

Renewable Energy
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Introduction to RES

①

Conventional Energy Sources:-

In the year 1973, oil prices shot up fourfold and causes severe energy crisis worldwide. As the commercial energy prices rises significantly, global inflation increases. Various governments of countries starts taking seriously the matter, starts huge investments in developing other alternative sources of energy.

→ Conventional Energy Resources

which are being traditionally used for many decades and were in common use around the oil crisis of 1973. These are called conventional Energy sources.

Ex. fossil fuels, nuclear and hydro sources etc.

⇒ Non-Conventional Energy Sources which are considered for large-scale use after the oil crisis of 1973 are called as non-conventional Energy resources.

Ex:- Solar, wind, Biomass etc.

Impact of Conventional Energy

→ Large hydro Power Plant effect significantly by submerging the ecology of land, forest, habitat and populated area. It change the ecology completely.

(2)

⇒ Green house effect: Coal fired Power

plants emit large amount of CO_2 gases.

CO_2 prevent the escape of heat from earth, which leads to global warming.

Other green house gases are methane, nitrous oxide, hydrofluorocarbons.

Sulphur hexafluoride and water vapour.

If global warming continues to increase and global average temperature increases by 2°C than all Arctic and Atlantic glacier will be completely melt out and a significant land mass will be submerged due to increase in sea level.

⇒ Pollution Thermal power Plant

Coal and Internal Combustion Engine emit

toxic gases such as CO_2 , SO_2 , NO_x , ClO_x , NO_2 , NO_3 , H_2O_2 , N_2O_3 increase

level of these in environment deteriorate human life as well as other living animals.

⇒ Radiation: Nuclear Power Plant

is cleanest source of power. Still it generates highly radioactive waste which cause serious health issue to living bodies. If comes into contact. They need secure dumps.

(3)

Renewable Energy sources.

Renewable Energy sources are occurring in nature and regenerative in nature.

Ex: Solar, wind, hydro power, geothermal, biomass, tidal and wave energy.

→ Renewable energy are seasonal

in nature. Like solar energy which is available from morning to evening, and its intensity is higher in summer season and lower in winter season.

→ Renewable energy sources are not available throughout the year and round the clock.

India's daily global.

Solar Energy - India's daily global radiation is around 5 kWh/m²/day. Further India receives clear sunshine days for 300 days a year. With proper storage system solar energy can.

sufficiently full fill India's total energy demand. Current installed capacity 30 GW.

Wind Energy - India has a total

potential of about 100 GW of wind power generation. Whereas current annual production capacity of wind turbines is about 9500 MW. A total

capacity of 22.5 GW has been established upto Dec 2014.

Biomass Energy! These are available from animal and vegetation. Principal biomass resources are.

→ Trees (wood, leaves, twigs)

→ Cultivated plants grown for energy.

→ Algae and other vegetation from ocean and lakes.

→ Urban waste (municipal/industrial waste).

→ Rural waste (agricultural/animal waste).

Geothermal Energy! It is derived from huge amount of thermal energy present in the core of earth. It requires a specific location where we can.

tap the geothermal energy conveniently and economically. Hawaii, El Salvador,

Lardarello in Italy are some of these locations where geothermal energy is being used on a large scale.

Ocean Tidal Energy! It is a form of generating hydro power by storing high tide and releasing it at low tide.

Ocean Current Energy! It is a form of energy where ocean currents are used to rotate turbines to generate electricity.

Ocean Thermal Energy! It is a form where the temperature difference b/w adjacent water in sea are used to generate Electricity.

Classification of Energy Resources:-

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i) Based on Usability of Energy.

a) Primary Resources:- These are resources available in the natural form, prior to any modification made by humans. Available in raw forms and cannot be used as such. These are located, explored, extracted, processed and converted to a form as required by the consumer.

Examples:- Coal, crude oil, sunlight, wind, running river water etc.

b) Intermediate Resources:-

These are obtained from primary sources by one or more conversion processes. Examples:- Petrol, Diesel, LPG.

c) Secondary Resources:-

The form of energy which is finally supplied to consumer for direct use is known as secondary energy. Example:- Electrical energy, Thermal energy, chemical energy.

2. Based on Traditional Use.

a) Conventional Energy Resources are those which are being used for many years before and during the oil crisis of 1973. Examples: fossil fuel, Nuclear, hydro.

b) Non-Conventional Energy Resources are those which are considered for large scale use after the oil crisis of 1973. Ex. Solar, wind, biomass.

3. Based on Long term Availability.

a) Non-Renewable Resources- (There are available in finite quantities, and are bound to get depleted after a certain time of use, and do not get refilled). Examples:- fossil fuels, uranium etc.

b) Renewable Resources- These type of sources are available in nature in limited quantities and getting renewed over a certain period and hence called Renewable Energy Resources.

Hybrid Energy system

(7)

As renewable resources are seasonal
in nature & a reliable source of
energy supply is not possible.
Conventional resources are reliable
in nature but polluting the environment.

As a trade-off we can use a hybrid

system of renewable and conventional
resources to make the supply of
energy more reliable and less
polluting. Hybrid systems can also
incorporate a storage system in it.

→ Normally Solar PV or Wind power
is combined with a of Diesel or
gas fired generator. When the
Solar/Wind power is available
the load is supplied only from the
renewable source. If solar/wind
power is not available DG supply the
required power.

→ Solar and Wind power are also
made hybrid to make a more reliable
source of energy. As Solar is available
from late morning to early afternoon and
wind is available more during morning
and in night mode.

→ Storage system can be added
to hybrid system to supply power
during failure of both system
for a short period of time.

Dispersed Generation

(8)

A Dispersed Generator is a system which caters to the specific demand of power of a small industries, small local area community of a village.

Dispersed Generations has a power output of upto 25 kW.

Diesel Generator (DG), small Solar PV installations, Micro Hydro Power Plant, small Biomass Thermal Power Plant, small Wind mills are used to supply demands of users. Dispersed Generations is required particularly in remote areas, where grid supply is not available or not possible due to complex terrain or deltas or islands.

Example: Sunderban is in West Bengal was electrified in 1997 using a 410 kW solar PV system and a Biomass-based power plant.

States like Keylong, Lahaul and Spiti, Himachal Pradesh was electrified on 1984 by 5 sets of 2x50 kW small hydro power plant using water from the rivers.

Distributed Generations

(9)

Distributed Generations systems used small capacity generations units mostly comprised of solar PV, wind or micro hydral unit, distributed over a wide area but connected through a central grid system.

Distributed Generations systems reduces the load on the grid, and the requirement of a large fossil fuel fired thermal power plant can be avoided.

As the unit size of each individual generation unit is small (i.e. up to 25 MW), any failure of individual unit does not effect the entire system as ^{all} other system can compensate the loss combinedly.

Distributed Generation reduces the transmission and distribution loss of the system to a great extent as the generation units are located close to the consumption areas.

-X-

After the meeting, I had dinner at
the hotel restaurant. There were
several 100+ passengers from various
backgrounds. Some were very
friendly and others had a more
distant, professional attitude.
I had a wonderful time and was
impressed by the variety of people
and the quality of the food.
After dinner, I went to the bar
and had a few drinks. I enjoyed the
atmosphere and the company.
I then went to my room and
had a nice time writing up
notes from the day's events.
I also had a nice time talking
with some of the other passengers
and getting to know them better.
Overall, it was a great trip and I
would definitely do it again.

SOLAR ENERGY

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The Sun

The sun has a diameter of 1.39×10^9 m and at an average distance of 1.495×10^{11} m from earth. The innermost core has a temperature of $8 \text{ to } 40 \times 10^6$ °K.

The core density is around 150 g/cm^3 and a pressure of 2.5×10^{11} atm. Such a high temp. & pressure is maintained by fusion reaction where two hydrogen atom combined to make one helium atom and releasing two helium atoms and releasing a huge amount of energy.

The surface temperature of sun is 5778 K. The sun radiates 2.8×10^{23} kWh/year of energy.

The Earth



The earth's diameter is 1.275×10^7 m. The average surface temperature is 288 °K (15 °C). Total sun energy reaching the earth is 1.5×10^{17} kWh/year.

Earth reflects 30% of sunlight it receives. This is called an albedo.

Spectral Energy Distribution of Solar Radiation

Although the sun radiates energy over a wide frequency range, the intensity was maximum within the range of $0.2 \mu\text{m}$ to $4 \mu\text{m}$ and peak intensity at $0.48 \mu\text{m}$ (Green light). At the outer atmosphere of earth the sun radiation has 8.4% of energy is contained in the ultraviolet region ($\lambda < 0.38 \mu\text{m}$), 48% of energy in visible spectrum ($0.38 < \lambda < 0.78 \mu\text{m}$) and remaining 43.6% in infrared region ($\lambda > 0.78 \mu\text{m}$). *

- The Term irradiance is defined as a measure of power density of sunlight received at a location and is measured in W/m^2 .
- Irradiation is the measure of energy density of sun light in KWh/m^2 . Denoted by symbol ' H '.
- Extraterrestrial radiation (F_{ext}), it is the solar radiation received at the outer atmosphere of the Earth.
- Solar Constant (F_{ee}); It is defined as the energy received from sun on the surface of earth outer atmosphere of earth. It has a fixed value of 1367 W/m^2 .

Solar Radiation

> Terrestrial Radiation

The solar radiation that reaches the earth surface after passing the earth's atmosphere is known as terrestrial radiation.

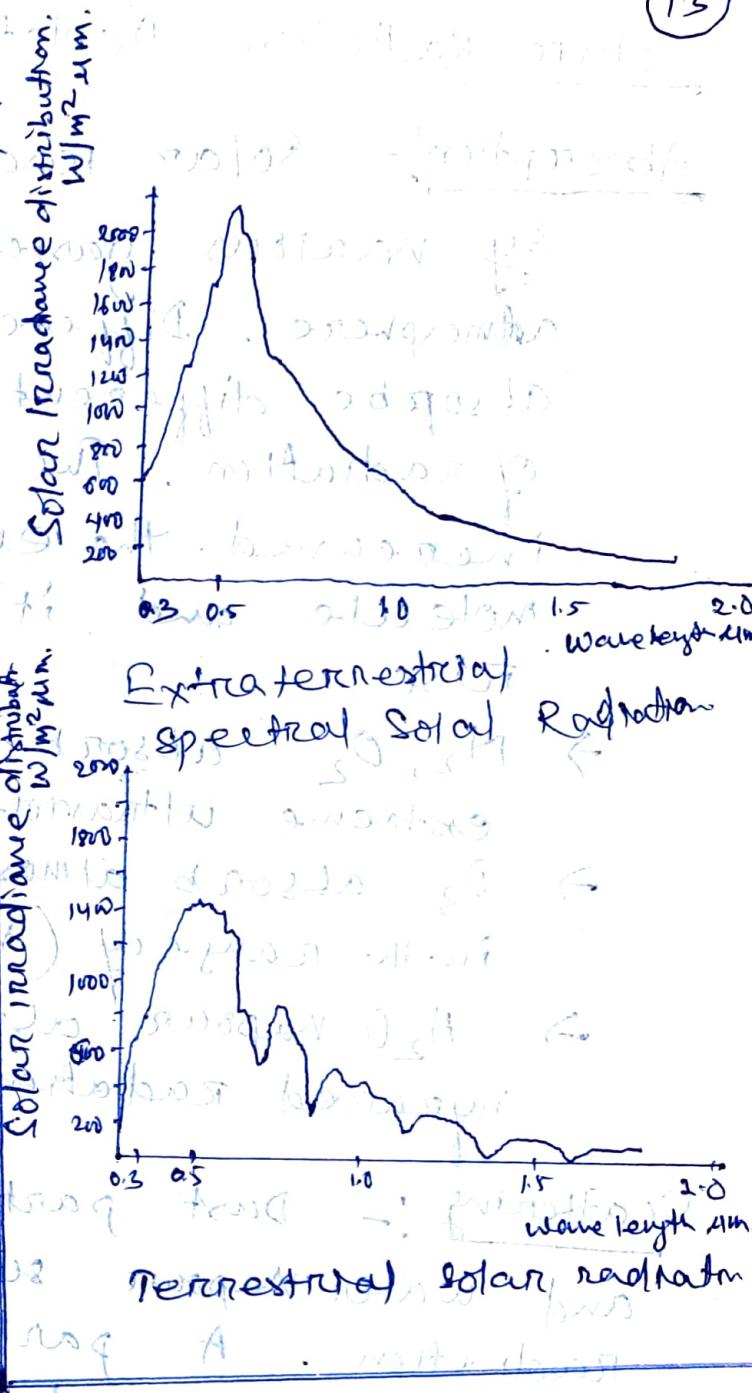
> Solar Insolation

It is the solar radiation received on a flat horizontal surface on earth.

Insolation also includes reflection from water surfaces, forests, built-up areas, and ice sheets.

* Short wave radiation in the range of $\lambda < 0.29 \mu\text{m}$ and long wave radiation of $\lambda > 2.3 \mu\text{m}$ are completely absorbed or reflected back by the earth atmosphere.

Thus, the earth surface receives solar radiation only in the range between $0.29 \mu\text{m}$ to $2.3 \mu\text{m}$.



Solar Radiation Depletion

Absorption:- Solar radiation get absorbed by various gasses molecules in the atmosphere. Different molecules absorb different / selective wavelength of radiation. The absorbed radiation increased the energy of the molecule and it gets a temperature rise.

- N_2, O_2 absorb X-rays, and extreme ultraviolet radiation.
- O_3 absorb almost all of ultraviolet in the range of ($\lambda < 0.38 \text{ nm}$)
- H_2O vapour absorb almost the infrared radiation in the range ($\lambda > 2.3 \text{ nm}$)

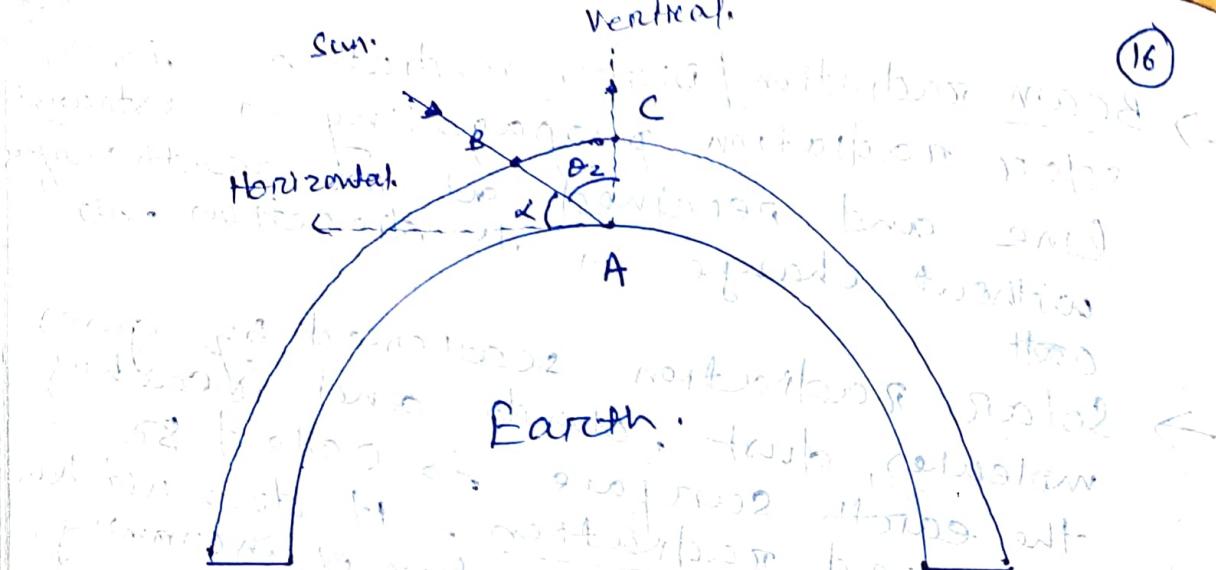
Scattering:- Dust particles, air molecules and water vapour scatter the solar radiation. A part of the scattered radiation lost towards the space and rest are redirected towards earth surface. Scattering makes

- The radiation energy reflected back to the space by reflection from clouds, atmosphere gases, dust particles, and earth surface is called as albedo.

- Beam radiation / Direct radiation is the solar radiation propagating in a straight line and received at the earth surface without change in its direction.
- Solar radiation scattered by gases molecules, dust, clouds and incoming Diffused radiation. It does not have a particular direction of incoming.
- The combination of Beam radiation and diffused radiation is called as Global radiation.
- On a clear sunny day we receive only beam radiation on completely cloudy day we receive only scattered radiation and on partial cloudy day we receive both beam as well as scattered radiation.
- Airmass, it is defined as the ratio of the path length through the atmosphere, which the solar beam actually travels with the vertical path length through the atmosphere.

Mathematically

$$\text{Airmass } m = \frac{\text{Path length travelled by the beam Radiation}}{\text{Vertical Path length of atmosphere}}$$



$$\text{Air mass } m = \frac{\sin \theta_1}{\sin \theta_2} = \sec \theta_2 = \text{constant}$$

θ_1 is the inclination angle of sun

θ_2 is the zenith angle of sun

→ At solar noon and on sea surface

the air mass will be 1 as referred

as AM₁.

→ At the outer atmosphere of earth, where there is no influence of atmosphere

the air mass will be 0 and is referred as AM₀.

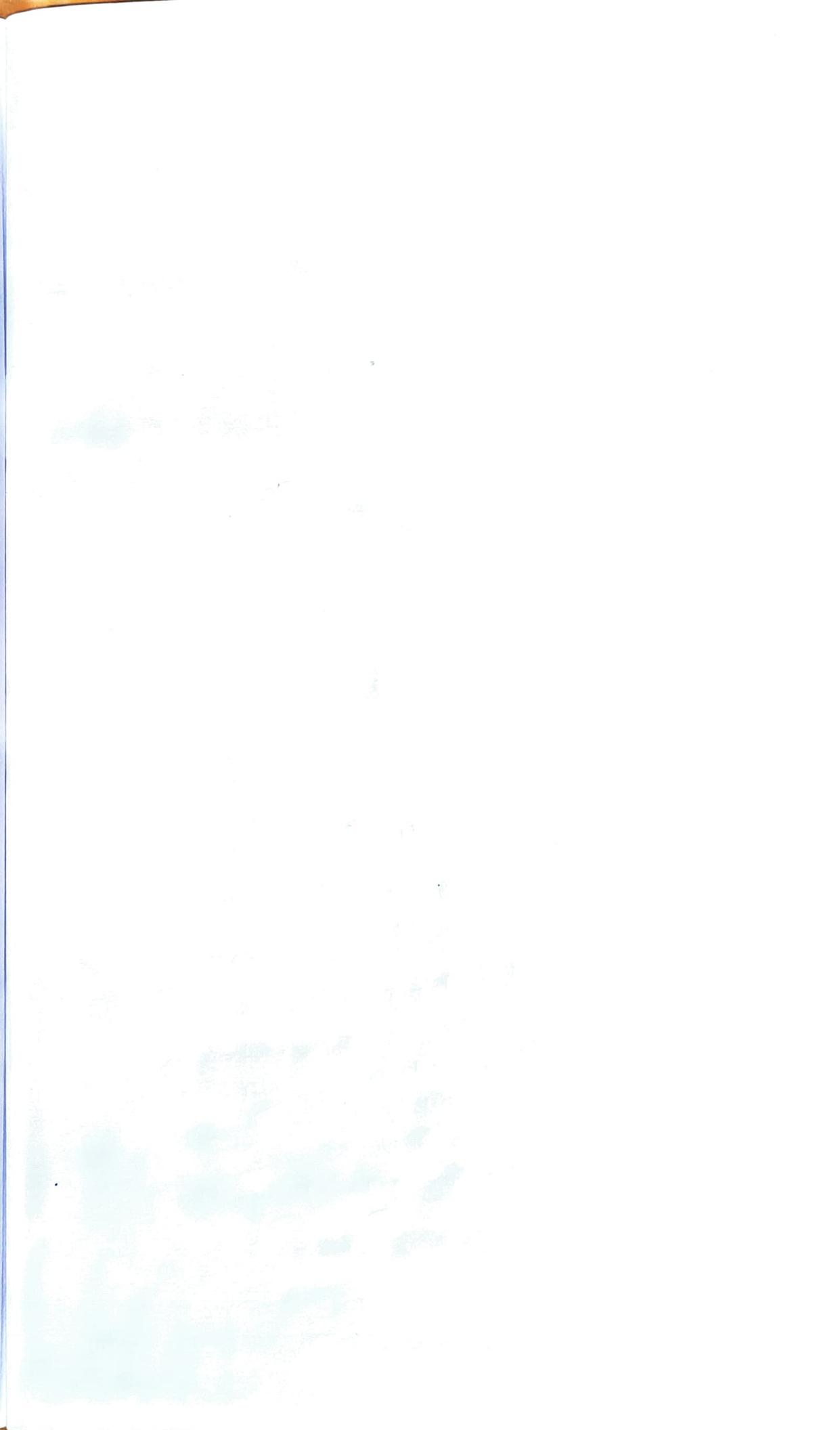
→ At $\theta_2 = 90^\circ$ $m = 2 \rightarrow \text{AM}_{2/3}$ and so on.

For the sun at zenith, the angle is 0°

and greater than 90° the angle is less than 0°

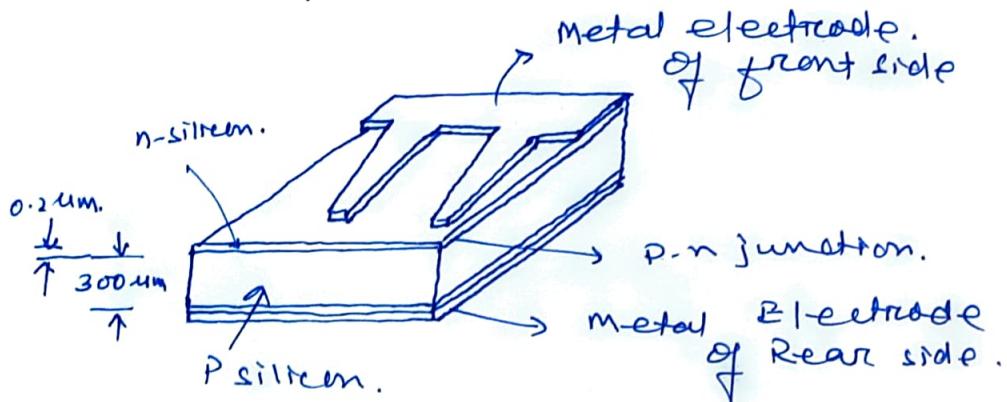
$\theta_1 = 0$ degrees

Planetary winds/



Semiconductor Material for Solar Cells:-

1) Single Crystal Silicon cells.

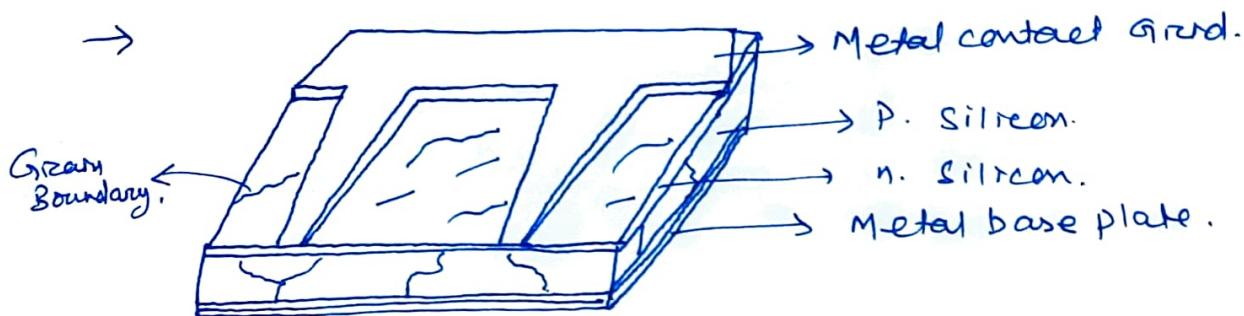


- A single crystal silicon uses basic raw material (SiO_2) sand, from which silicon is extracted and purified repeatedly to obtain pure Si.
- The pure silicon is converted into a single crystal ingot. It is a long cylindrical block of about 6 to 15 cm diameter.
- The cylinder is sliced in wafers of 300 μm thickness.
- The wafer undergoes through the process of surface preparation, dopants diffusion, anti-reflection coating, contact grid on the surface and base contact on the upper surface and on the lower one.
- The wafers are now converted into a single solar cells. Multiple solar cells are fixed or pasted on a board and connected in series and parallel combination to provide the required voltage and power to form a Photovoltaic Module.

- The solar module is sealed between a plate of toughened glass and layers of ethyl vinyl acetate (EVA).
- A terminal box is attached to the back of a module where the two ends of the solar strings are soldered to the terminals.
- Single PV modules of capacities 3 W_p (peak watt) to 250 W_p are available for different loads at different output voltages.
- Several panels of modules are arranged to constitute an array.
- For higher outputs an array of fields is created.
- A standard module constitute 30 cell each of 7.6 cm diameter, can produce a electrical ~~volt~~^{values} of 12 volts, 1.2 amp and 18 watt peak power.

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(ii) Multicrystalline Silicon Solar Cells:-



- Multicrystalline silicon solar cells are less energy intensive in their production and less costly as compared to single-crystal silicon cells.
- They are less energy efficient than single crystal silicon cells.
- Commercial multicrystalline cells have efficiency in the range of 10% to 14%.
- The formation of grain boundary has limited the achievable maximum conversion efficiency.
- Multicrystalline silicon can be obtained in thin ribbons drawn directly from molten silicon bath and cooled very slowly to obtain very large size crystalline.
- Large square shaped solids or thin ribbons can be obtained in multicrystalline leading to economy in material consumption and reduction in unit energy consumption.
- The ribbon is cut in square shape and converted into solar cells.

Amorphous Silicon cells:-

- Amorphous silicon cells are made from pure silicon with no crystal properties.
- It is highly light absorbent and requires only 1 to 2 μm of material to absorb photons of the incident light.
- Thin amorphous layers can be deposited on cheap substrates like steel, glass or plastic.
- Thin amorphous films of nearly 0.7 μm can produce solar cells comparatively at low cost.
- It has low efficiency in the range of 4% to 8%, and they degrade in outdoor application.
- Non-crystalline nature of amorphous material also results in very low mobility of carriers which makes it poor semiconductor material.
- The properties of amorphous silicon are improved when alloyed with hydrogen to get a a-Si:H material.
- By incorporating an intrinsic layer between P and n layers, a reasonable e⁻-hole pair generation region can be created.
- a-Si:H has a direct band gap of 1.75 eV.
- Efficiency can be improved by stacking a number of carefully tailored p-i-n junctions which also reduced the degradation significantly.



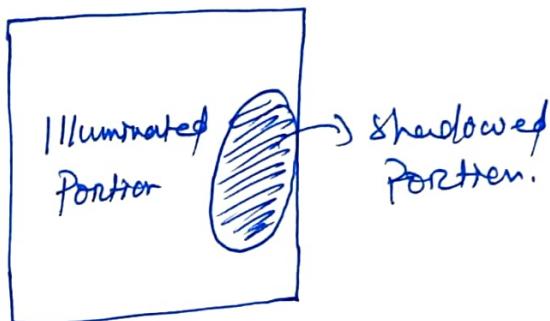
TCO - Transparent conductive oxide.

Solar PV Module:-

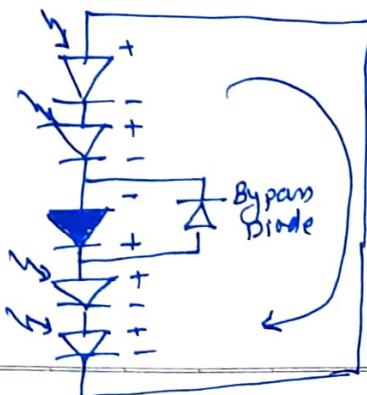
- The output voltage of a single cell is very small.
- Workable voltage and power is obtained by interconnecting an appropriate number of cells in parallel and series.
- The unit is fixed on a durable base cover of several square feet, with transparent cover on the top and sealed to make it suitable for outdoor applications.
- This assembly is known as a "PV module".
- 32 or 36 silicon cells are connected in series to make it charge a 12V storage battery.
- A single module is available in 12V, 24V or higher order voltage output and with a power output from 40W_p to 250W_p.
- ⇒ Cell Mismatch in a Module.
 - It is very important that each cells in a module should have same V_{oc} , I_{sc} , V_m & I_m .
 - Mismatch in cells leads to mismatch losses.
 - Peak power of combination of cells is always less than the sum of individual peak power of each cell.
 - To reduce mismatch losses, modules are fabricated from cells belonging to same batch.
- ⇒ Effect of shadowing!
 - When a cell is partially shadowed, the shadowed portion will not produce any power.
 - The power voltage generated by illuminated portion will forward bias the parallel diodes of the shadowed cells.
 - If the shadowed area is relatively small then the large circulating current through

it will result in excessive heating of the shadowed portion.

- This phenomenon is called as hot-spot effect and it may completely damage a module if exposed for prolonged partial shadowing.



- In a series string of $(n+1)$ cells with one cell completely shadowed, the voltages produced by n illuminated cells add up and appear as reverse bias voltage of nV volts across the shadowed cell.
- If the peak inverse voltage of the shadowed cell is less than the total reverse voltage appeared across it, current will flow through it and possibly damage the cell and the module.
- The damage can be avoided by connecting a bypass diode across the effected cells.



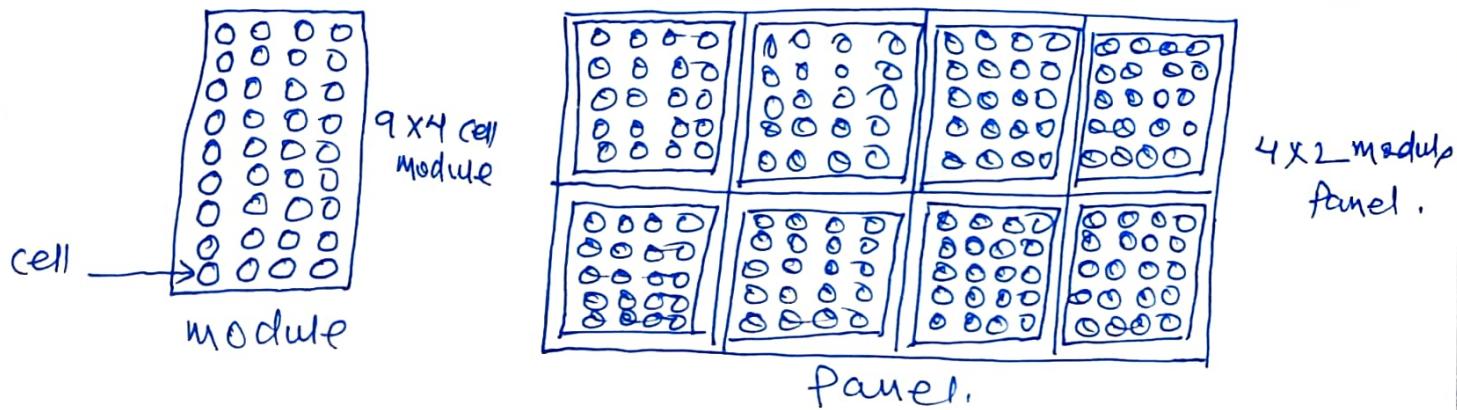
- In healthy operation, the finite reverse leakage current through the bypass diode causes some loss.
- Therefore, bypass diode is provided for every 18 crystalline silicon solar cells in a series string, which is provided in the junction box.

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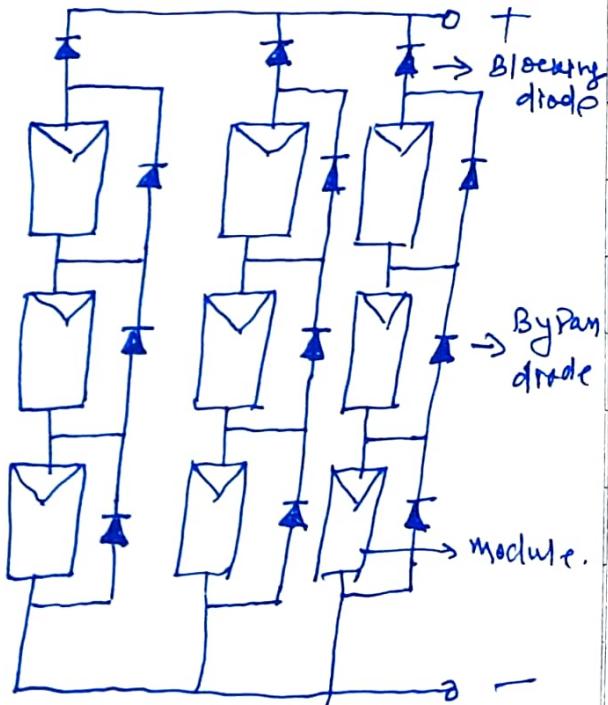
Solar PV Panel.

Solar PV Panel

- Several solar modules are connected in series and/or parallel to increase the voltage/current ratings.
- In series connection, each module's maximum power production ^{must} occur at same current.
- In parallel connection, each module's maximum power production must occur at same voltage.



- In Parallel Connection, blocking diodes are connected in series with each series string of modules.
- If any string fails, the power output of the remaining strings will not be absorbed by the failed string due to the presence of the blocking diode.



→ Bypass diode are installed across each module, so that if one module fails, the output of the remaining modules in a string will bypass the failed modules.

Solar PV array

- A large number of interconnected solar panels, known as solar PV array, are installed in an array field.
- The panels may be installed as fixed or with sun tracking mechanism.
- It is ensured that the shadow of one panel does not fall on the neighbour panels.

Maximum Power Point Tracker (MPPT)

- The output of a solar system is maximised in two ways.
- i) Mechanically tracking the sun and orient the sun panel in such a manner that it always receive the maximum solar radiation.
- ii) Electrically tracking the operating point by manipulating the load to maximise the power output under changing conditions of insolation and temperature.
- The operating point of an electrical system is determined by the intersection of source characteristics (source line) and load characteristics (load line).
- The mechanical tracking increases the installation cost significantly and also increases losses by appearance of tracking motors.

→ In Electrical tracking the load is changed accordingly to track the maximum power point.

(MPPT)

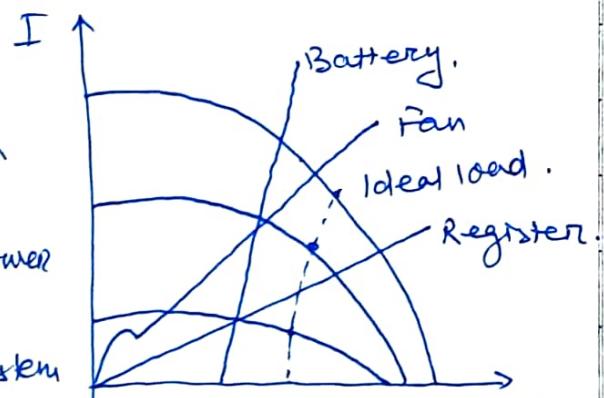
→ An ideal load is one that tracks the maximum power point.

→ An electronic Maximum power point tracker (MPPT) is used between the PV system and the load.

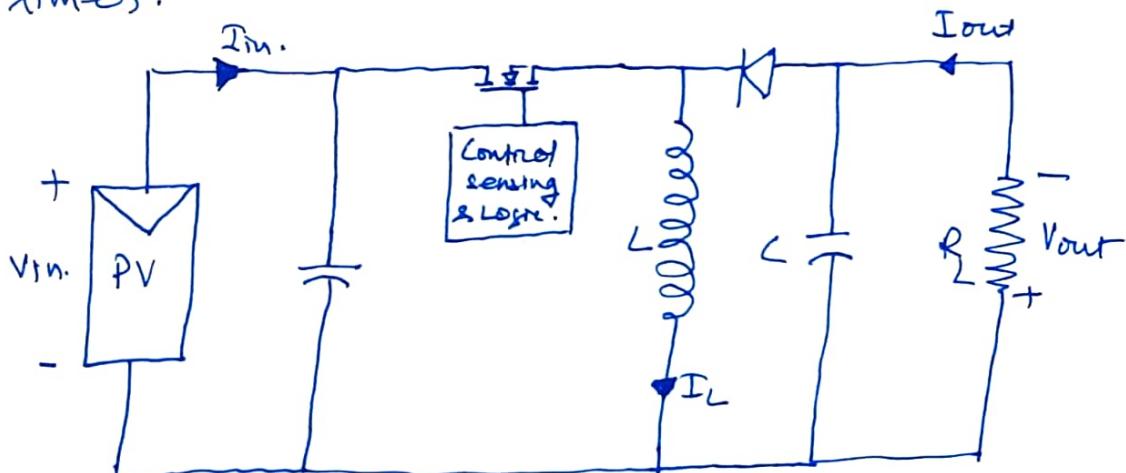
→ MPPT is an adaption of DC-DC switching voltage regulation.

→ Maximum power transfer may require either a higher voltage at a lower current or a lower voltage at a higher current.

→ A buck-boost scheme is used with voltage and current sensors in the feedback loop using a controller to vary the switching times.



Characteristics of PV and some load!



→ The output voltage of the buck-boost converter is given by $V_{out} = \frac{D}{1-D} V_{in}$
 D is the duty cycle of the MOSFET (OLDLI)

→ The power output of a PV system is given by

$$P = V \cdot I$$

with incremental change in current & voltage.

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

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

$$\Rightarrow \Delta P = I\Delta V + V\Delta I \quad \begin{cases} \text{as } \Delta I \Delta V \approx 0 \\ P = IV \end{cases}$$

The value of ΔP must be zero at peak point.

$$\therefore \Delta P = 0$$

$$\Rightarrow I\Delta V + V\Delta I = 0$$

$$\Rightarrow \frac{\Delta V}{\Delta I} = -\frac{V}{I}$$

$\frac{\partial V}{\partial I}$ is the dynamic impedance of the source.

→ Strategies of MPPT.

i) By monitoring Dynamic and static impedance.

→ A small signal current is periodically injected into the array bus and the dynamic as well as static bus impedances (Z_d & Z_s) are measured.

→ The operating voltage is adjusted until $Z_d = -Z_s$.

ii) By monitoring Power output.

→ As dP/dV is zero at maximum power point, the voltage is increased till power get increased.

iii) By fixing the output voltage as a fraction of V_{oc} .

→ As the ratio of V_m and V_{oc} is approximately constant ($\frac{V_m}{V_{oc}} = 0.72$ for crystalline silicon cell)

→ An additional identical unloaded cell is installed on the array and its V_{oc} is measured continuously. The V_m is set at the fixed ratio.

Solar photovoltaic System:-

i) Central Power Station- System:-

- Here the power generated is directly feeded to the grid.
- ~~lower~~ ^{now} central PV power stations has capacities starting from few megawatts peak to several hundred MW_p.
- As the cost of capital for solar system, has reduced significantly in recent years, and are now at par or even lower in some cases with respects to conventional thermal power plants or Diesel generators.
- Very large capacity (about 5000MW_p) ~~several~~ ^{new} PV power stations are being planned and are in various stages of installation across India.

ii) Distributed System:-

a) Stand-alone System:-

- It is located at the load centre and dedicated to meet all electrical loads of a village / community or an industrial units.
- During day time load is feed directly from the PV panels and during night time load is sourced from storage battery.
- The capacity of such system varied from few kW_p to few MW_p Power outputs.

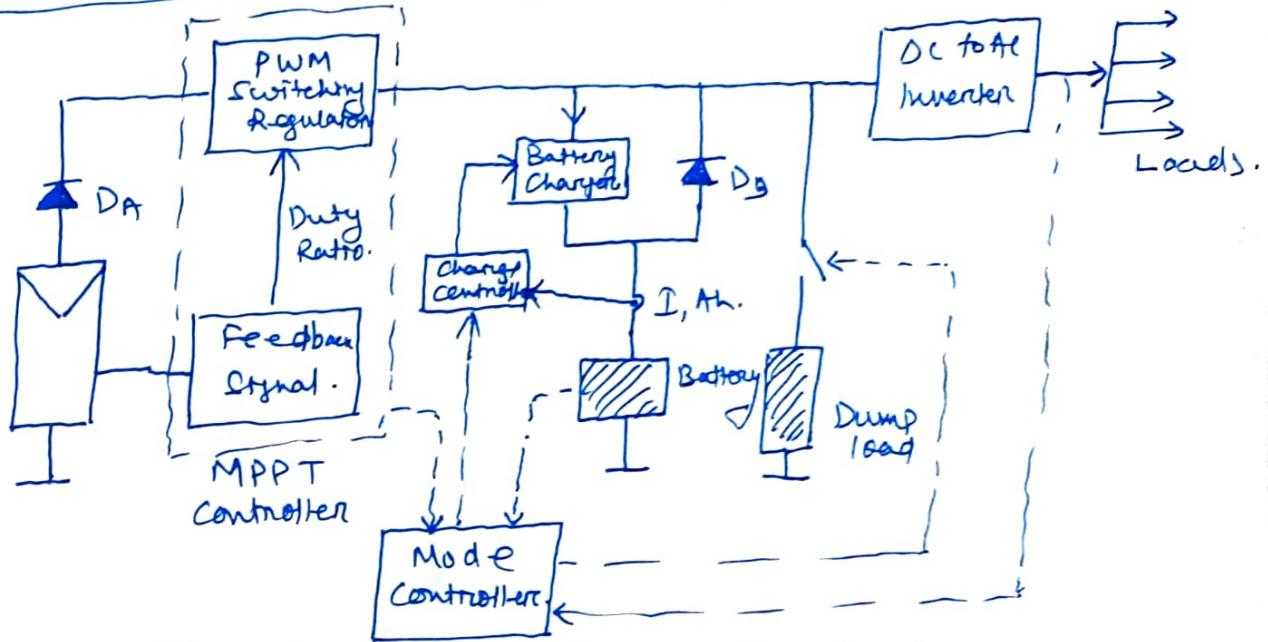
b) Grid-interactive system! -

- 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 larger system meant for the whole village or a community or by a industrial unit.
- It meets the daytime load requirement from the solar system, and surplus power is fed to the grid.
- During night time or peak hours the energy requirement is met from the grid.
- It omits the storage battery and the cost reduced significantly.

c) Small system for consumer Apperations! -

- This is for low power consuming demo.
- The capacity vary from micro watts to few watts.
- May be designed for indoor or outdoor use.
- examples are - calculators, watches, electronic items, mobile phones, solar lantern, solar street lights, solar pump etc.

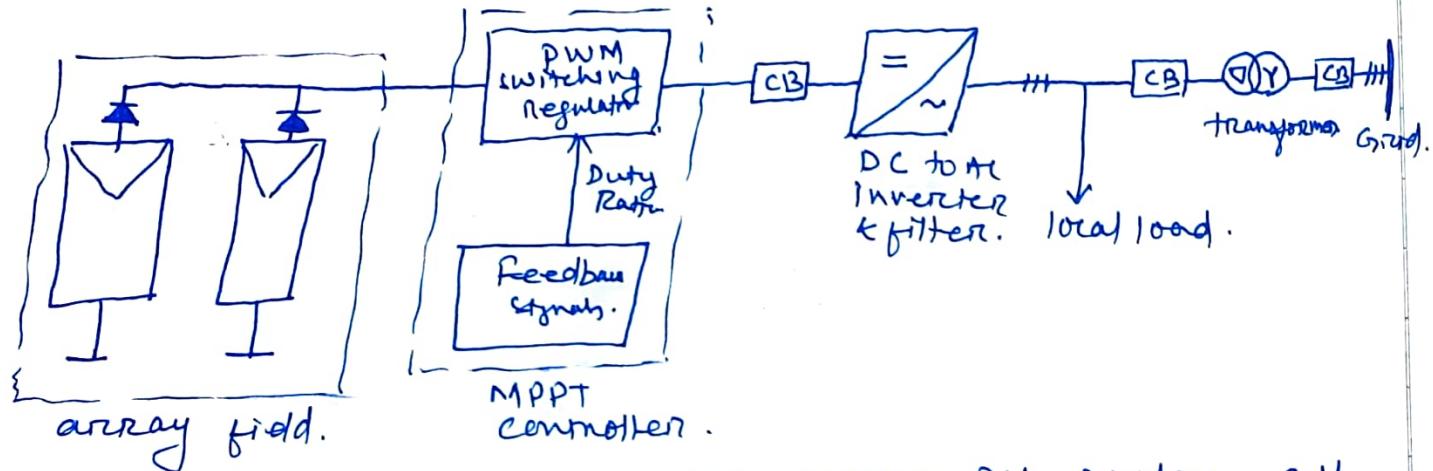
Stand - alone solar PV system.



Stand-Alone Solar PV system.

- The MPPT senses the voltage and current outputs of the array and adjusts the operating point to extract maximum power under the given climatic conditions.
- The output of the array after converting to AC is fed to loads.
- If excess power is still available after fully charging the battery, and after fully charging the battery it may be shunted to dump heaters.
- When sun is not available, the battery supplies the load.
- D₃ prevents the battery from over charged.
- D_A isolate the array from battery to prevent the battery to discharged through array at nights.
- The mode controller collects the signals and keep track of charge/discharge of battery, matched maximum power output and load by commanding charger and dump/load heater on-off.

Grid Interactive Solar PV-system.



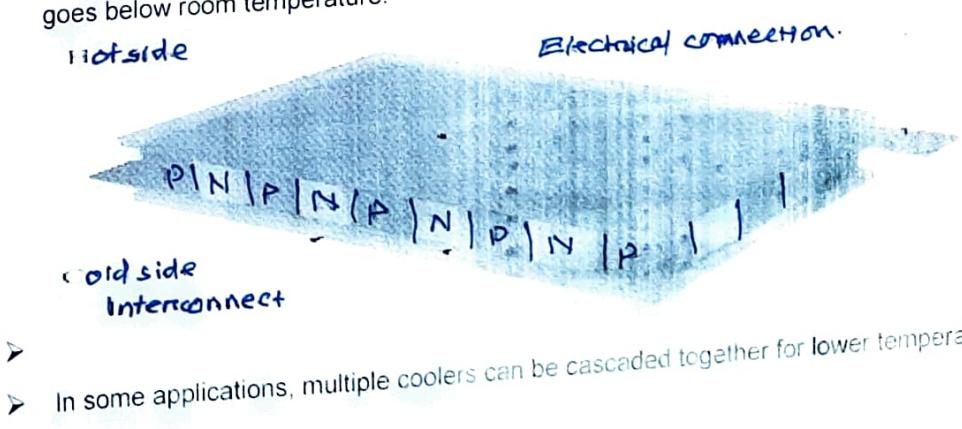
- In a grid interactive solar PV system, all excess power is fed to a grid and dump heaters are not required.
 - During absence of sunshine, supply of power is maintained from grid, and battery is eliminated.
 - Only requirement is synchronized operation. The DC power is converted to AC by an inverter, harmonics are filtered out and then only the filtered power is fed into the grid after adjusting the voltage level and phase angles.
- X —

Peltier cooler

- A Peltier cooler uses the Peltier effect to create a heat flux between the junction of two different types of materials.
- A Peltier cooler is a solid-state active heat pump which transfers heat from one side of the device to the other, with consumption of electrical energy, depending on the direction of the current.
- It can be used either for heating or for cooling. It can also be used as a temperature controller that either heats or cools.
- Advantages of a Peltier cooler are its lack of moving parts or circulating liquid, very long life, invulnerability to leaks, small size and flexible shape.
- Its main disadvantage is high cost and poor power efficiency
- A Peltier cooler can also be used as a thermoelectric generator
 - When operated as a cooler, a voltage is applied across the device, and as a result, a difference in temperature will build up between the two sides.
 - When operated as a generator, one side of the device is heated to a higher temperature than the other side, and as a result, a difference in voltage will build up between the two sides.

Operating principle

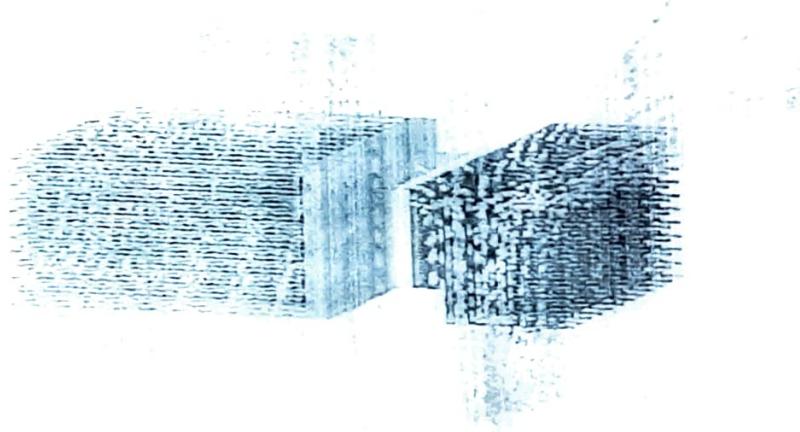
- Thermoelectric coolers operate by the Peltier effect
- The device has two sides, and when DC current flows through the device, it brings heat from one side to the other, so that one side gets cooler while the other gets hotter. The hot side is attached to a heat sink so that it remains at ambient temperature, while the cool side goes below room temperature.



- In some applications, multiple coolers can be cascaded together for lower temperature.

Construction

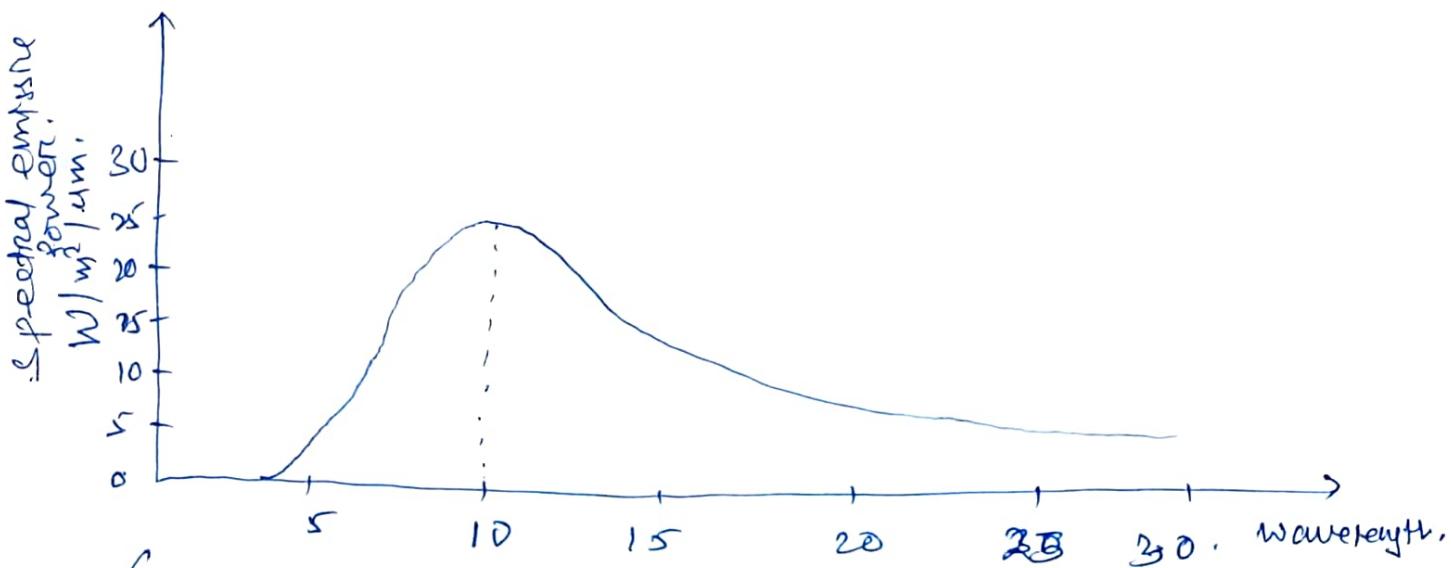
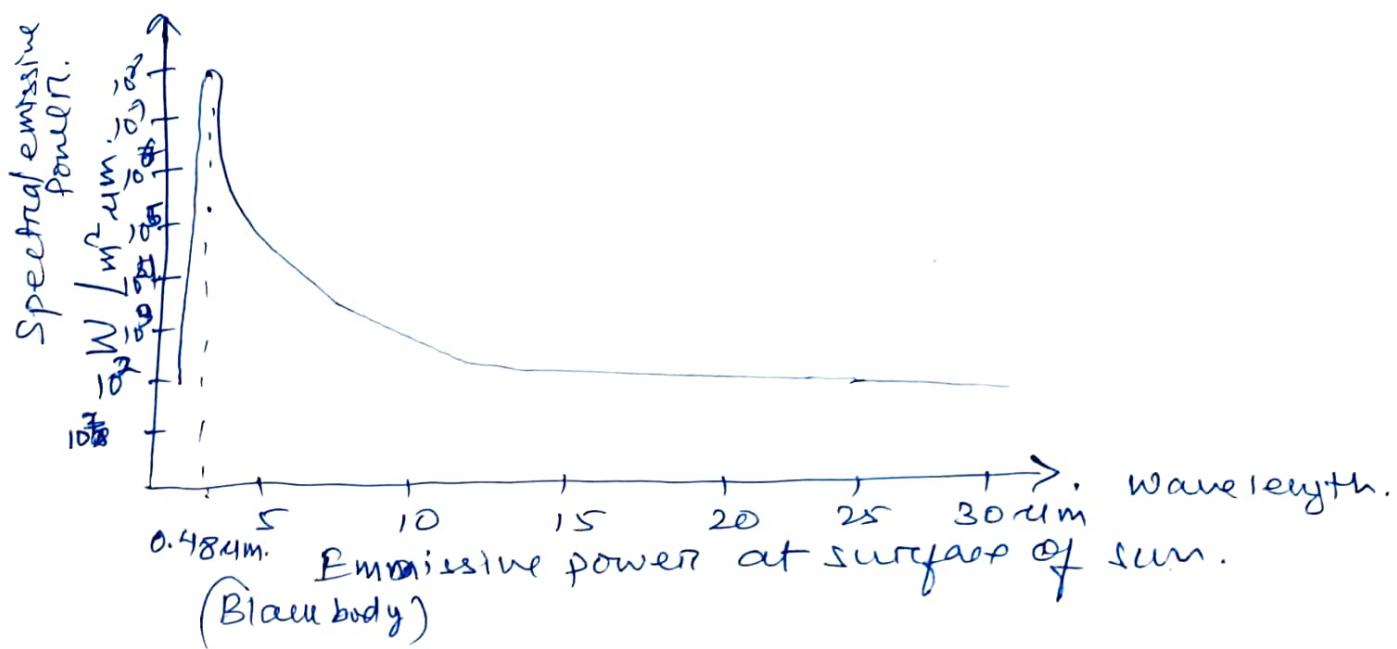
- Two unique semiconductors, one n-type and one p-type, are used because they need to have different electron densities
- The semiconductors are placed thermally in parallel to each other and electrically in series and then joined with a thermally conducting plate on each side.



- When a voltage is applied to the free ends of the two semiconductors there is a flow of DC current across the junction of the semiconductors causing a temperature difference. The side with the cooling plate absorbs heat which is then moved to the other side of the device where the heat sink is.
- Peltier cooler are typically connected side by side and sandwiched between two ceramic plates. The cooling ability of the total unit is then proportional to the number of Peltier cooler in it.

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Sun & Earth Radiation Spectrums.



(Black Body) Emissive power at surface of Earth.

Irradiance- It is defined as the measure of power density of sunlight received at a location on the earth and is measured in W/m^2 .

Irradiation- It is the measure of energy density of sunlight measured in kWh/m^2 denoted by (H).

Extraterrestrial Radiation. (I_{ext}) .

→ Solar radiation incident on the outer atmosphere of the earth is known as extraterrestrial radiation.

Solar Constant:- (I_{sc})

→ Solar constant is defined as the energy received from the sun per unit time, on a unit area of surface perpendicular to the direction of propagation of the radiation at the top of the atmosphere and at the earth's mean distance from the sun.

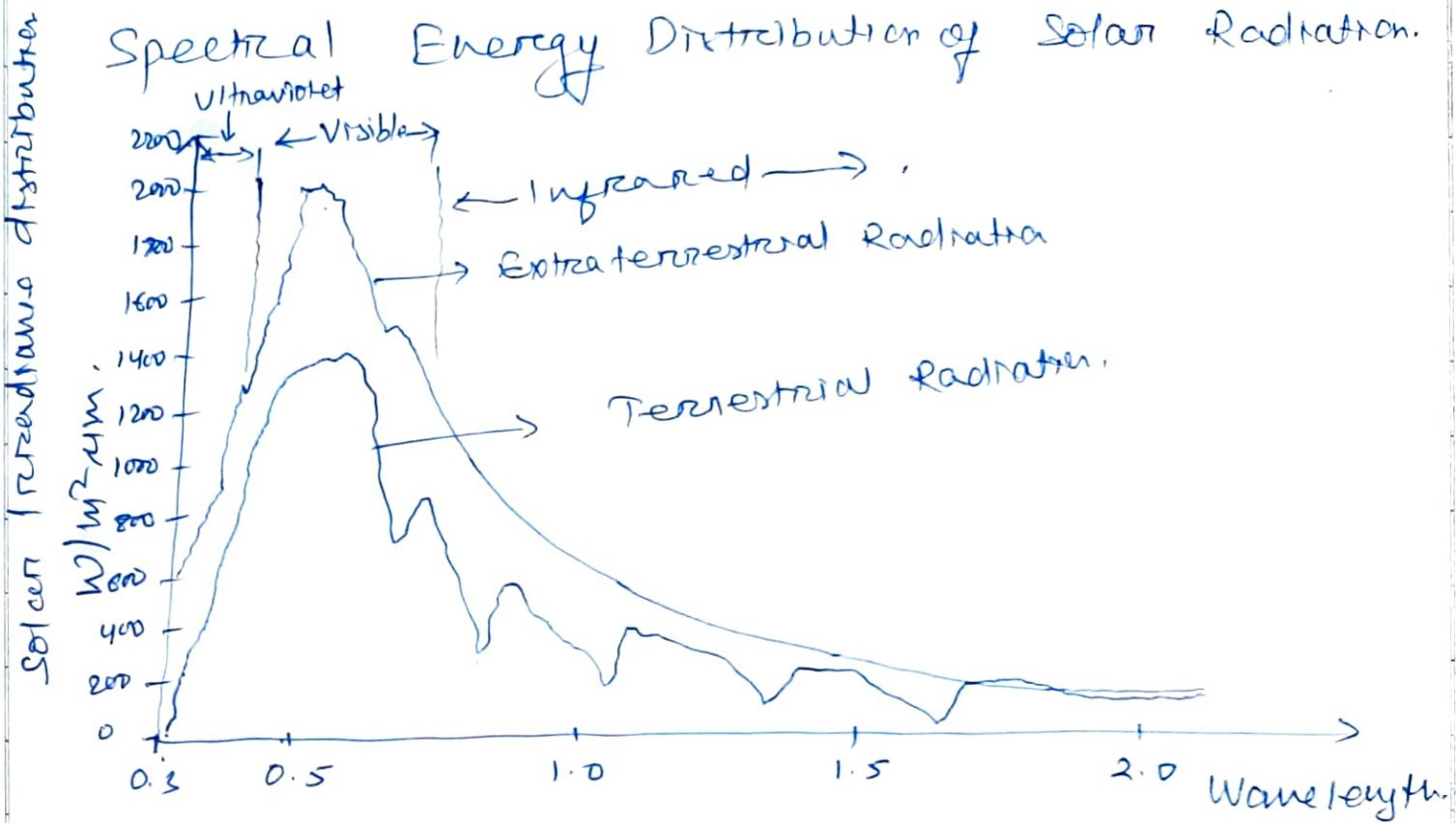
→ The solar constant is assumed by the World Radiation center as 1367 W/m^2 .

Terrestrial Radiation :-

→ The solar radiation that reaches the earth surface after passing through the earth's atmosphere is known as terrestrial radiation. 1000 W/m^2

Solar Insolation:-

→ It is defined as the solar radiation received on a flat horizontal surface on the earth.



- About 99% of the extraterrestrial radiation has wavelengths in the range from 0.2 to 0.48 μm. with maximum intensity at 0.48 μm.
0.48 μm → green portion of visible light rays.
- About 6.4% of radiation energy is contained in Ultraviolet region. ($\lambda < 0.38 \mu\text{m}$)
- 48% of radiation contained in visible region $0.38 < \lambda < 0.78 \mu\text{m}$.
- 45.6% is contained in Infrared region. ($\lambda > 0.78 \mu\text{m}$).
- The atmosphere absorb almost completely the radiation in short wave ($\lambda < 0.29 \mu\text{m}$) and long wave ($\lambda > 2.3 \mu\text{m}$).
- Terrestrial radiation is in the range of wavelength from 0.29 μm to 2.3 μm.

Direct Radiation (Beam Radiation).

Solar radiation propagating in a straight line and received at the earth surface without change of direction i.e. in line with the sun is called direct radiation.

Diffused Radiation:-

Solar radiation scattered by aerosols, dust and molecules is known as diffused radiation.

It does not have a unique direction.

Global Radiation:-

The sum of direct radiation and diffused radiation is known as Global radiation.

Air Mass :-

It is defined as the ratio of the path length through the atmosphere, which the solar beam actually traverses up to the ground to the vertical path length through the atmosphere.

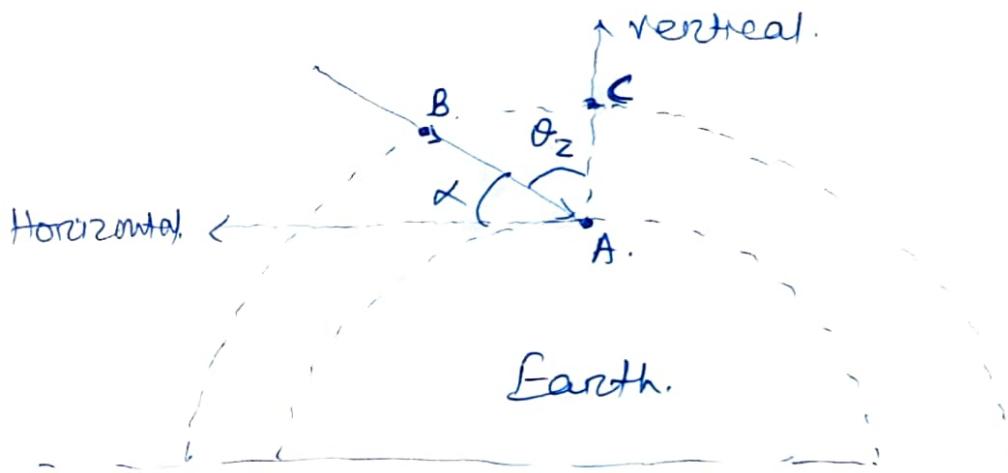
Airmass (m) =

$$\frac{\text{Path length traversed by beam radiation}}{\text{Vertical path length of atmosphere.}}$$

The notation AM_0 refers to zero-atmosphere i.e. radiation at outer space.

AM_1 refers to $m=1$, sun overhead, $\theta_z = 0^\circ$.

AM_2 refers to $m=2$, $\theta_z = 60^\circ$. . .



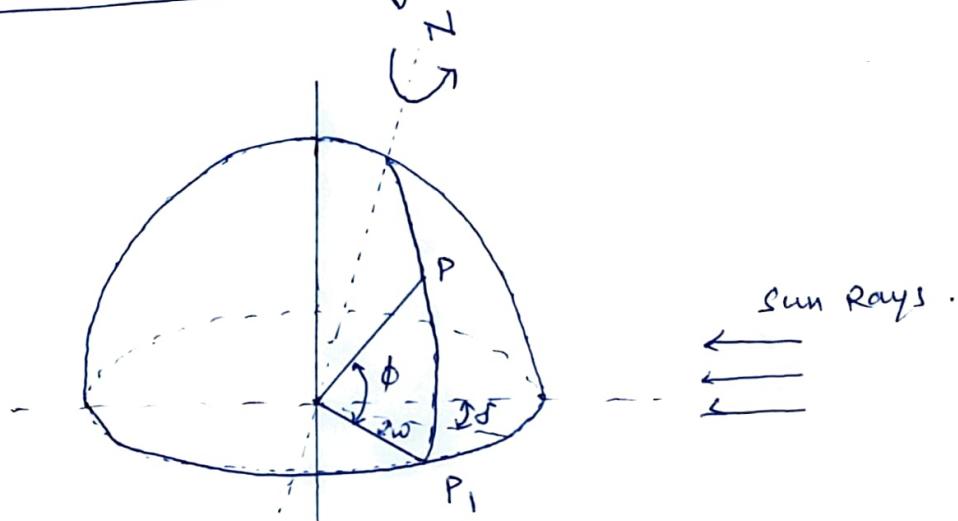
$$m = \frac{BA}{CA} \Rightarrow \text{Solar } \theta_z$$

$$= \text{See } \theta_z = \text{cosine } \alpha$$

θ_z is the zenith angle.
 α is the inclination angle.

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Solar Radiation Geometry.



Latitude (ϕ) - The latitude ϕ of a place is the angle subtended by the radial line joining the place to the centre of the earth, with the projection of the line on the equatorial plane.

→ The latitude of north hemisphere is measured (+).

Declination (δ) - It is the angle subtended by a line joining the centres of the earth and sun with its projection on equatorial plane of earth
 → It varies from max value of $+23.45^\circ$ on june 21 to a minimum of -23.45° on Dec 22.

→ The declination is zero on March 22 and September 22.

$$\text{It is calculated as } \delta = 23.45 \sin \left[\frac{360}{365} (284 + n) \right]$$

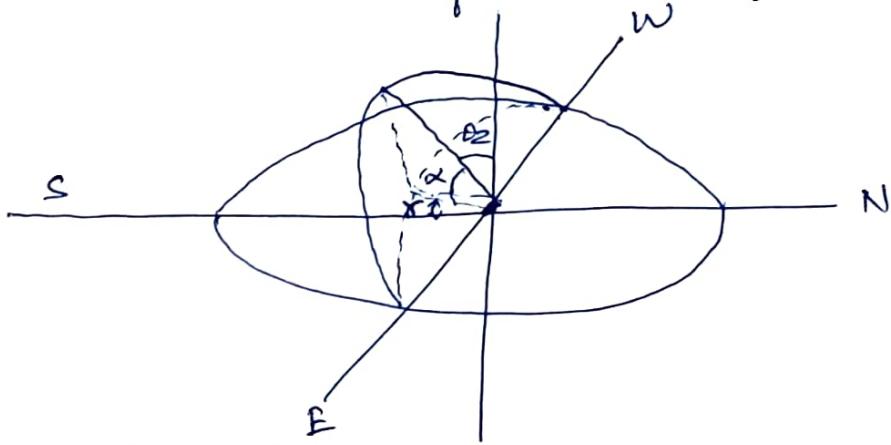
where n is the number of present day in the year.

$$\text{March 22} = 31 + 29 + 22 = 82$$

Hour angle (ω): Hour angle ω is the angle through which the earth must rotate to bring the meridian of the point directly under the sun.

- It is the angular measurement of time at the rate of 15° per hour.
- Hour angle is measured from noon.
- It is +ve in afternoon and -ve in forenoon.

Altitude Angle (α): It is a vertical angle between the direction of sun rays passing through the



(point) and its projection on the horizontal plane.

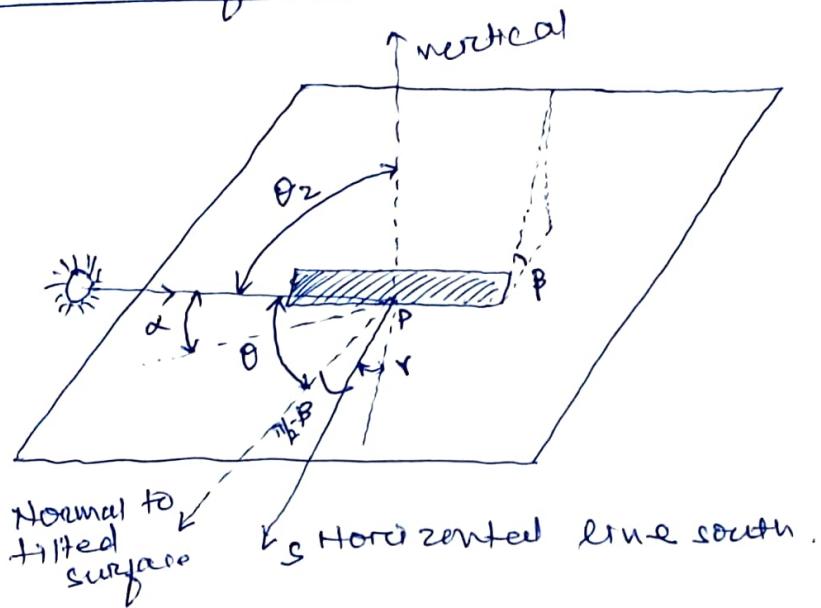
Zenith angle (θ_2): It is the vertical angle between the sun's rays and the line perpendicular to the horizontal plane through the point.

$$\theta_2 + \alpha = \pi/2$$

Surface azimuth angle (r): It is an angle subtended in the horizontal plane by the normal to the surface on the horizontal plane to the N-S direction.

It is +ve if sun is west of south and -ve if sun is east of south in north hemisphere.

Tilted surface



slope (β): It is an angle made by the plane surface with the horizontal surface.

→ The angle is taken positive for a surface facing south and negative for a surface facing north.

Incident beam energy falling on any surface

$$I = I_b \cos \theta$$

I_b → incident beam flux,

θ → the angle between the incident beam and the normal to the tilted surface.

$$\begin{aligned} \cos \theta = & \sin \phi (\sin \delta \cos \beta + \cos \delta \cos \gamma \cos \omega \sin \beta) \\ & + \cos \phi (\cos \delta \cos \omega \cos \beta - \sin \delta \cos \gamma \sin \beta) \\ & + \cos \delta \sin \gamma \sin \omega \sin \beta. \end{aligned}$$

i) For a vertical surface

$$\beta = 90^\circ.$$

$$\cos \theta = \sin \phi \cos \delta \cos r \cos \omega \\ - \cos \phi \sin \delta \cos r + \cos \delta \sin r \sin \omega$$

ii) For a horizontal surface.

$$\beta = 0^\circ.$$

$$\cos \theta = \sin \phi \sin \delta + \cos \phi \cos \delta \cos \omega$$

iii) In northern hemisphere, if the surface
is facing due south.

$$\gamma = 0^\circ.$$

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