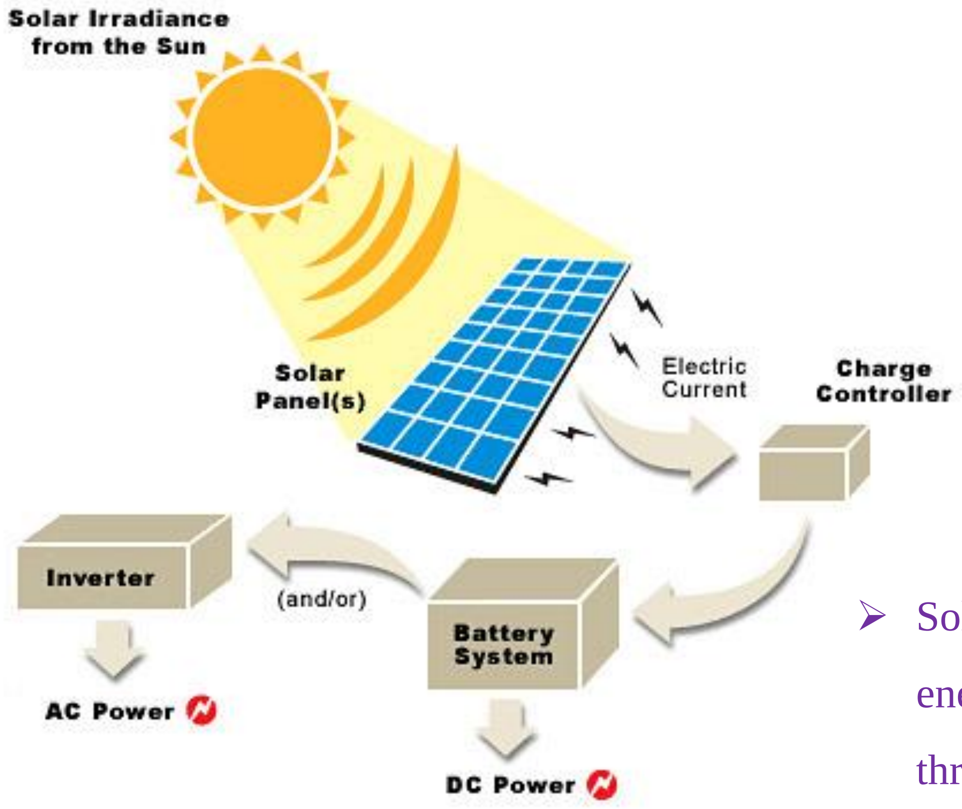


Unit – II
Solar Thermal Conversion and Solar PV Systems

- Solar technologies convert sunlight into electrical energy either through photovoltaic (PV) panels or through mirrors that concentrate solar radiation.
- This energy can be used to generate electricity or be stored in batteries or thermal storage.

Solar thermal energy

- Clean, cheap and abundantly available renewable energy which has been used since ancient times.
- The sun is a sustainable source of providing solar energy in the form of radiations, visible light and infrared radiation.
- Captured naturally by different surfaces to produce thermal effect or to produce electricity by means of photovoltaic or day lighting of the buildings.
- Converted into ‘thermal energy’ by using solar collector.
- It can be converted into ‘electricity’ by using photovoltaic cell.
- ‘Solar collector’ surface is designed for high absorption and low emission.

Advantages & Disadvantages

- Easily and abundantly available
- Re-usable source of energy
- Eco-friendly (i.e. pollution free)
- Reduces Green-house gas emissions

- Availability is limited to sun hours
- Need of storage
- Large area entails high capital cost
- To change in the position of sun, tracking is required

Applications

Solar water heating

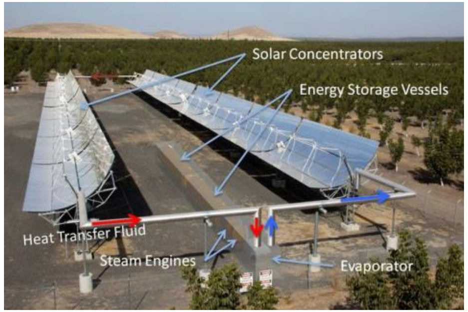
Solar pumping

Solar distillation

Solar cooking

Solar Furnace

Solar power generation



Solar steam generation

Solar Collectors

A device that collects and/or concentrates solar radiation from the Sun

- Solar power has low density per unit area (1 kW/sq. m. to 0.1 kW/sq. m.).
- It is to be collected by covering large ground area by solar thermal collectors.
- Solar thermal collector essentially forms the first unit in a solar thermal system.
- It absorbs solar energy as heat and then transfers it to heat transport fluid efficiently.
- The heat transport fluid delivers this heat to thermal storage tank / boiler / heat exchanger, etc., to be utilized in the subsequent stages of the system.

Classifications of Solar Collectors

Non-concentrating or Flat-plate type

The area of a collector to grasp the solar radiation is equal to the absorber plate and has concentration ratio of 1.

Concentrating or Focusing type

The area of collector is kept less than the aperture through which the radiation passes, to concentrate the solar flux and has high concentration ratio.

Sub Classifications of Solar Collectors

Non-concentrating	Concentrating	
	Focus	**Non Focus**
Flat-plate collectors	Parabolic trough collector	Compound parabolic concentrator (CPC)
	Mirror strip collector	
Evacuated Collectors	Fresnel lens collector	Flat-plate collector with adjustable mirrors
	Parabolic dish collector	

Selection of Collector for Various Applications

1. **Low temperature:**

   (t = 100°C)

   (*i*) Water heating
   (*ii*) Space heating
   (*iii*) Space cooling
   (*iv*) Drying.

   ...*Flat plate*

2. **Medium temperature:**

   (t: 100 to 200°C)

   (*i*) Vapour engines and turbines
   (*ii*) Process heating
   (*iii*) Refrigeration
   (*iv*) Cooking.

   ...*Cylindrical Parabola*

3. **High temperature:**

   (t > 200°C)

   (*i*) Steam engines and turbines
   (*ii*) Stirling engine
   (*iii*) Thermo-electric generators.

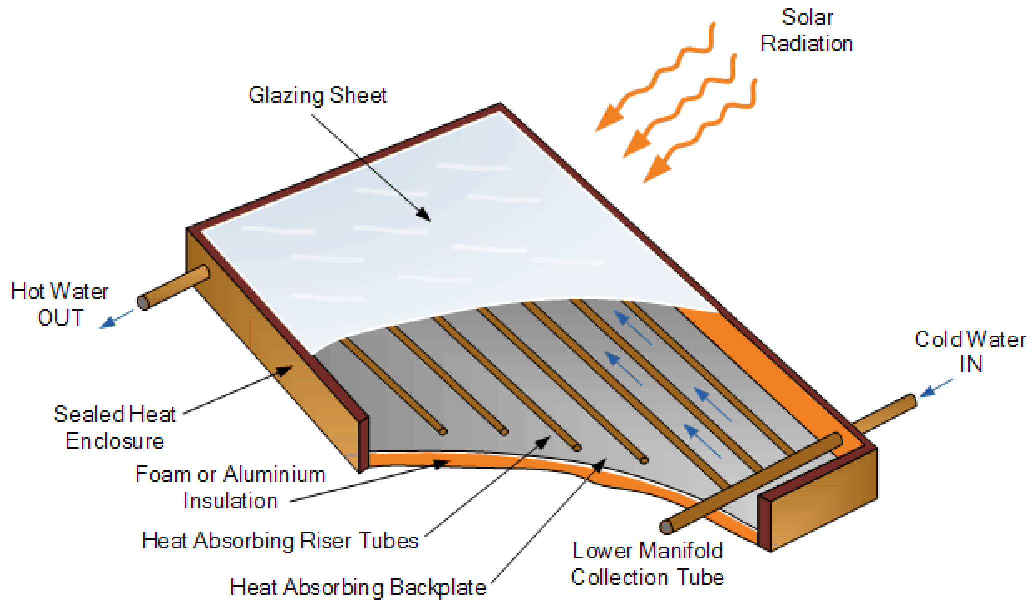
   ...*Parabolloid Mirror arrays*

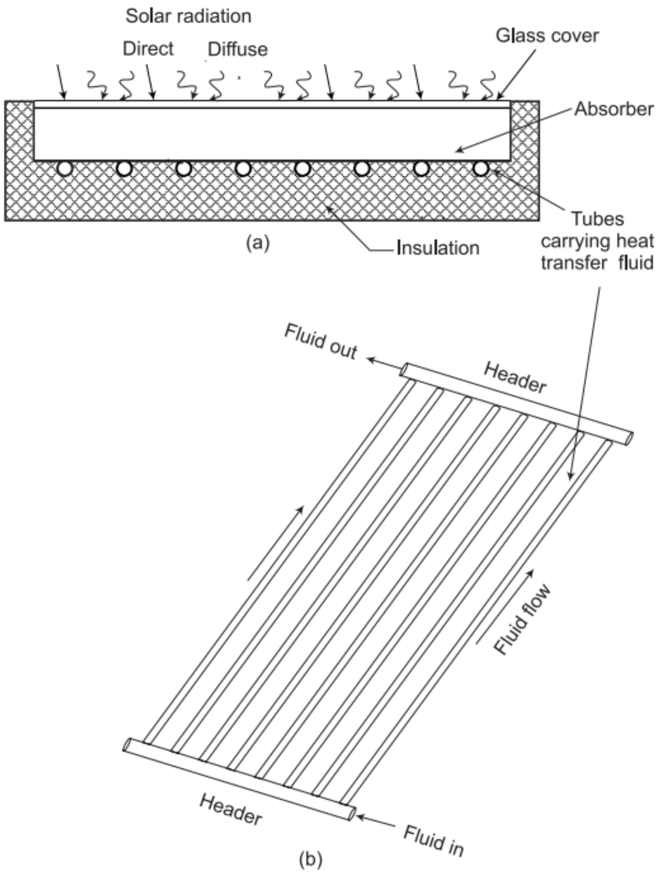
Comparison between Flat-Plate and Concentrating Collectors

S.No.	Aspects	Flat-plate collector	Concentrating collector
1.	*Absorber area*	Large	Small (comparatively)
2.	*Insolation intensity*	Less	More
3.	*Working fluid temperature*	Low temperatures attained	High temperatures attained
4.	*Material required by reflecting surfaces*	More	Less
5.	*Use for power generation*	Cannot be used	Can be used
6.	*Need of tracking system*	No	Yes
7.	*Flux received on the absorber*	Uniform	Non-uniform
8.	*Collection of beam and diffuse solar radiation components*	*Beam as well as diffuse* solar radiation components collected.	Only beam component collected (because diffuse component cannot be reflected and is thus lost).

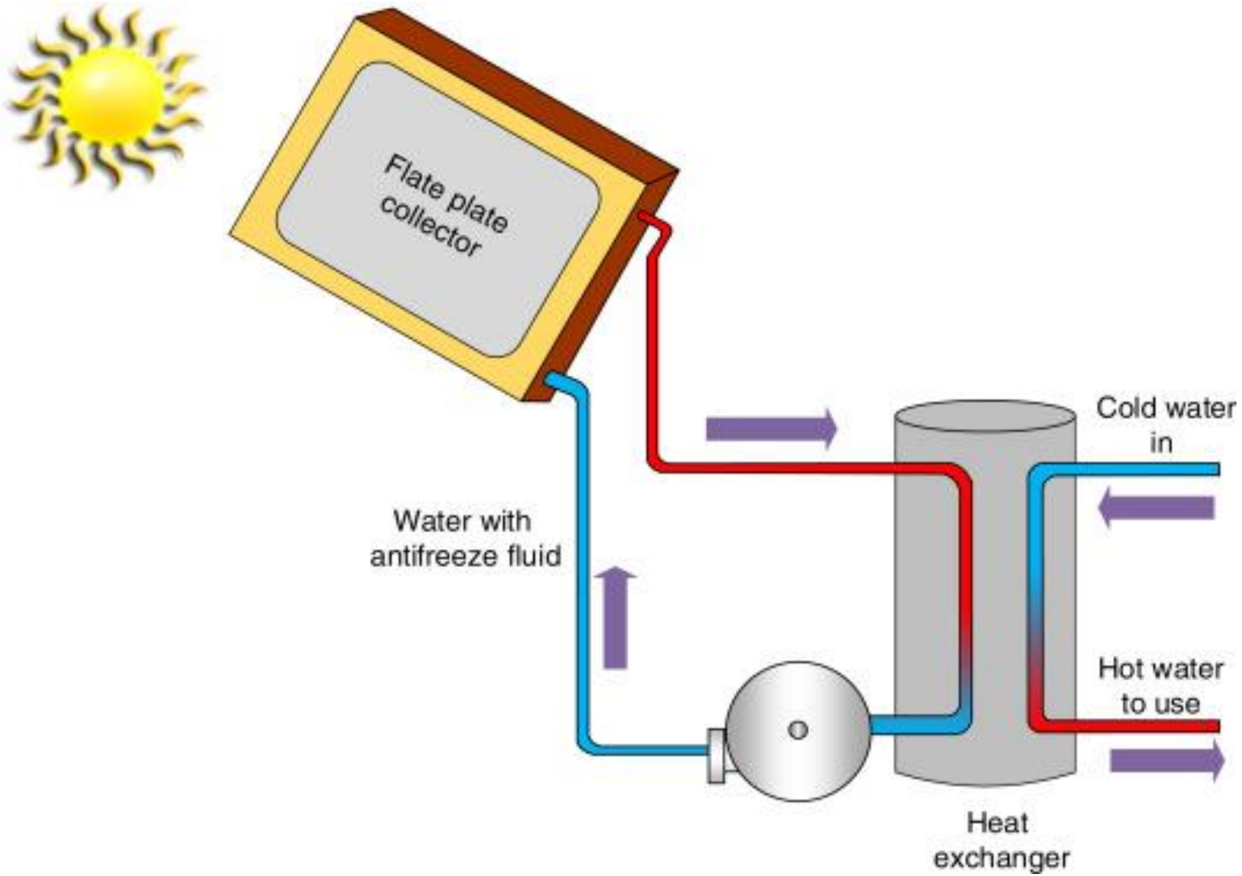
Flat plate collector (FPC)

A heat transport fluid (usually air or water) is used to extract the energy collected and passes over, under or through passages which form an integral part of the plate.



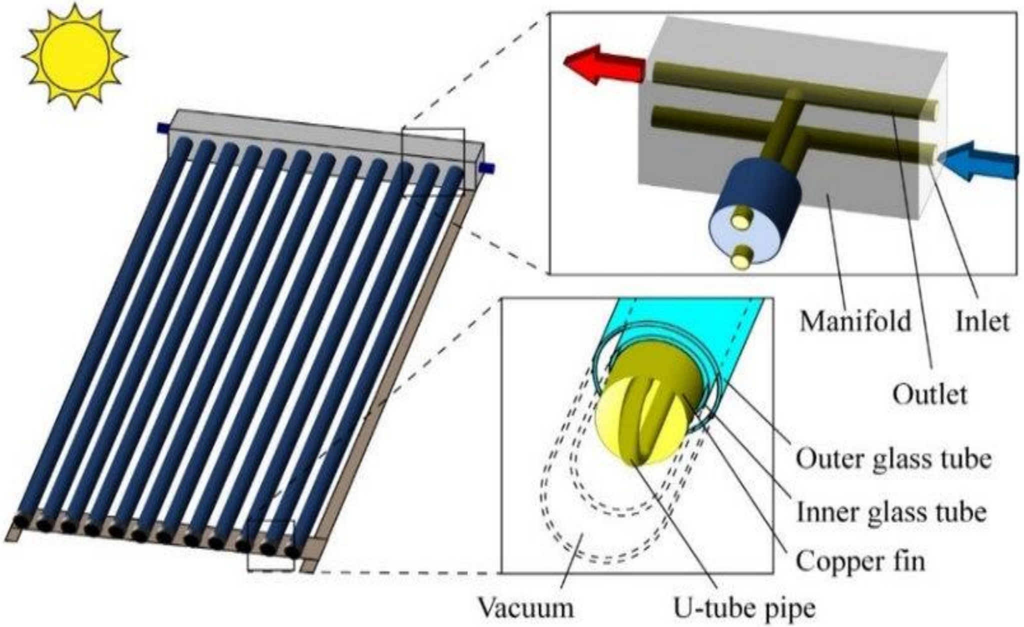


Flat plate collector (FPC) – Water Heating



Evacuated Collectors

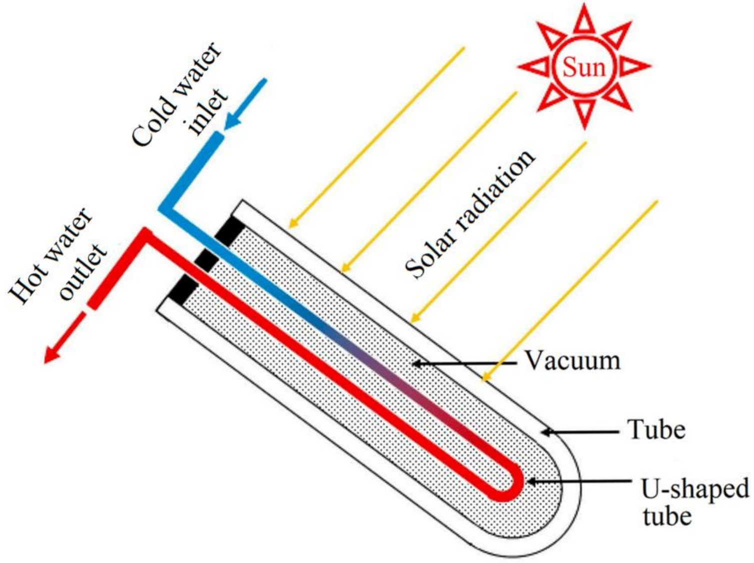
An evacuated-tube collector consists of parallel rows of glass tubes connected to a header pipe. Each tube has the air removed from it to eliminate heat loss through convection and radiation



Applications:

- **Water heating**
- **Air heating**
- **Desalination**

Evacuated Collectors – Working



Its working process is based on the following steps:

(1) Water (heat transfer fluid) flows through the header pipe,

(2) The water is guided toward the copper U-pipe that is surrounded by the evacuated tube, and

(3) The heat transfer fluid absorbs the energy of sunlight while it goes through the U-pipe.

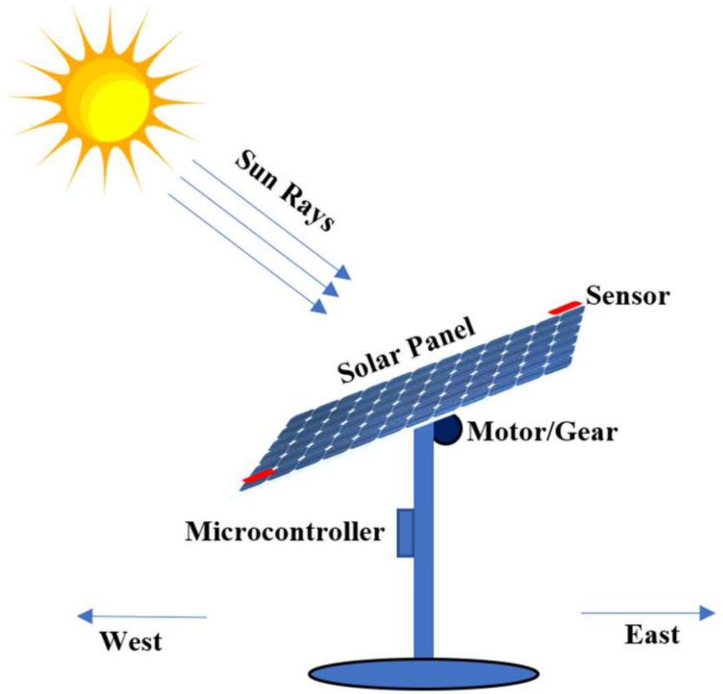
CONCENTRATING (OR FOCUSING) COLLECTORS

A device to collect solar energy with high intensity of solar radiation on the absorbing surface by the help of reflector or refractor

- It is a special form of flat-plate collector modified by introducing a reflecting (or refracting) surface (concentrator) between the solar radiations and the absorber
- Have radiation increase from low value of 1.52 to high values of the order of 10,000.
- Radiation falling on a relatively large area is focused on to a receiver (or absorber) of considerably smaller area.
- As a result of the energy concentration, fluids can be heated to temperatures of 500°C or more.

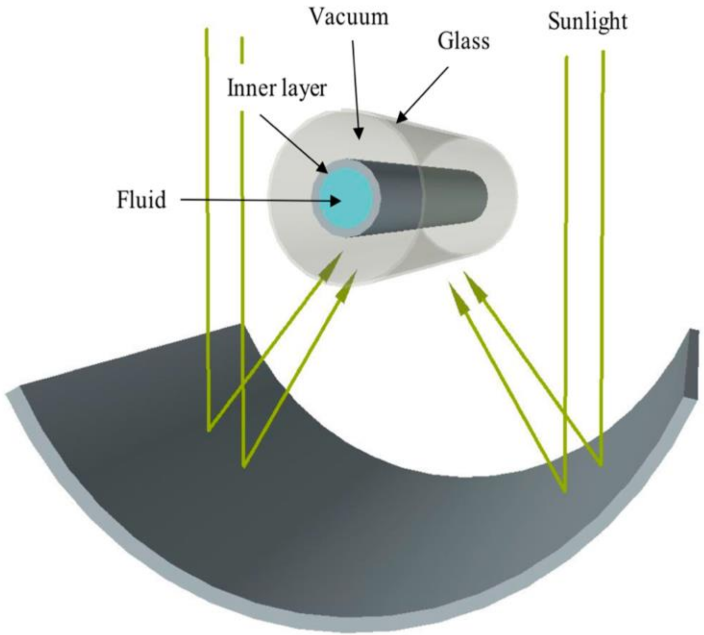
Need of Orientation in Concentrating Collectors:

- Orientation of sun from earth changes from time to time.
- So to harness maximum solar rays it is necessary to keep our collector facing to sun rays direction.
- This is the reason why orientation in concentrating collector is necessary.
- This is achieved by the use of "Tracking device".



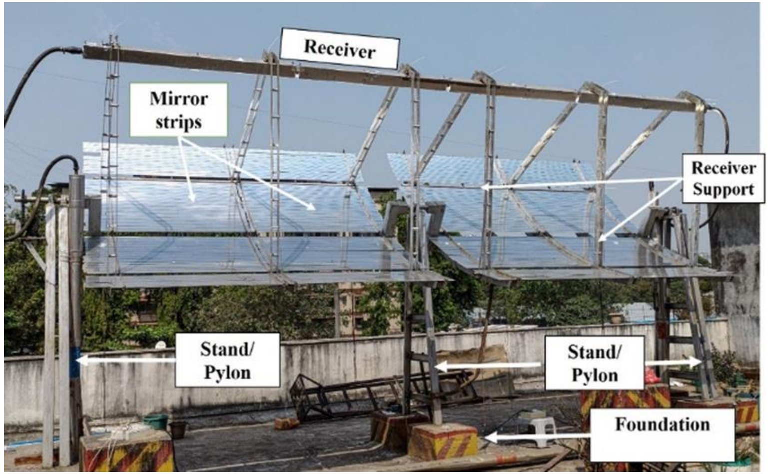
Parabolic Trough Collector

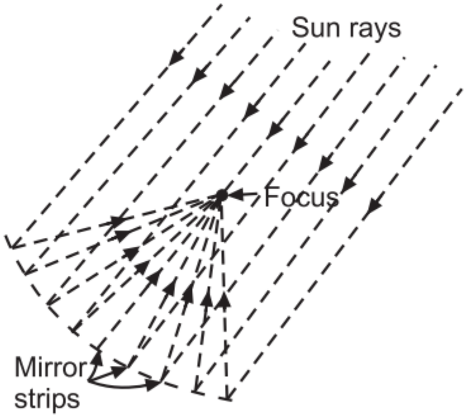
Solar radiation coming from the particular direction is collected over the area of reflecting surface and is concentrated at the focus of the parabola, if the reflector is in the form of a trough with parabolic cross-section, the solar radiation is focused along a line.



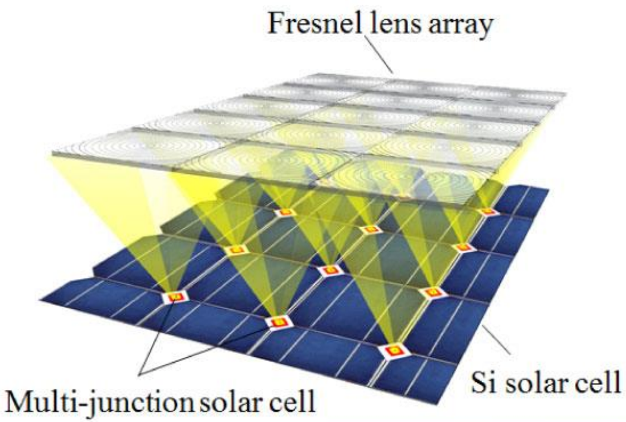
Mirror Strip Collector

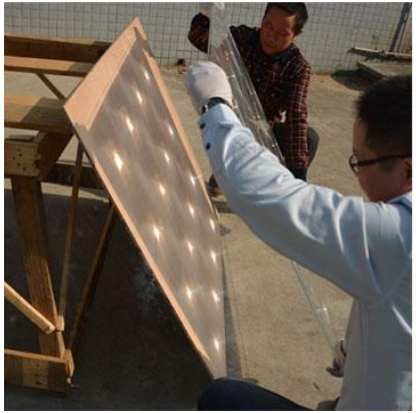
- A mirror strip collector has a number of planes or slightly curved or concave mirror strips which are mounted on a base.
- These individual mirrors are placed at such angles that the reflected solar radiations fall on the same focal line where the pipe is placed.
- In this system, collector pipe is rotated so that the reflected rays on the absorber remain focused with respect to changes in sun's elevation.





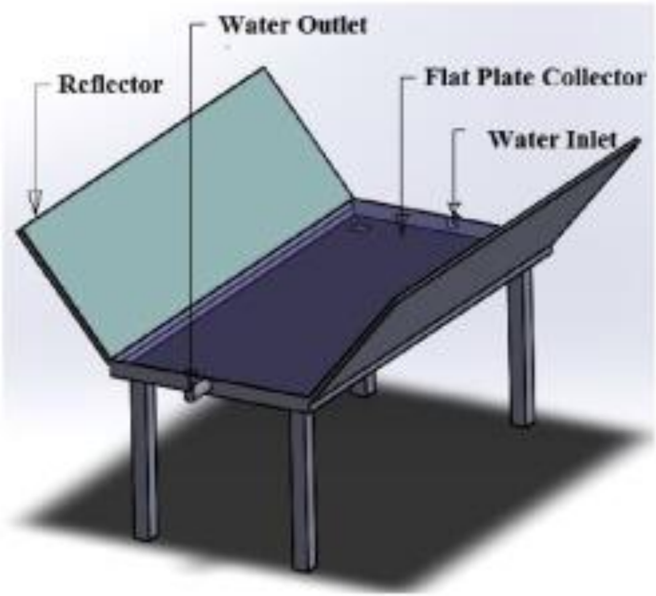
Fresnel Lens Collector

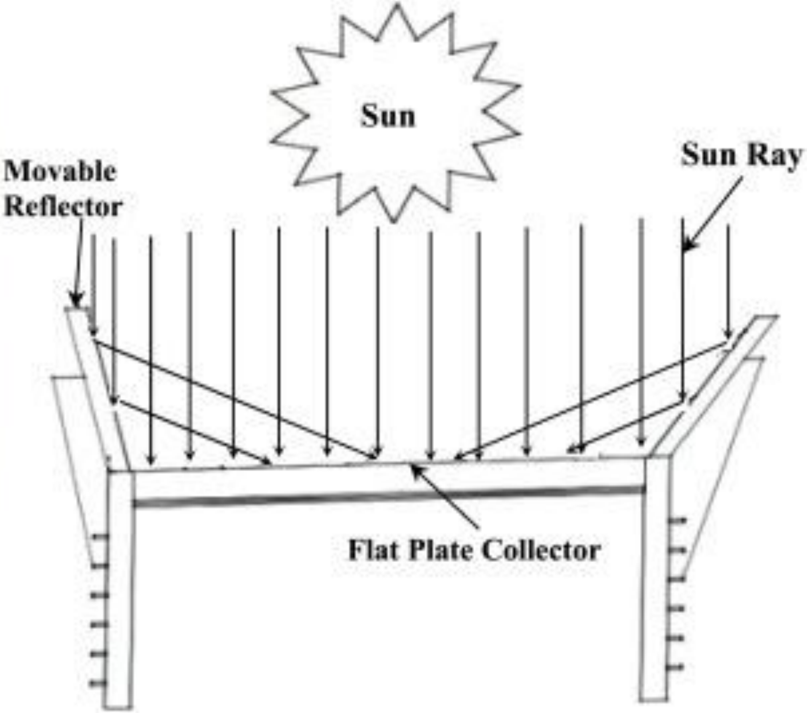


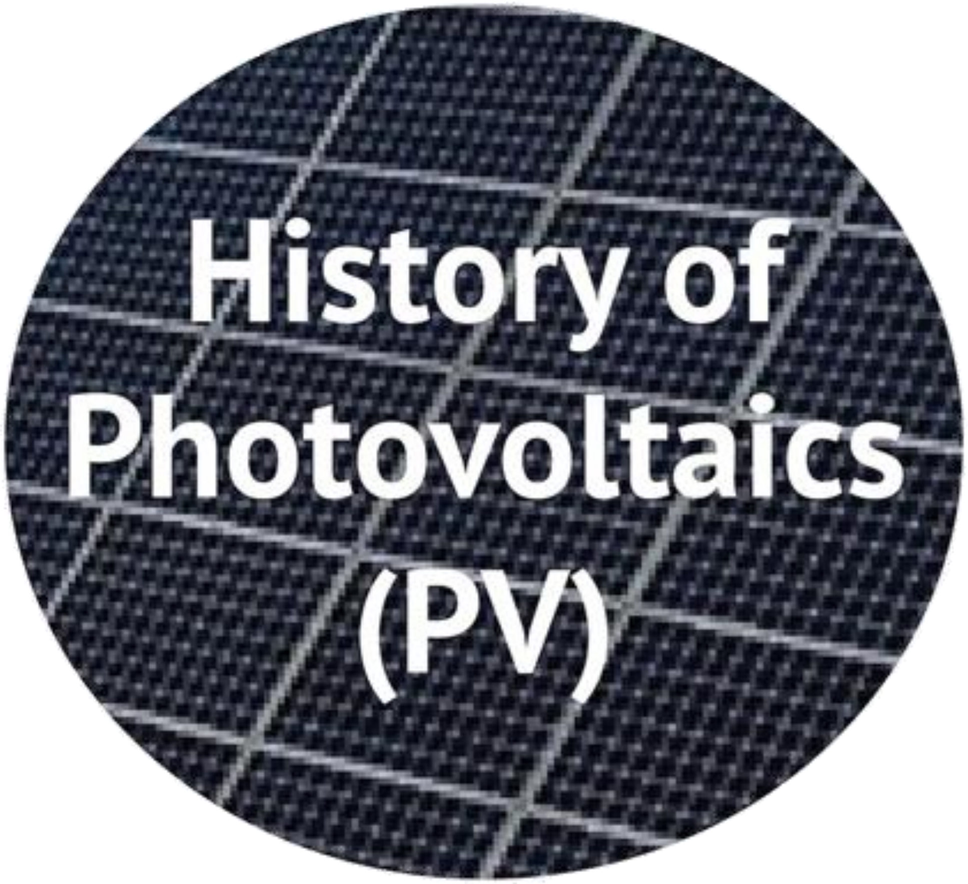


- A Fresnel lens is used in which linear grooves are present on one side and flat surface on the other.
- The solar radiations which fall normal to the lens are refracted by the lens and are focused on the absorber (tube).
- Both glass and plastic can be used as refracting materials for Fresnel lenses.

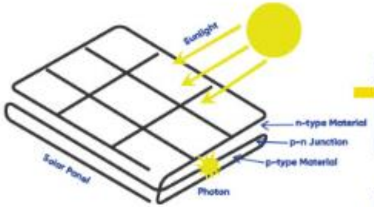
Flat-plate Collector with Adjustable Mirrors






History of
Photovoltaics
(PV)

HISTORY OF SOLAR ENERGY



1767 The Creation of the First Solar Cell

1839 The Discovery and Potential of the Photovoltaic Effect

1883 The First Solar Cells

1940 From Selenium to Silicon Solar Cells

Solar Hot Water and Early Research

1974 Stand-Alone Solar PV Systems

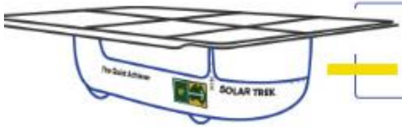
1976 The Alternative Technology Movement Begins

1978 Passive Solar Building Design

1980 Australia's PV Manufacturing Industry

1981 The First Solar (Thermal) Power Station

Inventions and Record-Breaking Achievements



1982 First Transcontinental Solar Car Journey

1983 Invention of the Passivated Emitter and Rear Cell (PERC)

1985 Manufacturing Off-Grid Solar Inverters

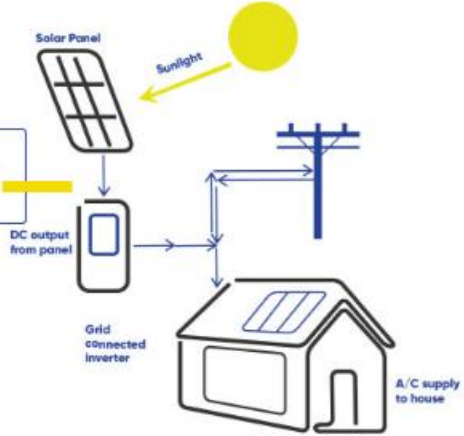
1985 Invention of the MPPT (Maximum Power Point Tracker)

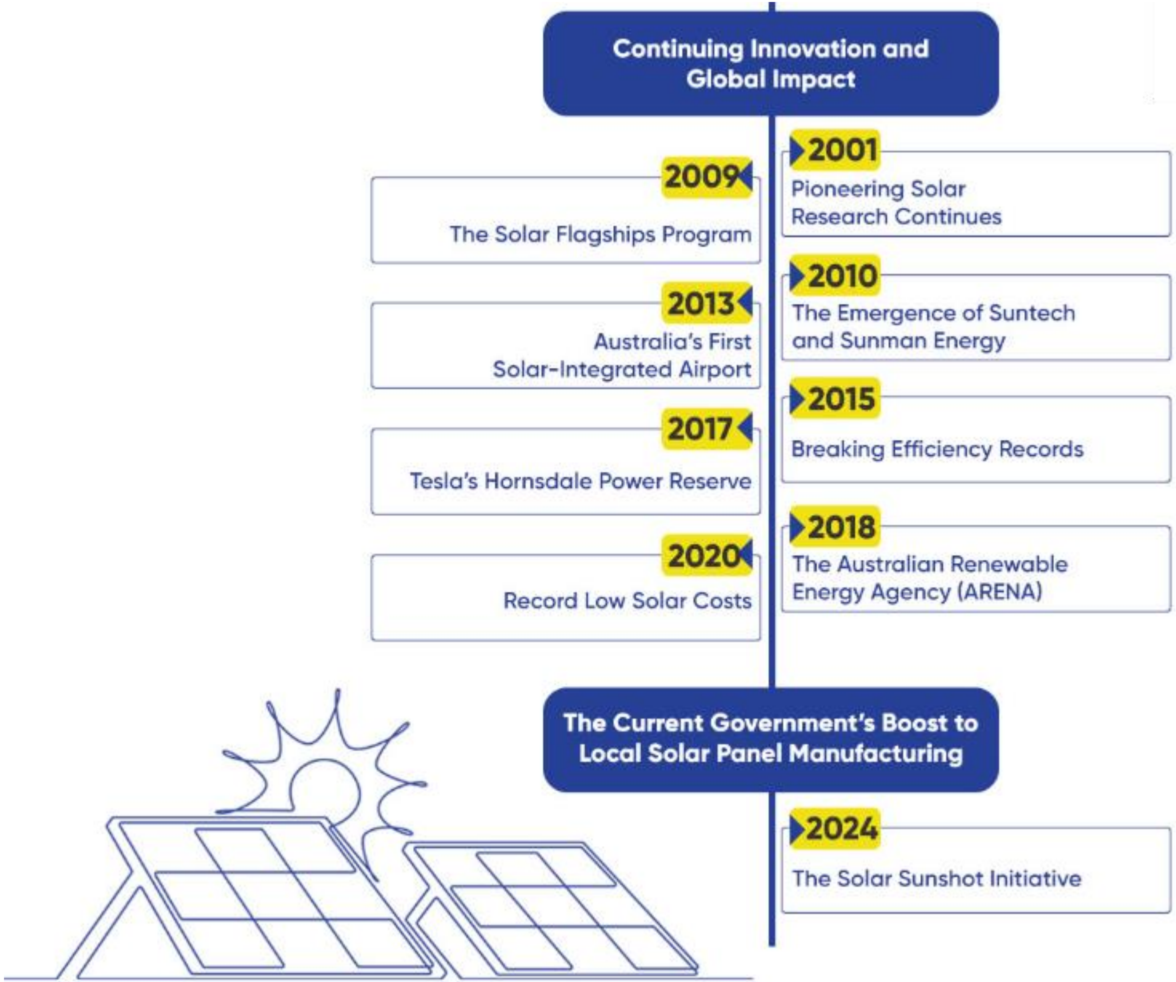
Grid-Connected Solar PV

1993 Australia's First Grid-Connected Solar/Wind PV System

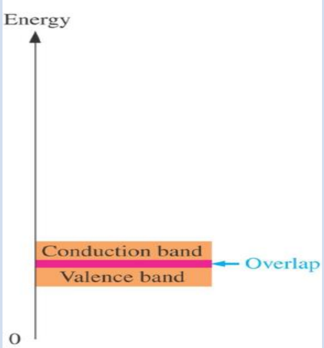
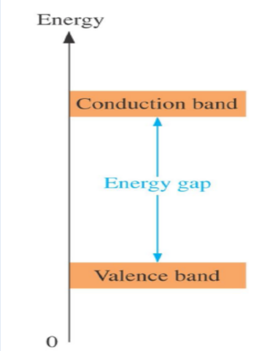
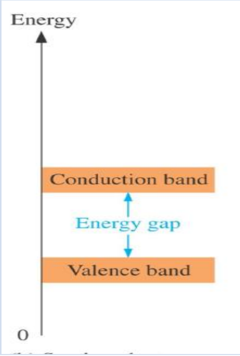
1994 First Residential Grid-Connected Solar PV System

1998 The Genesis of Australian Standards for Grid-Connect Solar




Continuing Innovation and Global Impact
2001
Pioneering Solar Research Continues
2009
The Solar Flagships Program
2010
The Emergence of Suntech and Sunman Energy
2013
Australia's First Solar-Integrated Airport
2015
Breaking Efficiency Records
2017
Tesla's Hornsdale Power Reserve
2018
The Australian Renewable Energy Agency (ARENA)
2020
Record Low Solar Costs
The Current Government's Boost to Local Solar Panel Manufacturing
2024
The Solar Sunshot Initiative

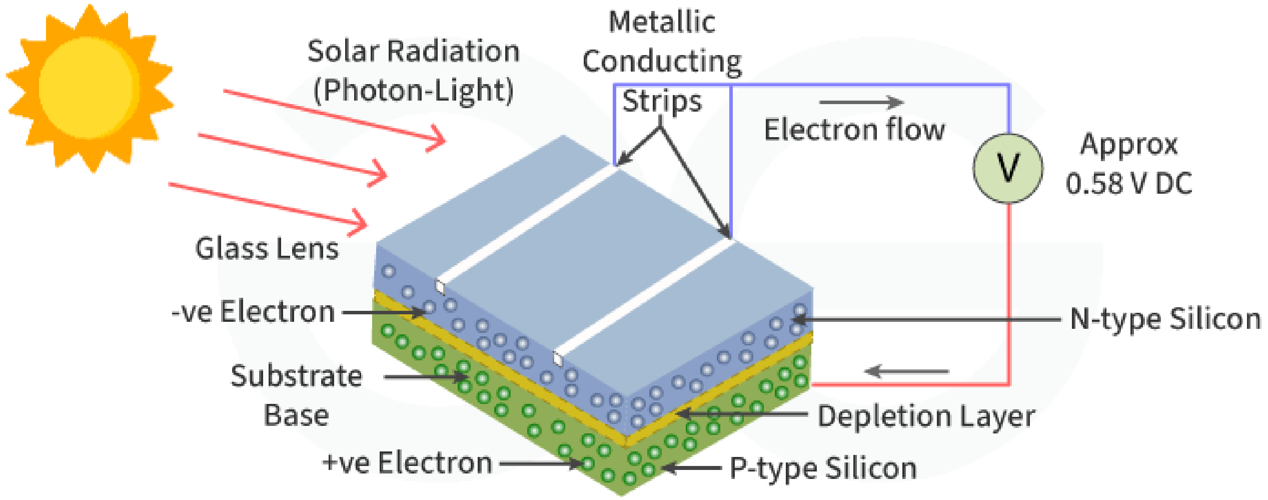
Semiconductor Theory

Conductors	Insulators	Semiconductors
➢ Good conductor of electricity ➢ Number of valence electrons : 1 or 2	➢ Poor conductor of electricity ➢ Outermost orbit → Completely filled	➢ Conductivity lying between conductor and insulator ➢ Outermost orbit → Partially filled
Copper, silver, gold, aluminum, & nickel, Brass & steel, Salt water	Glass, ceramic, plastics, & wood	carbon, silicon, and germanium are semiconductors.
 Valence and conduction band overlaps each other	 All electrons are in the valence band and conduction band is empty	 Valence band is partially filled and conduction band is almost empty

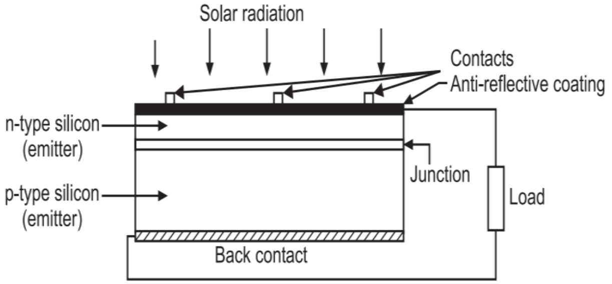
- **Intrinsic Semiconductors:** A pure semiconductor
- **Extrinsic semiconductors:** Impurity Semiconductors (P & N Type semiconductor)
- **Doping:** The process of adding impurity to the Intrinsic Semiconductors
- **N Type:** A small amount of pentavalent impurities such as arsenic, antimony or phosphorous is added to pure Semiconductors
- **P Type:** A small amount of trivalent impurities such as aluminium or boron is added to the pure semiconductor

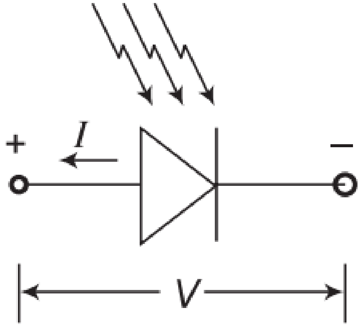
Solar Photovoltaic Cells

Silicon photovoltaic cell (Single crystal solar cell)



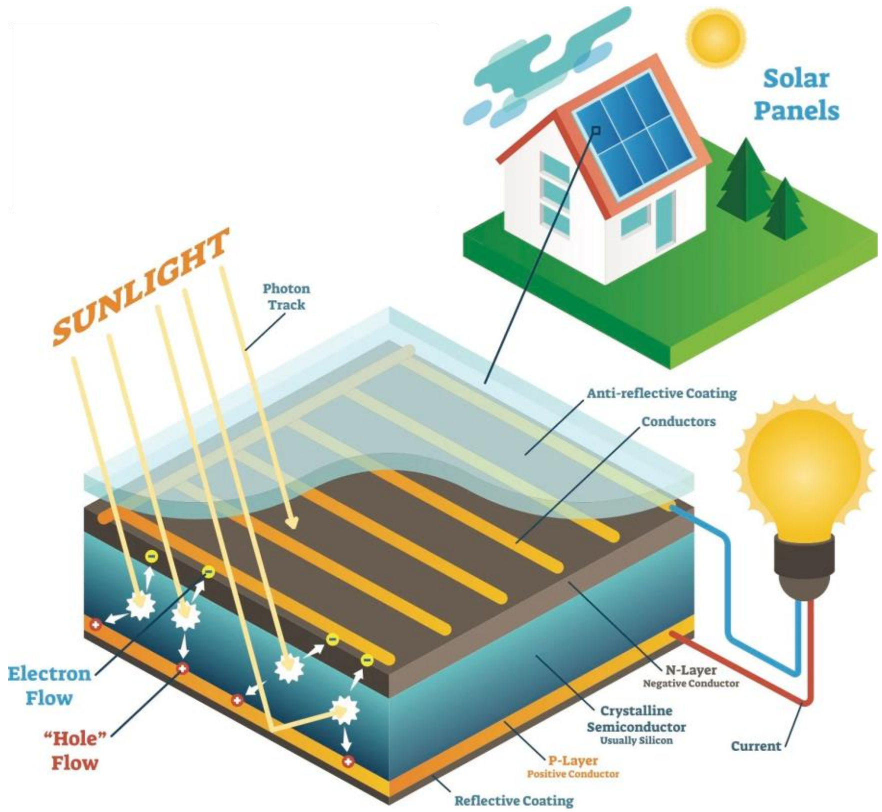
Construction





Schematic symbol

Photovoltaic Effect



- When a solar cell (p-n junction) is illuminated, electron-hole pairs are generated and the electric current I is obtained.
- I is the difference between the solar light generated current I_L and the diode current I_j

Mathematically, $I = I_L - I_j$

or, $I = I_L - I_0\left[\exp\left(\frac{eV}{kT}\right) - 1\right]$

where,

I_0 = Saturation current,

e = Electron charge,

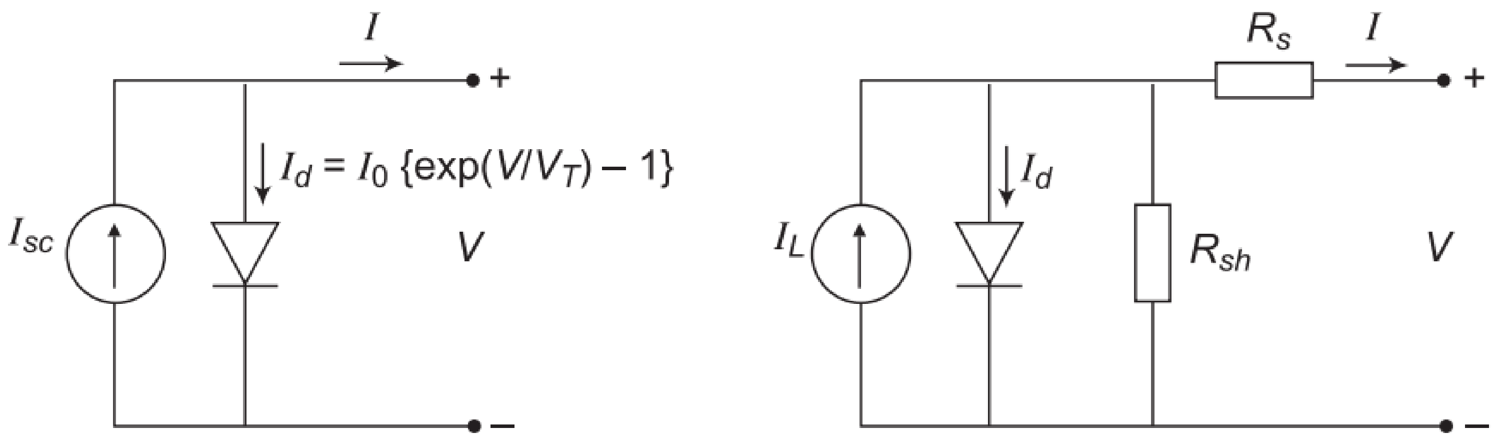
V = Voltage across the junction,

k = Boltzmann's constant,and

T = Absolute temperature.

This *phenomenon is known as the* **Photovoltaic effect**.

Equivalent Circuit of Silicon PV Cells



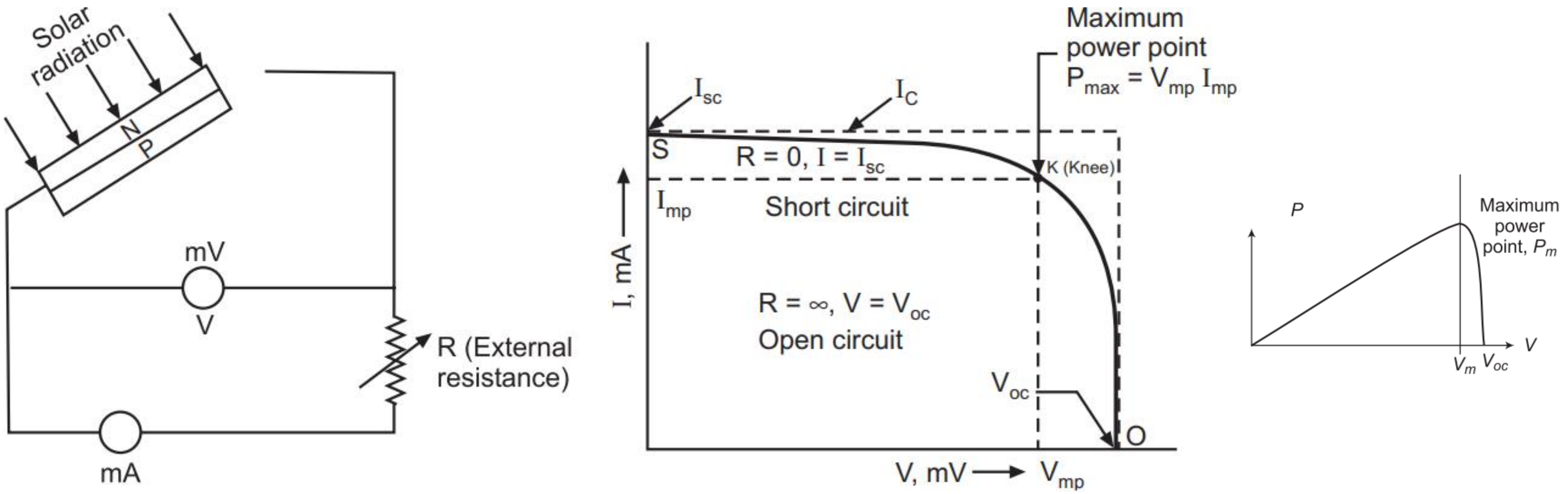
(a) ideal

(b) practical

$$I = I_L - I_o \left\{ \exp\left(\frac{V}{V_T} \right) - 1 \right\}$$

$$I = I_L - I_0 \left[\exp\left\{ \frac{(V + IR_s)}{V_T} \right\} - 1 \right] - \frac{(V + IR_s)}{R_{sh}}$$

Electrical Characteristics of Silicon PV Cells



- When external resistance R is high (mega-ohms range or infinity) the condition is called 'Open-circuit'.
- The open-circuit voltage V_{oc} of a solar cell is about 0.5 V.D.C. It is the maximum voltage across a PV cell. Open-circuit current is zero.
- If R is reduced gradually and the readings of the terminal voltage V and load current I are taken, we get V-I, characteristics of the PV cell (Above Fig).
- As R is reduced from high value to low value, the terminal voltage of the cell falls and current increases. A steep characteristic OK is obtained.
- At knee point 'K', the characteristic undergoes a smooth change and becomes flat for the portion Ks
- When the R is shorted, the short-circuit current I_{sc} is obtained. The V for the SC conditions is zero and maximum current delivered by the cell is I_{sc}.

Electrical Characteristics of Silicon PV Cells

Maximum power (P_{max}) = $V_{mp} I_{mp}$

Maximum efficiency (η_{max}): The ratio of maximum electric power output to incident solar radiation

$$\eta_{max} = \frac{V_{mp} I_{mp}}{I_s A_c}$$

I_s = Incident solar flux,
A_c = Cell's area

Fill factor (FF): the ratio of the peak power to the product of open circuit voltage and short circuit current

$$FF = \frac{I_{mp} V_{mp}}{I_L V_{oc}}$$

$$P_{max} = I_L \times V_{oc} \times FF$$

- Solar cell designers strive to increase the FF values, to minimize internal losses.
- FF for a good silicon cell is about 0.8

Voltage factor: It is determined by the basic properties of the materials in the cell

$$\frac{eV_{oc}}{E_g}$$

- About 0.5 for a silicon cell
- Eg = Forbidden energy gap

Causes of low efficiency of a solar cell:

The efficiency of a photovoltaic cell is 15% only

The major losses which lead to the low efficiency of the cell are:

- **Temperature** of the cell rises due to **solar radiation**, **leakage** across the cell **increases**. Consequently, power output, relative to solar energy input, **decreases**. For silicon, the output decreases by **0.5% per °C**.
- The **excess energy** of active photons given to the electrons **beyond the required amount** to cross the band gap cannot be recovered as **useful electric power**. It appears as heat, about **33 per cent**, and is lost.
- The electric current (generated) flows out of the top surface by a mesh of metal contacts provided to reduce **series resistance losses**. These contacts cover a definite area which **reduces the active surface** and proves an **obstacle to incident solar radiation**.

- **To achieve maximum efficiency the semiconductor with optimum band gap should be used.**

Power output of solar panel, array and module

Power per module, $P_{mod} = nP_c$, watts

Power per array or panel $P_p = m \times nP_c$ watts

Voltage across panel, $V_p = \dfrac{P_P}{I_P}$

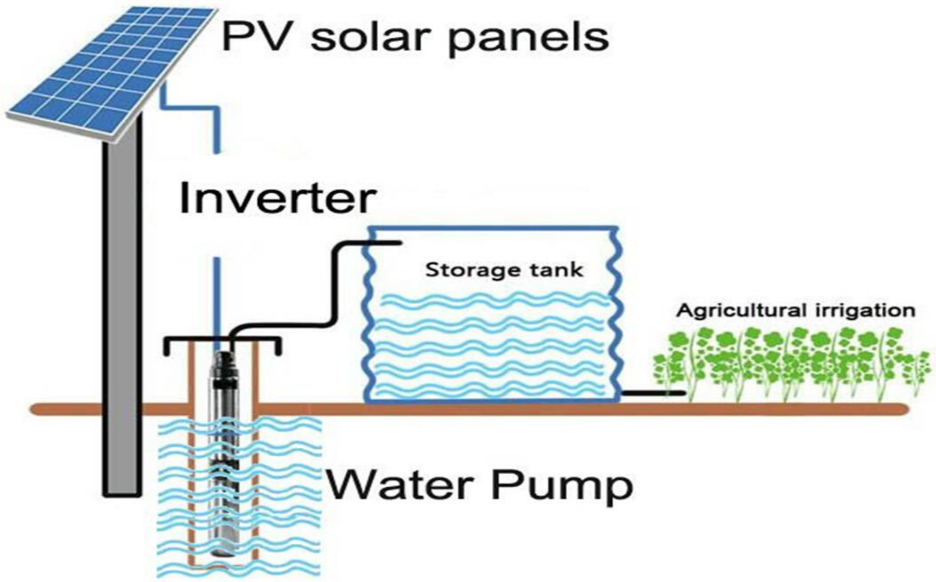
Current delivered by the panel, $I_p = \sqrt{\dfrac{P_P}{R}}$

n = Number of solar cells in a module,

m = Number of modules in an array or a panel, and

P_c = Power per solar cell, watts

Solar Panel Applications

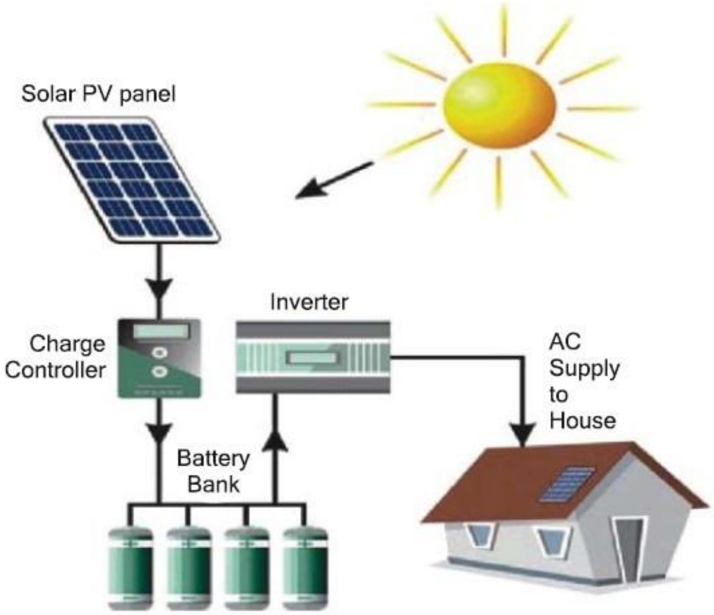


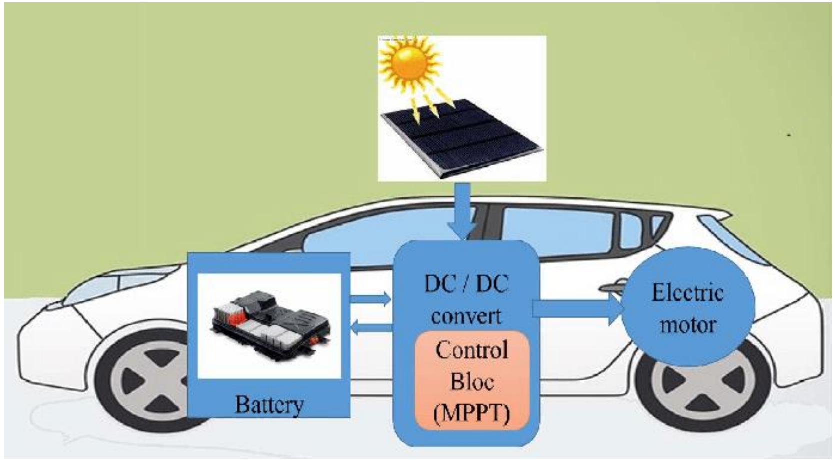
Water Pumping Systems

Street Lights

Traffic Signals

Solar Panel Applications

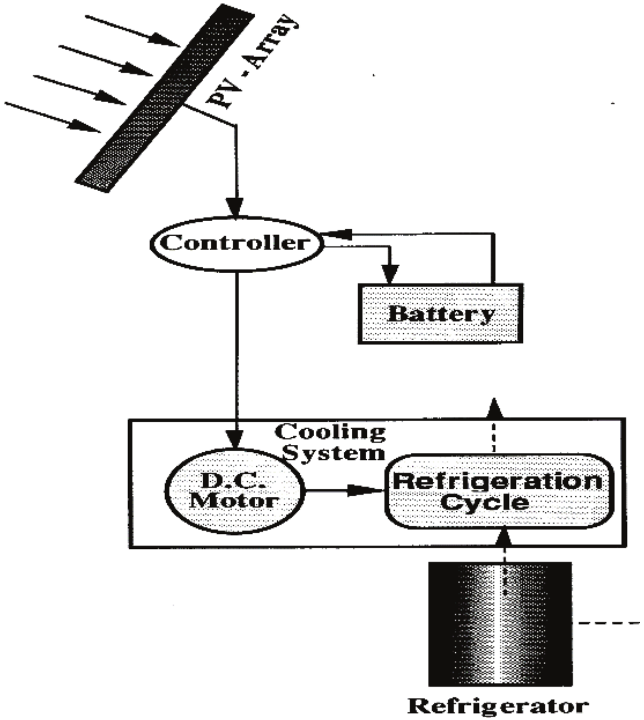




Home lighting systems

Solar vehicles

Solar Panel Applications

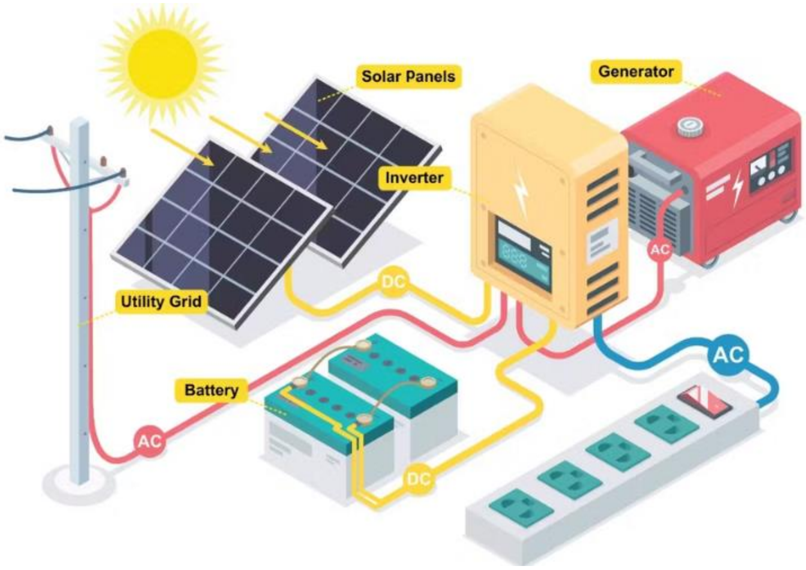


Medical Refrigeration

Solar vehicles

Solar Panel Applications

Weather monitoring



Battery charging