# Unit 3

## Utilization of Electric Power

**Conventional Sources of energy** : → Power that is produced from coal, oil or natural gas.

→ A resource that does not renew itself at a sufficient rate for sustainable economic extraction.

**Disadvantages of conventional sources** : (i) very limited supply

(ii) emission of greenhouse gases like $CO_2$, leads to climate change.

(ii) increased pollutants

**Non-Conventional / Renewable Energy Resources** – energy sources that can replenish with the passage of time

for eg. wind energy
solar energy
geothermal energy

**Wind Energy** : a form of solar energy generated from the wind.

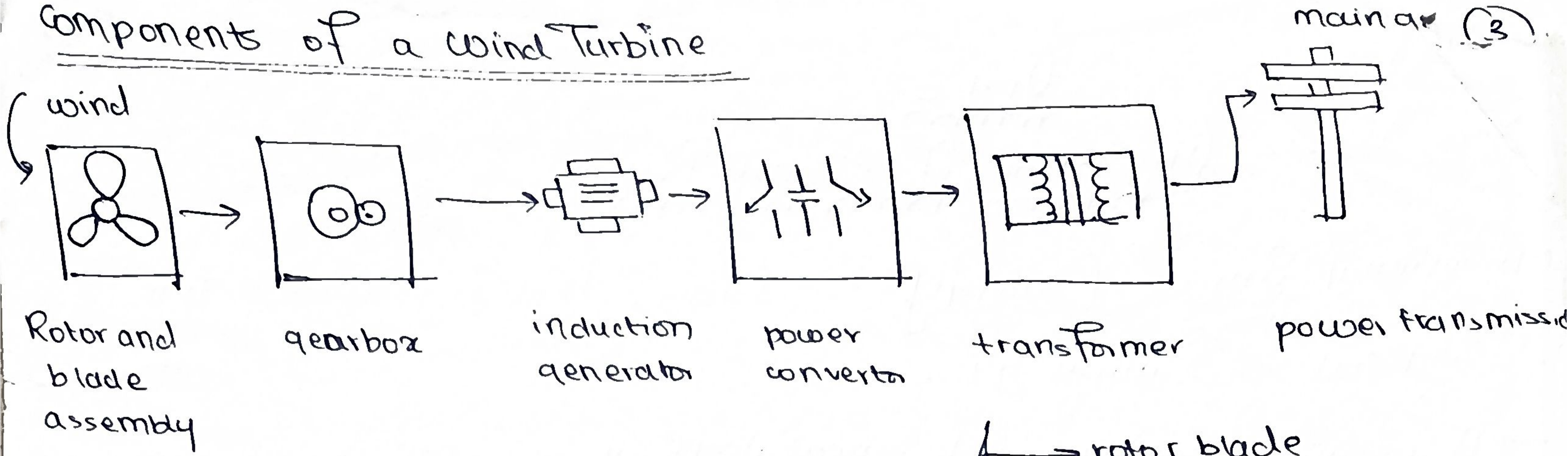
The generation of wind, utilized for wind energy is due to:

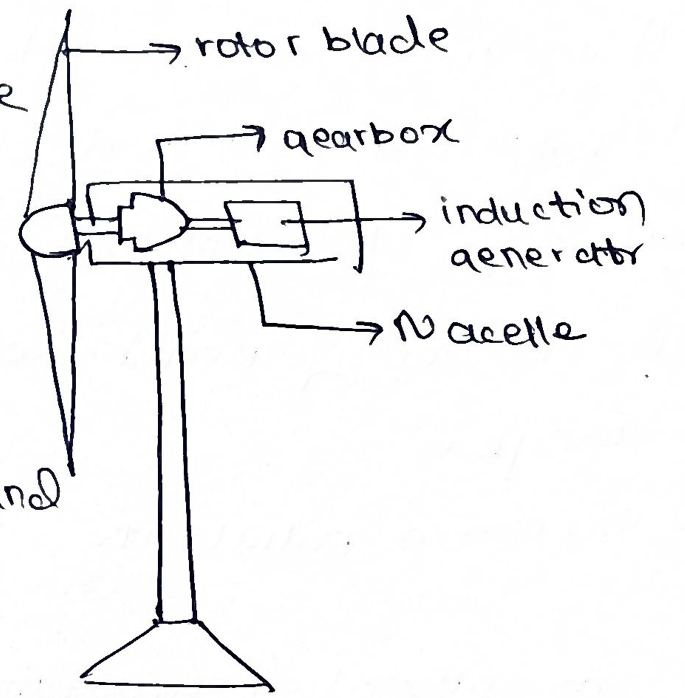
(i) uneven heating of the Earth's atmosphere

(ii) abnormalities existing on the surface of the earth, earth's rotation

(iii) Earth's terrain, water bodies & vegetation changes.

# Components of a Wind Turbine




(1) Nacelle: key components of the turbine are placed inside the nacelle

(2) blades : light weight, robust, corrosion free materials, that capture wind and spin

(3) rotor : hub around which blades are placed conversion of kinetic energy takes place here

(4) brake : used to stop rotor either electrically or mechanically during an emergency

(5) gearbox : connects low & high speed shafts helps in rotating the induction generator

(6) induction generator : a generator that rotates at asynchronous speeds, helps generate electric power from the wind.

(7) wind vane : finds direction of wind, and helps in changing orientation of turbine.

## Working

→ a wind turbine turns wind energy into electricity using the aerodynamic force from the rotor blades.

→ When wind flows across the blade, the air pressure on one side of the blade decreases. The difference in air pressure causes across the 2 sides causes both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin

→ The rotor is connected to a generator to a shaft. The translation of aerodynamic force to the rolation of a generator creates electricity.

## Calculation of wind power from a wind turbine

$$P = \frac{1}{2} c_p \rho A v^3$$

$c_p$ = maximum power coefficient of the wind turbine $(0.25-0.45)$

$\rho$ = density of air

$V$ = velocity of wind (m/s)

Another relation is:

$$\begin{cases} P = 0 & V < V_{in} \text{ or } V > V_{out} \\ P = P_r\left(\frac{V - V_{in}}{V_r - V_{in}}\right) & V_{in} \le V \le V_r \\ P = V_r & V_r \le V \le V_{out} \end{cases}$$

$V_{in}$ = cut-in wind speed

$V_{out}$ = cut-out wind speed

$V_r$ = rated wind speed

$P_R$ = rated output

# Power curve of a wind turbine

Start - up speed : wind speed at which rotor and blade starts to rotate without generating any power

Cut-in speed: minimum wind speed at which the rotor and blade assembly of the turbine rotate and generates usable power.

Rated speed: minimum wind speed at which the wind turbine rotates and generates the rated wind power = rated speed.

cut-out speed : speed at which the turbine stops generating wind power = cut-out speed. The turbine is shut down to prevent it from getting damaged

## Classification of Wind Turbines

(1) Based on wind speed / power generated:

(i) Utility scale : $P > 900kW$ is produced

(ii) Industrial scale : $50kW < P < 750kW$ - used along w/ existing diesel generator to reduce power consumption from the grid.

(iii) Residential : $P = 400W - 50kW$, used where utility power is not easy to install

(2) Based on axis of rotation of wind

(i) Horizontal Axis Wind Turbine (HAWT)

→ both wind & rotational axis are parallel to each other

→ rotor shaft, induction generator are placed at the tower top.

→ Further classified as upwind & downwind turbines

(ii) Vertical Axis Wind Turbine (VAWT)

→ wind & rotational axis are $\perp^r$ to each other

→ gear box & induction generator at the bottom level

## Advantages

→ wind is available in abundance

→ can generate large amounts of energy

→ pollution free

## Disadvantages

→ wind sources are unpredictable

→ high installation cost

→ generates noise

→ a threat to widlife, esp birds

## Applications

→ propelling sailboats

→ to run pumps to draw ground water

→ converted to mechanical energy to run flourmills to grind wheat

**Solar Energy** : capturing energy from the sun and subsequently converting it to electrical energy

→ solar cells / photo voltaic cells convert sunlight directly into electricity

**Working of solar panels** : → The Sun releases packets of energy called photons.

→ When photons hit a solar cell, they knock electrons loose from their atoms.

→ Conducting plates attached to either end of the solar cell form an electrical circuit, through which the electrons flow.

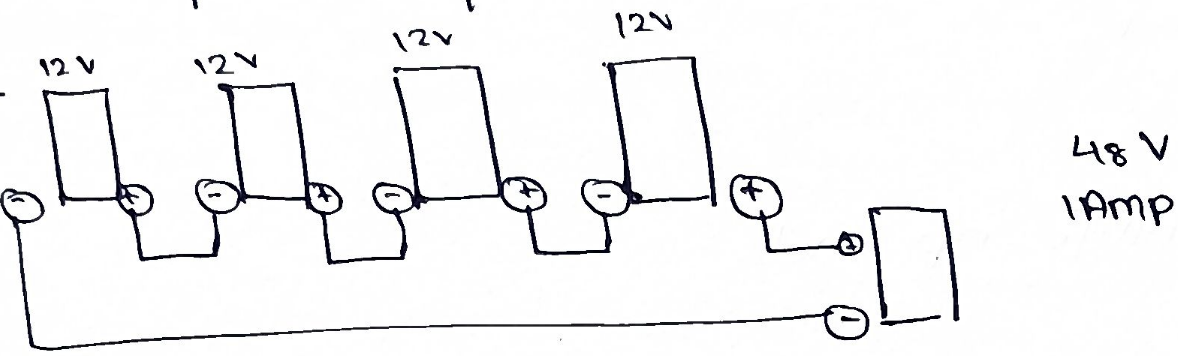
# Components of a Photovoltaic Power Generation System :

(1) Solar panels : → convert incident solar energy into electrical energy

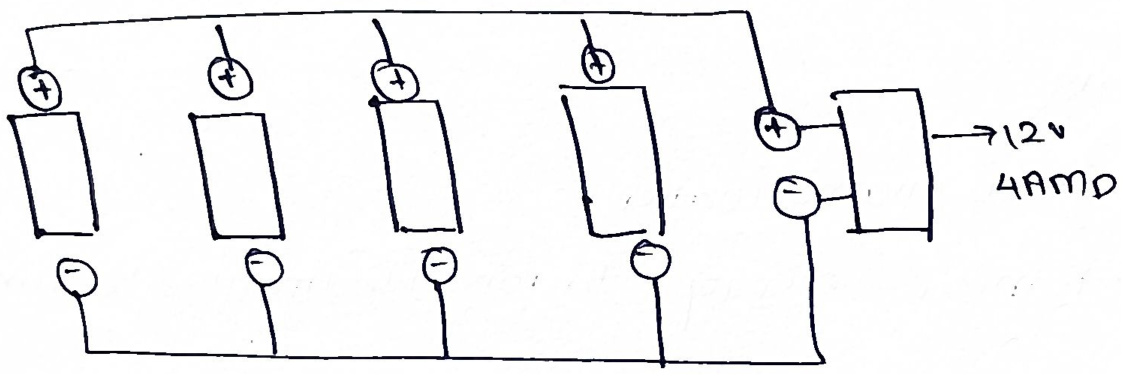
→ solar cells made up of silicon semiconductors

→ The rated voltage for each solar panel is 12V, Solar arrays are made by connecting these panels in series or parallel.

<u>Series</u>




<u>Parallel</u>




(2) Batteries : → To store the energy generated from the solar panels

→ lead acid batteries usually used

(3) Controller : → To regulate the current flow in and out of the battery

→ safe guards battery from overcharging.

→ balances the electrical power supplied to home appliances

(4) Inverter : → solar panels make DC power

→ inverter converts DC to AC

→ Also used to integrate solar power to main grid

→ There are central inverters and micro inverters

## Types of Solar PV power generation systems

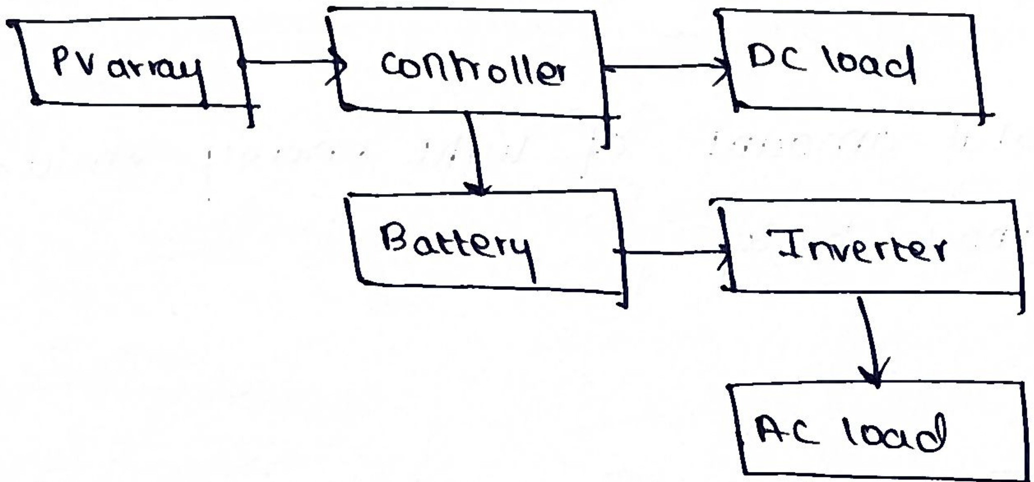


### ① Off grid / Stand - alone systems:

→ a simple and small set up

→ main grid is isolated from this system, used in places where usage of main grid power is difficult

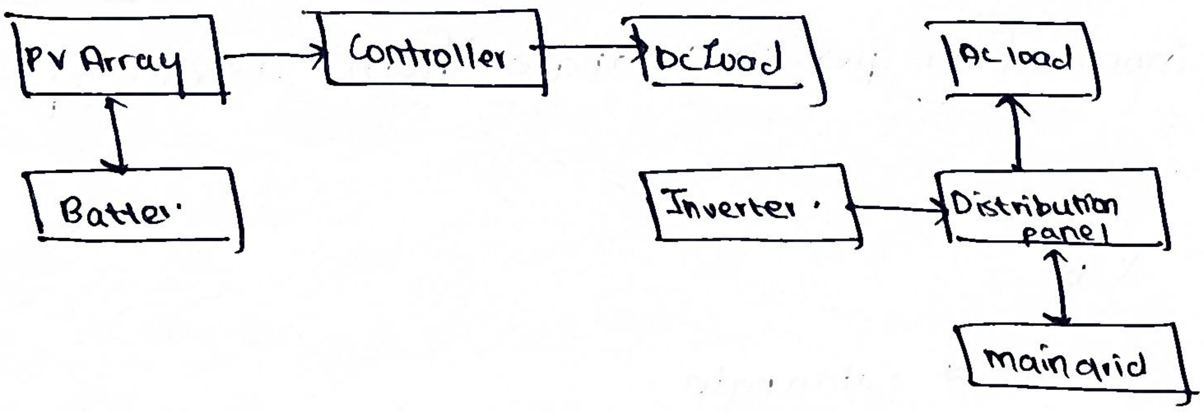
→ This system is mainly used to charge the battery which supplies the load




### ② Grid Connected System

→ generated electrical power is transmitted to the main grid.

→ used in urban areas where electric power from the main grid is more.




**Advantages**

→ non-polluting

→ low running cost

→ no noise

→ inexhaustible source

**Disadvantages**

→ high initial cost

→ needs large space

→ panels have low efficiency

## Applications

→ Solar water heating

→ solar cooking

→ solor furnace

## Illumination

**Light:** The radiant form of energy which produces a sensation of vision upon the human eye. made of photons.

**Luminous Flux:** The total amount of light energy emitted per second from a luminous body

unit = lumens

**Luminous Intensity:** The luminous flux emitted by the source per unit solid angle.

unit = candela (or) lumen/steradian

$$\text{solid angle} = \frac{\text{area}}{(\text{radius})^2}$$

**Lumens:** The luminous flux per unit angle from a source of one candle power.

$$\text{lumens} = CP \times \theta$$

CP ↓ candle power

θ → solidangle

**Candle Power:** The no. of lumens per unit solid angle

$$1\,CP = 4\pi \text{ lumens}$$

$$CP = \frac{\text{lumens}}{\theta}$$

Illumination: The luminous flux received by a surface per unit area is called illumination.

$$\text{Illumination} = \frac{\text{luminous flux}}{\text{area}}$$

$$= \frac{CP \times \theta}{\text{area}} \qquad = \frac{CP}{\text{area}} \times \frac{\text{area}}{r^2}$$

$$= \frac{CP}{r^2}$$

Brightness: luminous intensity per unit projected area of the surface in the given direction.

$$B_r = \frac{\text{luminous intensity}}{\pi \times A}$$

$$= \frac{CP \times \theta}{\pi \times A}$$

unit = candles per sq. m

MHCP

Mean Horizontal Candle power: mean of candle power in all directions in the horizontal plane

MSCP

Mean Spherical Candle power: mean of candle power in all directions in al planes.

Mean Hemispherical Candle Power: mean of the candlepower in all directions, within the hemisphere either above or below the horizontal plane.

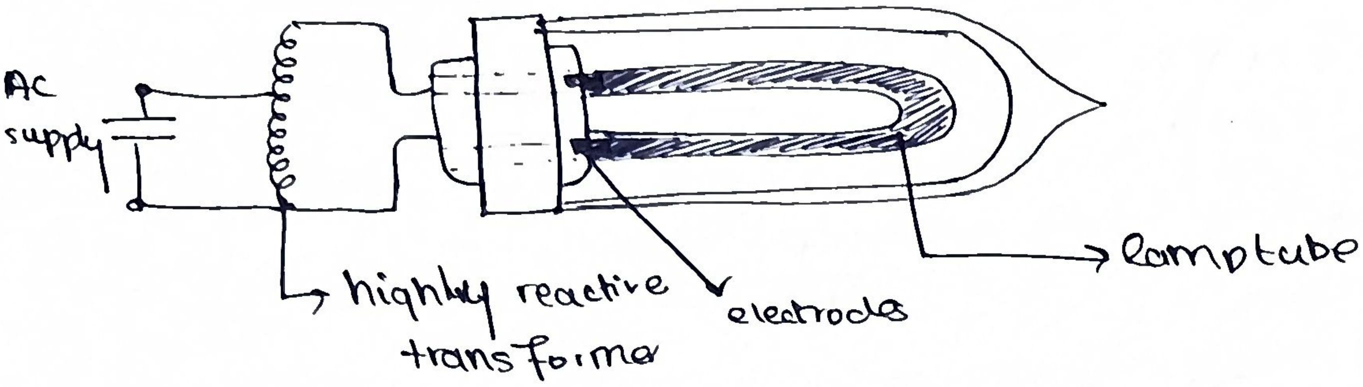
Reduction Factor: ratio of mean spherical candle power to mean horizontal candle power

$$\text{Reduction} = \frac{MSCP}{MHCP}$$

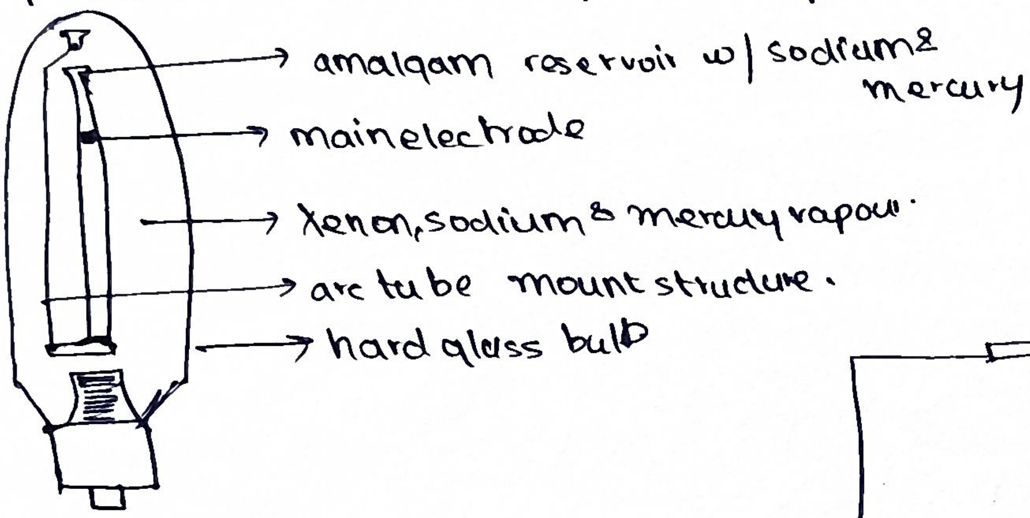
Do eq. from 227 onwards
Ppt: 45 - 50

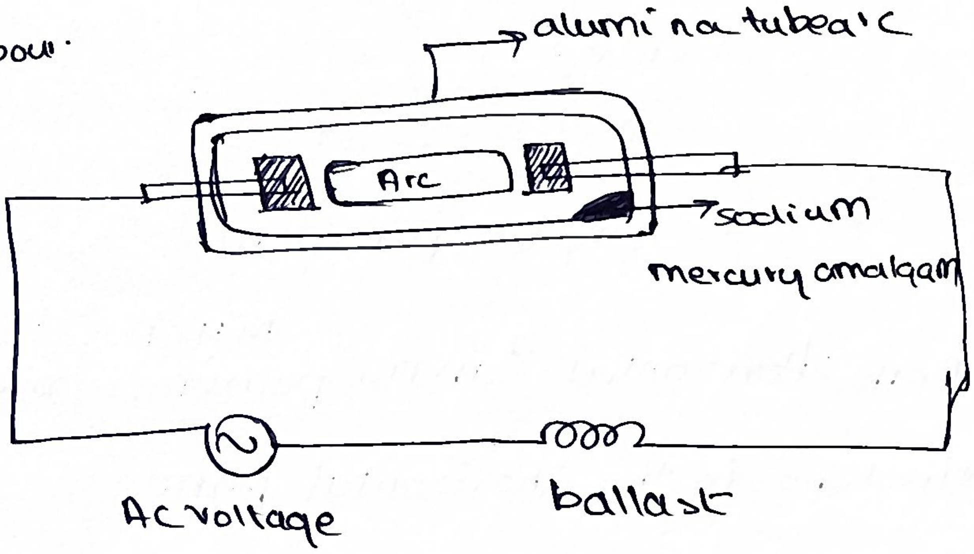
# Sodium Vapour Lamps

## Low Pressure Sodium Vapour Lamp




## High Pressure Sodium Vapour Lamp




→ A sodium vapour lamp is a type of gas-discharge lamp that uses sodium in an excited state to produce light.

**Construction**: → has low luminosity ⇒ ~~to~~ large tube length

→ has a U-tube, and 2 oxide coated electrodes

→ The tube has sodium & neon gas.

→ The tube is enclosed within a double walled vacuum flask to keep the temp within the working range.

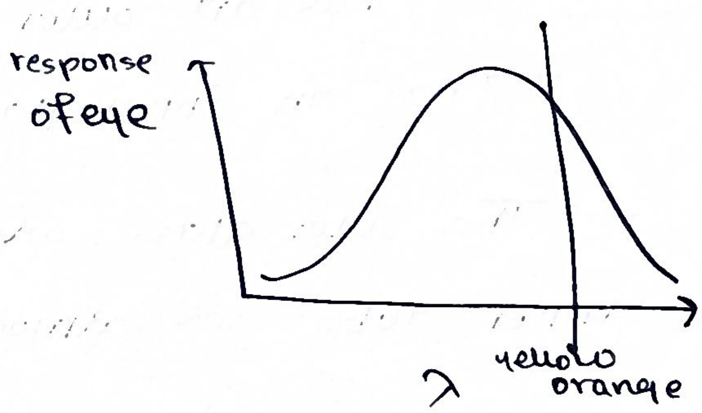
→ The external circuit has a capacitor, choke coil & a small step down transformer.

Working

→ When the sodium vapour lamp is turned on, there is an electric discharge within the neon gas which generates sufficient heat to evaporate the solid sodium. The sodium is usually deposited on the side walls of the tube when the lamp is not in operation.

→ The initial discharge of neon gas produces red-orange colored light.

→ Once the solid sodium becomes sodium vapour due to the heat, yellow light is produced.

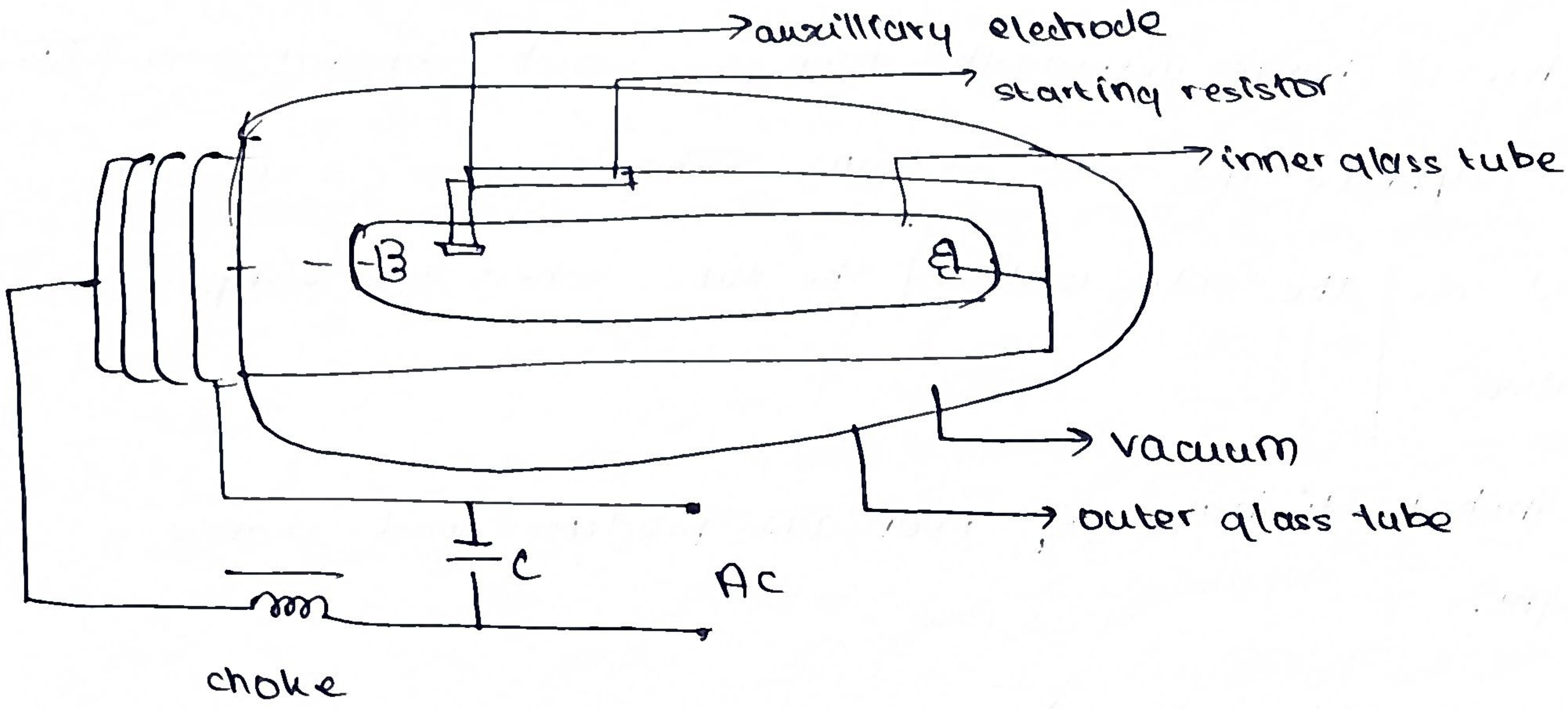



Advantages → high efficiency
→ comparitively long life
→ low heat

Disadvantages → low power factor
→ additional transformer required
→ take 5-10 mins to produce a complete o/p.

Applications → outdoor lighting
→ lighting in industries
→ use in advertisement lights

# Mercury Vapour Lamps




**Construction:** → has an outer glass tube w/ vacuum inside.

→ has an inner glass tube filled w/ mercury vapour.

→ The outer glass cover prevents direct contact between the inner tube & atmosphere and also absorbs UV rays

→ There are 2 electrodes : a main electrode & an auxilliary electrode.

**Working :**

→ a voltage is applied between the 2 main electrodes, it gets impressed across the auxilliary electrode & adjacent main electrode

→ This results in a glow discharge between the two.

→ This glow discharge sets up an arc discharge between the main electrodes

→ A ballast limits the current and a ~~choke~~ capacitor improves power factor.

**Advantages** : → produce clear white light

→ high intensity ligh

→ efficient

**Disadvantages** → takes 5 → 8 mins to warm up

→ takes time to cool

**Applications** : → household lighting

→ stairwells, security areas

**Fluorescent Tube** : A low weight mercury vapour lamp that uses fluoroscence to deliver visible light

**Construction** : → has a phosphor coated glass bulb

→ has ~~a~~ filament coils as electrodes

→ glass stem, filled w/ an inert gas

also has (i) a **Ballast**, which

→ provides the correct starting voltage because the lamp requires a higher voltage to start than to operate

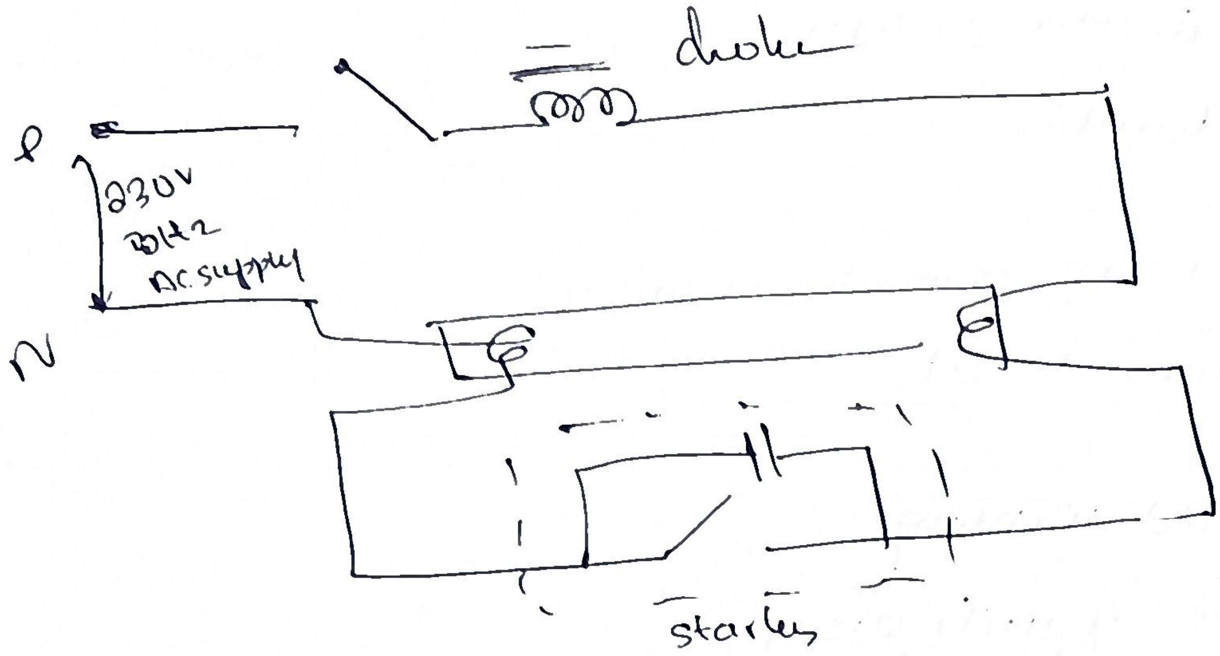
→ matches line voltage to the operating voltage

→ limits the lamp current to prevent destruction

(ii) **Starter** : → connects both ends of the lamp together and preheats the lamp ends

→ the current flowing through the lamp causes the starter's contacts to heat and open, interrupting the flow of current.

Circuit : refer lab manual




Working → The switch is turned on, initially, current cannot pass through the tube light as the gas inside the tube is not ionized.

→ The starter provides an initial high current to ionize the gas

→ The circuit is initially closed through the ballast and the starter.

→ The filaments at the end of the tube are heated up

→ Once the capacitor in the starter is fully charged, it acts as an open switch.

→ The circuit is now closed through the ballast, lamp & switch.

→ The heated ends allow a stream of electrons to flow from the cathode to the anode.

→ The mercury vapour inside is ionized, from the collision of electrons w/ mercury atoms.

→ This collision results in photons in the UV wavelength.

→ These photons hit the phosphor coating, lose some energy and emits the remaining energy as visible light.

## Types of Fluorescent Circuits

(i) rapid start : → rapid start ballasts continually heat the lamp filament
→ very short delay

(ii) instant start : → ballast provides high voltage, eliminates the need for a starter

(iii) preheat circuit : → used for compact fluorescents
→ separate starting switch for starter
→ takes time to turn on

**Batteries** : A device that converts stored chemical energy into electrical energy using chemical action. It is used in circuits to power other components.

**Construction** : (1) Anode : electrode at which oxidation takes place
materials = zinc & lithium

(2) Cathode : electrode at which reduction takes place
materials = metallic oxides

(3) electrolyte : medium through which electrons get transferred

Types of Batteries : Primary & Secondary

| Primary Batteries | Secondary Batteries |
|---|---|
| 1. Single-use or throw away batteries | 1. Can be recharged |
| 2. eg. alkaline batteries | 2. eg. nickel cadmium, lead acid batteries |

| | |
|---|---|
| (3) no maintenance required | (3) maintenance required |
| (4) low initial cost | (4) high initial cost |
| (5) used in portable applications | (5) less suited for portable applications |
| (6) not suited for heavy load application | (6) suited for heavy load applications |
| (7) limited to specific applications | (7) usable in most applications |

**Lead Acid Batteries** : most commonly used secondary battery

Construction:

cathode: lead peroxide - $PbO_2$ chocolate brown when fully charged

anode: sponge lead grey when fully charged

electrolyte : dil. $H_2SO_4$, 31% conc. $H_2SO_4$

Output : 2.1 V per cell 6 cells $= 6 \times 2.1 = 12.6$ V

Working : During discharging gal cell

at anode : $Pb + SO_4 \rightarrow PbSO_4$

at cathode : $PbO_2 + 2H + H_2SO_4 \rightarrow PbSO_4 + 2H_2$

(i) cathode coated w/ white $PbSO_4$

(ii) anode coated w/ white $PbSO_4$, converts grey plate to white

(iii) conc. of electrolyte decreases due to the formation of water

(iv) o/p falls to 1.8 under no load condition

(v) electrical energy produced from chemical energy

## During Charging

electrolytic cell external power

overcharging can happen

at anode : $PbSO_4 + 2H \rightarrow Pb + H_2SO_4$

at cathode : $PbSO_4 + SO_4 + 2H_2O \rightarrow PbO_2 + 2H_2SO_4$

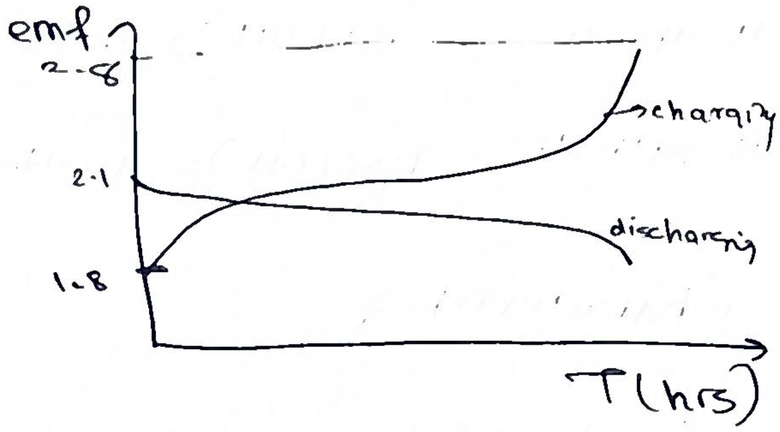
(i) cathode → $PbO_2$ = chocolate brown

(ii) anode → grey spongy lead

(iii) electrolyte conc. increases

(iv) o/p voltage = 2.1V

(v) chemical energy produced from electrical energy




### Advantages

→ high efficiency

→ environmental friendly

→ low cost

### Disadvantages

→ corrosion due to overcharging

→ ineffective at low temp

→ not possible to retain ideal condns for long

### Applications

→ used in automobile applications

→ emergency lighting, security alarm system.

## Nickel-Cadmium Battery

: efficient battery, that delivers all of the stored capacity

### Construction

Anode : cadmium

Cathode : Nickel hydroxide

Electrolyte : Alkaline KOH

Working : During discharging

at anode: $Cd + 2OH \rightarrow Cd(OH)_2$

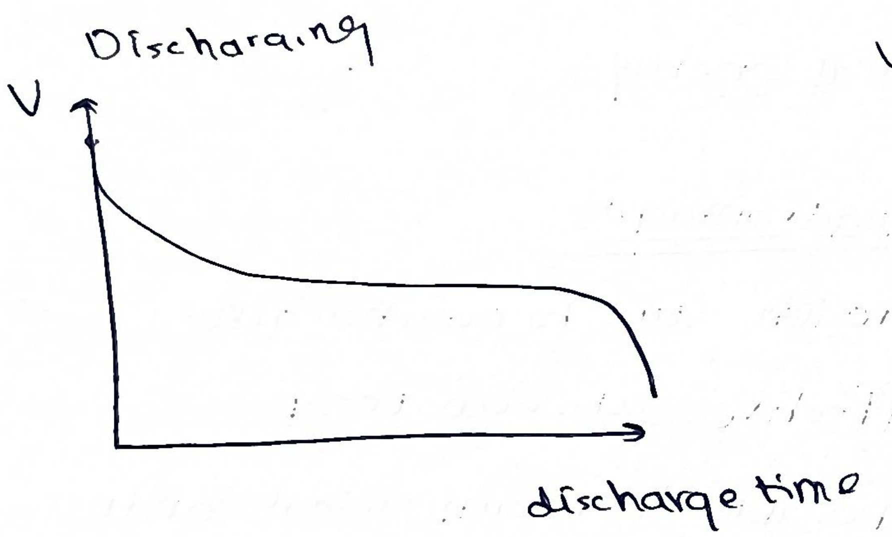
at cathode: $Ni(OH)_2 + H_2O \rightarrow Ni(OH)_2 + OH$

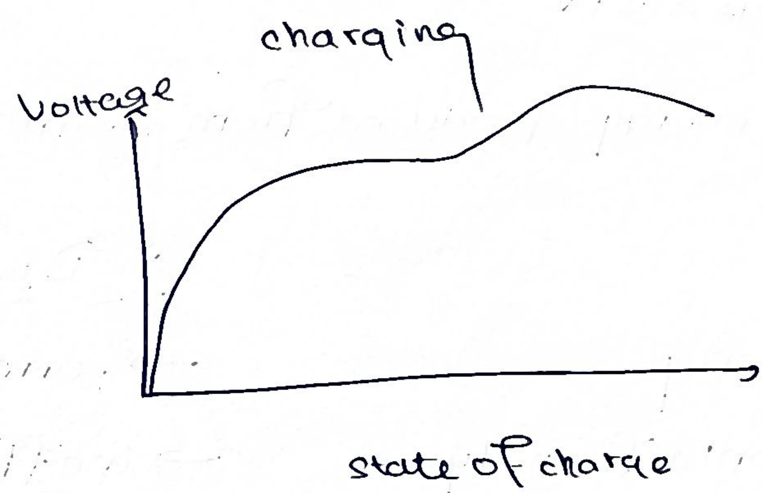
During charging

at anode: $Cd(OH)_2 + 2K \rightarrow Cd + 2KOH$

at cathode: $Ni(OH)_2 + OH \rightarrow NiO(OH) + H_2O$

Characteristics




Advantages

→ can be recharged many times

→ comp. of electrolyte does not change

→ can be kept in ideal pos for a long time

Disadvantages

→ env. pollution

→ electrolyte = hazardous

→ high initial cost

Applications

→ emergency lights, alarms

→ aircrafts, space satellite systems

**Lithium ion Battery** : battery most commonly used in electric vehicles

**Construction** : anode → Lithiated carbon

cathode : Lithium metal oxide

electrolyte: non aqueous electrolyte like ethylene carbonate

**Working** : → $Li^-$ ions move from -ve electrode to +ve electrode

= discharging

the opp. for charging

→ Rxns depend on cathode material

**Advantages**

→ low cost.

→ available in diff. shapes

→ eco - friendly

**Disadvantages**

→ deposition of ions causes decrease in flow of charge

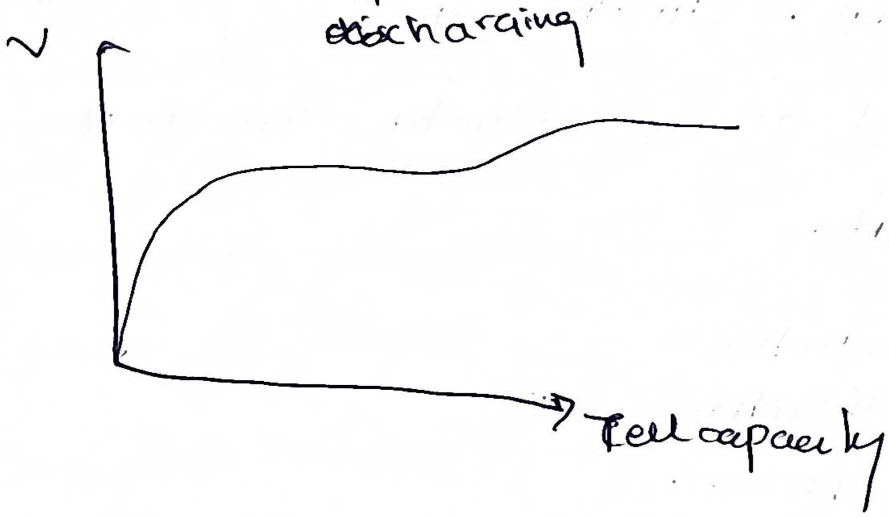
→ internal resistance gradually ↑, o/p ↓

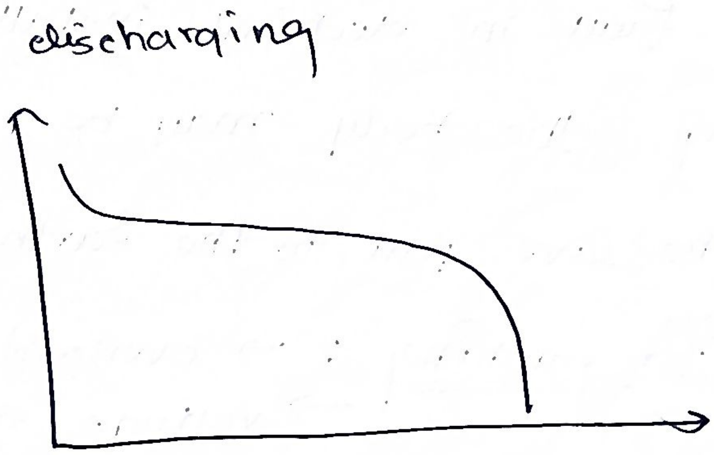
→ overcharging decreases capacity

**Applications** → used in military equipment

→ used in laptops & cell phones

**Characteristics**



## Comparison between secondary batteries

| Feature | Lead Acid | Nickel cadmium | Lithium Ion |
|---|---|---|---|
| Internal resistance | low | low | medium |
| Battery voltage | 2V | 1.2V | 3.2-3.7V |
| Maintenance | low | moderate | no maintenance |
| Cost | low | moderate | high |
| Toxicity | high | high | low |
| Thermal Stability | stable | stable | addn. ckt needed for stability |
| Efficiency | 90% | 70-90% | 99% |
| Charge Time | 8-16hrs | 1-2hrs | 1-4 hrs |

## Earthing

→ Connecting the electrically conductive part of an electrical equipment to the ground for safety.

→ Earthing protects an individual from accidental shock in the case of a fault in electrical installation. In the absence of earthing, the body may be used as a conducting medium from the live part to the earth part..

**Need for earthing** : → overload protection
→ voltage stabilization
→ injury & death prevention
→ fire prevention

## Components of an earthing system

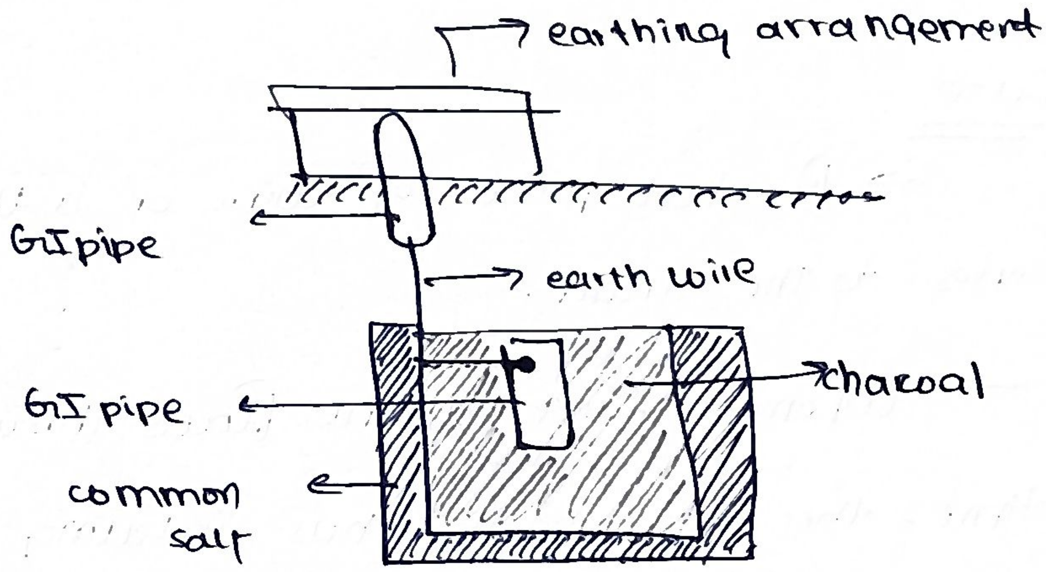
(i) Earthing continuity conductor : a conducting wire / strip that connects different electrical devices , connects earthing lead & diff. electrical devices

(ii) Earthing lead or earth conductor : conn. between electrical sys & earth electrode

(iii) Earth electrode : a conductor buried inside the ground

## Types of Earthing

### (1) Pipe Earthing




→ a GI pipe is used as the earth electrode

→ It is placed vertically and buried in wet ground.

→ Underground, charcoal / coke surrounds pipe , This is done because coke + salt decreases earth resistance

→ In summer, to prevent an increase in earth resistance, buckets of water are poured to a funnel connected to a GI pipe.

### (2) Plate Earthing

→ GI / copper plate is the earth electrode

→ buried with their faces vertical

→ distance between ground & plate should be > 2m.

→ plate should be at least 0.6m away from building foundations

→ covered by 15cm of coke & salt.

## Factors to be considered during Earthing?

① Distance ? distance between electrode & electrical sys should be > 1.5m

② cross-section of earthing lead

③ of earth cont. lead

④ electrode : same material for earth electrode & earth lead

⑤ earth resistance : max value should be 5 Ω.

## Fuse

→ A short piece of wire or a thin strip of metal, inserted in series to the circuit.

→ When a fault current flows through the fuse for a sufficient time, the fuse melts, thus isolating the circuit.

→ Under normal operation, the fuse is kept at a temperature below the melting pt. of the material used, so that it can carry the normal current w/o any rise in temperature.

→ When there is a fault, the temp. rises and the material melts or blows.

→ Greater the fault, lesser the time required to melt or blow out the fuse

**Advantages**
→ cheap
→ no maintenance
→ pollution free
→ easily breaks a large amt. of fault current

## Disadvantages

→ Rewiring a fuse is difficult

→ Discrimination between fuses connected in series is not possible.

## Desirable Characteristics of Fuse Element Materials

| | |
|---|---|
| → low melting point | tin, lead |
| → high conductivity | silver, copper |
| → least reactive to oxidation | silver |
| → affordable | lead, tin, copper |

In day-to-day activities, silver is used because

→ does not deteriorate in dry air

→ fast operation

→ high conductivity

→ small expansion coeff - can carry rated current for a long time.

## Definitions

① Current rating of fuse element : amt. of current that the fuse element can carry under normal operation

② Fusing current : minimum current at which the fuse element melts or blows away

③ Fusing Factor = $\dfrac{\text{Fusing current}}{\text{current rating}}$

## Classification of Fuses

1. Low voltage fuses:
   - semi-enclosed rewireable fuse
   - high rupturing capacity (HRC) fuse

2. High voltage fuse
   - cartridge type
   - metal-clad type
   - liquid type

**Tariff** : Refers to methods to charging a consumer for consuming electric power.

→ Tariff depends on the type of consumer: domestic, commercial or industrial

→ Also dependent on magnitude of consumption and load condition.

## Factors affecting the Tariff

① Nature of the load.:

industrial load vs. commercial load vs. domestic loads

② Maximum Demand:

→ Maximum demand is the maximum of all demands that a particular station supplies in a given period.

→ Tariff $\propto$ maximum demand (because max. demand $\propto$ investment cost)

③ Load Requirement Time

→ consumption of energy during peak and off-peak times

→ cost for peak time consumption > cost for off-peak time

④. Load Power Factor

→ power factor is inversely proportional to the tariff.

→ a low power factor means that additional devices are required to correct the power factor and hence the tariff would be higher.

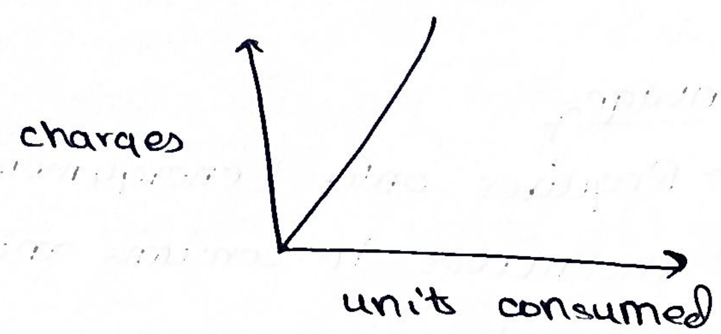
~~Characteristics~~

## Types of Tariff.

### ① Simple Tariff

→ a fixed rate for each unit of consumed energy

→ energy consumed w/ an energy meter




**Advantages**

→ simple, easy to understand

→ cost as per consumption

**Disadvantages**

→ no discrimination between different types of consumers

→ no incentives

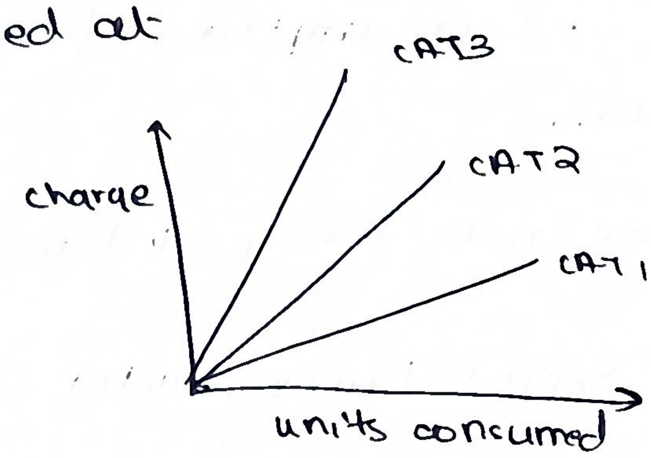
→ supplier cannot charge any amount when no energy is consumed even though there exists a connection.

For tube wells for irrigation

## (2) Flat - Rate Tariff

→ diff. types of consumers charged at different fixed rate per unit consumed.

→ fixed rate decided based on load & power factor




Advantages → fair
→ simple

for domestic consumers

Disadvantages → need for separate energy meters
→ no incentives
→ arrangement is complex & expensive

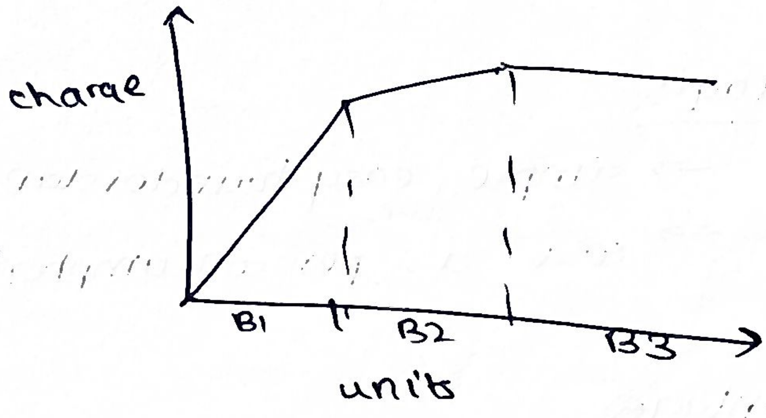
## (3) Block-rate Tariff

→ energy consumption is divided into different blocks, each block is charged a particular fixed rate.

major residential + small commercial

→ Successive blocks, are charged at progressively reduced rates

Advantages
→ Requires only 1 energy meter
→ incentives to consume more electricity




Disadvantages → supplier cannot charge when no electricity is consumed though there is a connection.

## (4) Two Part Tariff or Hopkinson Demand Rate Tariff

→ Total cost depends on 2 components, fixed & running charges

Total = [a × MD + b × UC]

MD = maximum demand of consumer

a = corresponding charge / kwhr

UC = units consumed by consumer

b = corresponding charge / kwhr.

industrial consumers where max. demand is significant

→ capital investment cost, taxes, operating cost come under fixed cost

Advantages → easy to understand

→ fixed charge is independent of units consumed by the consumer.

Disadvantages → irrespective of electricity consumed, consumer has to pay fixed charges

→ error in calculating maximum demand.

used ~~for~~ for industrial consumers

(5) Maximum-demand Tariff

→ same as 2 part tariff, except for the fact that a maximum-demand metre is installed. (large industries)

Advantage → eliminates error in max. demand calc.

Disadvantage → not suitable for small residential consumers

(6) Power-Factor Tariff : → power factor of the consumers' load is taken into consideration

→ high power ⇒ optimal operation

(1) KVA max-demand tariff : a 2 part tariff

Total = A (kVA) + B (kWh)

low power factor increases the kVA value

(ii) <u>KW and KVAR Tariff</u> : → both active power & reactive power consumptions are measured

$$\text{Total} = A(\text{KWh}) + B(\text{kVARh})$$

(iii) <u>Sliding-scale tariff</u> : → also called average power factor tariff

→ a particular value of power factor is taken as reference

→ if PF is lower than reference, consumer is penalized

→ if PF > reference, discount given

(7) <u>Three part Tariff</u> : → split into 3 parts, fixed, semi-fixed & running charges

$$\text{Total} = [c + A \times MD + b \times UC]$$

c = fixed charge (capital investment cost of 2° dist, labour cost)

for big consumers

Do examples pg. 271