

**A LECTURE NOTE  
ON  
RENEWABLE ENERGY  
(TH-4)**



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## Th4. RENEWABLE ENERGY SYSTEMS

(Elective – B)

Name of the Course: Diploma in Electrical Engineering			
Course code:		Semester	6 <sup>th</sup>
Total Period:	75	Examination	3 hrs
Theory periods:	4 P / week	Class Test:	20
Tutorial:	1 P / week	End Semester Examination:	80
Maximum marks:	100		

### A. RATIONALE:

It is well known that a plenty of energy is needed to sustain industrial growth and agricultural production. The existing sources energy such as coal, oil, uranium etc may not be sufficient to meet the ever increasing energy demands. These conventional sources of energy are also depleting and may be exhausted at the end of the century or the beginning of the next century.

Consequently sincere efforts shall have to be made by the scientists and engineers in exploring the possibilities of harnessing energy from several energy sources.

### B. OBJECTIVE:

After completion of this subject the student will be able:

1. Power production from pollution free forces and environment friendly resources.
2. Production of power form nature at free of cost.
3. Solar energy conversion is noiseless and cheap.

### C. Topic wise distribution of periods:

Sl. No.	Topics	Periods
1.	Introduction to Renewable energy	5
2.	Solar Energy	15
3.	Wind Energy	12
4.	Biomass Power	12
5.	Other Energy Sources	16
	<b>Total</b>	<b>60</b>

### D. COURSE CONTENTS

1. **Introduction to Renewable energy:**
  - 1.1. Environmental consequences of fossil fuel use.
  - 1.2. Importance of renewable sources of energy.
  - 1.3. Sustainable Design and development.
  - 1.4. Types of RE sources.
  - 1.5. Limitations of RE sources.
  - 1.6. Present Indian and international energy scenario of conventional and RE sources
2. **Solar Energy:**
  - 2.1. Solar photovoltaic system-Operating principle.

- 2.2. Photovoltaic cell concepts
    - 2.2.1. Cell, module, array, Series and parallel connections. Maximum power point tracking (MPPT).
  - 2.3. Classification of energy Sources.
  - 2.4. Extra-terrestrial and terrestrial Radiation.
  - 2.5. Azimuth angle, Zenith angle, Hour angle, Irradiance, Solar constant.
  - 2.6. Solar collectors, Types and performance characteristics,
  - 2.7. Applications: Photovoltaic - battery charger, domestic lighting, street lighting, water pumping, solar cooker, Solar Pond.
3. **Wind Energy:**
- 3.1. Introduction to Wind energy.
  - 3.2. Wind energy conversion.
  - 3.3. Types of wind turbines
  - 3.4. Aerodynamics of wind rotors.
  - 3.5. Wind turbine control systems; conversion to electrical power:
  - 3.6. Induction and synchronous generators.
  - 3.7. Grid connected and self excited induction generator operation.
  - 3.8. Constant voltage and constant frequency generation with power electronic control.
  - 3.9. Single and double output systems.
  - 3.10. Characteristics of wind power plant.
4. **Biomass Power:**
- 4.1. Energy from Biomass.
  - 4.2. Biomass as Renewable Energy Source
  - 4.3. Types of Biomass Fuels - Solid, Liquid and Gas.
  - 4.4. Combustion and fermentation.
  - 4.5. Anaerobic digestion.
  - 4.6. Types of biogas digester.
  - 4.7. Wood gassifier.
  - 4.8. Pyrolysis,.
  - 4.9. Applications: Bio gas, Bio diesel
5. **Other Energy Sources**
- 5.1. Tidal Energy: Energy from the tides, Barrage and Non Barrage Tidal power systems.
  - 5.2. Ocean Thermal Energy Conversion (OTEC).
  - 5.3. Geothermal Energy – Classification.
  - 5.4. Hybrid Energy Systems.
  - 5.5. Need for Hybrid Systems.
  - 5.6. Diesel-PV, Wind-PV, Microhydel-PV.
  - 5.7. Electric and hybrid electric vehicles.

**Syllabus coverage up to Internal assessment**

Chapters: 1, 2 and 3.

## Solar energy

①

Solar energy is one of the most reliable renewable energy sources. Energy produced and radiated by Sun reaches the earth.

Solar Insolation The amount of solar energy received by the earth's surface at a specific geographic location. It is usually measured in kilowatt-hours per square meter ( $\text{kWh}/\text{m}^2$ )

Solar irradiance This is the amount of solar energy incident on a surface per unit area per unit time. It is represented in  $\text{kWh}/\text{m}^2/\text{sec}$  or  $\text{kWh}/\text{m}^2/\text{day}$ .

### Types of Solar radiation

- 8% Ultraviolet radiation
- 46% visible light
- 46% infrared radiation

### Direct/beam radiation

It is the portion of solar radiation that doesn't get absorbed or scattered in the atmosphere & instead reaches directly. If it is interrupted by an opaque object, it casts a shadow.

### Diffuse radiation

This is the solar radiation which reaches the earth surface after multiple bounces due to scattering by molecules and ~~particulates~~ particulates present in the atmosphere.

## Global/Total Radiation

It is the sum of direct and diffuse radiation that falls on any horizontal surface on the earth.

$$\text{Global Radiation} = \text{Beam/direct radiation} + \text{diffuse radiation}$$

## Solar photovoltaic (PV) system

→ Solar photovoltaic is the process of directly converting sunlight into electricity using a device called known as a solar cell or photovoltaic cell.

→ Solar cells are made of semi-conductor materials. Silicon (Si) is the most commonly used semi-conductor material in the fabrication of solar cells.

## Solar cell parameters

### Short-circuit current ( $I_{sc}$ )

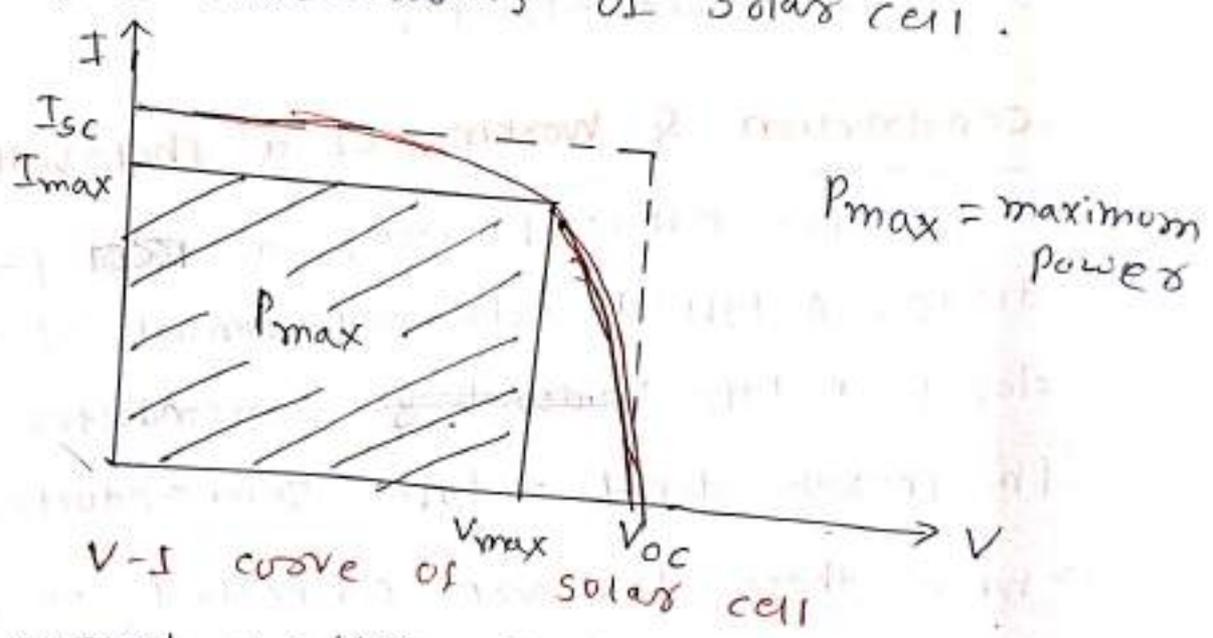
When the voltage across the cell terminals is zero, current flows through solar cell. The solar cell is short-circuited in this condition. The maximum current produced by a solar cell is denoted by  $I_{sc}$ .

### Open-circuit voltage ( $V_{oc}$ )

When no-load is connected, the open circuit voltage is measured across two terminals of the solar cell. The typical value of  $V_{oc}$  is 0.5 to 0.6 volt.

### V-I characteristics of solar cell

A graph of o/p voltage versus current for different levels of solar insolation & cell temperature is the V-I characteristics of solar cell.



The current at which maximum power occurs is denoted by  $I_{max}$ , and the voltage at which maximum power occurs is denoted by  $V_{max}$ .

### Maximum power point (MPP)

→ It is the maximum electrical power that a solar cell can produce under standard test conditions (STC).

→ In STC, solar intensity is  $1000 \text{ W/m}^2$  & solar cell temperature is  $25^\circ\text{C}$ .  
it is denoted by  $P_m$

It represents the point on V-I curve where the product of current & voltage is maximum. on the V-I curve of solar cell, it occurs at the bend point of the curve.

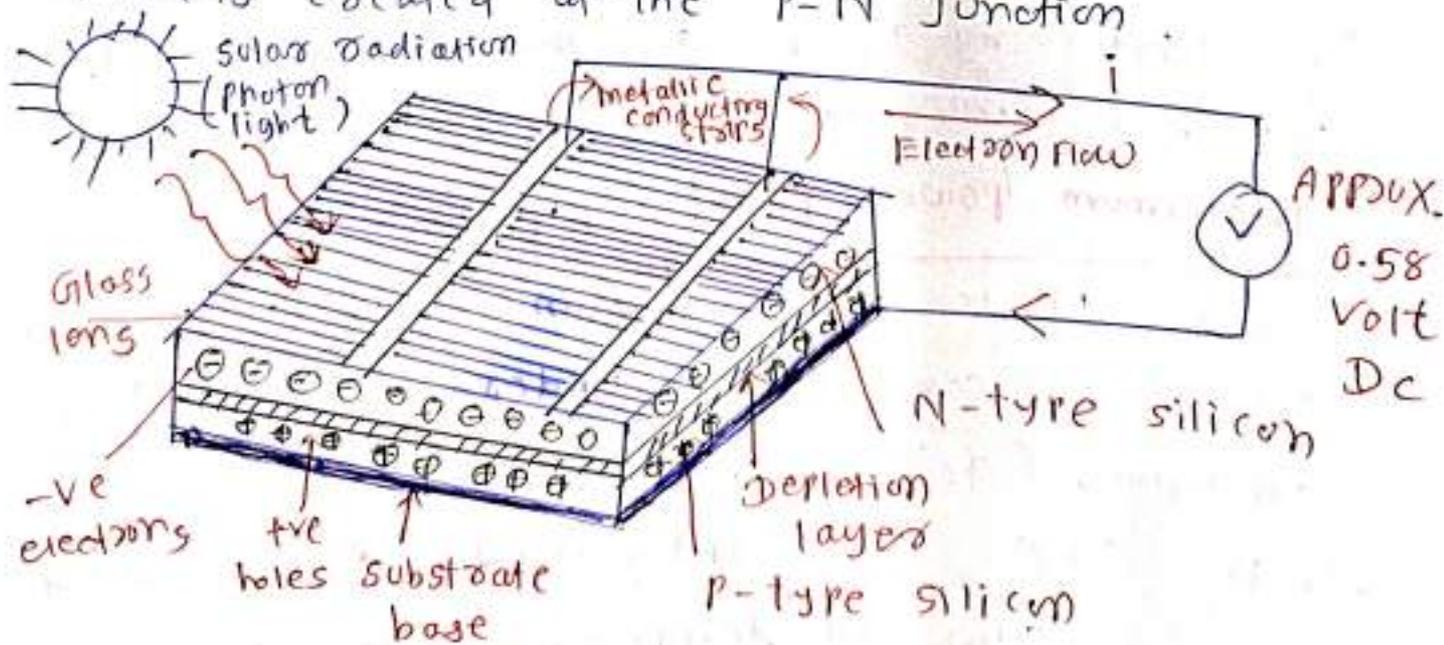
### Working of Photovoltaic (Solar) cell

When a photovoltaic cell is exposed to sunlight, it produces voltage or current, it is called as photo-voltaic effect.

### Construction & Working of a Photovoltaic cell

→ A solar cell is basically a P-n junction diode. A typical solar cell consists of a boron doped P-type semiconductor & a Phosphorous doped n-type semiconductor.

→ When these two are connected, an Electric Field is created at the P-N Junction.



Working of Solar cell

## Working

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- i) When sunlight strikes a solar cell, photons are absorbed. Some photons have energies greater than the energy difference b/w the valence & conduction bands of the solar cell's semiconductor material.
- ii) After absorbing such a photon, an electron in the semi-conductor material jumps to the conduction band, forming an electron-hole pair. These are known as light generated electrons & holes. The electric field created at the p-n junction gives them momentum & direction.
- iii) The electrons near the junction move to n-type side & hole moves to the p-type side. As a result, a potential difference is created between the two sides of the junction & if the two sides are connected by an external-load, current flows from positive (+) to negative (-ve).
- iv) A typical single PV cell is about the size of a compact disc. due to its small size, a single solar cell can only generate a limited voltage & current. it can generate 0.5 - 0.6 volts of direct current (DC) voltage.

The power generated by a solar cell is determined by its efficiency & its size.

## Types of Solar cell

Based on the types of crystal used, solar cells can be classified as.

1. Monocrystalline silicon cells
2. Polycrystalline silicon cells
3. Amorphous silicon cells

### 1. Monocrystalline silicon cells (1st generation)

The monocrystalline silicon ~~cell~~ <sup>cell</sup> is produced from <sup>pure</sup> silicon (silicon crystal), since the monocrystalline silicon is pure & defect free, the efficiency of cell will be higher.

### 2. Polycrystalline solar cell (2nd generation)

In polycrystalline solar cell, liquid silicon is used as raw material & polycrystalline silicon was obtained followed by solidification process. The materials contain various crystalline sizes. Hence the efficiency ~~is~~ of this type of cell is less than monocrystalline cell.

### 3. Amorphous silicon (Thin Film) solar cells

→ Amorphous silicon (Thin Film) was obtained by depositing silicon film on the substrate like glass plate.

→ The layer thickness amounts to less than 1  $\mu\text{m}$ .

- The efficiency of amorphous cells is much lower than that of the other two cell types.
- They are mainly used in low power applications.

Material	efficiency
Monocrystalline silicon	16-18%
Polycrystalline silicon	15-17%
Amorphous silicon	6-7%

Solar cell

A solar cell or photovoltaic cell is an electrical device that converts the energy of light directly into electrical energy by the photovoltaic effect.

Solar PV module

→ A base single cell cannot be used for outdoor energy generation by itself. It is because

- i) the o/p of a single cell is very small
- ii) it requires protection (encapsulation) against dust, moisture, mechanical shocks and outdoor harsh conditions. (0.5-0.6 volt)

→ A larger voltage & current can be generated by connecting a no. of solar cells together called solar module.

## Types of Solar cell

(8)

→ Most common commercial modules have a series connection of 32 or 36 silicon cells to make it capable of charging a 12 volt storage battery.

### Solar PV Panel

→ Several solar modules are connected in series/parallel to increase the voltage/current ratings.

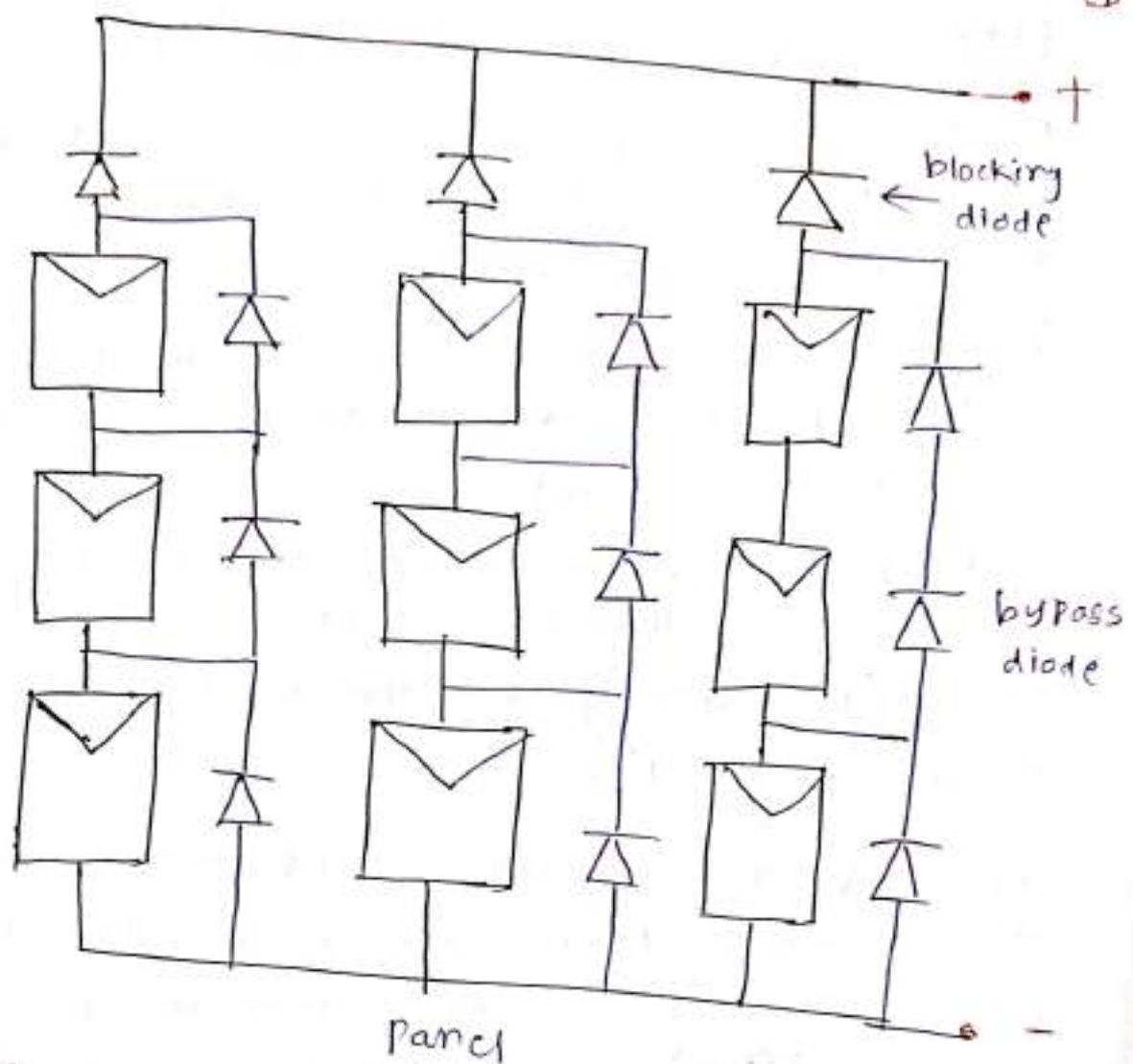
→ When modules are connected in series, it is desirable to have each module's maximum power production occur at the same current.

→ When modules are connected in parallel, it is desirable to have each module's maximum power production occur at the same voltage.

→ So solar panel is a group of several solar photovoltaic systems modules connected in series-parallel combination in a frame that can be mounted on a structure.

→ In parallel connection of ~~modules in a panel~~, blocking diodes are connected in series with each string of modules, so that if any string should fail, the power o/p of the remaining series strings will not be absorbed by the failed string.

→ Also bypass diodes are installed across each module, so that if one module should fail, the o/p of the remaining modules in a string will be bypass the failed module.



(Series-parallel connection of modules)

Solar PV-array

→ A large No. of interconnected solar panels, known as solar PV array, are installed in an array field. These panels must be installed as stationary or with sun tracking mechanism.

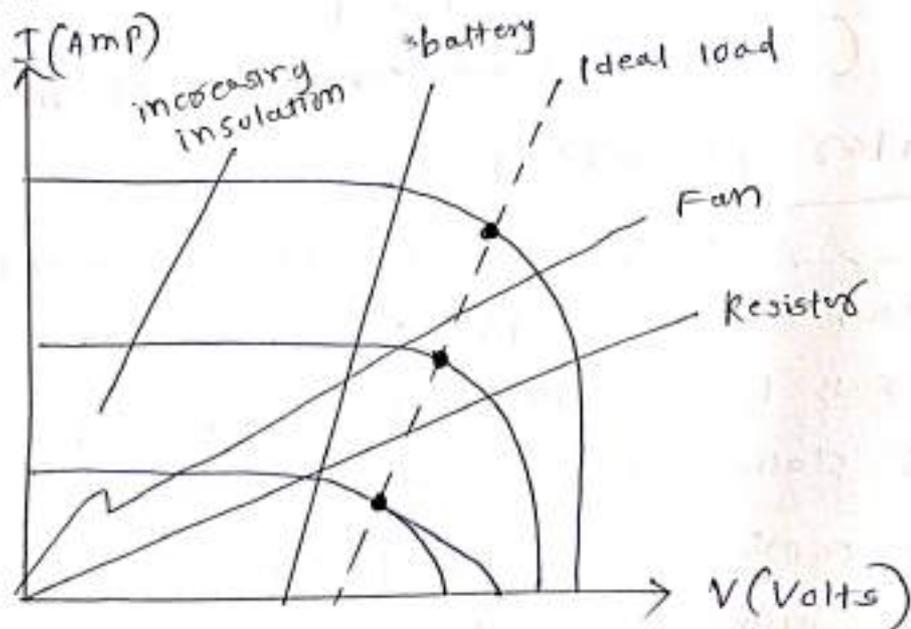
→ connecting many PV modules in series results in higher voltages, while connecting many PV modules in parallel results in higher current.

(The mixing of PV modules from different manufactures in a single PV array is not recommended)

## Maximum power point tracking (MPPT)

- i) When a solar PV system is deployed for practical applications, the I-V characteristics keeps on changing with insolation & temperature.
- ii) In order to receive maximum power the load must adjust accordingly to track the maximum power point.
- iii) MPPT is an electronic DC to DC converter that optimises the match between the solar array (PV panels) and the battery bank or utility grid. i.e.

→ The I-V characteristics of PV system along with some common loads are shown. An ideal load is one that tracks the maximum power point.



→ If the operating point departs significantly from maximum power point, it may be desirable to ~~impose~~ interpose an electronic maximum power

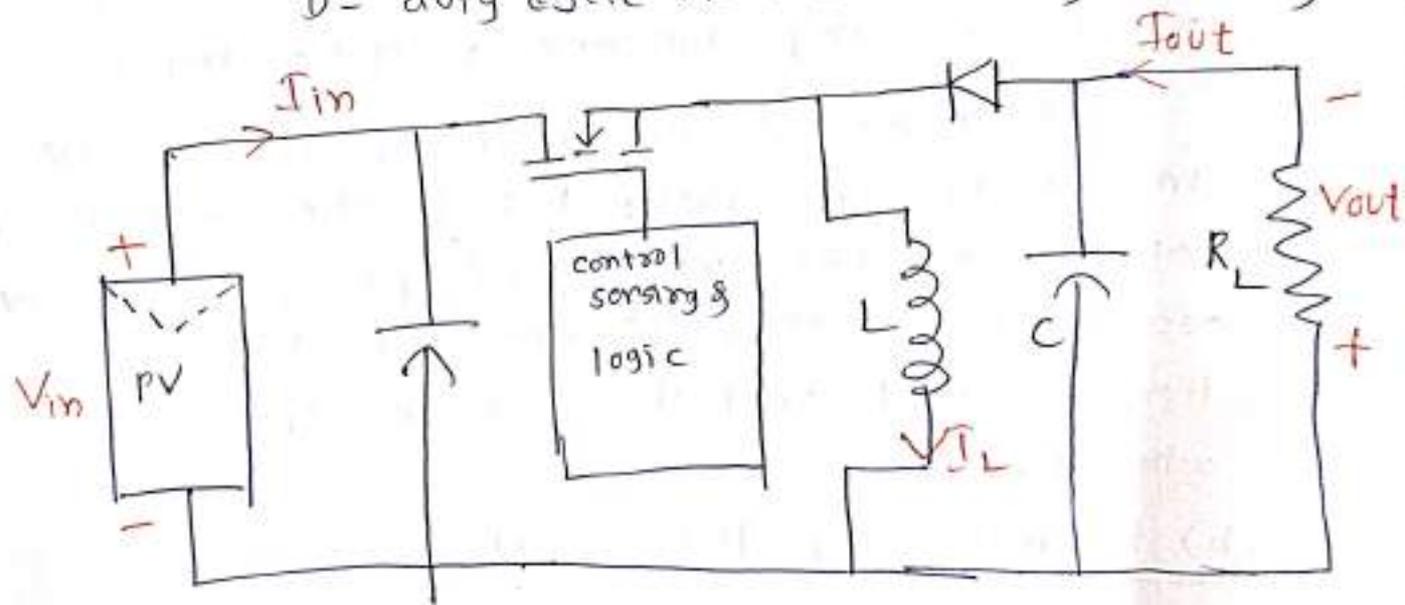
Point tracker (MPPT) between PV system & load.

(iv) Generally MPPT is an adaptation of dc-dc switching voltage regulator. Coupling to the load for maximum power transfer may require either providing higher voltage at lower current or lower voltage at higher current.

(v) A buck-boost scheme is commonly used with voltage & current sensors tied into a feedback loop using a controller to vary the switching times. The o/p voltage of a buck-boost converter is

$$V_{out} = \frac{D}{1-D} V_{in}$$

D = duty cycle of the MOSFET, (0 < D < 1)



(Maximum power point tracker using buck-boost converter)  
 $P = VI$

The power o/p of a PV system is given by

$$P \Delta P = (I + \Delta I) (V + \Delta V)$$

$$\Delta P = \Delta V \cdot I + \Delta I \cdot V$$

$\Delta P$  must be zero at peak points, therefore, at the peak point the above expression in the

limit becomes  $\frac{dV}{dI} = -\frac{V}{I}$

$\frac{dV}{dI}$  = dynamic impedance of the source, which is required to be equal to negative of static impedance  $\frac{V}{I}$ .

There are 3 possible strategies for operation of an MPPT.

- by monitoring dynamic & static impedance.
  - by monitoring power o/p
  - by fixing the o/p voltage as a ~~function~~ <sup>function</sup> of  $V_{oc}$ .
- a) by monitoring dynamic & static impedances

A small signal current is being periodically injected into an array bus & the dynamic as well as static bus impedances ( $Z_d$  &  $Z_s$  respectively) are being measured. The operating voltage is then adjusted until the condition  $Z_d = -Z_s$  is achieved.

b) by monitoring power o/p

From the shape of P-V characteristics, it is clear that the slope,  $\frac{dP}{dV}$  is zero at maximum power point. This property is utilised to track the maximum power point. Voltage is adjusted & power o/p is sensed. The operating voltage is increased as long as  $\frac{dP}{dV}$  is positive. That is voltage is increased

as long as we get increased ~~power~~ o/p. if  $dP/dV$  is sensed negative, the operating voltage is decreased. The voltage is held unaltered if  $dP/dV$  is near zero within a preset dead band.

c) by fixing the o/p voltage as a fraction of  $V_{oc}$

This method makes use of the fact that for most PV cells the ratio of the voltage at maximum power point to the open circuit voltage, is approximately constant (say  $k$ ). In order to implement this principle, an additional identical unloaded cell is installed on the array to face same environment as the module in use & its open circuit voltage  $V_{oc}$  is continuously measured. The implementation of this scheme is simplest among all the available schemes.

classification of energy source

i) central power stations

→ central PV power ~~system~~ stations are similar in concept to any other conventional central power station. They feed power to grid. These are being proposed in few MW range to meet day time peak loads only.

→ central PV power stations of upto 6 MW (Peak) capacities have already been experimentally within USA & future. While the concept ~~of~~ has been demonstrated through such experimental plants, the capital costs are currently somewhat high

For their commercial exploitation.

## (ii) distributed system

distributed form of energy use is unique and much more successful with solar and most other renewable energy sources. These systems can be subdivided into 3 parts.

### (a) standalone system

It is located at the load centre & dedicated to meet all the electrical loads of a village / community or a specific set of loads. Energy storage is generally essential. It is most relevant & successful in remote & rural areas having no access to grid supply.

### (b) Grid-interactive system

→ This system is connected to the utility grid with two-way ~~metering~~ metering system. It may be a small rooftop system meant for the whole village or community.

→ e It meets day time requirements of the house owners without any battery backup & surplus power is fed to the grid. During peak hours & nights, the energy shortage may be met from grid.

### (c) Small system for consumer Applications

These systems are meant for low energy consumer devices requiring power in the range of microwatts to high & mostly designed for indoor applications e.g. calculators, watches, electronic games etc.

## Extra-terrestrial and terrestrial radiations

→ The intensity of solar radiations keeps on attenuating as it propagates away from the surface of the sun, though the wavelength remains unchanged.

→ Solar radiation incident on the outer atmosphere of the earth is known as extra-terrestrial radiation ( $I_{ext}$ ).

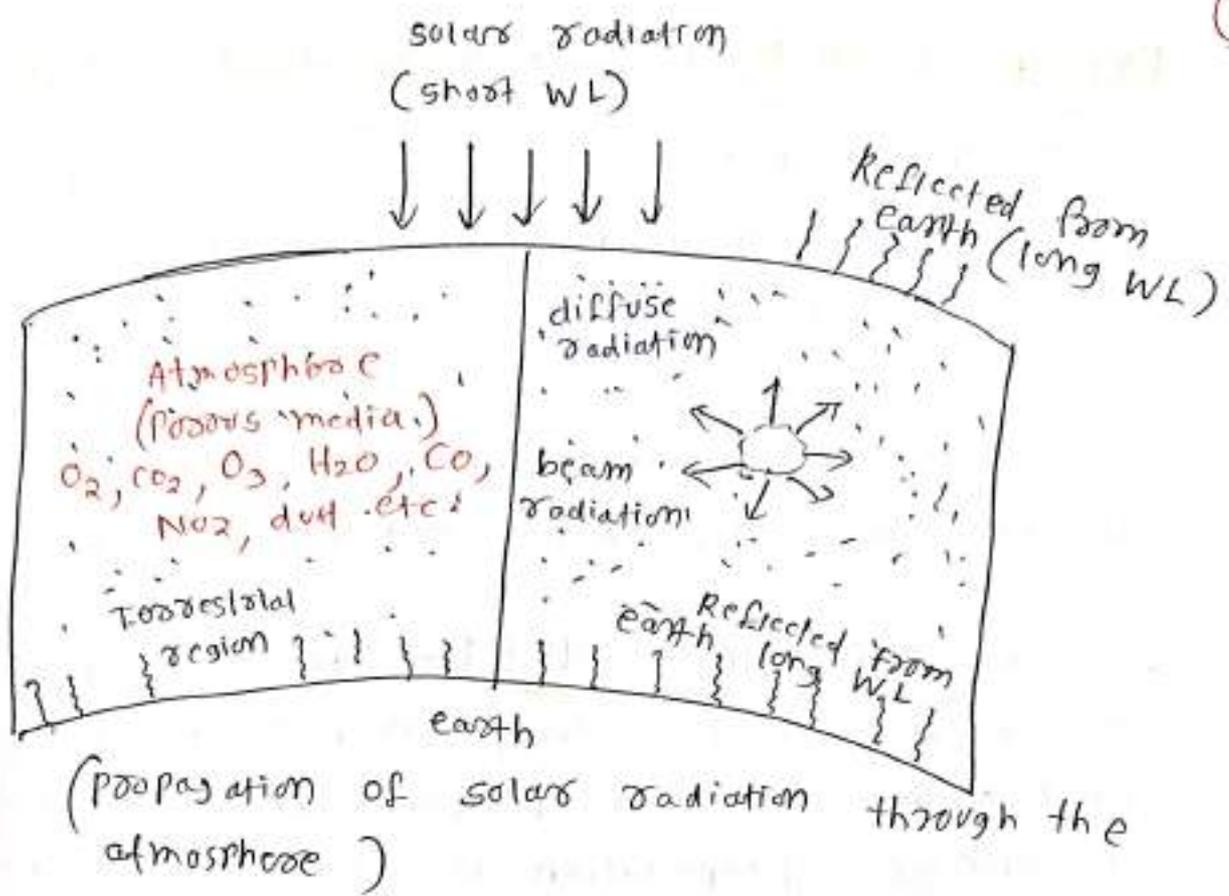
→ The solar constant ( $I_{sc}$ ) is defined as the energy received from the sun per unit time on a unit area of surface perpendicular to the direction of propagation of radiation at the top of the atmosphere and at the earth's mean distance from the sun.

→ The world radiation centre (WRC) has adopted the value of the solar constant as  $1367 \text{ W/m}^2$ .

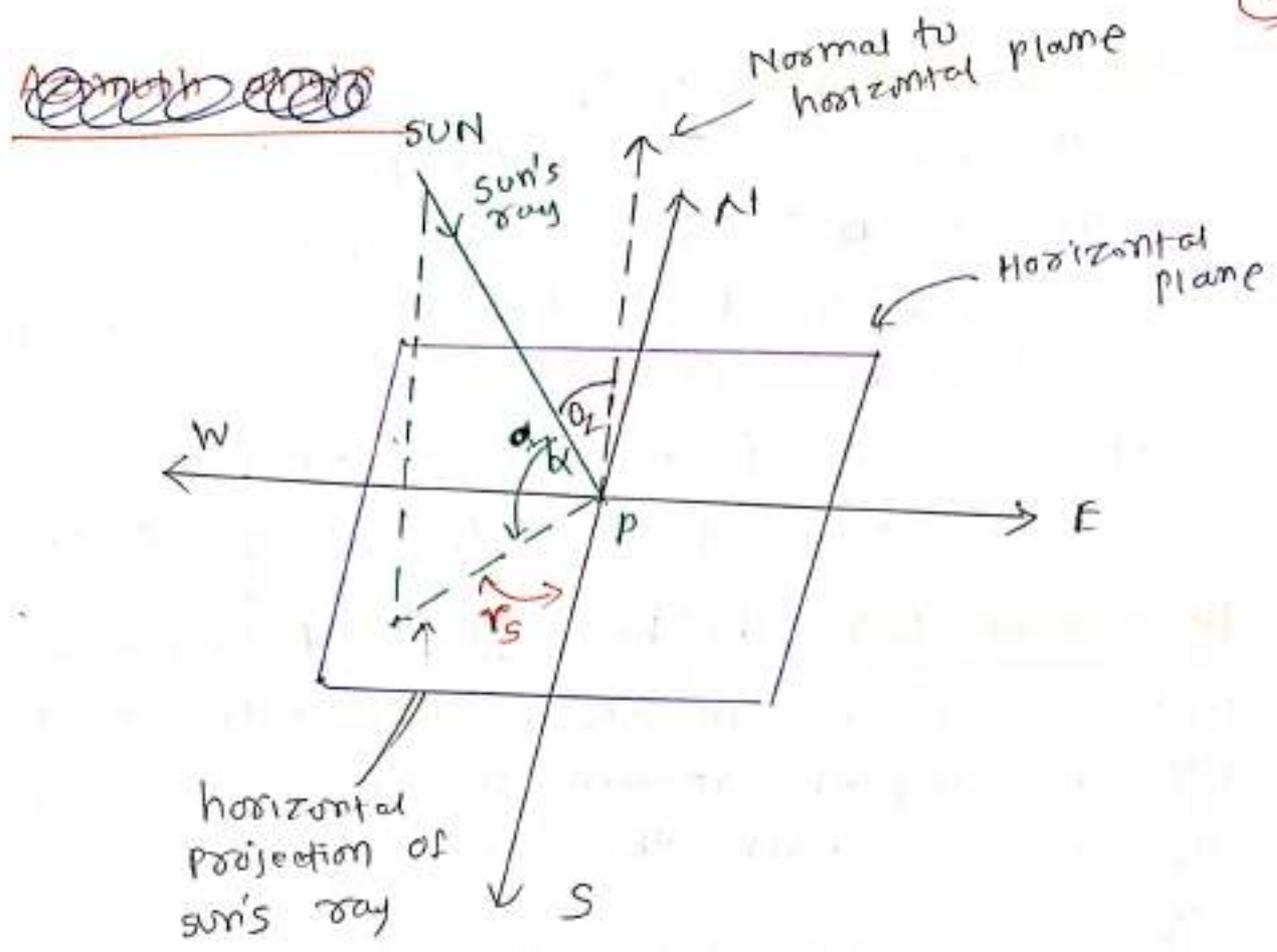
→ The extra-terrestrial radiation deviates from the solar constant value due to two reasons.

→ The 1st is the variation of in the radiation emitted by the sun itself. The variation due to this reason is less than  $\pm 1.5\%$  with different periodicities. The second is the variation of the earth-sun distance arising from the earth's slightly elliptic path. The variation due to this reason is  $\pm 3\%$  and is given by

$$I_{ext} = I_{sc} \left[ 1.0 + 0.033 \cos\left(\frac{360n}{365}\right) \right] \text{ W/m}^2$$



- The extraterrestrial radiation, being outside the atmosphere is not affected by atmospheric conditions.
- while passing through the atmosphere, it is subjected to mechanism of atmospheric absorption & scattering depending upon atmospheric condition, depleting its intensity.
- The solar radiation that reaches earth surface after passing through the earth's atmosphere is known as terrestrial radiation.
- The term solar radiation (incident solar radiation) is defined as the solar radiation received on a flat horizontal surface on the earth.



Inclination angle ( $\alpha$ ) The angle between sun's ray & its projection on a horizontal surface is known as the inclination angle ( $\alpha$ ).

$\alpha = 0^\circ$  at sun rise & sun set.

Zenith angle ( $\theta_z$ ) The angle between the sun's ray & the perpendicular (normal) to horizontal plane is known as the zenith angle ( $\theta_z$ ).

→ Zenith angle is complement of inclination angle (altitude angle).

i.e.  $(\alpha + \theta_z) = 90^\circ$

At sunrise zenith angle is  $+90^\circ$ ,  
 whereas at sunset it is  $-90^\circ$ .

Solar Azimuth angle ( $\gamma_s$ ).

→ The angle on a horizontal plane, between the line due south and the projection of sun's ray on the horizontal plane is known as solar azimuth angle ( $\gamma_s$ )

→ It is considered as positive when it is measured from south towards west.  $\overset{W}{\curvearrowright}$  +ve

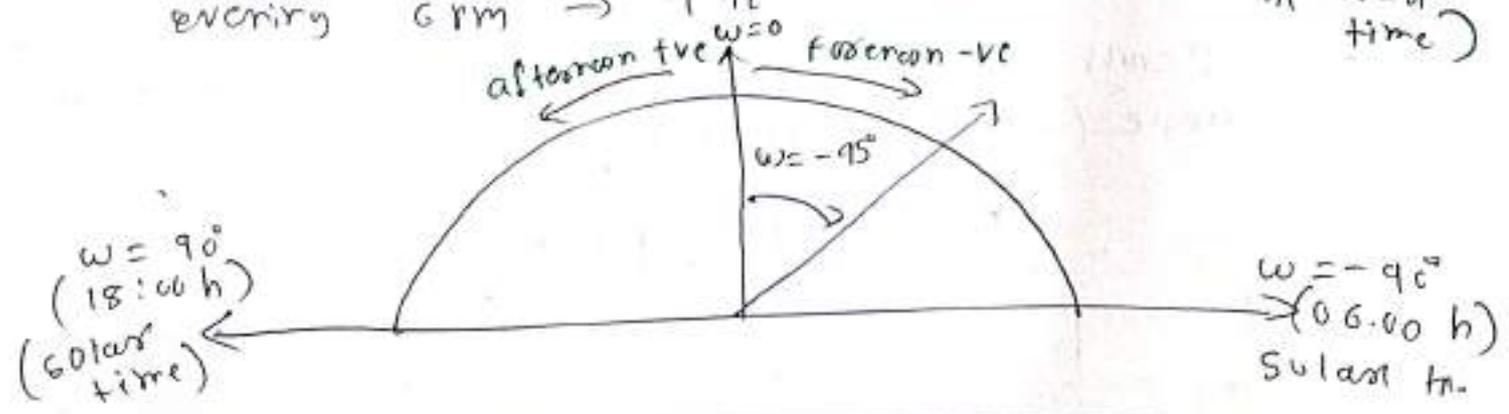
Hour angle ( $\omega$ ) The hour angle at any moment is the angle through which the earth must turn to bring the meridian of a point directly in line with the sun ray.

(0) it is the angle representing the position of the sun w.r.t. clock hour & with reference to sun position at 12:00 noon.

$\boxed{\omega = 15(LST - 12)}$  LST = Local solar time.

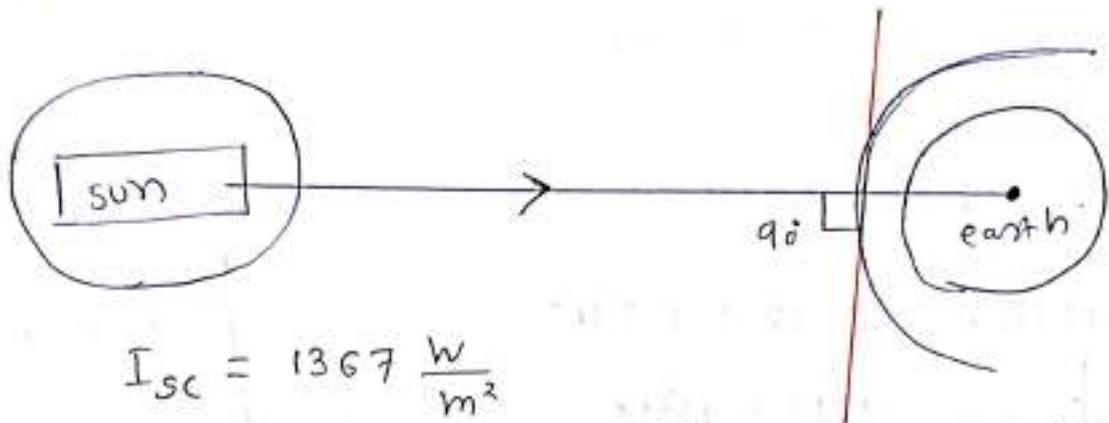
Hour angle ( $\omega$ ) (For Northern region) → Zero (at solar noon)  
→ Negative (morning time)  
→ Positive (afternoon time)

morning 6 AM →  $-90^\circ$   
evening 6 PM →  $+90^\circ$  Solar Noon, 12:00 (solar time)



## Solar constant ( $I_{sc}$ )

The rate at which energy is received from the sun on the earth atmosphere in perpendicular direction.



$$I_{sc} = 1367 \frac{W}{m^2}$$

$$\text{or } I_{sc} = 1.367 \frac{kW}{m^2} \rightarrow \text{at mean distance.}$$

$$I_{sc}' = I_{sc} \left[ 1 + 0.033 \times \cos \left( \frac{360^\circ}{365} \times n \right) \right]$$

no. of days

Farthest point  $\rightarrow$  21st June.

Closest point  $\rightarrow$  21st Dec.

Solar radiance This is the amount of solar energy incident on a surface per unit area per unit time. It is represented in  $kWh/m^2/sec$  or  $kWh/m^2/day$ .

## Solar collectors, types and performance characteristics:

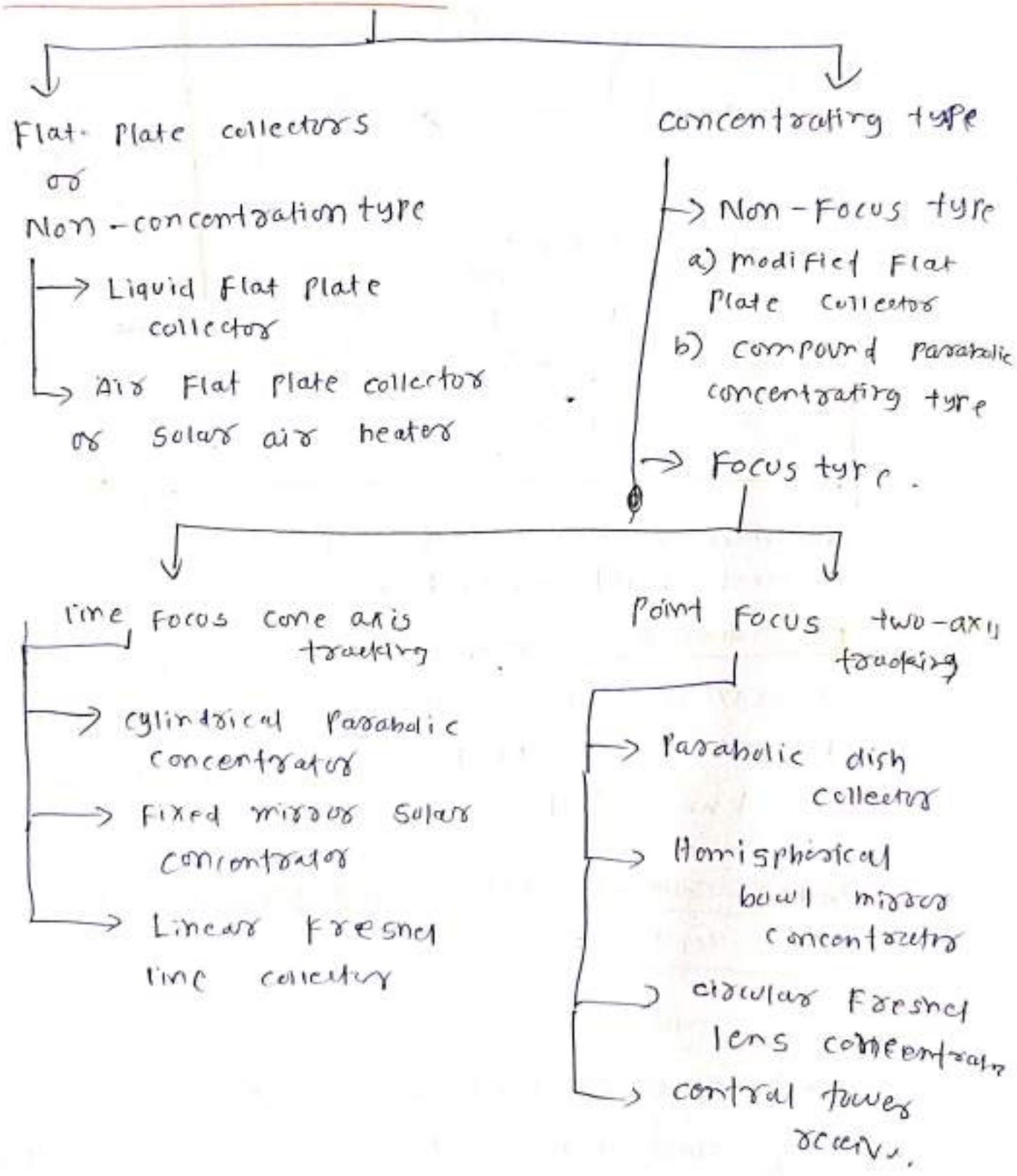
### Solar collector

i) ~~Energy per unit area per unit time~~ flux density

i) A solar collector is a device for collecting solar radiation & transfer this energy to the fluid passing in contact with it.

ii) It is basically a heat exchanger which transfers the radiant energy to the working fluid.

Types of solar collectors



## Performance characteristics

The performance characteristics of solar collectors are

- ① Collector efficiency It is defined as the ratio of energy actually absorbed and transferred to the heat-transport ~~liquid~~ fluid by the collector to the energy incident on the collector.
- ② Concentration Ratio It is defined as the ratio of the area of ~~aperture~~ <sup>aperture</sup> of the system to the area of receiver. The aperture of the system is the projected area of the collector facing <sup>normal</sup> the beam.
- ③ Temperature Range It is the range of temperature to which the heat transport fluid is heated up by the collector.

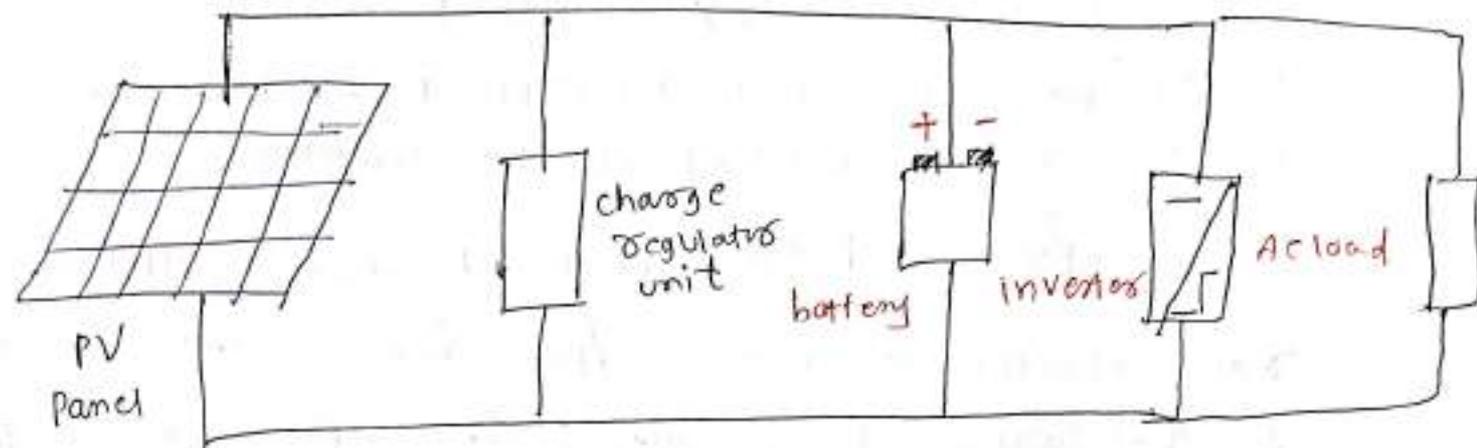
## Application

### ① Photo-voltaic - battery. charger

- i) Battery manufacturers specify the minimum no. of complete charge & discharge cycles as a function of depth-of-discharge (DOD).
- ii) Two of the main factors that have been identified as limiting criteria for the cycle life of batteries in photovoltaic power systems are incomplete charging & prolonged operation at a

low state of charge (SOC).

→ solar battery charger operates on the principle of that the charge control circuit will produce constant voltage.



Advantages

- Adjustable o/p voltage
- circuit is simple & inexpensive
- circuit used commonly available components
- zero light discharge when no sunlight on the solar panel.

Module 11A

### domestic lighting

- Home lighting systems are the most popular solar PV units typically designed to with two light points ~~with~~ and one TV point.
- When necessary, a small dc fan can be used from this system.

### Solar street lighting

- It described as a standalone PV power generating device.
- It comprises a compact fluorescent lamp, two 30 watt solar modules and 80 Ah tubular cell battery.

### Water pumping

- water pumps can be driven directly by solar heated water or fluid which operates either heat engine or turbine.
- For low heads, the pump driven by vapour of a low boiling point liquid heated by a flat plate collector is used as shown in fig.
- For larger head, a parabolic trough concentrator or parabolic bowl concentrator is installed to drive a steam turbine.

# Biomass power



bio → derived from greek word <sup>'bios'</sup> meaning life

## Energy from biomass

- Biomass is organic matter produced by plants, both terrestrial (that grown on land) and aquatic (those grown in water) and their derivatives.
  - it includes forest crops and residues, energy farms and animal manure.
  - unlike coal, oil & natural gas, which takes millions of years to ~~win~~ form, biomass can be considered a renewable energy source because plant life renews and adds to itself every year.
  - The energy obtained from biomass is known as biomass energy.
  - Animals feed on plants, and plants grow through the photosynthesis process using solar energy.
  - Thus, the photosynthesis process is primary responsible for generation of biomass energy.
- A small portion of the solar radiation is captured & stored in plants during the photosynthesis process. Therefore, it is an indirect form of solar energy. The average efficiency of ~~solar energy~~ photosynthetic conversion of solar energy into biomass energy is

(2)

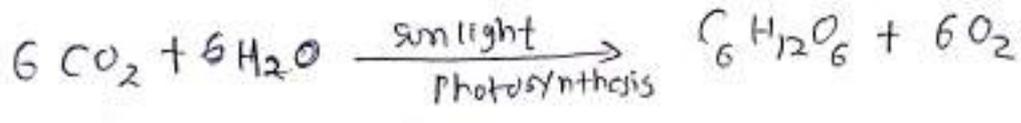
estimated to be 0.5 to 1.0% .

- To use biomass energy, the initial biomass may be transformed ~~into~~ by chemical or biological process to produce more convenient intermediate bio fuels such as methane, producer gas, ethanol & charcoal.
- on combustion, it reacts with oxygen to release heat, but the elements of the material should be available for ~~reducing~~ recycling in natural ecological or agricultural process.
- Thus the use of industrial bio fuels when linked carefully to the natural ecological cycle, may non-polluting and sustainable.
- For biomass to be ~~converted~~ considered as renewable, growth must at least keep pace with its use. It is disastrous that forest & firewood consumption is significantly outpacing their growth in ever increasing areas of the world.
- It is estimated that biomass, 90% of which comprises plant matter is equivalent to the current proven extractable fossil fuel reserves in the world. The dry matter ~~which~~ mass of biological material cycling in the biosphere is about  $250 \times 10^3 \text{ Tons/year}$ . The associated energy bound in photosynthesis is  $2 \times 10^{21} \text{ J/year}$ .

4.2 Biomass as renewable energy source

→ Biomass being organic matter from terrestrial and marine vegetation renews naturally in a short span of time, thus classified as renewable source of energy.

→ It is a derivative of solar energy as plants grow by the process of photosynthesis by absorbing CO<sub>2</sub> from the atmosphere to form <sup>glucose</sup> ~~carbohydrate~~ expressed by the reaction.



Solid Biomass also known as "Feedstock" which are solid or compressed pieces of organic matter in the form of pellets that release their stored energy through combustion & burning. solid biomass or feedstock materials include

→ wood or wood residues such as trees, shrubs, sawdust, pellets, chips and waste wood.

→ Agricultural residues such as straw, grasses, seeds, roots, dried plants, nut shells & husks.

→ Energy crops from charcoal, peat leaf litter & moss.

- ④
- Processed waste such as Bagasse plant waste.
  - Animals waste such as dried slurry & manure.
  - Municipal solid waste from ~~bees~~ household rubbish & garbage.

### Liquid Biomass

- Also known as biofuel is any kind of fluid or liquid produced from solid matter that is still growing or has been alive at some point which can be processed to produce a type of fuel. Liquid biomass or biofuel fluids include
  - Pure vegetable oils from sunflower and recycled or recycled waste vegetable oils.
  - Methanol, ethanol and alcohol based fuels fermented from corn, grain & other plant matter.
  - Biodiesel distilled from vegetable oils & animal fats.
  - P-grades fuels, which blend various solid & liquid matters together to produce a fuel.

### Gas Biomass

- Also known as "biogas" is any kind of natural forming gas given off by decaying plants, rotting rubbish, decomposing animals, slurry & manure that can be used as a type of fuel.

- Liquid ~~as~~ biomass or biogas include
- Methane from decomposing plants, animals & manure.
  - Biogas generating generated from rotting rubbish in landfills.
  - Hydrogen for batteries & fuel cells.
  - synthesis gas blended from carbon monoxide & hydrogen.
  - Natural gas from fossil fuels.

### Biomass conversion technologies

→ The biomass conversion process has several routes depending upon temperature, pressure, micro-organisms utilized, process & culture conditions.

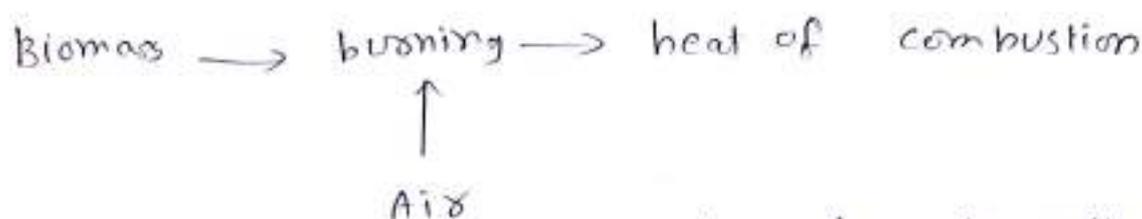
→ Biomass conversion can be done by any of the following processes.

- a) direct combustion (incineration)
- b) Thermo chemical conversion
- c) Bio chemical conversion

#### direct combustion

- i) direct combustion is the process of burning. (rapid oxidation accompanied by heat and light)
- ii) The combustion process is convenient and economical to burn solid, semi-dried biomass & obtained useful heat.

iii) The heat obtained from the combustion of biomass can be used for cooking, industrial heating, generation of electrical energy.



iv) The complete combustion to ashes is called incineration.

Thermo-chemical conversion

→ Thermo-chemical processes for the conversion of biomass include

a) Gasification

takes place by heating the biomass with limited oxygen or air to produce low heating blue gas.

b) Pyrolysis is the conversion into gases, liquids & solids through pyrolysis at a temp. of 500-900°C by heating in a closed vessel in the absence of oxygen.

Bio-chemical conversion

• Bio chemical conversion is done by two forms namely

- a) Anaerobic digestion
- b) Fermentation

## a) Anaerobic digestion process

- i) Anaerobic digestion is a controlled process involving microbial decomposition of organic matter in absence of oxygen.
- ii) Anaerobic digestion involves the process of decaying biodegradable material in the absence of any terminal electron acceptors like sulfate, nitrate & oxygen.
- iii) AD consists of a no. of ~~chemical~~ complex biochemical reactions carried out by several types of micro-organisms that survive oxygen free conditions. During this process, biogas is produced which is mainly composed of methane ( $CH_4$ ) & carbon dioxide ( $CO_2$ ) as major gases with trace amounts of hydrogen sulfide ( $H_2S$ ), Nitrogen ( $N_2$ ), hydrogen ( $H_2$ ) & water vapours.
- iv) The material left after anaerobic digestion process is called digestate which is rich in nutrients which is a wet mixture that can be separated into solid & liquid.

### Stages of Anaerobic digestion

There are 4 stages of anaerobic digestion.

- 1) Hydrolysis
- 2) Acidogenesis
- 3) Acetogenesis
- 4) Methanogenesis

① Hydrolysis of organic matter

The biomass is broken due to the action of water into simple soluble compounds i.e. polymers are converted into monomers which are completed in a day temp. at 25°C.

② Acidolysis : It is the process of acidic breakdown of oligopolymers and compounds into simpler molecules.

③ Acetogenesis : It is the process of formation of acetic acid with the help of acetogens. This reaction produces CO<sub>2</sub> & H<sub>2</sub> as the main byproduct.

④ Methanogenesis : This is the final step of anaerobic decomposition. It is a pH sensitive reaction that occurs between the range of pH 6.5 to pH 8. During this step, the intermediate product from other steps is used to produce methane, carbon dioxide & hydrogen.

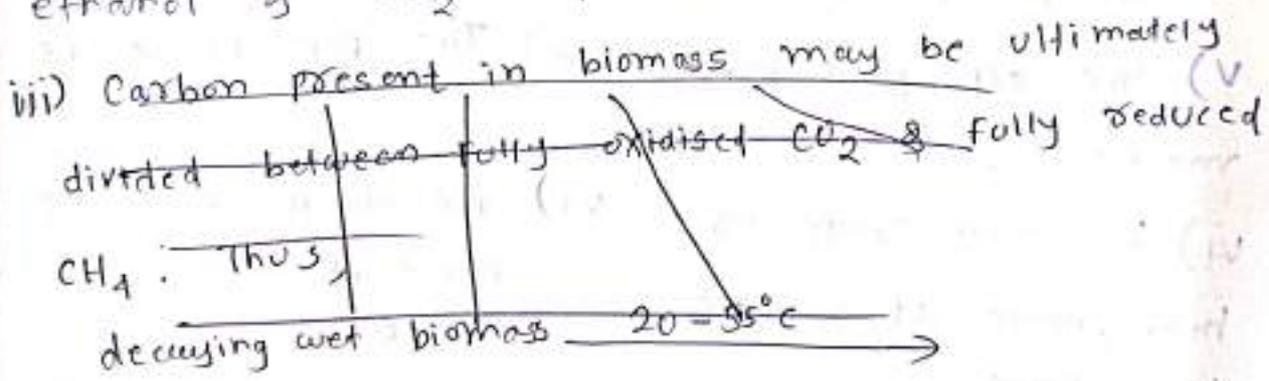
Advantages of Anaerobic digestion

1. The lower operating cost of the digester makes it commercially viable.
2. Sludge occupies less volume & easier to dry.
3. Reduce production of landfill gas, which when damaged leads to an outburst of methane.
4. Methane produced in the digester can be used as biogas, an alternative source of energy.

- 5. It reduces the energy footprint of conventional wastewater treatment technology.
- 6. It has reduced the use of chemical fertilizers as the digestate which can be used as fertilizers.

(b) Fermentation (Aerobic digestion)

- i) Fermentation is a process of decomposition of complex molecules of organic compound under the influence of micro-organism such as yeast, bacteria, enzymes etc.
- ii) The examples of fermentation process is the conversion of grains & sugar crops into ethanol & CO<sub>2</sub> in presence of yeast.



- iii) Fermentation is well established and widely used for conversion of grains & sugar crops into ethanol.

## Aerobic digestion

- i) It requires oxygen or air for degrading the substances.
- ii) Amount of sludge produce is high, resulting in high transportation loss.
- iii) It requires pumping of large quantity of air.
- iv) Sludge has less fertility contents.
- v) The off product is methane.
- vi) Reaction rate is high, hence it requires less time.

## Anaerobic digestion

- i) It does not require oxygen & use available  $CO_2$ .
- ii) Amount of sludge produced is low, resulting in low transportation loss.
- iii) It does not require pumping of air.
- iv) Sludge has high fertility contents.
- v) The p/p product is  $CO_2$ .
- vi) Reaction rate is low, hence it require long time.

## Biogas digester

→ A biogas digester is closed container in which the segregation and Feeding of the organic substrate takes place. In this digester, the biodegradation of substrate takes place under anaerobic conditions and in the presence of methanogenic bacteria, producing a methane-rich

biogas.

→ This generated biogas can be further used for cooking & for electricity generation.

→ The fully stabilized digested slurry (digestate) can be used as fertilizer conditioner depending upon its characteristics.

→ There are basically three main types of biogas digesters available on the basis of gas storage.

① Fixed dome type (Chinese type)

② Floating drum type (Indian type)

③ Bag type (Taiwanese type)

→ These digesters can be further divided into two ways based on feeding procedures.

i) Continuous mode (material is ~~added~~ added continuously & biogas production is uninterrupted)

ii) Batch mode (material is loaded in <sup>one</sup> single operation & left until biogas production ceases.)

① Fixed dome type digester

→ The Fixed dome consists of an air tight container or fermentation chamber (constructed of brick, stone or concrete), Feed and digestate pipes & Fixed dome on the

top of or biogas storage. The reaction and biogas storage chambers are connected.

→ The design of fixed dome type biogas digester originated in Jiangsu, China as early as 1936.

(not visible)

(not visible)

(not visible)

1 Fixed dome type digester

(not visible)

Construction It consists of a well like underground tank made of bricks & cement. This tank is called a digester & has an inlet and outlet valves. The roof of the tank is dome shaped. A gas outlet pipe at the top of dome is fitted. The dome of the digester act as storage tank of biogas. There is a mixing tank made above the ground level, which is connected to the inlet valve of the digester through a slopping inlet chamber below the ground level. on the other side of digester, a rectangular tank called an outlet chamber is constructed with bricks & cement. This outlet chamber is connected to the overflow tank which collects the slurry.

Working Animals dung is mixed with water to make a slurry. in the mixing tank. This slurry enters the digester through the inlet chamber. The digester is filled partially with slurry so that enough space is left above it in the dome for the collection of biogas. The slurry in the digester is left for about two months for fermentation. Anaerobic micro-organisms are responsible for this action. As a result of fermentation, biogas is formed which is collected in the dome.

it exerts a large pressure on the slurry & forced it to go into the overflow tank through outlet chamber. The biogas is taken out from the dome through a pipe & used for cooking food or heating water whenever required.

→ once the biogas plant starts functioning, more & more slurry may be fed into the digester to get the continuous supply of biogas.

## ② Floating drum type

→ Floating-drum plant consists of an underground digester (cylindrical or dome-shaped) and moving gas holder.

→ The gas-holder floats either directly on the fermentation slurry or in a water jacket of its own. The gas is collected in the gas-drum, which rises or moves down according to the amount of gas stored.

→ The floating drum type used in India is known as KVIC (Khadi & Village Industries Commission)

→ the two main parts in the plants are

- digester or pit
- Gas holder or drum

→ digester or pit is for digestion of the mass & the work dug & built below the ground level.

→ The depth of well varies from 3.5 to 6m & diameter varies from 1.2 to 6m.

→ There is a partition wall in the center which divides the digester vertically into two semi-cylindrical compartments. There are two slanting cement pipes which are used for inlet & outlet.

→ As inlet chamber near the digester at the surface level serves for mixing dung & water in the ratio of 4:5 & fed through the inlet pipe, flows into the bottom of the digester. The digester can hold raw material for 50-60 days. The outlet chamber is just below few centimeters from ground level.

→ due to continuous feeding of slurry every day, both compartments of digester will become full, then equivalent amount of fermented slurry flows out at the outlet & discharges into composite pit.

→ Gas holder of the digester is a drum type made of steel sheets with conical top.

→ It fits into the digester like a stopper, it (16)  
sinks slowly due to its weight & rests on a  
ring. As the gas is generated due to gas  
pressure, holder rises & floats inside the slurry  
inside down.

## Advantages & disadvantages of floating drum type

### Advantages

- i) It has less scum troubles.
- ii) The danger of mixing oxygen with the gas to form an explosive mixture is minimised.
- iii) Higher gas production per cubic centimetre of the digester volume is achieved.
- iv) No problem of gas leakage.
- v) constant gas pressure.

### disadvantages

- i) higher cost
- ii) Heat is lost through the metal gas holder since it troubles in colder periods.
- iii) Gas holder requires painting once or twice a year, depending on the humidity of the location.

Gasification It is a thermochemical process which converts carbon based raw materials into carbon monoxide, hydrogen & carbon dioxide.

→ This is achieved by reacting the material at high temperatures, without combustion with a controlled amount of oxygen and/or steam.

The resulting gas mixture is called SYN gas which is itself a ~~gas~~ <sup>Fuel</sup>.

# Types of Gasifier

## ① Fixed bed gasifier

- Updraft or counter current gasifier
- downdraft or co-current gasifier
- cross-draft gasifier

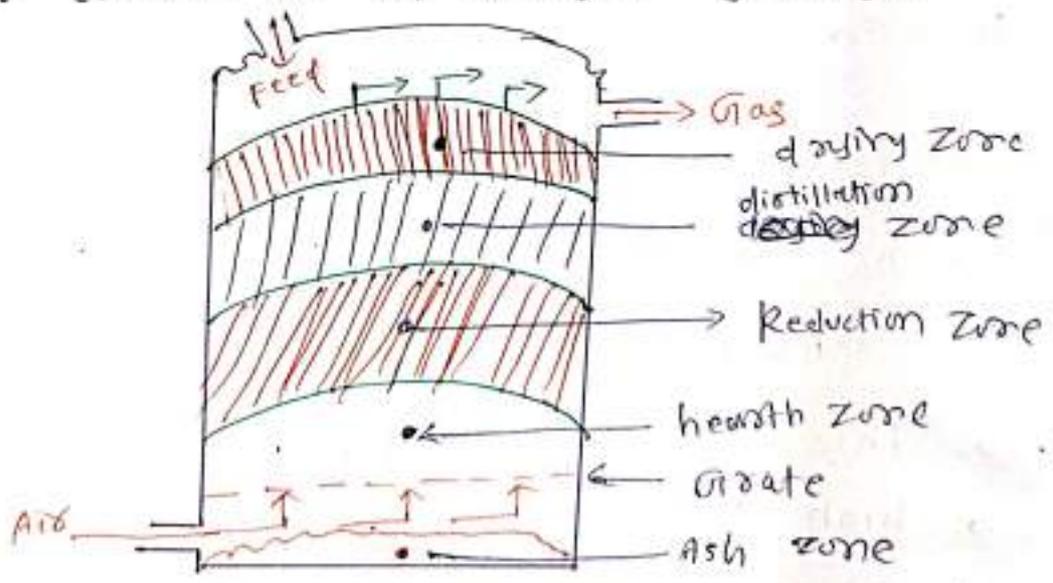
## ② Fluidized bed gasifier

- ① circulating fluidized bed gasifier
- ② bubbling fluidized bed gasifier

## ① Fix bed gasifier

### Up draught or counter current gasifier

→ The oldest & simplest type of gasifier is the counter current or up draught gasifier

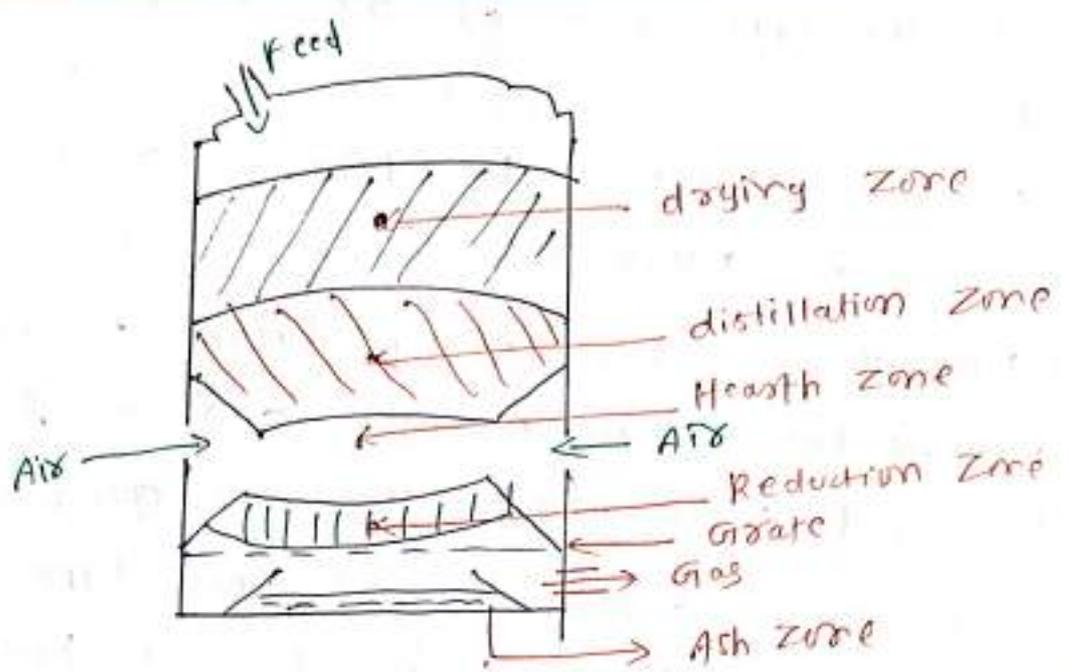


→ The air intake is at the bottom and the gas leaves at the top. Near the grate at the bottom the combustion reaction occurs, which are followed by reduction reactions somewhat higher

up in the gasifier.

- In the upper part of the gasifier, heating & pyrolysis of the feedstock occurs as a result of heat transfer by forced convection & radiation from the lower zones.
- The tars & volatiles produced during this process will be carried in the gas stream. Ashes are removed from the bottom of gasifier.
- The major advantage of this type of gasifier are its simplicity, high charcoal burn out & internal heat exchange leading to low gas exit temperatures & high equipment efficiency, as well as the possibility of operation with many types of feedstock (sawdust, cereal hulls etc)
- Major drawbacks result from the possibility of "channeling" in the equipment, which can lead to oxygen break-through & dangerous, explosive situations and necessity to install automatic moving grates, as well as from the problems associated with disposals of the tar-containing condensates that result from the gas cleaning operations.
- The latter is of minor importance if the gas is used for direct heat applications, in which case the tars are simply burnt.

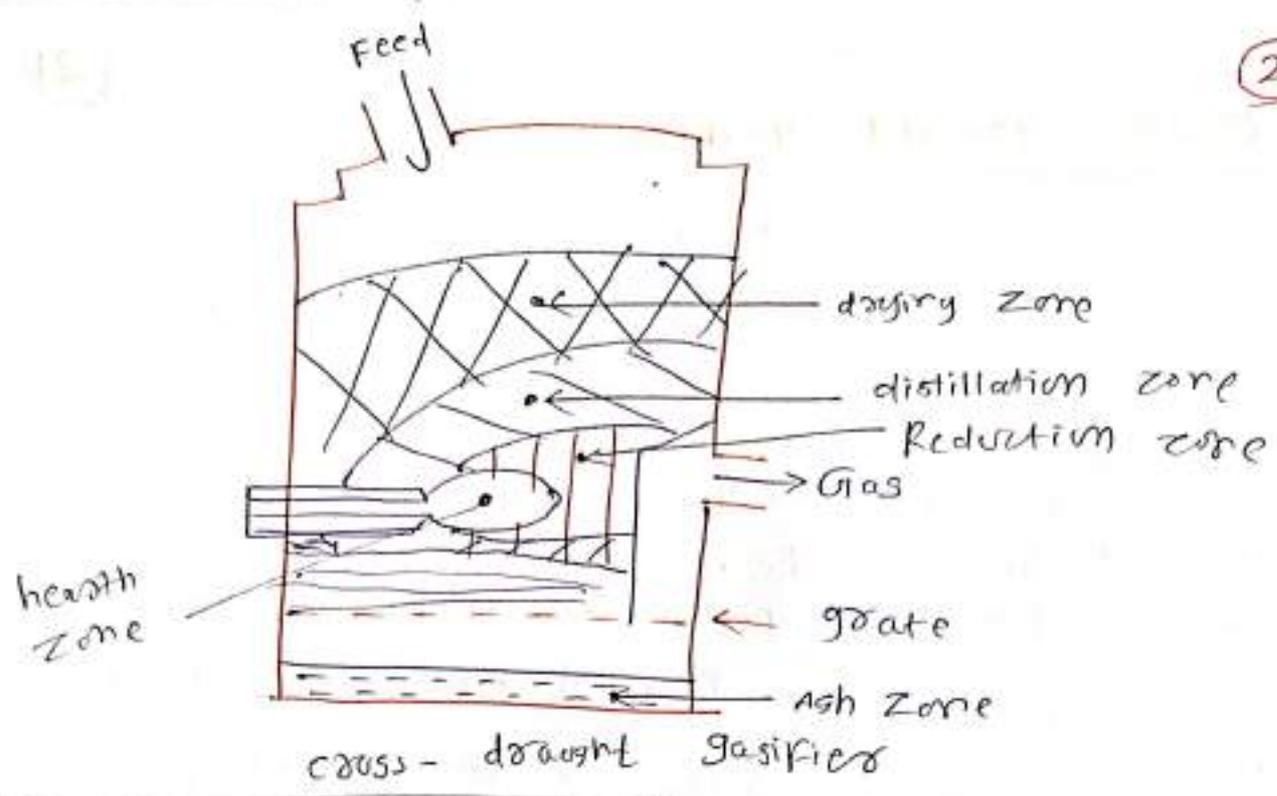
down draught or co-current Gasifiers



- A solution to the problem of tar entrainment in the gas stream has been found by designing co-current or down draught Gasifiers, in which primary gasification air is introduced at or above the oxidation zone in the gasifier.
- The producer gas is removed at the bottom of the apparatus, so that fuel & gas move in the same direction,
- on their way down the acid & tarry distillation products from the fuel must pass through a glowing bed of charcoal & therefore are converted into permanent gases hydrogen, carbon dioxide, carbon monoxide & methane.
- depending upon on the temp. of the hot zone and the residence time of tarry vapors, a more or less complete breakdown of the tars is achieved.

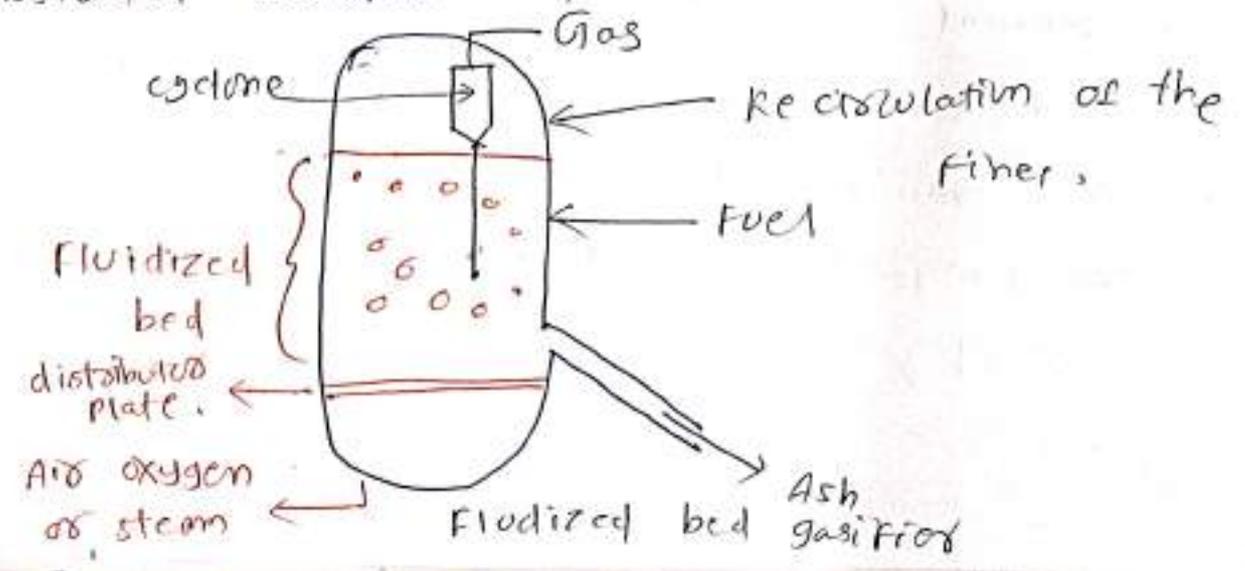
## Cross-draught gasifier

- Cross-draught gasifier, schematically illustrated in figure is an adaptation for the use of charcoal.
- charcoal gasification results in very high temp. ( $1500^{\circ}\text{C}$  & higher) in the oxidation zone which can lead to material problems.
- In cross draught gasifier, insulation against these high temperatures is provided by the fuel (charcoal) itself.
- Advantages of the system lie in the very small scale at which it can be operated. installation below 10 kW (shaft powers) can under certain conditions be economically feasible.
- The reason is the very simple <sup>gas</sup> cleaning train (only a cyclone & a hot filter) which can be employed when using this type of gasifier in conjunction with small engines.
- It is because of the uncertainty of charcoal that a no. of charcoal gasifiers employ the downdraught principle in order to maintain at least a minimal tar-tracking capability.
- A disadvantage of cross-draught gasifier is their minimal tar converting capabilities and the consequent need for high quality (low volatile content) charcoal.



**Fluidized bed gasifier**

- The operation of both up & down draught Gasifiers is influenced by the morphological, physical & chemical properties of the fuel.
- Problems commonly encountered are lack of bunker flow, slugging & extreme pressure drop over the gasifier.
- A design approach aiming at the removal of the difficulties in the fluidized bed gasifier illustrated schematically in figure.



- Air is blown through a bed of Solid particles at a sufficient velocity to keep these in a state of suspension.
- The bed is originally ~~extended~~ externally heated & the Feedstock is introduced as soon as a sufficiently high temp is reached.
- The Fuel particles are introduced at the bottom of the reactor, very quickly mixed with the bed material & almost instantaneously heated up to the bed temperature.

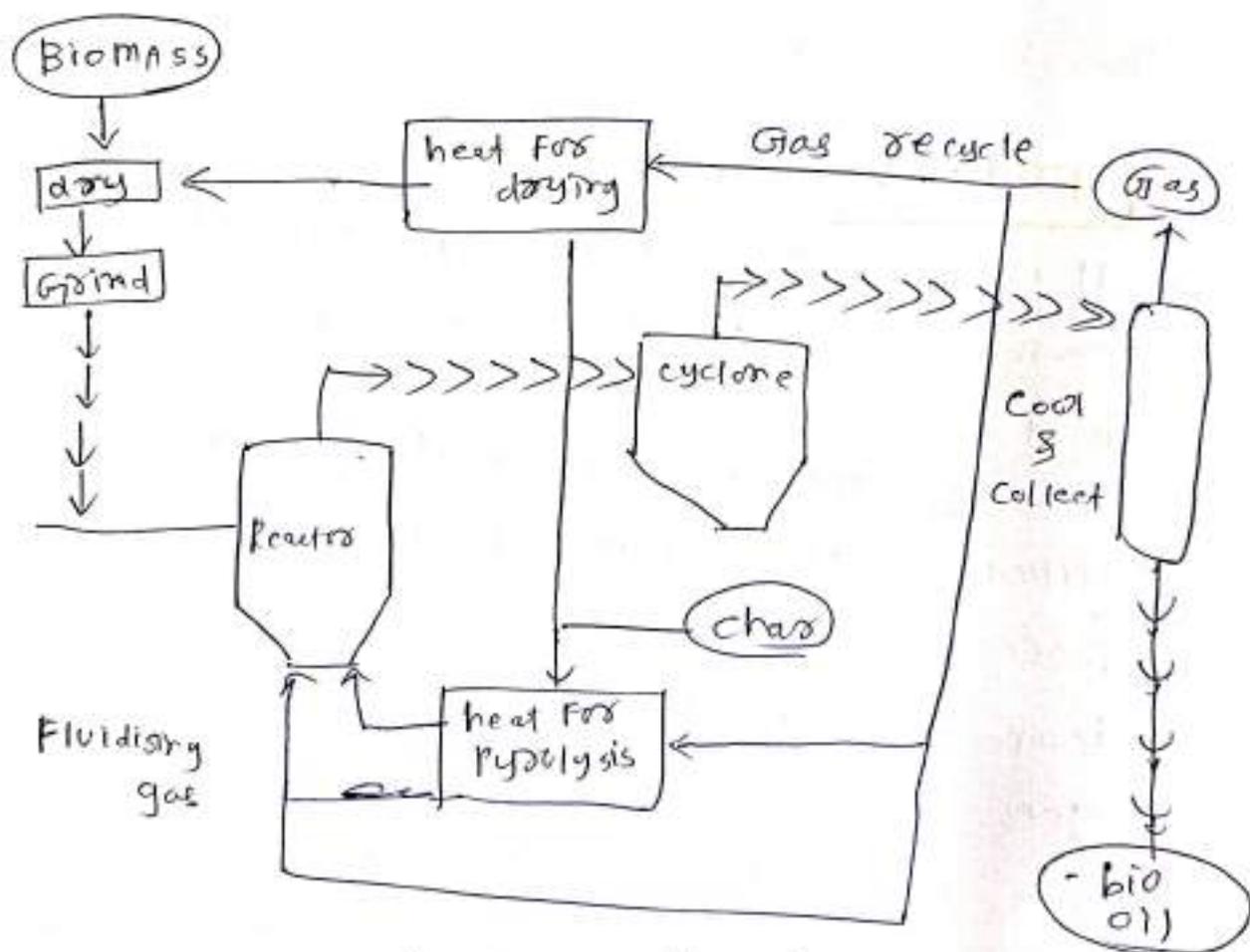
### Pyrolysis

- It is the chemical decomposition of organic (Carbon-based) materials through the application of heat.
- It is a thermo chemical treatment, which can be applied to any organic product. In this treatment process materials are exposed to a very high temperature and in the absence of oxygen, it goes through a chemical & physical separation into different molecules. The rate of pyrolysis increases with an increase in temperature.
- The most important point to be noted is that the process of pyrolysis brings about a chemical change in the substance subject to it.

## Pyrolysis - (Fibre separating)

→ Generally the substances, which are subjected to pyrolysis undergo a chemical decomposition process and are broken down into multiple product compounds.

→ The thermal decomposition process leads to the formation of new compounds. This allows receiving products with a different, often more superior character than original residue.



→ In industrial applications, the temp. used are often 430°C or even higher, whereas in small scale operations the temp. may be much lower.

- The process is commonly used to convert organic materials into a solid residue containing ash, carbon, small quantities of liquid & gas.
- Pyrolysis is also considered to be the initial step for other related processes like combustion & gasification.
- The pyrolysis process produces condensable liquids (called tar) and non condensable gas.

Uses of pyrolysis

- Utilization of renewable resources.
- Self sustaining energy.
- Reduces risk of water pollution
- Reduces country's dependence on other energy resources by generating energy from domestic resources.
- Waste management done with the help of pyrolysis technologies is inexpensive compared to disposal in landfills.

Biodiesel

→ biodiesel is a liquid biofuel obtained by chemical processes from vegetable oils or animal fats and an alcohol that can be used in diesel engines, alone or blended with diesel oil.

→ biofuel is considered to be source of <sup>(2g)</sup> renewable energy.

### Types of biofuel

1. Biogas
2. Ethanol
3. Biodiesel
4. hydrogen gas

### Biogas

- biogas is a type of biofuel, naturally produced from the decomposition of organic matter in the absence of oxygen.
- Biogas is primarily composed of methane gas carbon dioxide ( $\text{CO}_2$ ) and trace amount of nitrogen, hydrogen & carbon monoxide.
- Raw materials for biogas ÷ Agricultural wastes, municipal waste, plant material, sewage, food waste etc.

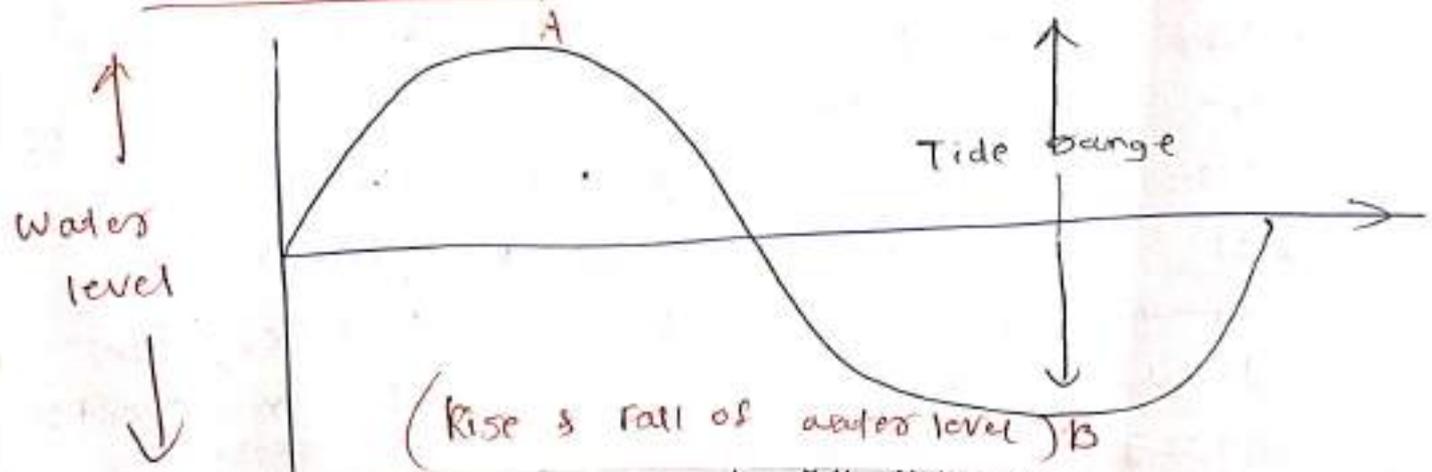
## Other energy sources

(1)

### Tidal energy

- Gravitational interaction b/w earth, the sun & the moon cause natural rise & fall in the sea water level. This regular change in the water level of sea & ocean is called tide.
- The rise and fall of water level is accompanied by periodic horizontal to & fro motion of water which is called as tidal currents. The tidal current flows in the horizontal direction & have kinetic energy. This energy is called as tidal current energy.
- The energy harnessed by converting the energy of tides into useful <sup>form of</sup> energy is called as tidal energy. Tidal energy is a form of renewable energy & has the great potential for future electricity generation.

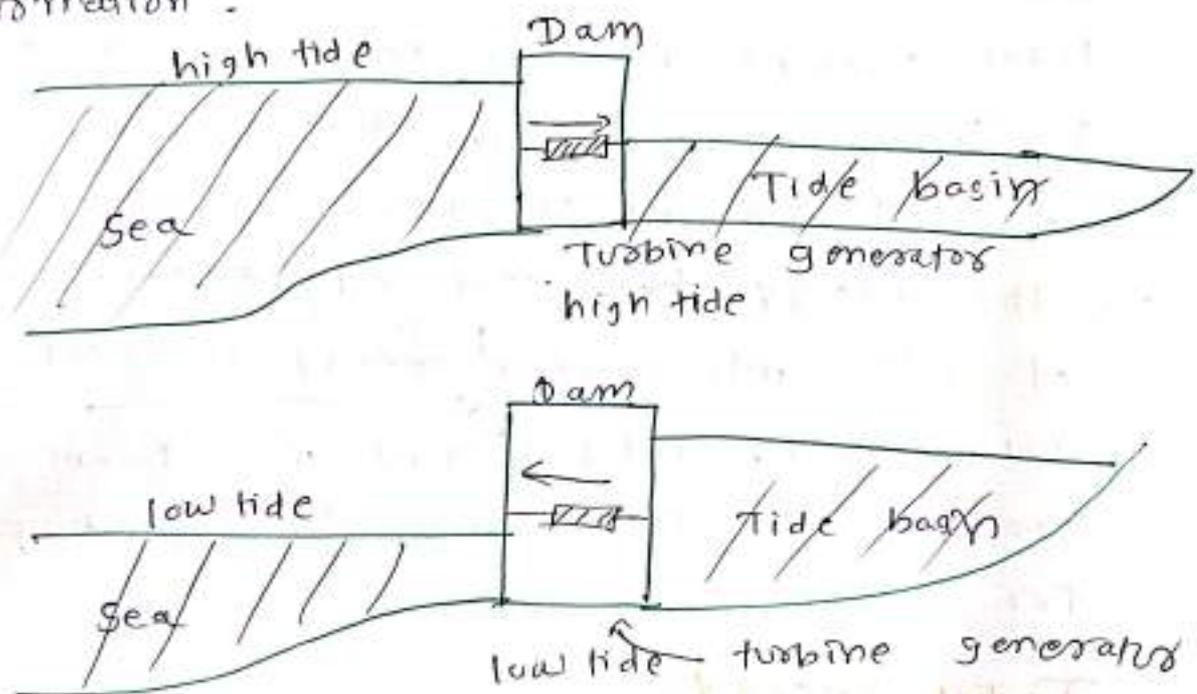
### Tidal energy



→ The difference b/w high & low water levels is called range of the tide.

### Basic Principle of tidal power

- Tides are produced mainly by the gravitational attraction of the moon & the sun on the water of solid earth & the oceans.
- About 70% of the tide producing force is due to the moon & 30% is due to sun.
- The moon is thus major factor in the tide formation.



- The main features of the tidal cycle is the difference in water surface elevations at the high tide & at the low tide.
- If this difference could be utilized in ~~opening~~ operating a hydraulic turbine, the tidal energy could be converted into electrical energy by coupling with a generator.

## Components of tidal power plant

There are '3' main components of a tidal power plant

- The power house
- The dam or barrage (low wall) to form pool or basin
- sluice-ways from the basins to the sea & vice versa.

### Power house

→ The main equipments of a power house are

- i) the turbine
- ii) Electric generator &
- iii) Auxiliary equipments

→ The function of dam is to form a barrier between the sea basin ~~or~~ ~~or~~ and the basin or between one basin and the other in case of multiple basins.

### Dam or barrage

→ barrage has been suggested as a more accurate term for tidal power schemes, because it has only to withstand heads of a fraction of the structure's height & stability problems are far more modest.

→ Tidal power barrages have to resist waves whose shock can be severe & where pressure changes sides continuously.

④

Sluice gates: These are the flow controlled devices used to fill the basin during high tide and to empty the basin during low tide. In most of the tidal power plants, vertical lift gates are being used.

Based on the basin used in plants, there are two types of tidal power plants.

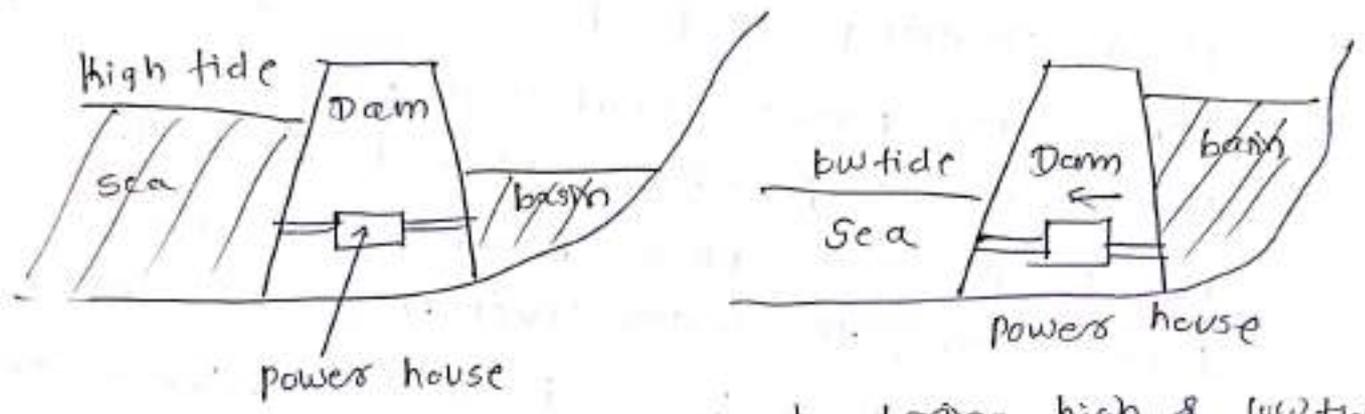
- ① single basin tidal power plant
- ② double basin tidal power plant

### ① single basin tidal power plants

- The single basin tidal power plants only have one basin. This is the simplest system to generate tidal power. The basin & sea are separated by ~~basin~~ a dam.
- The rise and fall of water level provides the potential head. The sluice gate is opened during the high tide to fill the basin.
- These plants generally use reversible water turbines in order to generate power during filling & emptying of the basin.
- Filling of the basin occurs when the sea is at high tide level & water in the basin is at low tide level.

(5)

→ The emptying of basin occurs when basin is at high tide level & sea is at low tide. The flow of water in both the directions is used to run the water turbine.



single basin power plant during high & low tide

## ② Double Basin Tidal power plants

→ In double basin plant, there are two basins at diff. levels. Basins situated in the upper part is called as upper basin, and other situated in the lower position is called lower basin.

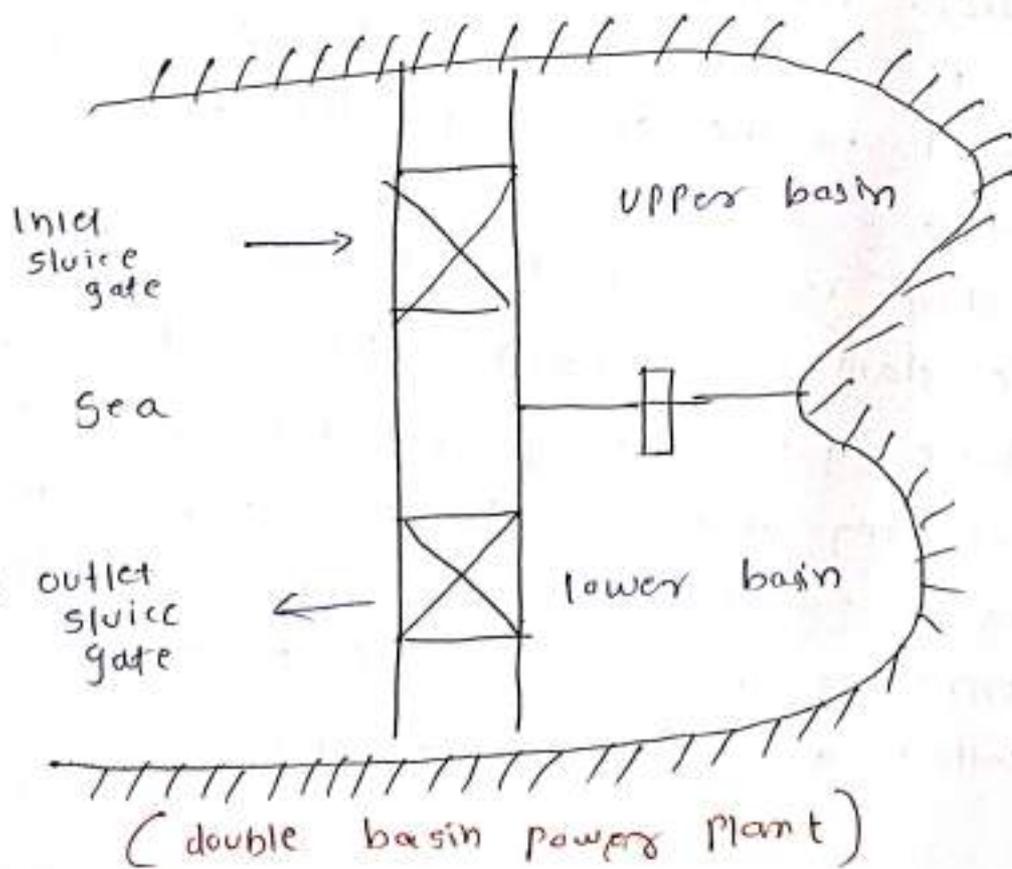
→ A dam is constructed b/w the two basins. The dam also contains power house. Two sluice gates are provided in the dam. Gate connecting the sea to the upper basin is known as inlet sluice gate & that connecting the sea to the lower basin is called as outlet sluice gate.

(1000) (1000) (1000)

(6)

→ The upper basin is filled with water during flood tide. When tide reaches its peak value, the inlet sluice gate is then closed. Water flows from upper basin to the lower through the turbines and then the turbine starts running and power is generated.

→ The water flow is controlled in such a way that continuous power is obtained from the plant. As water flows from upper basin to lower basin, the water level in upper basin falls & that in lower basin rises. When the rising level in lower basin becomes equal to the level of falling tide, the outlet sluice gates are opened.



## Advantages of Tidal Power plant

- i) Free from pollution as it doesn't use any fuel.
- ii) No extra land is required.
- iii) doesn't produce any unhealthy gas or ash.
- iv) It is everlasting & is not influenced by the changing mood of the nature like failure of monsoon.

### disadvantages

- i) power generation is not uniform due to variation in tidal range.
- ii) difficult to do sea in sea.
- iii) There is a chance of corrosion of the machinery due to corrosive sea water.
- iv) The cost of power transmission is high because the tidal power plants are located away from the load centers.

## Ocean thermal energy conversion (OTEC)

- i) Ocean thermal energy conversion (OTEC) system uses the temperature difference b/w the warm shallow part of the ocean water and cold deep ocean water to generate electricity.
- ii) The deeper parts of the ocean are cooler because the sunlight cannot penetrate very deep into the ocean water. The efficiency of the OTEC system depends on the temperature ~~gradient~~ difference. Greater the temp. difference, greater will be the

efficiency of the system.

iii) The maximum temp. difference in the ocean b/w warm shallow part & cold deep parts is around  $20^{\circ}\text{C}$  to  $25^{\circ}\text{C}$ . This energy source is freely & ~~abundantly~~ abundantly available as long as the sun shines & ocean current exists.

### Types of OTEC system

There are two types of OTEC Power generation system.

i) open cycle or Claude cycle OTEC system

ii) closed cycle or Anderson cycle OTEC "

This OTEC power generation plant generally consists of a working fluid, evaporator, turbine, condenser & pump.

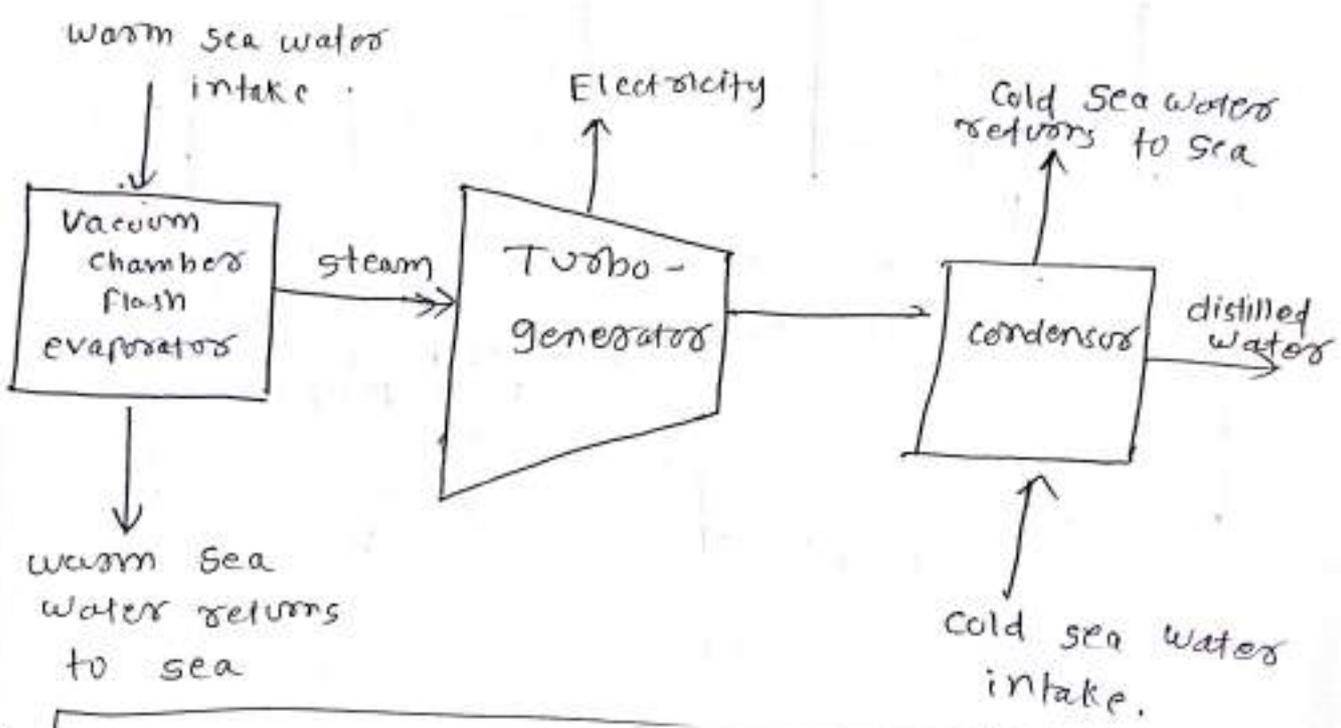
#### ① open cycle or Claude cycle OTEC system

→ In this system, sea water works as the working fluid. warm ocean water from the shallow part is pumped into flash evaporator. The pressure is lowered by a vacuum pump to the point where the warm sea water boils at ambient temperature. This process produces steam.

→ This steam is used to run a low-pressure turbo-generator which generates electricity.

(a)

→ After leaving the turbine, the steam is condensed in a heat exchanger with the help of cold deep ocean water. It also produces desalinated water.



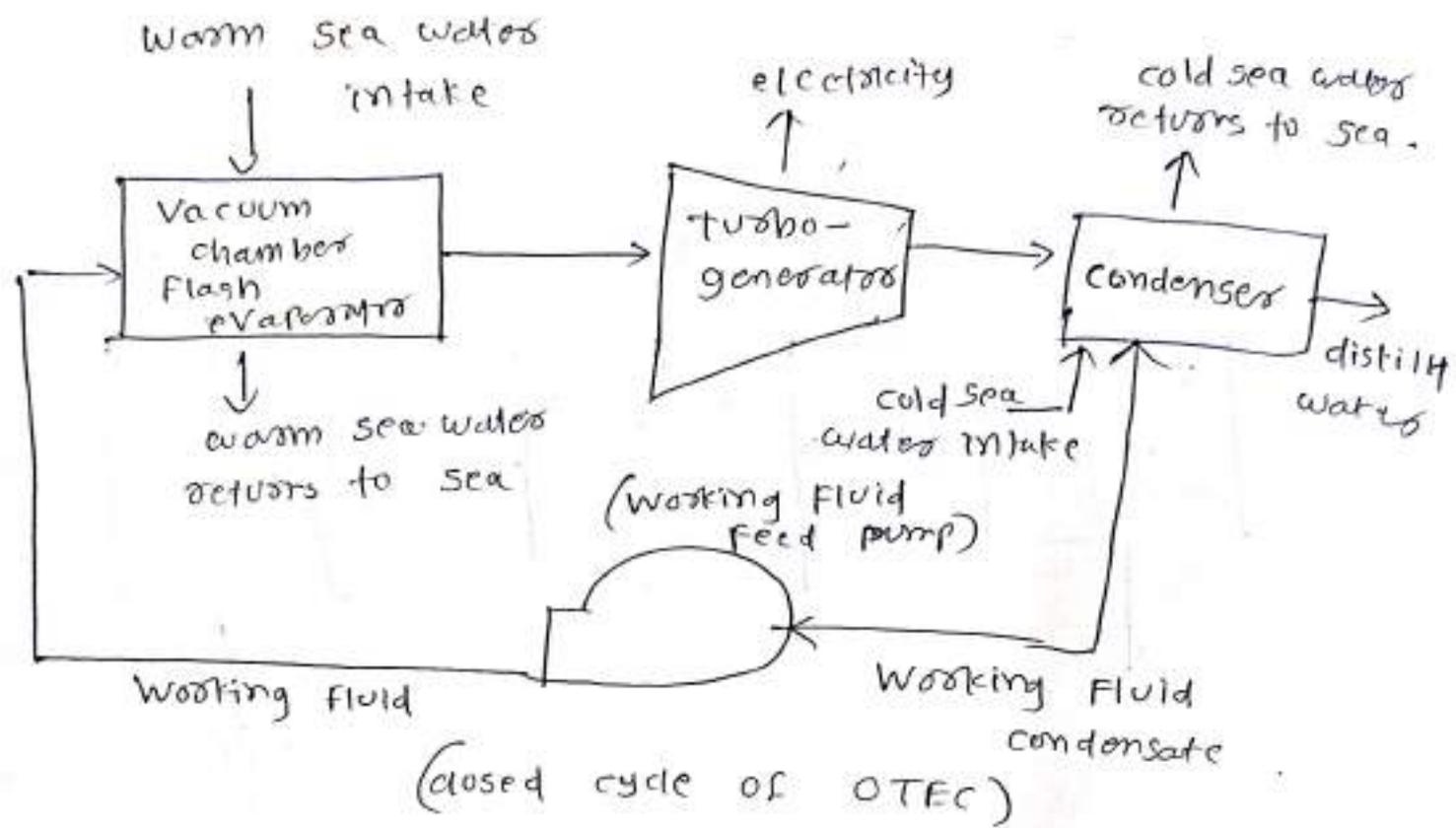
② Closed cycle or Anderson cycle or TEC system

→ In closed cycle system low boiling liquid like ammonia or freon is used as working fluid. The fluid is heated and then vaporized in a heat exchanger with the help of warm surface sea water.

→ The steam produced drives a steam turbine generator. After passing through the steam turbine, the exhausted steam is condensed in another heat exchanger.

→ It is cooled by ~~water~~ water drawn from the deep ocean. The working fluid is then pumped back through the warm water heat

exchanges. The cycle is repeated continuously.



Advantages

- i) OTEC is a kind of renewable energy source.
- ii) It can be used continuously for 24 hours throughout the year.
- iii) produces electricity without emission of greenhouse gases.

Disadvantages

- i) The installation & running costs are high.
- ii) causes disturbances in aquatic & marine life.
- iii) low conversion efficiency about 3-5%.

## Geothermal energy

Geothermal energy means the energy coming from the heat of earth. It is the thermal energy trapped within the solid crust of the earth. This energy is obtained in the form of steam and hot water. It is released naturally in the form of geysers, hot water springs & volcanic eruptions.

## Hydro-geothermal energy

→ Hydro-geothermal energy is generally associated with the steam & hot water that comes from the interior of the earth. Hot water or steam can be extracted from the production well.

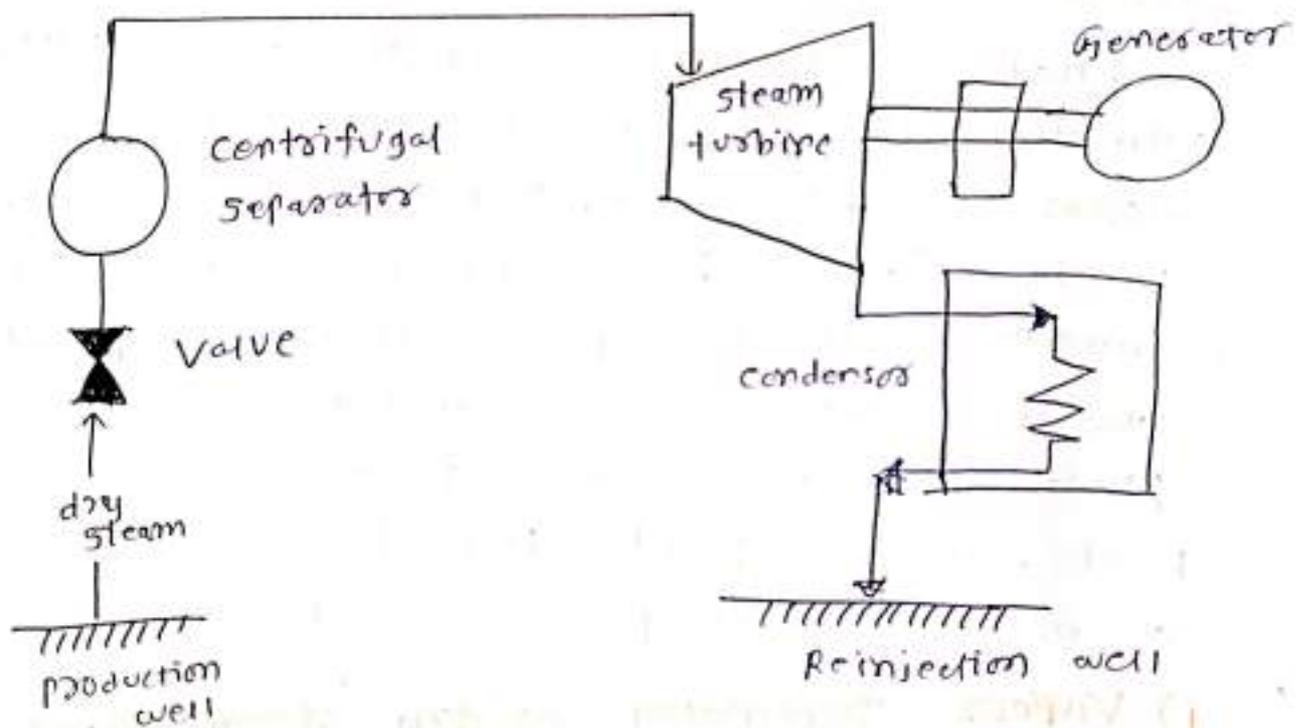
→ hydro-geothermal power generation plants are classified into vapor dominated or dry steam plants & liquid dominated or wet steam plants. In these plants, high temp. water & steam is used to produce electricity.

### i) Vapor Dominated or dry steam plants

→ These plants are simple & more efficient type of hydro-geothermal power plants. The geothermal fluid for these plants is dry steam at temp. b/w  $180^{\circ}\text{C}$  to  $240^{\circ}\text{C}$ .

→ dry steam from the production well is passed to centrifugal separator through valve.

- The centrifugal separator removes the impurities present in the steam. The steam is then allowed to pass through a steam turbine where steam expands and run the turbine.
- turbine is connected to a generator whose electricity is produced. The low pressure steam is condensed into water & reinjected into the earth through reinjection well.



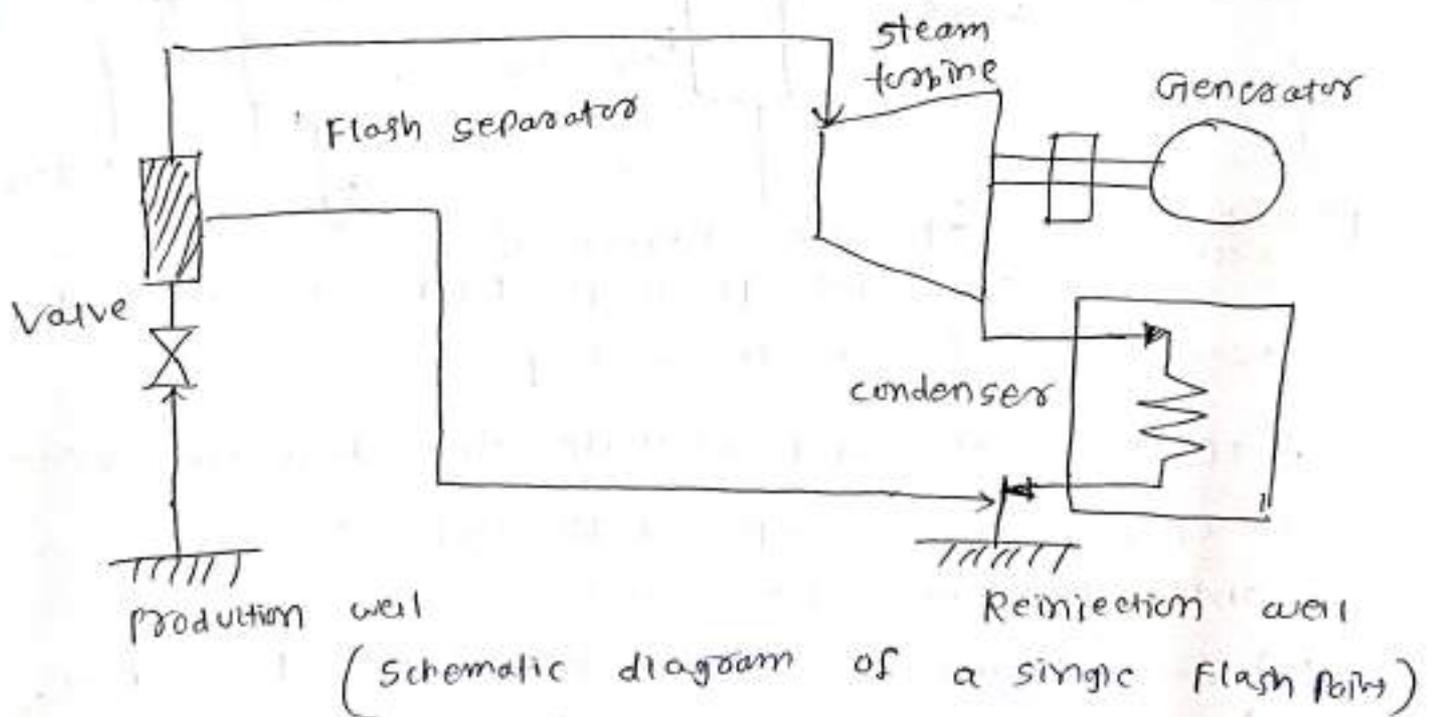
(Schematic diagram of Vapor dominated plant)

## ii) liquid Dominated or Flash steam Plants

In these plants, the mixture of hot water & steam under high pressure is used. The steam is separated and expands in the turbine to generate electricity.

(a) Single flash steam plant

- In this plant, mixture of steam & hot water extracted from the production well is passed through flash separator by decreasing its pressure.
- In flash separator, steam is separated from hot water and transmitted to the steam turbine to run it. Turbine is connected to a mechanical generator where electricity is produced.
- The cooled steam in the turbine is condensed into water by the condenser. A part of liquid from the flash evaporator is re-injected to the injection well.

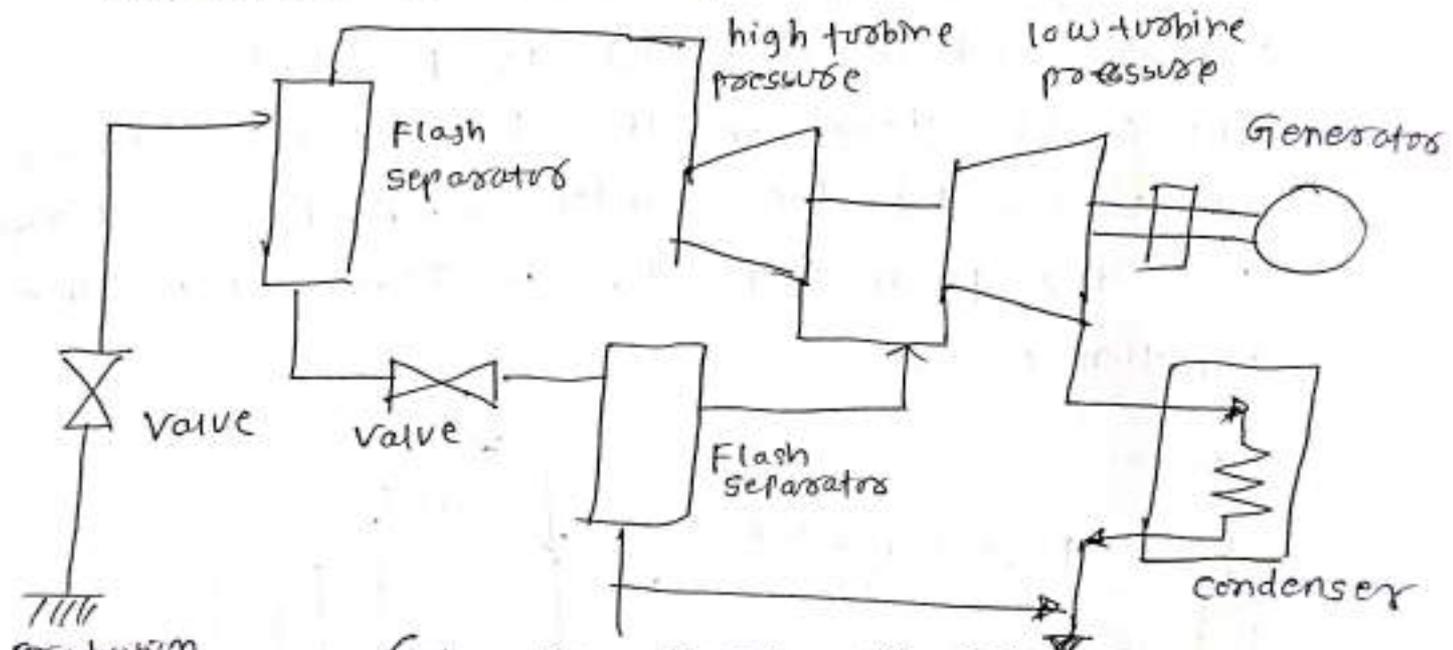


(b) double flash steam plant

In double flash steam plant, the flash process of fluid is applied in two separators.

The Fluid flows from production well to a high-pressure flash separator through a valve where steam is separated and is piped to a two-stage turbine.

→ Turbine is connected to a generator where electricity is produced. The exhausted steam in the turbine is condensed into water by the condenser. A part of liquid from the flash separator is reinjected to the injection well.



(Schematic diagram of a double flash plant) Reinjection well

Advantages of Geothermal power generation

- i) inexhaustible and available throughout the year.
- ii) cheaper as compared to with energies obtained from other sources.
- iii) doesn't involve combustion of any fossil fuel.
- iv) Hot water can directly be used for space heating.

disadvantages

- i) It causes thermal pollution.

- ii) large area is required for the extraction of geothermal energy.
- iii) it is not completely pollution free energy.
- iv) Emission of poisonous gases like  $H_2S$ , ammonia, methane &  $CO_2$ .

Hybrid energy systems

In hybrid systems two or more energy conversion devices combined together for power generation. These are specially preferred in remote areas for producing electrical power.

Need for hybrid systems

- i) solar water heaters, air heaters, solar distillation and wax melters, PV arrays, PV pumps operate at ~~high~~ optimal efficiency for the months of April to September when solar radiation contain high energy flux.
- ii) To meet the load demand during night & cloudy days, battery bank is provided.
- iii) During winter, load demand shoots up & solar energy reduces, so designer is compelled to select large size equipment, PV arrays & battery bank.
- iv) Two different energy systems installed at a location to ensure continuity of electrical supply is known as hybrid energy systems.
- v) For emergency, loads of hospitals, defense installation a back up source diesel generator is required.

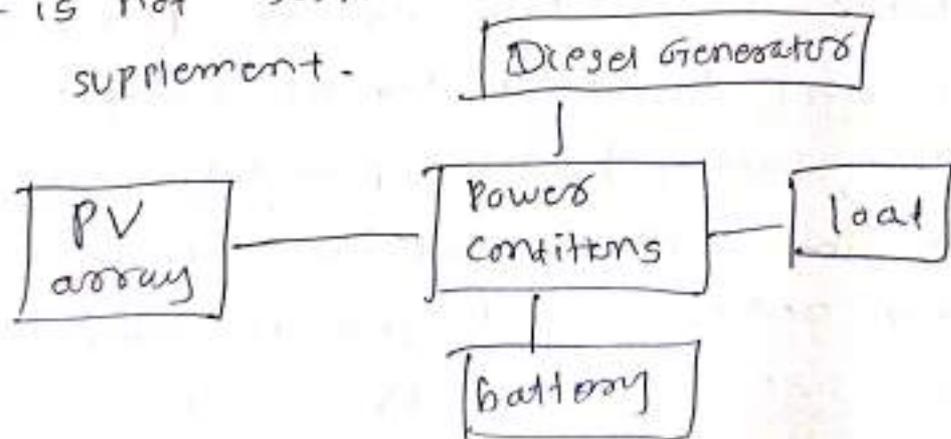
## Types of hybrid systems

- PV - Diesel
- wind - diesel
- Biomass - Diesel
- wind - PV
- Micro hydro - PV

## PV Hybrid with Diesel Generator

→ This power plant contains one PV array with a Diesel electric generator and a battery bank. Energy generated from PV array feeds load demand and then charges the battery bank.

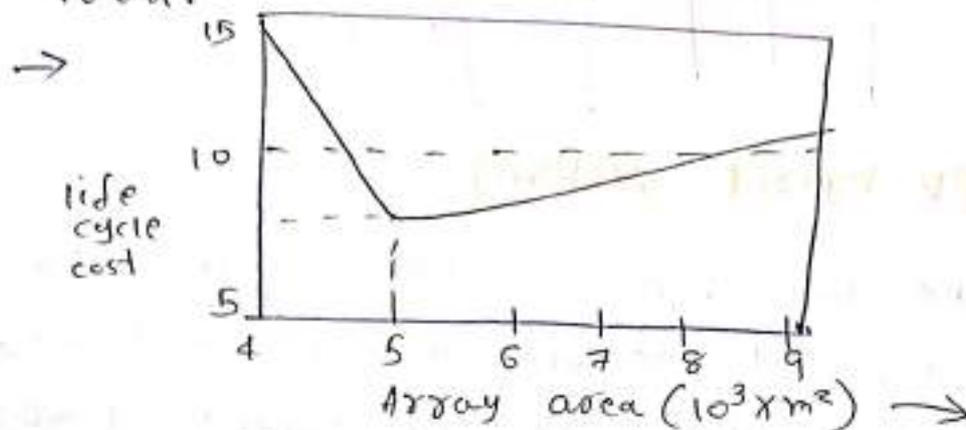
→ Diesel Generator keeps the battery fully charged and sometimes supplies load demand when PV output is not sufficient and battery charge is low to supplement.



(Block diagram of PV-Diesel hybrid power plant)

→ Here conditions performs 3 functions.  
 To convert AC current diesel generator o/p into direct current (DC) for charging battery bank. To invert direct current (DC) from

PV array and battery bank ~~feed~~ into AC for feeding load. To regulate battery current & voltage for I/P from generator & O/P for load.



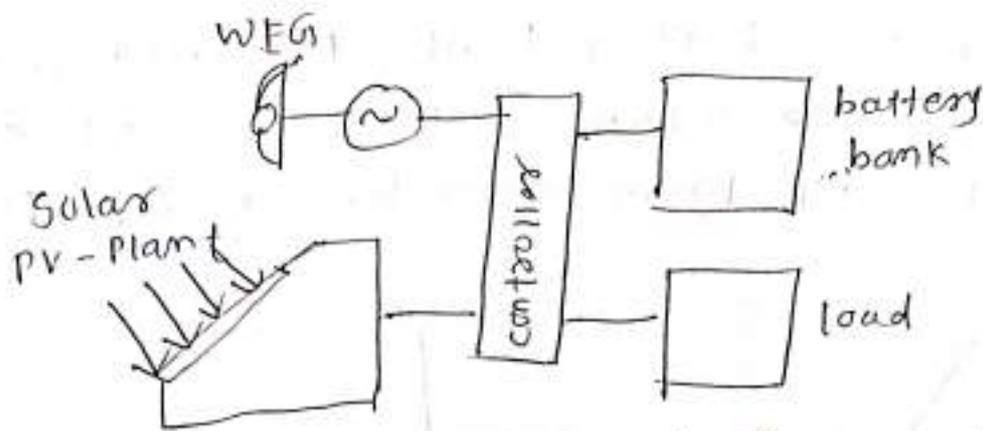
(Graph of PV-diesel system)

Graph indicates minimum cost point corresponding to a cost effective design for a PV-diesel hybrid power plant where PV has replaced 90% of the diesel fuel, had it been a diesel system only.

→ Thus a PV-diesel hybrid power plant ensures continuous power supply & is more cost effective as compared to stand alone PV system or stand-alone diesel.

### Wind - PV hybrid system

→ Wind & solar hybrid energy systems are located in open terrains away from multistoried buildings & forests. Locations are selected in those areas where the sunshine and wind are favorable for more than 8 months a year.

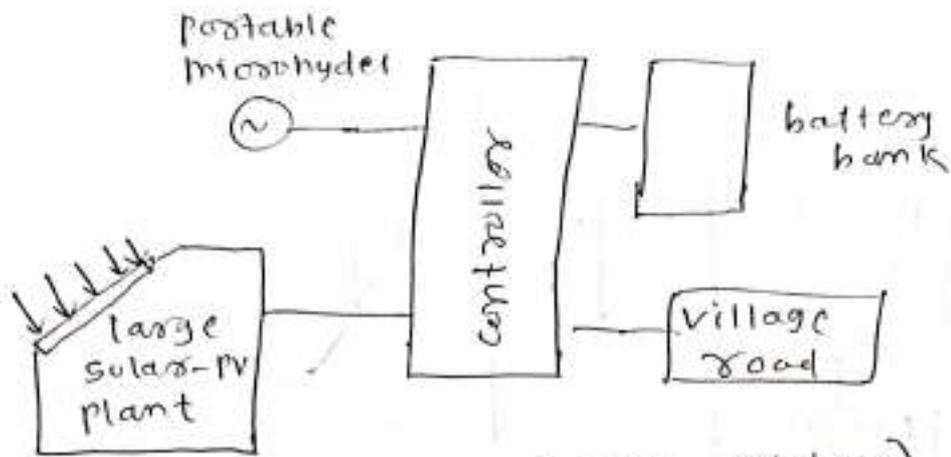


(wind-PV hybrid system)

- during the day when sun shines, the PV plant generates dc electric energy conditioner provided, converts dc to ac and supplies power to load.
- During favourable wind speed, wind turbine generator produce AC electrical power.
- It supplies power to the load and excess energy after conversion to DC & is stored in the battery bank. The plant may operate as stand-alone load or may be connected to the state grid.

### Micro Hydel - PV Hybrid Systems

- micro hydel (upto 100kW) power stations are low head (less than 3m) installations and provide decentralized power in mountain regions, also in plains or canal falls.
- portable micro hydel sets of 15kW capacities are installed with solar PV panels to complement each other.



(Micro hydel - PV hybrid system)

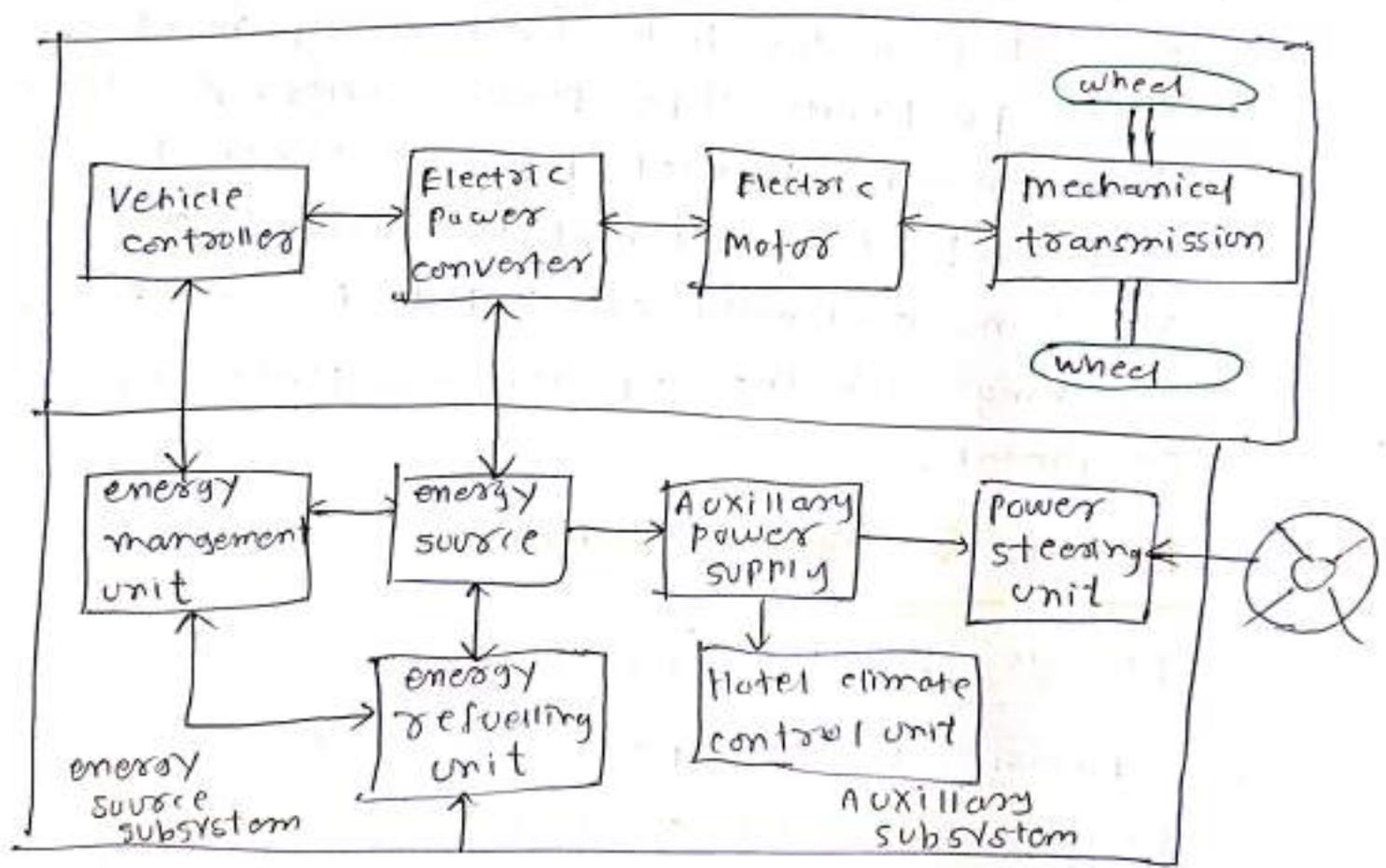
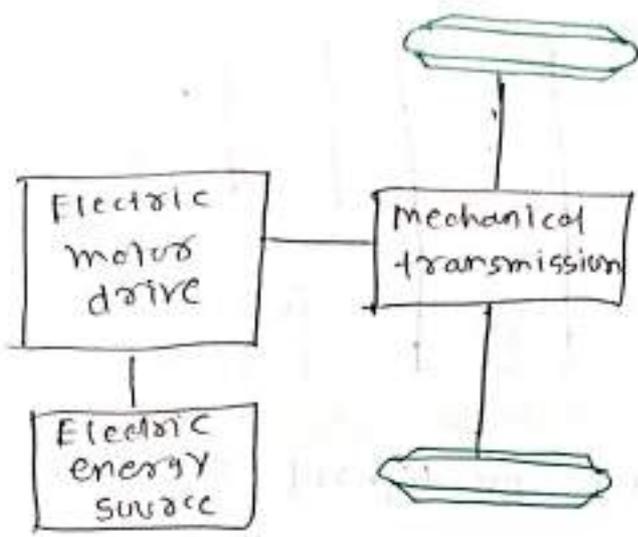
→ microhydel systems are provided with small dam store water to be used during night when solar PV panels stop power supply. A battery bank may be provided for emergency power supply. Load management is carried out to maintain continuity of supply for 24 hours matching with the capacity of generating equipment.

## Electric & hybrid vehicles

### Electric Vehicles (EVs)

→ Electric vehicles (EVs) use an electric motor for traction, and chemical batteries, fuel cells, ultra capacitors and or flywheels for their corresponding energy sources.

→ The EV was mainly converted from the existing ICEV by replacing the internal combustion engine and fuel tank with an electric motor drive and battery pack while retaining all other sources.



(Conceptual of general EV configuration)

- == mechanical link
- Electric link
- control link

→ The drive train consists of '3' major subsystems electric motor propulsion, energy source & auxiliary. The electric propulsion subsystem is comprised of a vehicle controller, power electronic converter, electric motor, mechanical transmission & driving wheels.

→ The energy source subsystem involves the energy source, the energy management unit & the energy refuelling unit. The auxiliary subsystem consists of the power steering unit, the hotel climate control unit and the auxiliary supply unit.

Applications of electrical vehicle

- Electric cars
- Aircraft
- Locomotives
- Railway station (internal transportation)
- Industrial utility Application
- Mining vehicles
- Excavators

Hybrid Vehicles

i) Hybrid <sup>electric</sup> vehicles are powered by an internal combustion engine & an electric motor, which uses energy stored in batteries. The battery can also power auxiliary loads & reduce engine idling when stopped.

- ii) Together, these features ~~can also power~~ ~~auxiliary loads~~ result in better fuel economy without sacrificing performance. A hybrid electric vehicle (HEV) has two types of energy storage units, electricity & fuel.
- iii) Electricity means that a battery is used to store the energy, and that an electric motor will be used as traction motor.
- iv) Fuel means that a tank is required and that an internal combustion engine (ICE) is used to generate mechanical power, or that a fuel cell will be used to convert fuel to electrical energy.

### Main components of Hybrid Vehicles

- Motor
- The battery pack
- Accessories

#### Motor

- Motor is the "workhorse" of Hybrid Electric Vehicle drive system. The electric traction motor drives the wheel of the vehicle.
- An electric motor provides full torque at low speeds. The motor also has low noise & high efficiency.
- The front-running motor technologies for HEV applications include PMSM (permanent magnet synchronous motor), BLDC (brushless DC motor), SRM (switched reluctance motor) &

AC induction motor.

**Battery** The battery pack in HEV has a much higher voltage than the SIL automotive 12 volts battery, in order to reduce the currents & the  $I^2R$  losses.

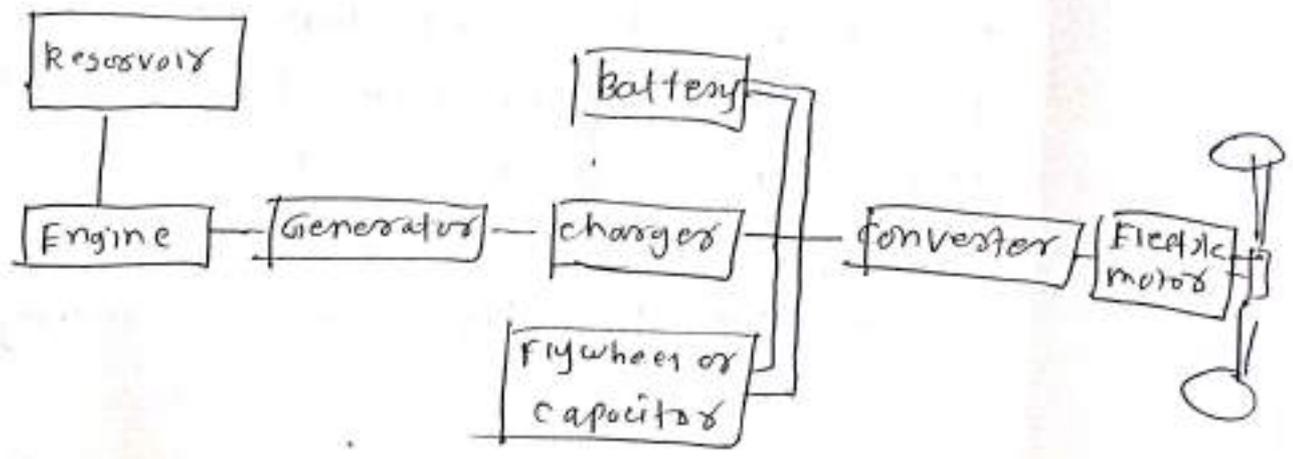
**Accessories**

- Accessories such as power steering & air conditioning are powered by electric motors instead of being attached to the combustion engine.
- This allows efficiency gains as the accessories can run at constant speed or can be switched off, regardless of how fast the combustion engine is running.

Types of Electric Vehicle

- Series hybrid vehicle
- Parallel hybrid vehicle
- Combined or parallel & series hybrid vehicle

**Series hybrid vehicle**

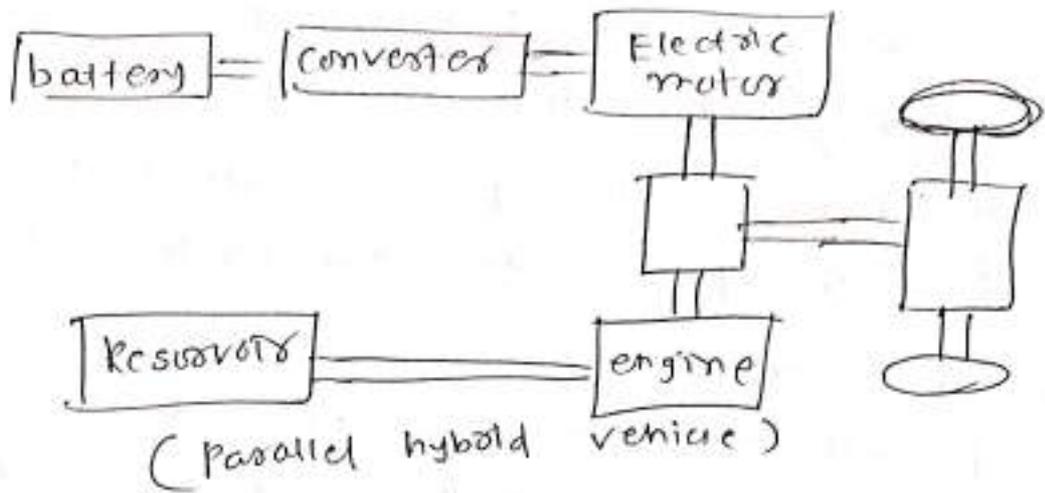


- In a series hybrid system, the combustion engine drives an electric generator usually a (3-ph generator plus rectifier) instead of directly driving the wheels.
- The electric motor is the only means of providing power to the wheels. The generator both charges a battery & powers an electric motor that moves the vehicle. When large amounts of power are required, the motor draws electricity from both the battery & the generator.
- They deliver peak energy during acceleration and take regenerative energy during braking.

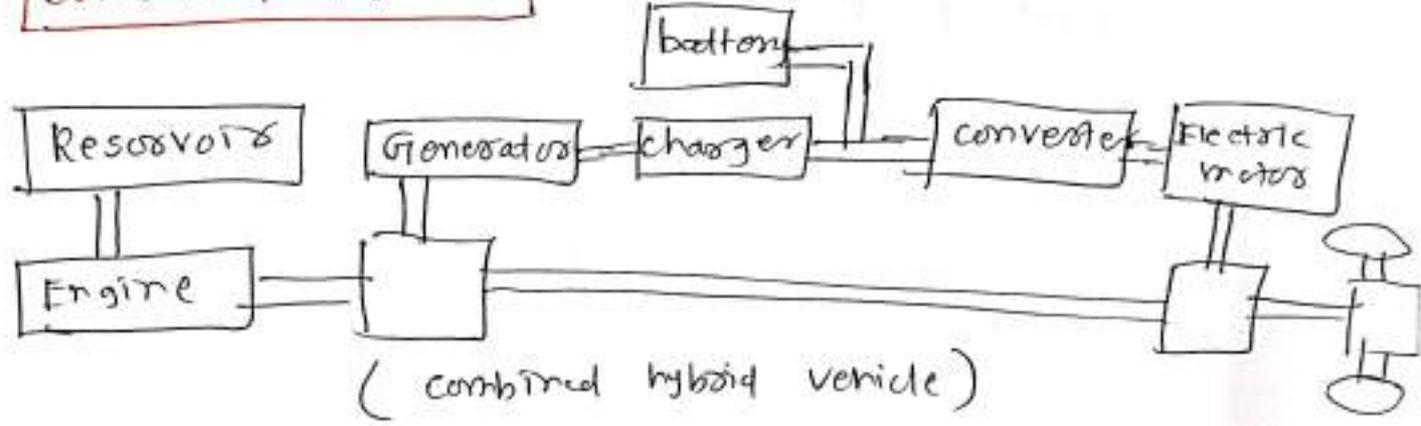
Parallel hybrid vehicle

- Parallel hybrid systems have both an internal combustion engine & electric motor in parallel connected to a mechanical transmission.
- most designs combine a large electrical generator and a motor into one unit, often located b/w the combustion engine & the transmission, replacing both the conventional starter motor & the alternator.
- The battery can be recharged during regenerative braking & during coasting.

→ As there is a fixed mechanical link between the wheels & the motor, the battery cannot be charged when the car isn't moving.



Combined hybrid



→ combined hybrid systems have features of both series & parallel hybrids. There is a double connection b/w the engine & drive axle; mechanical & electrical.

→ This split power path allows interconnecting mechanical & electrical power, at some cost in complexity.

→ power-split devices are incorporated in the powertrain.

→ The power to the wheels can be either mechanical or electrical or both. This is also the case in parallel hybrids. But the main principle behind the combined system is the decoupling of the power supplied by the engine from the power demanded by the driver.

→ This system is more expensive than a pure parallel system as it needs an extra generator, a mechanical split power system and more computing power to control the dual system.