RENEWABLE ENERGY SOURCES

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RENEWABLE ENERGY SOURCES

➢ Syllabus

UNIT–I	Fundamentals of Energy Systems
UNIT–II	Solar Thermal Systems
UNIT–III	Solar Photovoltaic Systems
UNIT–IV	Wind Energy
UNIT–V	Hydro, Tidal and Wave power systems
UNIT–VI	Biomass, fuel cells and geothermal systems

Text Books:

- Renewable Energy Resources by John Twidell and Tony Weir, Taylor &Francis Group
- Non-Conventional Energy Resources by B.H.Khan, Mc Graw Hill Education
- Non-Conventional Energy Sources by G.D.Rai, Khanna Publishers
- Non-Conventional Energy Sources and Utilisation by Er.R.K.Rajput, S.Chand

RENEWABLE ENERGY SOURCES

UNIT-I

Fundamentals of Energy Systems and Solar energy

UNIT–I

Fundamentals of Energy Systems and Solar energy

Topics:

- Energy conservation principle
- Energy scenario (world and India)
- Various forms of renewable energy
- Solar radiation
- Outside earth's atmosphere
- Earth surface
- Analysis of solar radiation data
- Geometry
- Radiation on tilted surfaces
- Numerical problems

ENERGY

➢ Introduction

- Energy can be defined as the capacity or ability to do work
- Energy is the primary and most universal measure of all kinds work by human beings and nature.
- Every thing what happens the world is the expression of flow of energy in one of its forms.
- One form of energy can be converted into other form by use of suitable arrangements.
- It plays an important role in our day to day life as it is required in every field like industry, transport, communication, sports, defence, household, agriculture and more.
- There are plenty of energy sources to get energy.
- Simply speaking more developed a country, higher is the per capita consumption of energy and vice-versa. India's per capita consumption of energy is only one eighth of global average. This indicates that our country has low rate of per capita consumption of energy as compared to developed countries.

➢ Different forms of energy

The different forms of energy are:

1. Mechanical energy (kinetic and potential)
2. Thermal (or) Heat energy
3. Chemical energy
4. Electrical energy
5. Nuclear energy
6. Electromagnetic energy
7. Gravitational energy

The S.I unit of energy is Joule or KJ or Watt.h.

Energy conservation:

- Energy conservation means reduction in energy consumption but without making any sacrifice in the quality or quantity of production.
- In other words, it means increasing the production from a given amount of energy input by reducing losses/wastages and maximizing the efficiency.

Various aspects of energy conservation

Saving of usable energy, which is otherwise wasted, has direct impact on

- economy,
- environment and
- long term availability of non-renewable energy sources

Principles of energy conservation:

Some general principles of energy conservation are

- Recycling of waste
- Modernization of technology
- Waste heat utilization
- Judicial use of proper type of fuel
- Cogeneration
- Training of manpower
- Adopting daylight saving time
- Proper operation and maintenance

These energy resources can be classified as Conventional and Non-conventional sources of energy

➢ Conventional sources of energy

- Conventional sources of energy are the natural energy resources (fossil fuels i.e, coal, petroleum, and natural gas), these are formed by the decomposition of the remains of dead plants and animals buried under the earth over hundreds of millions of years.
- These are non-renewable sources of energy, which, if exhausted, can not be replenished in a short time. Their reserves are limited and are considered very precious
- which are present in a limited quantity and are being used for a long time.
- These resources have been depleted to a great extent due to their continuous exploitation.
- It is believed that the deposits of petroleum in our country will be exhausted within few decades and the coal reserves can last for a hundred more years.
- The Uranium reserves in the world at present are small. These reserves are recoverable but are expensive.

➢ Non-Conventional sources of energy

- The sources of energy which are being produced continuously in nature and are in exhaustible are called renewable sources of energy (or) non-conventional energy.
- These cannot be exhausted easily, can be generated constantly so can be used again and again, e.g. solar energy, wind energy, tidal energy, biomass energy and geothermal energy etc.
- These sources do not pollute the environment and do not require heavy expenditure.
- They are called renewable resources as they can be replaced through natural processes at a rate equal to or greater than the rate at which they are consumed.

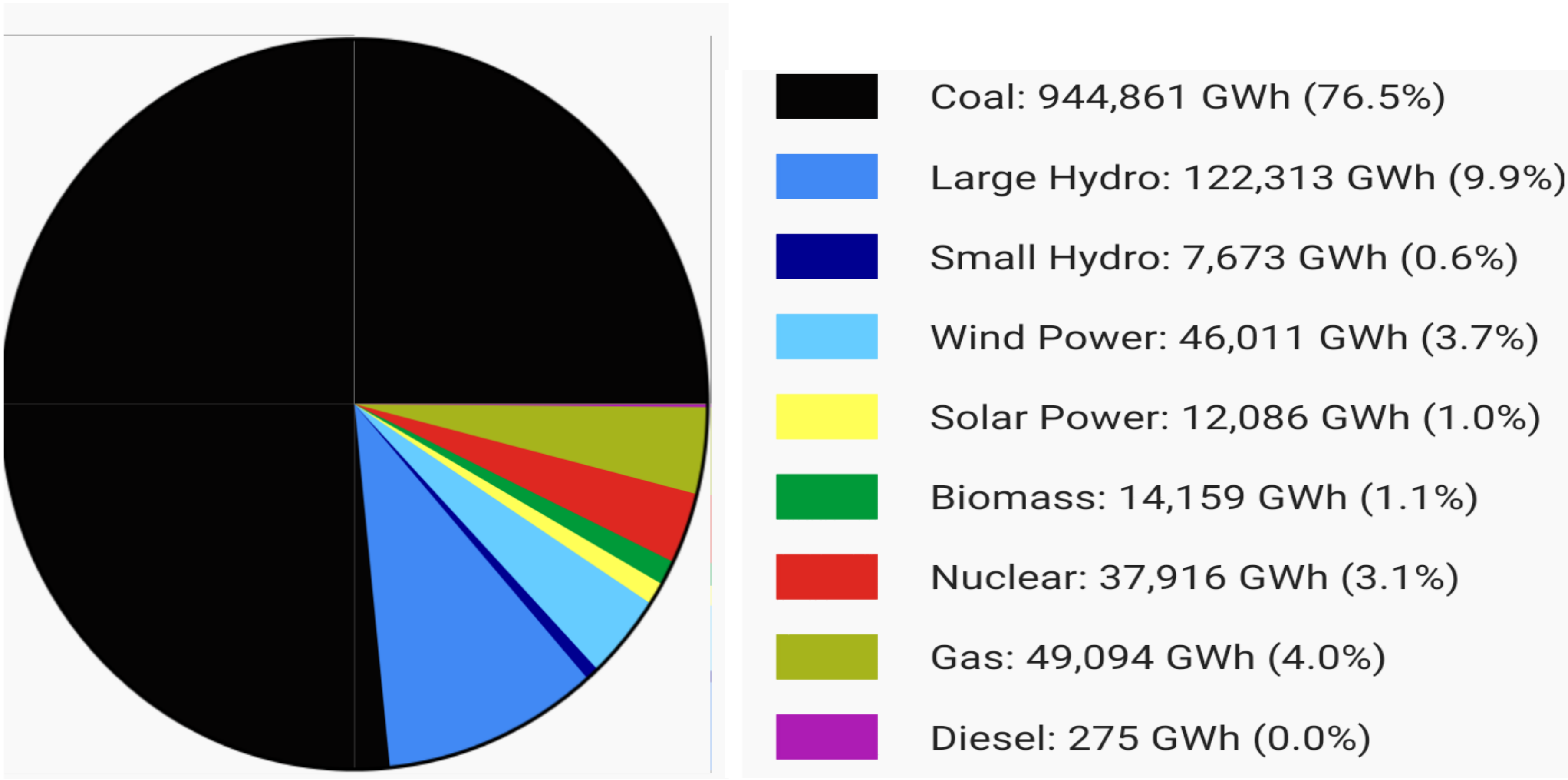
➢ MAIN ENERGY SOURCES

1. Non-Renewable Energy Sources or Conventional energy sources
   - Coal
   - Oil
   - Natural gas
   - Nuclear power
   - Large Hydro power
2. Renewable Energy sources or Non-Conventional energy sources
   - Solar energy
   - Wind energy
   - Bio-mass energy
   - Small and Micro hydro energy
   - Geo-thermal energy
   - Tidal and Wave energy
   - Fuel cell energy

Energy scenario in India and World

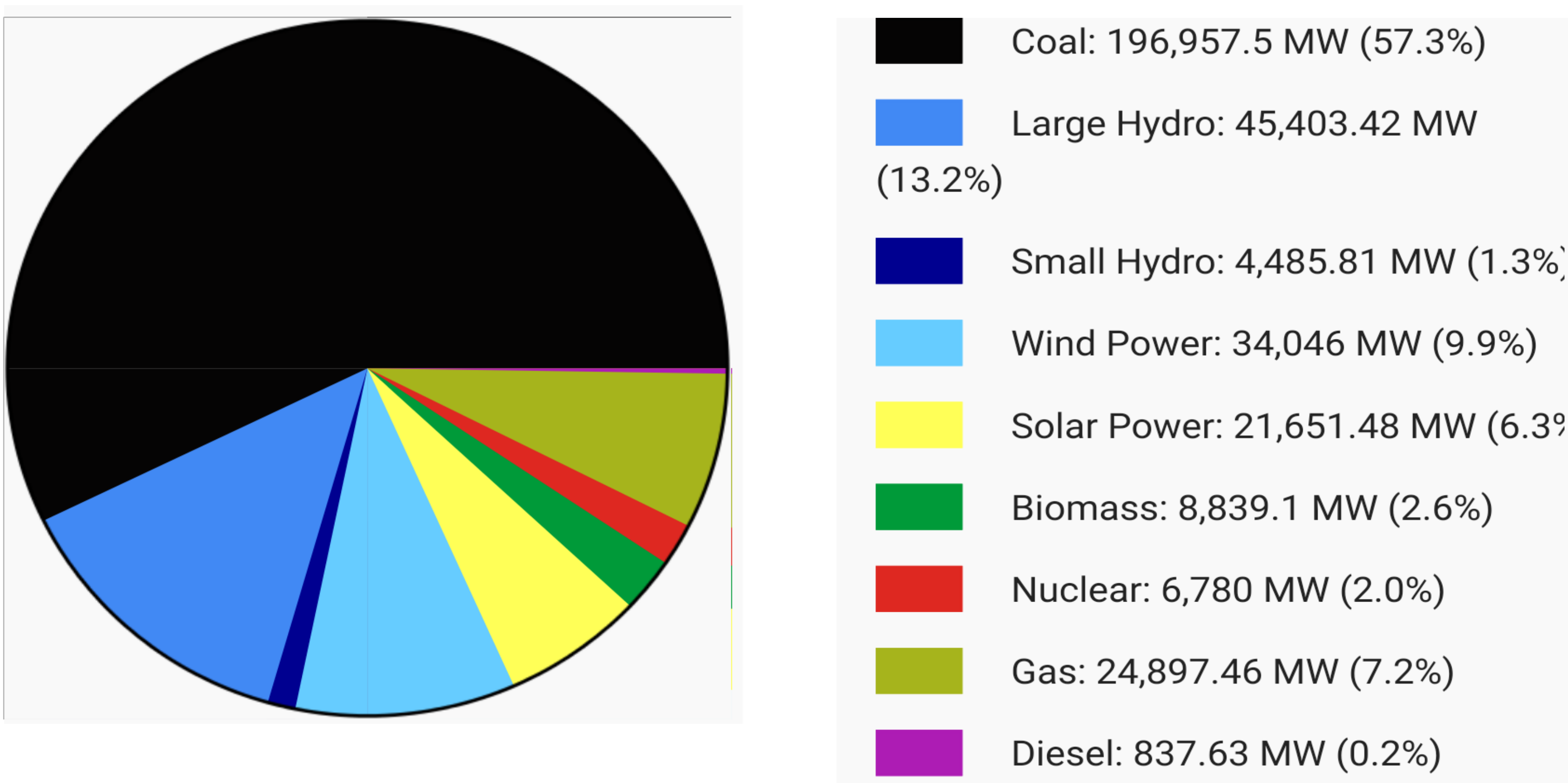
❑Energy scenario in India

➢ Installed capacity by source in India as on 2016-17



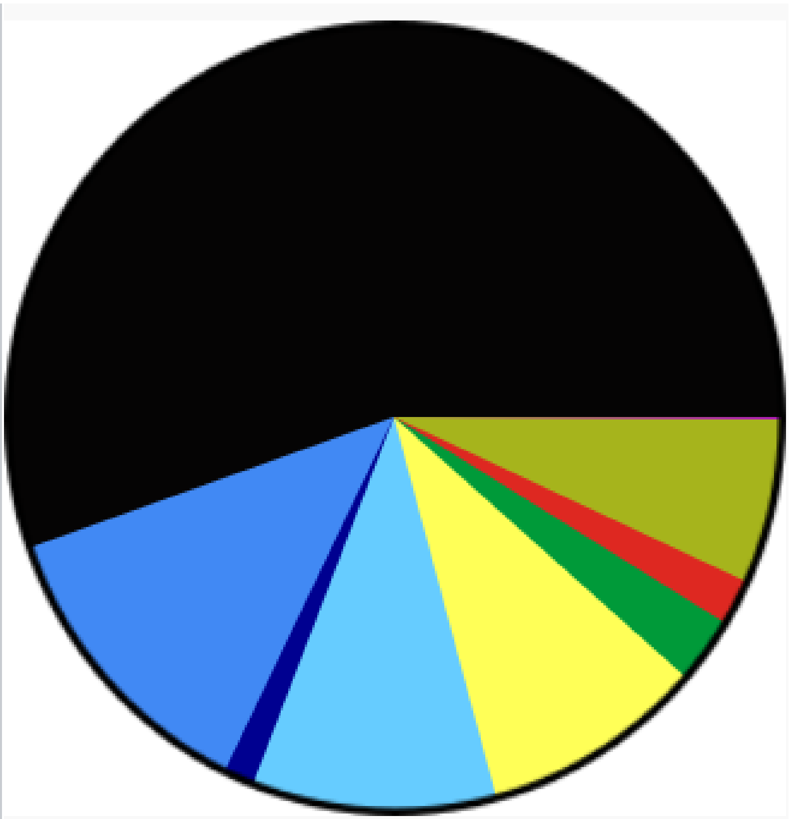
❑Energy scenario in India

➢ Installed capacity by source in India as on 31st May 2018



❑Energy scenario in India

➢ Installed capacity by source in India as on 31^{st} March 2020



Coal: 205,134.5 MW (55.4%)

Large Hydro: 45,699.22 MW (12.3%)

Small Hydro: 4,683.16 MW (1.3%)

Wind Power: 37,693.75 MW (10.2%)

Solar Power: 34,627.82 MW (9.4%)

Biomass: 10,022.95 MW (2.7%)

Nuclear: 6,780 MW (1.8%)

Gas: 24,955.36 MW (6.7%)

Diesel: 509.71 MW (0.1%)

❑Energy scenario in India

Grid connected installed capacity from all sources as of 31 March 2020[2]

Source	Installed Capacity (MW)	Share
Coal	205,134.50	55.43%
Large hydro	45,699.22	12.35%
Other renewables	87,027.68	23.51%
Gas	24,955.36	6.74%
Diesel	509.71	0.14%
Nuclear	6,780.00	1.83%
Total	**370,106.46**	**100.00%**

❑Energy scenario in India

Installed grid interactive renewable power capacity (excluding large hydropower) as of 31 March 2020[2][15]

Source	Total Installed Capacity (MW)	2022 target (MW)
Wind power	37,693.75	60,000
Solar power	34,627.82	100,000
Biomass power (Biomass & Gasification and Bagasse Cogeneration)	9,875.31	*10,000
Waste-to-Power	147.64	
Small hydropower	4,683.16	5,000
TOTAL	**87,027.68**	**175,000**

❑Energy scenario in India

- The estimated potential for geothermal energy in India is about 10000 MW. There are seven geothermal provinces in India : the Himalayas, Sohana, West coast, Cambay, Son-Narmada-Tapi (SONATA), Godavari, and Mahanadi.

- The Uranium reserves in the world at present are small. These reserves are recoverable but are expensive. The presently working power plants are:
  1) Tarapur atomic power station in Maharashtra
  2) Ranapratap sagar atomic power station near Tota, Rajasthan
  3) Kalpakkam atomic power station near Madras, Tamilnadu.
  4) Narora atomic power station in U.P

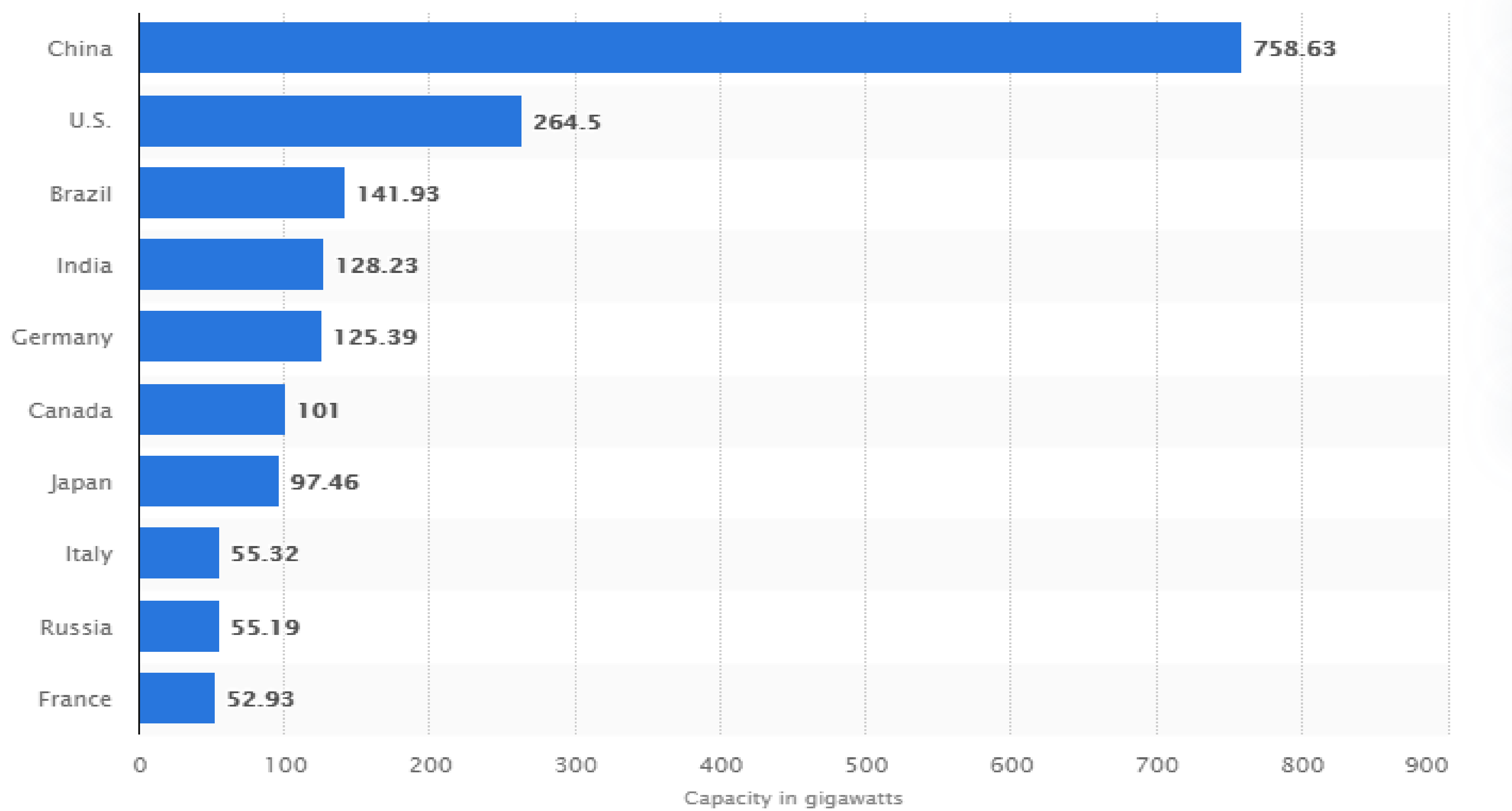
❑Energy scenario in India

Installed solar PV on 31 March

Year	Cumulative Capacity (in MW)
2010	161
2011	461
2012	1,205
2013	2,319
2014	2,632
2015	3,744
2016	6,763
2017	12,289
2018	21,651
2019	28,181
2020	34,627

❑Energy scenario in World

Installed renewable energy capacity worldwide in 2019 *in gigawatts*



❑Energy scenario in World-Top wind power producing countries

Country	Wind-power Production (TWh)
China	305
United States	257
Germany	106
United Kingdom	50.0
Spain	49.1
India	47.7
Brazil	42.3
Canada	28.8
France	24.7
Turkey	17.9

Conventional sources of energy

- These sources of energy are not abundant, present in limited quantity, e.g. coal, petroleum, natural gas
- They have been in use for a long time
- They are not replenished continuously. They are formed over a million years
- They are called non-renewable sources of energy
- They can be exhausted completely due to over-consumption except for hydel power
- They pollute the environment by emitting harmful gases and also contribute to global warming
- They are commonly used for industrial and commercial purposes
- Heavy expenditure is involved in using and maintaining these sources of energy
- They are used extensively, at a higher rate than the non-conventional sources

Non-conventional sources of energy

- These sources of energy are abundant in nature, e.g. solar energy, wind energy, tidal energy, biogas from biomass etc
- They are yet in development phase over the past few years
- They are replenished continuously by natural processes
- They are called renewable sources of energy
- They cannot be exhausted completely
- They are environment-friendly, do not pollute the environment
- They are used commonly used for household purposes
- Using these sources is less expensive
- They are not used as extensively as conventional sources

ADVANTAGES & DISADVANTAGES OF CONVENTIONAL ENERGY RESOURCES

ADVANTAGES:

1) Coal: as present is cheap.
2) Security: by storing certain quantity, the energy availability can be ensured for a certain period.
3) Convenience: it is very convenient to use.

DISADVANTAGES:

1) Fossil fuels(Coal, natural gas, oil)generate pollutants: CO, CO2, NOX, SOX. Particulate matter & heat. The pollutants degrade the environment, pose health hazards & cause various other problems.
2) Coal: it is also valuable petro-chemical & used as source of raw material for chemical, pharmaceuticals & paints, industries, etc. From long term point of view, it is desirable to conserve coal for future needs.
3) Safety of nuclear plants and radioactive pollution effect on living organism
4) Hydro electrical plants are cleanest but due to construction of big dams, large hydro reservoirs cause the following problems
   a) As large land area submerges into water, which leads to deforestation
   b) affect wild-life,Causes ecological disturbances such as earthquakes

The need for alternatives

1. The average rate of increase of oil production in the world is declining & a peak in production may be reached around 2015. There after the production will decline gradually & most of the oil reserves of the world are likely to be consumed by the end of the present century. The serious nature of this observation is apparent when one notes that oil provides about 30% of the world‘s need for energy from commercial sources & that oil is the fuel used in most of the world‘s transportation systems.
2. The production of natural gas is continuing to increase at a rate of about 4% every year. Unlike oil, there has been no significant slowdown in the rate of increase of production. Present indications are that a peak in gas production will come around 2025, about 10 years after the peak in oil production.
3. As oil & natural gas becomes scarcer, a great burden will fall on coal. It is likely that the production of coal will touch a maximum somewhere around 2050.
4. Finally, it should be noted that in addition to supplying energy, fossil fuels are used extensively as feed stock material for the manufacture of organic chemicals.

SALIENT FEATURES OF RENEWABLE ENERGY RESOURCES

- **Merits**:
  1) Renewable energy sources are available abundant in nature,
  2) free of cost
  3) They cause no or very little pollution.
  4) Environmental friendly
  5) They are inexhaustible
  6) Suitable for remote villages
- **Demerits:**
  1) Though available freely in nature, the cost of harnessing energy from RES is high, as in general, these are available in dilute forms of energy.
  2) Uncertainty of availability: the energy flow depends on various natural phenomena beyond human control.
  3) Difficulty in transporting this form of energy.

Various forms of Renewable Energy

Renewable Energy Sources or Non-Conventional energy sources

- The energy sources which are inexhaustible and can replenish once used are called Renewable Energy Sources
- Various forms of renewable energy sources are
  - Solar energy
  - Wind energy
  - Bio-mass energy
  - Small and Micro hydro energy
  - Geo-thermal energy
  - Tidal and Wave energy
  - Fuel cell energy

Solar Energy

- India is one of the leading Solar Energy producing countries in the world.
- By the time, the total installed grid connected solar power capacity is (about) 7,568 MW;
- however, the proposed target is 100,000 MW that set to achieve by 2022.
- With the total production of 1285.932 MW, **Rajasthan** is ranked first,
- followed by Tamil Nadu (1267 MW),
- Gujarat (1120 MW), and
- Andhra Pradesh (864 MW)

Wind Energy

- In 1986, the first wind power is set up at Ratnagiri in Maharashtra, Okha in Gujarat, and Tuticorin in Tamil Nadu
- At present, India is the fourth largest wind power installed country in the world.

Geothermal Energy

- Geothermal energy is thermal energy, which is generated through the natural hot springs.
- In India, by the time, geothermal energy installed capacity is experimental; however, the potential capacity is more than 10,000 MW.
- Following are the six most promising geothermal energy sites in India –
  - **Tattapani** in Chhattisgarh
  - **Puga** in Jammu & Kashmir
  - **Cambay Graben** in Gujarat
  - **Manikaran** in Himachal Pradesh
  - **Surajkund** in Jharkhand
  - **Chhumathang** in Jammu & Kashmir

Tidal Energy

- India is estimated to have a potential of 40 to 60 GW of Wave Energy all around its coastal area.
- **Sagar Shakthi** is a 1 MW OTEC (Ocean Thermal Energy Conversion) plant built off the Tuticorn coast.
- Located at **Borya** and **Budhal** villages in the coastal region of Ratnagiri district, are the major tidal energy plants in Maharashtra.

SOLAR ENERGY

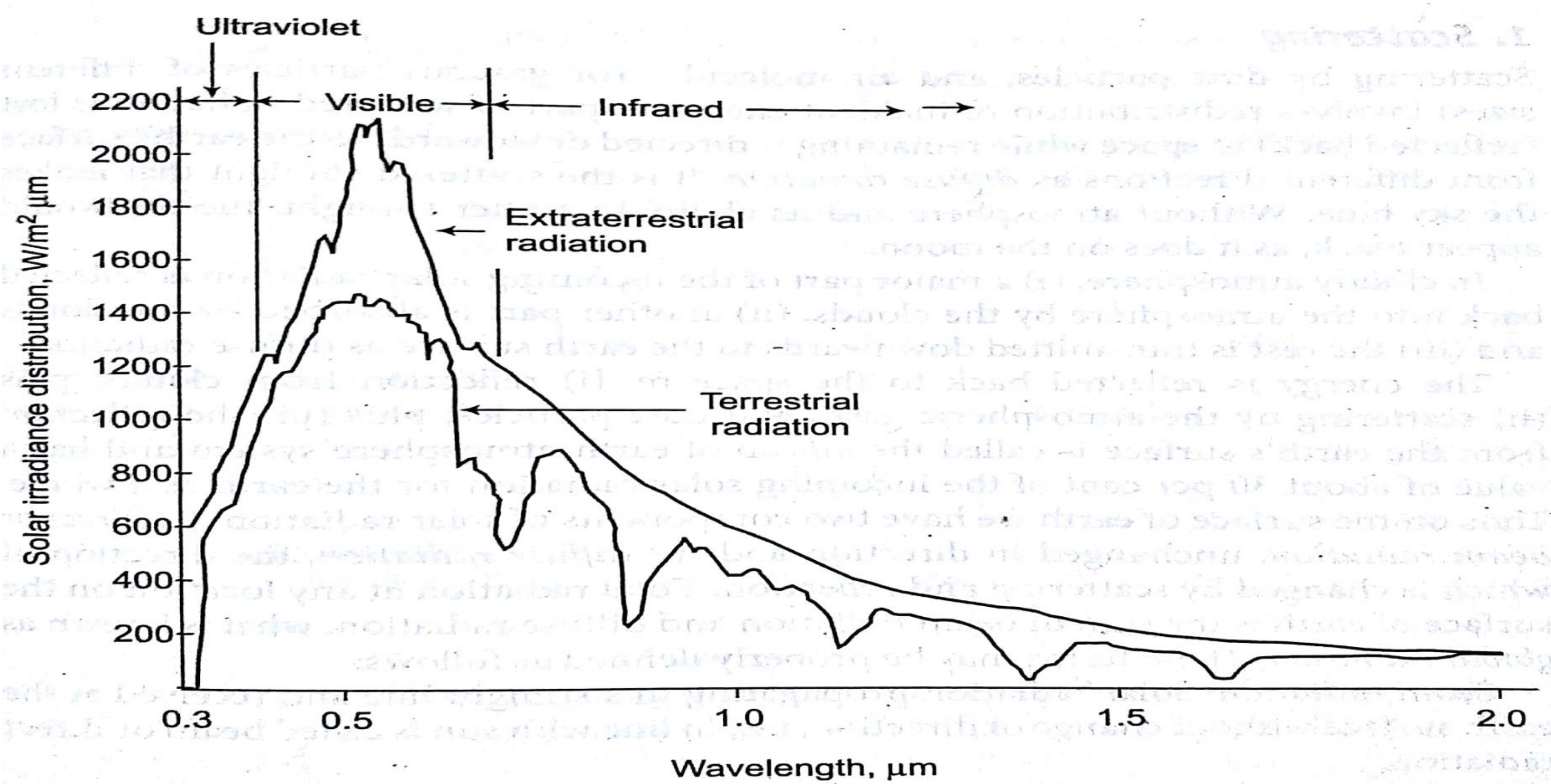
➢ Introduction

- Energy from the sun is called solar energy.
- The Sun's energy comes from nuclear fusion reaction that takes place deep in the sun. Hydrogen nucleus fuse into helium nucleus.
- The energy from these reactions flow out from the sun and escape into space.
- Solar energy is a very large, inexhaustible source of energy.
- The power from the Sun intercepted by the earth is approximately 1.8×10^{11} MW which is many thousands of time larger than the present consumption rate on the earth of all commercial energy sources.
- Thus, in principle solar energy could supply all the present & future energy needs of the world on a continuing basis.
- This makes it one of the most promising of the Renewable energy sources.
- Solar energy is received in the form of radiation, can be converted directly or indirectly into other forms of energy, such as heat & electricity.

SOLAR ENERGY

- This energy is radiated by the Sun as electromagnetic waves of which 99% have wave lengths in the range of 0.2 to 4 micro meters shown in Spectral distribution of solar radiation intensity.
- Solar energy reaching the top of the Earth‘s atmosphere consists about 8% U.V radiation, 46% of visible light, 46% Infrared radiation.

➢ Spectral distribution of solar radiation intensity



Merits of solar energy:

1) It is an environmental clean source of energy
2) It is free of cost
3) Available in adequate quantities in all most all parts of world

Demerits of solar energy:

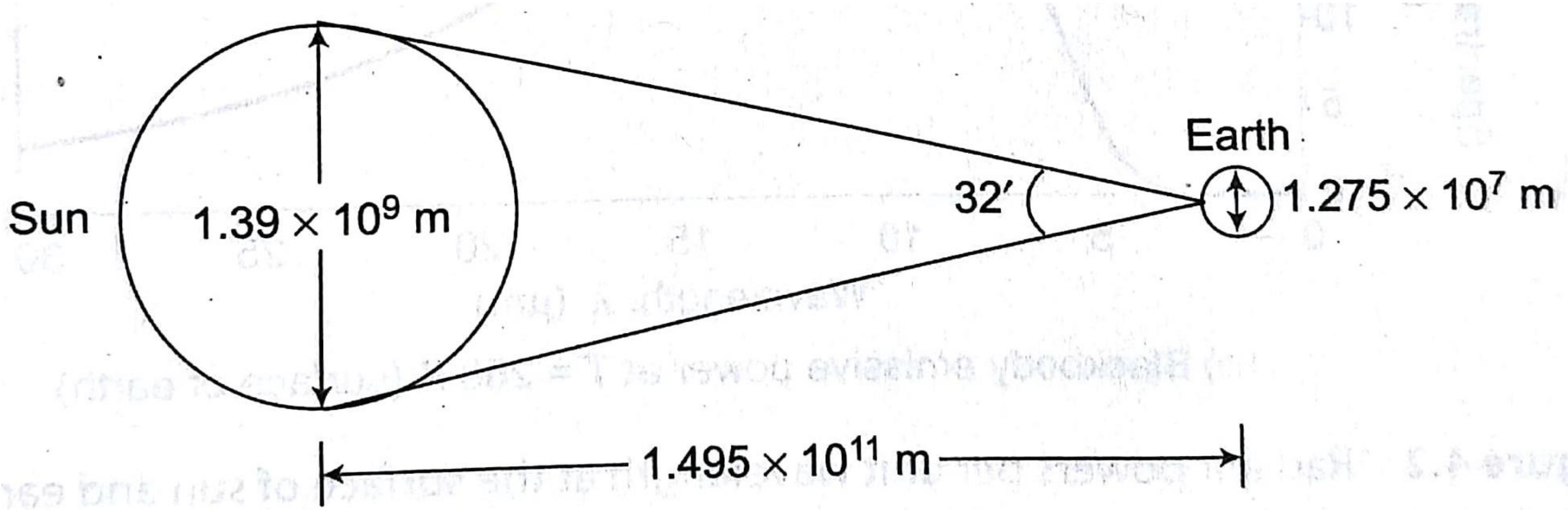
1) It is required large collecting areas are required in many applications & these results increase of cost.
2) Solar energy availability varies widely with time, it occurs because of the day-night cycle & also seasonally because of the Earth‘s orbit around the Sun [even local weather condition]
3) It is available in day time only(not in night time)

Solar Energy applications :

1) Heating and cooling of residential building
2) Solar water heating
3) Solar drying of agricultural and animal products
4) Salt production by evaporation of seawater
5) Solar cookers
6) Solar engines for water pumping
7) Solar Refrigeration
8) Solar electric power generation
9) Solar photo voltaic cells, which can be used for electricity
10) Solar furnaces
11) Distillation

➢ Solar Radiation

- Sun is a large sphere of very hot gases, the heat being generated by various kinds of fusion reactions.
- It's diameter is $1.39X10^9$m, while that of the earth is $1.275X10^7$m. It subtends an angle of 32minutes at the earth's surface.
- The mean distance between the two is $1.495x10^{11}$m



- This is because it is also at large distance.
- Thus the beam radiation received from the sun on the earth is almost parallel.
- The brightness of the sun varies from it’s center to it’s edge.
- However for engineering calculations.
- It is customary to assume that the brightness all over the solar disc uniform.

➢ **Solar Constant(Isc)**:

- “The rate at which solar energy received in unit time on a unit area perpendicular to the sun’s direction at the mean distance of the earth from the sun is called solar constant Isc”
- Because of the sun’s distance and activity vary through out the year, the rate of arrival of solar constant is thus an average from which the actual values vary up to 3 percent in either direction.

Extra-Terrestrial Solar Radiation

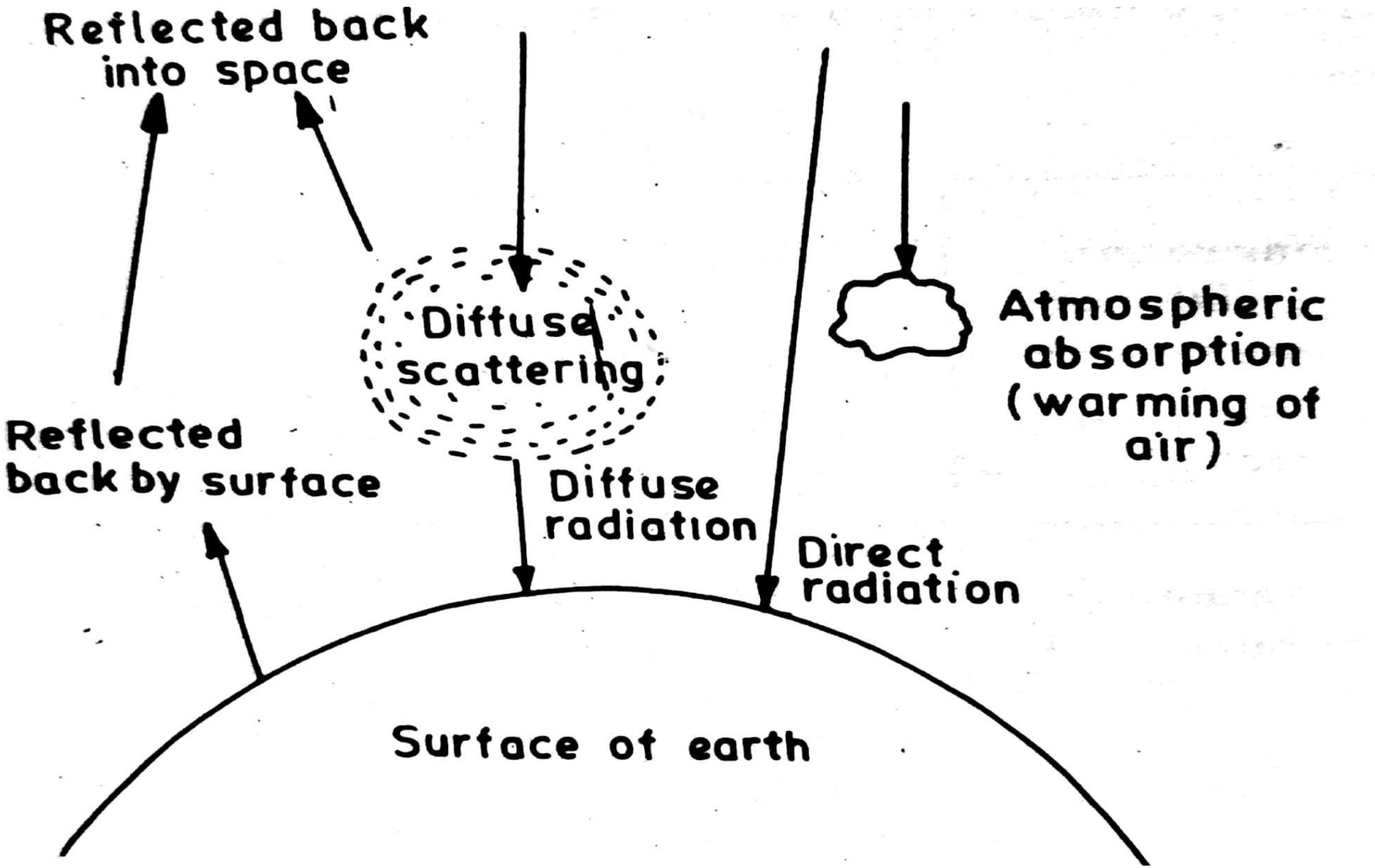
and

Terrestrial Solar Radiation

Extra-terrestrial Solar Radiation
(or)
Solar Radiation at Outside earth's atmosphere

- The sun emits a large amount of heat in the form of radiations on the earth.
- As the size of the sun is far greater than that of earth, some of the radiations are incident outside the earth's atmosphere.
- These radiations called as Extra-terrestrial radiations.
- They are beam or direct radiation type.
- The Extra-terrestrial radiation varies due to the variation in the distance between the sun and the earth.
- So in summer the sun remains closer to the earth and moves further during the winter.
- However,this variation produces a sinusoidal variation in the intensity of radiation on a specific time of a year.

Solar Radiation at the Earth's Surface(Terrestrial)

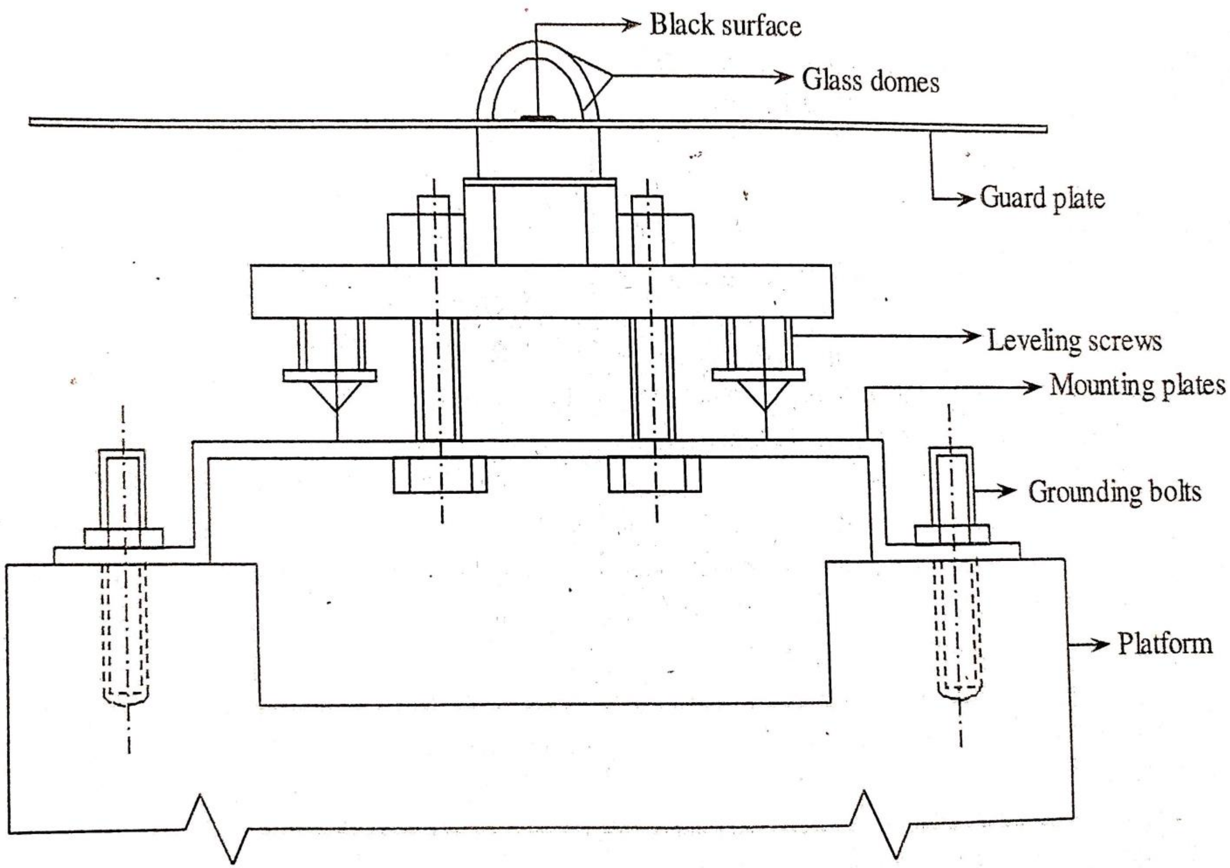


- **Instruments used for measuring solar radiation**
  - **Pyranometer**
  - **Pyrheliometer**
  - **Sun Shine Recorder**

Instruments used for measuring solar radiation

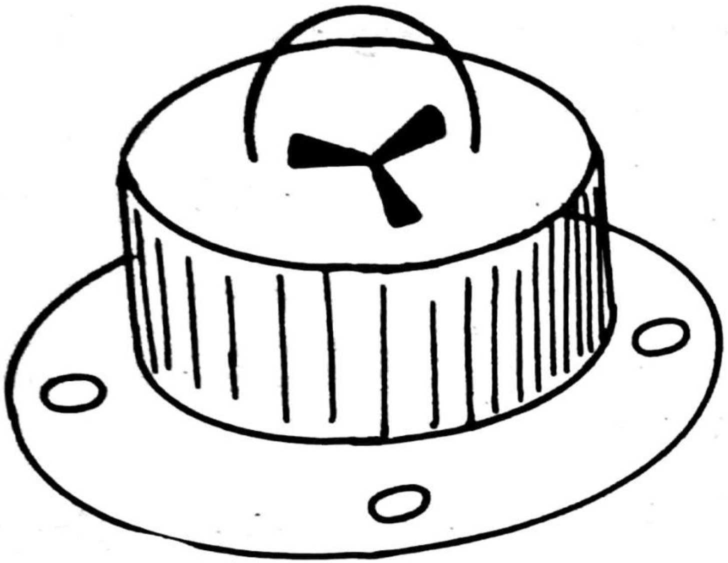
➢ Pyranometer:

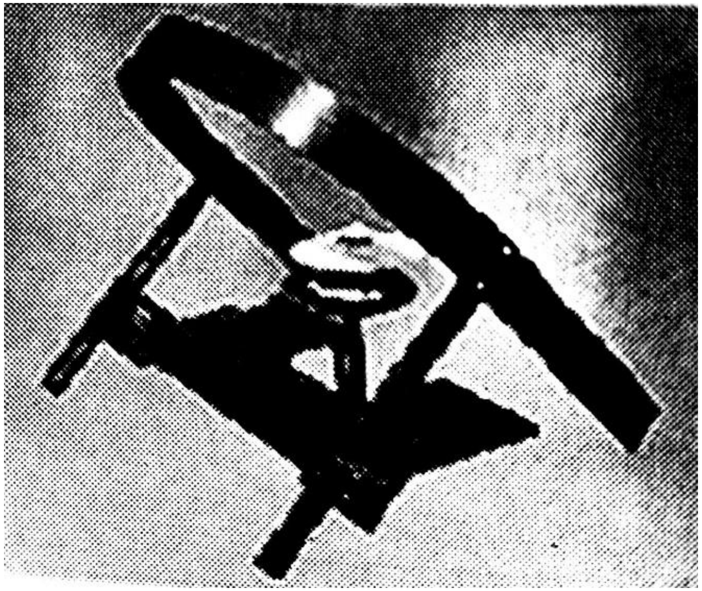
A pyranometer is an instrument which measure's either global or diffuse radiation falling on a horizontal surface over a hemispherical field of view



Instruments used for measuring solar radiation

- **Pyranometer:**





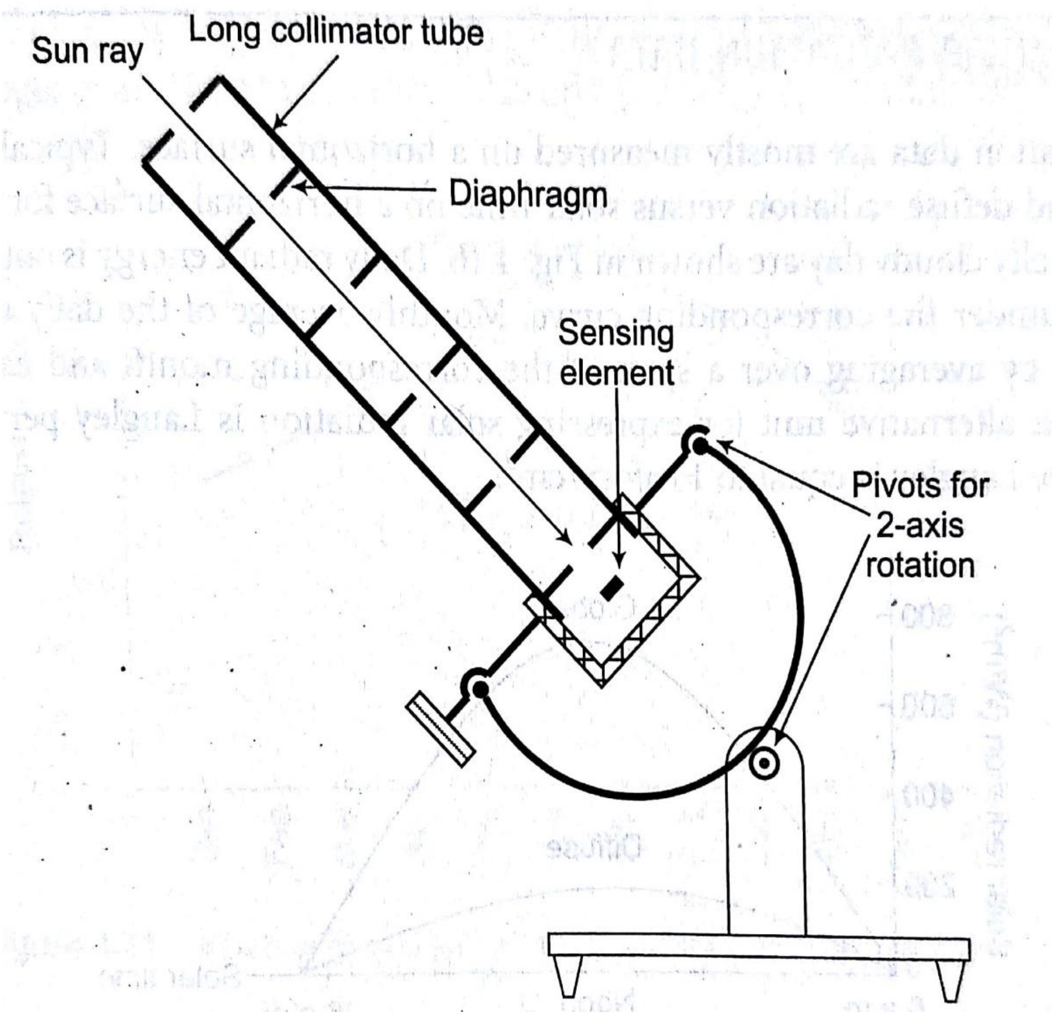
Instruments used for measuring solar radiation

Pyranometer:

- Pyranometer consists of a black surface which heats up when exposed to solar radiation.
- It's temperature increases until the rate of heat gain by solar radiation equals the rate of heat loss by convection, conduction and radiation.
- The hot junctions of thermopile are attached to the black surface, while the cold junctions are located under a guard plate so that they do not receive the radiation directly.
- As a result an emf is generated. This emf which is usually in the range of 0 to 10mv can be read, recorded or integrated over a period of time and is a measure of global radiation.
- The pyranometer can also be used for measurement of diffuse radiation. This is done by mounting it at the center of a semi circular shading ring.
- The shading ring is fixed in such a way that it's plane is parallel to the plane of path of sun's daily movement across the sky and it shades the thermopile element and two galss domes of pyranometer at all the times from direct sun shine.
- Consequently the pyranometer measures only the diffuse radiation received from the sky.

Instruments used for measuring solar radiation

- **Pyrheliometer:**
  - This is an instrument which measures beam radiation falling on a surface normal to the sun's rays.



Instruments used for measuring solar radiation

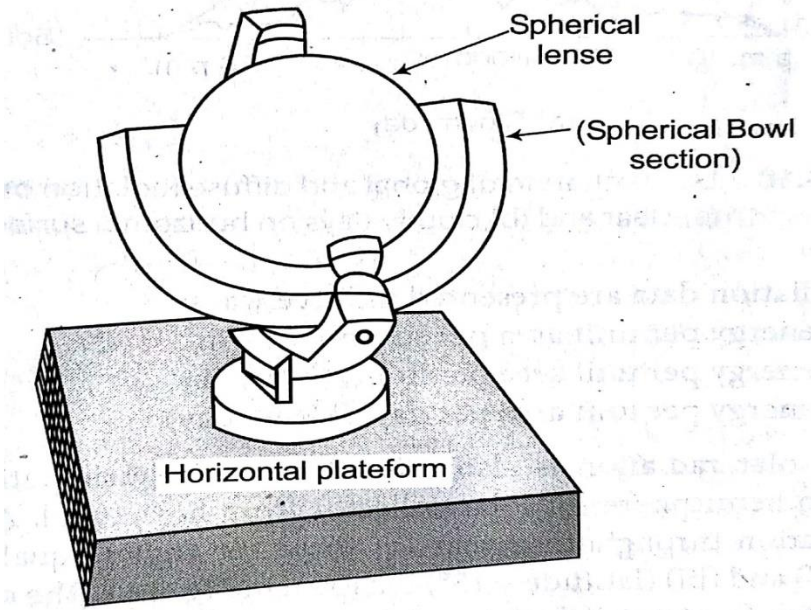
Pyrheliometer:

- In contrast to a pyranometer, the black absorber plate (with hot junctions of a thermopile attached to it) is located at the base of a collimating tube.
- The tube is aligned with the direction of the sun's rays with the help of a two-axis tracking mechanism and alignment indicator.
- Thus the black plate receives only beam radiation and a small amount of diffuse radiation falling within the acceptance angle of the instrument.

Instruments used for measuring solar radiation

➢ Sun Shine Recorder :

- The duration of bright sun shine in a day is measured by means of a sunshine recorder. the sun's Rays are focused by a glass sphere to a point on a card strip held in a groove in a spherical bowl mounted concentrically with the sphere. Whenever there is bright sunshine, the image formed is intense enough to burn a spot on the cord strip.
- Though the day as the sun moves across the sky, the image moves alone the strip.
- Thus, a burnt trace whose length is proportional to the duration of sunshine is obtained on the strip.



Solar Radiation Geometry

Solar Radiation Geometry

- In solar radiation geometry, the following angles are used

1) Solar altitude angle(α)
2) Zenith angle(θz)
3) Solar Azimuth Angle(γ_s)
4) Angle of Declination(δ)
5) Hour angle(ω)
6) Solar Incident angle(θ)
7) slope(β)
8) surface azimuth angle(γ)
9) Latitude angle(ϕ_l)

Solar Radiation Geometry

➢ Definitions:

Solar altitude angle(α):

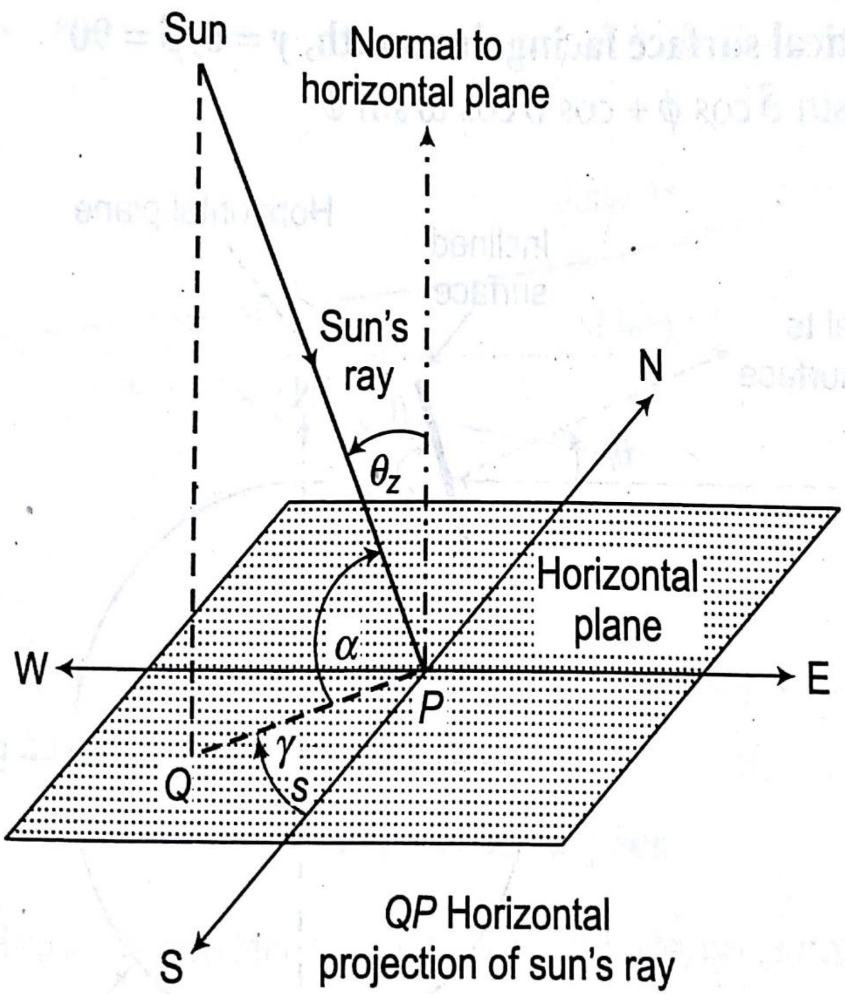
- Altitude Angle is the angle between the Sun's rays and projection of the Sun's rays on the horizontal plane (α) = $\frac{\pi}{2} - \theta_z$

Zenith angle(θz):

- It is Complementary angle of Sun's Altitude angle It is a vertical angle between Sun's rays and line perpendicular to the horizontal plane through the point i.e. angle between the beam and the vertical $\theta_z = \frac{\pi}{2} - \alpha$

Solar Azimuth Angle(γ_s): It is the solar angle in degrees along the horizon east or west of north or south.

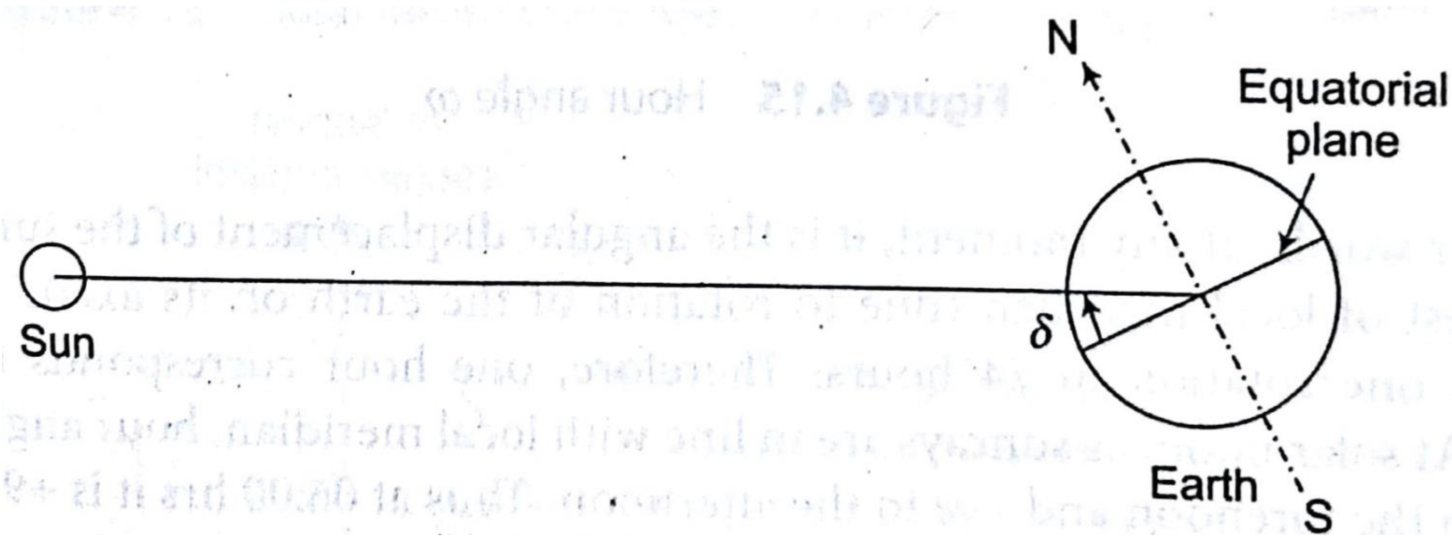
- It is the horizontal angle measured from north to the horizontal projection of sun's rays. $Cos(\gamma_s) = \frac{\cos\theta_z \sin\emptyset - \sin\delta}{\sin\theta_z \cos\emptyset}$



Solar Radiation Geometry

➢ Angle of Declination(δ):

- It is the angle between a line extending from the Centre of the Sun and center of the earth and projection of this on earth‘s equatorial plane.
- The declination is given by the formula Where n is the day of the year

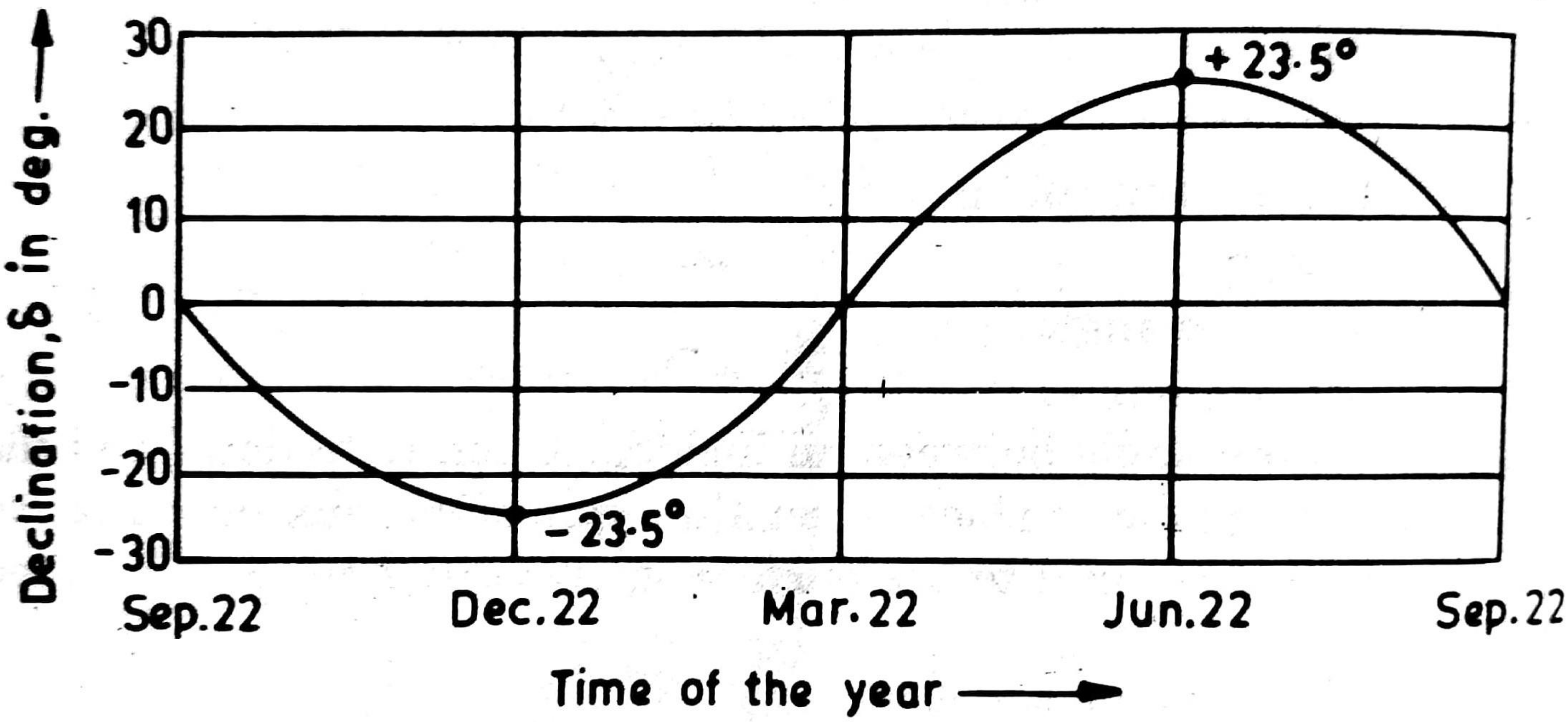


$$\delta(in\ degrees) = 23.45 \sin[\frac{360}{365}(284+n)]$$

Solar Radiation Geometry

➢ Angle of Declination(δ):

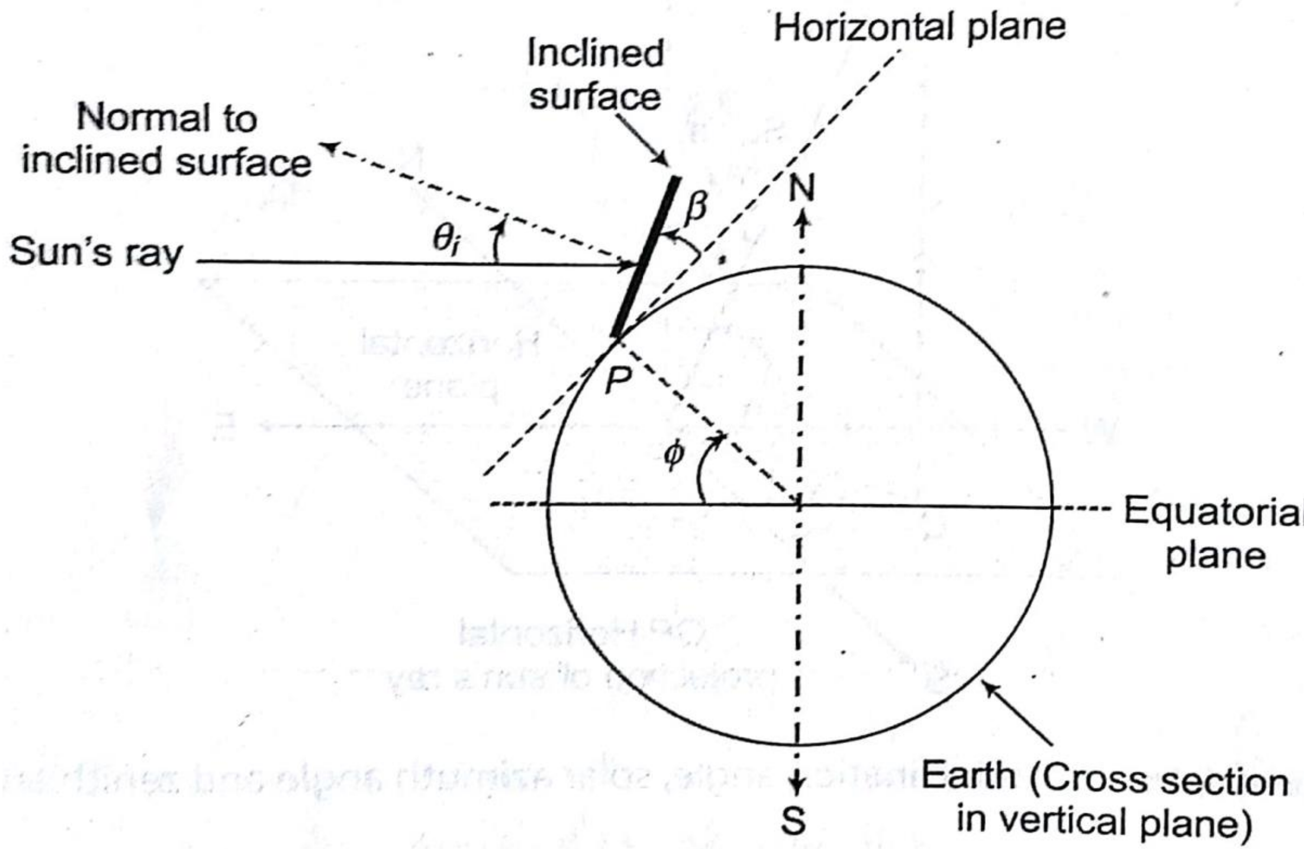
- Declination is the direct consequence of earth's tilt and It would vary between 23.5 degrees on June 22 to – 23.5 degrees on December 22. On equinoxes(day and night are of equal length) of March22 & Sept22 declination is zero. Below figure shows variation of sun declination.



Solar Radiation Geometry

➢ Solar Incident angle(θ):

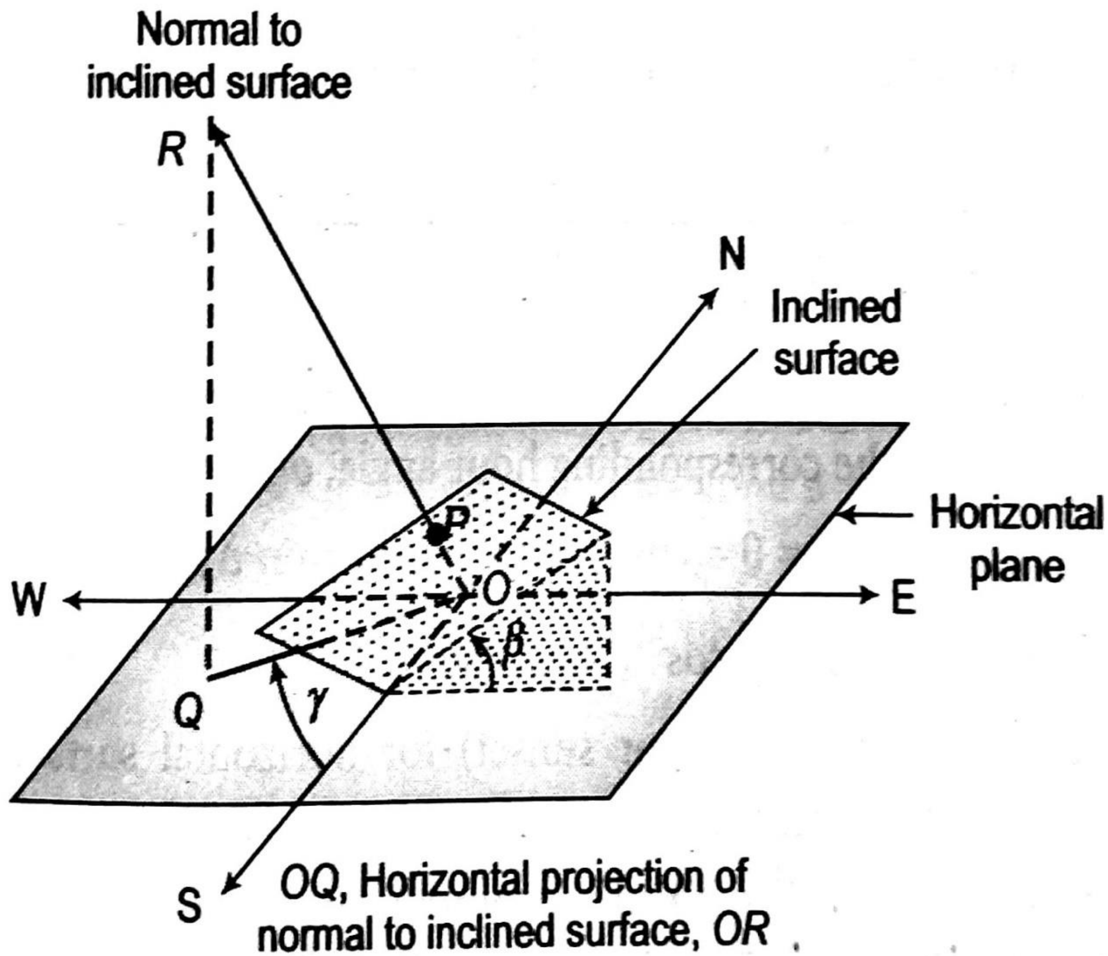
- It is the angle between an incident beam radiation falling on the collector and normal to the plane surface.
- It is dependent upon the position of the sun.



$$\cos\theta_i = \sin\phi(\sin\delta\cos\beta + \cos\delta\cos\gamma\cos\omega\sin\beta) + \cos\phi(\cos\delta\cos\omega\cos\beta - \sin\delta\cos\gamma\sin\beta) + \cos\delta\sin\gamma\sin\omega\sin\beta$$

Solar Radiation Geometry

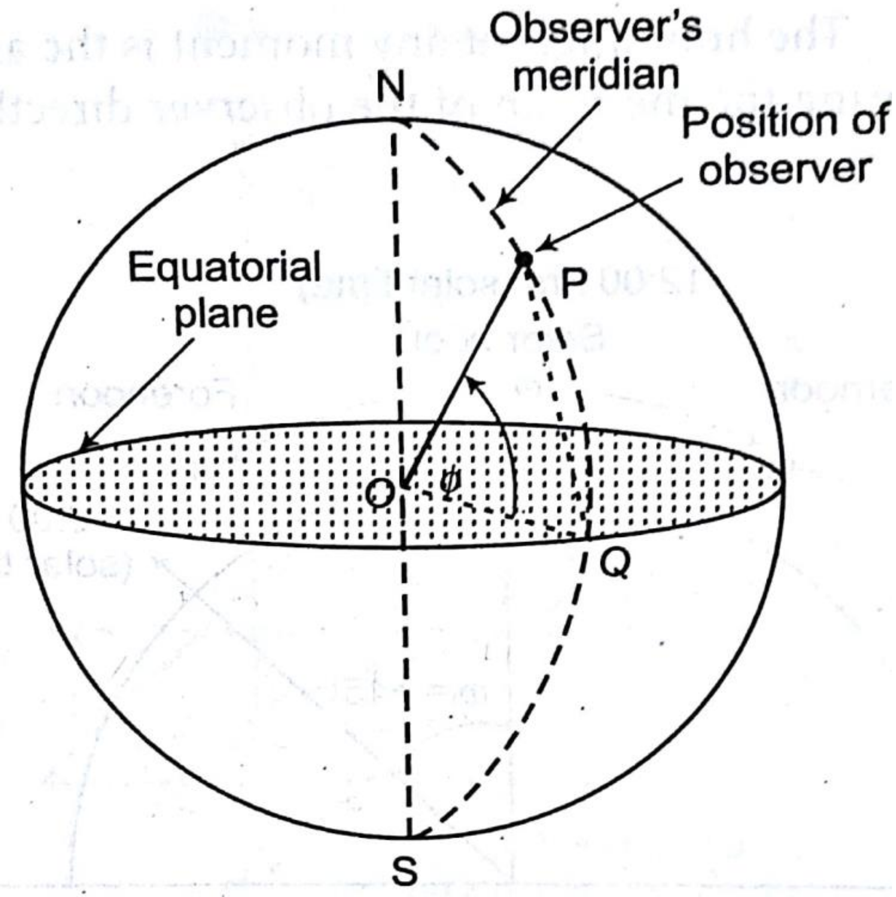
- **slope(β):**
  - Angle between the collector surface with the horizontal plane is called slope(β).
- **surface azimuth angle(γ):**
  - Angle between the normal to the collector and south direction is called surface azimuth angle(γ)



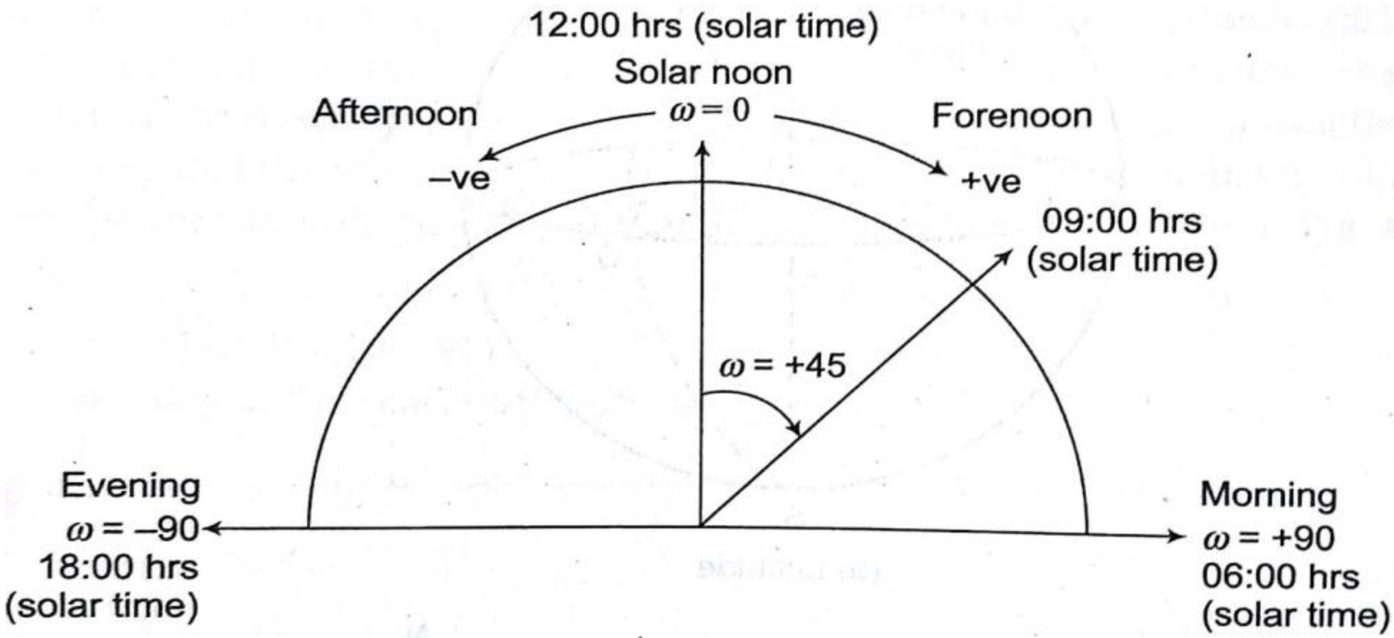
Solar Radiation Geometry

➢ Latitude angle(ϕ_l):

- Angle made by radial line joining the location to the centre of the Earth and the projection of that line on the equatorial plane.



Solar Radiation Geometry



Hour angle(ω):

- Hour angle is the angle through which the earth must turn to bring meridian of the point directly in line with the sun's rays.
- Hour angle is equal to 15^0per hour.
- It is measured from Noon,based on the local solar time(LST) or local apparent time,being positive in the morning and negative in the afternoon as shown above.
- Hour angle corresponding to sunrise or sunset , for horizontal surface is

$$\omega = \omega_s = cos^{-1}(- \tan\emptyset \tan\delta)$$

Here $\theta_z = 90^0$

Solar Radiation Geometry

➢ Sunrise hour angle(ω_s):

- During the sunrise a beam(ray) of light making an angle with the surface of the earth for every hour is called as sunrise hour angle.
- It depends upon the latitude of location,season and day in a year.

For the horizontal surface on the ground,the angle of incident is

$cos\theta = sin\delta\ sin\emptyset + cos\delta\ cos\emptyset\ cos\omega$ ----------------- (1)

The hour angle(ω)varies during the day

At sunrise the ray of light is parallel to the earth surface

The angle of incidence θ=90^0 and cos θ=0

By substituting in equation (1)

$cos\theta = sin\delta\ sin\emptyset + cos\delta\ cos\emptyset\ cos\omega$ ----------------- (1)

0= $sin\delta\ sin\emptyset + cos\delta\ cos\emptyset\ cos\omega$

$cos\delta\ cos\emptyset\ cos\omega$= - $sin\delta\ sin\emptyset$

$cos\omega= \frac{-\ sin\delta\ sin\emptyset}{cos\delta\ cos\emptyset}$

- ω=(ω_s) $= cos^{-1}$(- tan$\emptyset$ tanδ)
- The sunrise hour angle is positive

Solar Radiation Geometry

➢ Sunset hour angle(ω_s):

- During the sunset a beam(ray) of light making an angle with the surface of the earth for every hour is called as sunset hour angle.
- Similarly as sunrise hour angle

$$\omega=(\omega_s) = cos^{-1}(- \tan\emptyset \tan\delta)$$

- The sunset hour angle is negative

➢ Day Length:

- It is defined as the time interval between two successive passages of sun across the meridian of observer.
- It depends upon the latitude of location, season and day in a year, as the angle of latitude changes the difference in the day length also changes.
- At the time of sunset or sunrise the zenith angle $\theta z=90^0$
- Since 15^0 of the hour angle are equivalent to 1 hour
- The day length(hrs) is given by

$$t_d= \frac{2}{15}\,\omega_s = \frac{2}{15}\,cos^{-1}(- \tan\emptyset \tan\delta)$$

➢ Meridian:

- Meridian is the imaginary line passing through a point or place on earth and north and south poles of the earth

Solar Radiation Geometry

➢ Local Solar Time(LST) or Local Apparent Time (LAT):

- The time used for calculating the hour angle (ω) is the local apparent time.
- Local apparent Time can be calculated from standard time by applying two corrections.
- The first correction arises due to the difference in longitude of the location and meridian on which standard time is based.
- The correction has a magnitude of 4minutes for every degree difference in longitude.
- Second correction called the equation of time correction is due to the fact that earth's orbit and the rate of rotation are subject to small perturbations. Thus,
- Local Solar Time=Standard time± 4(Standard time Longitude-Longitude of the location)+(Equation of time correction)
- The Negative sign in the first correction is applicable for the eastern hemisphere ,while the positive sign is applicable for the western hemisphere.
- At the time of sunrise or sunset, the Zenith angle θ_z=90^0

Factors affecting Energy radiation incident

- ✓ Latitude and longitude of the geographical location
- ✓ Climatic conditions such as presence of clouds, water vapor etc.
- ✓ Time of the day
- ✓ Time of the year
- ✓ Angle of tilt
- ✓ Collector design

Analysis of Solar radiation Data

Analysis of Solar radiation Data

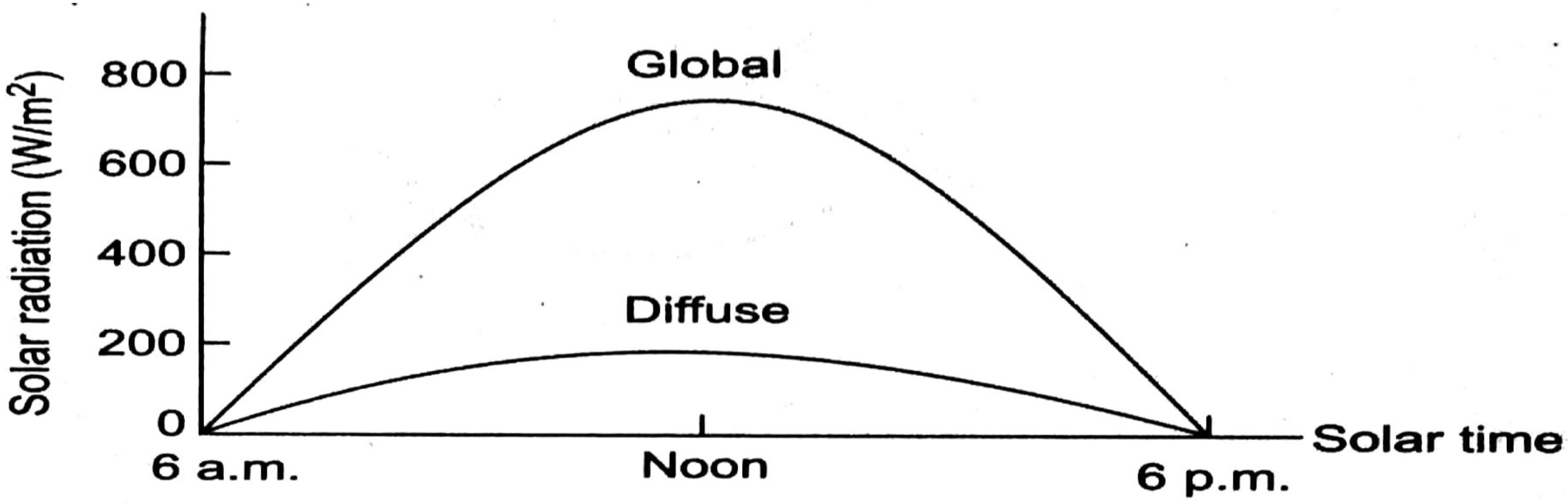
- **Solar radiation data are available in several forms and should include the following information**

1) The Solar radiation data is of either instantaneous or integrated with a certain period of time(days or hours)
2) The orientation of receiving surface(horizontal, vertical or inclind)
3) The period of measurements
4) Type of measurements(direct,diffuse or total radiation)
5) Type of instrument used for measurements
6) If the average of measurements is considered, then the period over which they are averaged

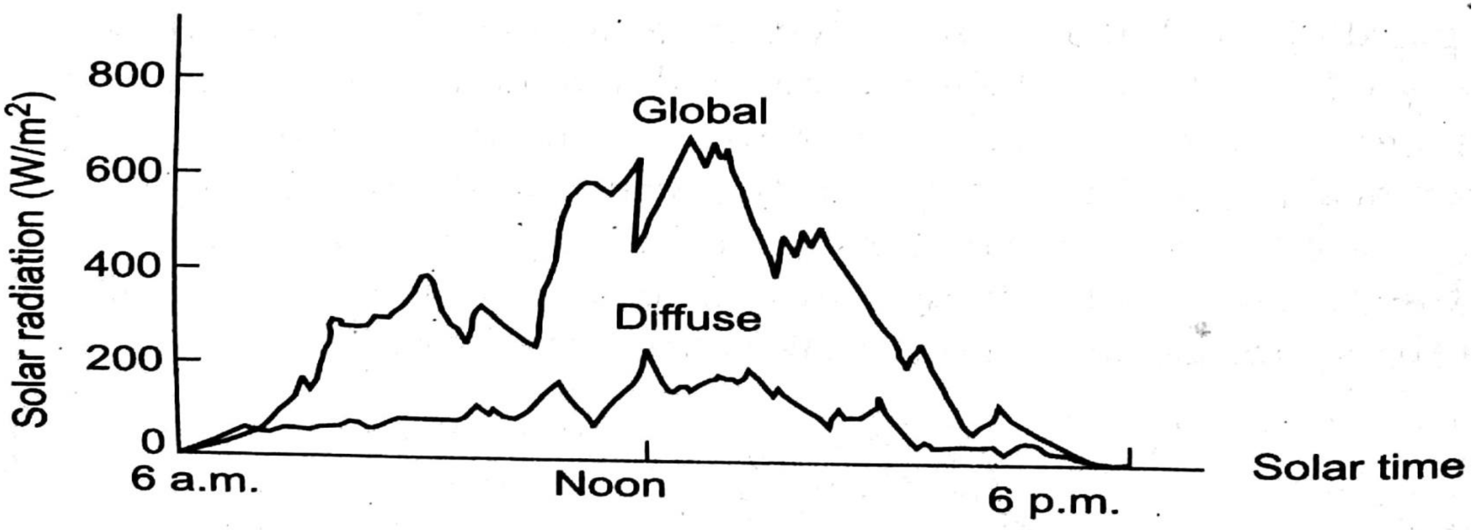
- **Solar radiation Data of India**

- Solar radiation flux generally reported in langleys per hour per day(1 langley=1cal/cm^2).
- The unit langley has been adopted in honour of **Samuel Langley** who made the first measurement of spectral distribution of the sun.
- India lies between latitude $7^0$and 37^0N and receives an annual average intensity of solar radiation between 16,700 to 29,260 KJ/m^2/day(400-700cal /cm^2/day)
- The peak value is generally measured in April or May

Analysis of Solar radiation Data



(a) Clear day



(b) Cloudy day

Solar Radiation on Tilted surfaces

Solar Radiation on Tilted surfaces

- The rate of receipt of solar energy on a given surface on the ground depends on the orientation of the surface with reference to the sun.
- The total solar radiation incident on the tilted surface comprises the following
  - Beam solar radiation
  - Diffuse solar radiation
  - Reflected solar radiation on to the surface from the surroundings
- To determine the total radiation incident on an inclined /tilted surface, It is required to calculate the sum of the beam radiation, diffuse solar radiation and reflected radiation.

Solar Radiation on Tilted surfaces

➢ Beam solar radiation

- TILT FACTOR(r_b): The ratio of beam radiation flux falling on the tilted surface to that of horizontal surface is called the TILT FACTOR for beam radiation.

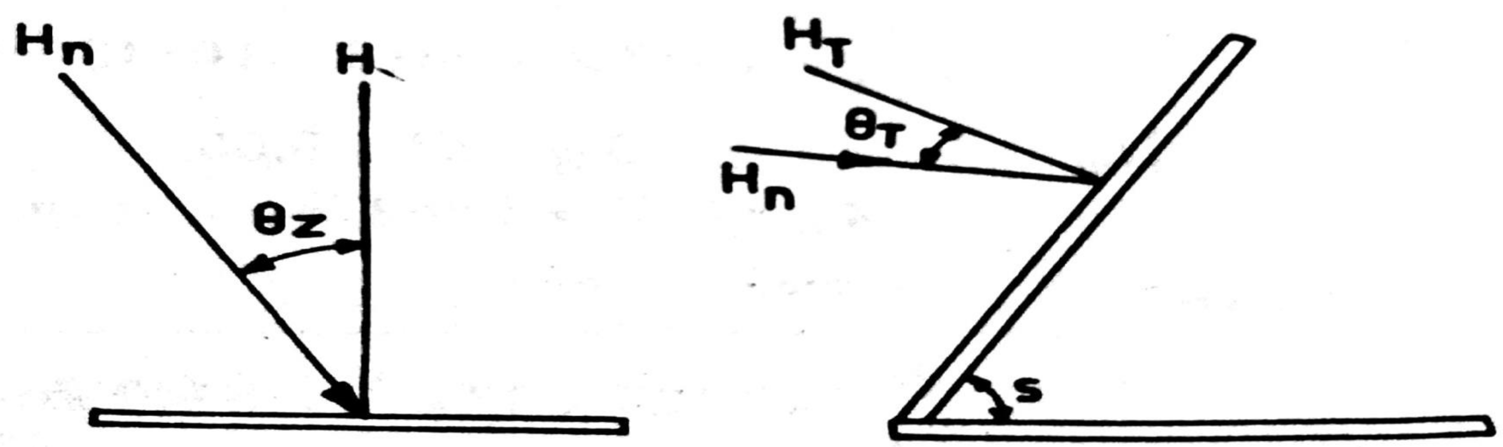
For case of tilted surface facing due south γ=0

$$cos\theta = sin\delta \sin(\emptyset - \beta) + cos\delta\, cos\omega \cos(\emptyset - \beta)$$

While for a horizontal surface,

$$cos\theta_z = \sin\emptyset\, sin\delta + cos\emptyset\, cos\delta\, cos\omega$$

Hence $r_b = \frac{H_T}{H} = \frac{H_n \cos\theta}{H_n \cos\theta_z} = \frac{cos\theta}{cos\theta_z} = \frac{sin\delta \sin(\emptyset-\beta)+cos\delta\, cos\omega \cos(\emptyset-\beta)}{\sin\emptyset\, sin\delta+cos\emptyset\, cos\delta\, cos\omega}$ -------> (1)



Radiation on Horizontal and Tilted surface

Solar Radiation on Tilted surfaces

➢ Diffuse solar radiation

- TILT FACTOR (r_d):The ratio of diffuse radiation flux falling on the tilted surface to that of horizontal surface is called the TILT FACTOR for diffuse radiation.
- Its value depends on the distribution of diffuse radiation over the sky and the portion of the sky dome seen by the tilted surface.

Assuming that the sky is an isotropic source of diffuse radiation, for a tilted surface with slope β, we have

$$r_d = \left[\frac{1+cos\beta}{2}\right] \text{ ------> (2)}$$

(1+ cosβ)/2 is the shape factor for a tilted surface w.r.t. sky

➢ Reflected Solar Radiation

- It is defined as the radiations obtained from the ground and surrounding objects. It becomes to the reverse of diffused radiations, if the considered reflection radiations are diffuse and isotropic.
- It is expressed as $r_r = \left[\frac{1-cos\beta}{2}\right]\rho$ ---------> (3)

Where ρ=Reflection coefficient of ground

= 0.2 for ordinary ground

= 0.7 for snow covered ground

Solar Radiation on Tilted surfaces

The total radiation incident on an inclined / tilted surface at any instant given by Liu and Jordan as,

$$I_T = I_b r_b + I_d r_d + (I_b + I_d) r_r$$

Substituting equations 1,2 and 3 in the above equation we get,

$$I_T = I_b [\frac{cos\theta}{cos\theta_z}] + I_d [\frac{1+cos\beta}{2}] + (I_b + I_d)[\frac{1-cos\beta}{2}]\rho$$

RENEWABLE ENERGY SOURCES

UNIT-II

Solar Thermal Systems

UNIT–II
Solar Thermal Systems

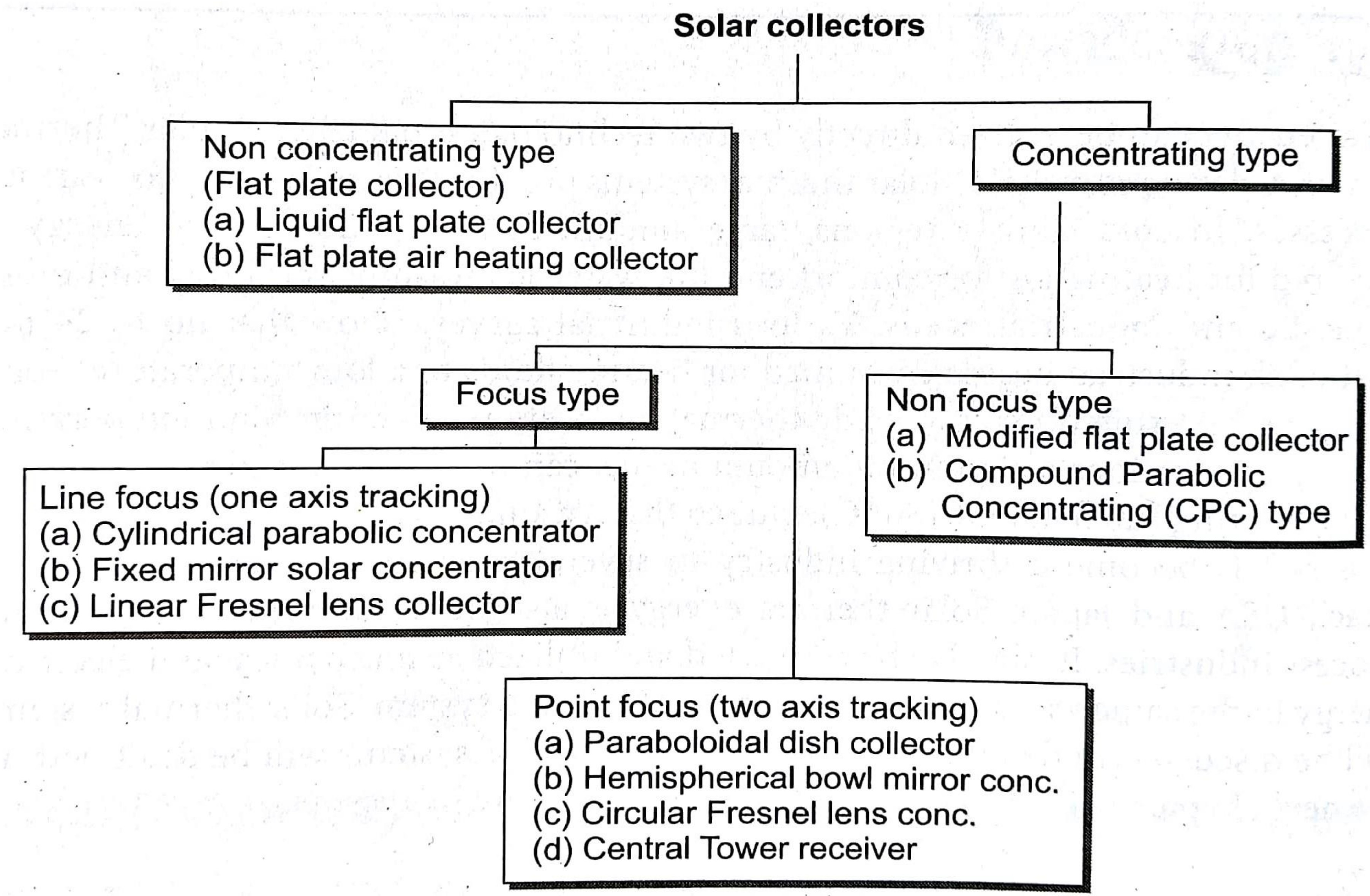
Topics:

- Liquid flat plate collectors
- Performance analysis
- Transmissivity– Absorptivity product
- collector efficiency factor
- Collector heat removal factor
- Numerical problems
- Introduction to solar air heaters
- Concentrating collectors
- solar pond
- solar still
- solar thermal plants

Solar collectors

- Solar collector is a device for collecting solar radiation and transfer the energy to a fluid passing in contact with it.

Classification of Solar Collectors



Flat Plate Collector

- Flat plate collector absorbs both beam and diffuse components of radiant energy and convert into heat.
- They are made in rectangular panels, about 1.7 to 2.9 sq.m with simpe in design.
- Sun rays striking the absorber plate are absorbed causing rise of temperature of transport fluid(air,water,oil,or gas).
- In a non-concentrating (Flat plate collector) type the area of the absorber is equals the area of the collector(has concentration ratio of 1.)
- They have high absorption and low emission.
- The maximum temperature achieved in this type is about 100° C.

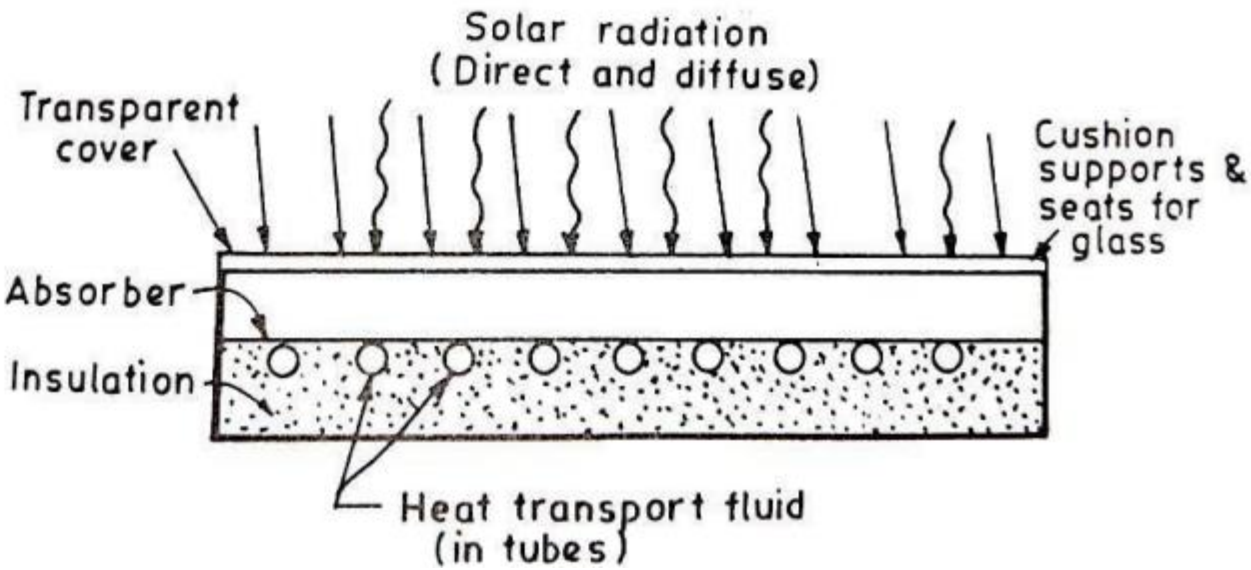
➢ Flat plate solar collectors are divided into two types based on the type of heat transfer fluid used.

They are

1.Liquid heating collectors are used for heating water

2.Air or Gas heating collectors are employed as solar Air heaters

The constructional details of Liquid Flat plate collector

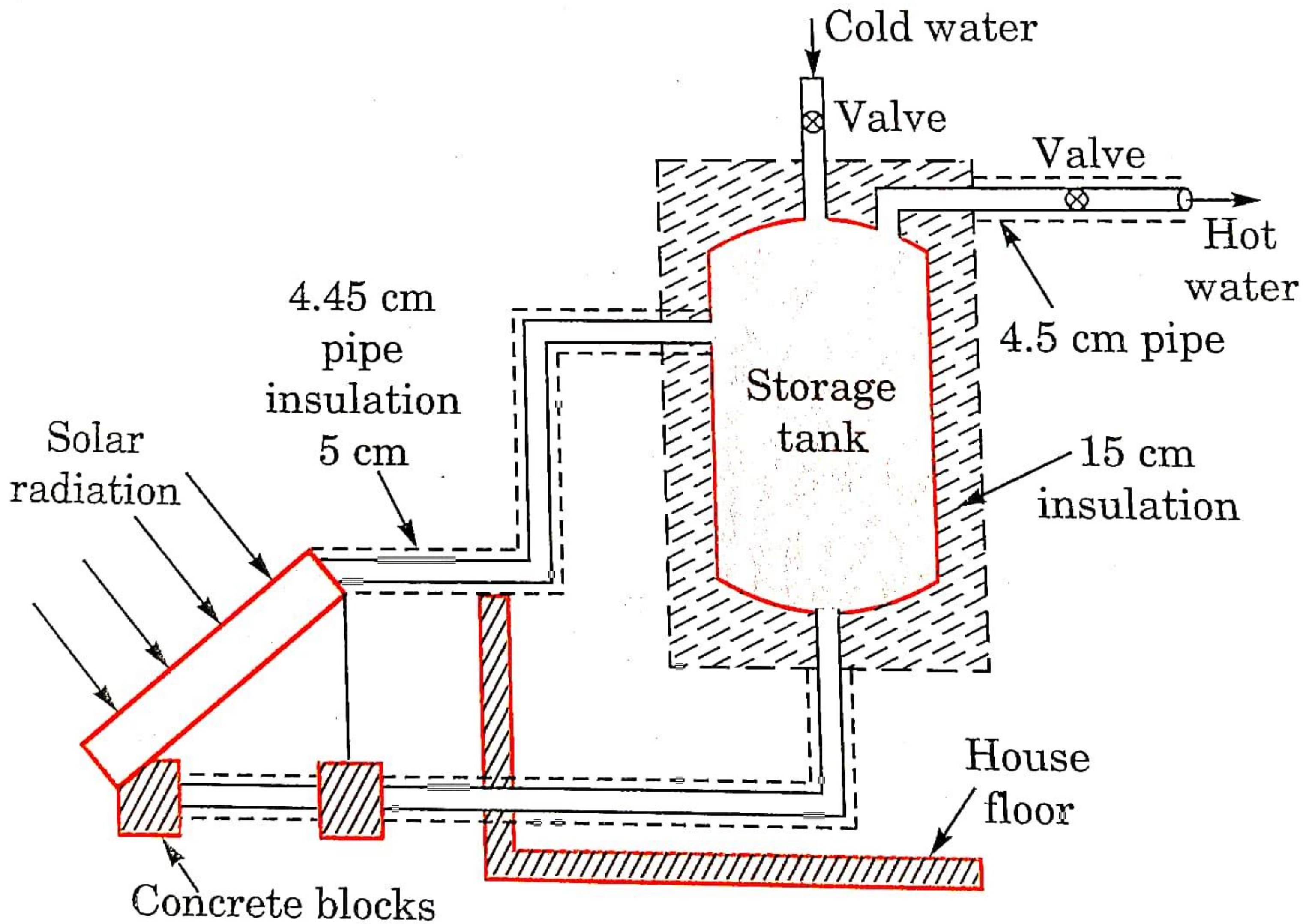


➢ **The main components of the Flat plate collector are**

(1) Absorber Plate:

- It intercepts and absorbs the solar energy.
- The absorber plate is made of copper, aluminum or steel and is in the thickness of1 to 2 mm.
- The plate absorbs the maximum solar radiation incident on it and transfers the heat to the tubes in contact with minimum heat losses to atmosphere.
- The plate is black painted and provided with selective material coating to increase its absorption and reduce the emission.
- The absorber plate has high absorption (80-95%) and low transmission/reflection.

Solar water heater



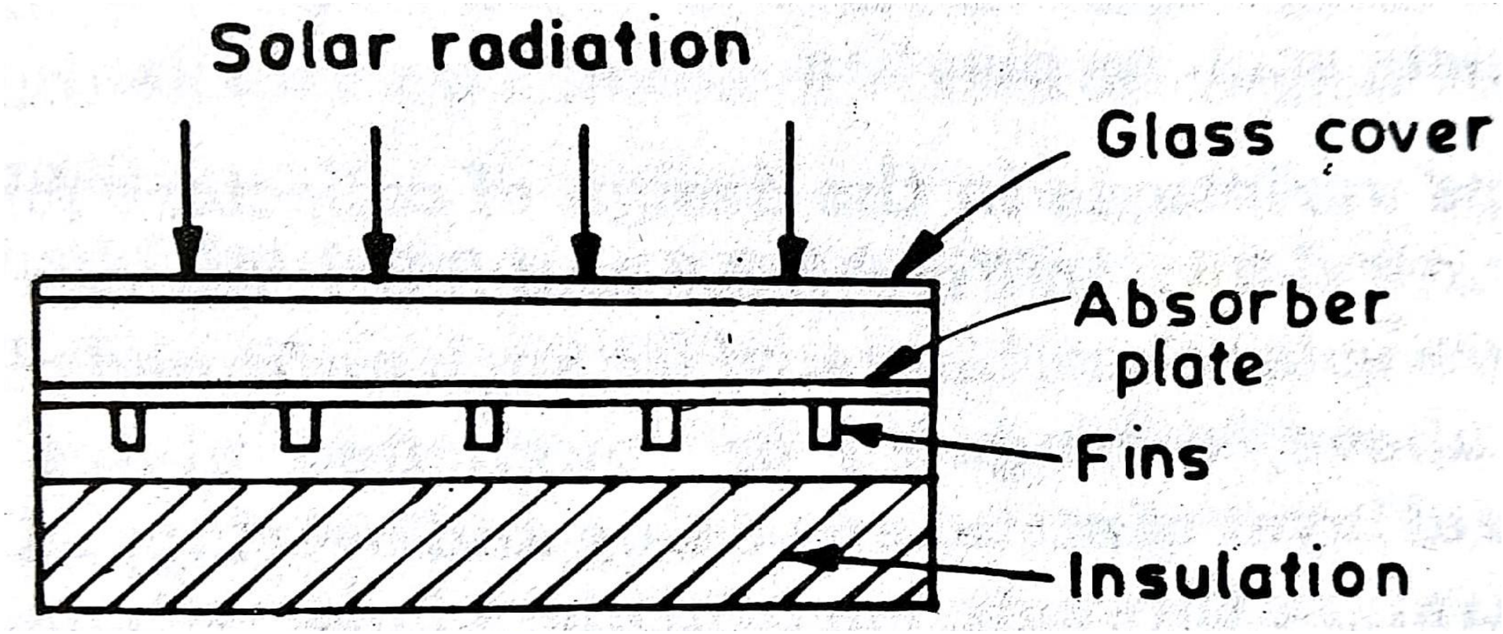
Solar Air Heaters (collectors)

(1) Non-porous absorber plate type collectors:

- In this type of Air heaters the air stream does not flow through the absorber plate.
- Air may flow above or behind the absorber plate ,In most of the designs, the air flows behind the absorbing surface.
- Air flow above the upper surface increases the convection losses from the cover plate and therefore is not recommended.
- As shown in figure the air stream is heated by the back side of the collector plate.
- Fins attached to the plate increase the contact surface.
- The back side of the collector surface is heavily insulated with mineral wool.
- The most favorable orientation of a collector, for heating only is facing due south at an inclination angle to the horizontal equal to the latitude plus 15^0.

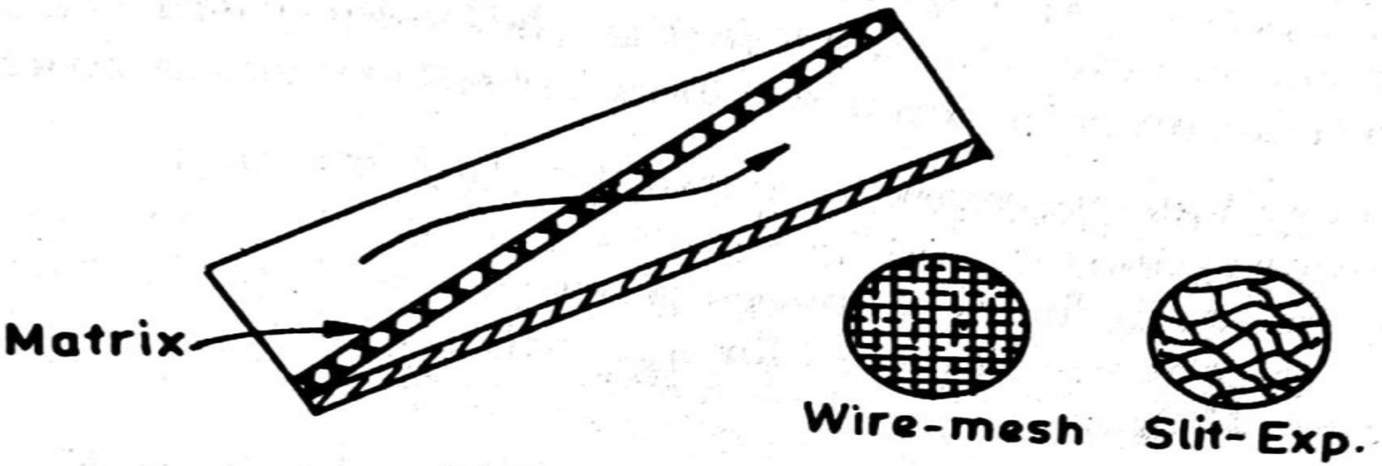
Solar Air Heaters (collectors)

Non-Porous Absorber type Air heaters(collectors)

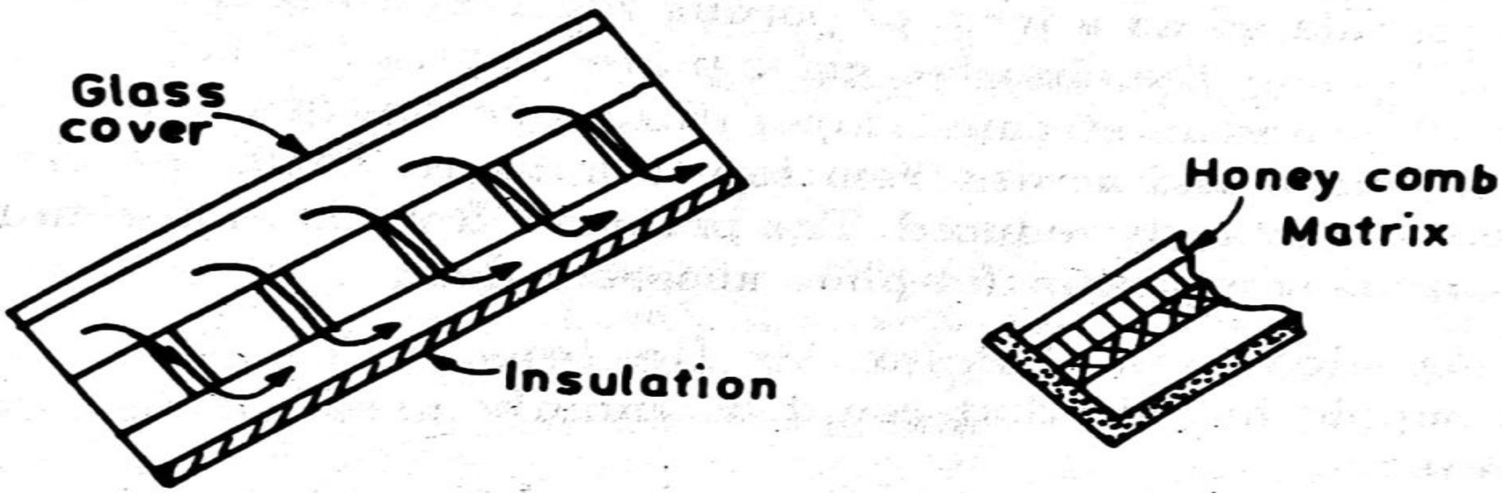


Solar Air Heaters (collectors)

- 2. Porous Absorber type Solar air heaters:



(a) Slit or expanded metal.



(b) Transpired Honey Comb.

Solar Air Collector

➢ 2. Porous Absorber type Solar air heaters:

- In this type of solar air heaters, the absorber being porous, air circulate all through it.
- In this collector, solar radiation is absorbed gradually and depends on matrix structure.
- The steam of air which is introduced from the top surface of the matrix gets heated up by the top layers first and then by bottom layer.
- From top to bottom of the matrix as the air circulates through it, gets warmed up.
- The pressure drop in this solar air collector is lower than the non porous absorber.
- Crushed glass layers can be used for absorbing the solar radiation for heating the air.
- Another method involves use of broken glass with clear glass on the top and dark glass at the bottom

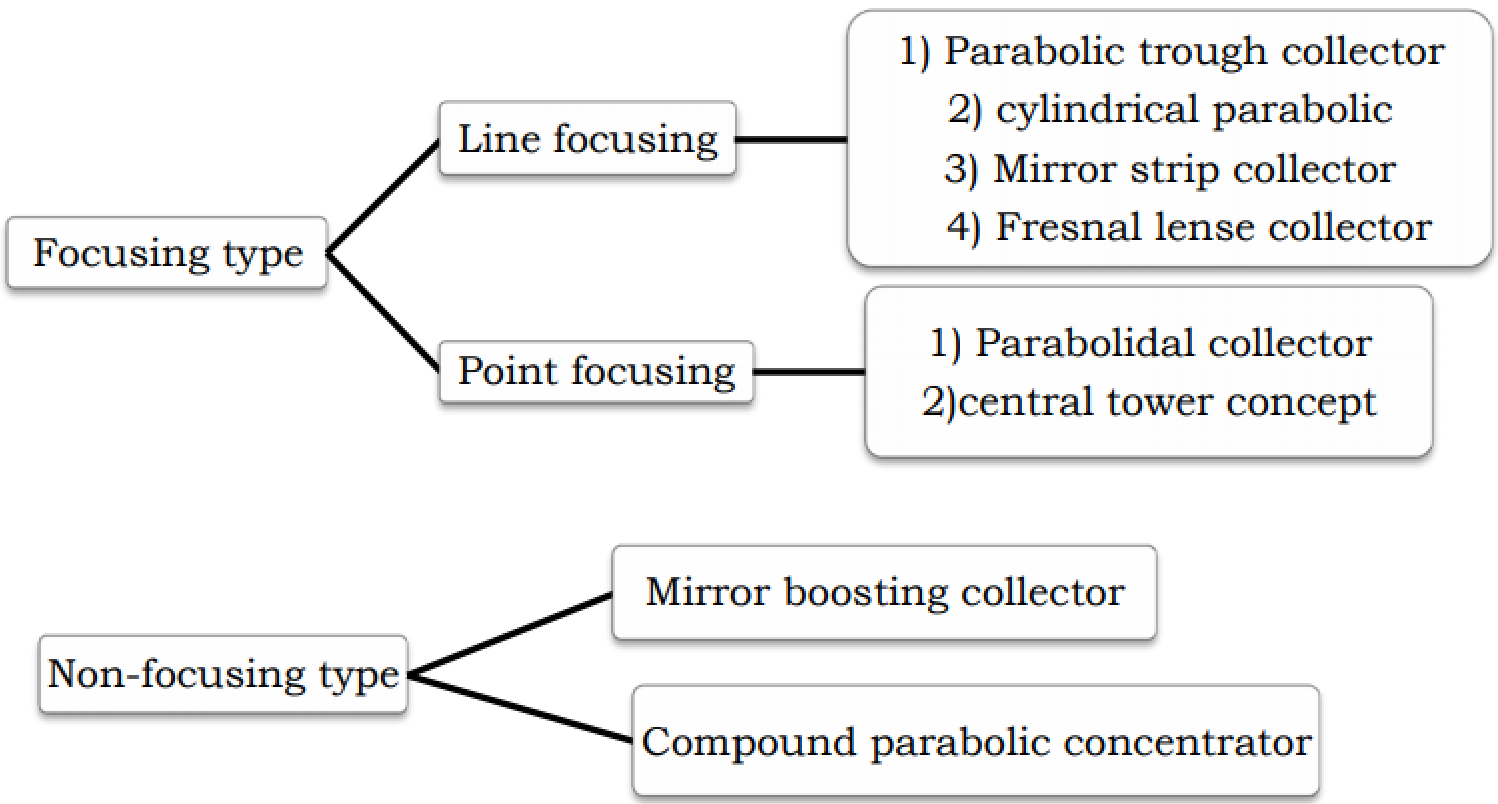
Solar Air Heaters

- **Applications of Solar air heaters**
- Solar heaters is applied in drying organic materials like fruits, vegetables,timber etc.
- Heating buildings.
- Drying agricultural products and lumber.
- Heating green houses(A building with glass walls and roof for cultivation and exhibition of plants under controlled conditions)
- Curing of industrial products such as plastics.
- Heat sources for a heat engine such as a Brayton or Stirling cycle.
- Space heating for comfort(the heating of a limited area, room etc)

Flat plate collector

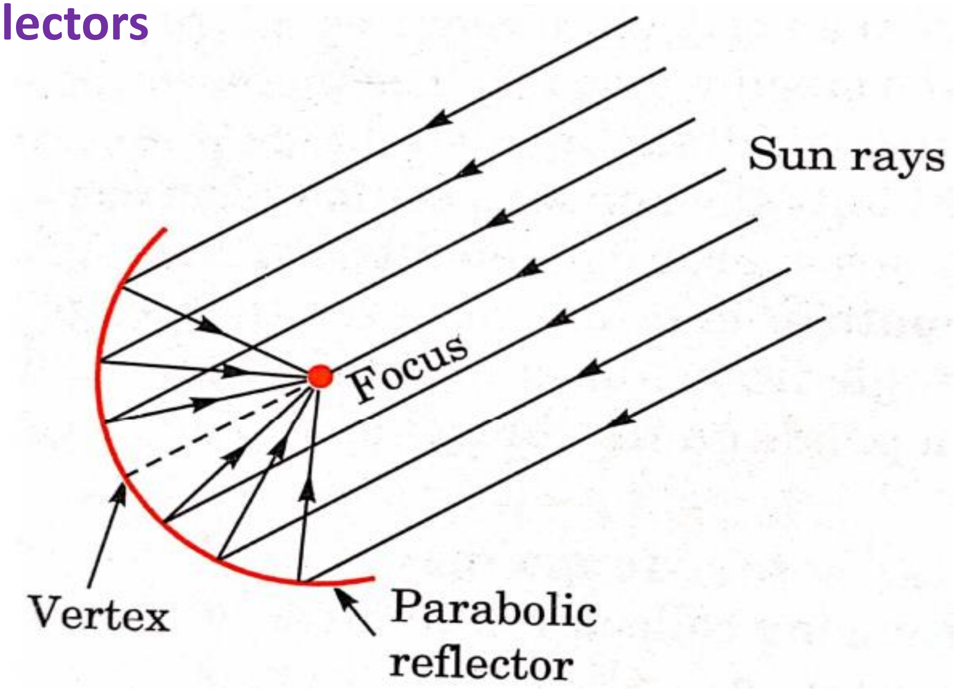
- Applications of flat plate collector:
  1. Solar water heating systems for residence, hotels, industry.
  2. Desalination plant for obtaining drinking water from sea water.
  3. Solar cookers for domestic cooking.
  4. Drying applications.
  5. Residence heating.
- Maintenance of flat plate collector:
  1. Daily cleaning
  2. Seasonal maintenance (cleaning, touch-up paint)
  3. Yearly overhaul (change of seals, cleaning after dismantling)

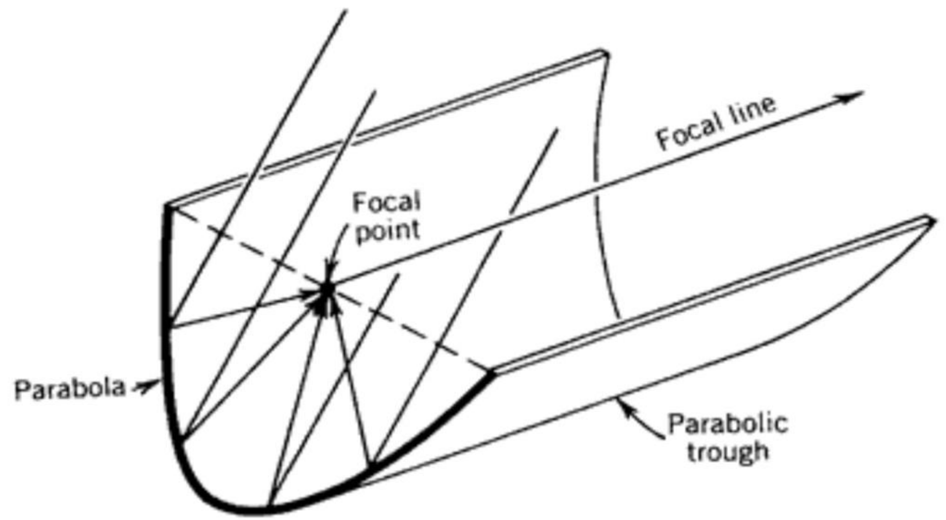
Classification of Concentrating collector



Line Focusing Type Collectors

- **(1) Cylindrical Parabolic Concentrator (Parabolic Trough Reflector or Collector)**
- Solar radiation coming from the particular direction is collected over the area of reflecting surface and is concentrated at the focus of the parabola.
- In which absorber is placed along focus axis.
- The length of the reflector unit may be 3 to 5m and the width about 1.5 to 2.4m.
- Ten or more such units are often connected end to end in a row, several rows may also be connected in parallel.

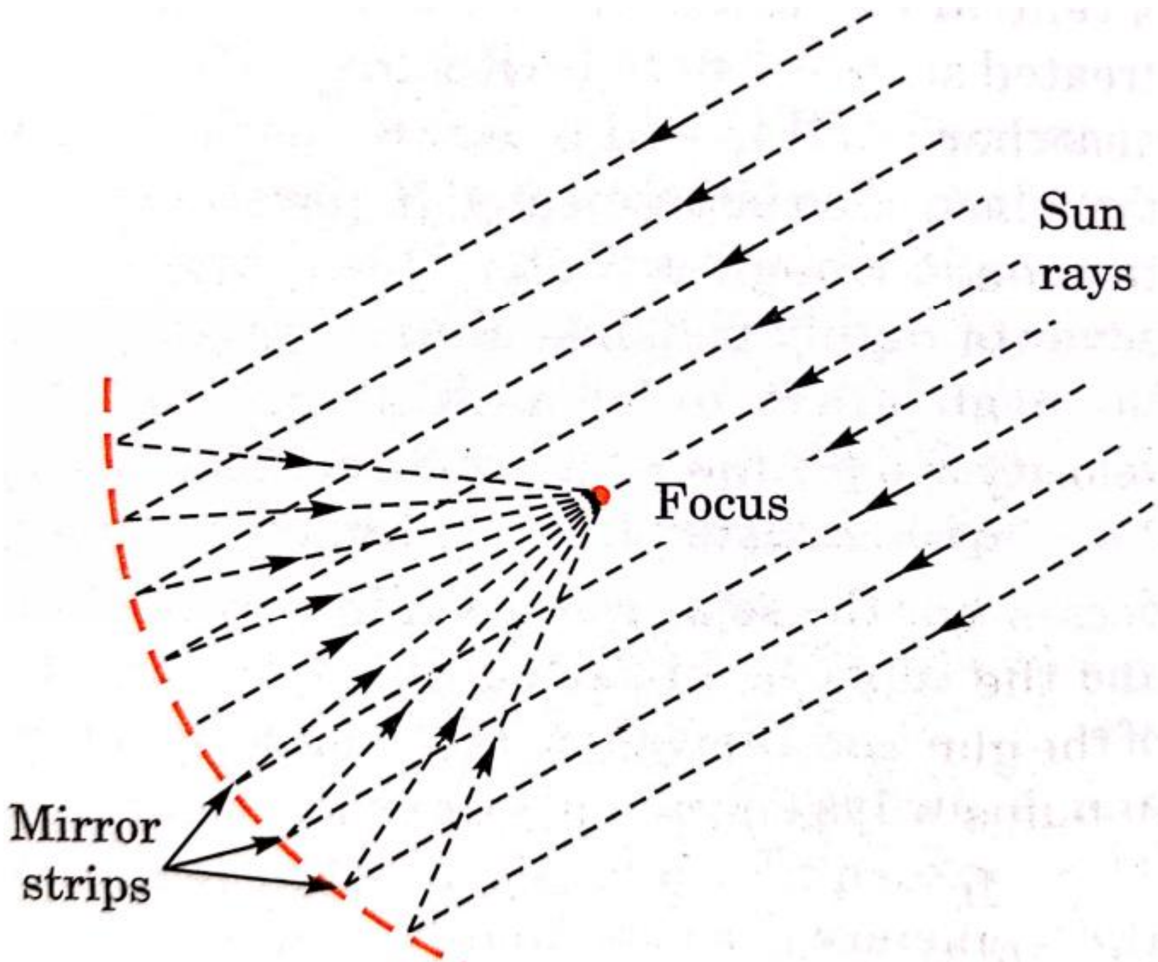





Parabolic Trough
COLLECTOR

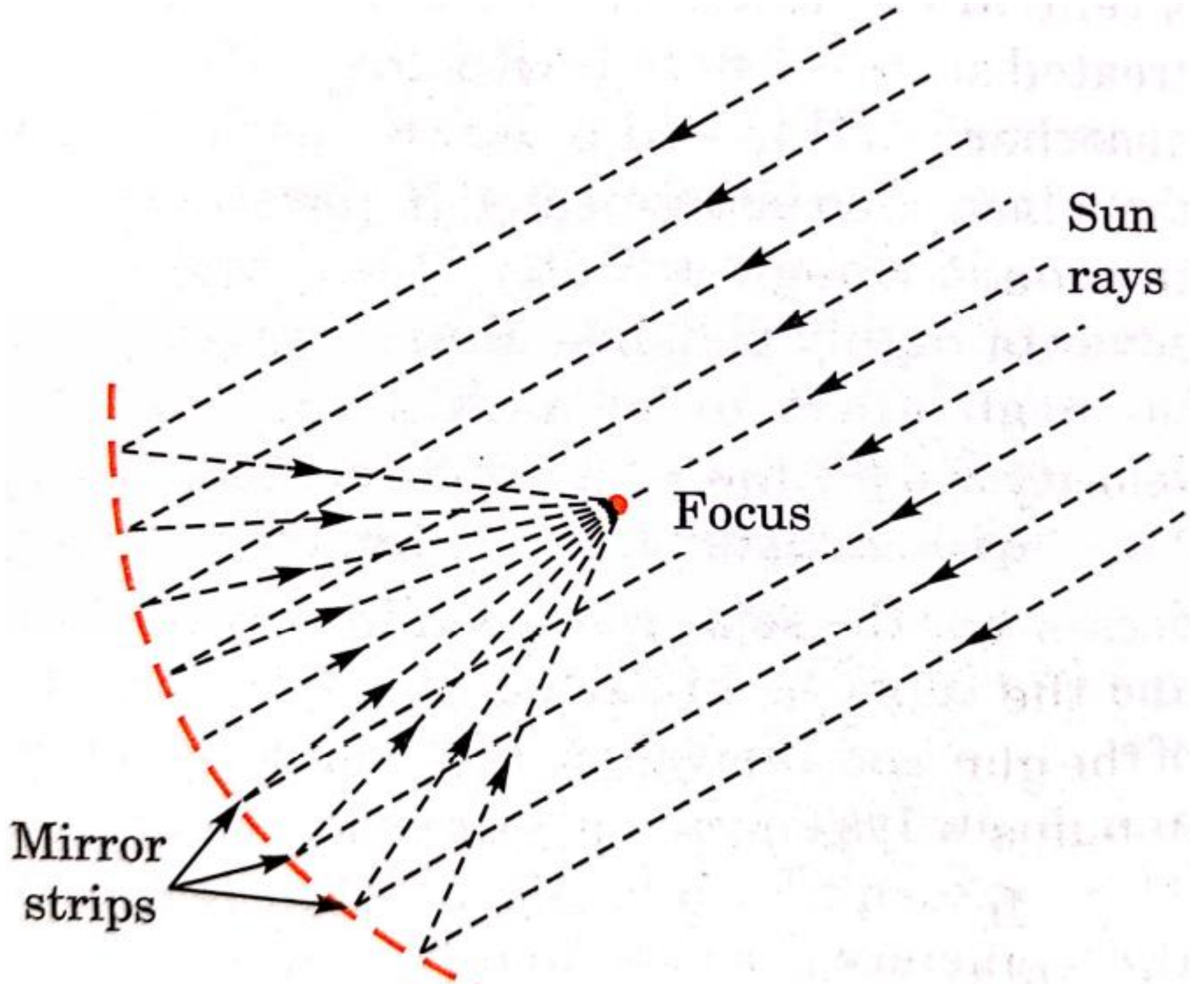
Line Focusing Type Collectors

- **(2) Mirror Strip Reflector or Fixed mirror solar collector:**
  - In this focusing collector a number of plane or slightly curved (concave)mirror strips are mounted on a flat base.
  - The angles of the individual mirrors are such that they reflect solar radiation from a specific direction on to the same focal line.

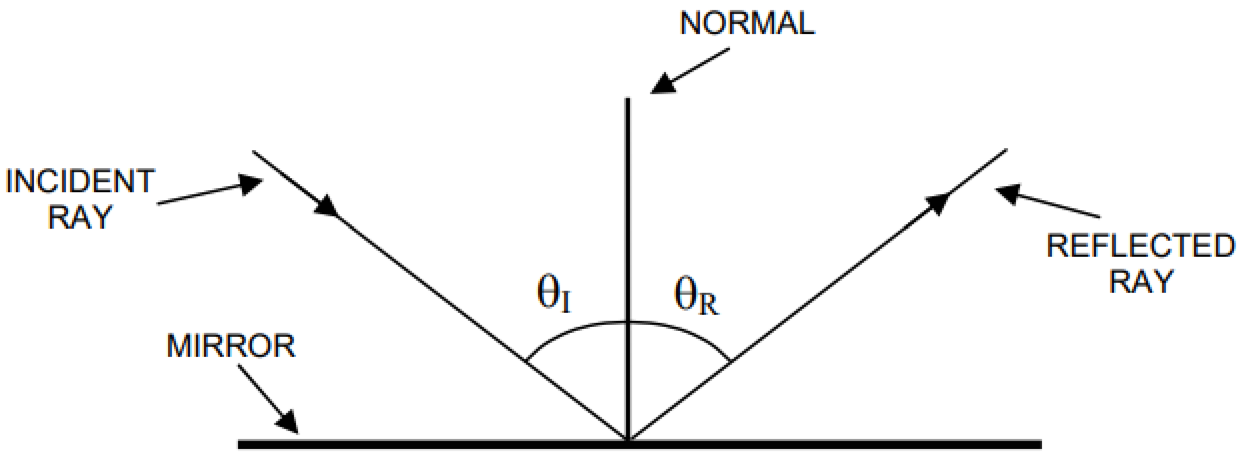


Line Focusing Type Collectors

- (2) Mirror Strip Reflector or Fixed mirror solar collector:
  - The angles of the mirrors must be adjusted to allow for changing in the sun's elevation, while the focal line(for collector pipe) remains in a fixed position.
  - The mirrors are placed as reflecting surface to concentrate more radiations on absorber.
  - These collections utilize direct and diffuse radiation.



Reflection occurs when an incident ray of light bounces off of a smooth flat surface like a mirror.



Refraction occurs when a ray of light that is traveling in one medium, let's say air, enters a different medium, let's say glass, and changes the direction of its path.

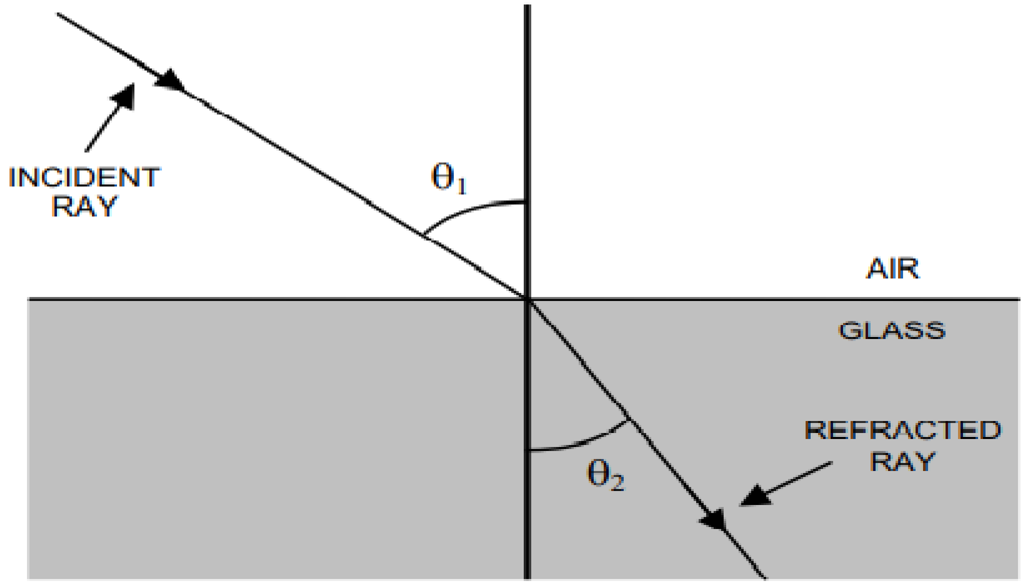


Fig.Reflection and Refraction of the incident beam

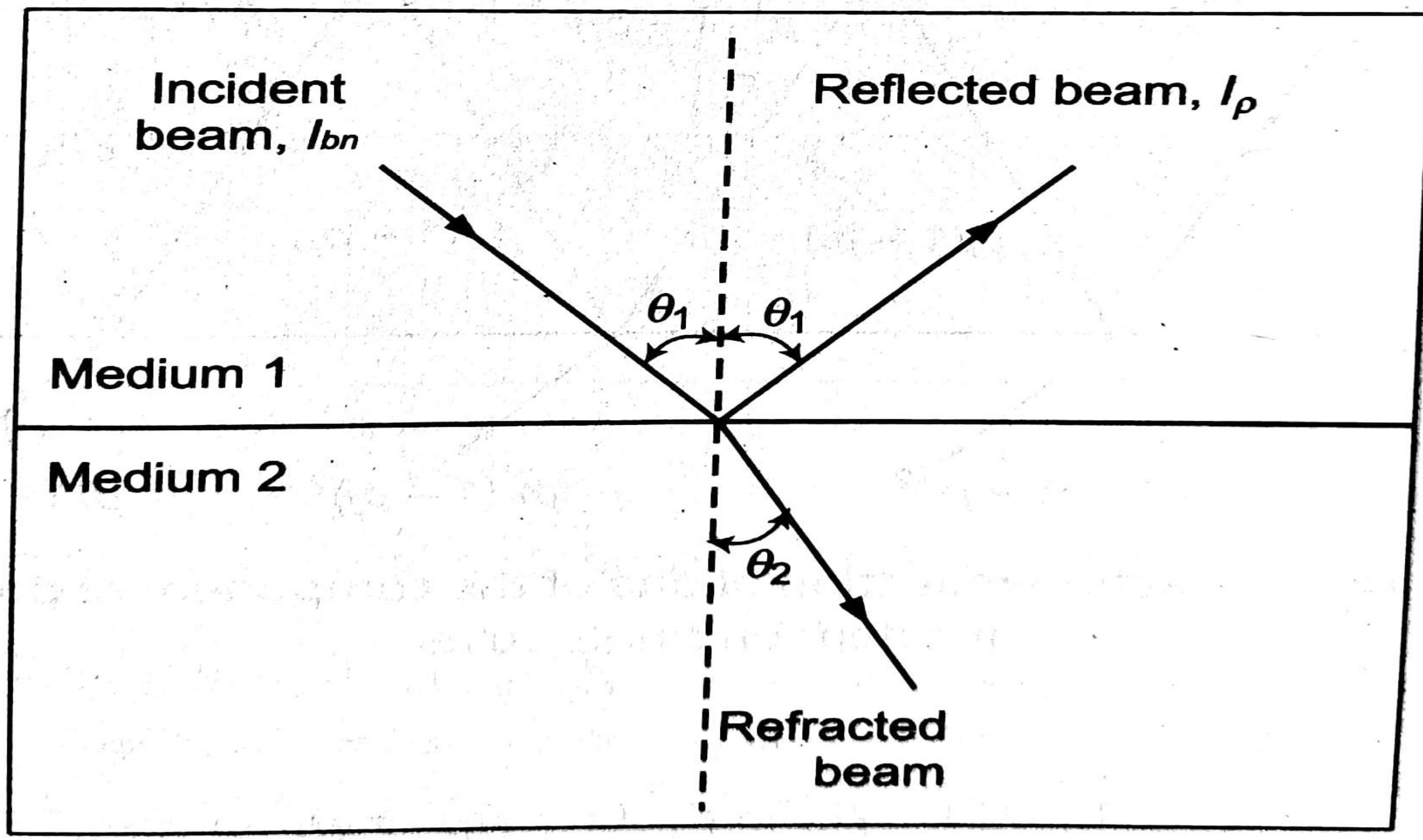
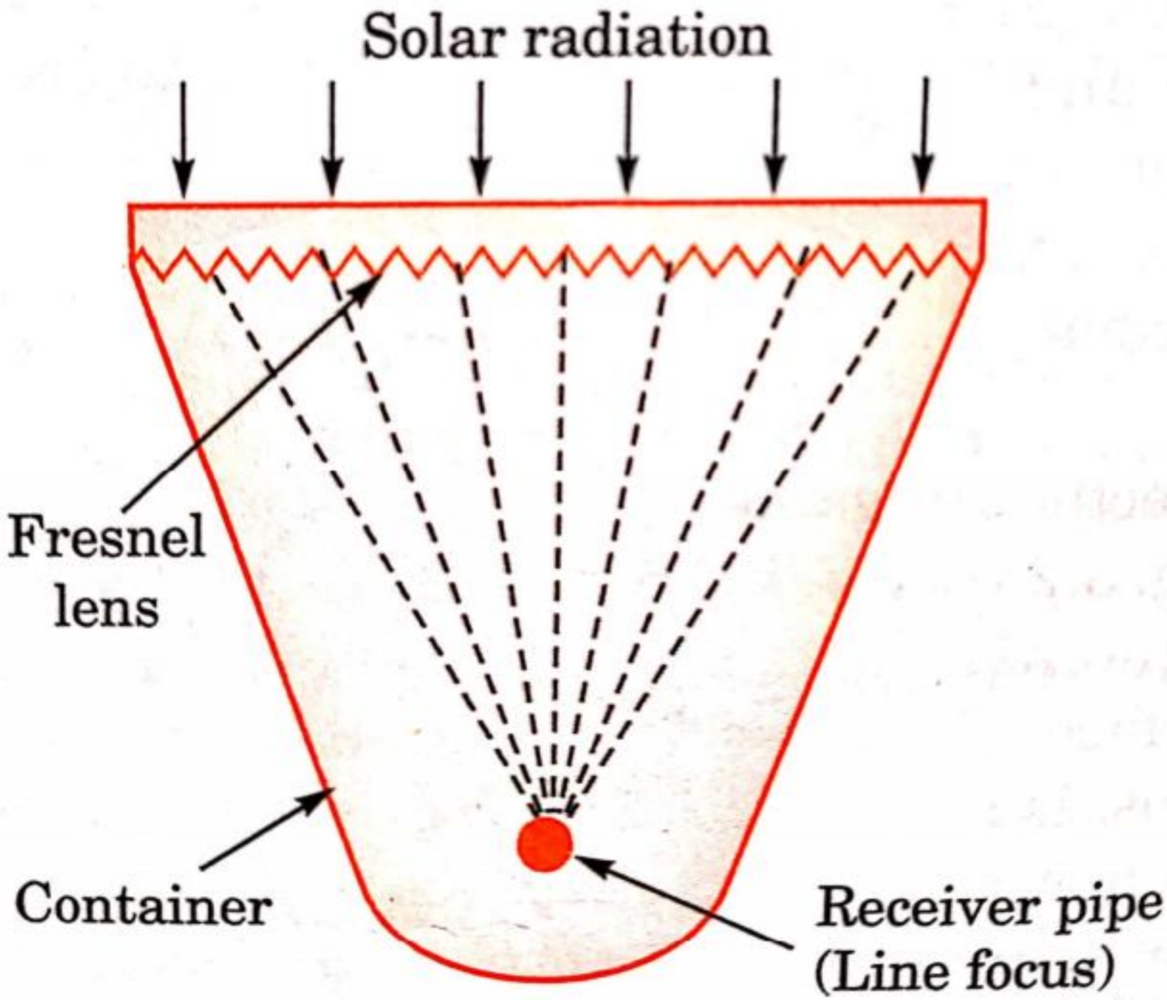


Fig.Reflection and Refraction of the incident beam

Line Focusing Type Collectors

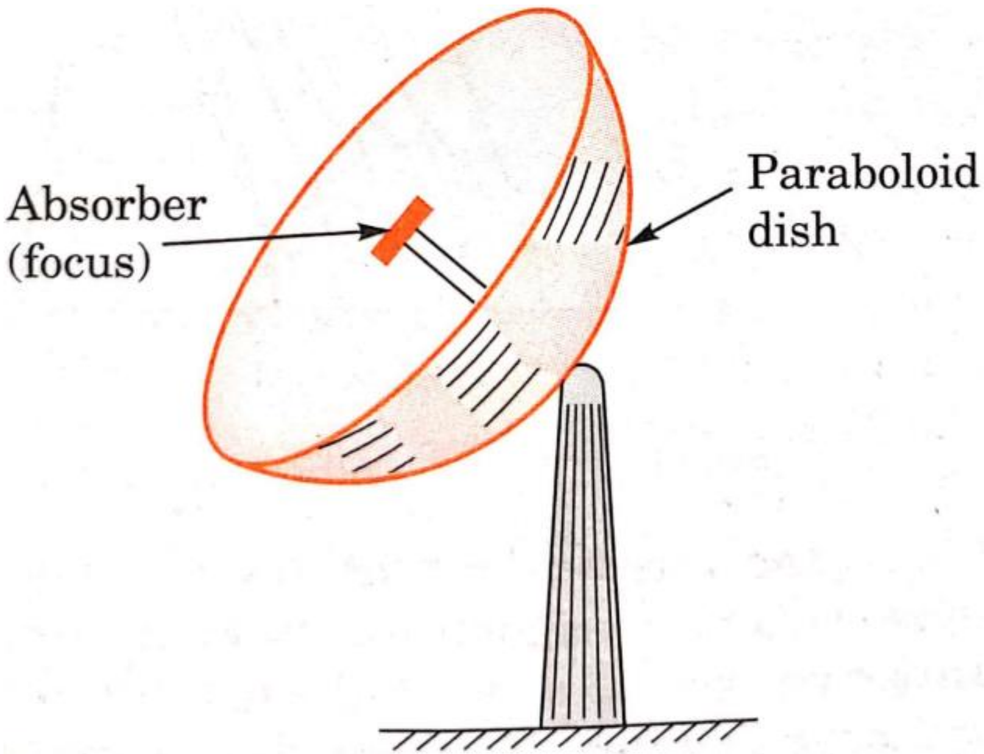
- (3) Fresnel Lens Collector:
- In this type of collector, a refraction type of focusing collectors has been developed.
- It utilizes the focusing effect of a Fresnel lens as shown in figure.
- The shape of the lens is in rectangle, about 4.7m in overall length and 0.95m in width.
- It is made in sections from cost acrylic plastic.



Point Focusing Collectors

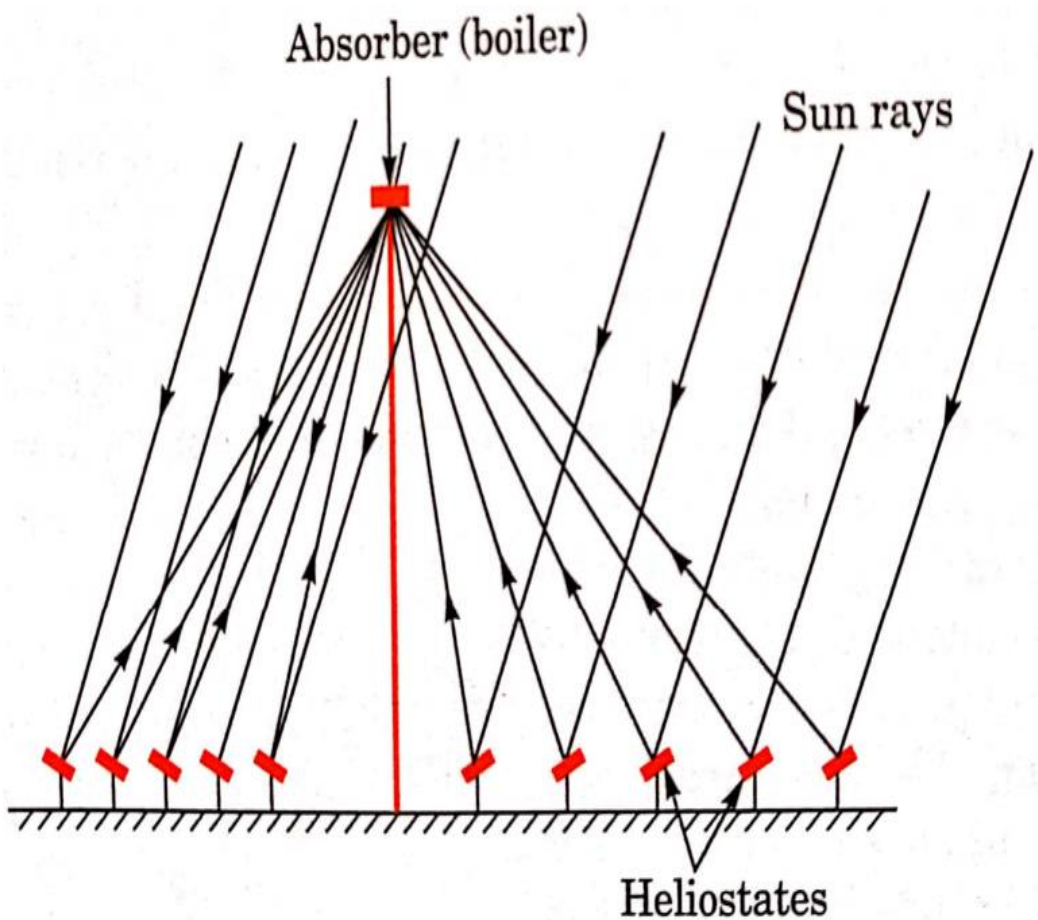
(1) Paraboloidal dish Type Collector:

- A paraboloidal dish collector brings solar radiation to a focus at a point actually a small central volume.
- Paraboloidal dish collectors of 6- 7m in diameter has been made from about 200 curved mirror segments forming a paraboloidal surface.
- The absorber, located at the focus is a cavity made of a zirconium-copper alloy with a black chrome selective coating.
- The heat transport fluid flows into and out of the absorber cavity through pipes bonded to the interior.



Point Focusing Collectors

- (2) Central Tower Receiver(Solar Power Tower)
- In this system number of mirrors distributed over an area on the ground.
- Each mirror called a heliostat(An instrument consisting of a mirror moved by clockwork ,by which a sun beam is steadily directed to one spot), can be steered independently about two axes.
- So that the reflected solar radiation is always directed towards an absorber mounted on top of the tower as shown in figure.

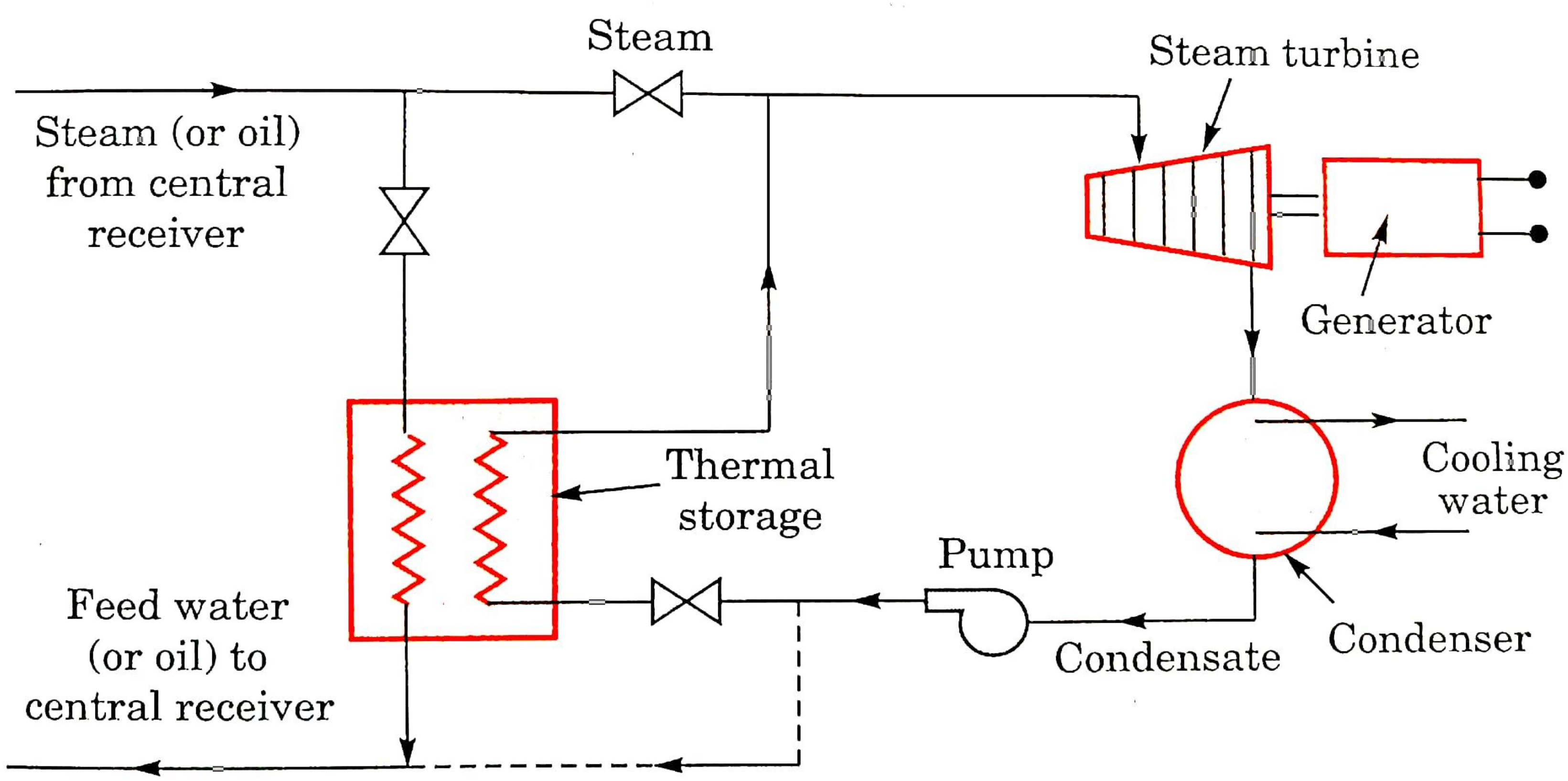


Solar Tower Power Plant

Principle and Working:

- In this system as already stated, 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 about two axes and are called heliostats.
- A schematic view of an electric power plant using gas turbine or gas turbine power plant working on Brayton gas power cycle.
- The mirrors are installed on the ground and are oriented so as to reflect the direct beam radiation into an absorber or recceiver (boiler) which is mounted on the top of a tower located near the centre of the field of mirrors to produce high temperature.
- This make it possible to position the boiler in the field of view of all mirrors, at all hours of the day.
- 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

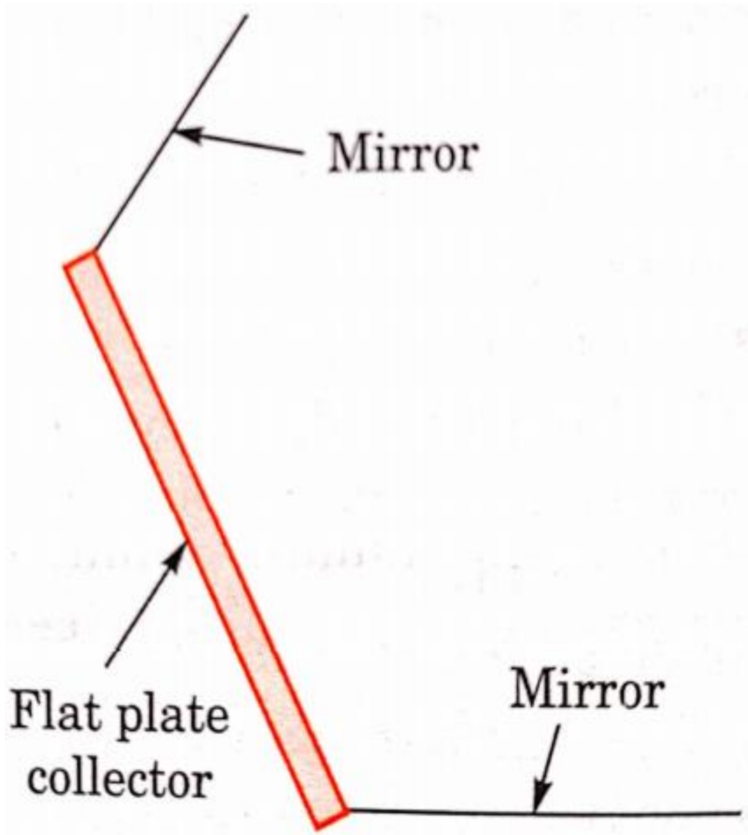
Solar Tower Power Plant
Electric power generation using thermal storage



Non Focusing Type Collectors

(1) Modified Flat plate Collector:

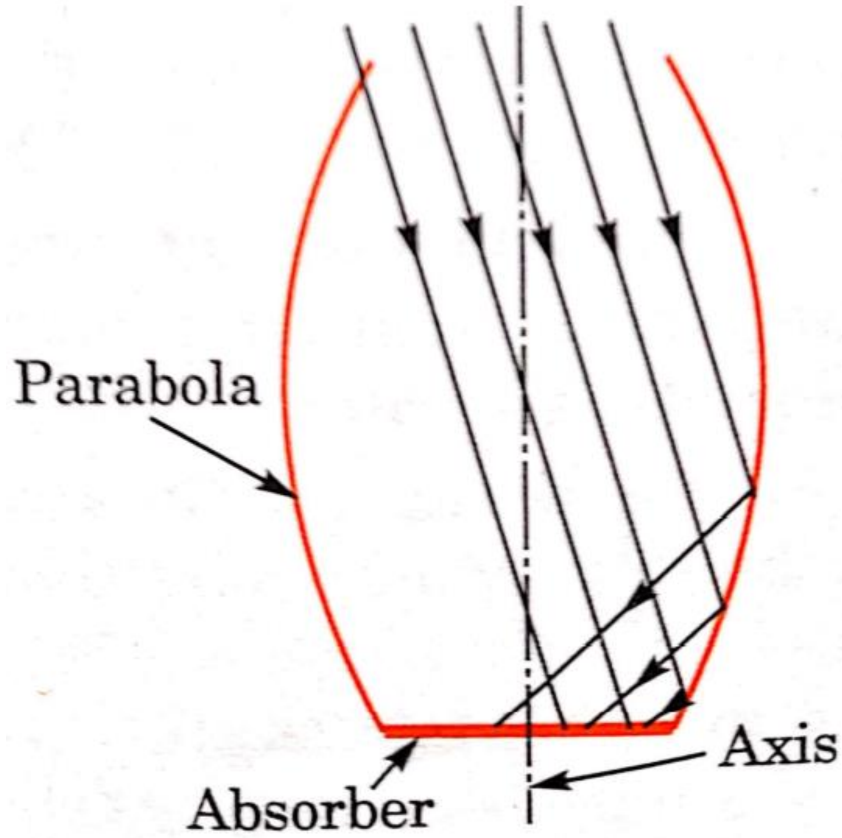
- It consists of a flat plate facing south with mirrors attached to its north and south edges as shown in figure.
- If the mirrors are set at the proper angle, they reflect solar radiation on absorber plate.
- The mirror cutoff part of the scattered radiation that would otherwise have reached the absorber plate, and only part of the scattered radiation falling on the mirrors will be reflected on to the absorber.
- Thus the concentrating effect mainly from the increase in direct radiation reaching the absorber plate.
- The angles should be adjusted continuously as the suns altitude changes.
- For this only a relatively small increase in the solar radiation falling on the absorber, so these are not widely used.



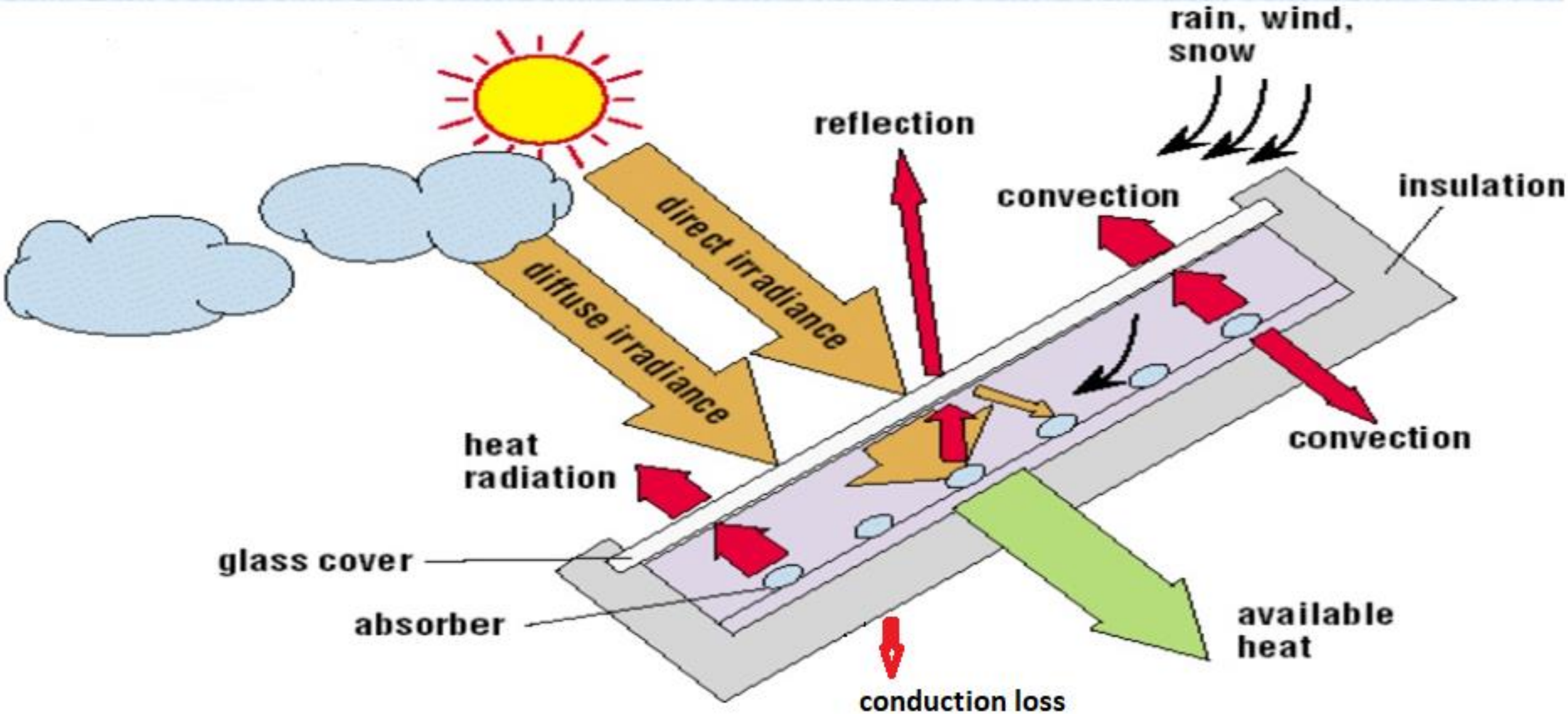
Non Focusing Type Collectors

Compound Parabolic Concentrator (CPC):

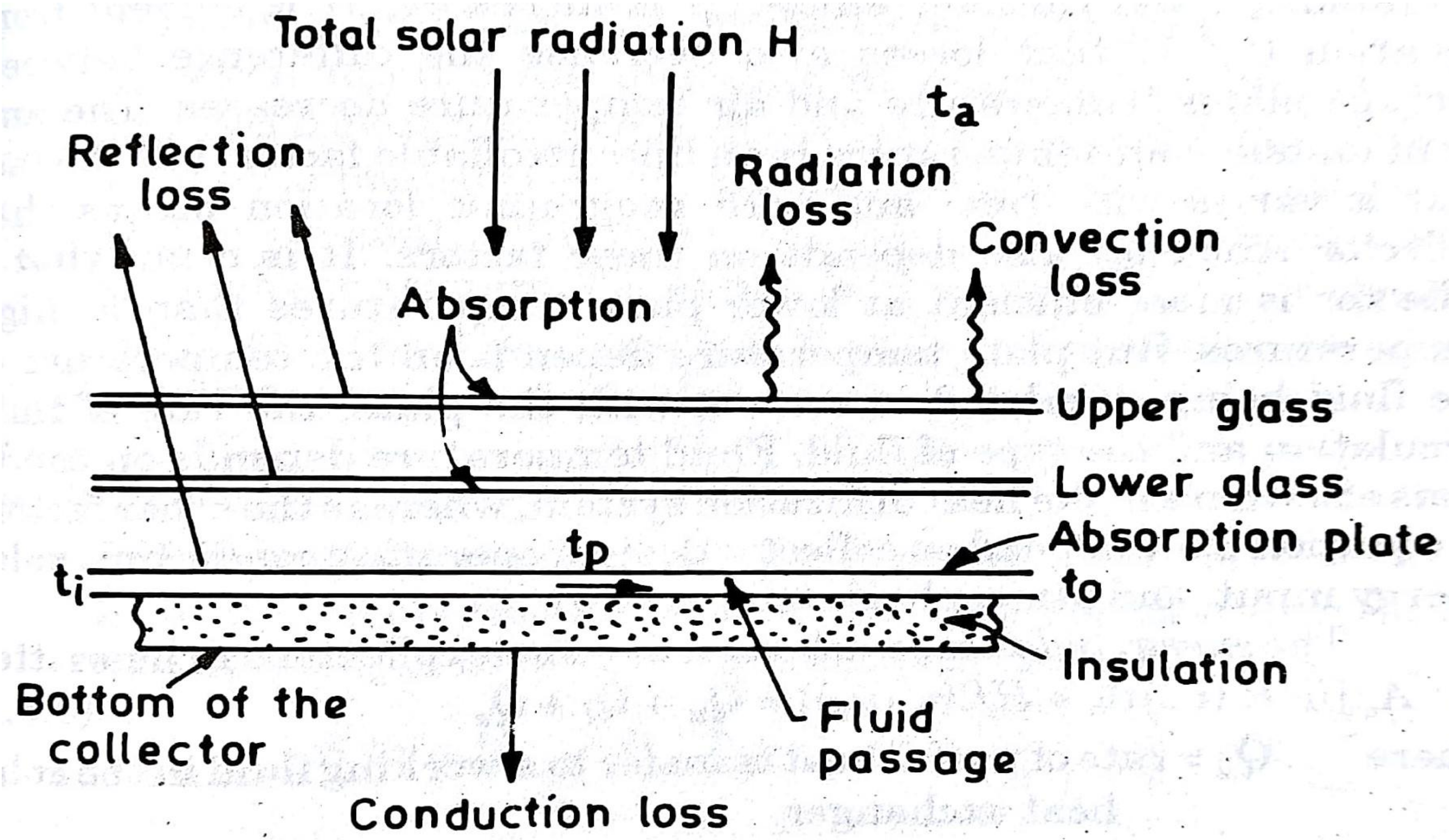
- The CPC is non-focusing, but solar radiation from many directions is reflected towards the bottom of the trough.
- Because of this characteristics a large proportion of the solar radiation, including diffuse(scattered) radiation, entering the trough opening is collected(concentrated) on a small area.
- They are suitable for the temperature range of 100 to 150^0C



losses in Solar Collector



losses in Solar Collector



$$\text{Absorbed Energy} = A_c \cdot HR \cdot \tau \cdot \alpha$$

$$\text{Effective heat loss} = A_c U_L (t_p - t_a)$$

➢ Transmissivity-Absorptivity product $(\tau\alpha)$:

- For solar collector analysis, it is required to calculate the transmissivity-absorptivity product $(\tau\alpha)$.

  Here τ is the transmissivity of glass cover

  α is the absorptivity of absorber plate
- It is defined as the ratio of solar flux(radiation) absorbed by the absorber plate to the solar flux(radiation) incident on the cover system.
- Solar radiation after passing through the cover system falls on the absorber plate, where some radiation is reflected back to the cover system.
- Out of the reflected part, a portion is transmitted through the cover system and a part reflected back to the absorber plate.
- This activity is absorption and reflection is shown in figure. Which goes on indefinitely.

Transmissivity-Absorptivity product ($\tau\alpha$):

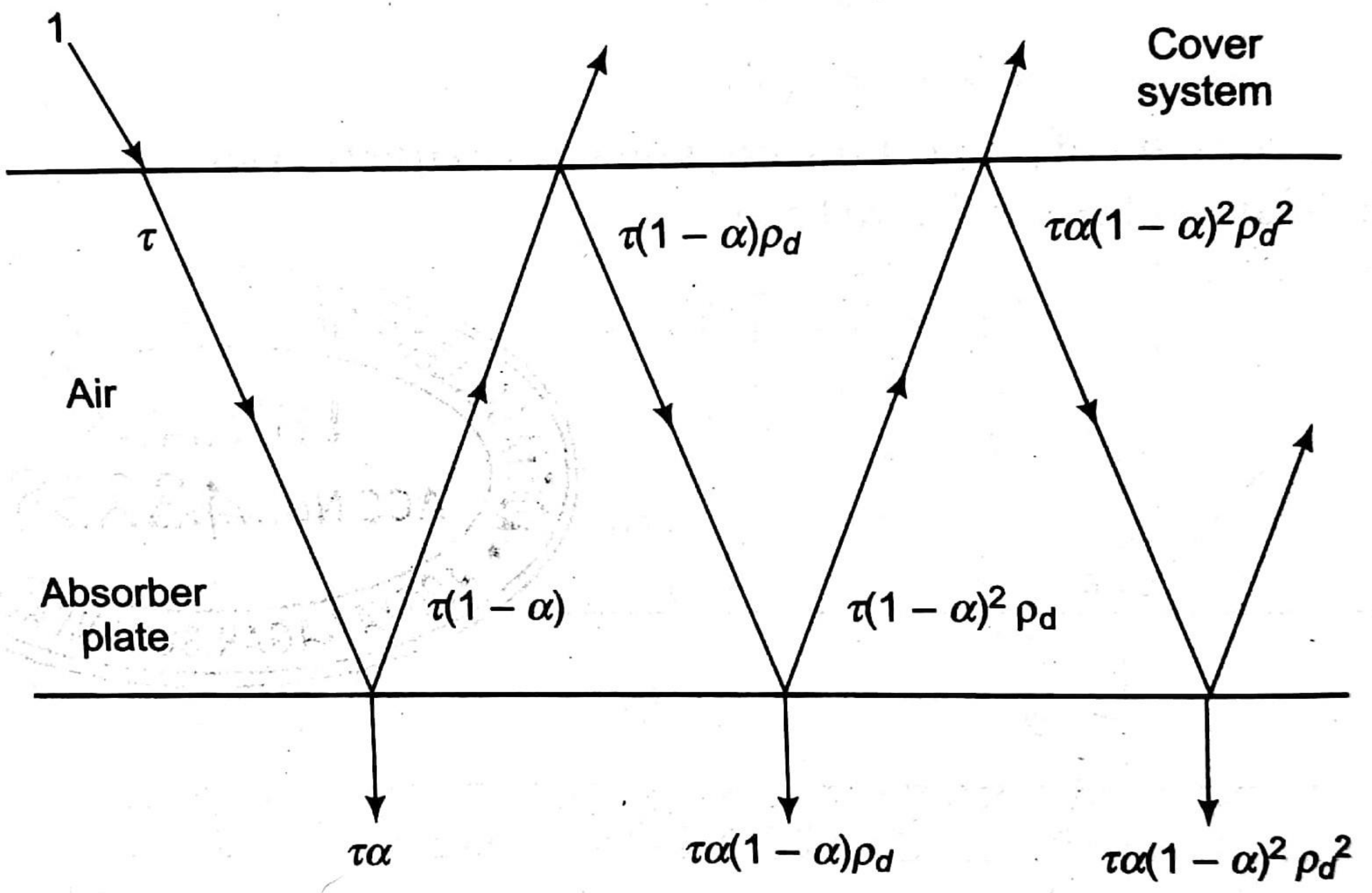


Fig. Absorption and Reflection at the absorber plate

Energy balance equation and collector efficiency

- The performance of solar collector is described by an energy balance equation that indicates the distribution of incident solar radiation into the useful energy gain and various losses.
- The energy balance equation is given as

$$Q_u = F_R\ A_C\ [\text{HR}\ (\tau\alpha) - U_L\ (t_p - t_a)]$$

Where

Q_u ------ is the useful energy gained by the collector in watts,

A_C ------ is the collector area in m2,

F_R...........Is collector heat removal factor

HR ------is the solar energy received on the upper surface of the inclined collector,

τ ---------is the fraction of incoming radiation that is transmitted through the cover system and is known as transmissivity,

α-------- is the fraction of solar energy reaching the surface that is absorbed and is known as absorptivity.

The *energy balance equation* on the whole collector can be written as:

$$A_c\,[\{HR\,(\tau\,.\,\alpha)_b + HR(\tau.\,\alpha)_d\}] = Q_u + Q_l + Q_s$$

where, Q_u = rate of useful heat transfer to a working fluid in the solar heat exchanger.

Q_l = rate of energy losses from the collector to the surroundings by re-radiation, convection and by conduction through supports for the absorber plate and so on. The losses due to reflection from the covers are included in the $(\tau.\,\alpha)$ terms; and

Q_s = rate of energy storage in the collector.

Collector efficiency η_c, is the collector performance and is defined as the ratio of useful gain over any time period to the incident solar energy over the same time period.

$$\eta_c = \frac{q_u}{H_b R_b}$$

- The performance of a solar collector is evaluated on the basis of following features:

1. Collector efficiency
2. Temperature range
3. Concentration ratio(C_R)
4. Heat Removal Factor (F_R)
5. Fin efficiency
6. Overall Heat loss coefficient (U_L)

- The performance of a solar collector is evaluated on the basis of following features:
- Collector efficiency:
  - Efficiency is the most important factor for a system. This factor determines the system's output
  - Collector efficiency is defined as the ratio of the energy transferred to the heat transport fluid by the collector (useful energy) to the total incident radiation on the collector.

$$\eta = \frac{\int Qu\, dt}{\int HR\, dt} = \frac{\text{the total useful heat gain in the collector}}{\text{the total incident radiation on the collector}}$$

  - The value of efficiency is dominated by parameters like product of glazing's transmittance and absorbing plate's absorptance, intensity of global radiation falling on the collector, water inlet temperature and ambient air temperature
- Temperature range:
  - It is the range of the temperature to which the heat transport fluid is heated up by the collector.

➢ Concentration ratio(CR):

- It is defined as the ratio of the area of aperture of the system to the area of the receiver(absorber)
- The aperture of the system is the projected area of the collector facing (normal) the beam.
- In flat plate collectors, no optical system is utilized to concentrate the solar radiation and hence the concentration ratio is only 1.

➢ Heat Removal Factor (FR):

- Heat removal factor represents the ratio of the actual useful energy gain to the useful energy gain if the entire collector were at the fluid inlet temperature.
- It depends upon the factors like inlet and outlet water temperature, the ambient temperature, area of the collector etc.
- The importance of heat removal factors remains with the efficiency of the system.
- For a highly efficient system a higher value of heat removal factor is must

➢ Fin efficiency:

- It is the ratio of the actual heat transfer from the fin to that the heat that would be dissipated if whole surface of the fin is maintained at base temperature.

➢ Overall Heat loss coefficient (U_L):

- Estimation of heat loss coefficient of the flat plate collector is important for its performance evaluation.
- All the heat that is generated by the collector does not resulted into useful energy. Some of the heat gets losses to the surroundings.
- The amount of heat losses depends upon the convective, conductive and radiation heat loss coefficients.
- A higher value of heat loss coefficient indicates the lower heat resistance and hence the lower efficiency.
- Among all heat loss parameters the top loss contributes the most.
- The top heat loss coefficient is a function of various parameters which includes the temperature of the absorbing plate, ambient temperature, wind speed, emissivity of the absorbing and the cover glass plate, tilt angle etc.
- The heat loss from the bottom of the collector is first conducted through the insulation and then by a combined convection and infrared radiation transfer to the surrounding ambient air.
- Typical value of the back surface heat loss coefficient ranges between 0.3 to 0.6 W/ $m^{2\,0}k$.

Solar Energy Storage

- **Need of Solar energy storage:**
- The need for energy storage of some kind is almost immediate evident for a solar electric system.
- An optimally designed solar-electric system will collect and convert when the insolation is available during the day.
- Unfortunately the time when solar energy is most available will rarely coincide exactly with the demand for electrical energy, though both tend to peak during the day light hours.
- There is also the problem of clouds and cloud cover for several days may result in substantially lowered electrical output compared to high insolation cloud-free days.
- Obviously during such days energy previously stored during high insolation times could be used to provide a continuous electrical output or thermal output.
- Thus the addition of storage can increase the reliability of being able to deliver power at an arbitrary needed time.

Solar Pond

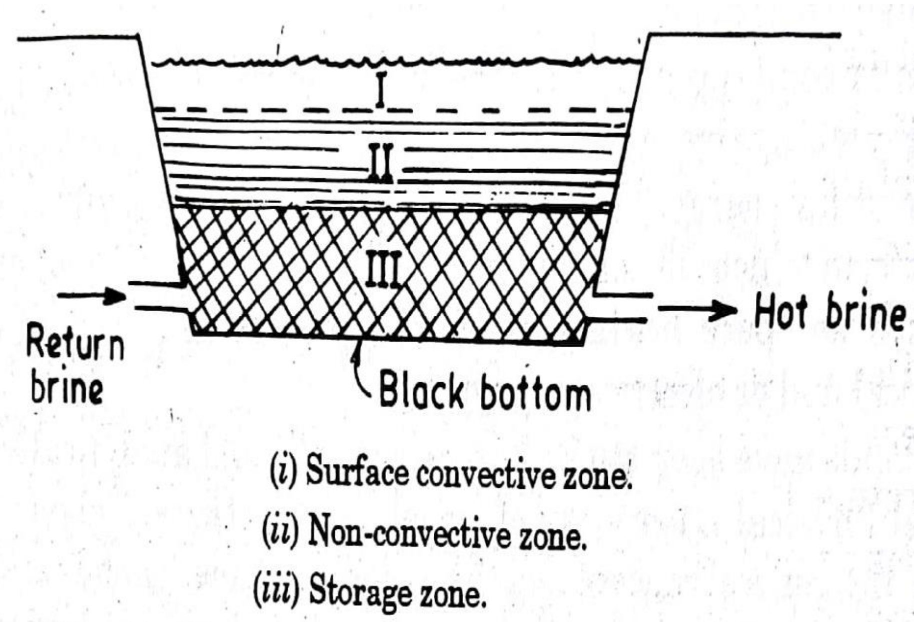
- The concentration of the salt at the surface is low-usually less than 5 percent by weight and thus the water is relatively light.
- The salt concentration steadily increases with depth until at the bottom where it is very high, around 20 percent.
- Thus a solar pond has three zones with following salinity with depth:
- (i) Surface convective zone or upper convective zone

  (0.3–0.5 m), salinity < 5%.

  (ii) Non-convective zone 1 to 1.5m, salinity increases with depth.

  (iii) Storage zone or lower convective zone

  1.5 to 2 m, salinity =20%



Solar Pond

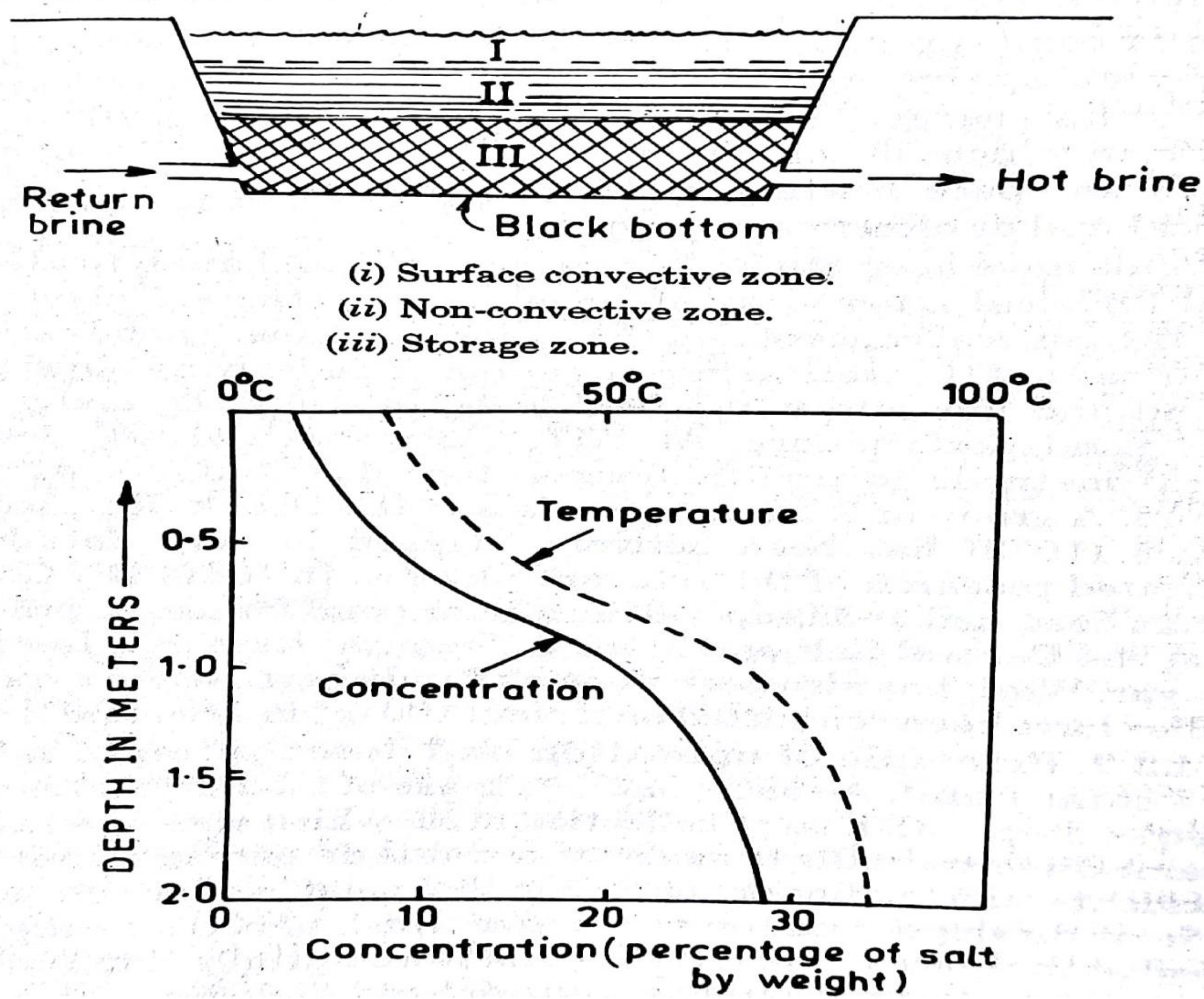
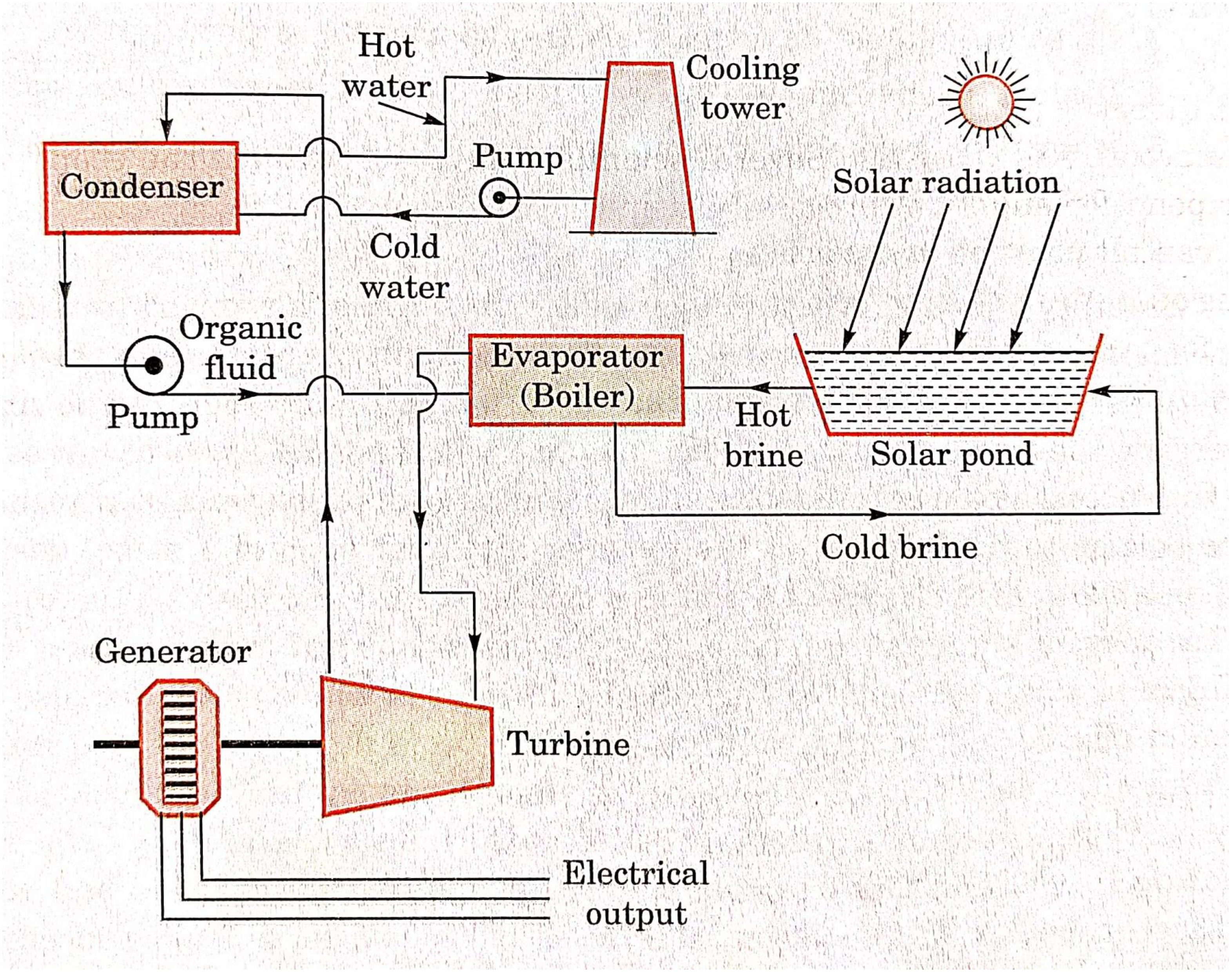


Fig.Temperature and concentration profile for a typical pond

Solar Pond Electric Power Plant



Applications of Solar Ponds

1) Heating and cooling of buildings
2) Production of power
3) Industrial process heat
4) Desalination
5) Heating animal housing and drying crops on farms
6) Heat for biomass conversion

Thank you

RENEWABLE ENERGY SOURCES

UNIT-III

Solar Photovoltaic Systems

UNIT–III

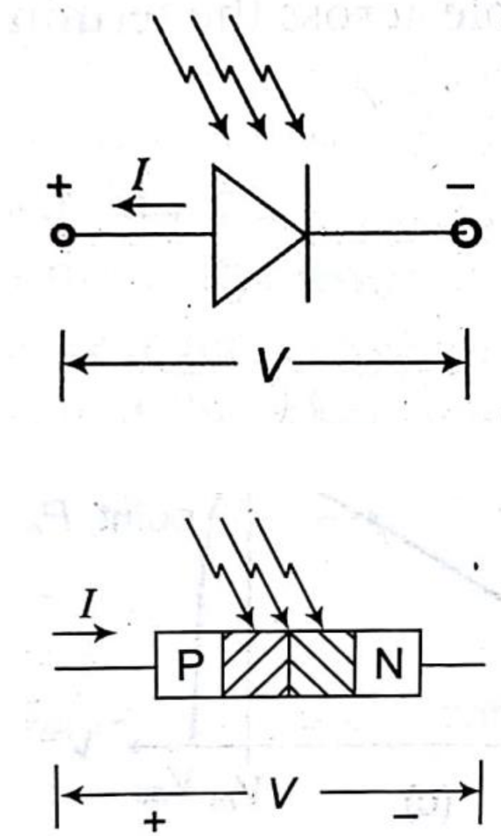
Solar Photovoltaic Systems

Topics:

- Solar photovoltaic cell, module, array
- construction
- Efficiency of solar cells
- Developing technologies
- Cell I-V characteristics
- Equivalent circuit of solar cell
- Series resistance
- Shunt resistance
- Applications and systems
- Balance of system components
- System design: storage sizing – PV system sizing
- Maximum power point techniques: Perturb and observe (P&O) technique – Hill climbing technique.

Solar cell or Photovoltaic cell

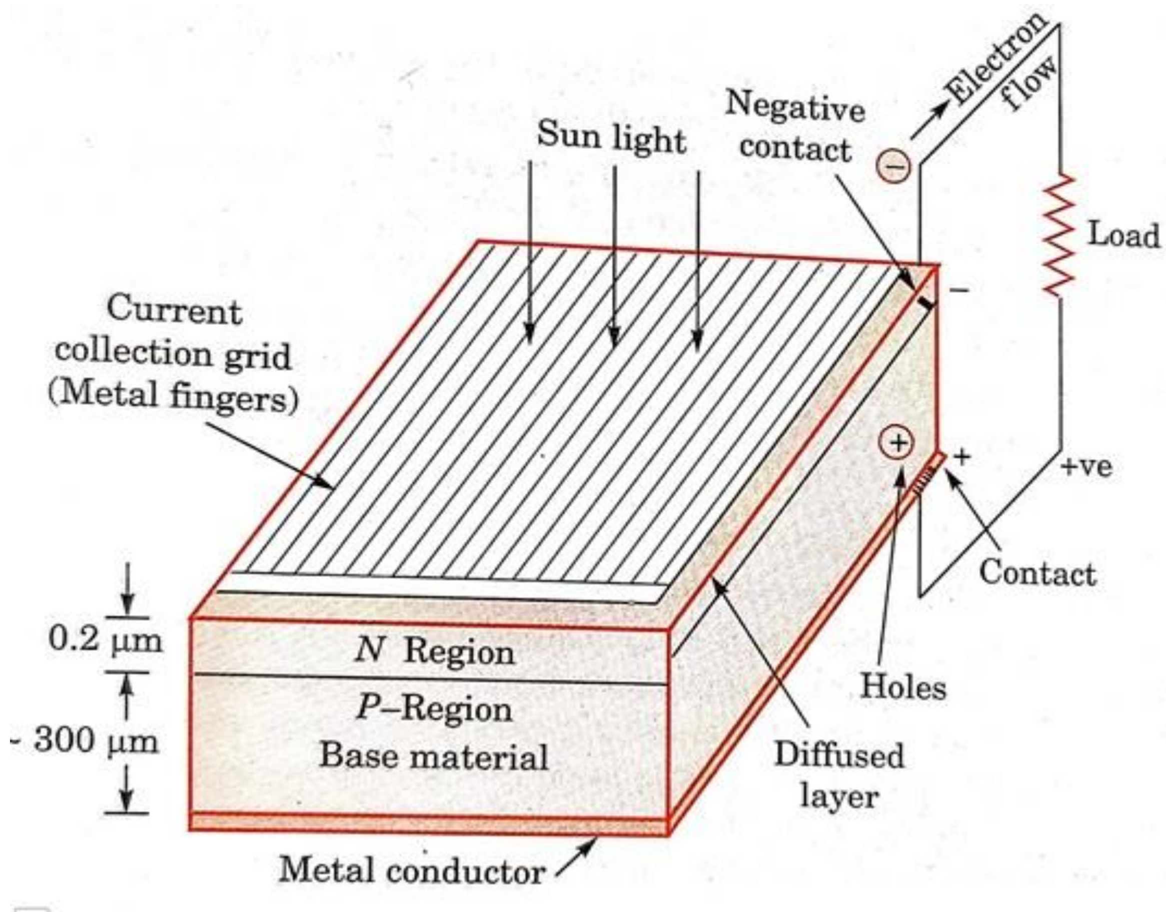
- Solar photovoltaic (PV)systems convert Solar energy directly into electrical energy.
- A solar cell is first produced in 1954.
- A solar cell is is the most expensive component in a Solar PV system(about 60% of the total system cost).
- Commercial photo cells may have efficiencies in the range of 10-20% and can produce energy of 1-2 kwh per square meter per day in ordinary sunshine.
- It has a lifespan in excess of about 20 years.
- As a PV system has no moving parts, it gives almost maintenance free service for long periods and work quite satisfactorily with beam or diffuse radiation.
- Workable voltage and reasonable power is obtained by interconnecting an appropriate number of cells.
- It requires protection against dust,moisture,mechanical shocks and outdoor harsh conditions.



Schematic symbol of a photovoltaic cell

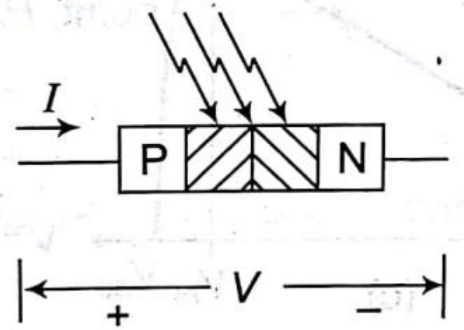
➢ Construction of Solar Cell

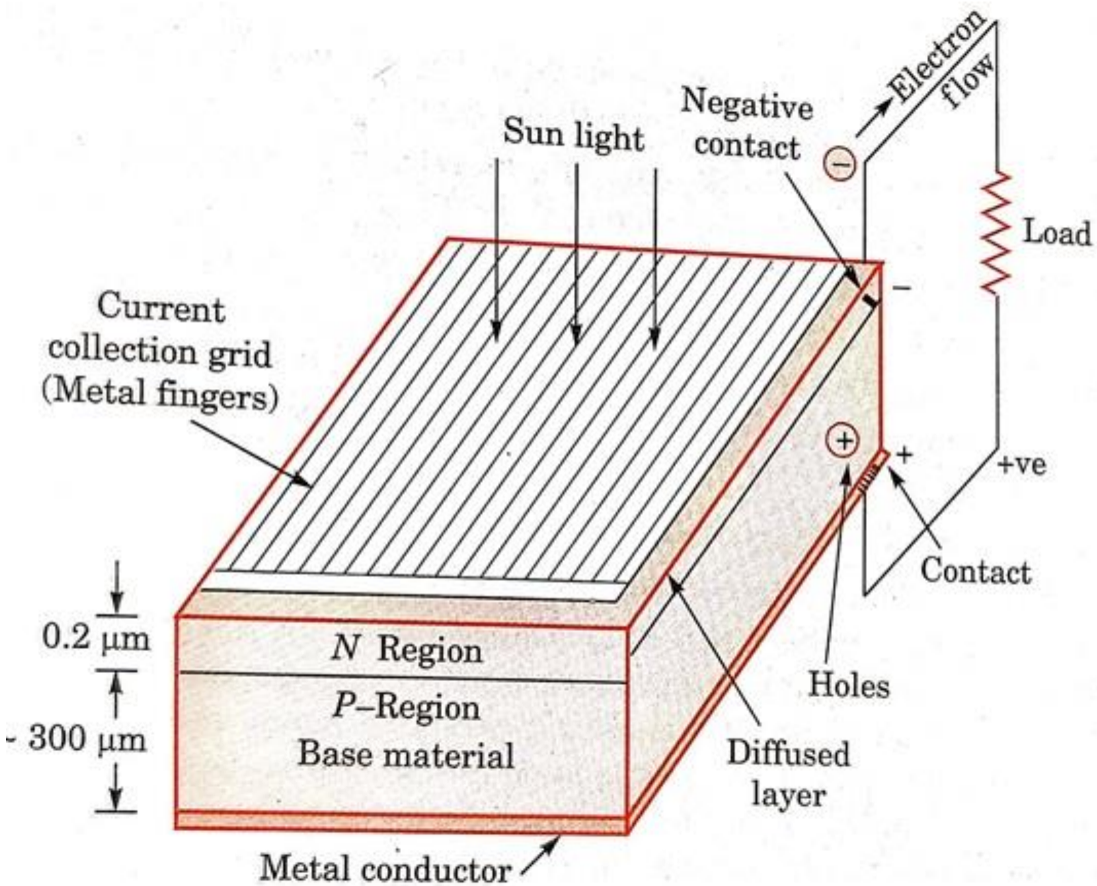
- A solar cell is basically a junction diode, although its construction it is little bit different from conventional p-n junction diodes.
- The semiconductor materials like arsenide, indium, cadmium, silicon, selenium and gallium are used for making the PV cells. Mostly silicon and selenium are used for making the cell.
- A very thin layer of n-type semiconductor is grown on a relatively thicker p-type semiconductor.



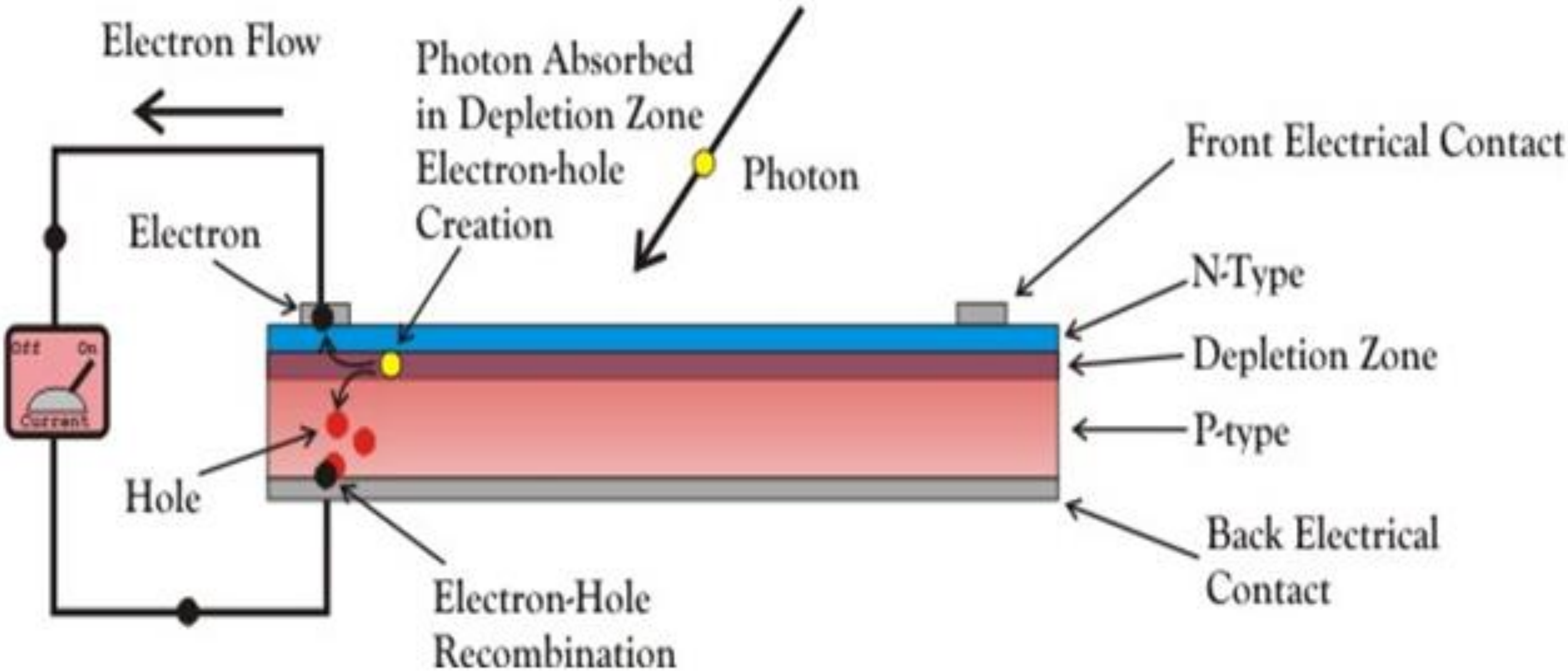
➢ Working Principle of Solar Cell

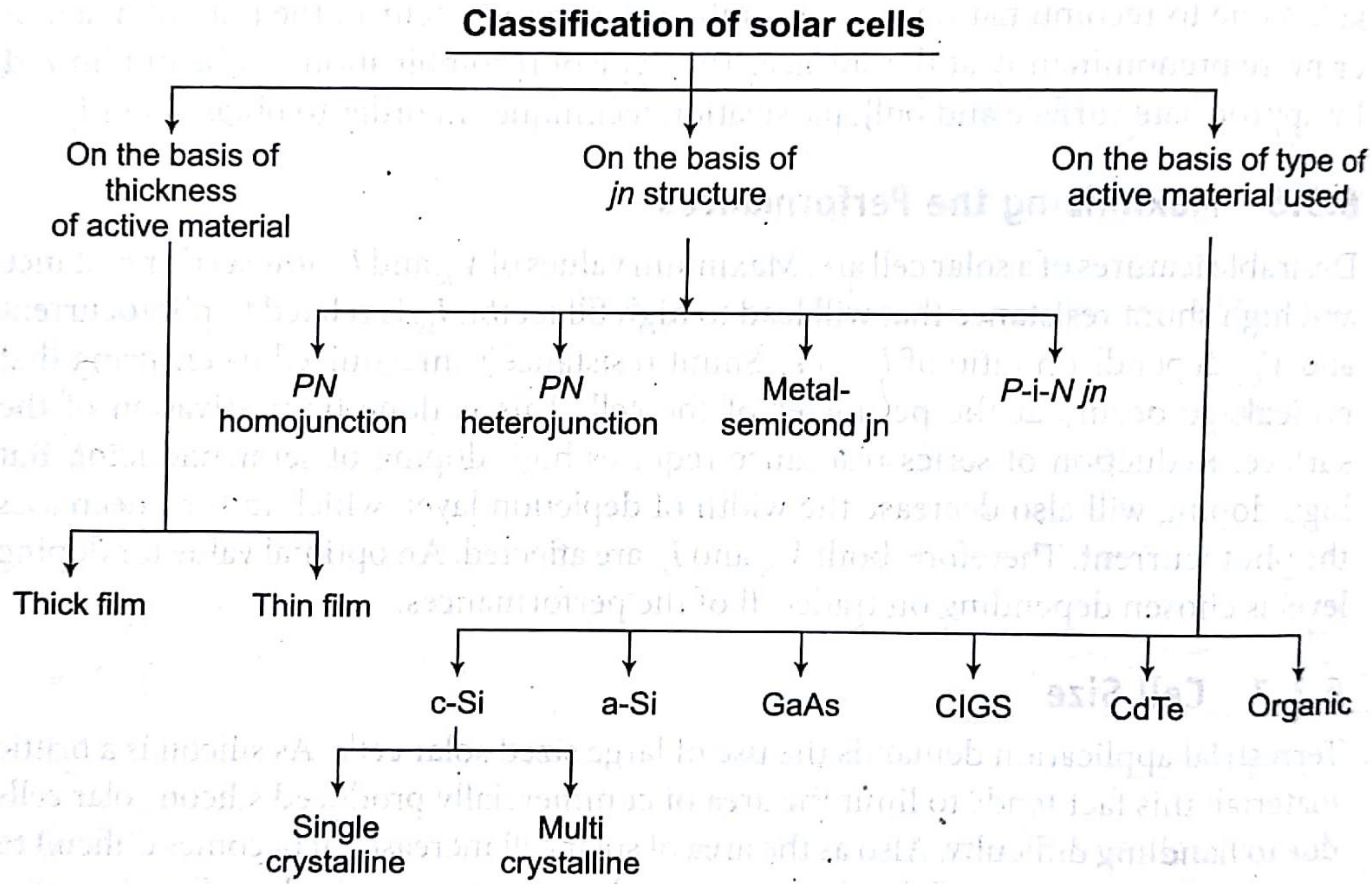
- A solar cell is essential a PN junction with a large surface area. The N-type material is kept thin to allow light to pass through to the PN junction.
- When light reaches the p-n junction, the light photons can easily enter in the junction, through very thin n-type layer.
- The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs.
- The incident light breaks the thermal equilibrium condition of the junction(barrier potential of the junction)





➢ Working Principle of Solar Cell

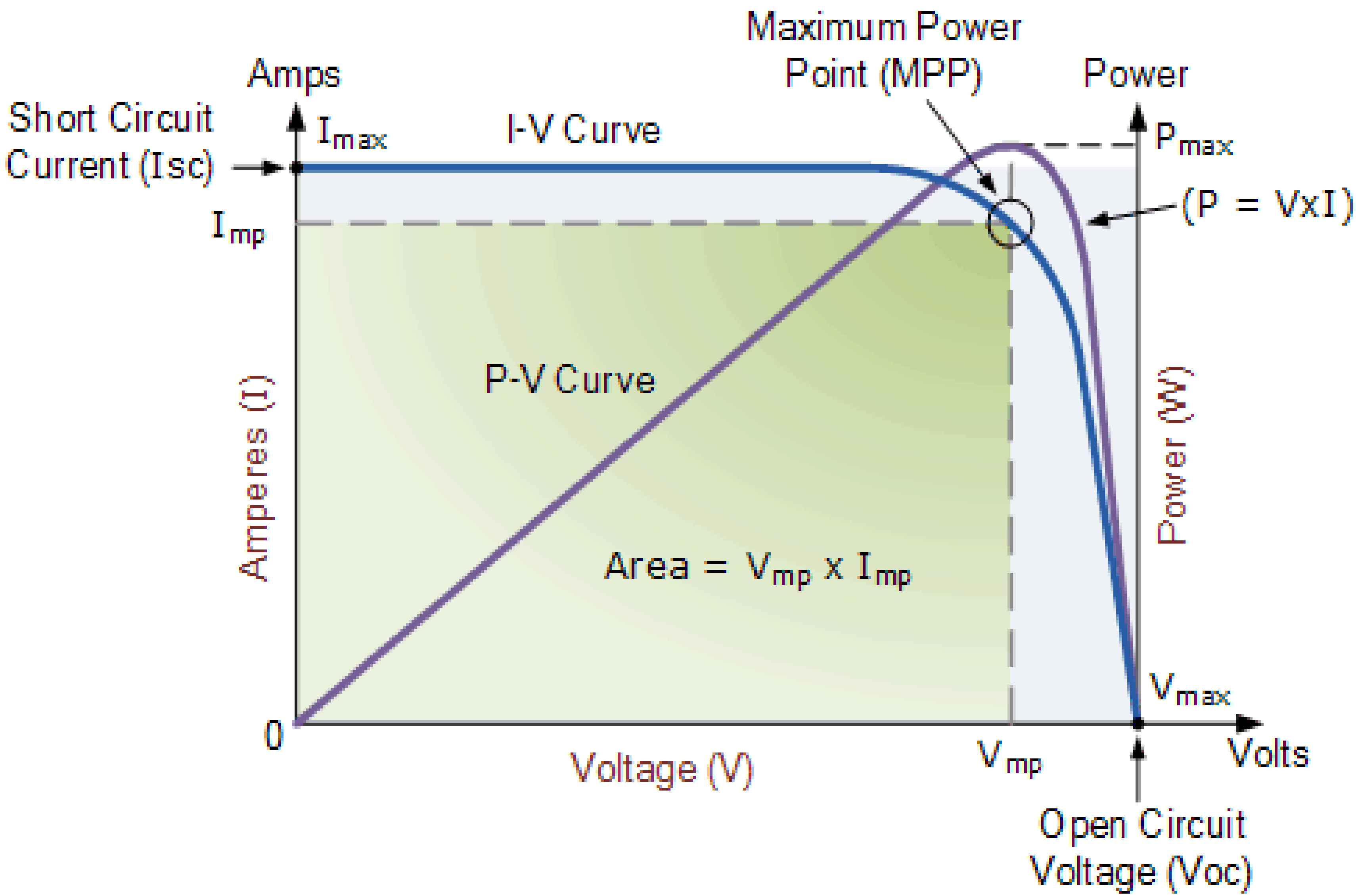



Classification of solar cells
On the basis of thickness of active material
On the basis of jn structure
On the basis of type of active material used
PN homojunction
PN heterojunction
Metal-semicond jn
P-i-N jn
Thick film
Thin film
c-Si
a-Si
GaAs
CIGS
CdTe
Organic
Single crystalline
Multi crystalline

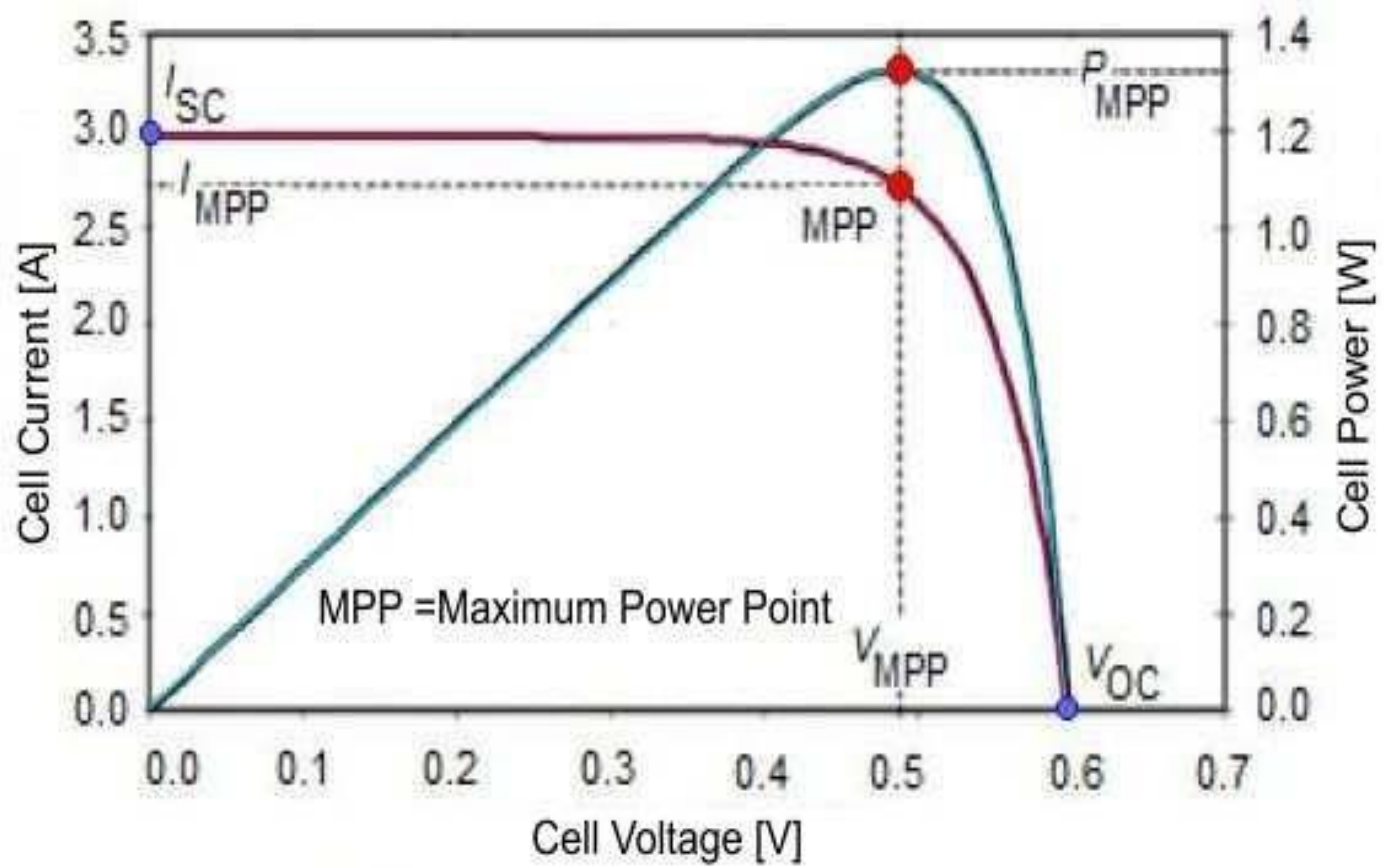
The Performance Characteristics of Solar cell

- The point at which the cell generates maximum electrical power and this is shown at the top right area of the green rectangle. This is the “maximum power point” or MPP.
- Therefore the ideal operation of a photovoltaic cell (or panel) is defined to be at the maximum power point.
- Maximum power=P_m=$V_m I_m$
- The ratio $\frac{I_m V_m}{I_{SC} V_{OC}}$ is called Fill factor(FF)
- Its(FF) value obviously lies between 0 and 1
- Maximum efficiency=$\frac{P_m}{P_{in}}$=$\frac{V_m I_m}{P_{in}}$=$\frac{FF * \text{Isc} * \text{Voc}}{P_{in}}$

The Performance Characteristics of Solar cell



The Performance Characteristics of Solar cell



Solar Array Parameters

- **V_{OC}** = open-circuit voltage: –
  - This is the maximum voltage that the array provides when the terminals are not connected to any load (an open circuit condition).
  - This value is much higher than Vmp which relates to the operation of the PV array which is fixed by the load.
  - This value depends upon the number of PV panels connected together in series.
- **I_{SC}** = short-circuit current –
  - The maximum current provided by the PV array when the output connectors are shorted together (a short circuit condition).
  - This value is much higher than Imp which relates to the normal operating circuit current.

Solar Array Parameters

- **MPP** = maximum power point –
  - This relates to the point where the power supplied by the array that is connected to the load (batteries, inverters) is at its maximum value, where MPP = Imp x Vmp
  - The maximum power point of a photovoltaic array is measured in Watts (W) or peak Watts (Wp)
- **Maximum conversion Efficiency** –
  - The maximum conversion efficiency of a photovoltaic array is given by the ratio of the maximum useful power to the incident solar radiation hitting the array.

Maximum efficiency= $\eta_{max} = \frac{P_m}{P_{in}} = \frac{V_m I_m}{I_T A_C} = \frac{(FF)\, I_{SC} V_{OC}}{I_T A_C}$

Where I_T ...incident solar radiation
A_C ... area of the cell

  - The efficiency of a typical solar array is normally low at around 10-12%, depending on the type of cells (monocrystalline, polycrystalline, amorphous or thin film) being used.

Solar Array Parameters

➢ Fill Factor(FF):

- The FF is defined as the ratio of the maximum power from the solar cell to the product of Voc and Isc.

$$FF = \frac{P_m}{I_{sc} V_{oc}} = \frac{I_m V_m}{I_{sc} V_{oc}}$$

- This fill factor value gives an idea of the quality of the array and the closer the fill factor is to 1 (unity), the more power the array can provide.
- Typical values are between 0.7 and 0.8.
- The above equations show that a higher voltage will have a higher possible FF.
- The difference between the maximum open-circuit voltage measured for a silicon laboratory device and a typical commercial solar cell is about 120 mV, giving maximum FF's respectively of 0.85 and 0.83.

➢ Effect of variation of Insolation and Temperature on characteristics of solar cell

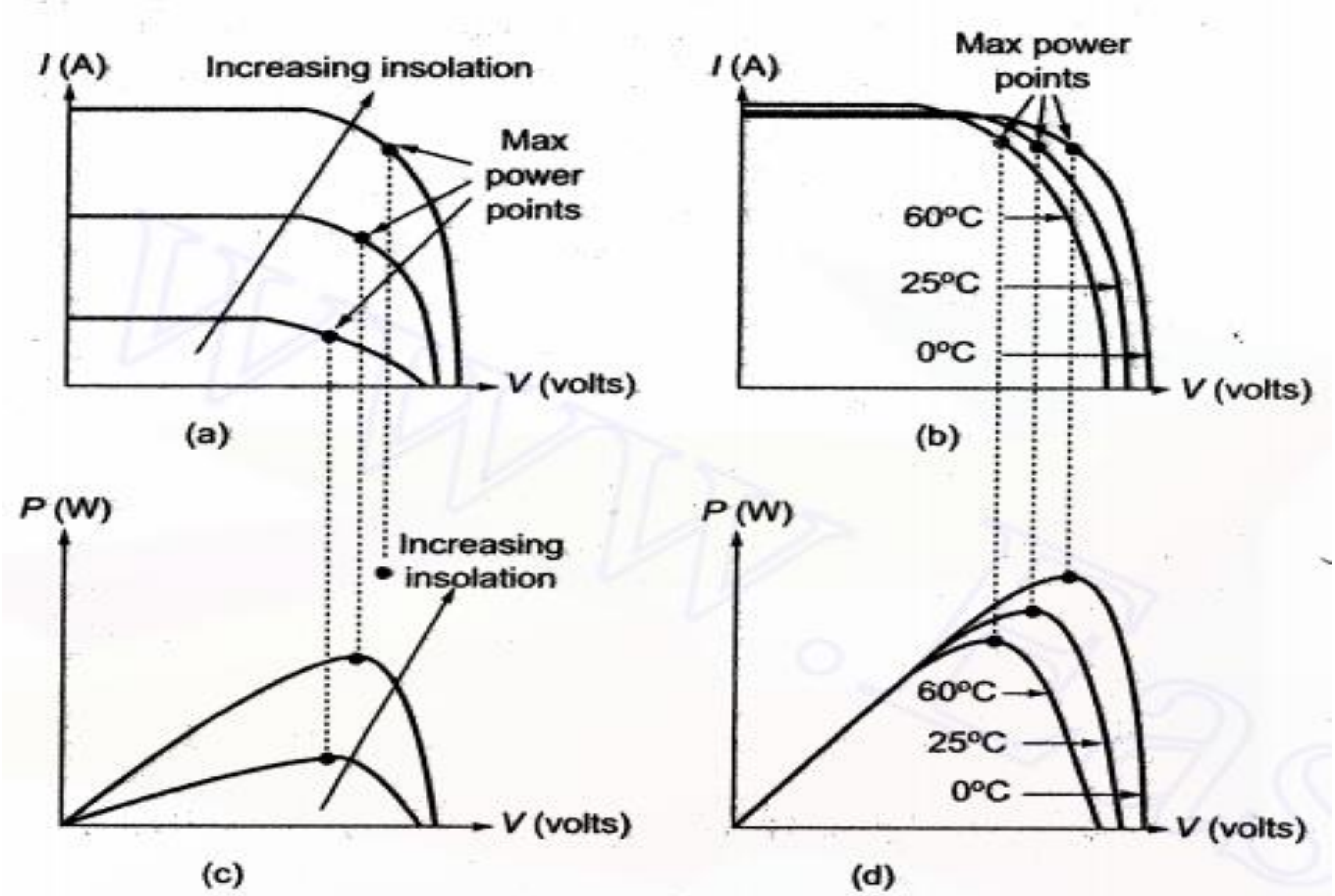


Fig: Effect of variation of (a) and (c) insolation and (b) and (d) temperature on the characteristic of solar cell

SOLAR CELL

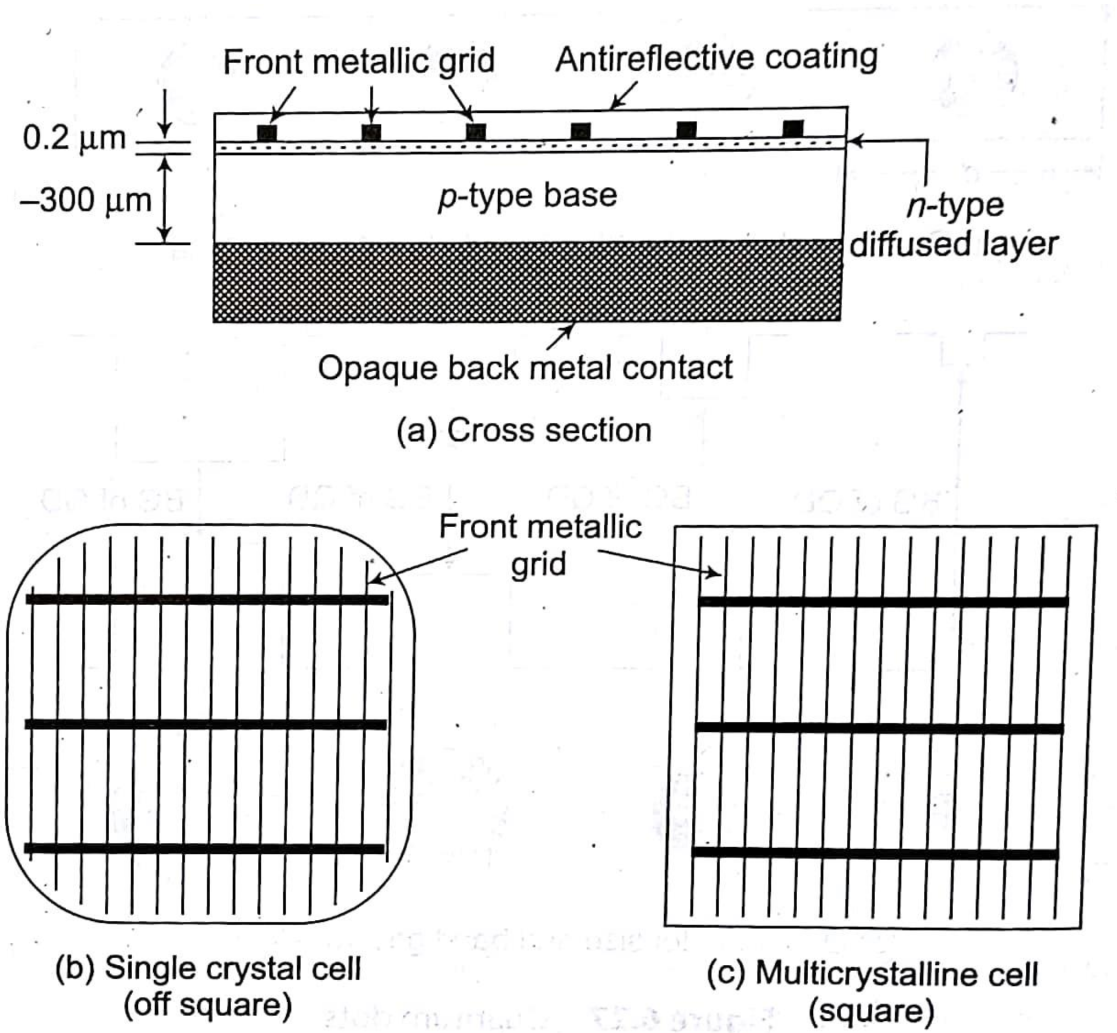


Fig.Construction of bulk silicon solar cell

SOLAR PV MODULE

- A bare single cell cannot be used for outdoor energy generation by itself.
- It is because (i) the output of a single cell is very small, and (ii) it requires protection (capsulation) against dust, moisture, mechanical shocks and outdoor harsh conditions.
- Workable voltage and reasonable power is obtained by interconnecting an appropriate number of cells.
- The unit is fixed on a durable back cover of several square feet, with a transparent cover on the top and hermetically sealed to make it suitable for outdoor applications.
- This assembly is known as solar module -a basic building block of a PV system.
- The most common commercial modules have a series connection of 32 or 36 silicon cells to make it capable of charging a 12-V storage battery.
- However, larger and smaller capacity modules are also available in the international market.

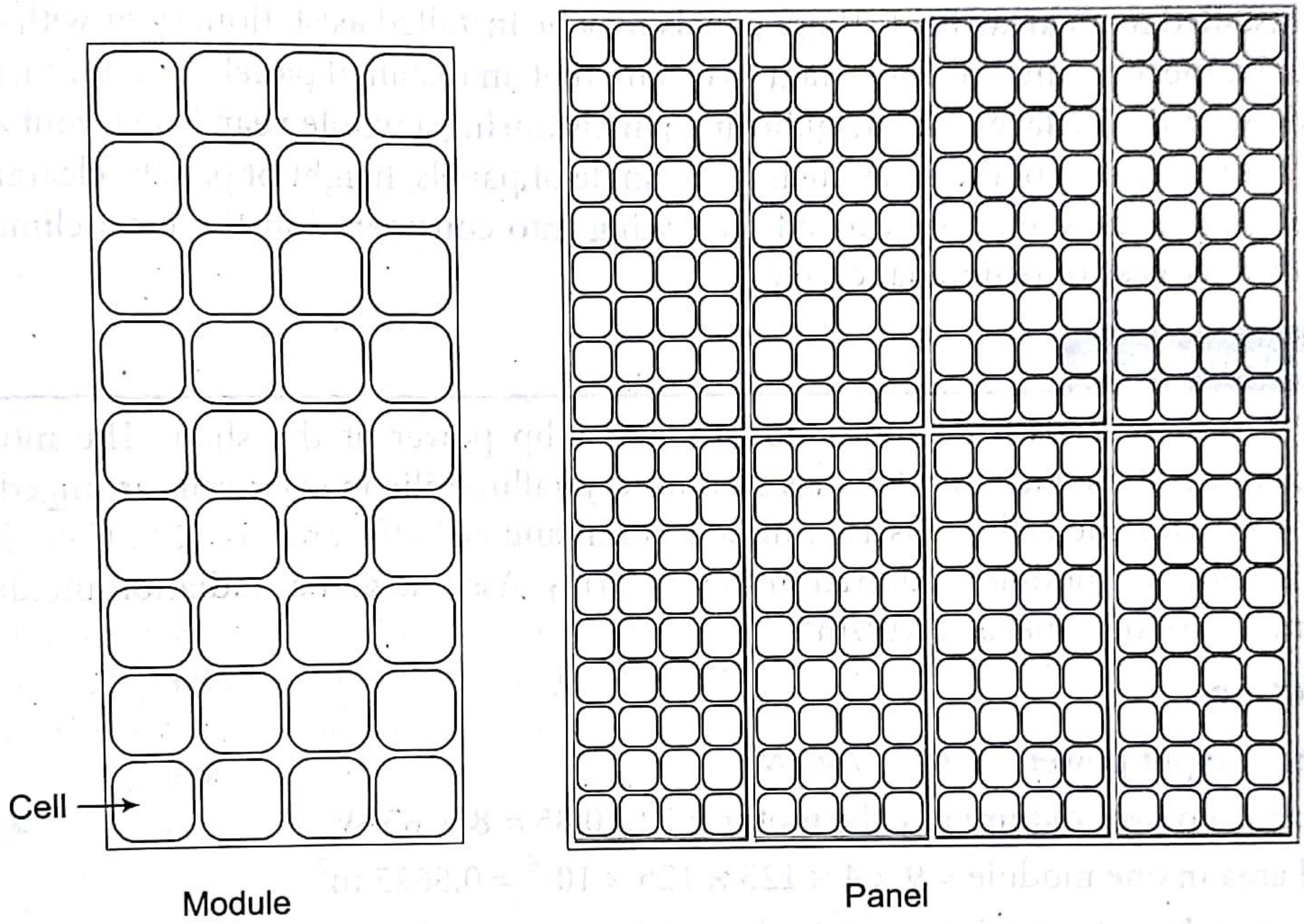


Fig.SOLAR CELL, MODULE, PANEL

Solar PV Panel

- Figure shows a series-parallel connection of modules in a panel.
- In a parallel connection, blocking diodes are connected in series with each series string of modules, so that if any string should fail, the power output 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 output of the remaining modules in a string will bypass the failed module. Some modern PV modules come with such internally embedded bypass diodes.

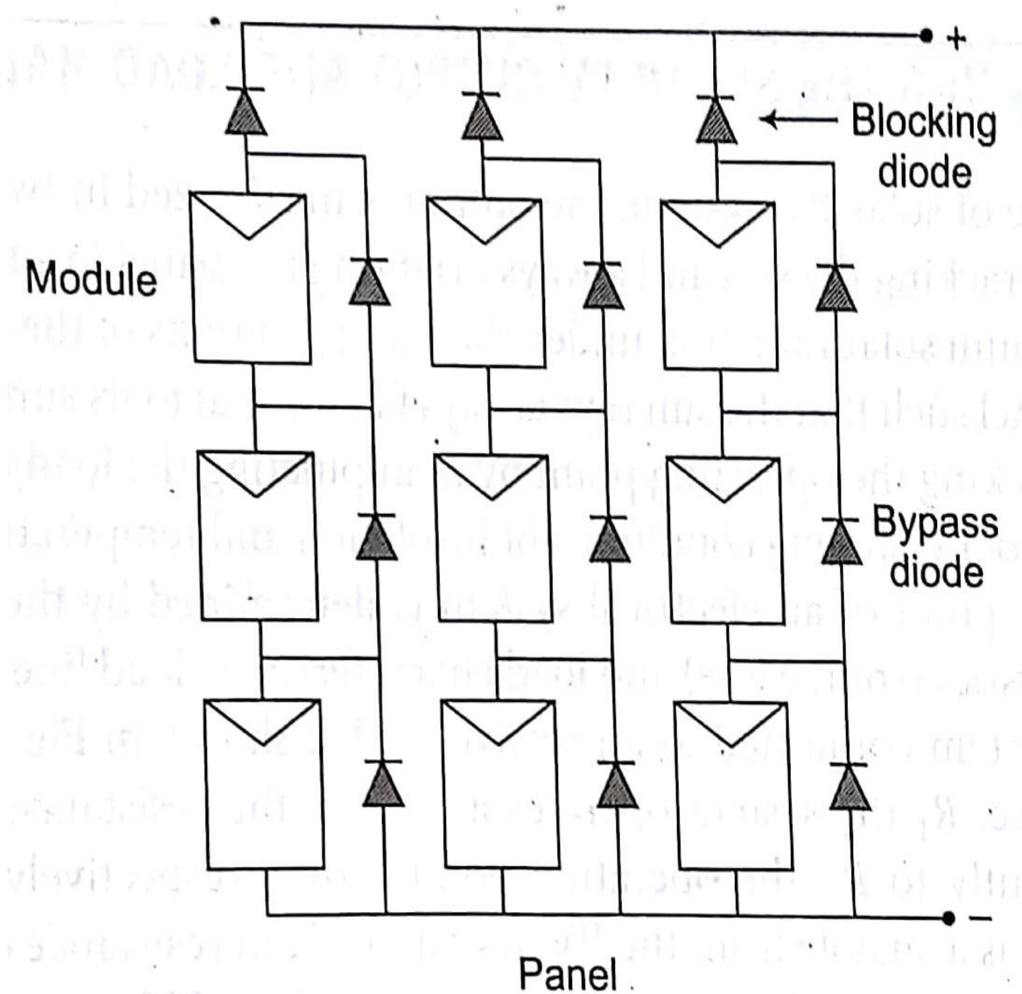
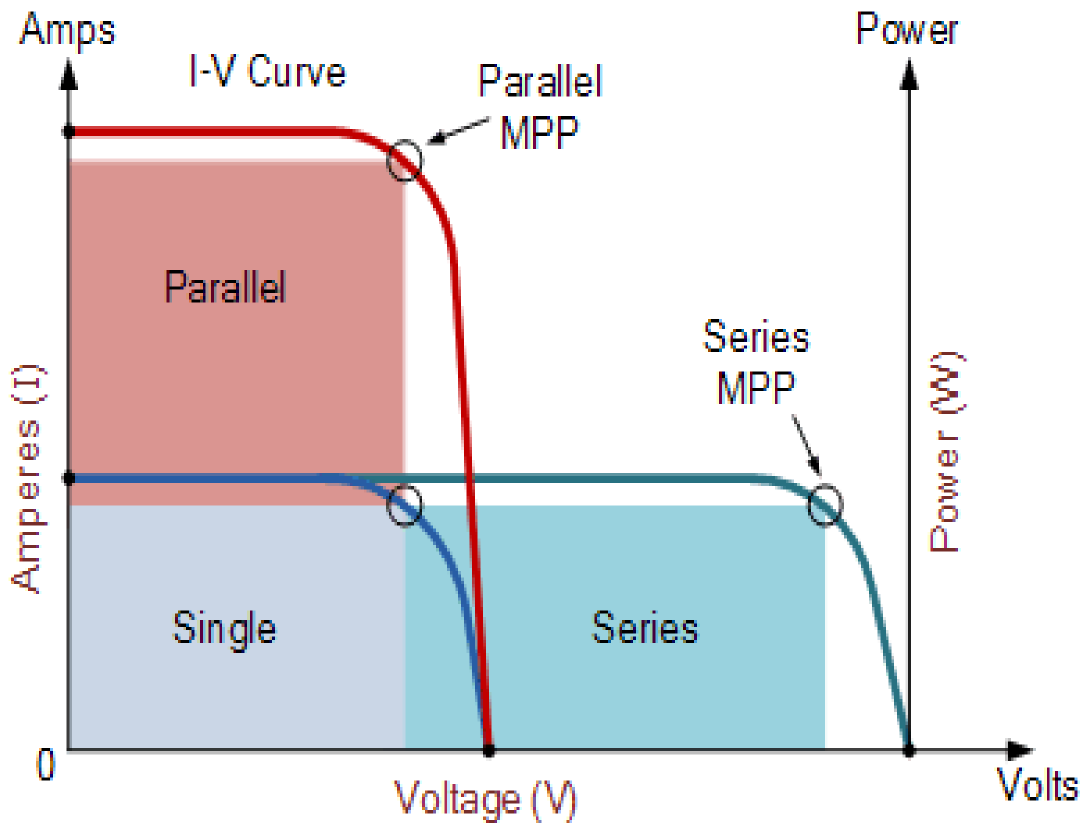


Fig. A typical panel series-parallel connection of modules

➢ Solar Panel I-V Characteristic Curves

- Photovoltaic panels can be wired or connected together in either series or parallel combinations, or both to increase the voltage or current capacity of the solar array.
- If the array panels are connected together in a series combination, then the voltage increases and if connected together in parallel then the current increases.
- The electrical power in Watts, generated by these different photovoltaic combinations will still be the product of the voltage times the current, (P = V x I).
- However the solar panels are connected together, the upper right hand corner will always be the maximum power point (MPP) of the array.



Cell Mismatch in a Module

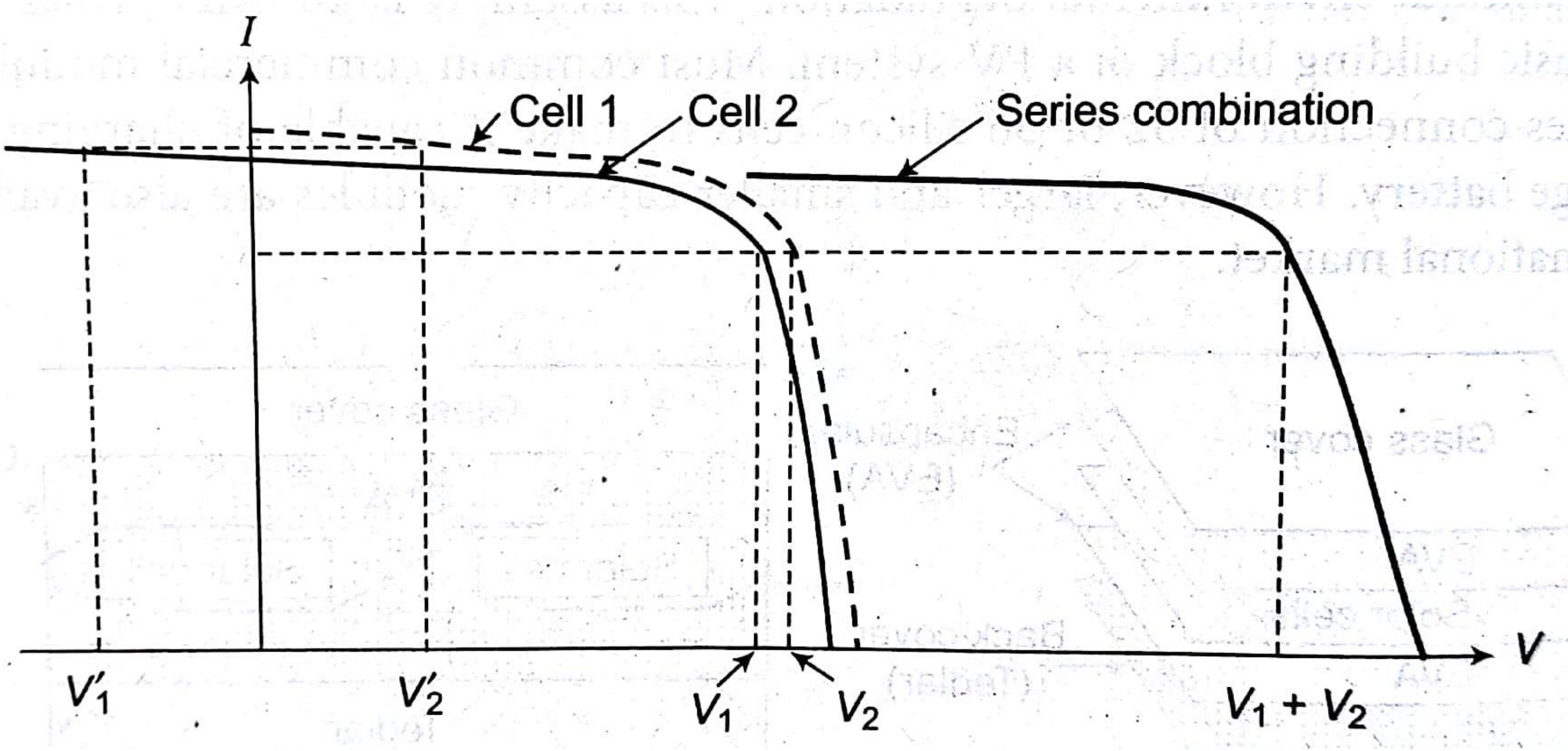


Fig.Composite characteristic of two cells in series

Effect of Shadowing

- The output of a cell determines when shaded by a tree branch, building or module dust.
- Shading is a problem in PV module since shading just one cell in the module can reduce the power output to zero.
- Current output of the cell is proportional to radiation on it.
- The cell in module are all connected in series shading a single cell causes the current in the string of cells to fall to the level of the shaded cell.
- One shaded cell in a string reduces the current through the good cells, causes the good cells to produce higher voltages that can after reverse bias the bad cell.

Effect of Shadowing

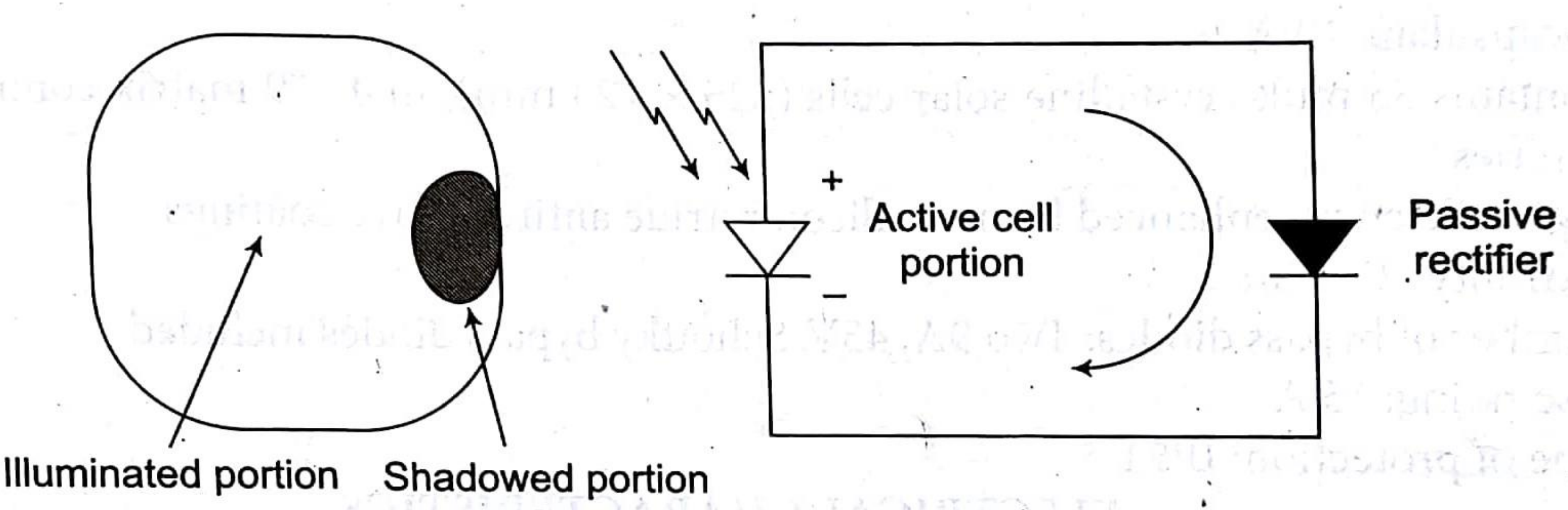


Fig.Patrial shadowing of cell

Effect of Shadowing

- A short-circuited, series string of (n + 1) cells with one cell completely shadowed is shown in Figure
- Here, the voltages produced by * illuminated cells add up and appear as reverse bias voltage of nV volts across the shadowed cell.
- As long as peak inverse voltage (PIV) of the shadowed cell is more than the reverse bias, no current will flow.
- If, however, the PIV is less than the total reverse voltage appearing across the shadowed cell, current will flow through the string, dissipating large power in the shadowed cell, thus leading to possible damage of the module.
- The chances of damage to the shadowed cell due to excessive heating increase with the number of cells in the string.
- If the string supplies a load instead of being short-circuited, the chances of damage still persist through to a lesser extent.

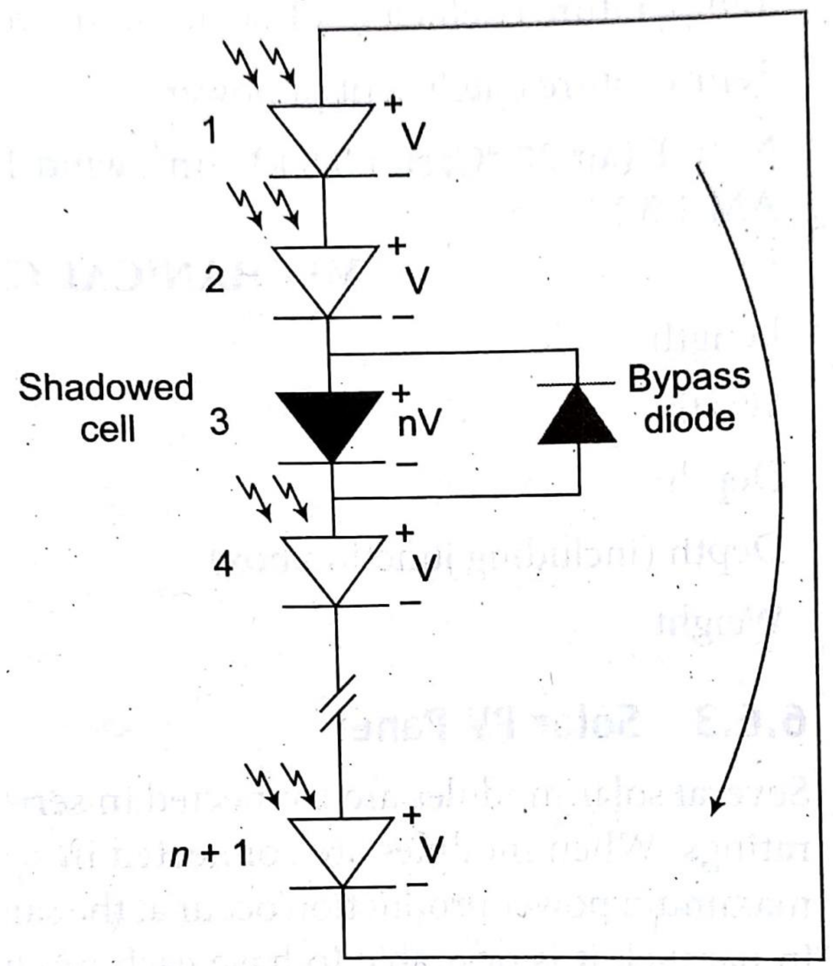


Fig.Shadowed cell and bypass diode connection

MAXIMIZING THE SOLAR PV OUTPUT AND LOAD MATCHING

- The operation for a solar PV system connected to a resistive load is shown in Figure.
- For a low value of resistance, R_1, the system operates at Q_1.
- As the resistance is increased to R_2 and then to R_3, the operating point moves respectively to Q_2, and Q_3 ,
- Maximum power is available from the PV system for a load resistance of R_2.
- Such load matching is required for extracting maximum power from a PV system.

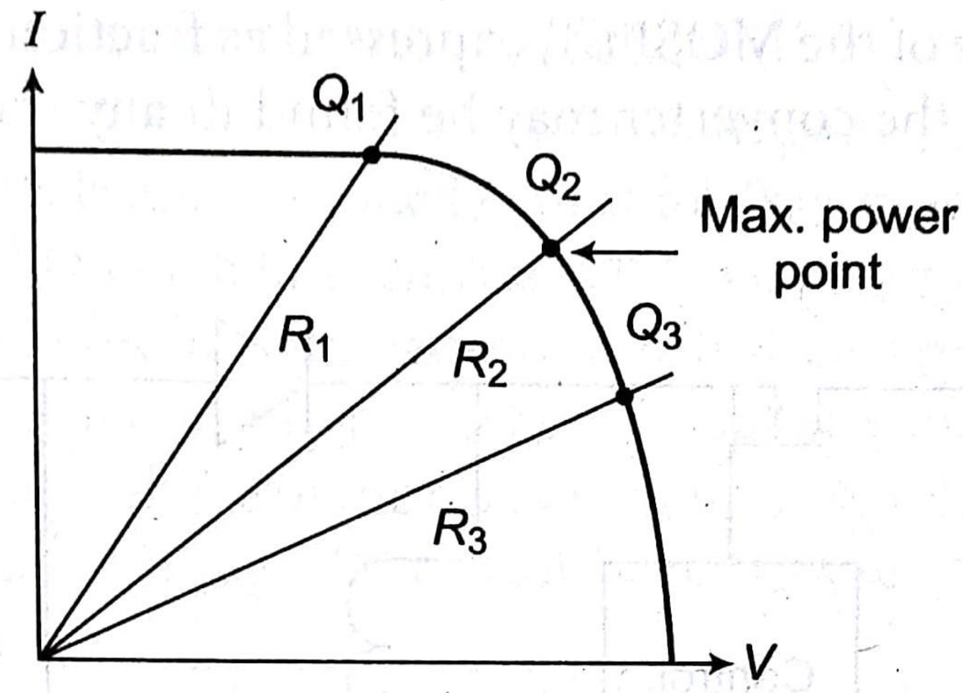


Fig. Load matching with Resistive load

Maximum Power Point Tracker(MPPT)

- It is defined as an electronic device or controller that tracks the variations of electrical operating point of systems or modules, to extract maximum power from the system.
- This tracking system is usually employed in "Battery less grid –tied photovoltaic inverters" to extract maximum power.
- Then converting into AC and then fed to load.

The Features of MPPT :

1) MPPT is used, if operating point is varying considerably from the maximum power point.
2) The MPPT technique is useful to obtained uniform output power from varying resistance conditions.
3) MPPT regulators are usually used in cold weather and cloudy conditions or even when the batteries are deeply discharged.
4) It is used to drive motors directly connected to solar panels

- The intensity of ambient solar radiation varies throughout the day .
- It is not possible to obtain uniform operating point at maximum or close to maximum power output.
- Thus,the effective use of MPPT makes the PV module to extract maximum power output.

Maximum Power Point Tracker(MPPT)

- If the operating point departs significantly from the maximum power point, it may be desirable to interpose an electronic maximum power point tracker (MPPT) between PV system and load.
- Generally, MPPT is an adaptation of dc-dc switching voltage regulator.
- Coupling to the load for maximum power transfer may require either providing a higher voltage at a lower current or lower voltage for higher current.

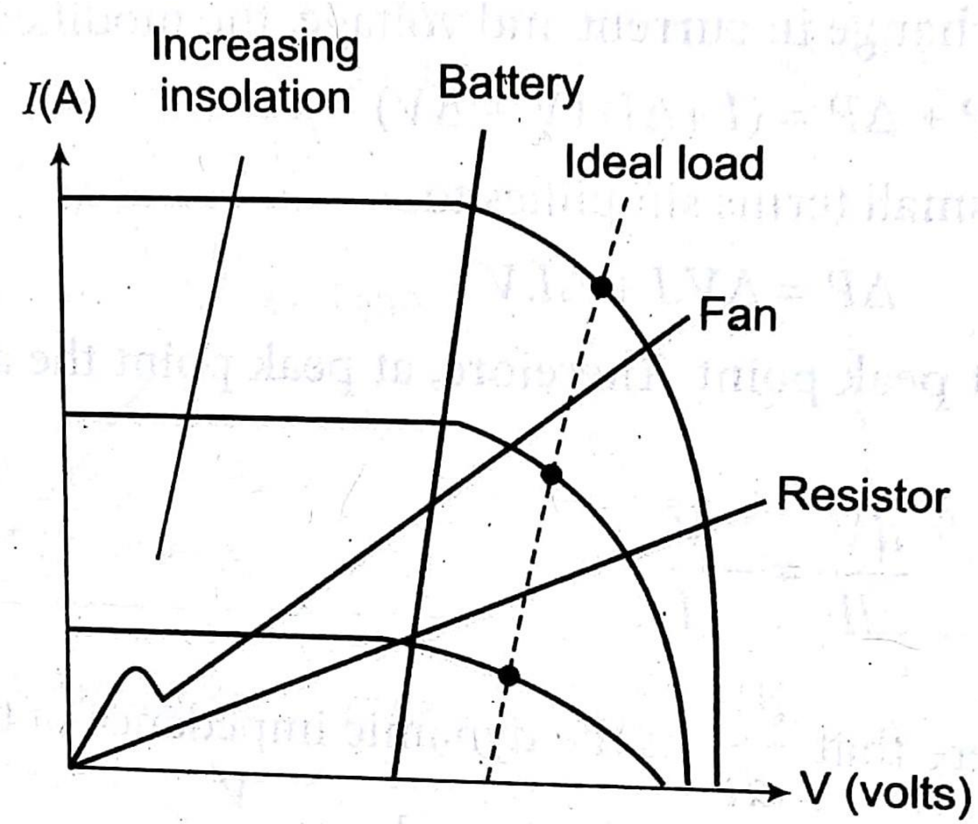


Fig. Characteristics of PV and some loads

Maximum Power Point Tracker(MPPT)

- A buck-boost scheme is commonly used with voltage and current sensors tied into a feedback loop using a controller to vary the switching times.
- This converter is also called as an inverting converter as it provides a reversal in the output voltage polarity without a transformer.
- Basic elements of a buck-boost converter that may be used in an MPPT are shown in Figure.

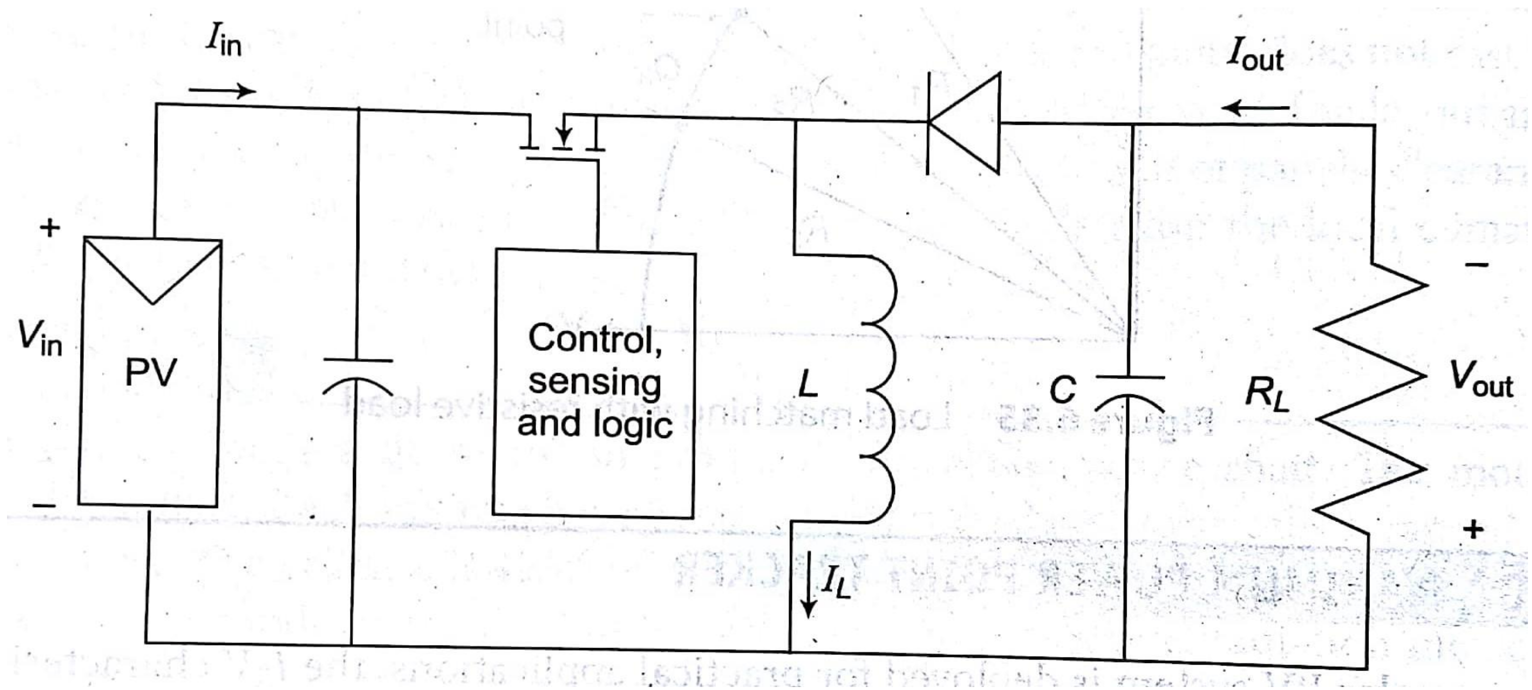


Fig.Maximum power tracker using Buck-Boost converter

Maximum Power Point Techniques:

The Various Techniques(algorithm) used in MPPT for a photovoltaic system are:

1) Perturbation and Observation(P&O) technique
2) Hill climbing (HC) technique
3) Incremental Conductance (INC) method’
4) Fractional short circuit current
5) Fractional open circuit voltage
6) Neural networks
7) Fuzzy logic

Hill climbing (HC) technique

- The hill climbing algorithm locates the maximum power point by relating changes in the power to changes in the control variable used to control the array.
- Hill-climbing algorithm involves a perturbation in the duty ratio of the power inverter. In the case of a PV array connected to a system, perturbing the duty ratio of power inverter perturbs the PV array current and consequently perturbs the PV array voltage. Figure (Characteristics of PV array Power curve) shows the characteristic of PV array curve.
- In this method, by incrementing the voltage, the power increases when operating on the left of the MPP and decreases the power when on the right of the MPP.
- Therefore, if there is an increase in power, the subsequent perturbation is kept at same point to reach the MPP and if there is a decrease in power, the perturbation is reversed.
- The process is repeated periodically until the MPP is reached.
- The system then oscillates about the MPP.
- The oscillation is minimized by reducing the perturbation step size.

Hill climbing (HC) technique

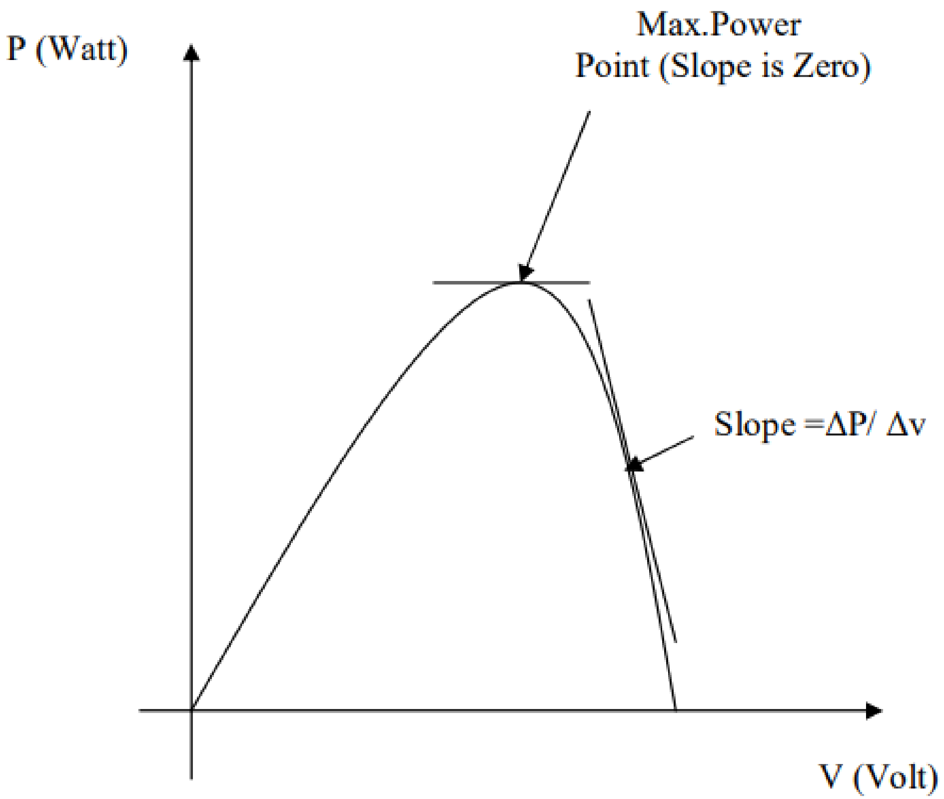


Fig.Characteristics of PV array Power curve

Hill climbing (HC) Technique

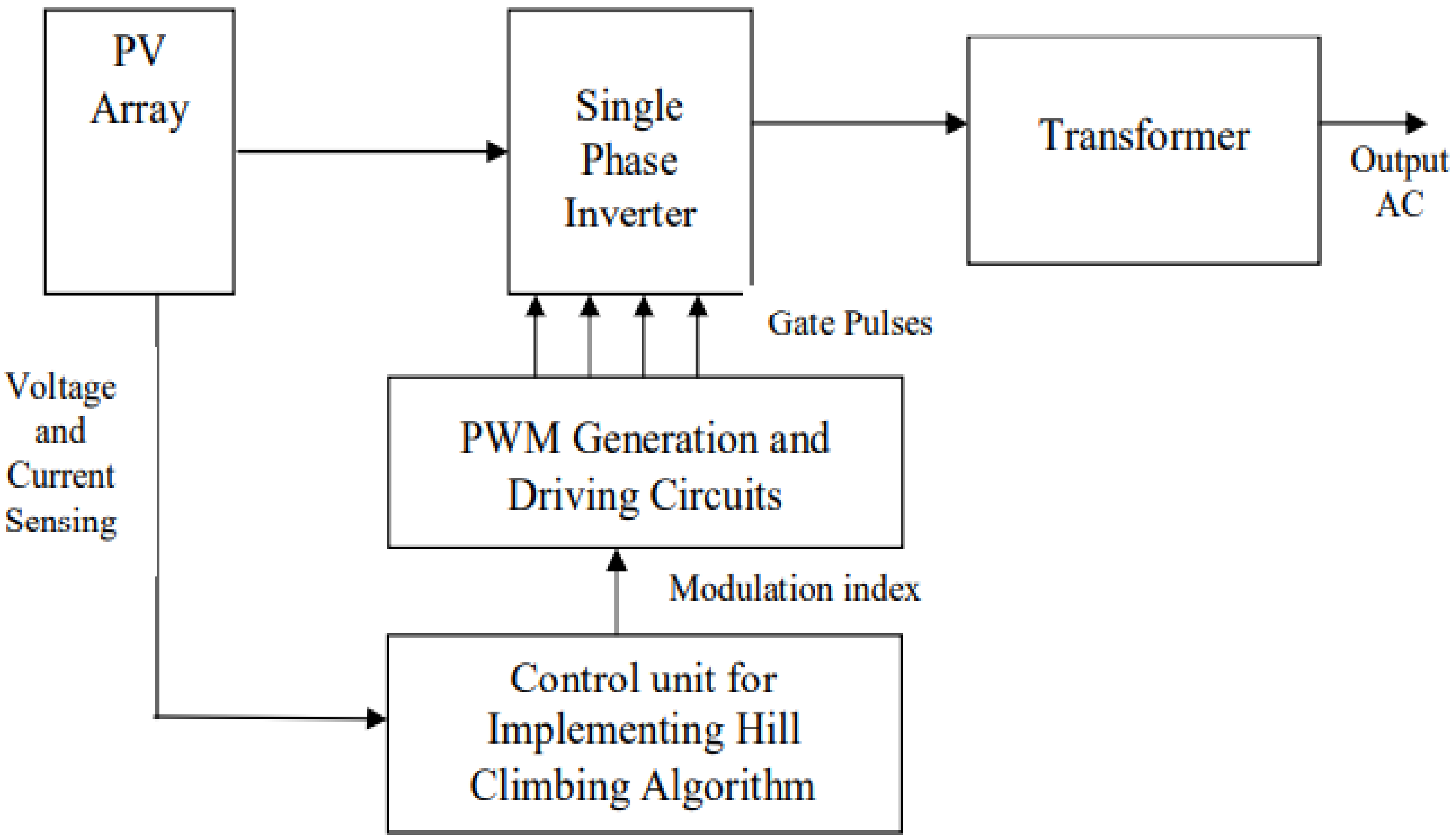
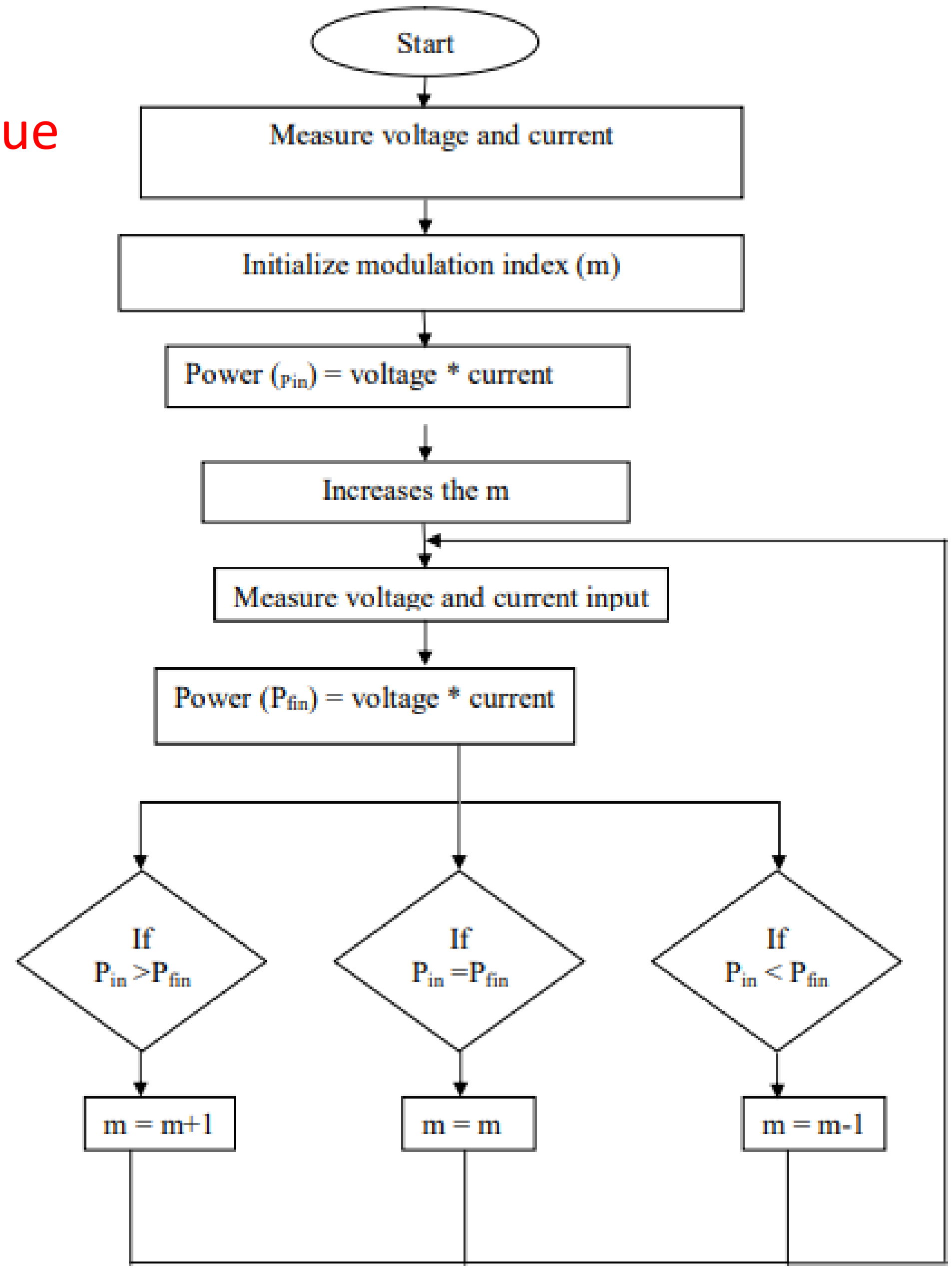


Fig.Block diagram

Hill climbing (HC) Technique

- Flow chart:



Perturbation and Observation(P&O) Technique (or) Perturb & Observe Method(Algorithm):

- To maximize the utilization of solar cells and lower system cost, maximum power point tracking (MPPT) method is employed to extract the peak available power from PV arrays.
- Among numbers of methods for MPPT, the perturbation and observation (P & O) algorithm is most widely used in PV systems due to its simplicity and ease of implementation.
- It is most widely used and simple algorithm employed in MPPT of photovoltaic system.
- It is generally used for determining the maximum power of PV system.
- This can be done by iteration,perturbation,observation and comparison of generated power of PV system.

Perturbation and Observation(P&O) technique

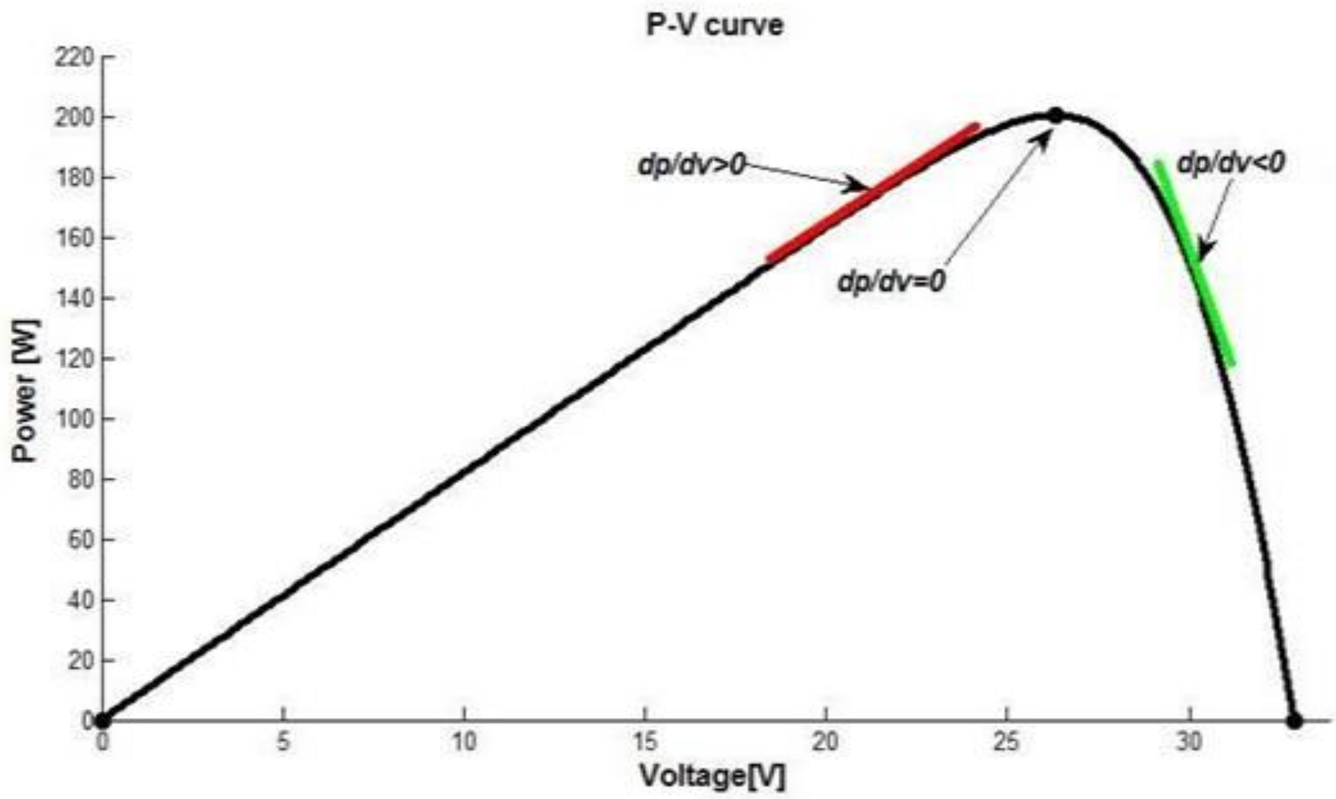


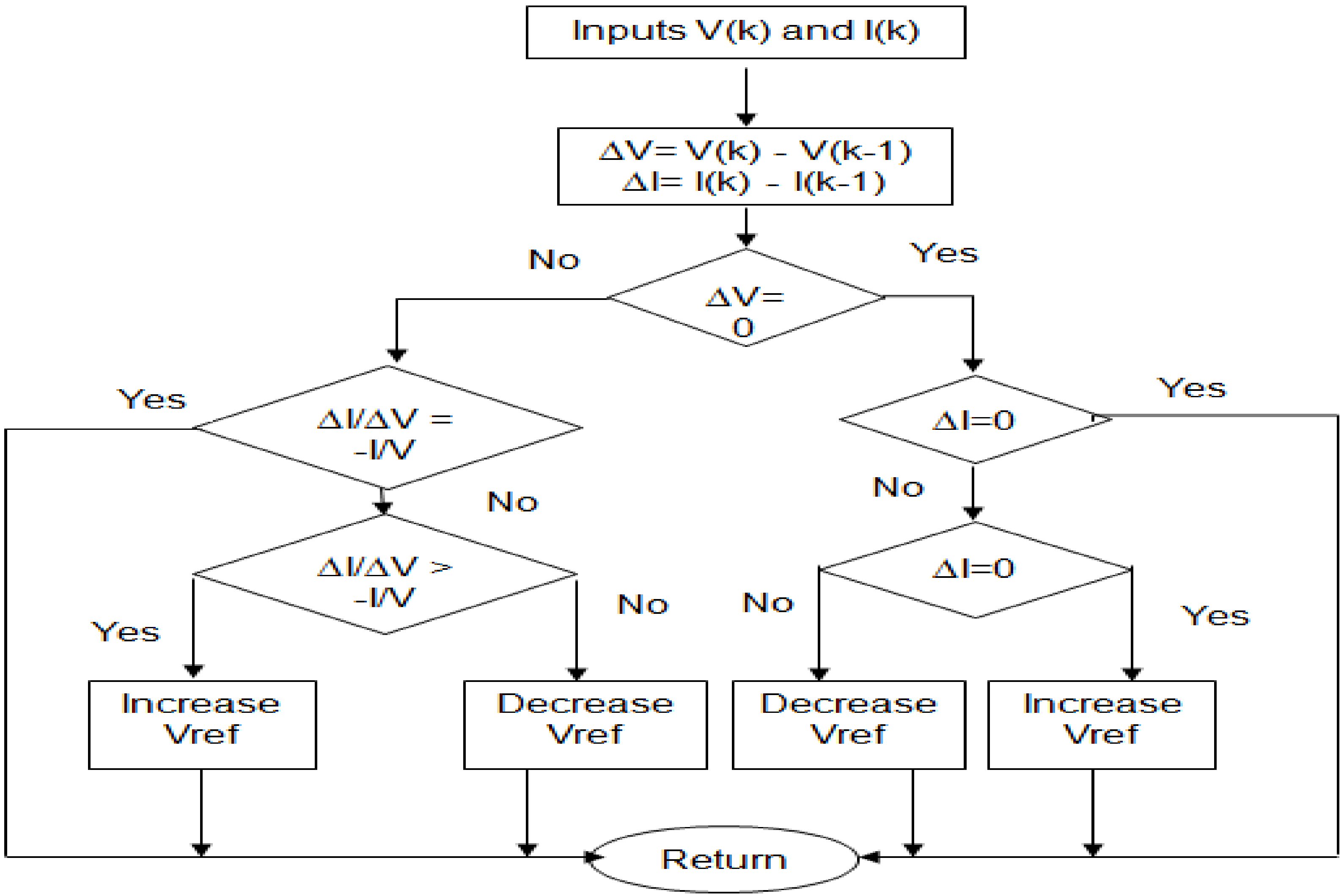
Fig.P-V characteristics of a PV module

Incremental Conductance Algorithm

- The incremental conductance algorithm of MPPT was used derivative of conductance to determine the maximum power point (MPP).
- The MPP is determined by comparing instant conductance I/V to the incremental conductance ΔI/ΔV and the INC technique is based on the fact that slope of P-V curve is zero at MPP as shown in Figure.

- This algorithm performs better than P&O algorithm in rapidly varying environment and is robust to the rapidly varying solar radiation.
- The MPPT speed and accuracy was improved by introducing automatically adjustable variable step size to conventional INC technique.
- When MPP is far from operating point, the step size is large for fast tracking while during operating point closer to MPP, the step size becomes small to reduce steady state oscillation.

Flow chart of Incremental Conductance Algorithm



➢ BALANCE OF SYSTEM COMPONENTS

- The balance of system (BOS) components include mounting materials for the module, wire and all wiring components (including distribution panel, junction box and miscellaneous connectors), lightning protectors, grounding connections, battery fuses, battery cables and battery containers. In some cases, the connected loads are also considered to be part of BOS, for example, when the System is installed to operate a specific load.

- Certain BOS components are regulated by codes or standards.
- Array mounts, for example, must meet wind-loading requirements of applicable building codes.
  Battery compartments are covered in the NEC (National Electrical Code).
- Also, BOS components may need to be appropriate for environmental considerations.

SOLAR PV SYSTEMS

- Solar PV systems are broadly classified as follows:

(i) Central Power Station System

- Central PV power stations are conceptually similar to any other conventional central power station.
- They feed power to grid.
- These are being proposed in few MW range to meet daytime peak loads only.
- Central PV power stations of up to 6 MW (peak MW) capacities have already been experimented within USA and Europe.
- While the concept 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 further divided into three groups:

(a) Stand-alone System:

- It is located at the load centre and 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 and successful in remote and rural areas having no access to grid supply. Indicative capacity of such a system is 10 W_p -100 kW_p

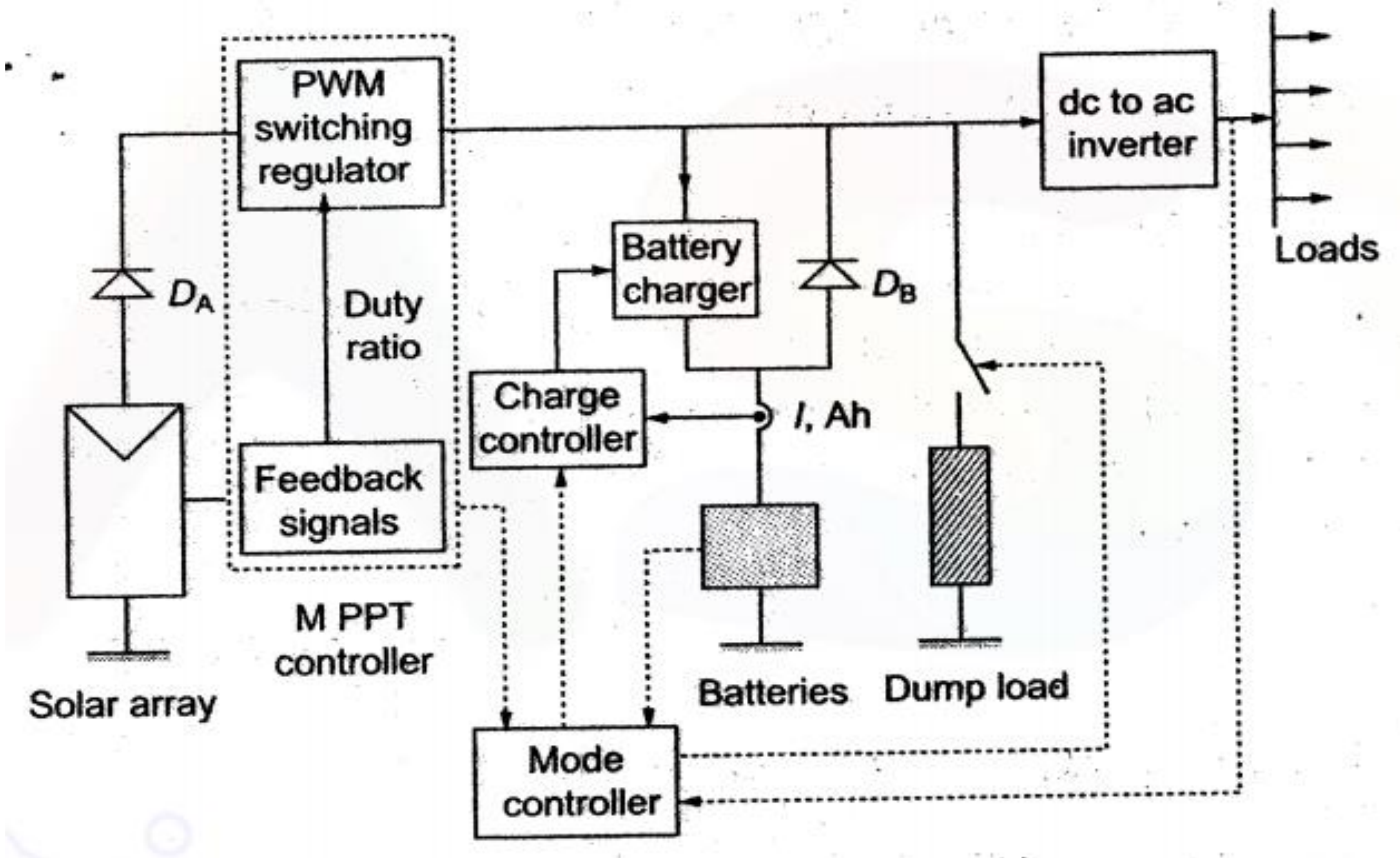
(b) Grid-interactive System :

- This system is connected to the utility grid with two-way metering system.
- It may be a small rooftop system owned and operated by the house owner or a relatively bigger system meant for the whole village or a community.
- It meets daytime requirements of the house owner without any battery backup and surplus power is fed to the grid.
- During peak hours and during 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 10 W_p and mostly designed for indoor applications, eg, calculators, watches, electronic games, etc)

Stand Alone Solar PV System



Fig, A general stand alone solar PV system

Grid-Interactive Solar PV System

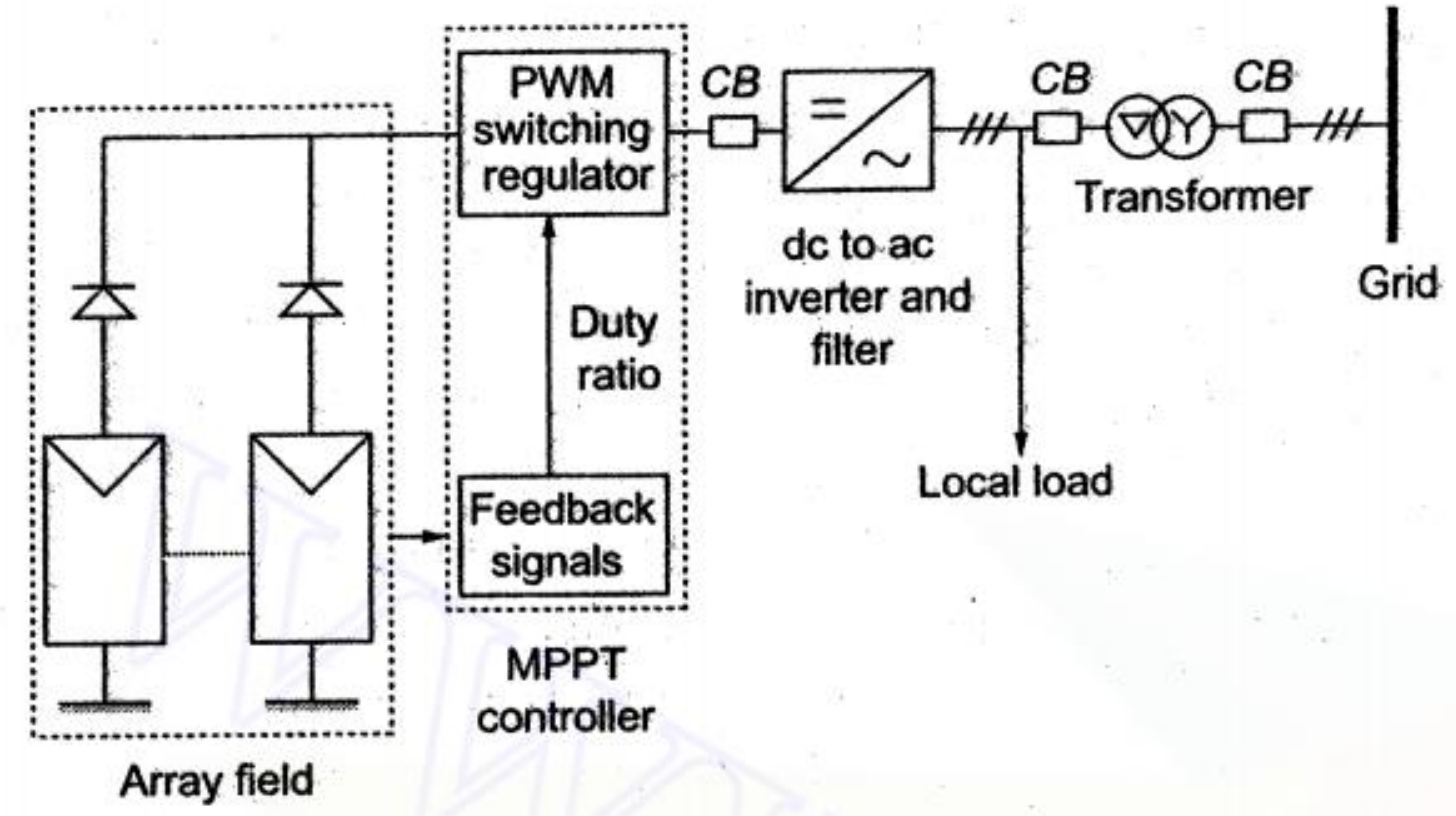


Fig. A general Grid-Interactive Solar PV System

PV system sizing

- Sizing is the basis for PV system electrical designs, and establishes the sizes and ratings of major components needed to meet a certain performance objective.
- The sizing of PV systems may be based on many number of factors, selection of location, system size, and array type, orientation and tilt angle and depending on the type of system and its functional requirements.

- The sizing principles for interactive and stand-alone PV systems are based on different design and functional requirements.
  - Utility-Interactive Systems (without energy storage):
    Provide supplemental power to facility loads.
    Failure of PV system does not result in loss of loads.
  - Stand-Alone Systems (with energy storage):
    Designed to meet a specific electrical load requirement.
    Failure of PV system results in loss of load.

Sizing Stand Alone PV Systems

Load Analysis:

- The energy consumption for electrical loads is estimated on an average daily basis for each month of the year.
- Use worksheets to list each load, its average power, daily time of use and compute energy consumption.
  - List AC and DC loads separately, and apply inverter efficiency to determine the DC energy required for AC loads.
  - The daily DC energy required is used to size the battery and PV array.
  - The peak AC power demand dictates the size of inverter required.
- Explore opportunities for improvements in load efficiency and end-use practices to reduce size and costs of PV system required.

❑ Factors Affecting Battery Sizing:

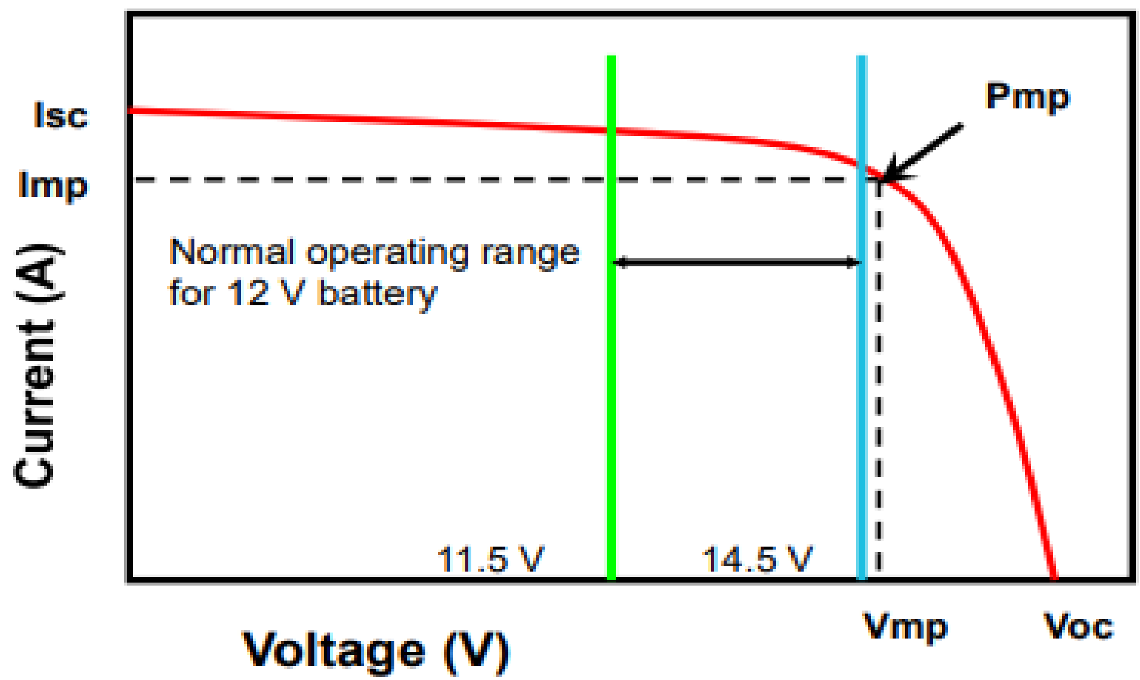
- Greater autonomy periods increase the size of the battery and increase availability, and decrease average daily depth-of- discharge.
- Maximum depth-discharge defines the usable battery capacity and is defined by the load cutoff voltage.
    - Greater allowable DOD provides greater system availability, but at the expense of battery health.
    - Depth-of-discharge must be limited in cold climates to protect lead-acid batteries from freezing.
- Rated battery capacity is affected by temperature, discharge rate and age of the battery.

Sizing the PV Array

- The PV array for stand-alone systems is sized to meet the average daily load during the critical design month.
- System losses, soiling and higher operating temperatures are factored in estimating array output.
- The system voltage determines the number of series-connected modules required per source circuit.
- The system power and energy requirements determine the total number of parallel source circuits required.

➢ PV Array Battery Charging:

- Standard silicon PV modules with 36 series-connected cells are optimally suited for charging a nominal 12 V lead-acid battery.



Applications of Solar Photovoltaic System

- Various solar photovoltaic systems have been developed and installed at different sites for demonstration, and field trial purposes.

  The terrestrial applications of these include provision of power supply to:

  (i) water pumping sets for micro irrigation and drinking water supply,

  (ii) radio beacons (a tower with a light) for ship navigation at ports,

  (iii) community radio and television sets,

  (iv) weather monitoring,

  (v) railway signaling equipment,

  (vi) battery charging,

  (vii) street lighting.
- The major application of photovoltaic systems lies in water pumping for drinking water supply and irrigation in rural areas. The photovoltaic water pumping system essentially consists of:

  (a) a photovoltaic (PV) array,

  (b) storage battery,

  (c) power control equipment,

  (d) motor pump sets, and

  (e) water storage tank.

Thank you

RENEWABLE ENERGY SOURCES

UNIT-IV

WIND ENERGY

UNIT-IV

WIND ENERGY

Topics:

- Sources of wind energy
- Wind patterns
- Types of turbines
- Horizontal axis and vertical axis machines
- Kinetic energy of wind
- Betz coefficient
- Tip–speed ratio
- Efficiency -Power output of wind turbine
- Selection of generator(synchronous, induction)
- Maximum power point tracking
- wind farms
- Power generation for utility grids

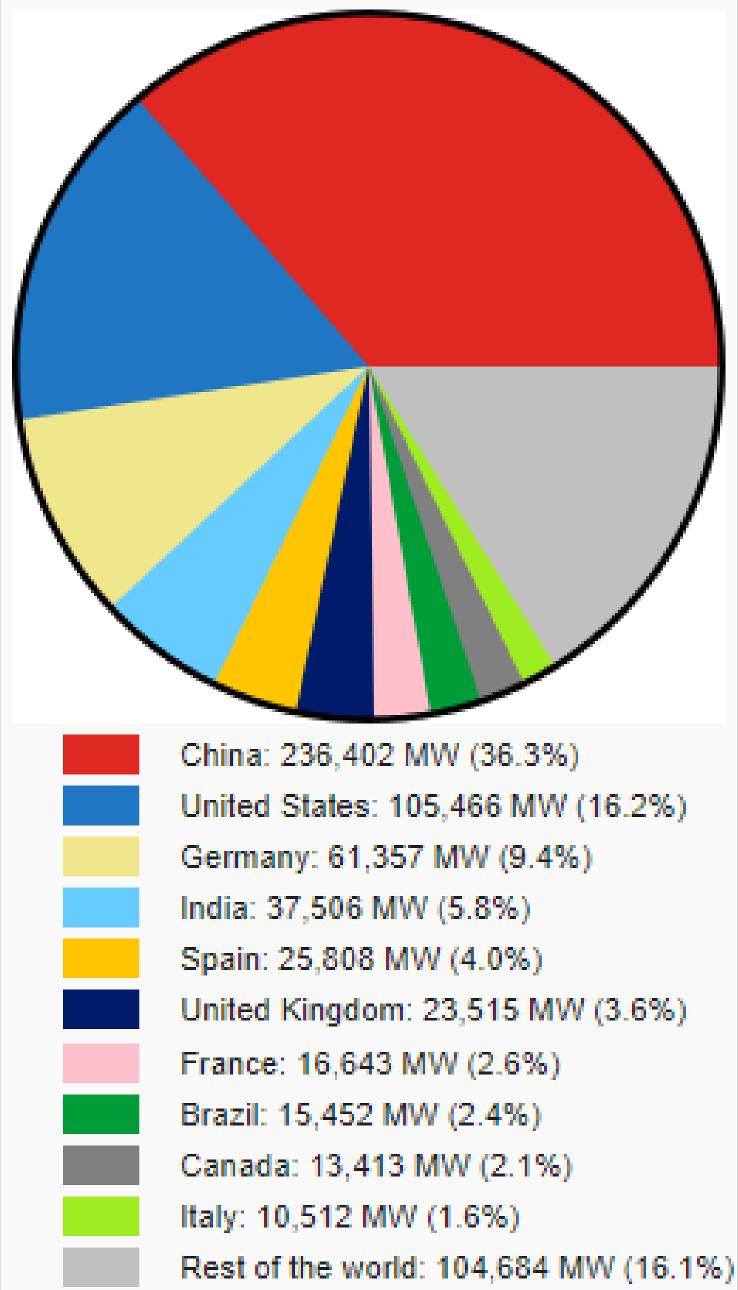
WIND ENERGY

➢ Introduction

- Wind is caused by the uneven heating of the atmosphere by the sun, variations in the earth's surface, and rotation of the earth. Mountains, bodies of water, and vegetation all influence wind flow patterns
- Wind energy is an indirect form of solar energy.
- Wind energy is the kinetic energy of air in motion, which can be used to run a wind mill which in turn drives a generator to produce electricity.
- A wind energy system transforms the kinetic energy of the wind into mechanical or electrical energy for practical use.
- Mechanical energy is most commonly used for pumping water in rural or remote locations.
- Wind electric turbines generate electricity for homes and businesses and for sale to utilities.

WIND ENERGY

- Top Ten Countries in Wind Energy production in the World
- Wind power has become an important source of energy generation around the world, with global capacity reaching over 651GW in end of 2019.
- The construction of new wind power varies year to year and by region



ORIGIN OF WINDS

- The origin of winds may be traced basically to uneven heating of earth surface due to sun.
- This may lead to circulation of widespread winds on global basis, producing planetary winds or may have a limited influence in a smaller area to cause local winds.

Global (or Planetary) Winds:

Two major forces determine the speed and direction of wind on global basis.

(i) Primary force for global winds is developed due to differential heating of earth at equator and Polar Regions.

- In the tropical regions there is net gain of heat due to solar radiation, whereas in the Polar Regions there is net loss of heat.
- This means that the earth's atmosphere has to circulate to transport heat from tropics towards the poles. On a global scale, these atmospheric currents work as an immense energy transfer medium.
- Ocean currents act similarly, and are responsible for about 30 per cent of this global heat transfer.

(ii) Spinning of earth about its axis produces Coriolis force, which is responsible for deviation of air currents towards west.

ORIGIN OF WINDS

Global (or Planetary) Winds

- Spinning of earth about its axis produces Coriolis force, which is responsible for deviation of air currents towards west.
- Between 30°N and 30°S heated air at the equator rises and is replaced by cooler air coming from north and south. This is known as Hadley circulation.

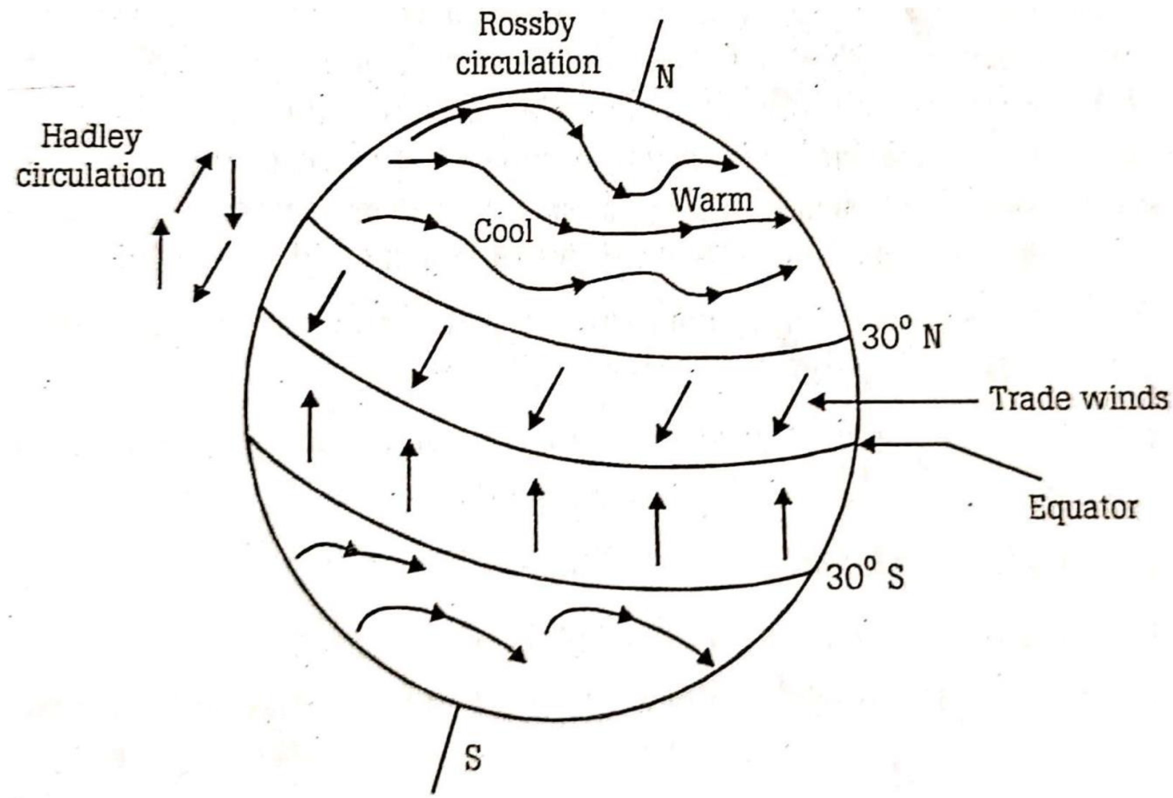


Fig.Global circulation of wind

- Due to Coriolis force,
  these winds deviate towards west. These air currents are also known as trade winds because of their use by sailing ships for trading in the past

Wind Data

➢ Wind speed in India

- The seasonal as well as instantaneous changes in winds both with regard to magnitude and direction need to be well understood to make the best use of them in windmill designs.
- Winds are known to fluctuate by a factor of 2 or more within seconds (and thus causing the power to fluctuate by a factor of 8 or more).
- This calls for a proper recording and analysis of the wind characteristics.
- The hourly mean wind velocity as collected by the meteorological observations is the basic data used in a windmill designs.
- The hourly mean is the one averaged over a particular hour of the day, over the day, month, year and years.
- For Electrical power generation wind speed required is 5m/s

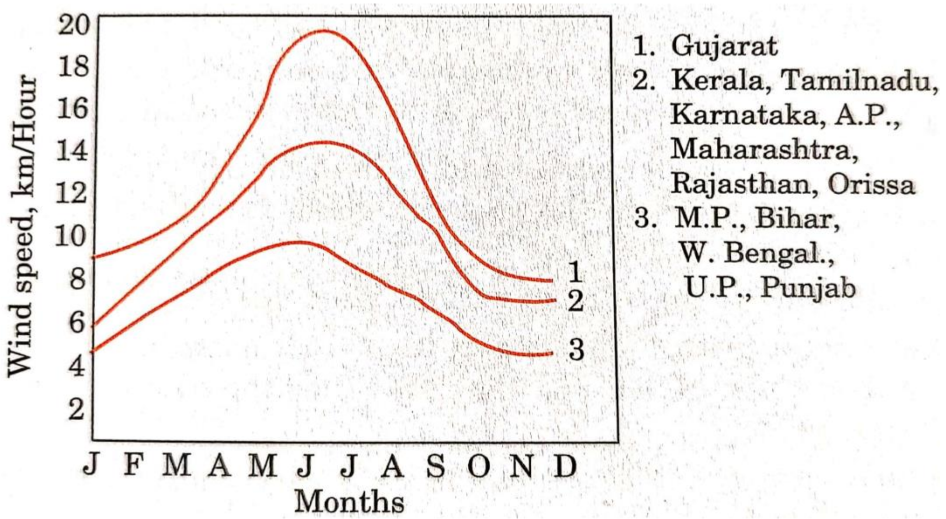


Fig.Wind speeds in India (average over 30 years)

Selection of site for WECS

- Availability of anemometry data.
- High annual average wind speed.
- Availability of wind curve at the proposed site.
- Wind structure at the proposed site.
- Altitude of the proposed site.
- Terrain and its aerodynamics.
- Local ecology.
- Distance to roads or railways.
- Nearness of site to local Centre/users.
- Favorable land cost.
- Nature of ground.

Classification of WEC Systems(Wind Mills)

1.First there are two broad classifications:

(i).Horizontal axis machines-The axis of rotation is horizontal.

(ii).Vertical axis machines-The axis of rotation is vertical

➢ Main Classification of WEC Systems(wind mill)

There are two broad classifications :

Depending on their axis of rotation, relative to the wind stream

I. When the axis of rotation is parallel to the air stream (i.e., horizontal) the turbine is said to be a **Horizontal Axis Wind Turbine (HAWT)**

II. When it is perpendicular to the air stream (i.e., vertical) it is said to be a **Vertical Axis Wind Turbine (VAWT).**

Horizontal Axis Wind Turbine(Mill)

- **Main Parts**

- Turbine Blades
- Hub
- Nacelle
- Yaw Control Mechanism
- Tower
- Generators

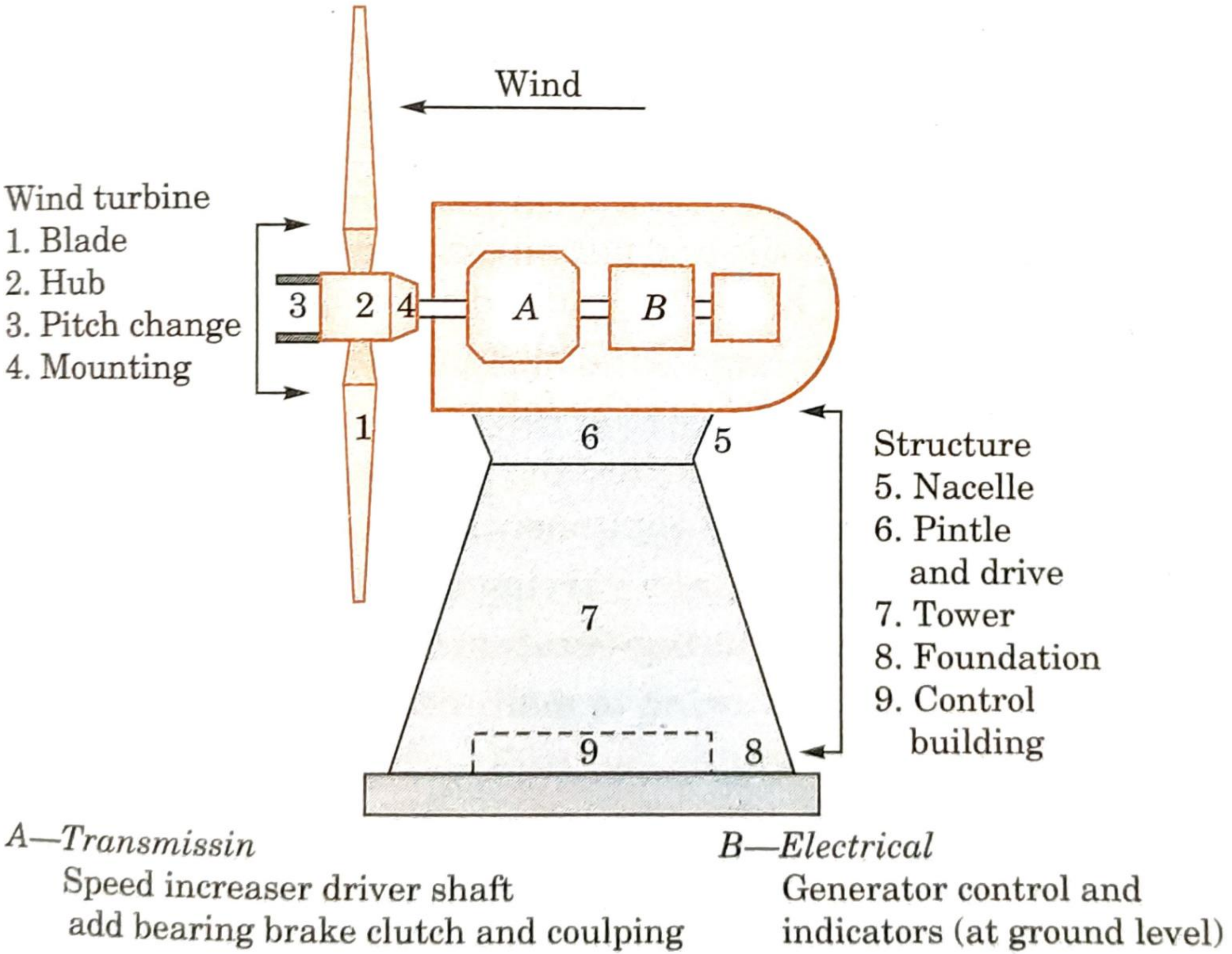
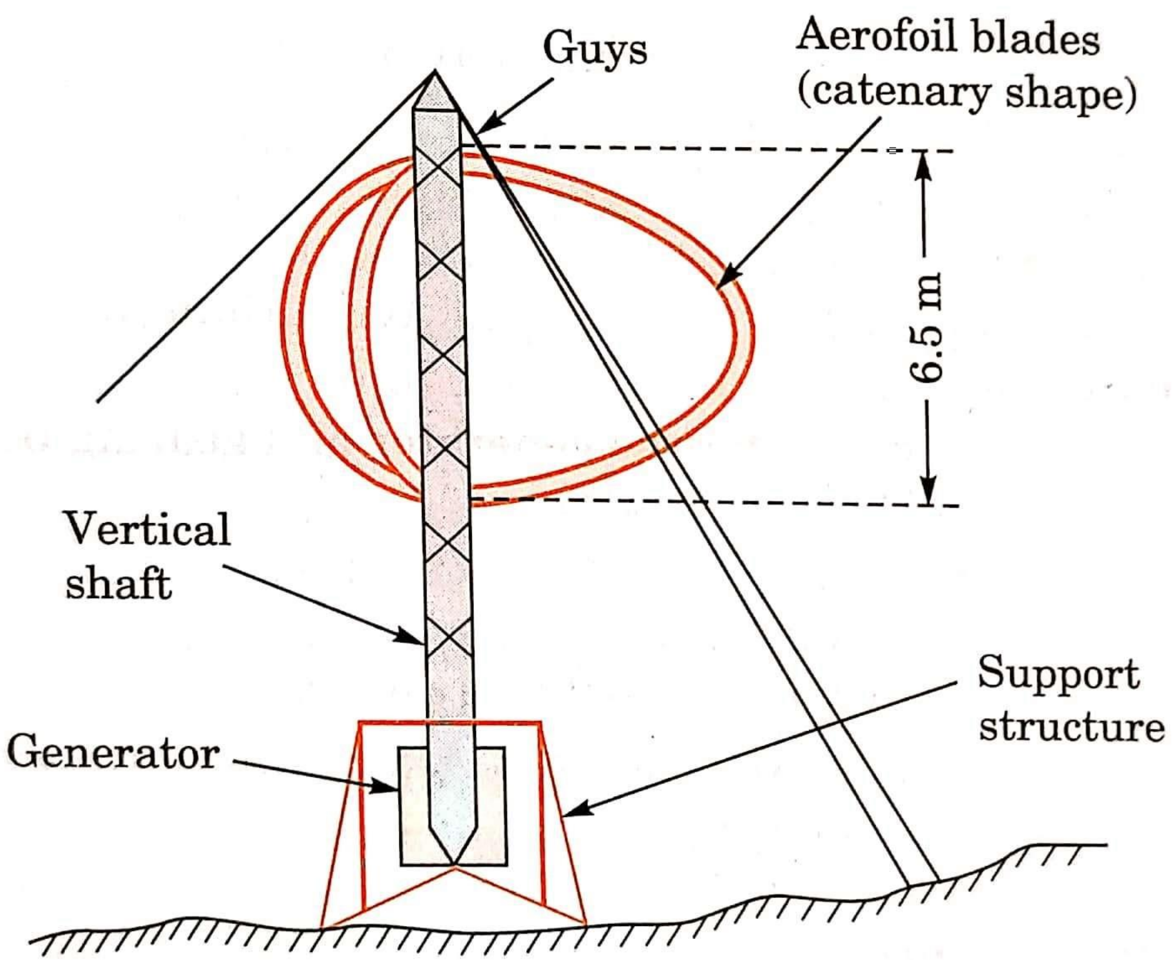


Fig:Physical embodiment of wind electric generating station

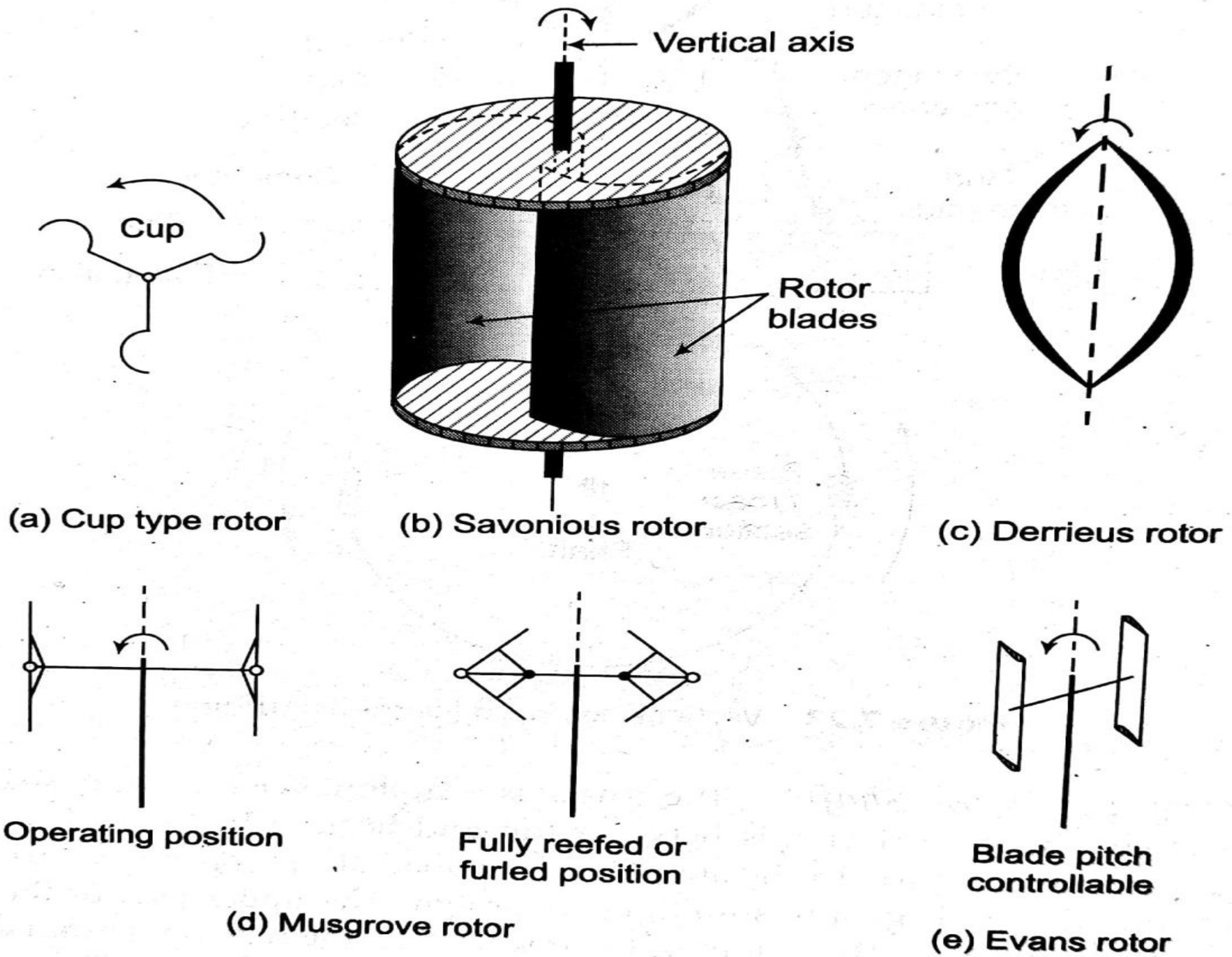
Horizontal Axis Wind Turbine(Mill) Major Parts

- Nacelle of Wind Turbine
- Rotor Blades of Wind Turbine
- Shaft of Wind Turbine
- Gearbox
- Generator
- Power Converter
- Turbine Controller
- Anemometer
- Tower of Wind Turbine

Vertical Axis Wind Turbine(Mill)



Various types of Rotors for VAWT



(a) Cup type rotor (b) Savonious rotor (c) Derrieus rotor

(d) Musgrove rotor (e) Evans rotor

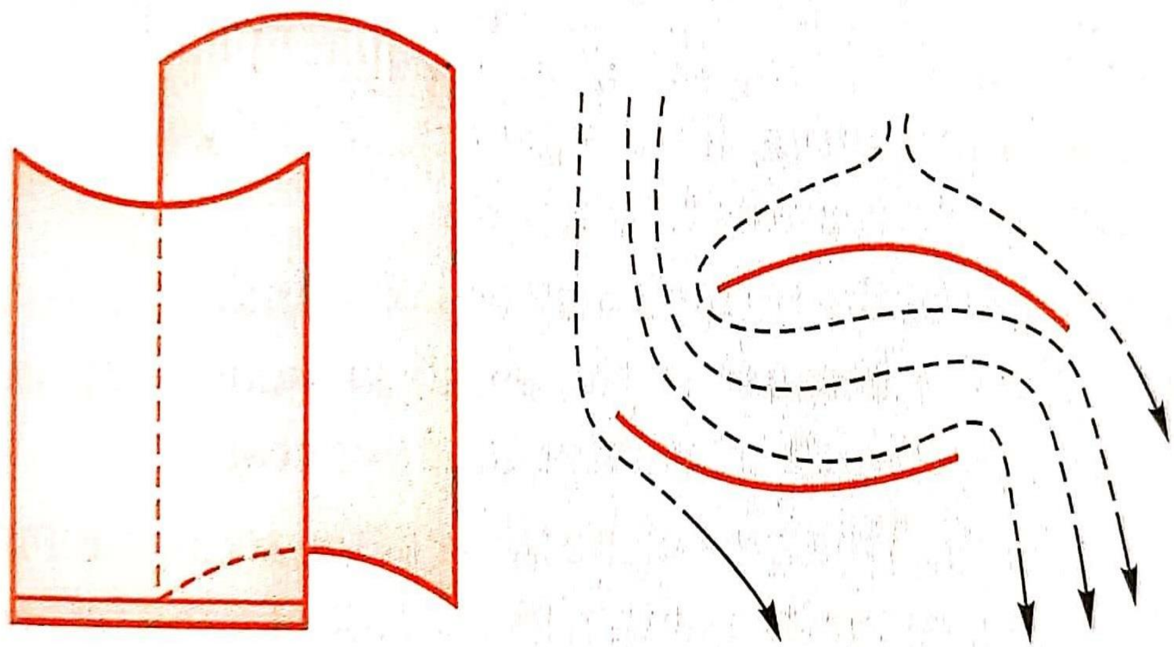
Main types of Rotors for VAWT

- The vertical axis windmill or machine is again subdivided into two major type, based on the working speed of the machine and the velocity ranges required by the machine for operation,

    (1).Savonius or 'S' type rotor wind mill (low velocity wind).
    (2).Darrieus type rotor wind mill (high velocity wind)

Savonius or S-rotor

- Irrespective of the wind direction the rotor rotates such as to make the convex sides of the buckets head into the wind.
- From the rotor shaft we can tape power for use like water-pumping, battery charging, grain winnowing etc.
- The wind curving around the back side of the cupped face exerts a reduced pressure much as the wind does over the top of an air-foil and this helps to drive the rotation.
- The wide slot between the two inner edges of the half cylinders, lets the air whip around inside the forward moving cupped face, thus pushing both in the direction of the rotation.



(a) (b)

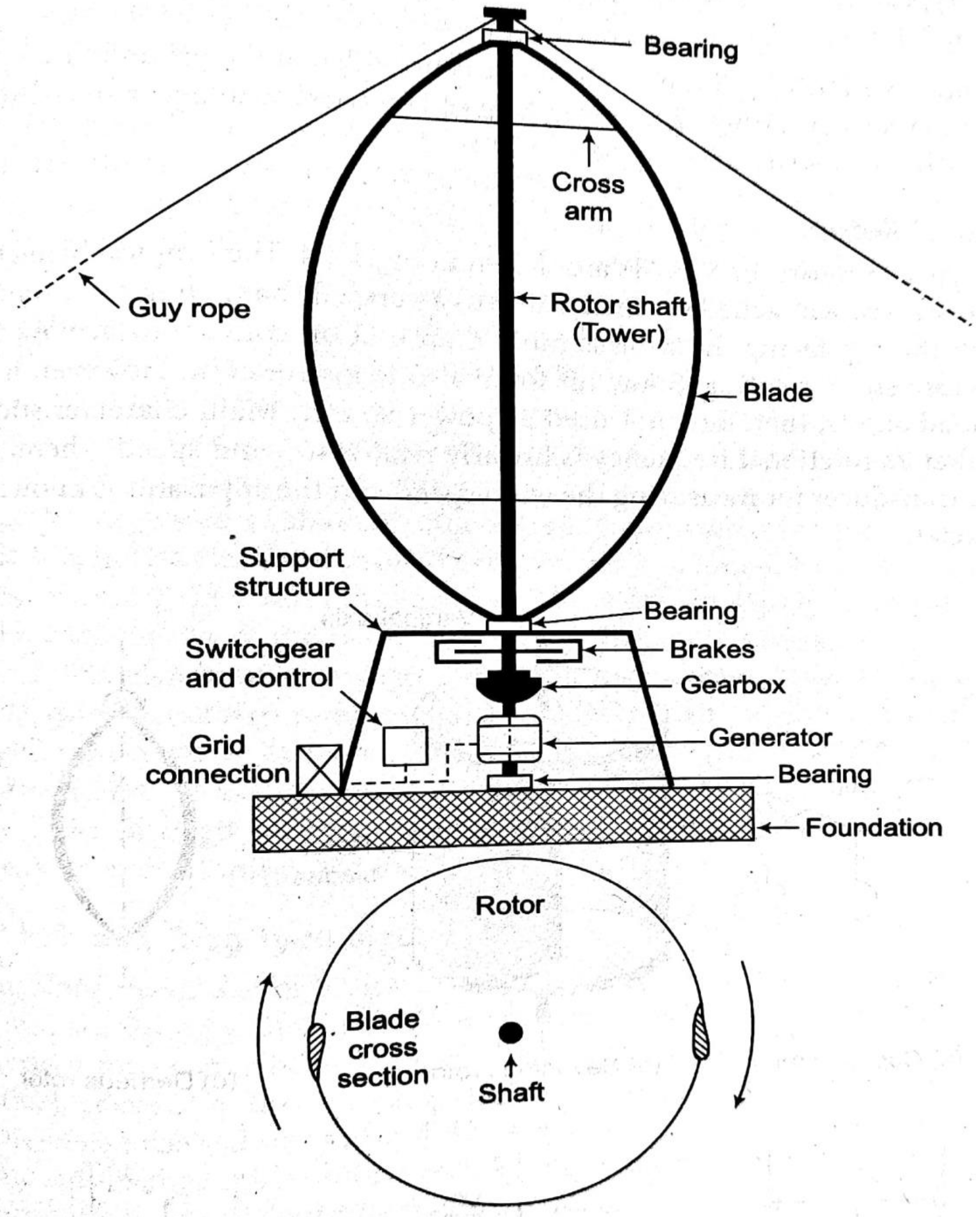
Fig.The Savonius rotor and its stream flow.

Vertical Axis Wind Turbine

Darrieus Rotor:

➢ Main Components:

1) Tower (Rotor Shaft)
2) Blades
3) Support Structure



Basic Components of a WECS (Wind Energy Conversion System)

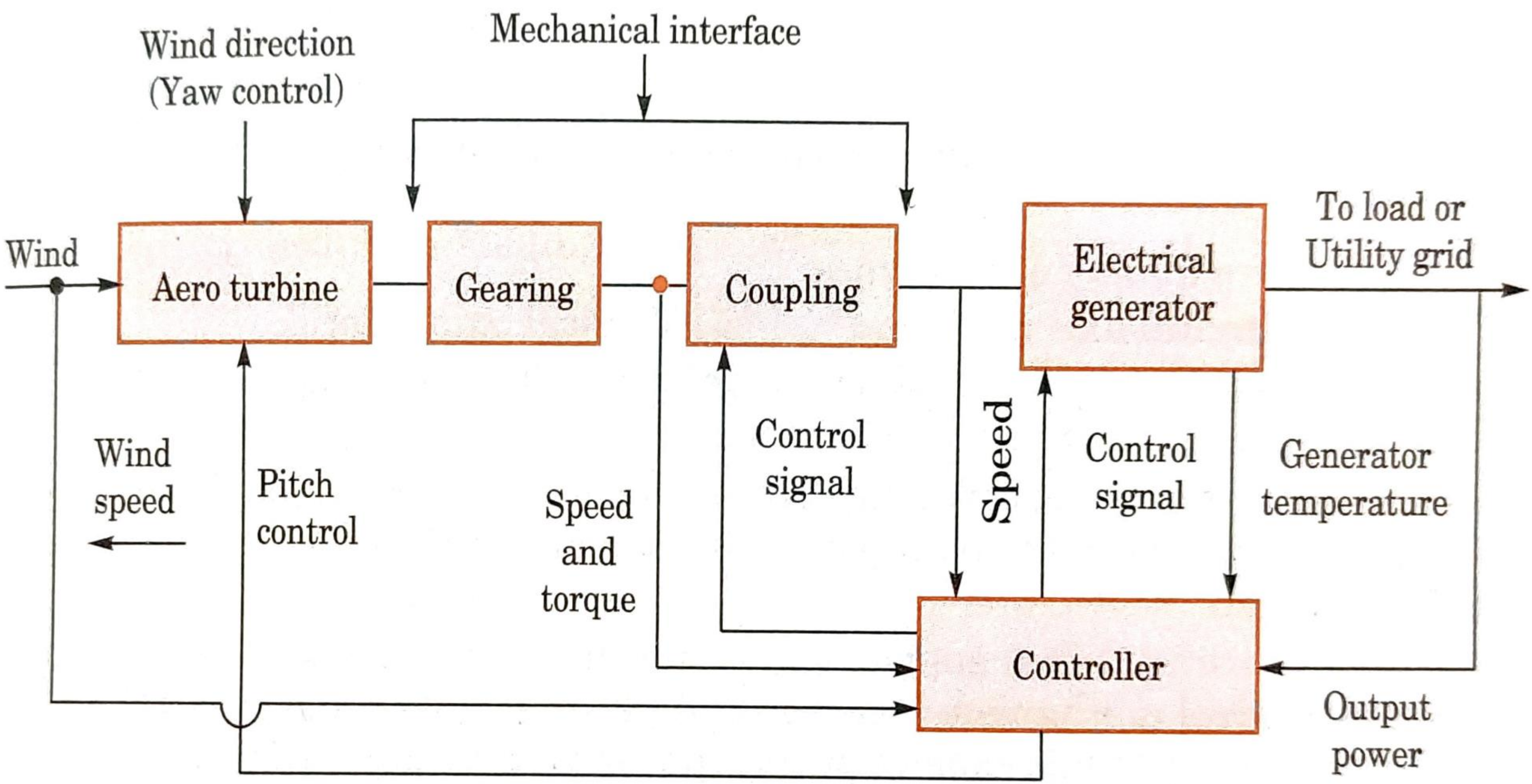


Fig:Basic components of a wind electric system

Operating characteristics of Wind mills

- Power versus Wind speed characteristics of a wind turbine have four separate regions as shown in figure

i) **Low speed region (zero to cut-in speed) :**

- In this region, the turbine is kept in braked position till minimum wind speed (about 5 m/s.), known as cut-in speed becomes available.
- Below this speed the operation of the turbine is not efficient.

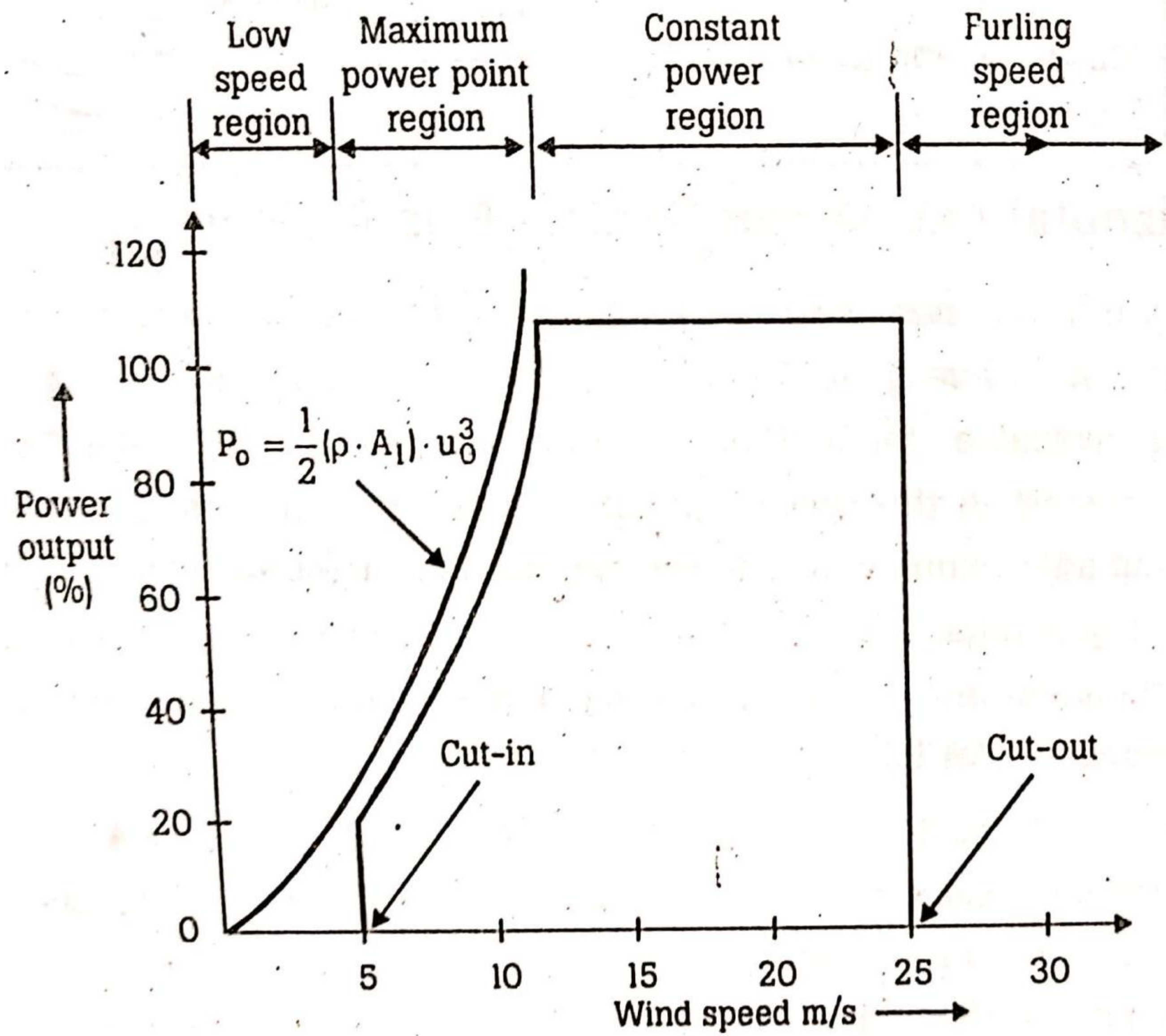


Fig.Power versus Wind speed characteristics

➢ Betz coefficient (or) Betz limit:

- It is the flow of air over the blades and through the rotor area that makes a wind turbine function.
- The wind turbine extracts energy by slowing wind down .
- The theoretical maximum amount of energy in the wind that can be collected by a wind turbines rotor is approx.59.3%
- This factor 0.593 is known as the Betz coefficient (from the name of the man who first derived it). It is the maximum fraction of the power in a wind stream that can be extract.
- In practice a more typical efficiency is 35% to 45%
- The Betz critirian, derived using the principles of conservation of momentum and conservation of energy, suggests a maximum possible turbine efficiency (or power coefficient)of 59%

➢ Tip Speed ratio(TSR) ʎ :

- The ratio of the speed of the rotor blade tips to the speed of the wind is called the Tip-speed ratio.
- Every rotor has an optimum tip-speed ratio at which its maximum efficiency is achieved and which also characterizes the rotor.
- Tip-speed ratio roughly 6 to 10

$$\text{Tip-speed ratio} = \frac{V_{tip}}{V}$$

Where V_{tip} – speed of the rotor tip

V - free wind speed

- A rotor with a high TSR needs less material and can have relatively slender blades.
- As the TSR increases the number of blades decreases as shown in below table

Tip speed ratio (TSR)	Number of blades
1	6–20
2	4–12
3	3–8
4	3–5
5–8	2–4
8–15	1–2

Tip Speed ratio(TSR)

- It is used to characterize a windmill rotor by comparing its curve of efficiency with its TSR.
- The efficiency is usually expressed as the C_p (power coefficient or performance coefficients).
- This is the fraction of wind energy passing through the rotor disc that is converted into shaft power.

$$\text{Efficiency} = \eta_A = \frac{\text{Useful shaft power output}}{\text{wind power input}}$$

$$= C_p = \text{Coefficient of performance}$$

- Thus the coefficient of performance of an aero turbine is the fraction of power in the wind through the swept area which is converted into useful mechanical shaft power.
- The overall conversion efficiency (η_0) of an aerogenerator of the general type is

$$\eta_0 = \frac{Useful\ power\ output}{wind\ power\ input} = \eta_A \cdot \eta_G \cdot \eta_C \cdot \eta_{Gen}$$

Where η_A = Efficiency of the aeroturbine

η_G = Efficiency of the gearing

η_C = Efficiency of the mechanical coupling

η_{Gen} = Efficiency of the generator

- The relationship between C_p and Λ for various types of rotors is shown graphically in figure.
- Maximum practically obtainable value of power coefficient is approximately 0.5.
- A wind turbine, achieving a value of power coefficient as 0.4 or above is considered to have good performance.

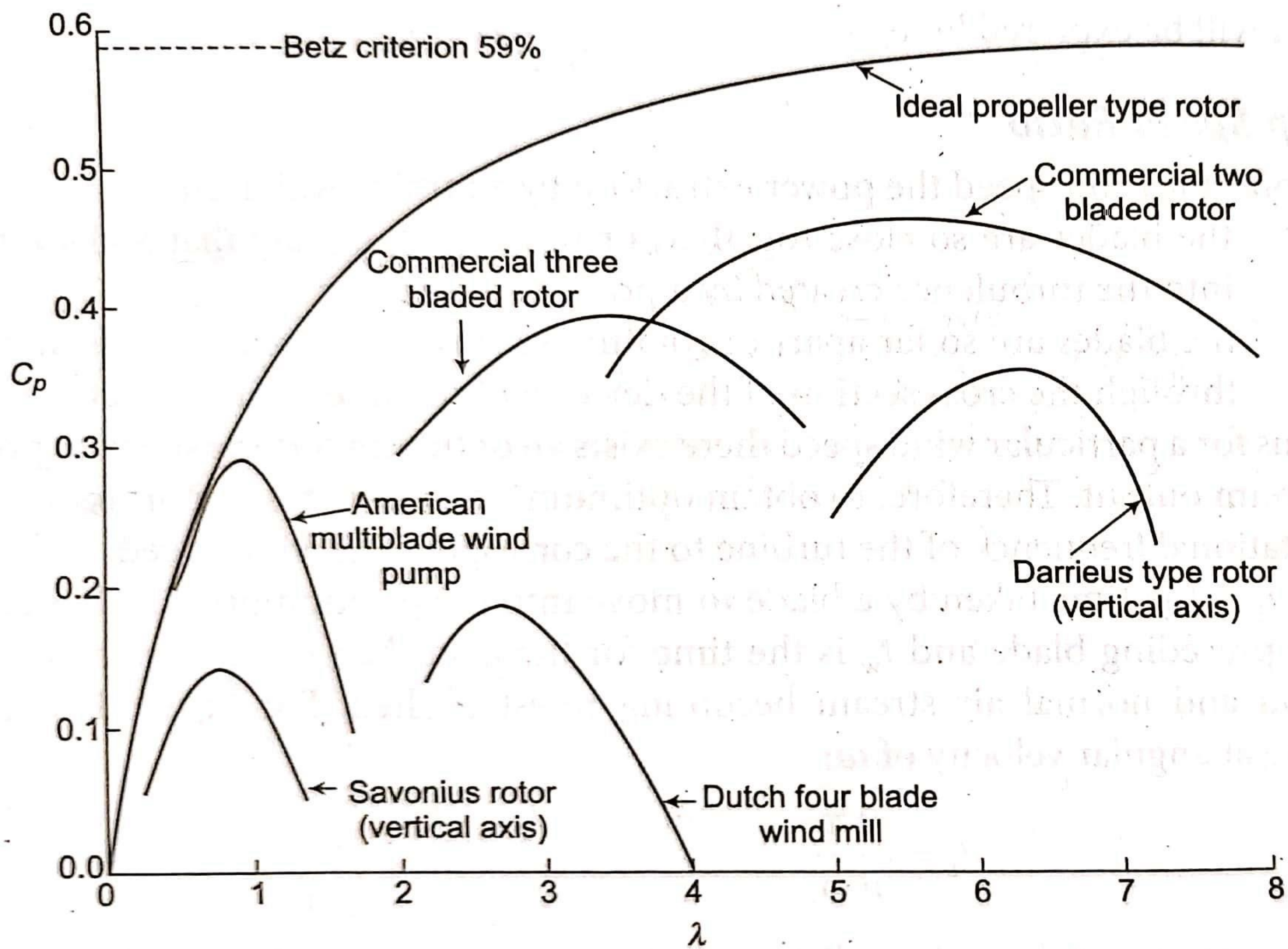
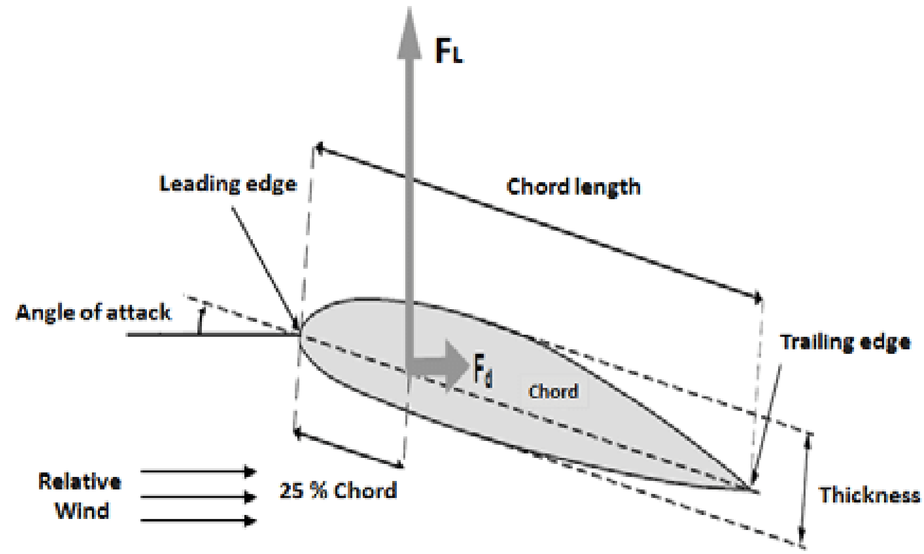
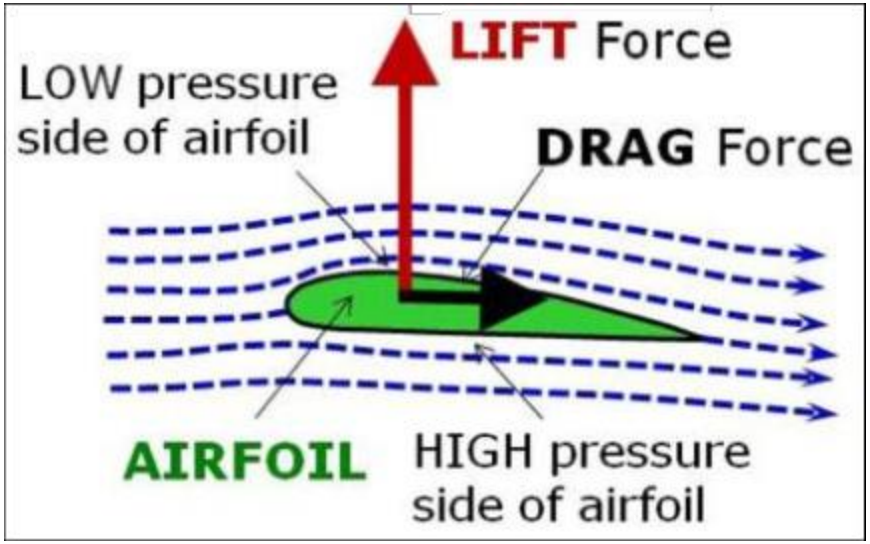


Fig. Power coefficient (C_p) versus Tip speed ratio(Λ)

Lift and Drag Forces

- Drag Force F_D :
  - Incremental force acting on the blade element in the direction of relative velocity of wind
- Lift Force F_L :
  - Incremental force acting on the blade element in a direction perpendicular to the relative velocity of wind





Techniques used in MPPT for wind power systems

MPPT has two techniques, they are

1.Base on relative comparison

2.Based on absolute values

1.Base on relative comparison:

- In this technique, the frequency of wind power is changed only in one direction to increase the power output.
- If the power output gradually increases, then the frequency direction will continues.
- In case the power output decreases, then the direction of frequency changed to other or positive.
- This technique is simple and easy to implement but it has difficulties in detecting a local maximum value.

2.Based on absolute values:

- In this technique, an absolute value is scanned through complete frequency spectrum band to obtain maximum power output.
- Thus a frequency of an optimum or scanned absolute value is so adjusted to maintain gradually
- Increased power output.
- This technique has many complications in practical use,so as to pass through all frequencies in wind power system at varying environmental conditions.

Selection of Generators for Wind Mill

- The choice of an electrical generator and control method to be employed if any) can be decided by consideration of the following three factors:
  - (i) the basis of operation i.e., either constant tip speed or constant tip speed ratio.
  - (ii) the wind power rating of the turbine and
  - (iii) the type of load demand e.g., battery connection.
- Wind power ratings can be divided into three convenient grouping,
  - For small scale-up to 1 kW -permanent magnet d.c. generators
  - For medium scale-up to 50 Kw-permanent magnet d.c. generators, induction generators, synchronous generators
  - For Large scale - induction generators, synchronous generators
- **Main features of various types of generators and their suitability in wind power generation:**

(i).DC generator :

- Conventional de generators are no more favored due to their high cost weight and maintenance problems due to commutator. However, permanent magnet brushless and commutator less de machines are considered in small rating (below hundred kW) isolated systems.

Selection of Generators for Wind Mill

(ii).Synchronous generator :

- Synchronous generators produce high quality output and are universally used for power generation in conventional plants.
- However, they have very rigid requirement of maintaining constant shaft speed and any deviation from synchronous value immediately reflects in the generated frequency.
- Also precise rotor speed control is required for synchronization. Due to this reason a synchronous machine is not well suited to wind power generation
- Requirement of dc current to excite rotor field, which needs sliding carbon brushes on the slip rings also poses limitations on its use.
- The need of dc field current and brushes can be eliminated by using reluctance rotor.
- The reliability greatly improved while reducing the cost
  The machine rating, however is limited to tens of kW. Synchronization of a wind driven generator with the power grid also poses problems especially during gusty winds
- Main advantage is that it generates both active as well as reactive powers.

Selection of Generators for Wind Mill

(iii) Induction generator :

- Primary advantages of induction machines are the rugged, brushless construction, no need of separate dc field power and tolerance of slight variation of shaft speed ($\pm$10 %) as these variations are absorbed in the slip.
- Compared to dc and synchronous machines they have low capital cost, low maintenance and better transient performance.
- For these reasons induction generators are extensively used in wind and micro hydroelectric plants.
- The machine is available from very low to several megawatt ratings

➢ Schemes for electric generation

Several schemes for electric generation have been developed. These schemes can be broadly classified under three categories:

(1) Constant speed constant frequency systems (CSCF)
(2) Variable speed constant frequency systems (VSCF)
(3) Variable speed variable frequency systems (VSVF)

➢ (3)Variable speed variable frequency systems (VSVF):

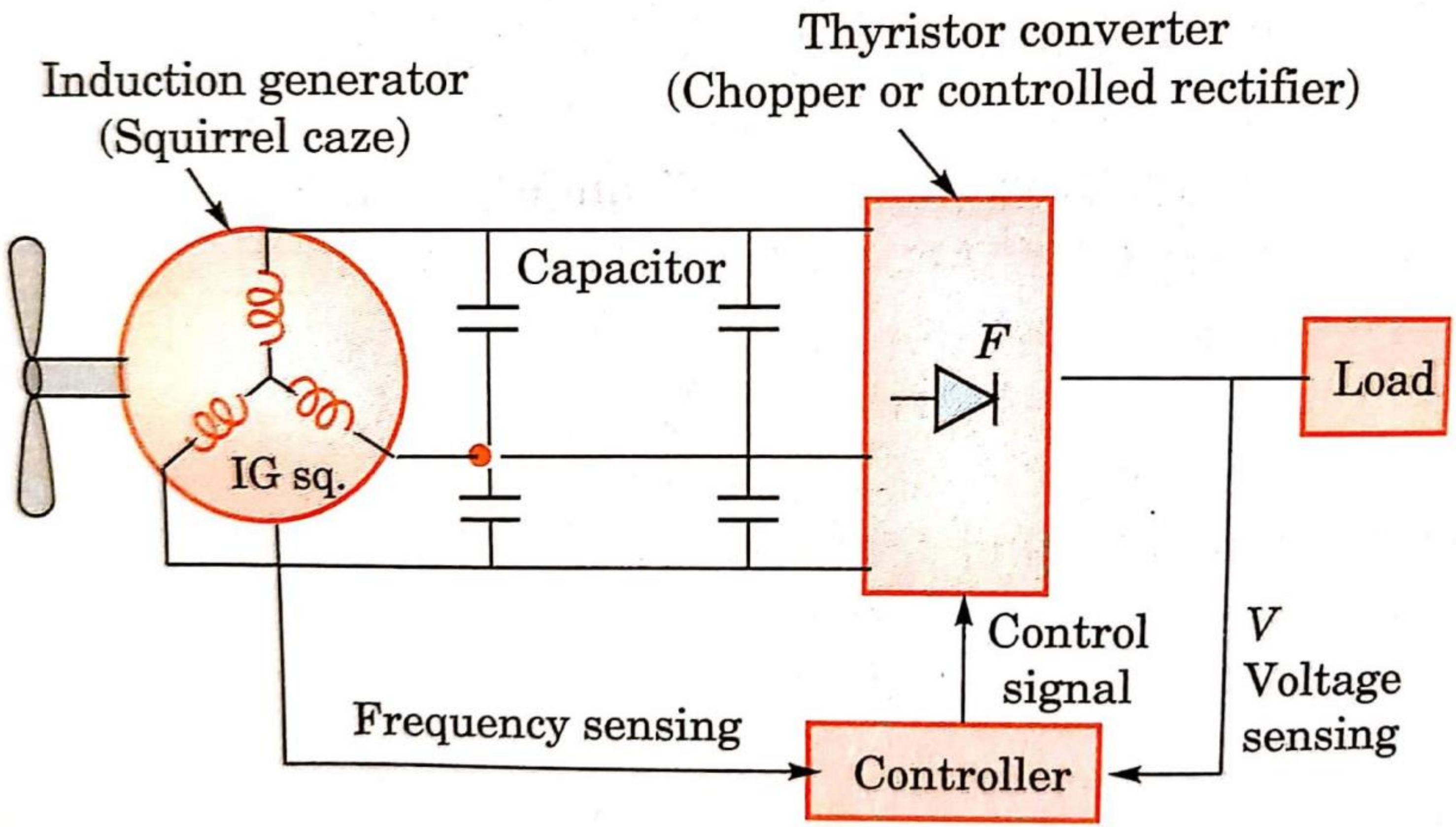


Fig.Schematic diagram of capacitor self excited (squirrel cage) induction generator

WIND ENERGY CONVERSION SYSTEMS (WECS)
Power generation for utility grids

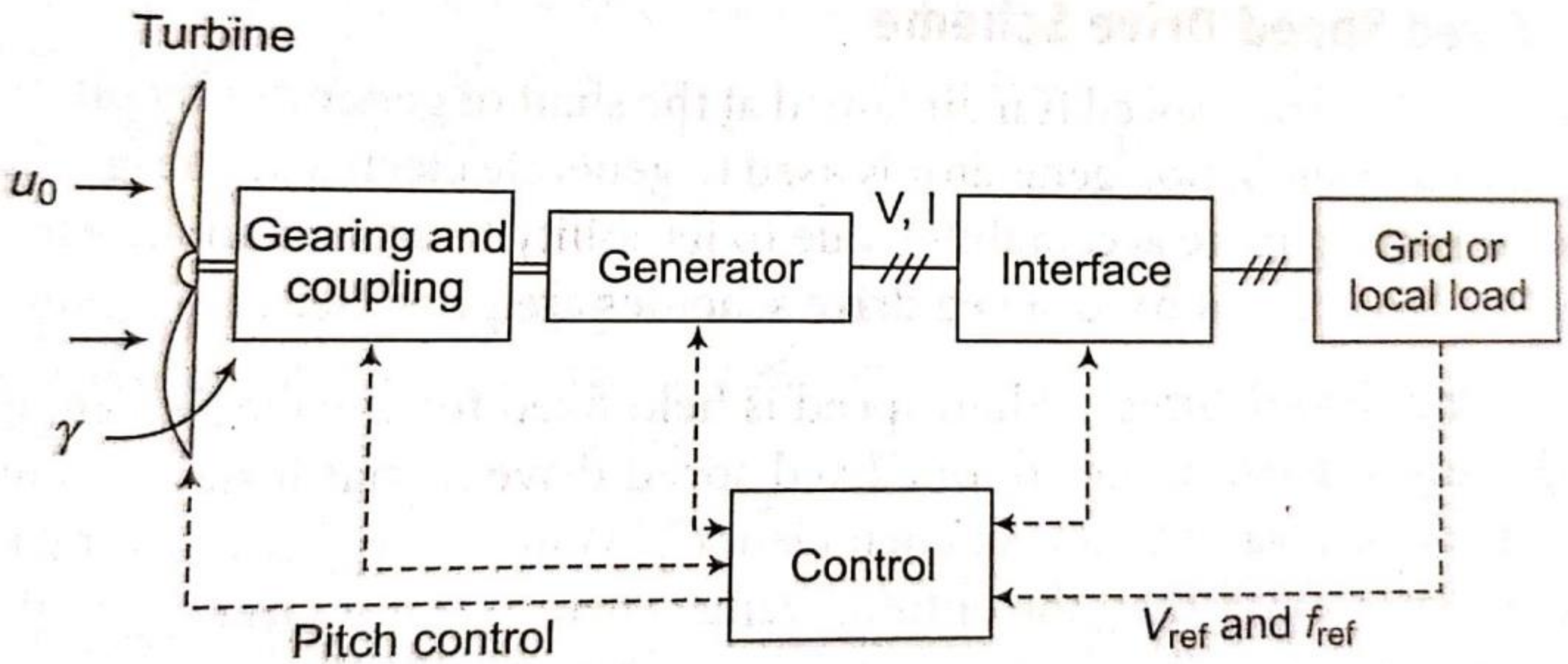


Fig.General block diagram of a WECS

Maximum wind power

The principle on which the wind mill works is the principle of momentum.
The work done by the turbine rotor is the difference between the kinetic energies of incoming and out going streams through the rotor.
As the kinetic energy is extracted by turbine the exit velocity V_e is less than V_i ;
The pressure at exit P_e is almost equal to pressure at the entrance P_i
Applying total energy equation and taking air density ρ= constant
$\rho E_1 = \rho E_2$

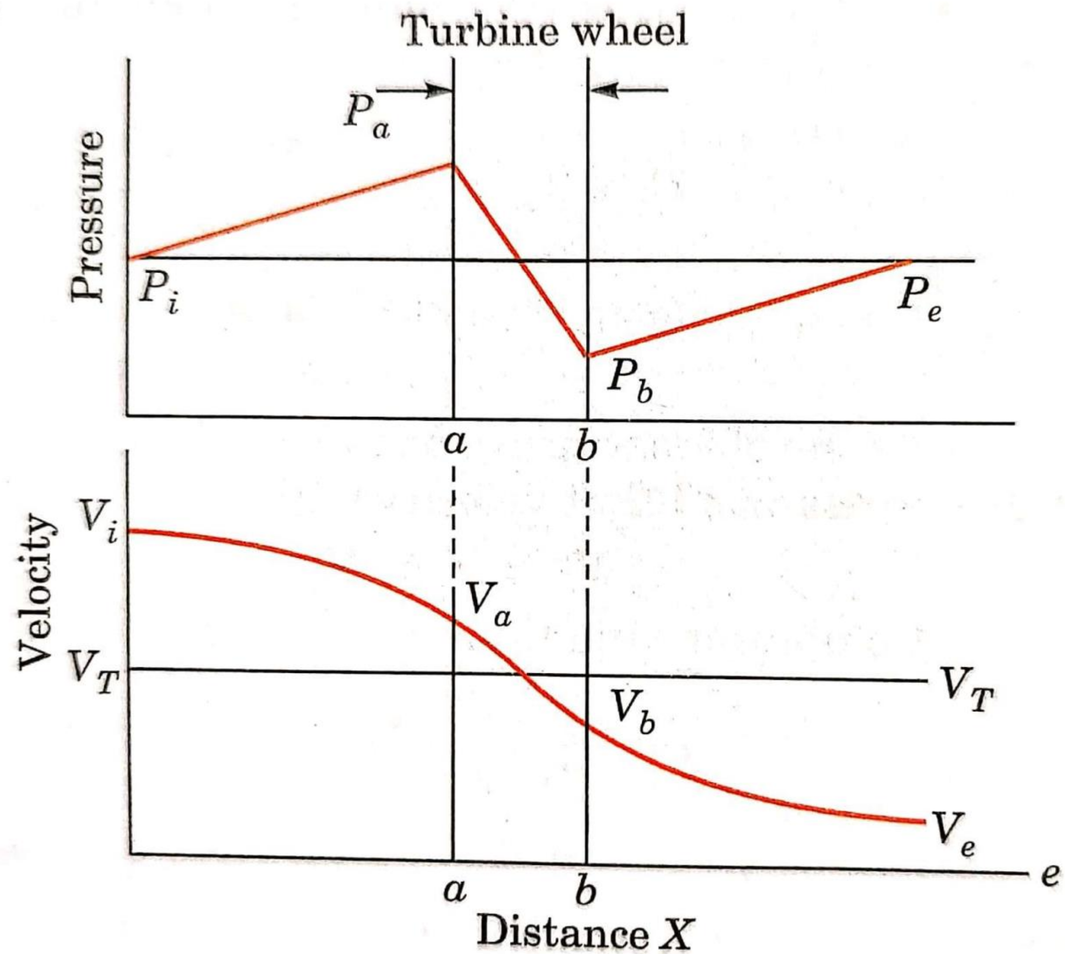


Fig.Pressure and velocity profiles of wind moving through a horizontal axis propeller type wind turbine

Maximum Power. As stated above, that the total power can not be converted to mechanical power. Consider a horizontal-axis, propeller-type windmill, henceforth to be called a wind turbine, which is the most common type used today. Assume that the wheel of such a turbine has thickness $a\,b$, as shown in Fig. 6.3. Let P_i and V_i are the wind pressure and velocity at the upstream of the turbine, and P_e and V_e are pressure and velocity at downstream of the turbine. V_e is less than V_i because kinetic energy is extracted by the turbine.

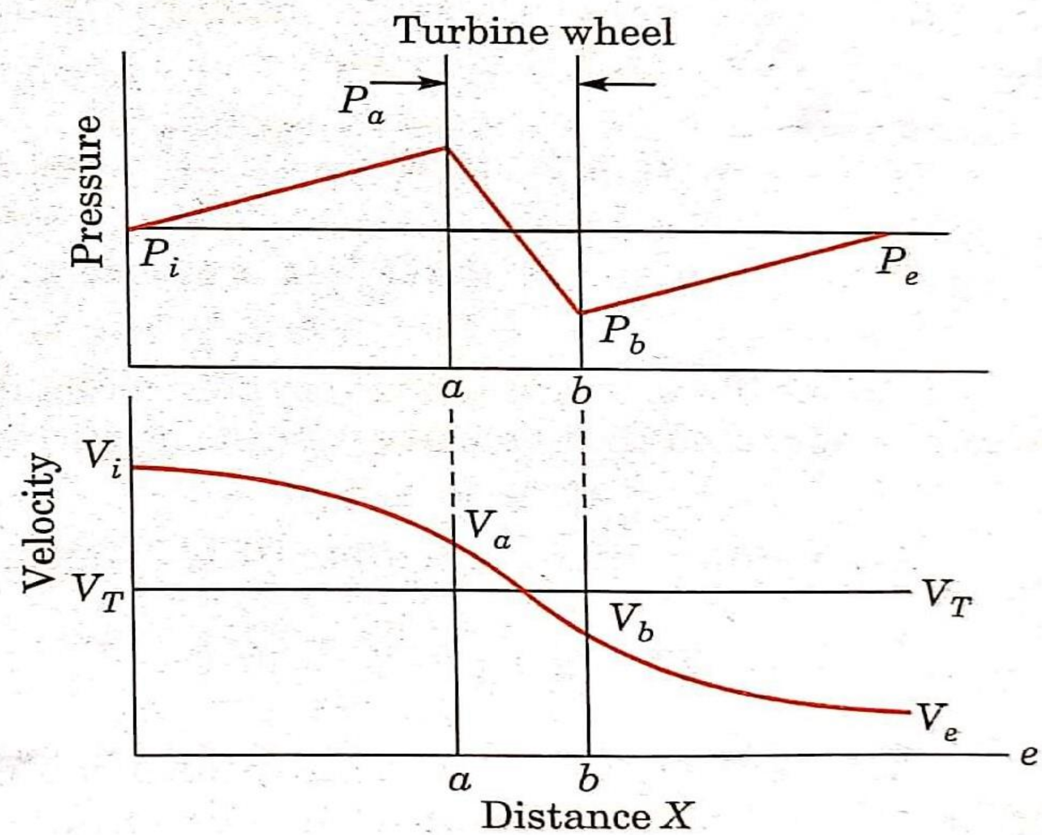


Fig. 6.3. Pressure and velocity profiles of wind moving through, a horizontal-axis propeller-type wind turbine.

Considering the incoming air between i and a as a thermodynamic system, and assuming that the air density remains constant (since changes in pressure and temperature are very small compared to ambient), that the potential energy

Thank you

RENEWABLE ENERGY SOURCES

UNIT-V

HYDRO,TIDAL ENERGY

Small Hydro Resources

- Large Hydropower Although definitions vary, DOE defines large hydropower as facilities that have a capacity of more than 30 megawatts (MW).
- Small Hydropower Although definitions vary, DOE defines small hydropower as projects that generate 10 MW or less of power. Micro Hydropower
- A micro hydropower plant has a capacity of up to 100 kilowatts. A small or micro-hydroelectric power system can produce enough electricity for a home, farm, ranch, or village

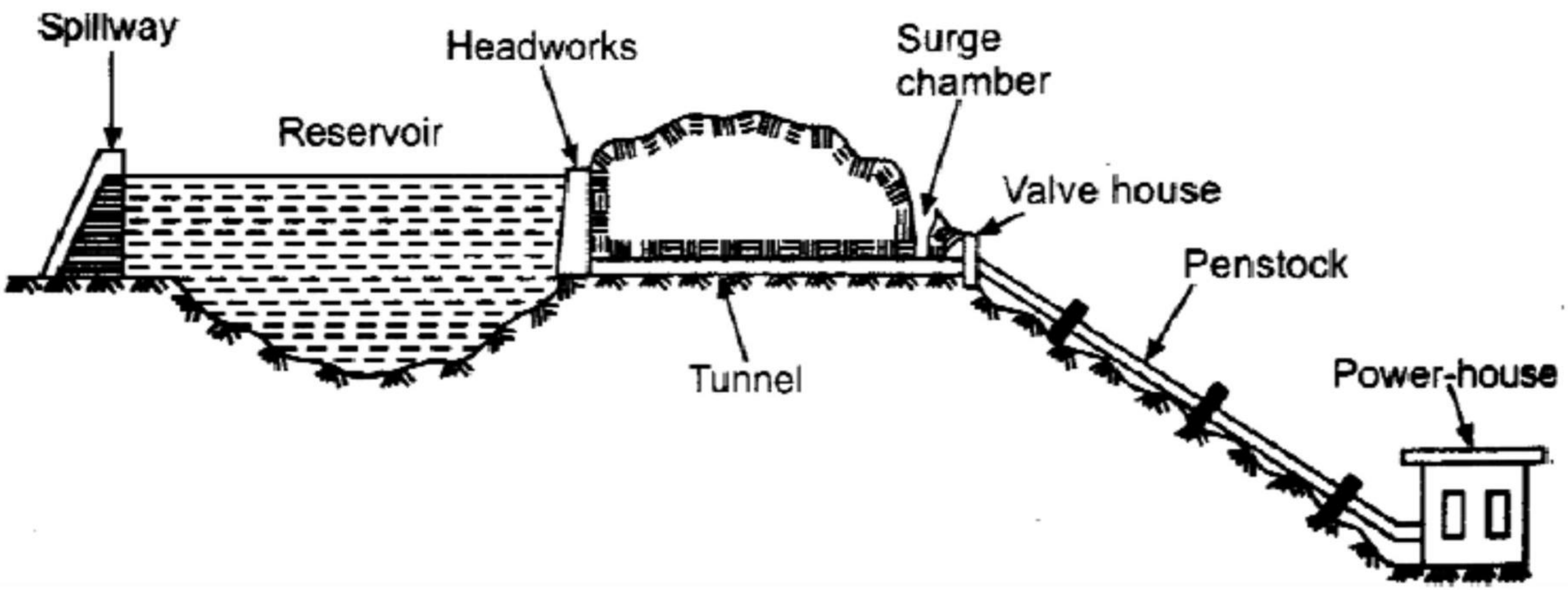
Classification of Hydro Electric Power Plants

A. According to Availability of Head	
1.	High Head Power Plants
2.	Medium Head Power Plants
3.	Low Head Power Plants

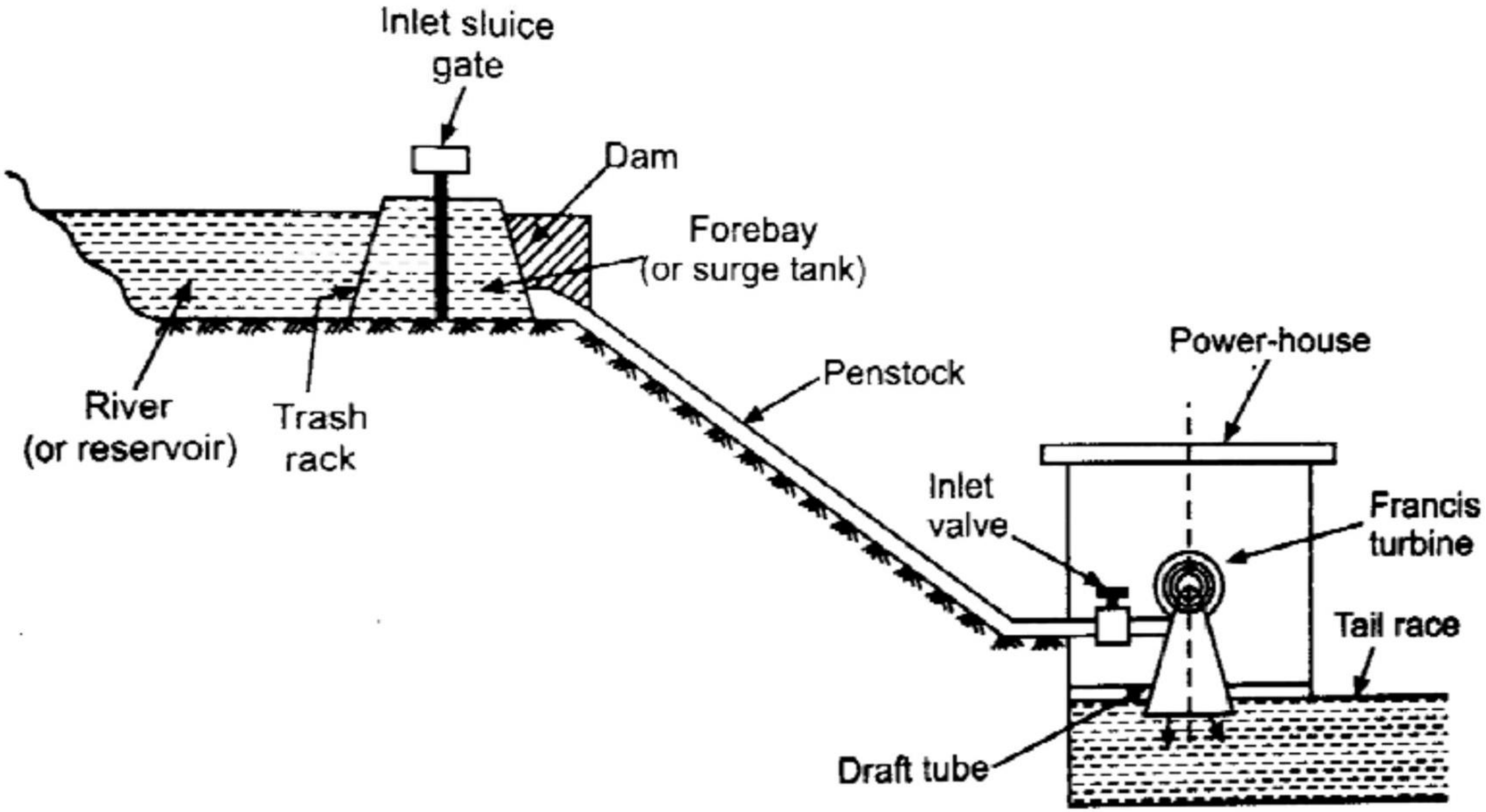
B. According to the Nature of the Load	
1.	Base Load plants
2.	Peak Load Plants

C. According to the Quantity of Water Availability	
1.	Run-Off River plant without pondage
2.	Run-Off River plant with pondage
3.	Storage type plants
4.	Pumped Storage Plants
5.	Mini and Micro Hydel Plants

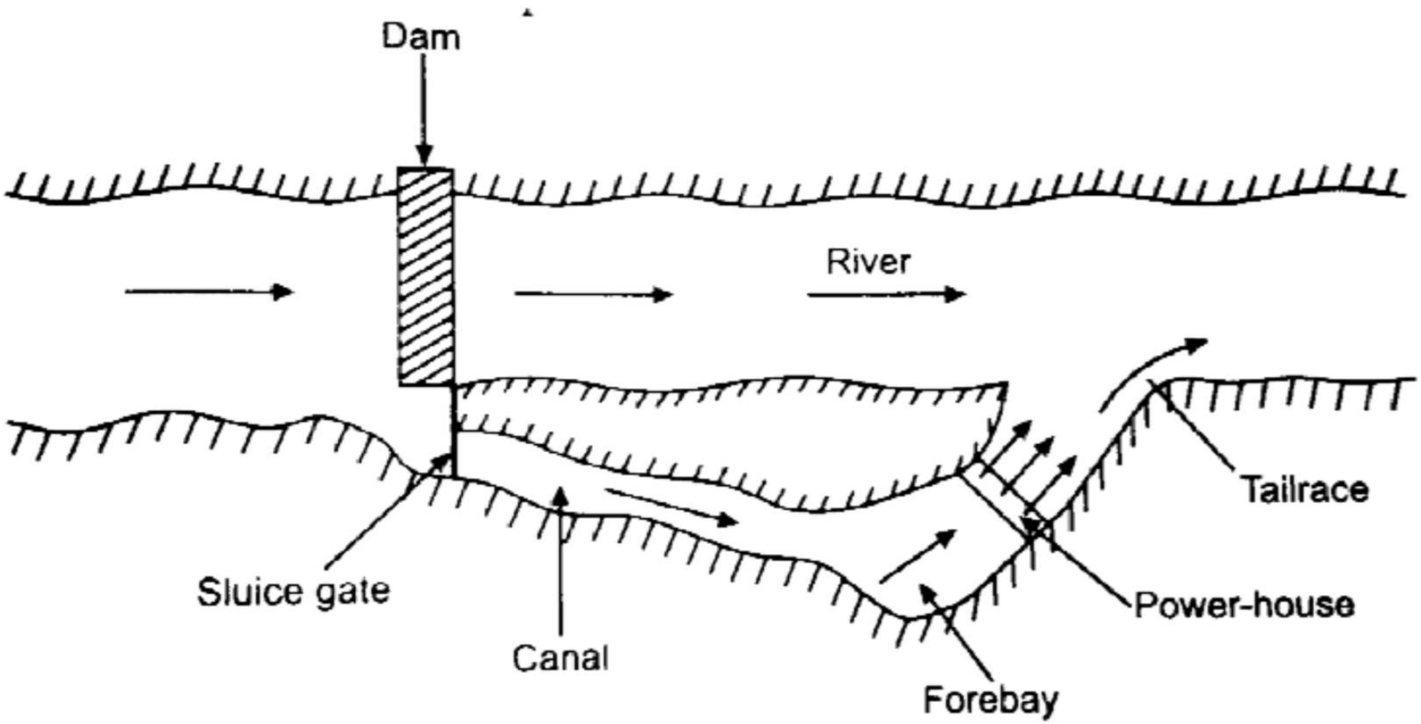
High Head Power Plants



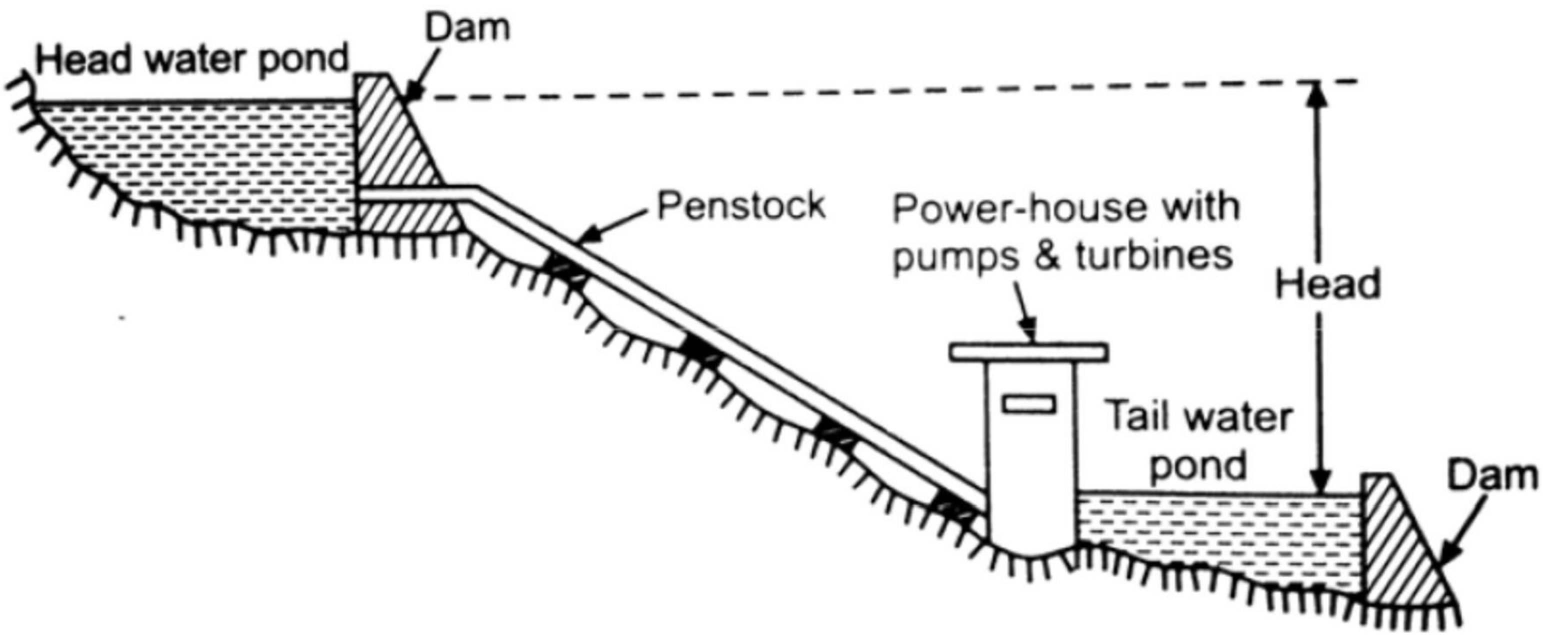
Medium Head Power Plants



Low Head Power Plants



Pumped Storage Power Plants



Base Load and Peak Load Plants

Base Load Plants: The plants cater to the base load of the system are called base load plants.

Peak Load Plants: The plants which can supply the power during peak loads are known as peak load plants.

HYDRO ENERGY

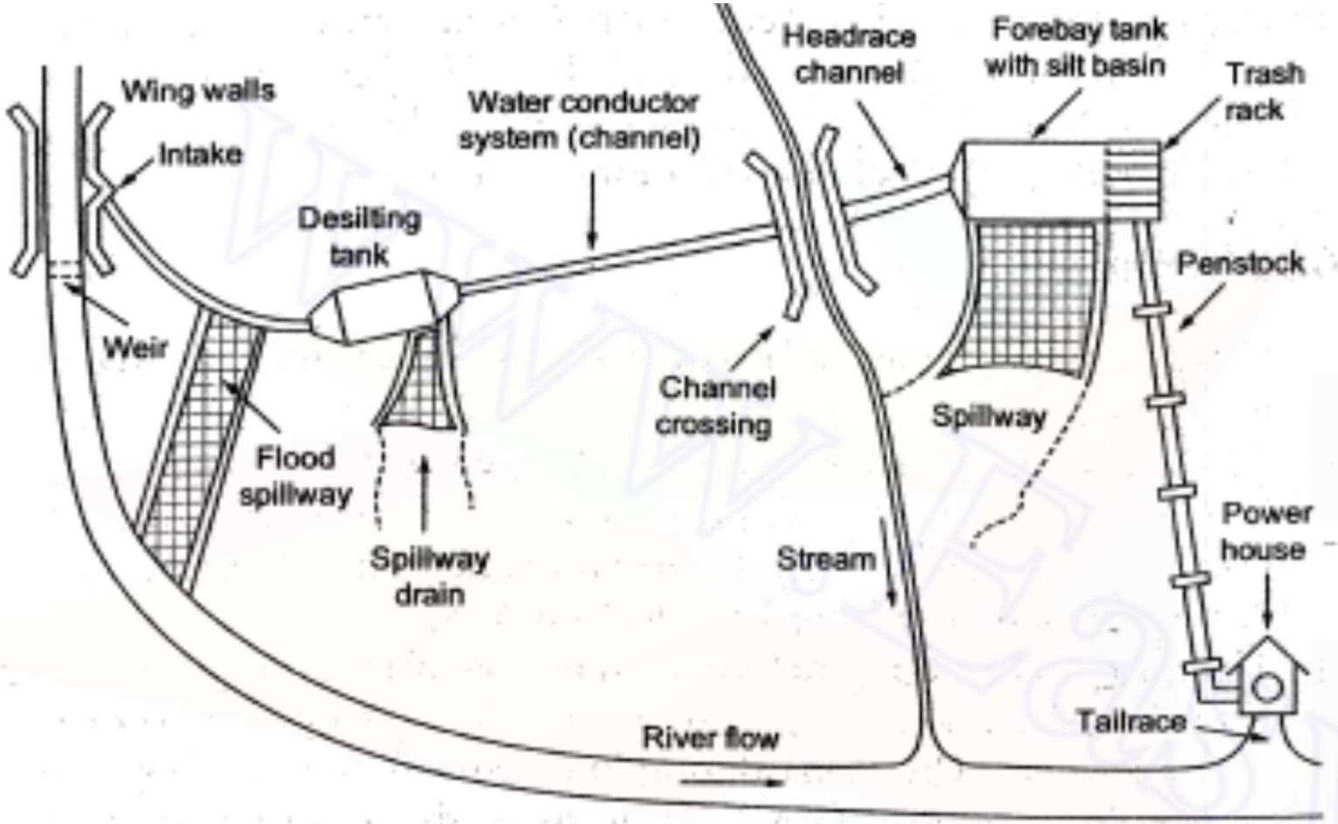


Fig. 11.1 *Typical layout of a microhydro power station*

Hydraulic Turbines for Hydro Electric Power Plants

According to the head & quantity of water available:

(i) Impulse Turbine: Requires high head and small quantity of flow.

(ii) Reaction Turbine: Requires low head and high quantity of flow.

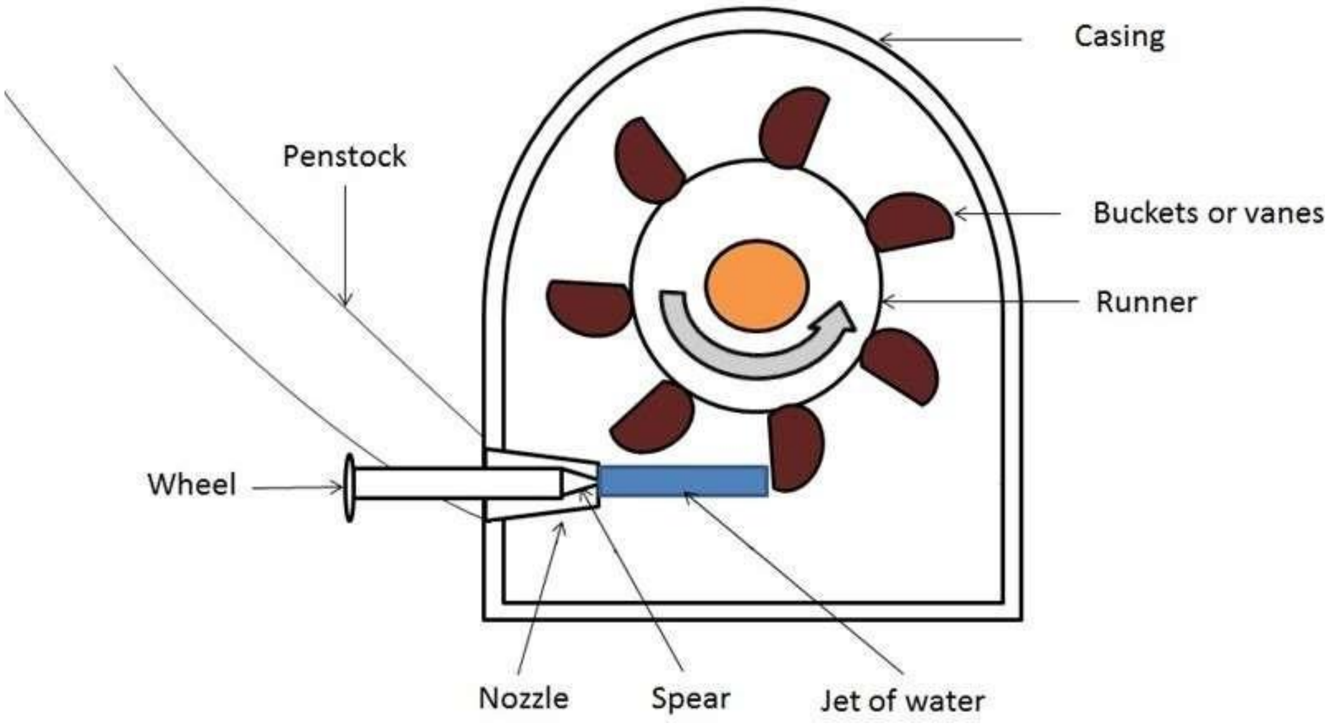
According to the name of the originator:

(i) Pelton wheel (for high head and low discharge)

(ii) Francis Turbine (for medium high to medium low head and medium small to medium large quantities of water flow).

(iii) Kaplan Turbine (for low heads and large quantities of water)

Pelton Turbine:



Pelton Turbine:

TIDAL ENERGY

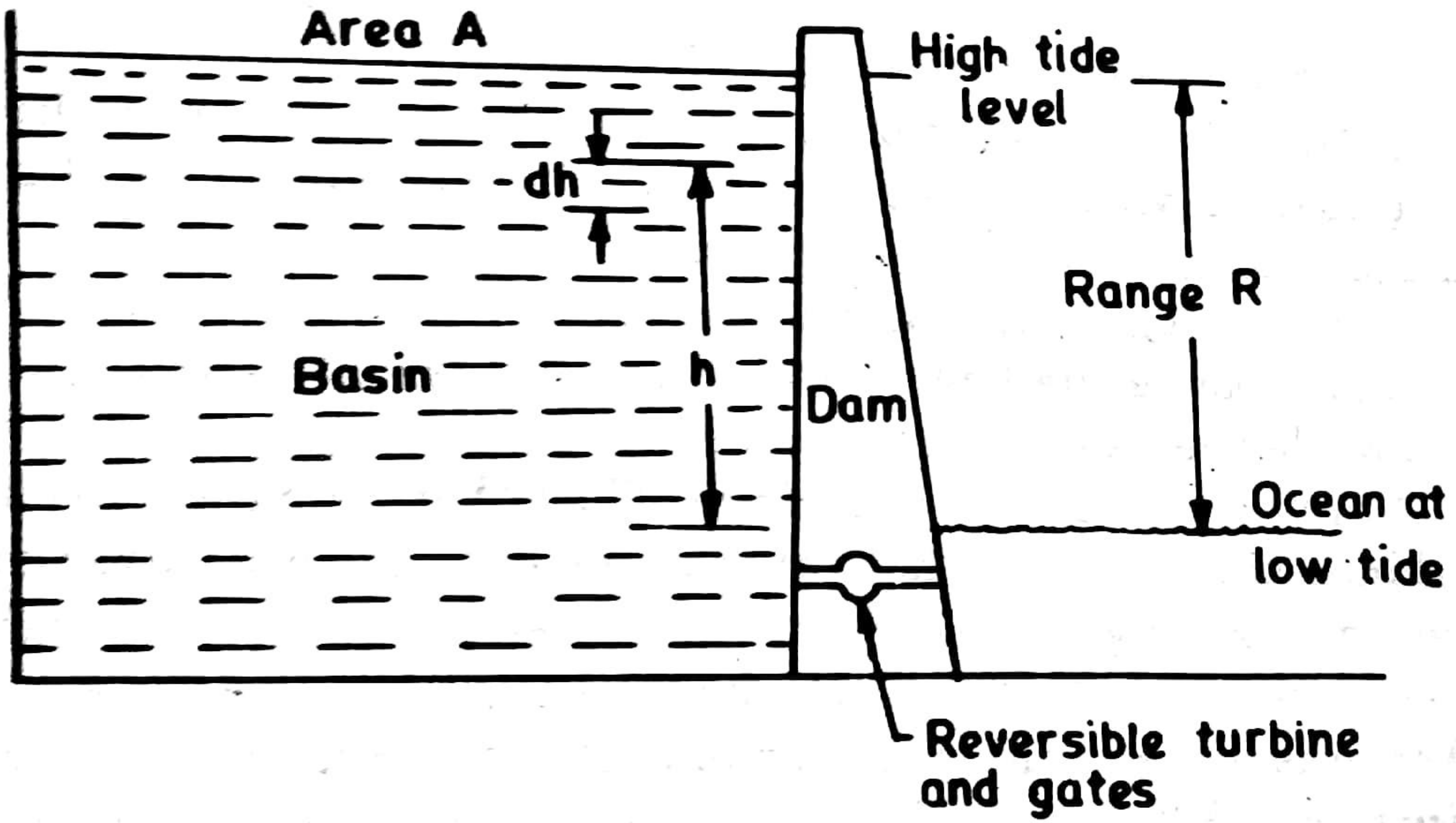
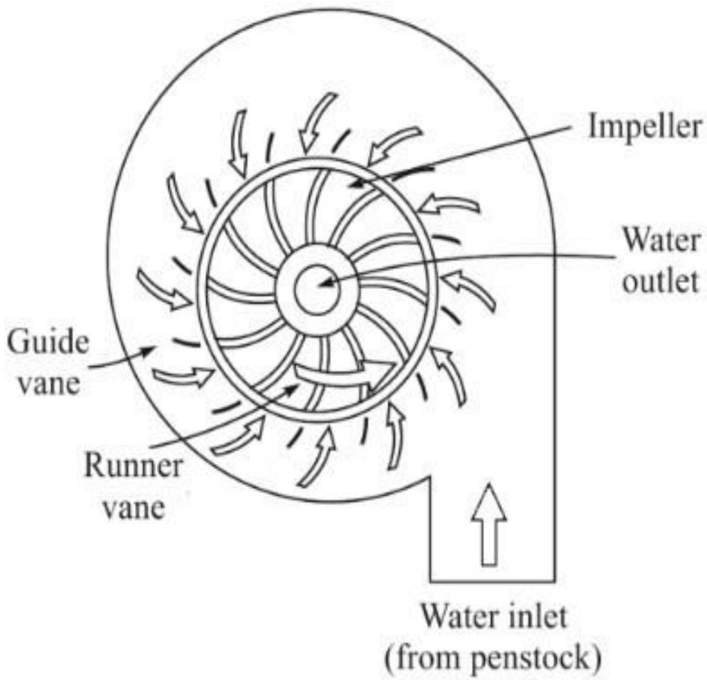
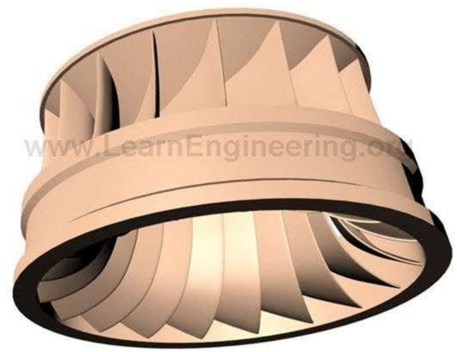


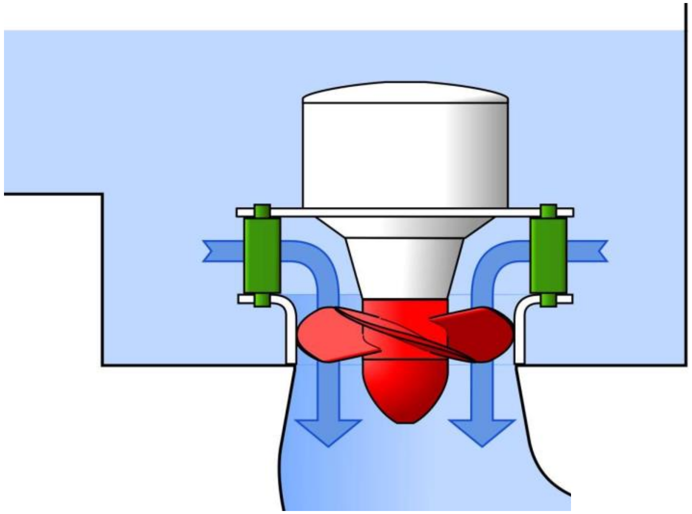
Fig. 9.3.5.1. Single Basin Tidal System.

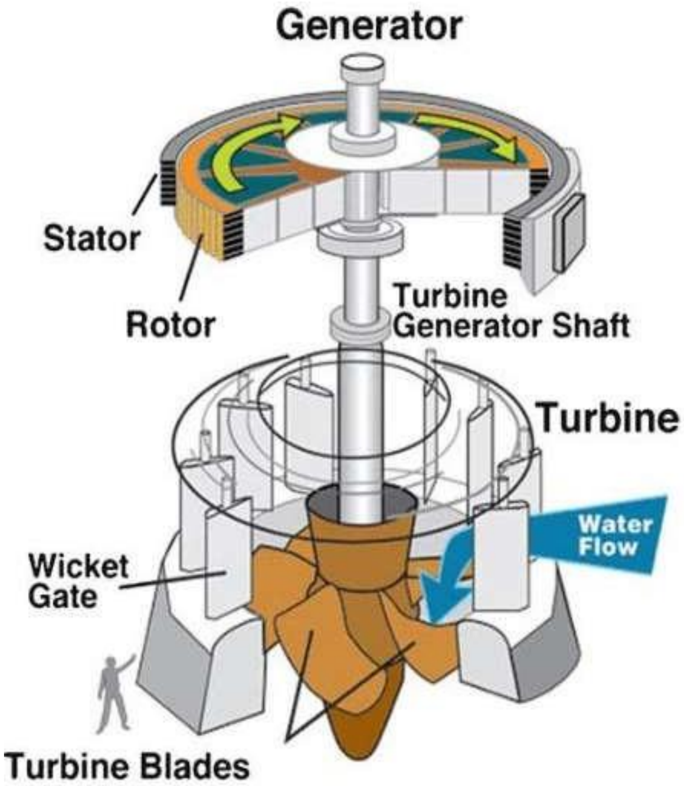
Francis Turbine





Kaplan Turbine





Small Hydro Power Programme in India

Ministry of New and Renewable Energy has been vested with the responsibility of developing Small Hydro Power (SHP) projects up to 25 MW station capacities.

The estimated potential for power generation in the country from such plants is about 20,000 MW. Most of the potential is in Himalayan States as river-based projects and in other States on irrigation canals.

The SHP programme is now essentially private investment driven. Projects are normally economically viable and private sector is showing lot of interest in investing in SHP projects.

The viability of these projects improves with increase in the project capacity. The Ministry's aim is that at least 50% of the potential in the country is harnessed in the next 10 years.

WAVE ENERGY

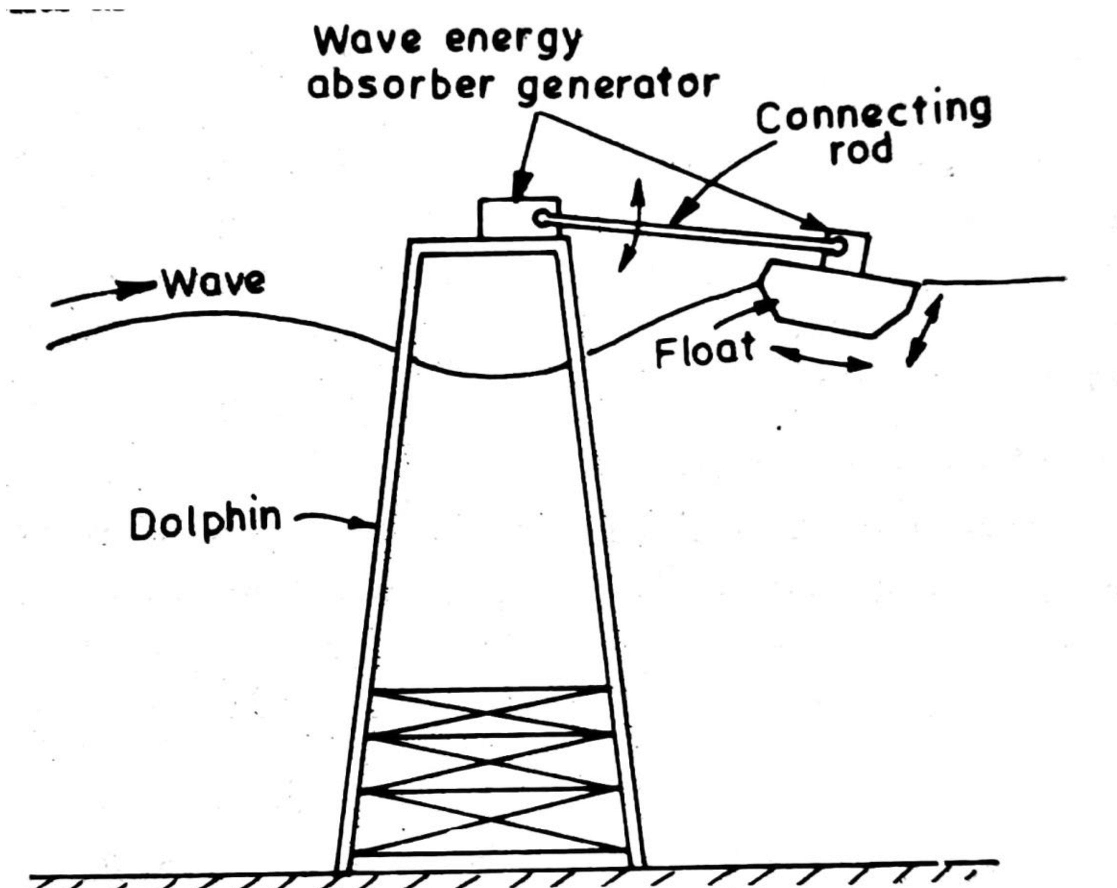


Fig. 9.4.4.3. Schematic of the Dolphin-type wave generator.

Tidal power or **Tidal energy**

Tidal power or **tidal energy** is the form of hydropower that converts the energy obtained from tides into useful forms of power, mainly electricity.

Although not yet widely used, tidal energy has potential for future electricity generation. Tides are more predictable than the wind and the sun. Among sources of renewable energy, tidal energy has traditionally suffered from relatively high cost and limited availability of sites with sufficiently high tidal ranges or flow velocities, thus constricting its total availability.

However, many recent technological developments and improvements, both in design (e.g. dynamic tidal power, tidal lagoons) and turbine technology (e.g. new axial turbines, cross flow turbines), indicate that the total availability of tidal power may be much higher than previously assumed, and that economic and environmental costs may be brought down to competitive levels.

Historically, tide mills have been used both in Europe and on the Atlantic coast of North America. The incoming water was contained in large storage ponds, and as the tide went out, it turned waterwheels that used the mechanical power it produced to mill grain.

The earliest occurrences date from the Middle Ages, or even from Roman times. The process of using falling water and spinning turbines to create electricity was introduced in the U.S. and Europe in the 19th century.

The world's first large-scale tidal power plant was the Rance Tidal Power Station in France, which became operational in 1966. It was the largest tidal power station in terms of output until Sihwa Lake Tidal Power Station opened in South Korea in August 2011. The Sihwa station uses sea wall defense barriers complete with 10 turbines generating 254 MW.

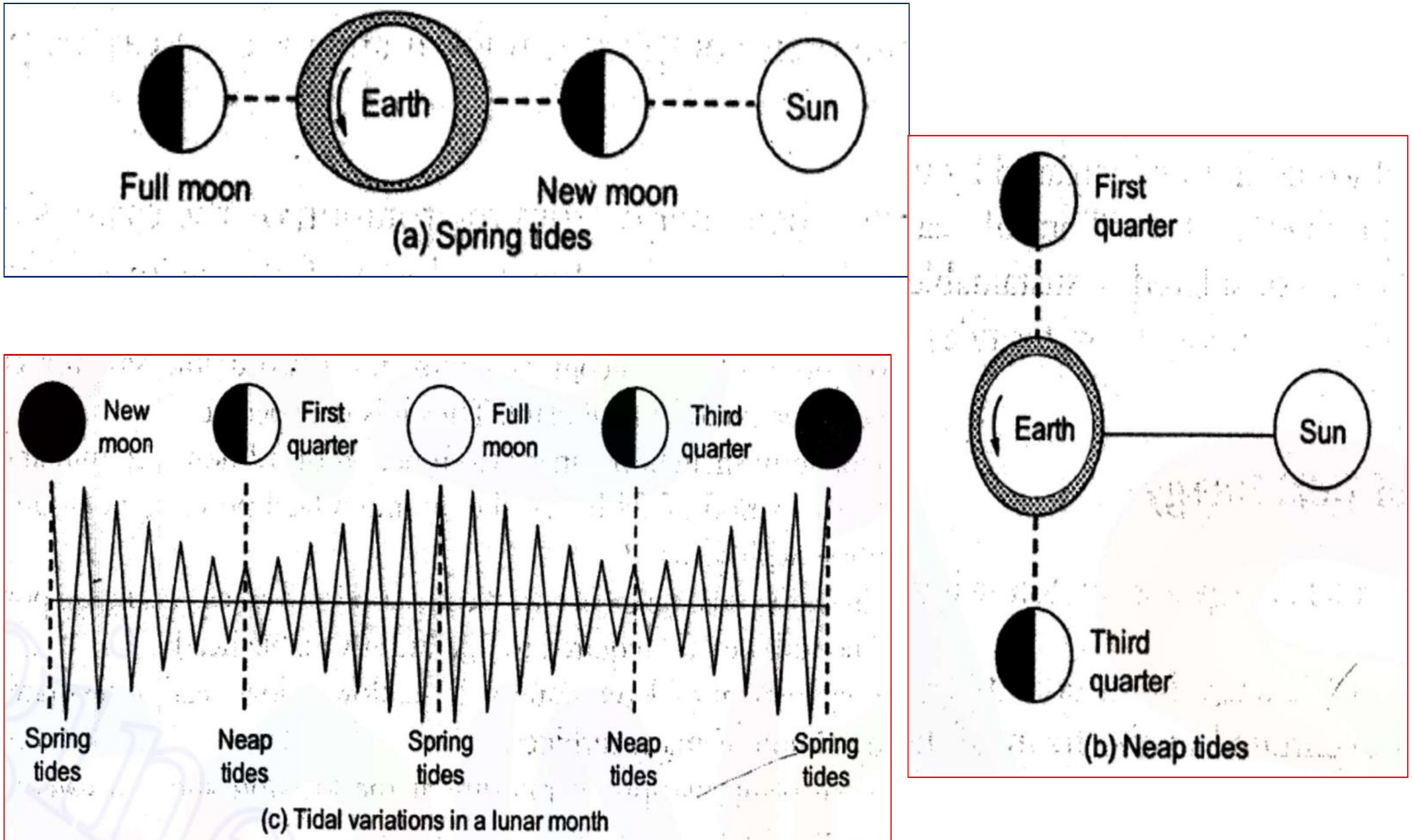
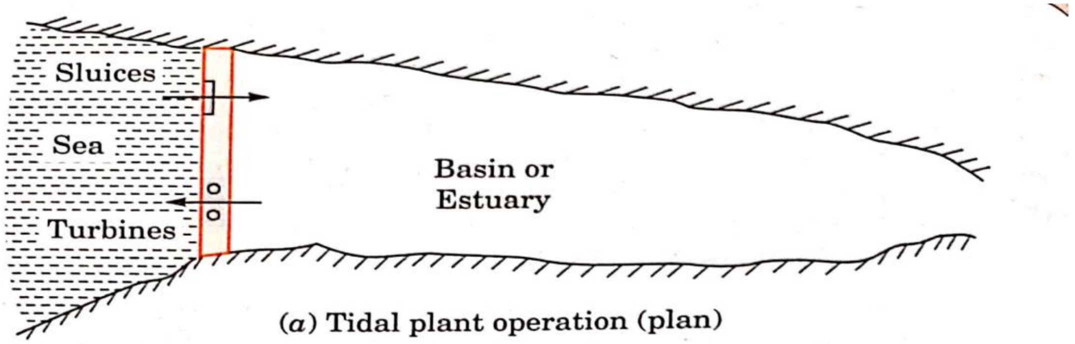
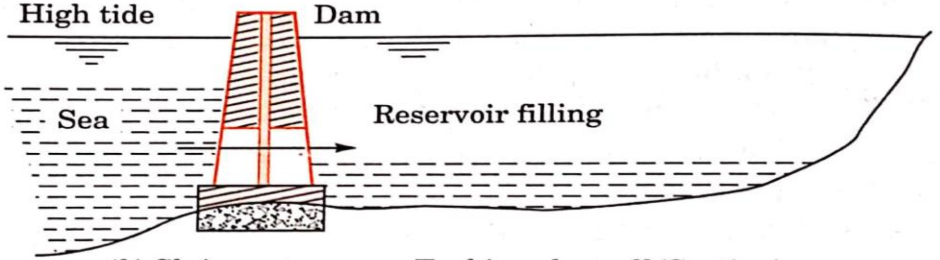


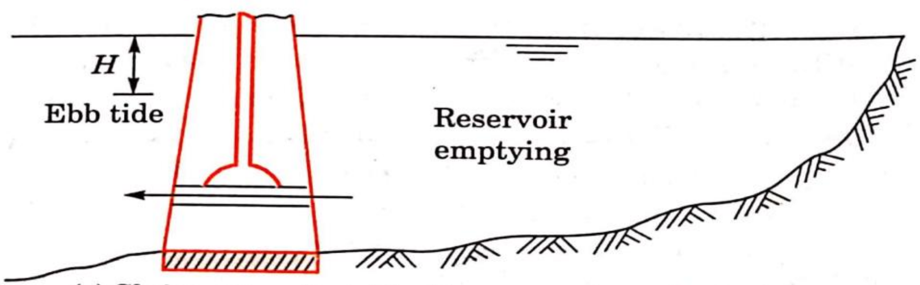
Fig. 10.2 *Nature of tides*



(a) Tidal plant operation (plan)



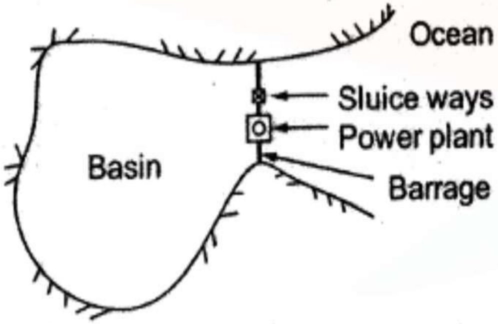
(b) Sluice gates open, Turbine shut off (Section)



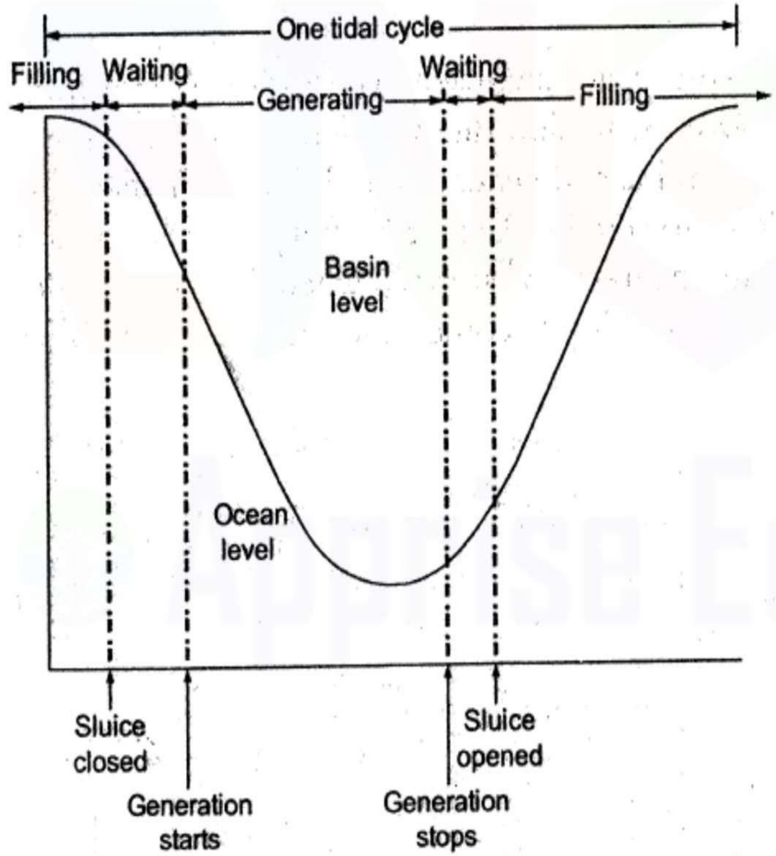
(c) Sluice gates shut, Turbine operation (Section)

Fig. 9.10. Tidal power plant (single basin operation).

Single basin tidal energy



(a) Layout of single-basin tidal energy conversion scheme



(b) Sequence of operation

Double Basin Arrangement

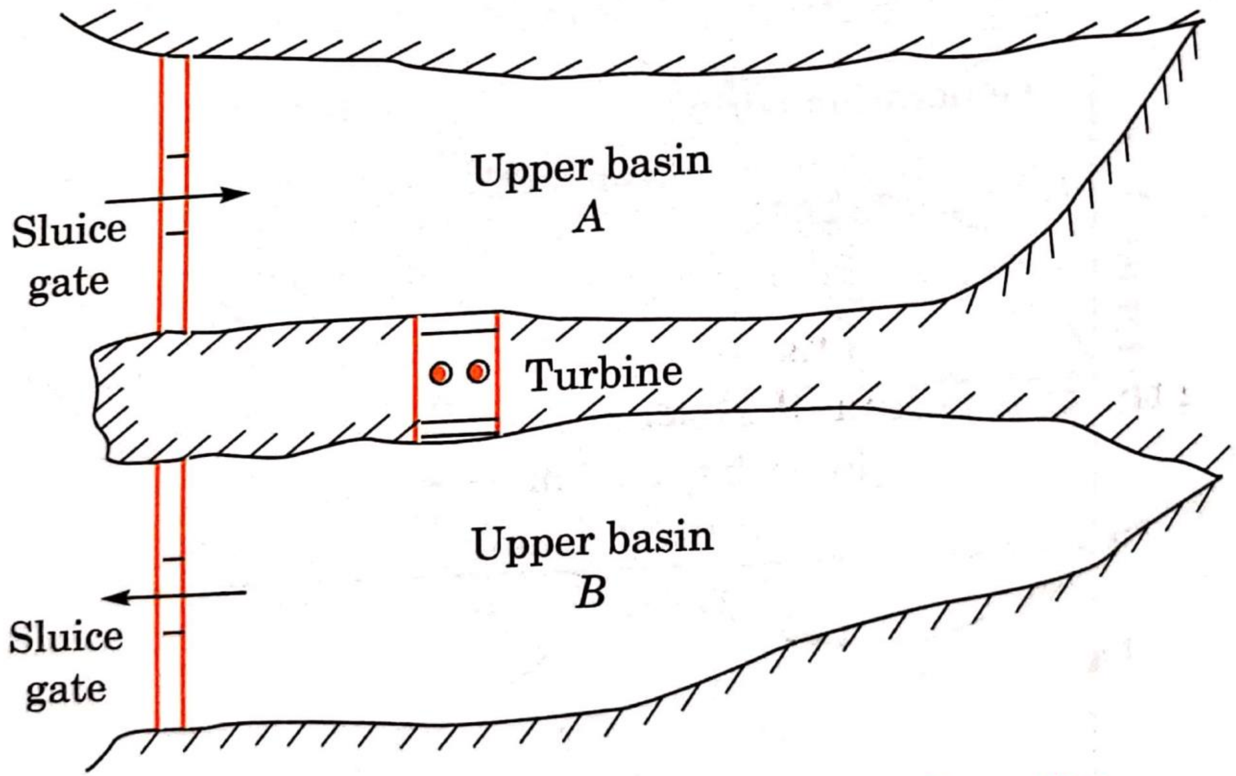


Fig. 9.13. Tidal power plant Double Basin Operation.

Advantages of Tidal Power Generation:

1. Tidal power generation is free from pollution
2. These plants do not demand large area of valuable land because they are on the bays (sea shore)
3. Peak power demand can be effectively met when it works in combination with thermal or hydroelectric system.

Limitations:

1. The fundamental drawback to all methods of generating tidal power is the variability in output caused by the variations in the tidal range.
2. The tidal ranges is highly variable and thus the turbines have to work on a wide range of head variation. This affects the efficiency of the plant.
3. Sea water is corrosive and it was feared that the machinery may be corroded.
4. Construction in sea or in estuaries is found difficult.
5. Cost is not favorable compared to the other sources of energy.

Thank you

RENEWABLE ENERGY SOURCES

UNIT-VI

GEOTHERMAL,BIO-MASS,FUEL CELL

GEOTHERMAL ENERGY

- Energy present as heat in the earth's crust; the more readily accessible heat in the upper most (10km) or so, of the crust constitutes a potentially useful and almost inexhaustible source of energy.

- This heat is apparent from the increase in temperature of the earth with increasing depth below the surface. Although higher and lower temperatures occur, the average temperature at a depth of 10 km is about 200^0C.

- Valcanoes, geysers, hotsprings and boiling mud pots are visible evidence of the great reservoirs of heat that lies within earth.

- As per US Geological survey the entire heat content of the earth's crust upto a depth of 10km and above 15^0C is defined as geothermal source. As such geothermal source is estimated to be more than $2.11 * 10^{25}$ J.

- Historically the first applications of geothermal energy were for space heating, cooking and medicinal purposes.

GEOTHERMAL ENERGY

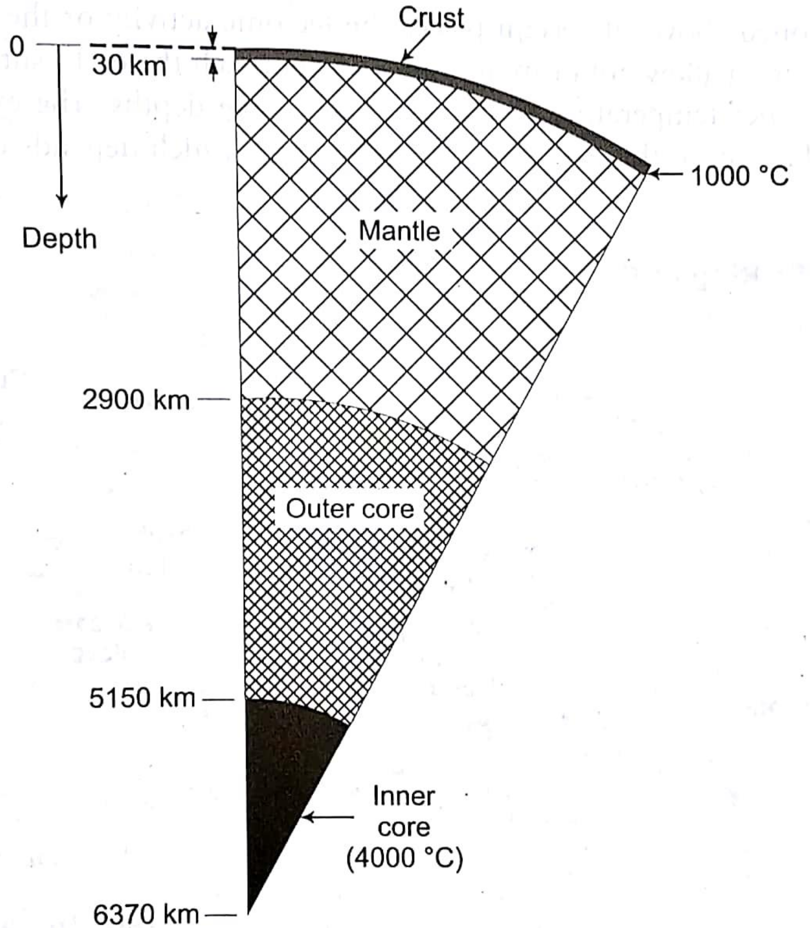


Figure 9.1 Cross section of the earth

GEOTHERMAL ENERGY

- The first attempt to produce electricity took place at Larderello, Italy in 1904 with an electric generator that powered 4 light bulbs.
- By 1914, 8.5MW of electricity was being produced. By 1944 it was producing 127 MW.
- It was expanded and eventually reached 360 MW in 1981.

Potential geothermal development in Puga Valley/ Kashmir

- Till now only one pilot plant is in operation in puga valley, in Jammu and Kashmir, having 20MW capacity.

- Another plant in Parvati valley, Himachal pradesh is under construction

- A 7.5 tonne capacity cold storage pilot plant based on geothermal was installed at Manikaran, Himachal pradesh

- A 5KW pilot power plant is under fabrication at National Aeronautical Laboratory, Bengaluru.

GEOTHERMAL ENERGY

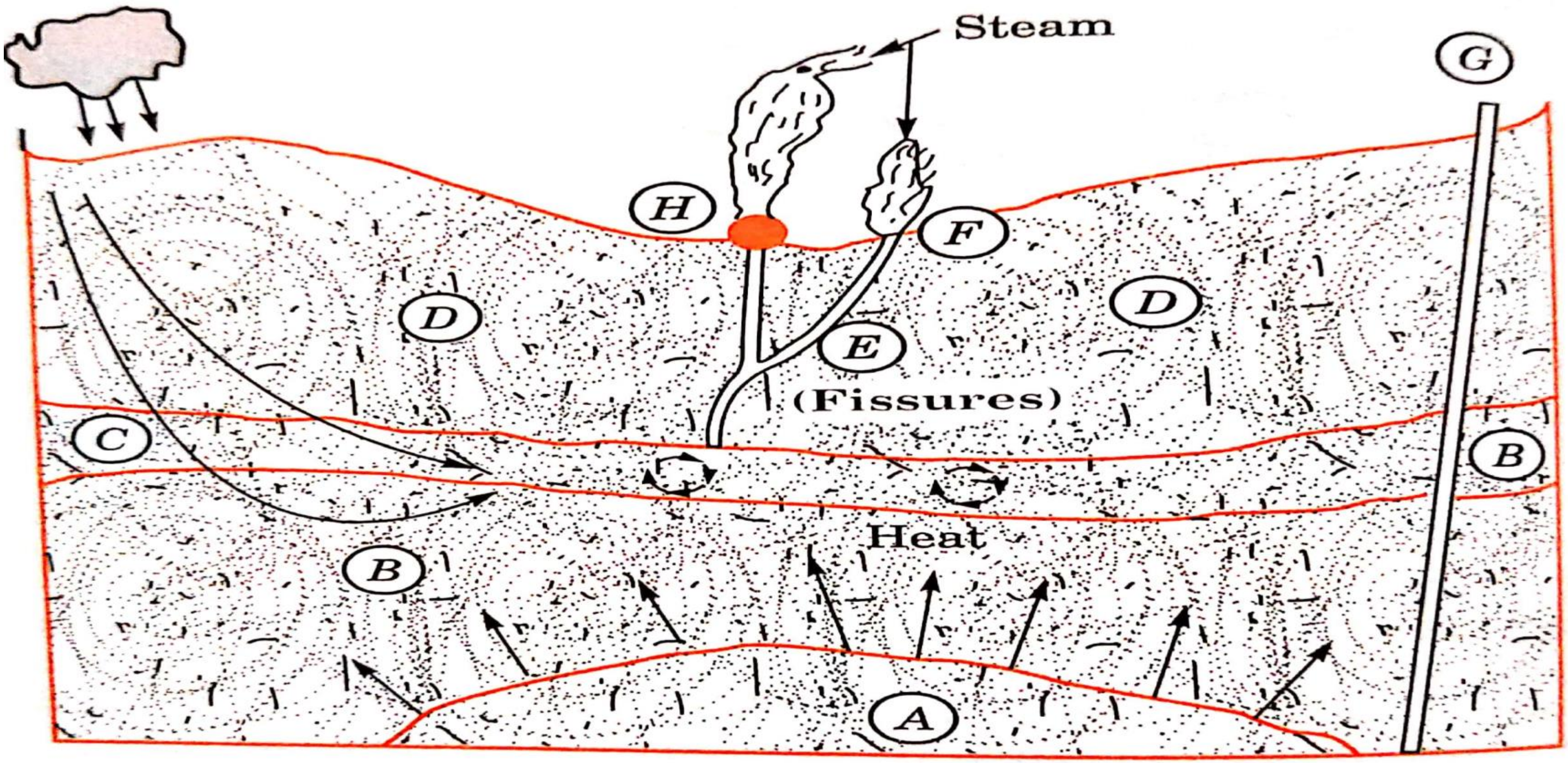


Fig. 8.1. A typical geothermal field.

Nature of Geothermal Fields:

A) Hyperthermal Fields:

1) Wet fields
2) Dry fields

B) Semithermal Fields

Geothermal Sources:

Five general categories of geothermal resources have been identified:

1) Hydrothermal convective systems

   a) Vapour dominated or dry steam fields
   b) Liquid dominated system or wet steam fields
   c) Hot water fields

2) Geo pressure resources

3) Petro-thermal or Hot dry rocks (HDR)

4) Magma resources

5) Volcanoes

Vapor dominated systems (Dry steam fields)

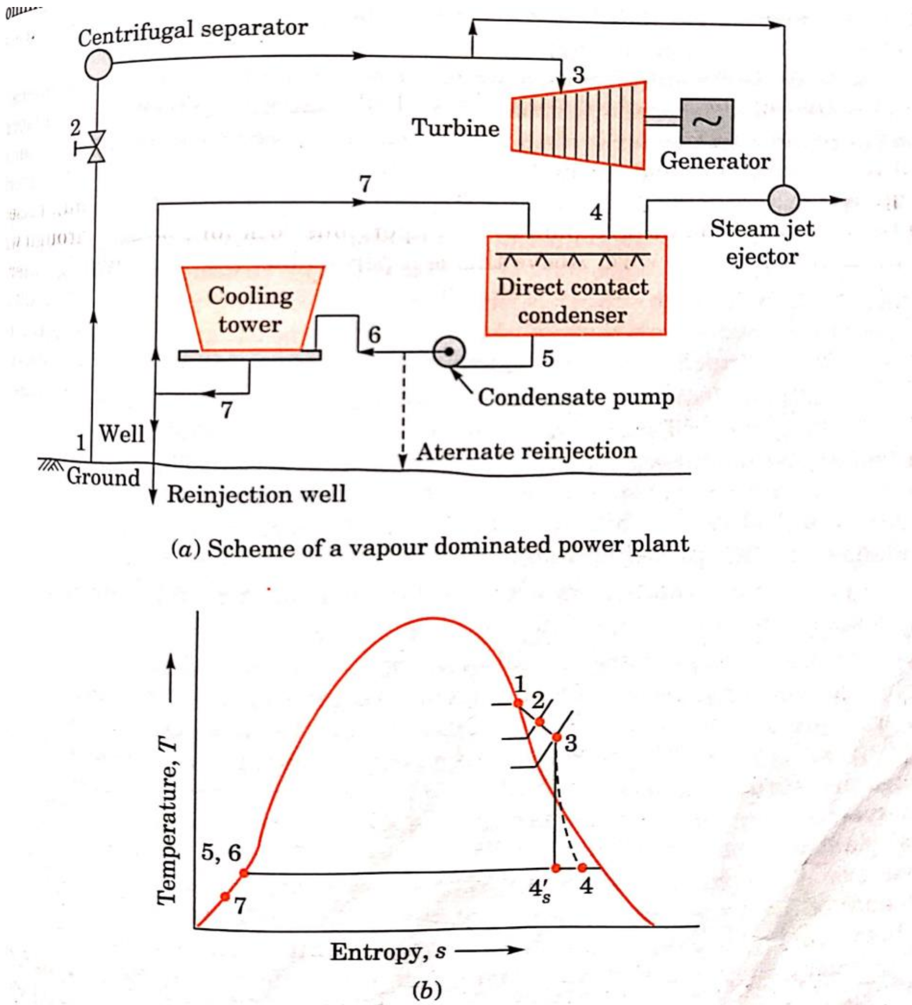
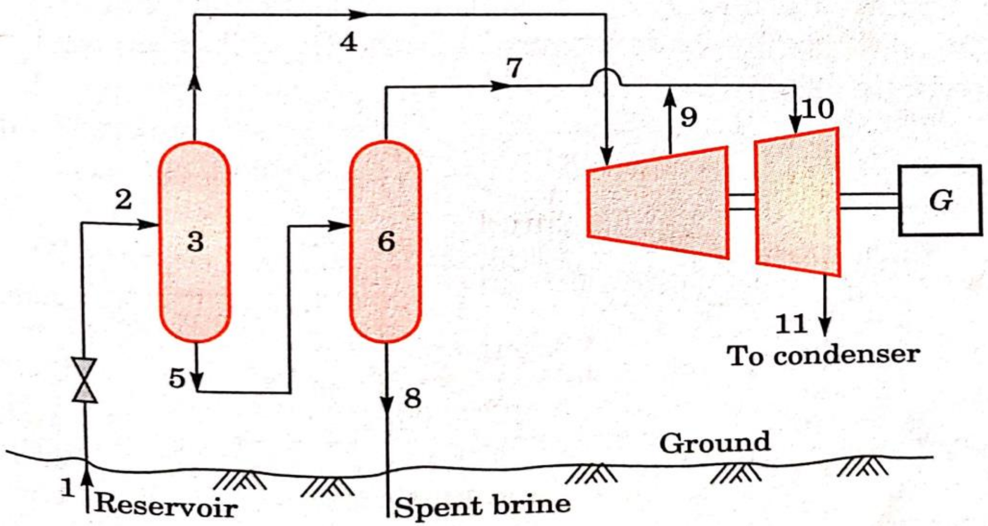
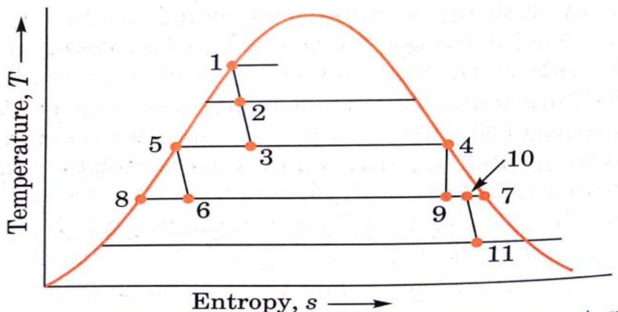


Fig. 8.2. Vapour dominated system on T.S. diagram.



(a) Schematic of liquid dominated double flash steam system.



(b) T-S diagram of the liquid dominated double flash system.

Hot Dry Rock Resources or Petrothermal Systems

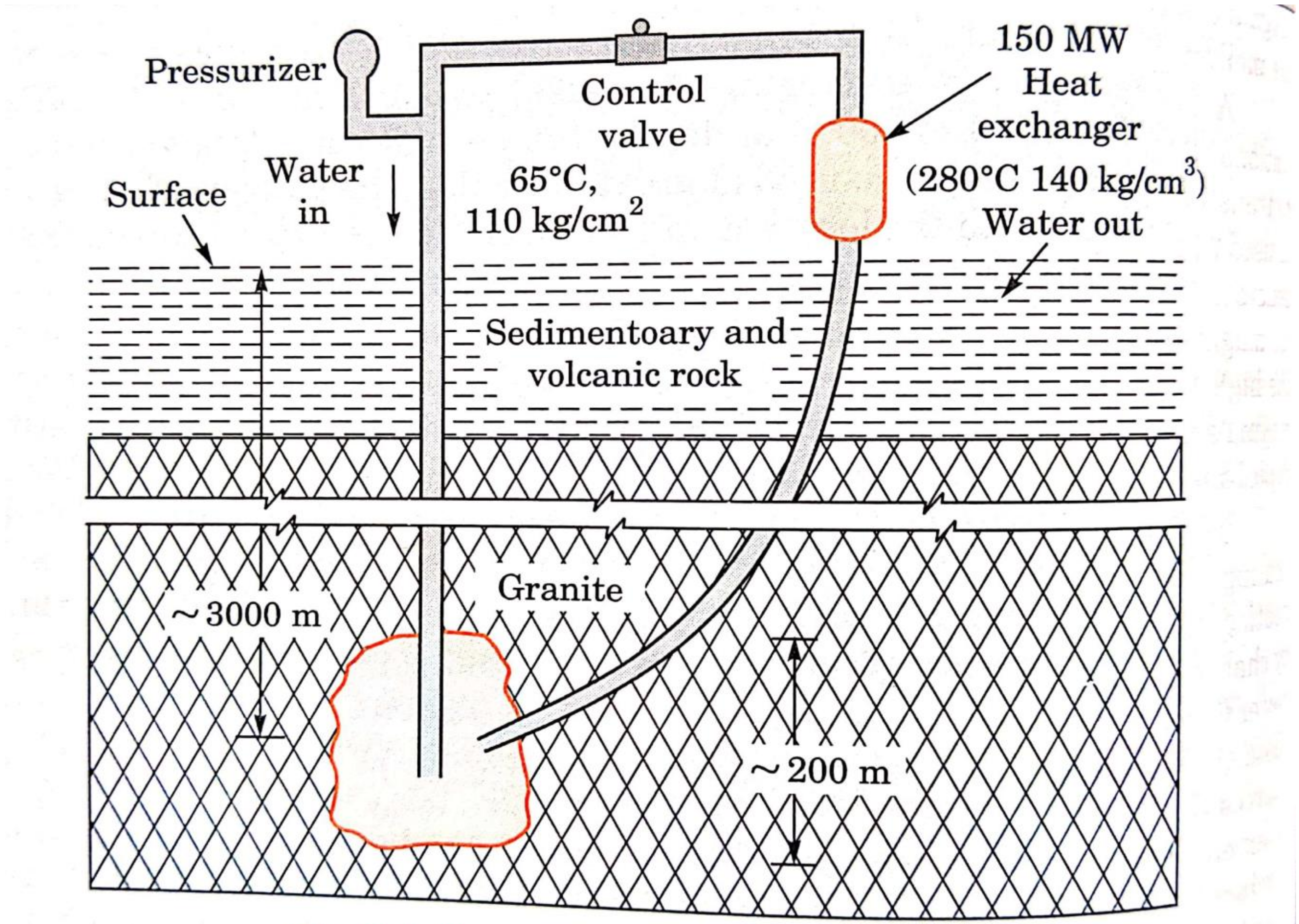


Fig. 8.7. Heat extraction from hot dry rocks.

Operational and Environmental Problems:

1. Solid particles and non condensable gases
2. Re-injection
3. Land-Erosion
4. Noise
5. Water-borne poisons
6. Air-borne poisons
7. Heat pollution
8. Subsidence
9. Seismicity
10. Escaping Steam

Geothermal Energy in India:

Geothermal Occurrence in India

1. N.W. Himalaya Geothermal Province
2. North India Precambrian province
3. Cambay Graben province
4. East Indian Archean province
5. N.E. Himalayan Geothermal Subprovince
6. Naga-Lushai Geothermal Province
7. Damodar Valley Graben province
8. Mahanandi Valley Graben province
9. Narbada Tapti Graben province
10. Godavari Valley Graben province
11. South Indian Archean Precambrian Geotherman province
12. West coast Geothermal province and
13. Andaman Nicobar Geothermal province

Biomass Energy

Biomass Energy

Usable forms of BIOMASS, their composition and fuel properties:

1. Fuel Wood:

Wood is the most obvious and oldest source of biomass energy. This was the main source of energy used by mankind for centuries. Direct combustion is the simplest way to obtain heat energy. Its energy density is 16-20MJ/kg. It can also be converted to more useful forms as charcoal and producer gas.

2. Charcoal:

Charcoal is a clean (smokeless), dry, solid fuel of black color. It has 75-80 percent carbon content and has energy density of about 30 MJ/kg. It is obtained by carbonization process of woody biomass to achieve higher energy density per unit mass, thus making it more economical to transport. It can be used as fuel in domestic environment as it burns without smoke.

3. Fuel Pellets and Briquettes:

Crop residue such as straw, rice husk etc. and waste wood are pressed to form lumps, known as fuel pellets or briquettes and used as solid fuel.

4. Bio-diesel

Some vegetable oils, edible as well as non-edible can be used in pure form or its blend with petroleum diesel as fuel in a compression ignition (diesel) engine. Bio-diesel is simple to use, biodegradable, nontoxic and essentially free of sulfur and aromatics.

5. Bio-ethanol

Ethanol (C_2H_5OH) is a colorless liquid biofuel. Its boiling point is 78 Cand energy density is 26.9 MJ/kg. It can be derived from wet biomass containing sugars, starches or cellulose. Ethanol is largely produced from sugar cane.

6. Biogas

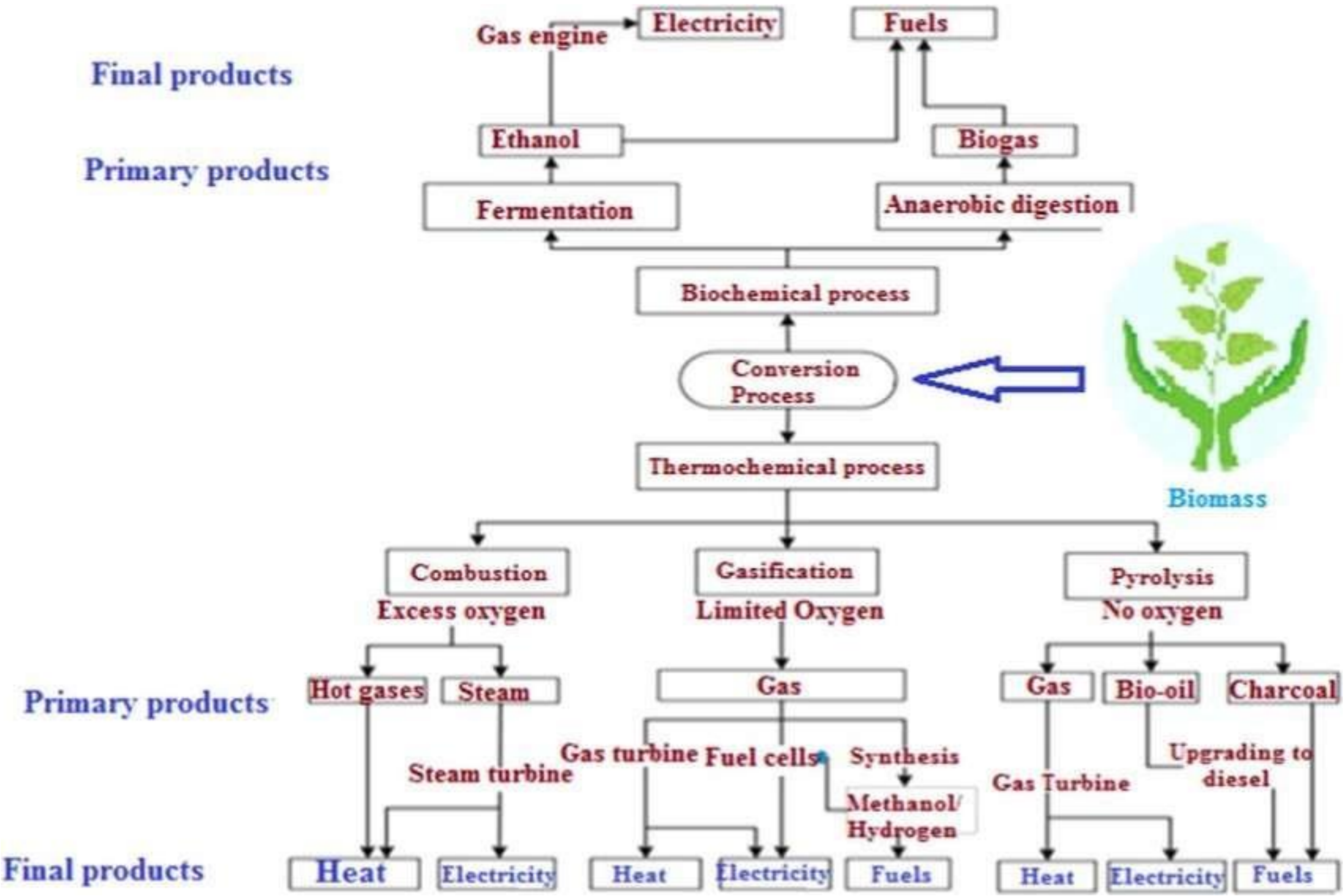
Organic Wastes from plants, animals and humans contain enough energy to contribute significantly to energy supply in many areas, particularly the rural regions of developing countries. Biogas is produced in a biogas fermenter or digester.

If raw material is cow manure, the output biogas will contain about 50-60 percent CH_4, 30- 40 percent CO_2, 5-10 percent H_2, 0.5-0.7 percent N_2 with trace amounts of O_2 and H_2S. Energy density is about 23MJ/m3.

7. Producer Gas:

Woody matter such as crop residue, wood chips, bagasse, rice husk, coconut shell etc., can be transformed to producer gas (also known as synthesis gas, wood gas, and water gas or blue gas) by a method known as thermal gasification of solid fuel.

For wood chips as input the typical gas composition is 19 percent CO, 18 percent H2, 1percent CH4, 11 percent CO2 and the rest N2. Energy density of 4-8 MJ/m3.

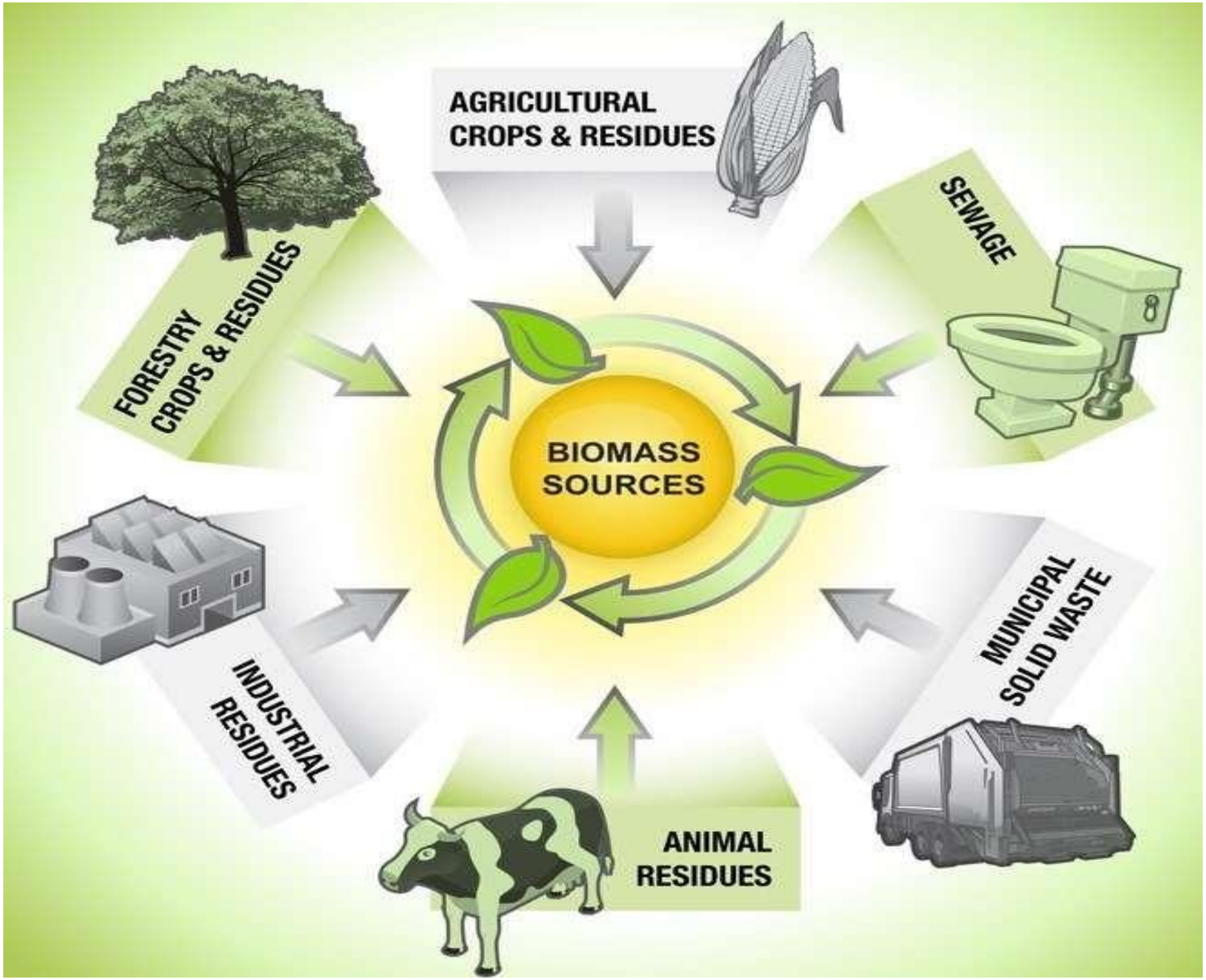

Final products
Primary products
Gas engine
Electricity
Fuels
Ethanol
Biogas
Fermentation
Anaerobic digestion
Biochemical process
Conversion Process
Biomass
Thermochemical process
Combustion
Excess oxygen
Gasification
Limited Oxygen
Pyrolysis
No oxygen
Primary products
Hot gases
Steam
Gas
Gas
Bio-oil
Charcoal
Steam turbine
Gas turbine
Fuel cells
Synthesis
Methanol/ Hydrogen
Gas Turbine
Upgrading to diesel
Final products
Heat
Electricity
Heat
Electricity
Fuels
Heat
Electricity
Fuels

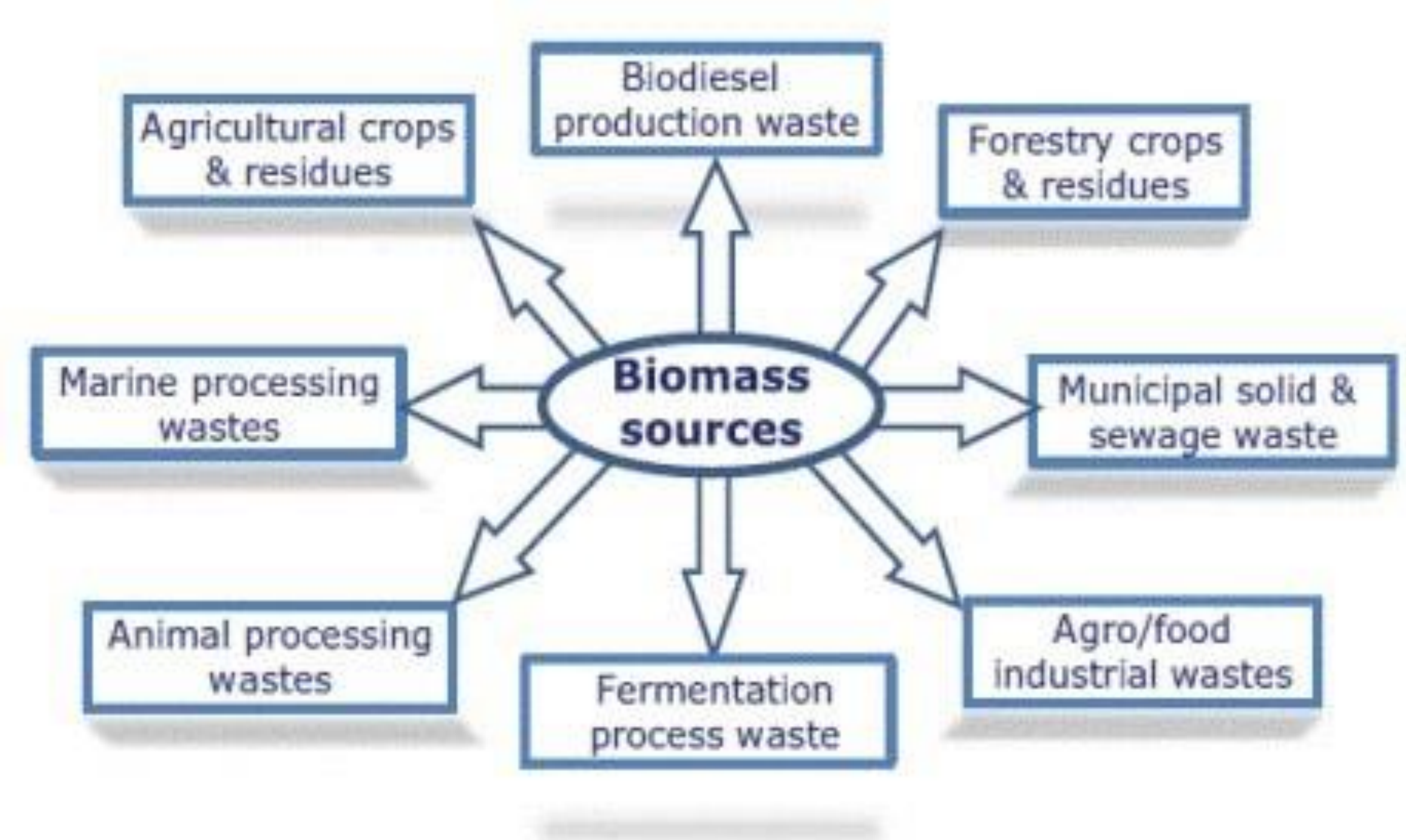
Biomass Resources

1. Forests: a) wild plants
   b) agriculture crops

2. Agriculture Residues

3. Energy Crops


AGRICULTURAL
CROPS & RESIDUES
FORESTRY
CROPS & RESIDUES
SEWAGE
BIOMASS
SOURCES
INDUSTRIAL
RESIDUES
MUNICIPAL
SOLID WASTE
ANIMAL
RESIDUES


Biodiesel production waste
Agricultural crops & residues
Forestry crops & residues
Marine processing wastes
Biomass sources
Municipal solid & sewage waste
Animal processing wastes
Fermentation process waste
Agro/food industrial wastes

Biomass Conversion Technologies:

1. Physical method
   a) Palletisation
   b) Briquetting

2. Direct Combustion (Incineration)

3. Thermochemical conversion
   a) Gasification
   b) Liquefaction

4. Biochemical conversion
   a) Anaerobic Digestion
   b) Fermentation

Wet Processes:

1. Anaerobic digestion
2. Fermentation

Ethyl alcohol is produced by the fermentation of sugar solution by natural yeasts.

After about 30 hours of fermentation the brew contains 6-10% alcohol and this can be readily be removed by distillation.

Sugarcane also be manufactured from vegetable starches and cellulose, maize, wheat grain or potatoes must be ground or pulped and then cooked with enzymes to release starch and convert it into fermentable sugars.

One tonne of sugar will produce upto 520 lts of alcohol, a tonne of grain 350 lts, a tone of wood 260-540 lts.

3. Chemical Reduction

It involves pressure – cooking animal waste or plant cellulosic slurry with alkaline catalyst in the presence of CO at temp's between 240C to 400C. --- mixture of Oils.

Dry Processes:

1. Pyrolysis
2. Liquefaction
3. Gasification
4. Steam-Gasification
5. Hydrogenation

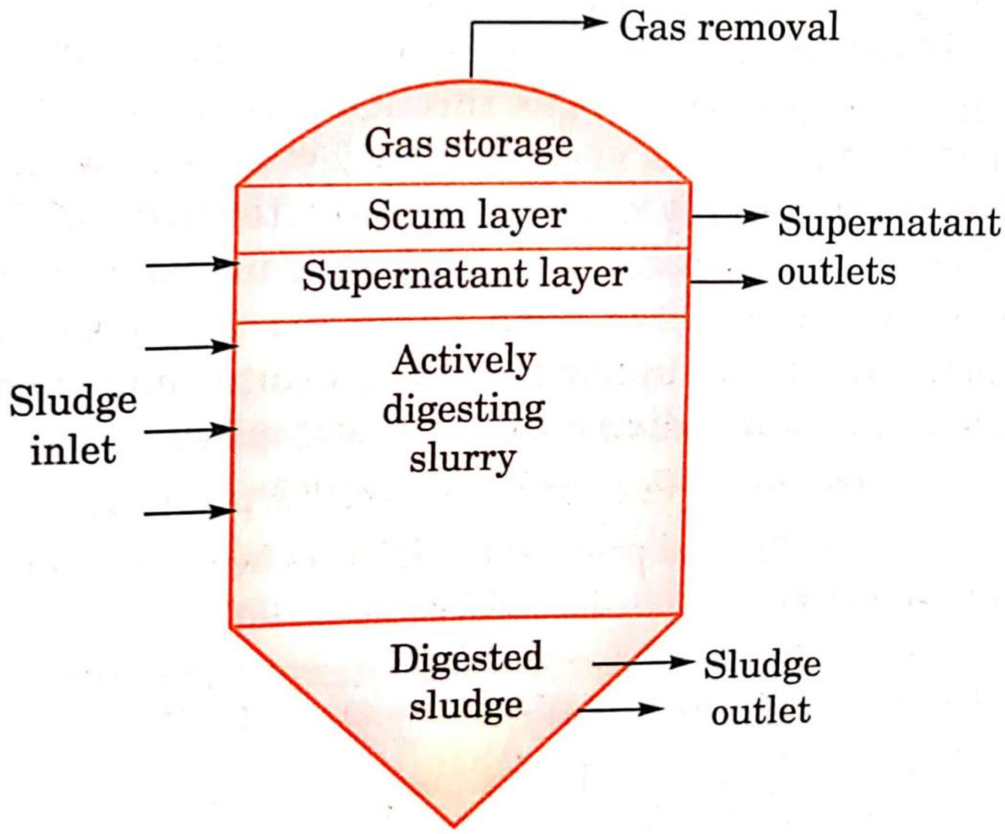


Fig. 7.2. Schematic of single process conventional digester.

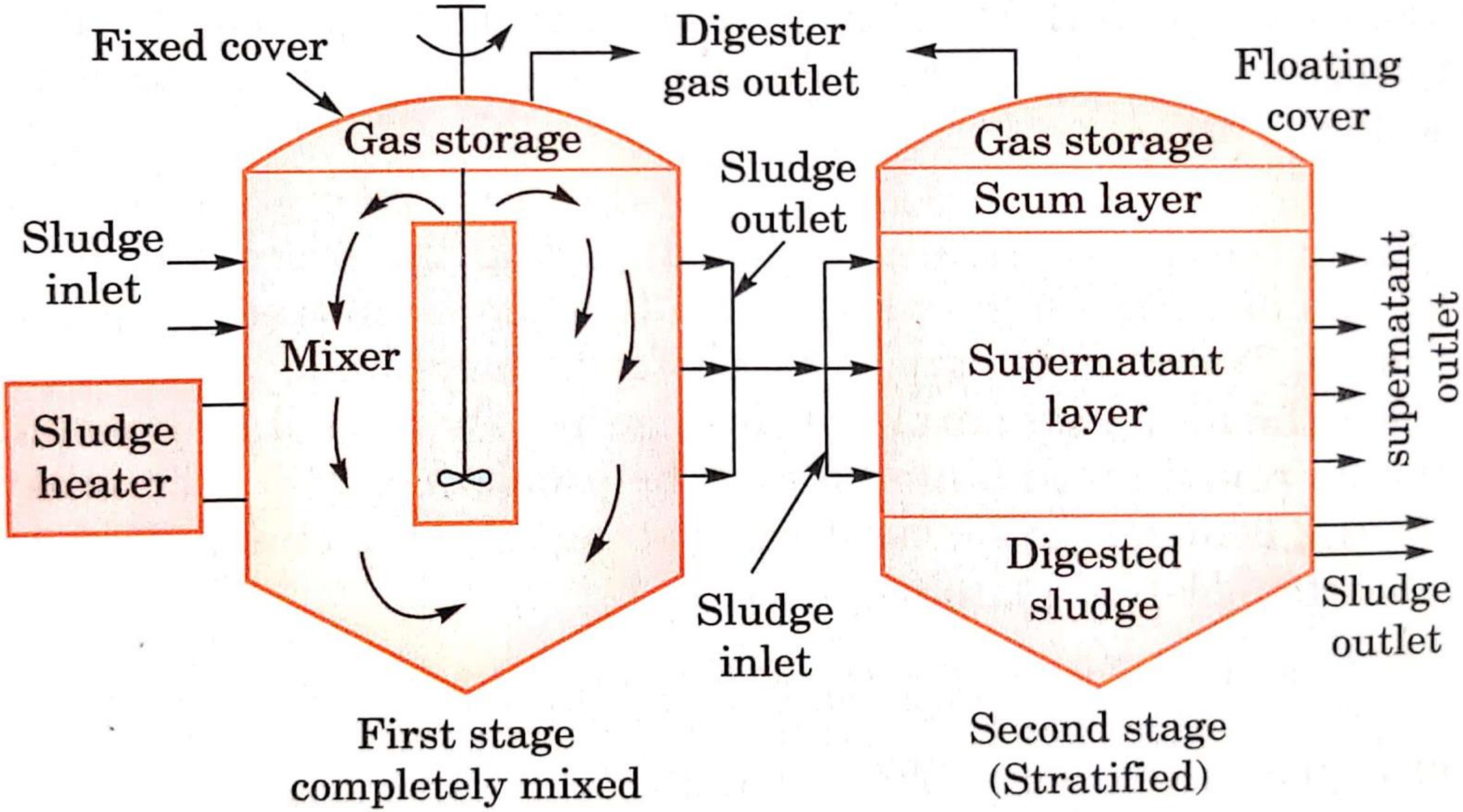


Fig. 7.3. Schematic of two-stage digestion process.

BIO-MASS ENERGY

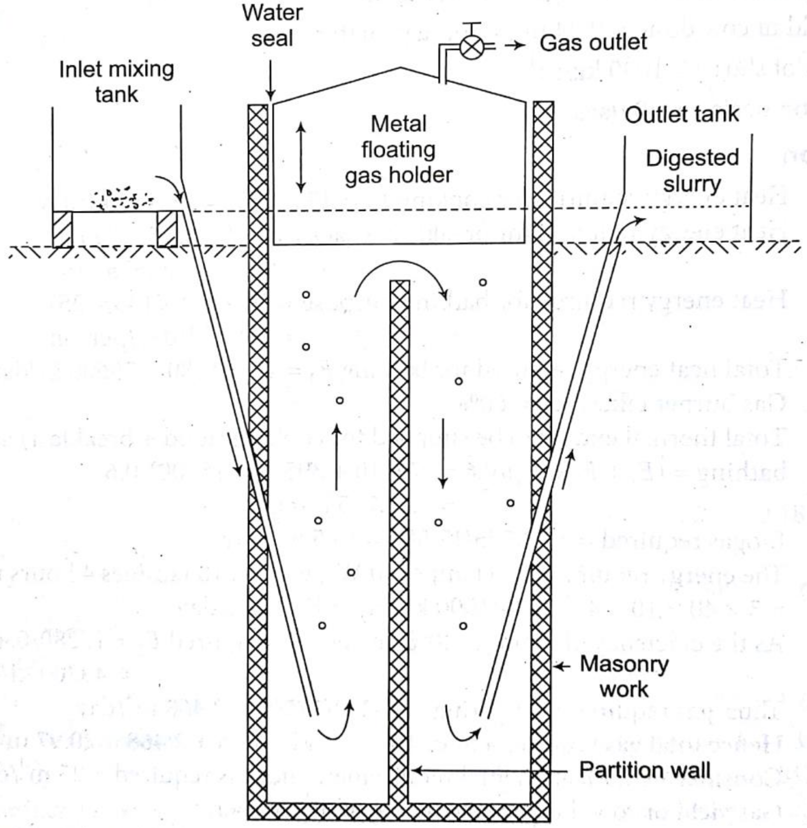


Figure 8.12 Floating drum type biogas plant

BIO-MASS ENERGY

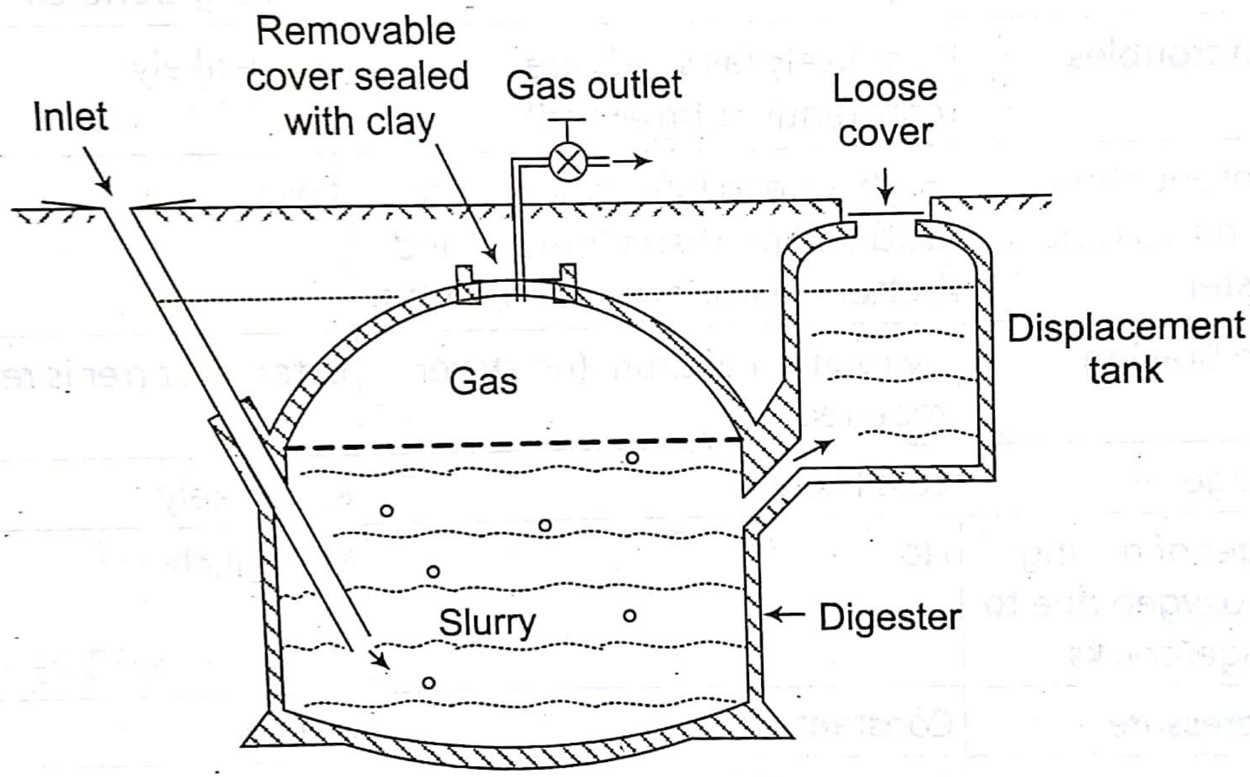


Figure 8.13 Fixed dome type biogas plant

Selection of site for a Biogas Plant:

1 Distance

2 Open Space

3 Water table

4 Seasonal run off

5 Distance from wells

6 Space requirements

7 Availability of water

8 Source of cow dung / materials

FUEL CELL

A Fuel cell is an electrochemical energy conversion device that continuously converts chemical energy of a fuel directly into electrical energy.

Continuous operation requires supply of fuel and oxidant and removal of water vapour, spent fuel, spent oxidant, inert residue and heat etc.

It is known as a cell because of some similarities with a primary cell. It is also a static power conversion device.

Fuel is supplied at the negative electrode, also known as fuel electrode and oxidant is supplied at positive electrode, also known as oxidant electrode.

Fuel cells can be classified in several ways.

(a) Based on the Type of Electrolyte

(i) Phosphoric Acid Fuel Cell (PAFC)
(ii) Alkaline Fuel Cell (AFC)
(iii) Polymer Electrolytic Membrane Fuel Cell (PEMFC) or Solid Polymer Fuel Cell (SPFC) or Proton Exchange Membrane Fuel Cell (PEMFC)
(iv) Molten Carbonate Fuel Cell (MCFC)
(v) Solid Oxide Fuel Cell (SOFC)

(b) Based on the Types of the Fuel and Oxidant

(i) Hydrogen (pure)–Oxygen (pure) fuel cell
(ii) Hydrogen rich gas–air fuel cell
(iii) Hydrazine–Oxygen/hydrogen peroxide fuel cell
(iv) Ammonia–air fuel cell
(v) Synthesis gas–air fuel cell
(vi) Hydrocarbon (gas)–air fuel cell
(vii) Hydrocarbon (liquid)–air fuel cell

(c) Based on Operating Temperature

(i) Low temperature fuel cell (below 150°C)
(ii) Medium temperature fuel cell (150°C–250°C)
(iii) High temperature fuel cell (250°C–800°C)
(iv) Very high temperature fuel cell (800°C–1100°C)

(d) Based on Application

(i) Fuel cell for space applications
(ii) Fuel cell for vehicle propulsion
(iii) Fuel cell for submarines
(iv) Fuel cell for defense applications
(v) Fuel cell for commercial applications

(e) Based on the Chemical Nature of Electrolyte

(i) Acidic electrolyte type
(ii) Alkaline electrolyte type
(iii) Neutral electrolyte type

FUEL CELL

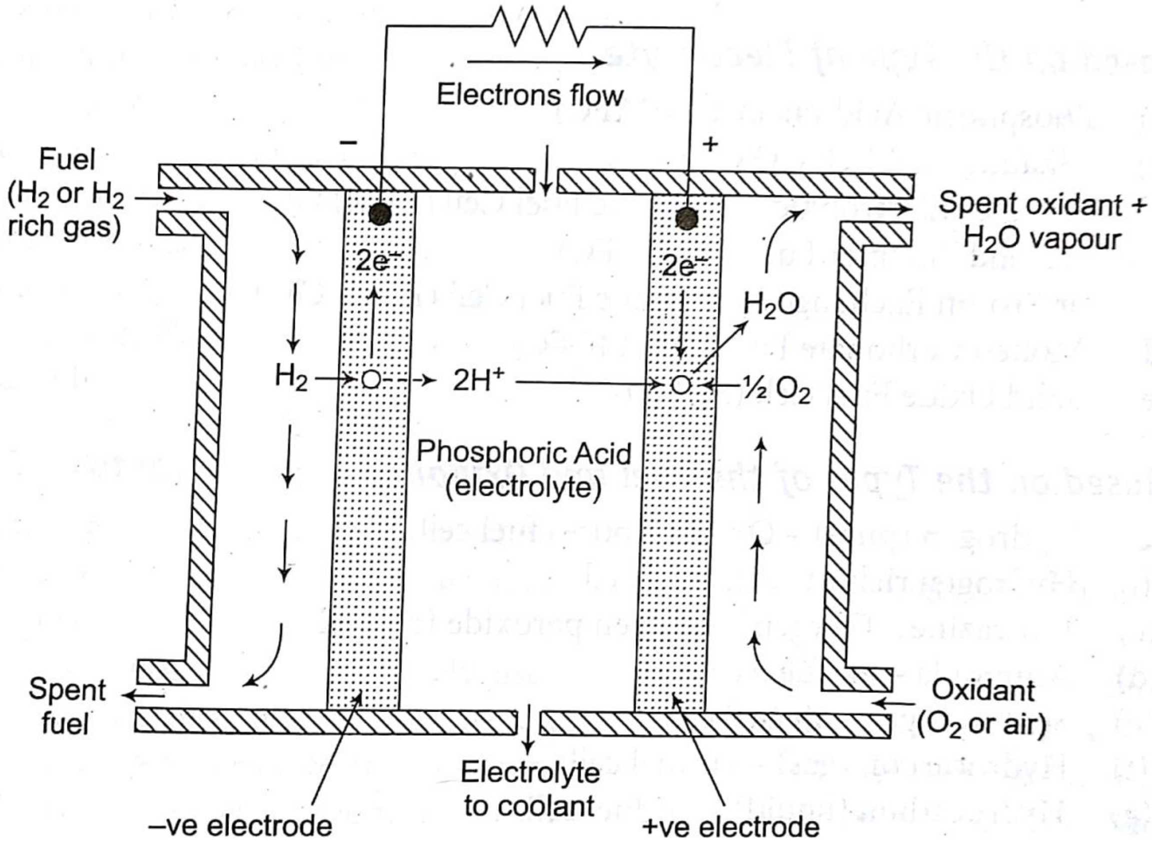


Figure 12.1 Phosphoric Acid Fuel Cell

FUEL CELL

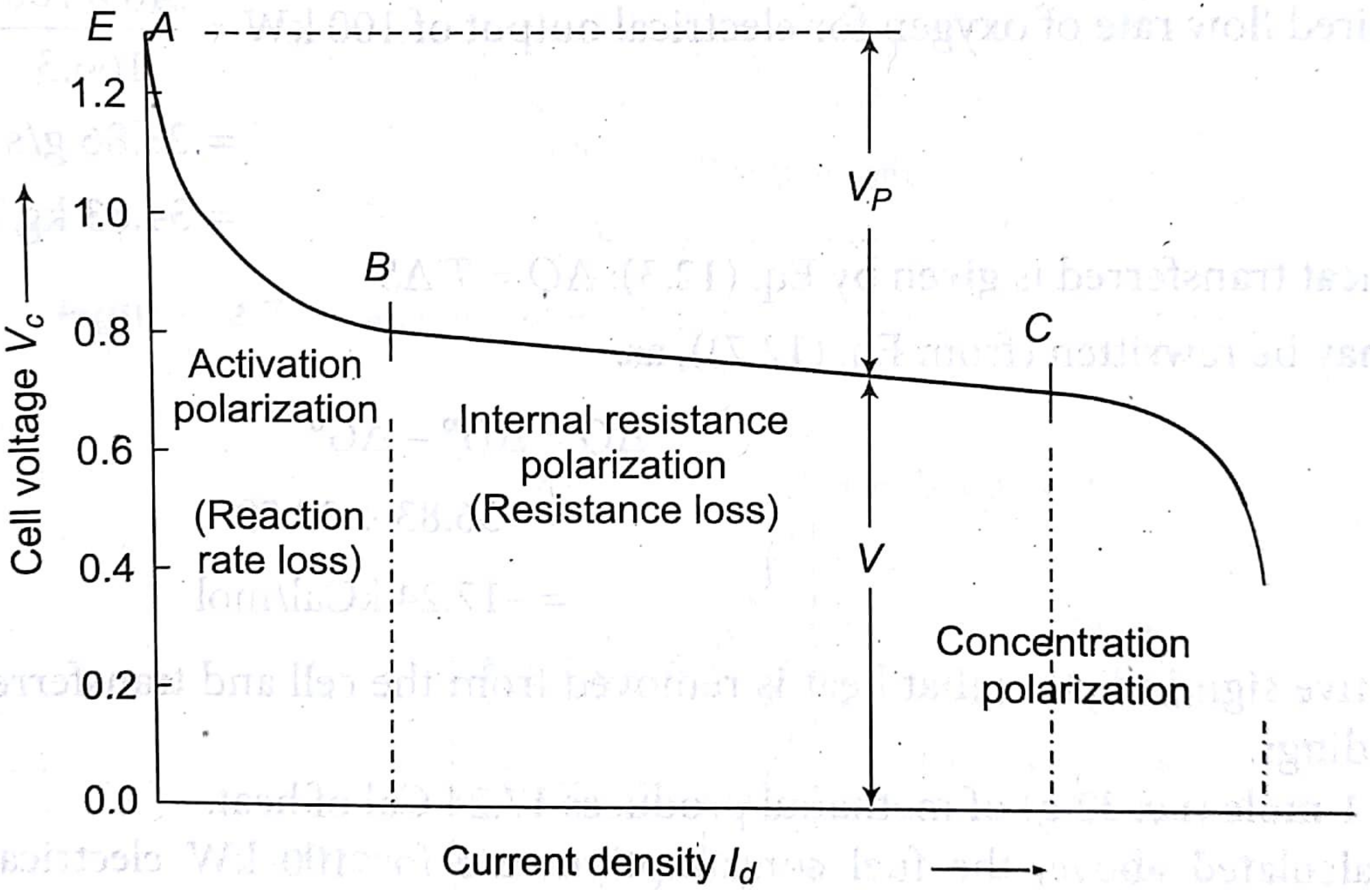


Figure 12.6 VI characteristic of fuel cell

Thank you