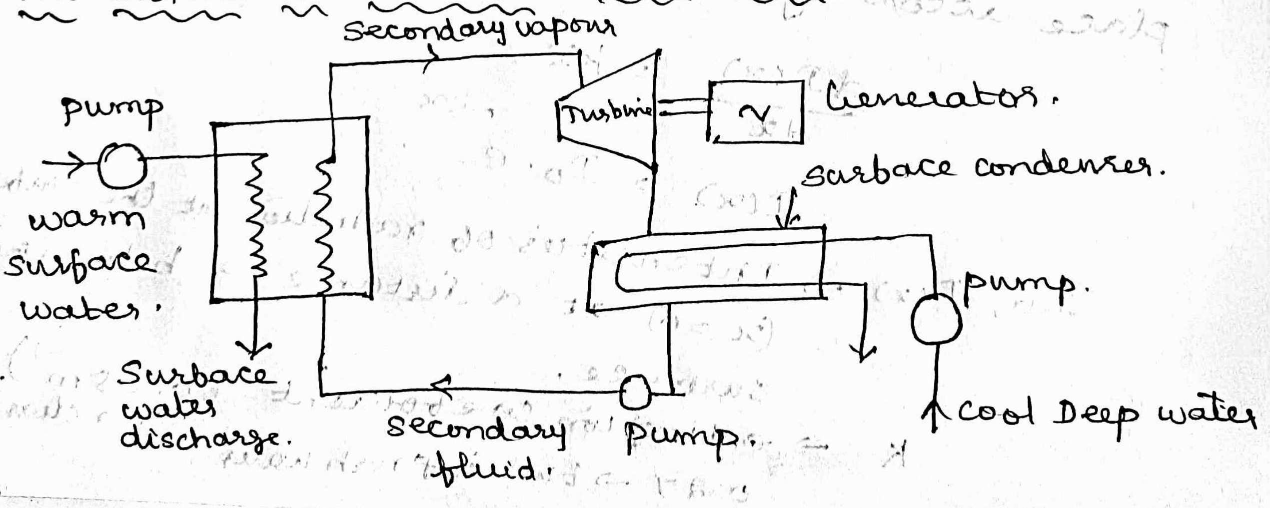
The warm surface water is passed to dearator where the non condensible gases present in the water are removed. The warm surface water is caused to boil by lowering the pressure, without supplying any additional heat.

The low pressure steam produced then drives a turbine, and the exhaust steam is condensed by the deep colder water and is discarded. A heat exchanger is not required in the evaporator The condensate need not be returned to the evaporator.

The cold water from depth of the ocean (about 1000 - 1500 m) can be used in the condensor. A heat exchanger is necessary in the condenser i.e direct contact between the exhaust steam and a cold water spray.

Due to low energy content of the low pressure steam, very large turbines or several smaller units operating in parallel required to achieve a useful electric power output.

The closed or Andersson OTEC cycle :



In the closed cycle system, a liquid working fluid such as ammonia or propane is vaporized in an evaporator (or boiler).

The heat required for vaporization is transferred from the warm ocean surface to the liquid by means of a heat exchanger. The high pressure vapour leaving the evaporator drives an expansion turbine (steam turbine). The turbine is connected to an electric generator.

The low pressure exhaust from the turbine is cooled and converted back into liquid in the condenser. The cooling is achieved by passing cold, deep ocean water from a depth of 700 to 900m or more through a heat exchanger. The liquid working fluid is then pumped back as high pressure liquid to the evaporator.

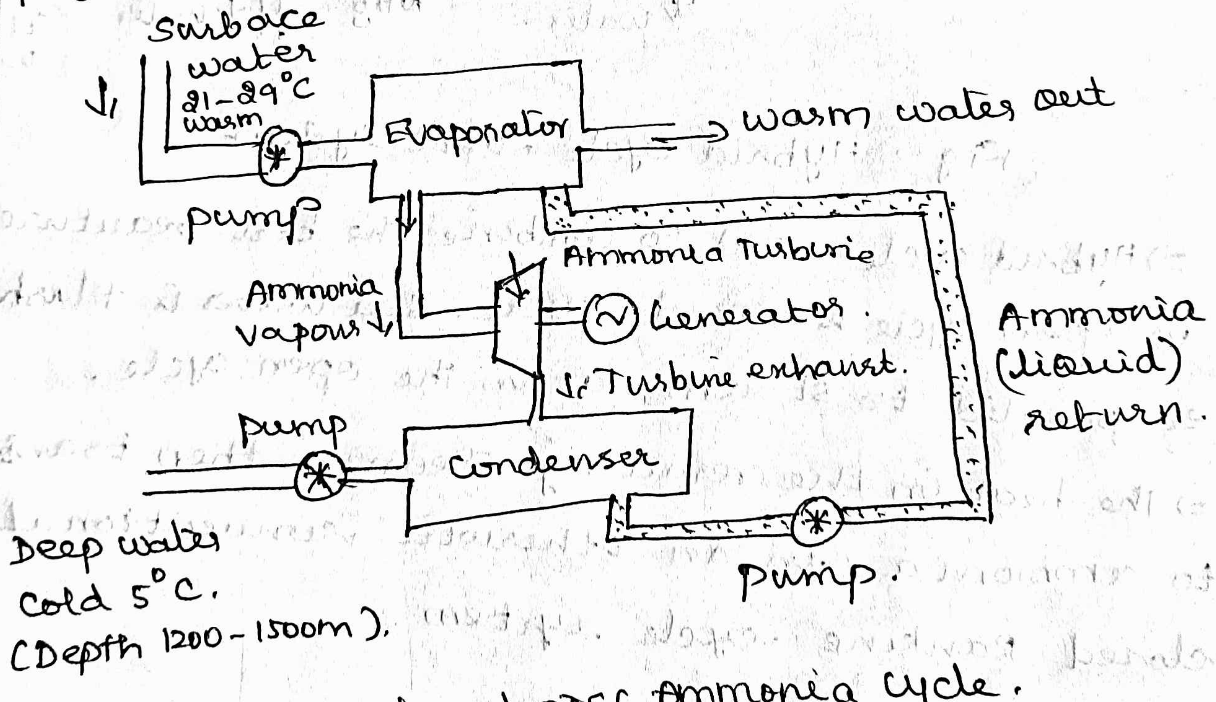


Fig : closed OTEC Ammonia cycle.

The working fluid may be ammonia, propane or a Freon, the operating pressures at the boiler and condenser are much higher than those of water. (10 bar) at the boiler.

The temperature difference in the boiler and condenser must be kept as low as possible, this cycle uses thin plate type heat exchangers which minimizes the mass and the amount of material and hence cost.

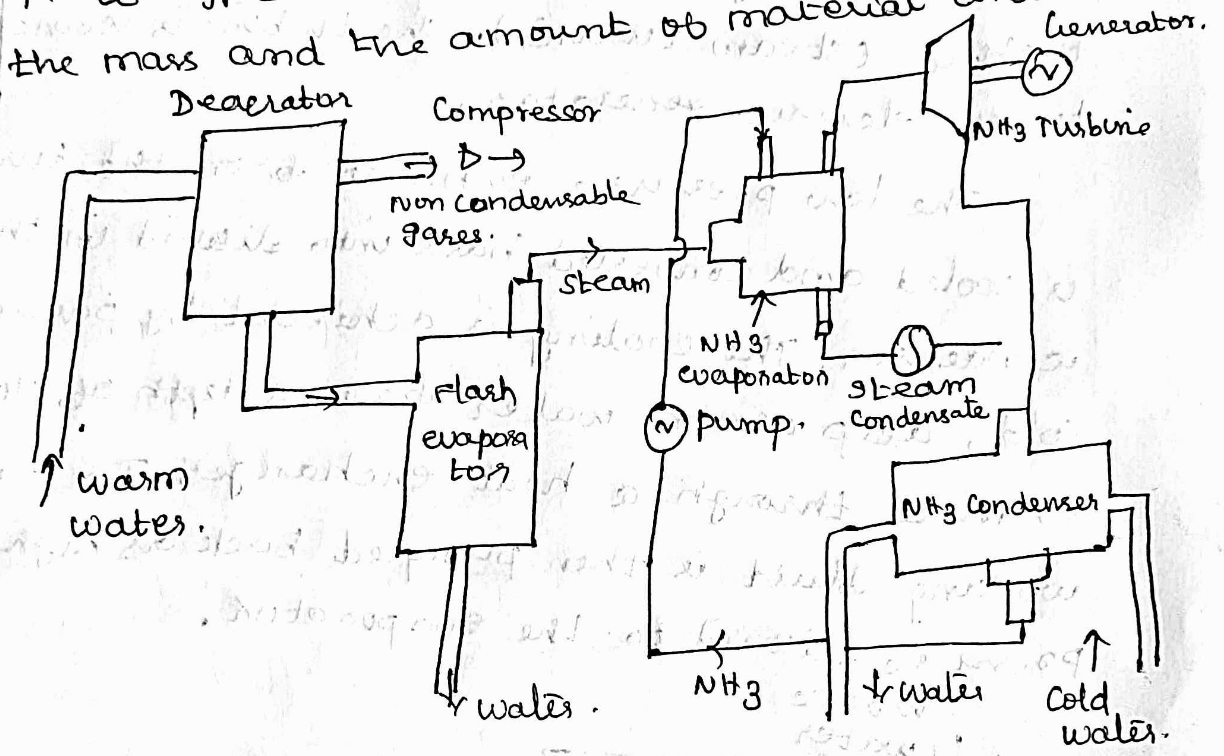


Fig : Hybrid cycle - OTEC system

=) Hybrid cycle used to combine the best features in open cycle & closed cycle. sea water is flash evaporated to steam, as in the open cycle.

=) The heat in the resulting steam is then transferred to ammonia in an otherwise conventional closed Rankine cycle system.

Heat Exchangers : (Evaporators)

The maximum efficiency for the conversion of heat into mechanical work in a turbine depends on the drop in temperature of the working fluid in its passage through the turbine and the turbine inlet temperature.

The temperature drop in the turbine is 10°C inlet temperature is 20°C (20 + 273 = 293 K).
Maximum thermal efficiency is $\frac{10}{293}$ = 0.034 or 3.4 %.

The following materials used for heat exchangers:
1) Titanium 2) Aluminium 3) Alloy of copper & nickel.
4) Plastic.

Hydrogen Production

Production of hydrogen is carried out by the steam reformation or partial oxidation of hydro. carbons (natural gas, naphthas or crude oil):

① Electrolysis Production of Hydrogen :-

The process of splitting water into hydrogen and oxygen by means of a direct electric current is known as electrolysis. Simplest method of hydrogen production.

Electrolysis cell consists of two electrodes, flat metal or carbon plates immersed in an conducting solution called the electrolyte.

A source of direct current voltage is connected to the electrodes so that an electric current flows through the electrolyte from the +ve electrodes (anode) to the negative electrode (cathode).

Cathode:

Water in the electrolyte solution is decomposed into hydrogen gas (H_2) released in cathode and oxygen (O_2) released at anode.

Electrolyte KOH solution is required because water is a very poor conductor of electricity.

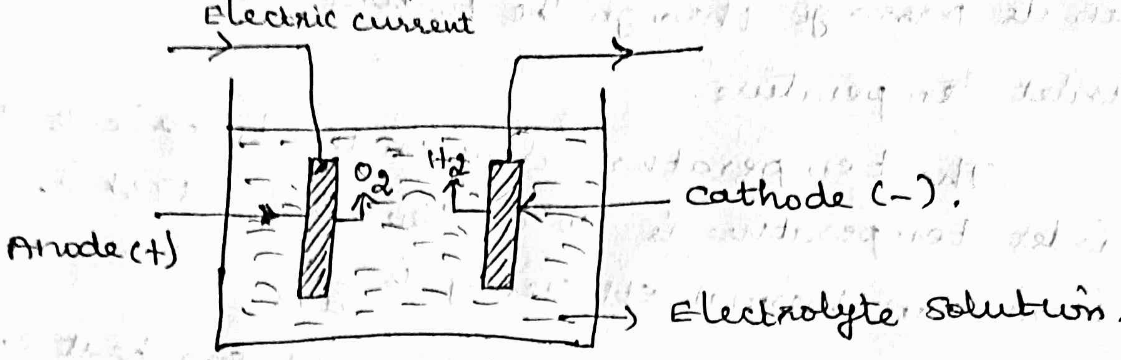


Fig: simple electrolytic cell.

A voltage of 1.23 volts sufficient for the electrolysis of water at normal temperature and pressure.

The effective electrode surface area is increased by depositing porous nickel on a wire gauge, a highly corrugated steel base.

Diaphragms prevent electronic contact between adjacent electrodes and passage of dissolved gas or gas bubble. Asbestos is the most common material for cell diaphragms.

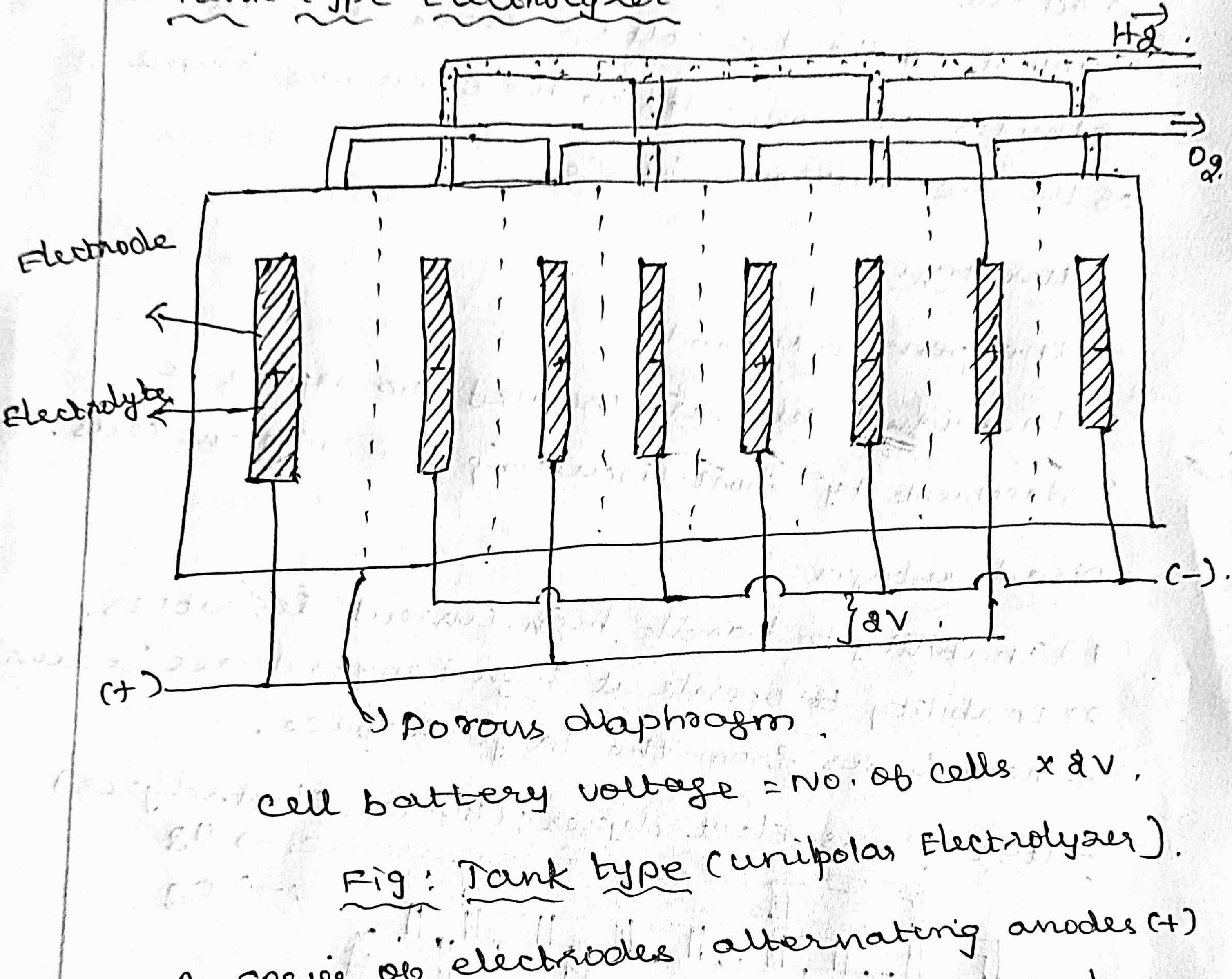
3 factors determine the usefulness of electrochemical cell for hydrogen production:

1) cell operating voltage.
2) capital cost of the plant.
3) Life time of the cell and its maintenance requirement.

Two types of electrodes arrangements are used by industry for electrolysis of water:

1) Tank type Electrolyzer.
2) Filter press or bipolar electrolyzer.

1) Tank type Electrolyzer :-



Cell battery voltage = No. of cells × 2V.

Fig : Tank type (unipolar Electrolyzer).

A series of electrodes alternating anodes (+) and cathode (−) are suspended vertically and parallel to one another in a tank filled with a 20-30 % solution of potassium hydroxide in demineralized water.

cathode.

=) Alternate electrodes usually cathodes are surrounded by porous diaphragms (e.g.: Asbestos) prevent the gas from one electrode to another electrode.

=) All the anodes are connected to the same positive terminal of the d.c voltage source and all the cathodes are connected to the same -ve terminal of the d.c current source.

Advantages:

1) Inexpensive Method.

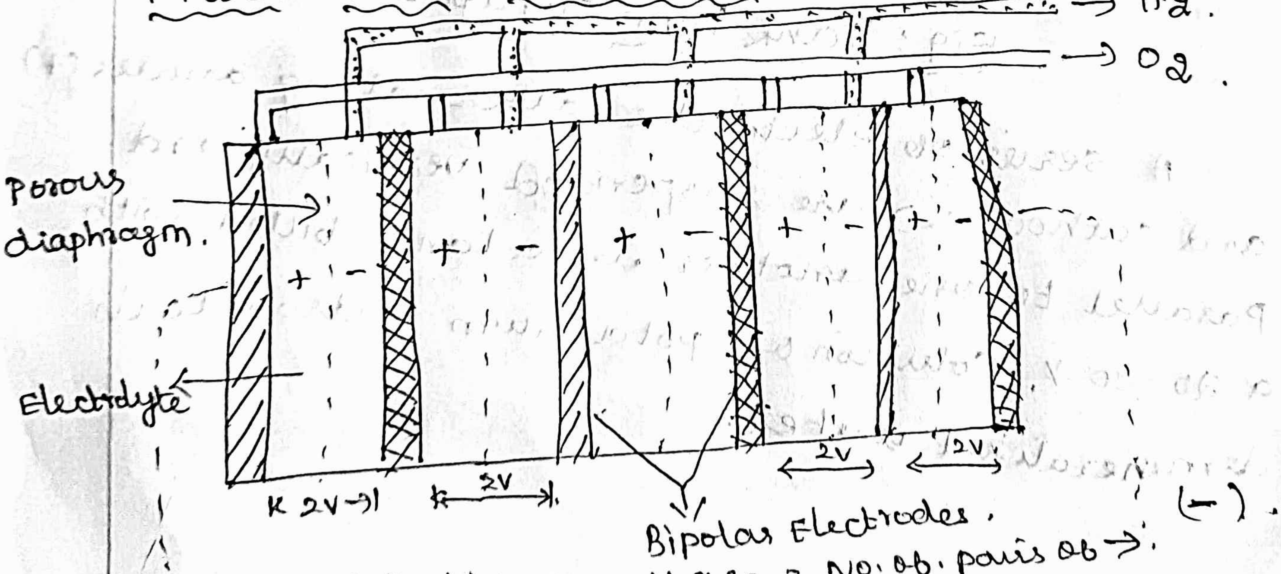
2) Individual cells are isolated for repair or replacement by short circuiting two adjacent cells.

Disadvantages:

1) Inability to handle high current densities.

2) Inability to operate at high temperatures because of heat losses from the large surface.

Filter-Press Electrolyzer: (Bipolar Electrolyzer)



(+) ← Cell Battery voltage = No. of pairs of electrodes × 2V.

One face of each plate electrode is an anode and the other face is the cathode. The cells are connected in series with an anode at one end and a cathode at the other end of the series. Total voltage required is ~~2~~ 2C volts.

C → No. of. cells in series.

The filter press electrolyzer is generally preferred because it occupies less space and can be operated at a higher current density than the tank type.

Disadvantages :

1) More difficult to maintain
2) Breakdowns in filter-press electrolyzer are rare, but occurs it is difficult and takes large time to recover.

Thermochemical Methods :-

Over all efficiency of hydrogen production would be only 25 to 30 %. The heat produced by the primary fuel could be used directly to decompose water, without the intermediary of electrical energy. The temperature required is atleast 2500° C.

A sequential chemical reaction series can be devised in which hydrogen and oxygen are produced, water is consumed, the operation is called thermochemical cycle. Energy is supplied as heat at one or more of the chemical stages. Water is taken up in one stage & H_2 & O_2 produced in separately different stages.

Chemical reaction sequences are

$$2CrCl_2 + 2HCl \rightarrow 2CrCl_3 + H_2.$$

$$2CrCl_3 \rightarrow 2CrCl_2 + Cl_2.$$

$$H_2O + Cl_2 \rightarrow 2HCl + \frac{1}{2}O_2.$$

Possible cycle for hydrogen production

① $C + H_2O \rightarrow CO + H_2.$ $\rightarrow 725^\circ C.$

$CO + 2Fe_3O_4 \rightarrow 3Fe_2O_3 + C.$ $\rightarrow 225^\circ C.$

$3Fe_2O_3 \rightarrow 2Fe_3O_4 + \frac{1}{2}O_2.$ $\rightarrow 1425^\circ C.$

② $Cd + H_2O \rightarrow CdO + H_2.$ $\rightarrow 125^\circ C.$

$CdO \rightarrow Cd + \frac{1}{2}O_2.$

③ $3FeCl_2 + 4H_2O \rightarrow Fe_3O_4 + 6HCl + H_2.$

$Fe_3O_4 + \frac{1}{4}O_2 \rightarrow \frac{3}{2}Fe_2O_3.$

$\frac{3}{2}Fe_2O_3 + 9HCl \rightarrow 3FeCl_3 + \frac{9}{2}H_2O.$

$\frac{3}{2}FeCl_3 \rightarrow 3FeCl_2 + 3/2\,Cl_2.$

$\frac{3}{2}H_2O + \frac{3}{2}Cl_2 \rightarrow 3HCl + 3/2\,O_2.$

Westinghouse Electrochemical Thermal Sulfur cycle

Two chemical reactions:

④ $H_2SO_4 \xrightarrow{1000^\circ K} H_2O + \frac{1}{2}O_2 + SO_2.$ (Thermolysis).

$2H_2O + SO_2 \xrightarrow{298-373\,K} H_2 + H_2SO_4.$ (Electrolysis).

cathode : $2H^+ + 2e^- \rightarrow H_2.$

Anode : $H_2SO_3 + H_2O \rightarrow 2H^+ H_2SO_4 + 2e^-.$

Fossil Fuel Methods :

Gaseous mixture of carbon monoxide and hydrogen is formed in the first stage, in the production of hydrogen by using a fossil fuel (natural gas, petroleum product or coal).

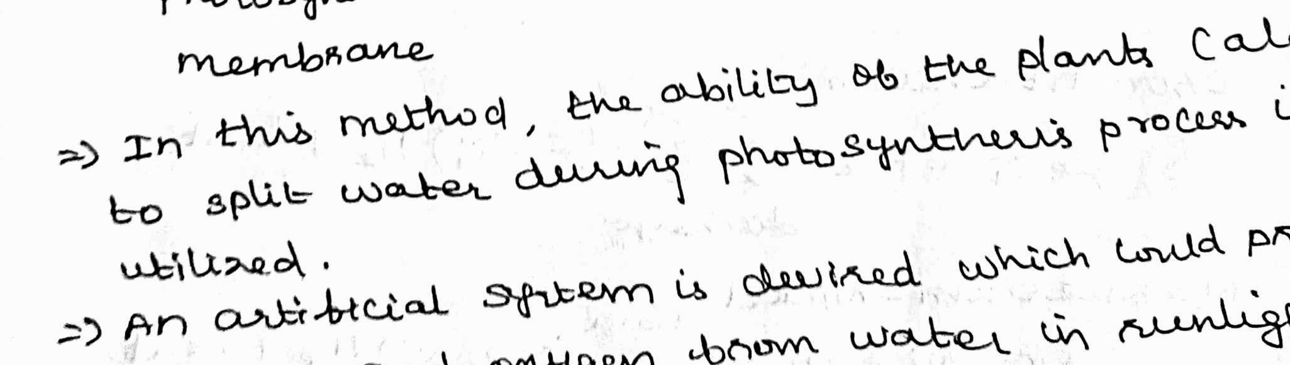
To remove the carbon monoxide, the mixture is submitted to the water gas shift reaction with steam.

$$CO + H_2O = CO_2 + H_2 + 1440 \, kJ/kg.$$

If the small amount of carbon-monoxide and dioxide remaining are undesirable, they can be converted into methane.

$$\underset{\text{Iron}}{Fe} + \underset{\text{steam}}{H_2O} \xrightarrow{1095^\circ C} \underset{\text{Iron oxide}}{FeO} + \underset{\text{Hydrogen}}{H_2}.$$

Biophotolysis :



=> In this method, the ability of the plants (algae) to split water during photosynthesis process is utilized.

=> An artificial system is desired which would produce hydrogen and oxygen from water in sunlight

Chemical ...

using isolated photosynthetic membrane and other catalysts.

=> This process is essentially a decomposition of water using photons in the presence of biological catalysts, the reaction is called Photolysis of water.

Hydrogen Storage.

1) Hydrogen can be stored as a discrete gas or liquid or in a chemical compound. For a given amount of energy, hydrogen weighs about one third of the fossil fuels. It is bulkier.

2) In gaseous form it occupies 3.6 times the volume occupied by natural gas and in liquid form it occupies 3.8 times the volume occupied by gasoline.

3) The volume penalty is 20 to 50 %. less since hydrogen can be converted to other forms of energy at the user end more efficiently than fossil fuels.

Lanthanum - Nickel:

$$LaNi_5 + 3H_2 \underset{Discharge}{\overset{Charge}{\rightleftharpoons}} (LaNi_5)H_6 + heat.$$

Iron Titanium

$$FeTi + H_2 \underset{discharge}{\overset{Charge}{\rightleftharpoons}} (FeTi)H_2 + heat.$$

Magnesium - Nickel

$$Mg_2Ni + 2H_2 \underset{discharge}{\overset{charge}{\rightleftharpoons}} (Mg_2Ni)H_4 + heat.$$