Hydro electric power station

Potential energy of water stored at high level is Converted into Kinetic energy to generate electrical energy.

→ These stations are generally located at hilly areas where dams can built Conveniently forms a large water reservoirs.

→ From dam reservoir water led to water turbine Captures water falling energy into mechanical energy

→ These mechanical energy Converts into electrical energy.

→ These stations are important in flood Controlling during rainy seasons & provide drinking, irrigation purposes.

Advantages

→ water is used as fuel which is available at free of cost

→ No smoke or ash particulates means clean power generation

→ running costs is very low

→ Instantly start the generation

→ It has longer life

→ such plants serve many purposes such as power generation, irrigation & drinking water.

Selection of site

→ Availability of water: Requires huge quantity of water with suitable head.

→ Storage of water: water should be stored by Constructing a dam across the river flow. storage helps in equalising flow of water.

Cost & type of land: land should be available at reasonable cost & should withstand the heavy construction.

Transportation: site should be accessible to transport by rail or road so that necessary equippments could be easily transported.

water head: It is necessary to provide ample quantity of water at sufficient head. An increase in head for a given o/p reduces the quantity of water.

Distance from load center: plant must be located nearer to load, to minimise cost of errection & maintenance of transmission

Disadvantages of Hydro power plant

→ Construction of dam involves high capital cost

→ Constructing a dam shows impact on environment like alter aquatic habitat, relocation of local communities, loss of forest

→ Hydropower depends on amount of rainfall

→ Not possible to construct any where

→ Highly skilled & experienced hands are required to construct the plant

→ Maximum of these plant located in hilly areas increases the cost of transmitting power.

Layout or Schematic arrangement of Hydro power

→ Dam is constructed in rainfall catchment areas forms a reservoir at the back of the dam.

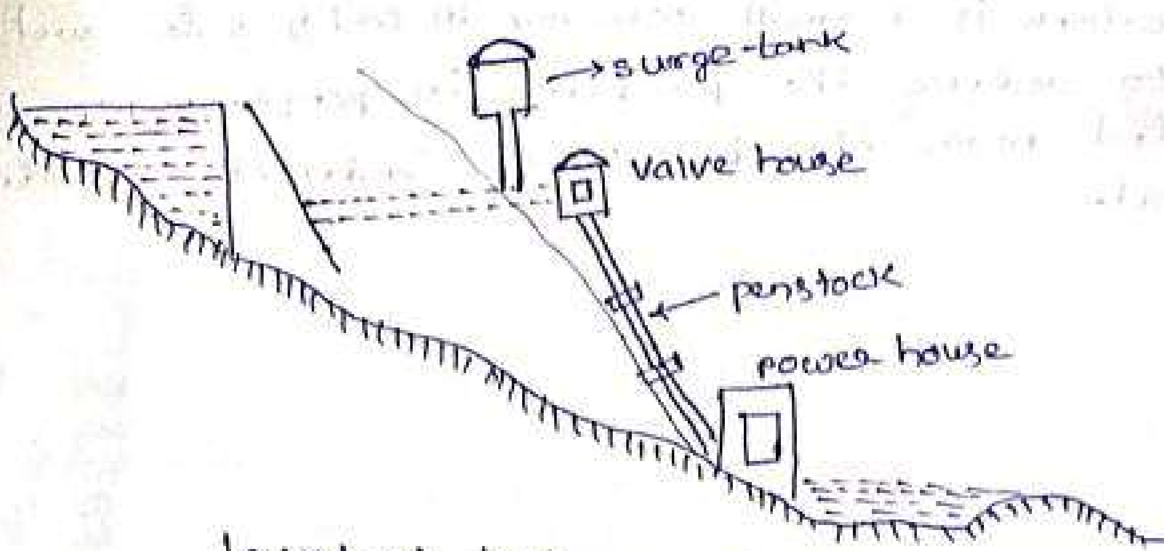
→ Pressure tunnel is taken from reservoir & water is bought to valve house through penstock

→ Valve house consists 2 values

① Main sluice: Controls water flow to power house

(2) isolating automatic values cutts off supply of water during penstock bursts. A penstock is a steel pipe.

→ From the value water is taken to turbine through penstock. turbine Mechanical converts into electrical power



Layout of hydro power plant

Main constituents of hydro power is
① Hydraulic structure (II) water turbines & (III) electrical components

① Hydraulic structure : related to dam like spillways, headworks, penstock, surge-tank etc

(i) Dam : It is a big steel & RCC structure built across river to store & creates water head.

(ii) Spillways : Discharges excess water into river down stream side. These are also a Concrete structure provided with gates located at the top of the main gates.

(iii) Head works :- It is an diversion structure at the head of an intake. These structure diverts the floating debris, sluices for by-passing debris & sediments

(iv) Surge-tank : An open channel doesn't requires any protection, since inflow at head works is controlled by gates & spillway discharges excess water.

When closed conduit or channel are used, protection needs necessary to limit the abnormal pressure in the channel or pipe. For this reason closed conduits are always provided a surge tank.

A surge tank is a small reservoir in which water level varies to reduce the pressure in penstock pipe. It is located near the begining of Conducit or Conduit or channel.

(V) penstock:

A penstock is a open or closed conduit or channel to carry water to turbine. These are of steel or concrete made. Concrete penstocks are suitable to low heads i.e less than 30mtrs. Steel type penstocks are suitable for any heads, thickness of penstock depends on head.

A penstock is provided with protection valves such as butterfly value which shutts off water supply during penstock bursts where as Air Value maintains air pressure which is equal to outside atmospheric pressure.

(2) water turbines: Converting kinetic energy of water into mechanical energy. The principle of these turbines are (i) impulse turbine (ii) Reaction turbines

(i) Impulse turbine: Example is pelton wheel turbine

→ Entire pressure of water converted into kinetic energy at the nozzle.

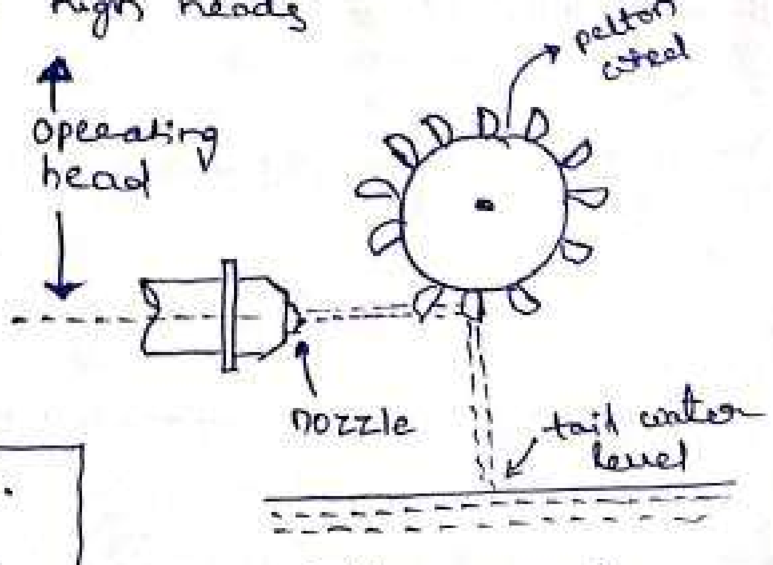
→ A nozzle provide a jet of water drives the pelton wheel.

→ It is suitable for high heads

→ pelton wheel is a circular wheel fitted elipitical bucket above the surface of wheel.

→ Force of water jet from nozzle strikes the buckets drives the wheel.

→ A nozzle will controls the jet of water flow



pelton wheel

(ii) Reaction turbine:

→ suitable for low & medium heads.
→ These turbines uses pressure & velocity of water generates rotational force.
→ A runner is placed in the water stream, allowing the water to flow over the blades rotates.
→ Examples are ⓐ francis turbines ⓑ Kaplan turbines.
→ francis turbine suitable to low to medium heads & Kaplan is suitable to
→ A Kaplan turbine is used for low heads which uses the water flow radially inwards

③ Electrical equipment: This station includes alternators, transformers, circuit breaker & other switching & protecting devices.

Important formula's

→ Weight of water W = Volume of water * density
→ Electrical energy available = $W * H * \eta_{oa}$ = W-secs
   (H → Head; η_{oa} → overall efficiency)
→ firm Capacity = plant efficiency * Gross plant efficiency
→ Yearly gross o/p = firm Capacity * Hours in a year
   Hours in a year = no: of days in a year * no: of hours per day
   = 365 * 24 = 8760 hrs
→ Volume of water per Kg = (V * 1000)
   Volume of water in newton = V * 1000 * 9.81 N
→ Quantity of water or volume of water used per year
   = Catchment area * Annual rainfall * Yield factor

⑥

Calculate average power in KW that can be generated in a hydro-electric plant having following data:
Catchment area = $5 \times 10^9 m^2$, Head of plant H = 30m
Annual rainfall F = 1.25m, Yield factor K = 80%, overall efficiency = 70%, load factor is 40%. What is the ratings generators installed.

Average power = $\frac{\text{energy generated / annum}}{\text{no. of hours / annum}}$

Given data: Catchment area = $5 \times 10^9 m^2$, $\eta_{oa} = 70\% = 0.7$
Head of plant H = 30m, yield factor K = 80%
Annual rainfall F = 1.25m, load factor = 40%

→ Electrical energy generated per annum = $W \times H \times \eta_{oa}$ W-sec

Weight of water W = Volume of water × 9.81 N × 1000

Volume of water V = Catchment area × Annual rainfall × Yield factor

$V = 5 \times 10^9 \times 1.25 \times 0.8 = 5 \times 10^9 m^3$

→ weight of water $W = 5 \times 10^9 \times 1000 \times 9.81 = 49.05 \times 10^{12} N$

→ Electrical energy generated/annum = $49.05 \times 10^{12} \times 30 \times 0.7$ [illegible]

$= \frac{49.05 \times 10^{12} \times 30 \times 0.7}{[illegible]} = \frac{2.86 \times 10^8 \text{ W-sec}}{[illegible]}$

= [illegible] × $\frac{1}{[illegible]}$ × $\frac{1}{[illegible]}$ = [illegible] KW

1000W = KW
$1W = \frac{1}{1000}$ KW

60sec = 1min
60min = 1hr

60 × 1min = 1hr
60 × 60 sec = 1hr
$1 sec = \frac{1}{3600}$ hr

→ [illegible] $\frac{\text{Energy generated}}{\text{no. of days × no. of}}$

average power = $\frac{\text{Energy generated/annum}}{\text{no. of hours in a year}}$ (7)

$= \frac{2.86 \times 10^8}{365 \times 24} = 32648\ kW$

→ load factor = $\frac{\text{Average power demand}}{\text{Max. power demand}}$

Max. power = $\frac{32648}{\text{Load factor}} = \frac{32648}{0.4} = 81620\ kW$.

(2) Reservoir area = 2.4 sq km & Capacity is $5 \times 10^6\ m^3$. Head of water is 100 mtrs. penstock (η_p) = 95%, turbine (η_t) = 90% & generator (η_g) = 85%.

(i) Calculate total electrical energy generated from power station

(ii) if a load of 15000 kW has supplied for 3 hours, find fall in reservoir level.

Sol

$H = 100$ mtrs, Area of reservoir = $2.4\ km^2 = 2.4 \times 10^6\ m^2$

Capacity or volume of water $V = 5 \times 10^6\ m^3$

Volume of water in Newton = $V \times 1000 \times 9.81$

$= 5 \times 10^6 \times 1000 \times 9.81 =$

Overall efficiency $\eta_{oa} = \eta_p \times \eta_t \times \eta_g = 0.95 \times 0.9 \times 0.85$

$\eta_{oa} = 0.726$

→ weight of water W = Volume of water in newton ×

→ Energy generated = $\frac{W \times H \times \eta_{oa}}{1000 \times 3600} = \frac{5 \times 10^6 \times 1000 \times 9.81 \times 100 \times 0.726}{1000 \times 3600}$

→ Average power = $\frac{\text{energy generated}}{\text{no. of days in year} \times \text{no. of hrs in a day}} = \frac{989175}{365 \times 24}$

$= 112.919\ kW$

) Let (x) be ~~distance~~ fall in reservoir water level in 3 hrs

$$\text{Average discharge/sec} = \frac{\text{Area of reservoir} \times x}{\text{no. of hours in sec}} = \frac{2.4 \times 10^6 \times x}{3 \times 60 \times 60}$$

$$= 222.2x \ m^3$$

Weight of water available/sec = Average of water × 1000 × 9.81

Catchment area of reservoir is 50km² & head of water available is 50m. If overall efficiency of plant is 60%. Determine rate at which water level will fall when station is generating 30KW.

Sol

Catchment area = $50 km^2 = 50 * 1000 * 1000 \ m^2$

$= 50 * 10^6 m^2$

Head h = 50m , $\eta_{oa} = 60\%$ or 0.6

Average power generation is 30KW

Electrical energy generated = $\frac{W * H * \eta_{OA}}{1000 * 3600}$

$$P = \frac{W * H * \eta_{OA}}{1000 * 3600}$$

W = Q * 1000 * 9.81

P = Q × 1000 * 9.81

$$30 * 10^3 = \frac{Q * 1000 * 9.81 * 50 * 0.6}{1000 * 3600}$$

$$Q = \frac{30 * 10^3 * 1000 * 3600}{1000 * 9.81 * 50 * 0.6} = 366972.4 \ m/s$$

rate at which the water fall level = $\frac{Q}{A} = \frac{366972.4}{50 * 10^6}$

$= 7.33 * 10^{-3} m/s = 7.33 mm/s$

10

Thermal Power Stations

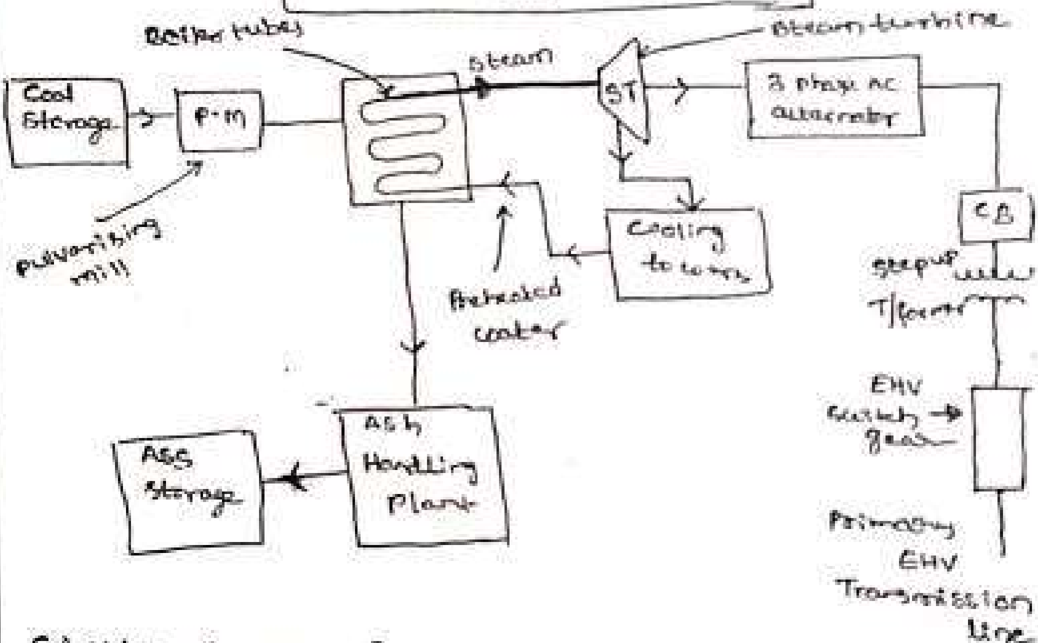
Water is converted into a high pressure steam used as mechanical energy will be converted into electrical power by using prime mover & generator. Steam can be produced by combusting the coal.

The main source generating thermal power is coal & water.

Low grade coal is available in India, low grade coal has 3 major problems.

* Calorific value is low
* More fuel is required to improve efficiency
* Produces high ash content after burning
* Requires extra equipments to collect ash.

Layout of thermal Power Station



Selection of site for thermal power station

(1) It must be nearer to transport
(2) Vast availability of land required for future extension.
(3) Requires ample amount of water
(4) It is located far away from the populated areas.

1MW = 10-15 tonnes of coal is required
1MW requires 4-5 acres of land.

Components in TPS

11

(1) coal Handling plant : collect coal from mines being transported by rail or road.

performs 3 functions : remove debris, crush into pieces removes moisture.

(2) coal storage : coal is stored in coal bunkers.

(3) Ball mill : where coal can cut into pulverised coal. so that wastage of coal is reduced & increases burning efficiency.

(4) Boilers : It is a closed vessel where water is boiled by the combustion of coal. It is made up of cast Iron having many number of tubes.

classified as 2 types

(i) water tube boiler : Here tubes is filled with water & heats sourrounding surface of tubes.

(ii) fire tube boilers : Heat is passed through the inside tubes which heats sourrounding water.

so Most of TPS uses water tube boilers.

At High temperature & pressure Produces steam & burning of coal produces ash.

(5) super heater

* purpose to increase the temperature of steam. It consists of tubes where flue gases is allowed through the tubes becomes heat absorbed by steam.

* Here temperature increases to 540°c without change in pressure.

(6) Turbine : Act as a prime to generator so that mechanical energy is converted as electrical power using generator

Here also Impulse & reaction types turbines are used.

(7) Generator : synchronous generators are used

Turbo generator → upto 500 MW (6.6 or 11 or 13.2 kV)

Modern turbo generator → 500 MW - 1000 MW
2.2 kV - 30 kV

12

* overall efficiency

$$\eta_o = \eta_b * \eta_t * \eta_g$$

or

$$\eta_o = \frac{\text{Heat equivalent of electrical energy in kwh}}{\text{Heat of Combustion of coal in K cal}}$$

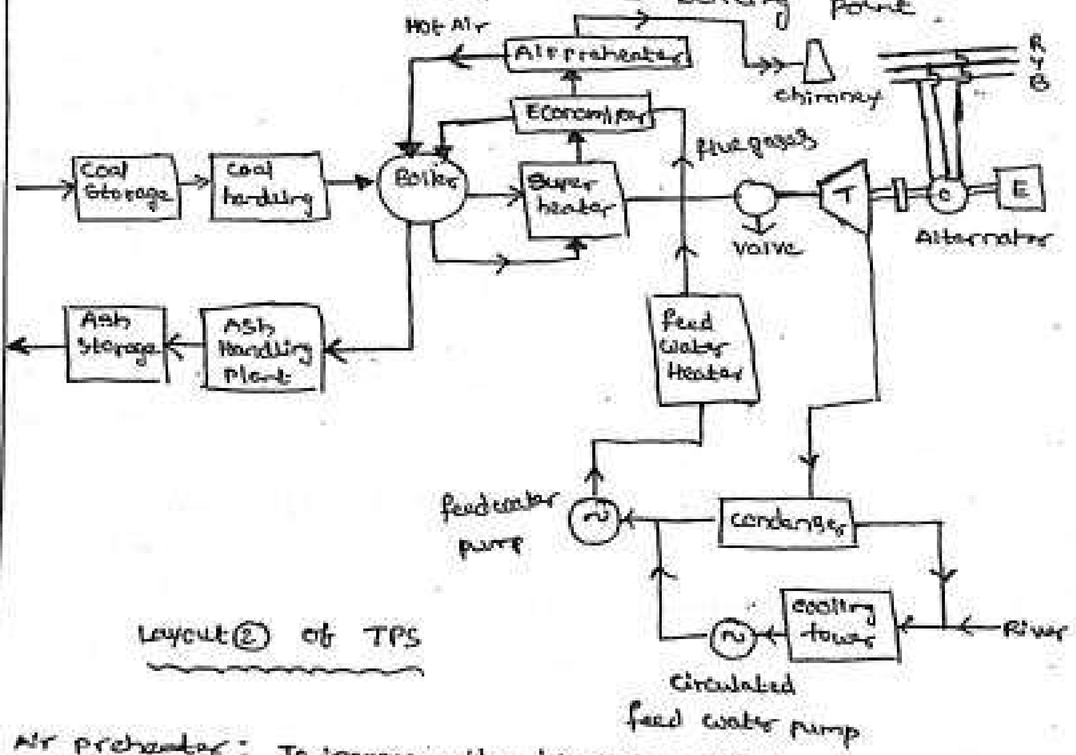
η_T = thermal efficiency = $\eta_b * \eta_t$

or

$$\eta_T = \frac{\text{Heat equivalent of mechanical energy in KJ}}{\text{Heat of Combustion of coal in Kcal.}}$$

(8) Economiser: These are used to reduce the energy consumption by utilising the exhaust gases. These are usually fitted with boiler, which are preheating a fluid used to fill. in the boiler. These are acting as a heat exchangers.

In Economiser exhaust gases from boiler heat feed water beyond the boiling point.



Layout (2) of TPS

Air preheater: To increase the burning efficiency of coal, sufficient air is required. Here forced draught fan supplies air to air preheater which heats the air using flue gases.

(13)

condenser : water from the turbine is having high Pressure & high temperature. The process of reducing the temperature & pressure of the steam is condenser.

* By increasing the cross sectional area of Condenser, the pressure & temperature of steam is reduced by using cool water.
* After Condensation temperature of steam 40°c & Pressure is 0.4 kg/m² is achieved.
* The Condensated steam is used as feed water to the boiler.

Electrostatic Precipitator

After burning coal, along with ash flue gases also released. This gases like SO_2, CO, CO_2 have poisonous in nature.

These can be separated using electrostatic precipitator. The ash is collected in a separate device known as Hopper.

Draught fans : 2 types

① forced draught fan :
* arranged at the bottom of chimney
* purpose is to collect flue gases & send them to atmosphere

② [redacted] Induced draught fan
* arranged at the boiler furnace
* purpose is used as air preheater to supply natural air to the furnace
* used to exempt the flue gases

cooling tower

* If continuity of water is available, no need of cooling tower requirement.
* If water availability is not sufficient, it can be re-utilized using cooling towers.
* Its purpose is to remove the vapour particles in the steam during Condensation.
* Here we get the cool water which can be re-utilized.

(14)

Nuclear Power

(14)

→ Power generation is similar to steam power plant (thermal plant).

→ By using radio active materials, heat can be produced which can boils the water produce steam.

fuel: Radio active materials

Its weight is measured in Atomic mass unit.

1AMU = 1.67×10^{-27} kg

→ Heat released by radio active material is measured by eV or MeV

1 AMU = 931 MeV

1 kg of nuclear material = 4500 tonnes of coal will produce 1MW for 365 days.

Selection of site for the location of nuclear plant

* Located nearer to the load centers, to reduce the transmission costs.
* Ample water is of available, to condensate & to produce the steam
* Accessible to road or rail transport
* facility to store & dispose nuclear waste material. Either to buried or dumped into the sea.

Advantages

* Amount of fuel required is less
* Load factor of plant is high i.e > 80%.
* Cost of transmission reduces because it is located nearer the load centers
* Land requirement is less

(15)

nuclear power disadvantages

(1) Installation cost is high

(2) skilled employees are needed to operate the plant

(3) Atmospheric pollution is high, during radio active materials.

(4) Maintenance cost is very high

(5) waste disposal is biggest problem.

Nuclear fission → splitting of heavy atom into 2 or more smaller atoms is termed as nuclear fission.

It is one of the nuclear reaction to generate nuclear power.

In this high speed neutron is able to collide with atomic molecule, so that it is converted into a smaller atomic molecules along with free neutron & certain amount of heat is released.

$$_0n^1 + U^{235}_{92} \longrightarrow Ba + Kr + 3\,_0n^1 + 200 mev$$

Released neutron once again participated in nuclear fission, each neutron releases 3 more neutrons & it will continue till radio active exhaust. It is called as chain reaction.

Uranium U^{238} is used as fuel & thorium also used as a fuel.

Multiplication factor or reproduction factor (K)

$$K = \frac{\text{no. of neutrons released in a cycle}}{\text{no. of neutrons lost in same cycle}}$$

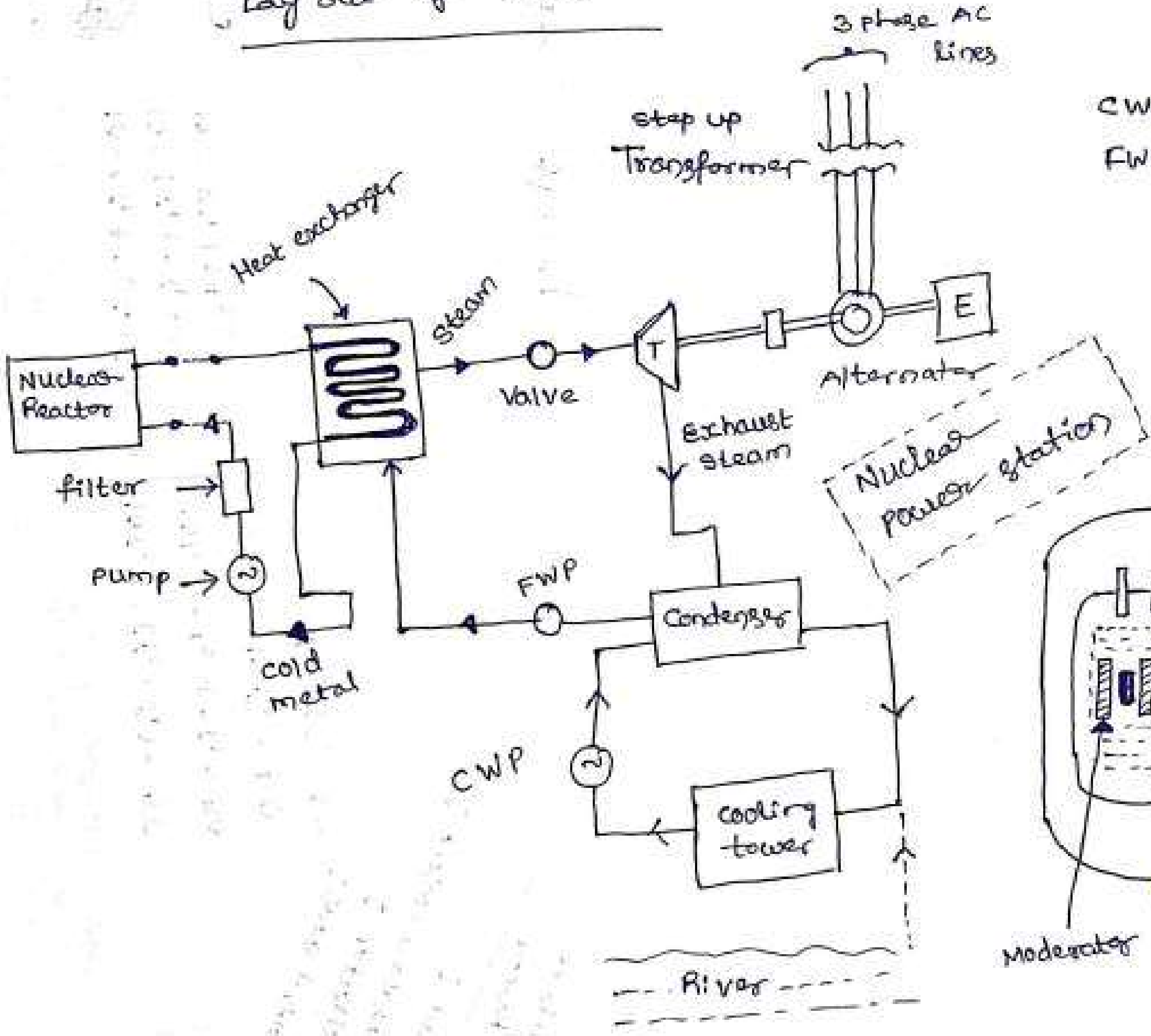
$K = 1.0$ critical condition

$K > 1.0$ nuclear reaction build up

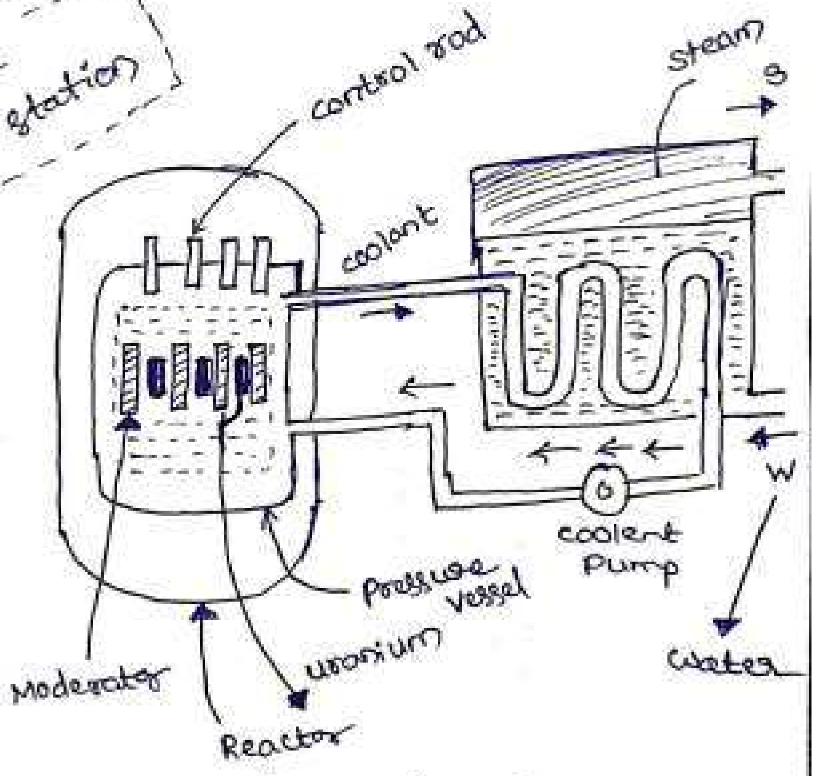
$K < 1.0$ " " slow down

Heat exchanger : Heat produced in reactor is removed by coolent is collected by the heat exchanger to raise the steam. Exhaust steam from turbine is cooled then fed to the nuclear reactor. (15)

Lay out of NPS



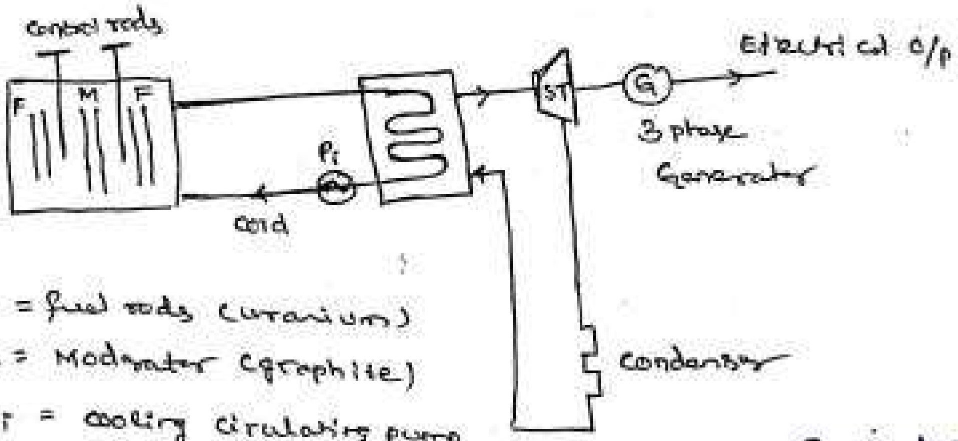
CWP → Circulating water pump
FWP → feed water pump



Nuclear Reactor

(16)

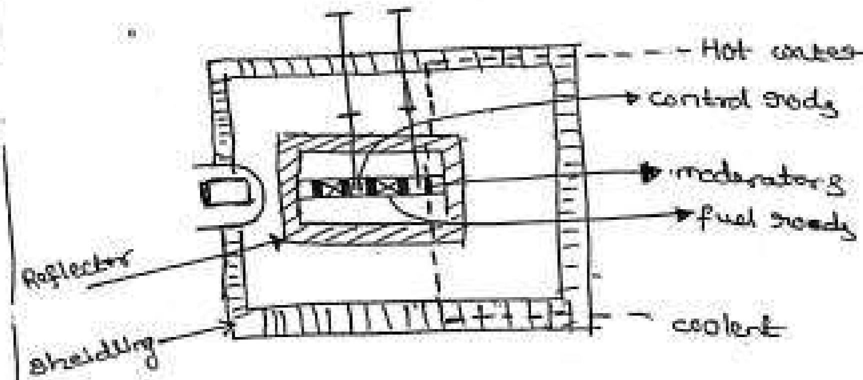
Layout of Nuclear plant



F = fuel rods (uranium)
M = Moderator (graphite)
P_1 = cooling circulating pump
control rods : Cadmium

Control rods
↓
downwards
M → absorbs neutrons
chain reaction decreases
→ o/p decreases

Details of nuclear Reactor



fuel rods

uranium isotopes are mainly used as fuel rods in power generation.

$^{235}_{92}U$ → Natural Uranium → 0.7 % of uranium

$^{238}_{92}U$ → enriched uranium → 99.3 %

India's most of the nuclear reactor uses natural uranium.

Moderator : The speed of the neutrons is controlled by using moderator.

(17)

Reflector

these are used to avoid the escaping of neutrons during nuclear fission.

Graphite or Beryllium

Shielding

During nuclear fission along with neutrons, β & γ particles are also released. The velocity of β & γ particles are very high.

Reflector cannot stop the β & γ particles to escape. When these particles released into the atmosphere, then radio active pollution takes place. Here β and γ particles are restricted by RCC wall called as shielding. When these particles hit the shielding the particles losses its energy & it becomes dead.

Control rods

It is used to control the nuclear reaction in the nuclear reactor. The control rods which are capable of absorbing the neutrons.

If control rods is in down position, intensity of nuclear reaction is low in this case loss of neutrons is more than that of neutrons released.

Boron or Cadmium are used as control rods.

Coolant

During nuclear fission, along with neutrons certain amount of heat is liberated & is collected by reactor is converted into steam, this coolant is used.

Here coolant purpose is to collect heat, in nuclear reactor & got exchange with feed water produce steam.

Liquids → H_2O, D_2O → heavy water
gases → H_2 or Helium
liquid metal → Na or K

Reactors

A reactor is a closed vessel where a nuclear reaction is carried out.

Reactors

- (I) Thermal reactors
  - (a) Pressurised water reactor (PWR)
  - (b) Boiling water reactor
  - (c) CANDU Reactor
- (II) Fast Breed reactors
  - * A fast breed reactor in which there is no moderator & fission is caused by high energy neutrons.
  - * These are designed to produce more plutonium.
  - * Here plutonium is a fissionable material.
  - * In this nuclear reaction more number of neutrons are generated instead of consuming.

(a) PWR

fuel → $^{238}_{92}U$ → Enriched uranium

H_2O → used as moderator & coolant

Graphite → Reflector is made up of graphite

Control rods → either Boron or Cadmium

Pressure → steam pressure is 140 kg/cm²

Here pressure of steam in nuclear reactor is less than pressure of steam in thermal plant.

Draw back: efficiency is only 20% only.

It can be increased to 30% using boiling water.

(b) Boiling water Reactor

fuel is enriched uranium $^{238}_{92}U$

H_2O → Moderator & coolant

Graphite → used as reflector

Control rods → Boron or Cadmium

efficiency is 30%.

(c) CANDU → Canada Deuterium Uranium (19)

fuel → Natural uranium U^{235}_{92}

Moderator & coolant → D_2O called as Heavy water

Reflector → made of graphite

Control rods → not needed

Nuclear reaction is Controlled by allowing more heavy water to reactor until neutron velocity is going to zero.

Majority of reactors in india are CANDU type.

(II) Fast Breed Reactors.

fuel → U^{238}_{92} enriched uranium

Moderator → not required

Coolant → Helium

Reflector → graphite

Control rods → Boron or Cadmium.

Safety Precautions

→ Proper design, plant layout & adequate shielding must be done

→ Proper inspection is needed to measure the radiation leakage

→ If Radiation levels 200 REMS indicates slightly shows impact on human body cells & leads to damage

→ If Radiation levels 400 REMS Can pollute the environment as well as, severage damage the human life.

→ nuclear waste properly Collected & stored in safe areas or dispose properly to avoid radiation leakages

→ Proper observation is needed to protect from terrorist attack.

Natural uranium

Mainly composed of 3 isotopes

U-238 → 99.2%.

U-235 → 0.7%. → not sufficient in chain seaction

U-234 → 0.005%.

Most of the nuclear seactors uses a higher concentration of uranium 235.

Enoiched uranium

The process of increasing the percentage of U235 to 3.5%. - 4.5% by the process of isotope separation is Enriched uranium.

LESSON PLAN

Isotope: It is defined as atoms of an element is having same atomic number but different atomic masses is Isotope

or

An atom of an element have same number of protons & different number of neutrons is called isotopes.

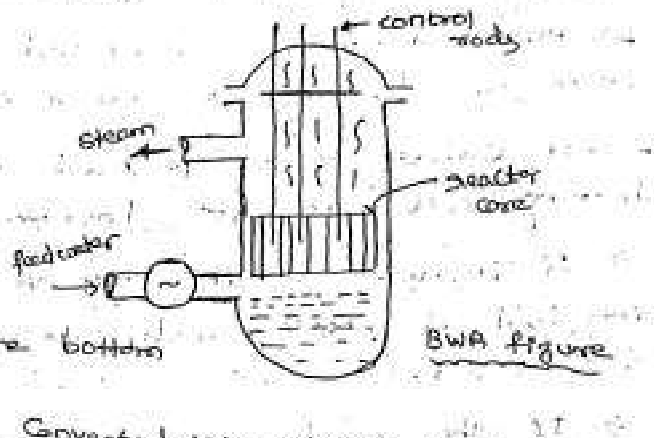
isotope
- → Same atomic number, different atomic mass
- or
- → Atom have same element of protons & different neutrons

Nuclear Reactors

NR-1

Power reactors are commonly used in nuclear power plants. These are classified as (I) Boiling water Reactors (II) Pressurised water Reactor (PWR) (III) CANDU Type reactor

(I) Boiling water reactors (BWR)

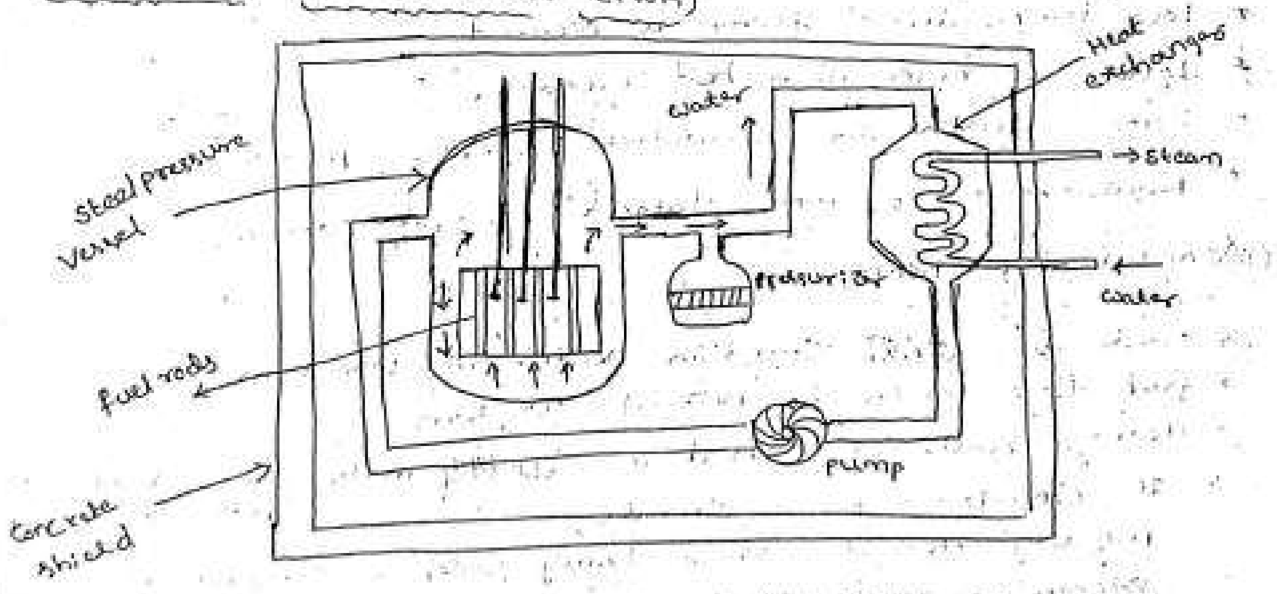


* Consists of steel pressure tunnel surrounded by concrete shell.
* fuel is used as enriched uranium.
* water is used as both coolent & moderator
* feed water is provided at the bottom of the reactor
* By fission feed water gets converted into steam collected at the top.

Advantage: Small size pressure vessel produces high steam pressure.
* construction is simple * No heat exchanger is needed this results reduces the construction cost. * efficiency is 33%

Disadvantages:
* chance of leakage of radiation takes place
* elaborate safety measurements are needed to avoid radio active contamination.
* wastage of steam results lowering the efficiency.
* cannot meet a sudden increase in load.

(II) Pressurised water Reactor (PWR)



→ It is a thermal reactor
→ fuel used here as enriched uranium
→ water is used as both coolent & moderator

NR2

→ Here Pressure vessel is made up of steel, heat exchanger both are surrounded by Concrete shield.

→ Hot water from reactor flows to a heat exchanger where its heat is transferred to feed water

→ Here steam is condensed & returns to the heat exchanger forming a closed circuit.

→ It consists of a pressure vessel which is having a heating coil at the bottom & steam vessel at the top.

→ If pressure at the top vessel decreases, heating coil gets energized & boils water to form steam collects at the top vessel.

→ If the pressure at the vessel is too high than it is cooled by the cold water.

→ Here the temperature is about 250°c & Pressure is 42kg/cm²

→ overall efficiency is 33%.

Advantages

* Compactness
* Possibility of breeding plutonium
* Possibility of separating the radio active materials

drawbacks

* Strong Protection is needed for pressure vessel
* Low temperature steam is occured
* Losses is high from heat exchanger
* Some auxillaries requires extra power
* Requirement of more elaborate safety devices.

(III) CANDU type Reactor

→ Stands for Canadian Deuterium uranium.
→ fuel to reactor is natural uranium
→ Heavy water is used as moderator & light water is used as coolant.
→ It consists of 2 circuits
Primary circuit where heavy water is circulated
Steam is Produced in Secondary Circuit
→ Such reactors does not require any Control rods
→ Reactor Control is achieved by Controlling the moderator

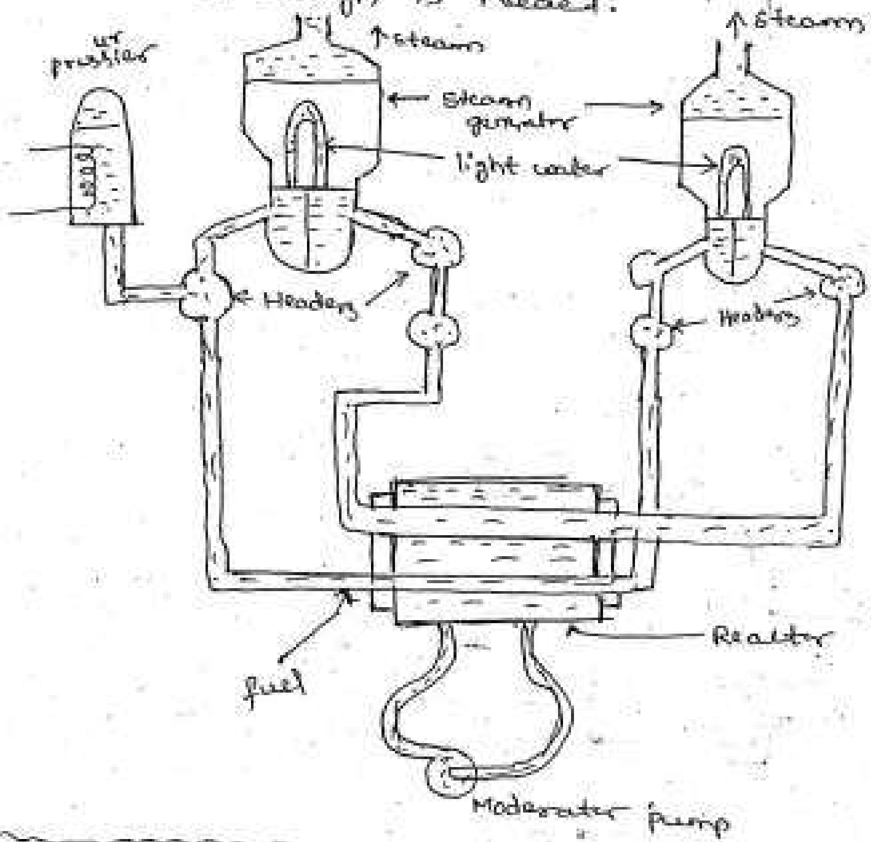
Advantages

NR3

→ no control rods, means simple control
→ high multiplication factor (K=1.0, K<1.0, K>1.0)
→ Low fuel consumption (C.C, N.R.C.D, N.R.Build)
→ Moderator operated at low temperature.

Draw backs

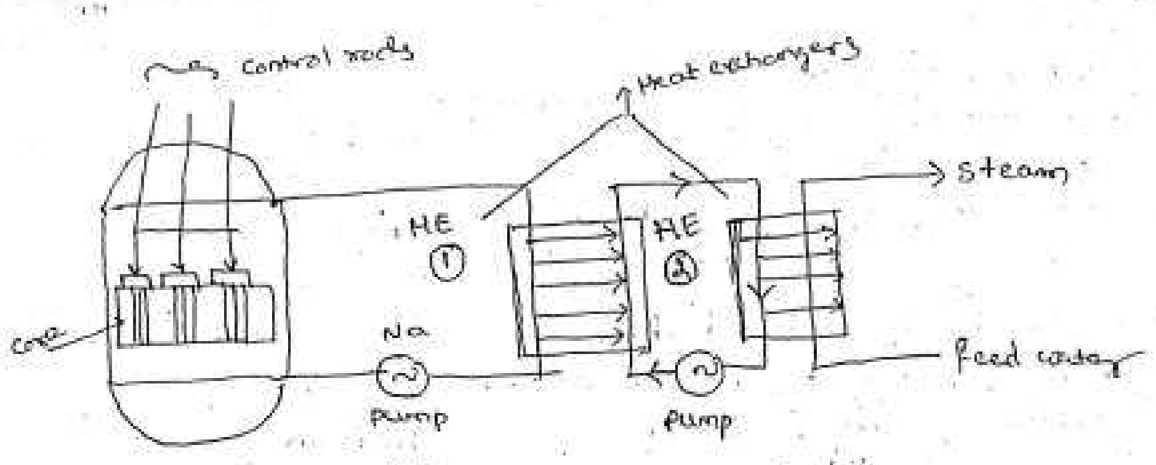
→ cost of heavy water, is high
→ chance of leakage of radiations
→ standard design is needed.

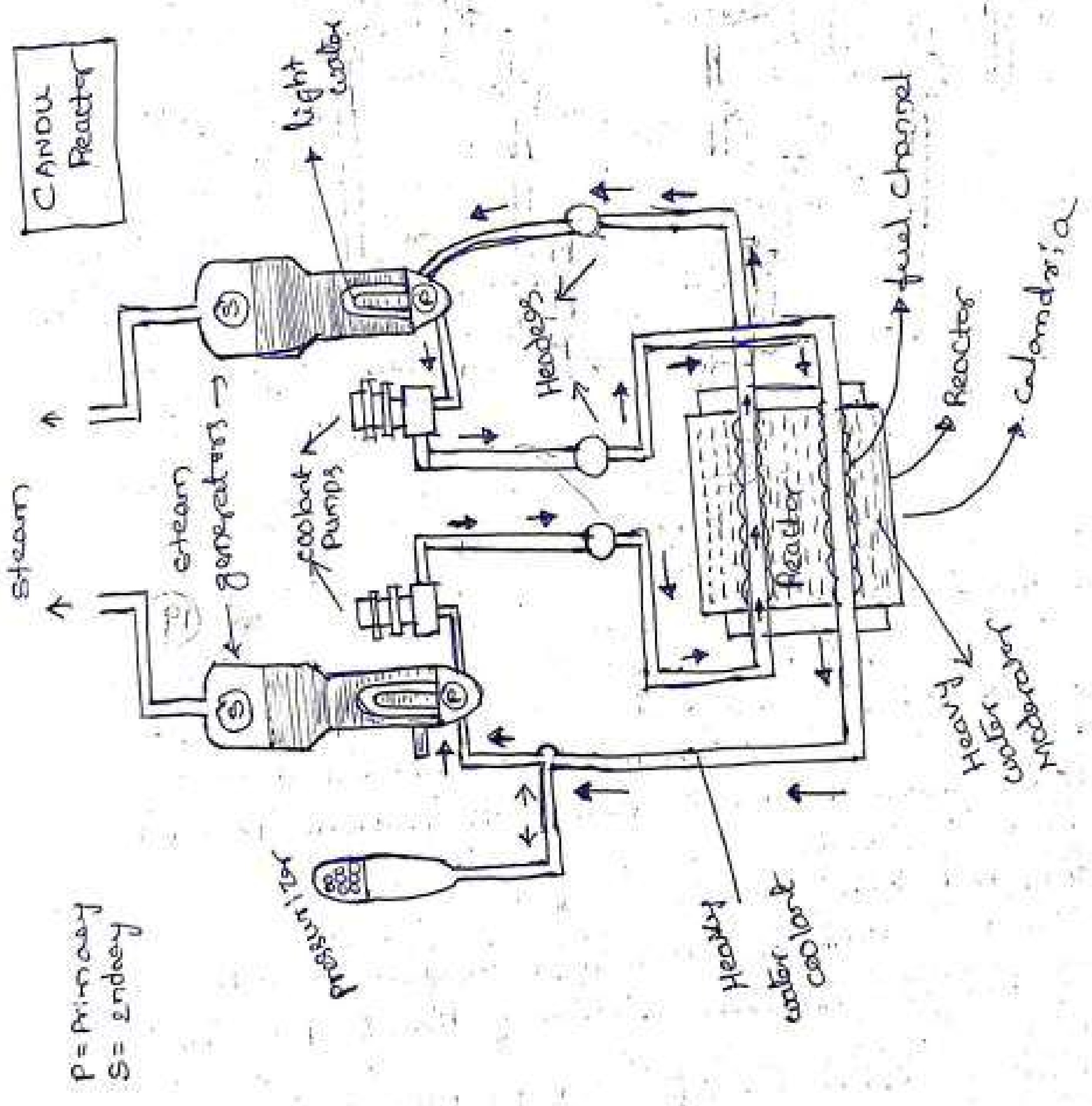


Fast Breeder Reactor :→

(19)

→ fuel is enriched uranium, able to produce more plutonium
→ No moderator is required
→ fuel core is surrounded by fertile material U-238.
→ fertile material U-238 absorbs the neutrons produced by nuclear fission.
→ Two heat exchangers are used.
→ liquid sodium or pottassium is used as coolant
→ In both heat exchanger sodium or liquid potassium is used as coolent.
→ neutron shielding is provided by boron
→ Gamma shielding is provided by lead or concrete.


control rods
Heat exchangers
steam
HE
①
HE
②
core
Na
pump
pump
feed water


CANDU Reactor
light water
steam
steam generators
coolant pumps
Headers
fuel channel
Reactor
Calandria
Reactor
Heavy water moderator
Heavy water coolant
pressurizer
P = Primary
S = Secondary

Date :

CANDU - Reactor

* This Reactor uses heavy water as neutron moderator.
* This heavy water some times acts as primary coolant
* Heat is transferred from primary coolant to 2ndary steam generators
* the moderator of this reactor uses natural uranium than enriched uranium as fuel.
* A candu fuel channel consists of 12 or 13 bundles of fuel elements held together by Zircaloy end plates. the fuel in reactor is calandaria is Moderator
* 25 Kg/s of coolant produces upto 7MW of power from Candu fuel.
* A Candu reactors uses 25 to 30 % of less Uranium Compared to light water reactors (PWR)

Advantages of CANDU Reactor

① fuel efficiency: High efficiency which uses 25% of uranium fuel to generate power

② uses Natural uranium, no need for an enrichment facility

③ Refueling: These reactors can be refueled in one line without shutting down reactor

④ Easy to Control the chain reaction by allowing or absorbing the heavy water

Disadvantages of CANDU - Reactor

* Heavy water: Cost of producing D_2O is high which uses as a moderator
* Heavy water absorbs neutrons releases tritium which reduces intensity of radio active process
* These reactors requires high design standards as well as needs advanced technology.
* Leakage of radiations takes place during chain reaction.

Date :

Radiation hazards & shielding

Nuclear power plants have several safety measures to protect radiation hazards including the following

① Design: High quality design & Construction, fail safe design & quality Control.

② Monitoring: frequent monitoring & regular testing to detect failures

③ Equippment: Equippment to prevent human errors or operational disturbances.

④ ionizing radiation: At high doses, ionizing radiation can cause immediate damage to body, including radiation & death. At lower doses, it can cause health effects such as cardiovascular disease, Cataracts, Cancer.

⑤ shielding: Proper shielding around the nuclear reactor can trap the β & r radiations to avoid radio active pollution.

⑥ Nuclear waste: Improper storage & disposal of nuclear waste can result environmental Contamination & accidental leakage of radiations.

⑦ use of remote handling equippments: Radiation exposure is minimised by the use of remote handling equippments for many operations

⑧ limiting the time work: limiting the time workers spend in areas of radiation level

Safety precautions:

→ proper design, plant layout & adequate shielding must be done.

→ Proper inspection is needed to measure the radiation leakage

→ If radiation levels 200 REMS, indicates slightly showing impact on human body cells & leads to damage.

→ If Radiation levels 400 REMS, can pollute environment as well as severe damage to human life.

→ nuclear waste properly collected & stored in safe areas or dispose properly to avoid radiation leakages

→ proper observation is needed to protect from terrorist attack.

SUBSTATIONS

Location of substations

its location is dictated by voltage levels, voltage regulation costs, costs of Primary feeders, main feeders & distribution transformers.

To select the substation location, the following rules

(1) Substation is located as much as feasible to the load center where maximum amount of load available.

(2) Reduces the distance from substation to load area

(3) Proper voltage regulation can be obtained without taking extensive measures

(4) Also select the substation location allows for future growth

(5) Also select the substation location should be accessible for incoming subtransmission lines & outgoing primary feeders.

(6) Selecting substation location should have enough space for future extension.

(7) Selected substation location should help to minimise the discontinuity of supply at consumers side.

(8) Selected substation should not opposes the land regulation

(9) A l substation should located should be nearer to existing road for better transport.

(10) A substation should be located free from chemical factories or sea cost

(11) location of substation should be outdoor, indoor or underground. This is based on availability of space

Rating or size of substations

It depends on

(I) load density growth (II) utilization of transformer capacity (III) Fault levels (IV) flexibility in operation.

The choice of voltage levels depends on load density & distance over which feeders have to run. In india standardise voltage levels are 11 KV for High voltage distribution & 400 V are used as Low voltage distribution.

Generally size of substation is very large & is in compact especially in urban area because of space availability. Present trend is relatively small sized, feeding load by few short feeders rather than large substation. The reasons are

(I) when outgoing feeders are a few, it is feasible to have bus regulation by means of automatic tap changing equipment in transformers.

(II) Reduction of major outages if short feeders are used

(III) Small size in substation allows to increase loads in steps, thus saving in cost.

(IV) Small substations are easily installed & maintainence becomes easily compare large size distribution substation.

Substation service area with N Primary feeders

Assume 'n' primary feeders serves the substation area. 'n' feeders have uniformly distributed load. Each feeder serves a triangular shape area.

Let dA be the differential area have differential load served by the feeder.

$$dS = D\,dA \text{ KVA} \rightarrow (1)$$

↳ differential load served by feeder

D is the load density

$A = l_n \tan\theta$

$S_n = S = l_n \tan\theta * D$

$$\tan\theta = \frac{y}{x+dx} \rightarrow (2)$$

$$y = \tan\theta(x+dx) \rightarrow (3)$$

$$y \cong x + \tan\theta$$

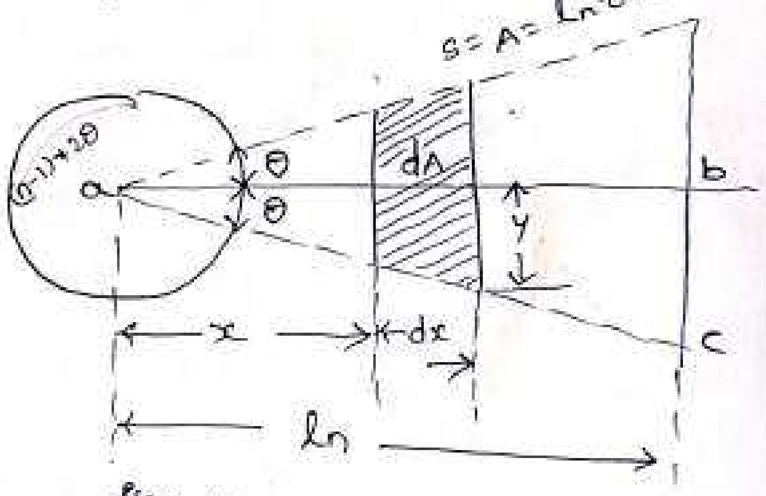


fig: distribution substation area served by 'n' feeders

total area served by 'n' feeders

$$A_n = \int_{x=0}^{l_n} dA \Rightarrow \int_{x=0}^{l_n} l_n \tan\theta \, dA$$

$$= l_n^2 \tan\theta \rightarrow (4)$$

total KVA load served by n feeders $(S = D * l_n \tan\theta)$

$$S_n = \int_{x=0}^{l_n} dS = D * l_n^2 * \tan\theta \rightarrow (5)$$

Total load is located at a point on main feeder at a distance of 2/3 l_n from feeding point a. Therefore % voltage drop

$$\%VD_n = \frac{2}{3} * l_n * K * S_n = \frac{2}{3} * K * D * l_n^3 \tan\theta \rightarrow (6)$$

or

$$n(2\theta) = 360 \Rightarrow \theta = \frac{360}{2n} \rightarrow (7)$$

$$\%VD_n = \frac{2}{3} * K * D * l_n^3 \tan\left(\frac{360}{2n}\right) \rightarrow (8)$$

Optimal substation allocation

Every Consumer in utility s/m derives Power from nearest substation. A substation delivery s/m should be as short as possible to avoid feeder Cost, size & service interruption.

For optimal location, the following methods are adopted. (a) load Center location (b) Perpendicular bisector rule b/w existing substation (c)

(a) Load Center location

For locating substations, treat load in substation as masses. the location point of substation is established by reference points X & Y-axis. Algebraic sum of all moments of Y-axis & X-axis are Calculated & divided by total load.

To set X, Y coordinates for proposed substation

$$(\text{Total load}) \cdot X = L_1X_1 + L_2X_2 \text{ ------}$$
$$(\text{Total load}) \cdot Y = L_1Y_1 + L_2Y_1 + \text{------}$$

X_1, X_2 & Y_1, Y_2 are distance of loads L_1, L_2

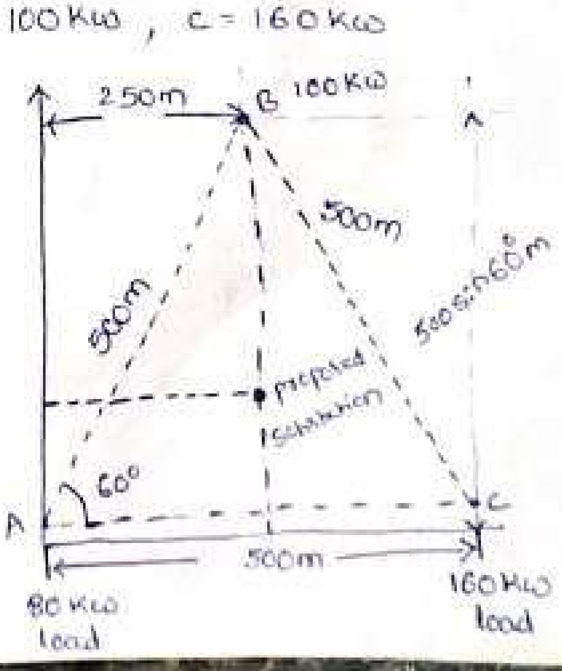
Explaination

Let A, B, C are load serving area having 500m equal distance b/w the loads A, B, C.

Respective load are A = 80 KW, B = 100 KW, C = 160 KW having unity p.f shown in fig (1).

For finding load Center, the following equations are obtained as

$$X(\text{total load}) = L_1X_1 + L_2X_2 + L_3X_3$$
$$X(A+B+C) = (80*0) + (100*250) + (160*500)$$
$$X(340) = 1,05,000$$
$$X = 308\text{ m}$$



$$Y(\text{Total loads}) = \overset{AB}{L_1 Y_1} + \overset{BC}{L_2 Y_2} + \overset{CA}{L_3 Y_3}$$

$$Y(A+B+C) = [illegible] + [illegible]\ (80 * 0) + (160 * 0) + 500 \sin 60° * 100$$

$$Y(340) = 43{,}301$$

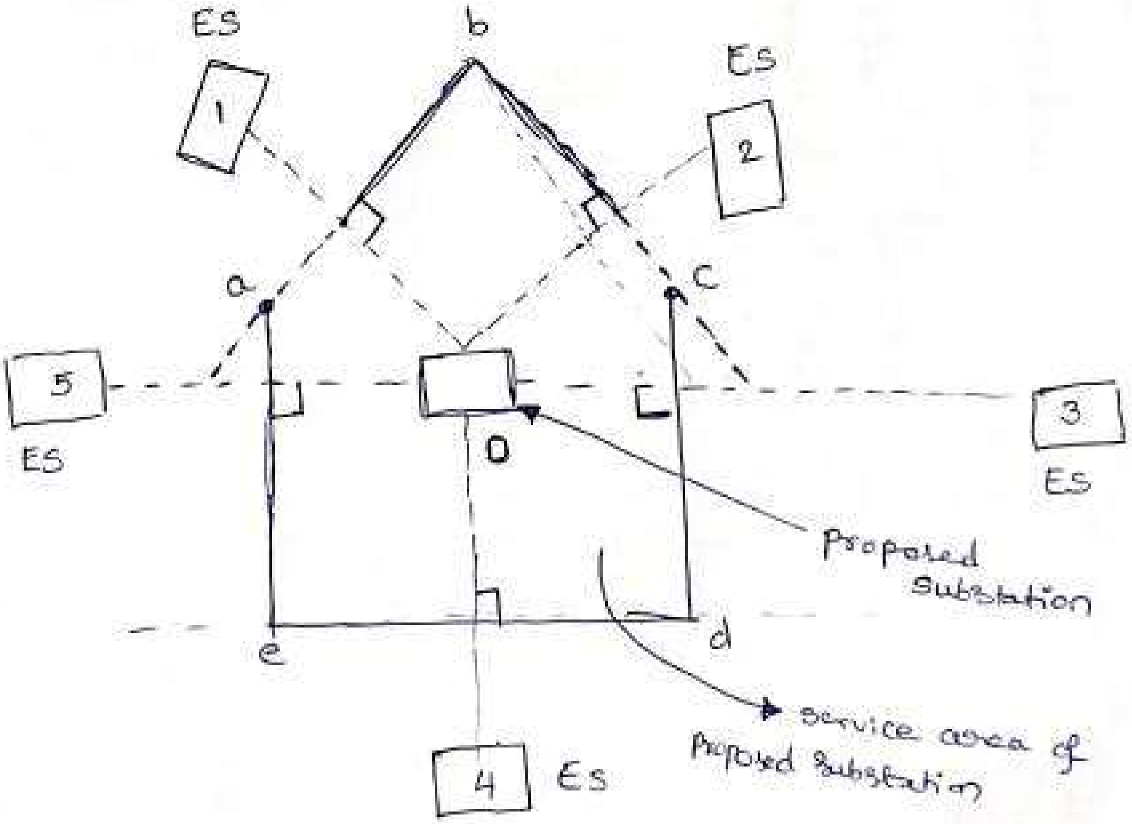
$$Y = 127\,m$$

load Center ordinates x, y are $308, 127$

Location of substation based on perpendicular bisector rule b/w existing substation

It is a graphical method of obtaining optimal location of substation for serving Consumers.

ES: existing substation



ES → existing substation 1, 2, 3, 4, 5

a-b, b-c, c-d, d-e, e-a are perpendicular bisectors of existing substations

Proposed substation service areas are a-b-c-d-e-a

The following are the steps involved are

(I) Draw the location of substation approximately in the existing substation.

(II) Draw a straight line b/w a proposed substation to each existing substation.

(III) Bisects each of the straight line connected b/w the proposed & existing substation.

(IV) The set of all Bisectors around the proposed substation indicates its service area.

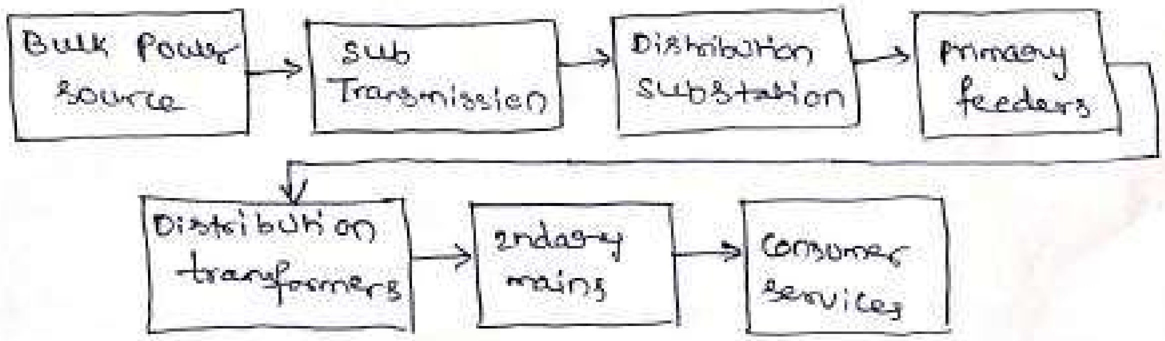
∴ target load for proposed substation is sum of all loads in service area.

In the step 3, a set of lines that are equidistant b/w proposed & existing substation.

Classification of substations

Distribution is a part of electric utility s/m lies b/w the power source & consumers. This s/m includes the following components

(1) subtransmission s/m (2) Distribution substation (3) primary feeders (4) Distribution transformers (4) Secondary mains (5) Service drops.



Functions of substation or switching station

→ Receiving high voltage from generating station via transmission lines

→ Reduce the high voltages levels to local distribution voltage levels

→ Provide the facilities for switching

→ Maintains the proper voltage levels within their limits

→ These substation also improves power factor

Substations are simply either switching or converting substation. Switching substations have different connections b/w various transmission lines. Converting substations are used to converting the supply either AC or DC or converting the frequency from higher to lower or vice versa.

Classification of substations

These classification depends on 3 ways according to

(1) Service requirement

(I) T/former substation (II) switching substation (III) Power factor correction substation (IV) frequency changer substation (V) Converting substation (VI) Industrial substation

(2) Constructional features

(I) in-door substation (II) out-door substation (III) under ground & (IV) pole mounted substation.

(3) Insulation

(I) Air insulated (II) SF_6 gas insulated (III) Hybrid.

According to the Constructional features of substation it is classified as

ⓐ Indoor Stations

For voltages upto 11KV, equippment of substation is installed in-door because of economic Considerations.

ⓑ out-door substations

For voltages greater than 11KV & beyond 66KV, equippment is installed at out-door. It is because of circuit breakers, Space between Conductors, other equippments requires more space & so large. It is not economical to instal at indoor.

ⓒ under ground substation

Densly population areas, space availability is limited, Cost of land is high, under that situations these are installed in underground.

ⓓ pole-mounted substations

This is an out-door substation with all equippments installed overhead & H-pole & four pole structure. It is more economical & cheap way installing such substation having voltage levels not exceeding 11KV & 33 KV. Almost distributed in localities through substations.

ⓐ Indoor Substations

According to Construction, of transformers in substations & high voltage switch boards these are further divided as

① integrally built type: Apparatus is installed on site & Constructed of Concrete & brick structure

Composite build type:

Some Connections are assembled in factories are brought to substation area & installed on site. The components are of metal Cabinets, enclosures, circuit breakers, switch gears, transformers.

factory fabricated Substations & metal clad switch boards

fabricated Substations are built in electrical engineering workshop & are shipped to site for further assembled. After installations, switch boards, Connections to incoming & outgoing are required to made.

Outdoor substations
- pole mounted
- fundation mounted substation

① pole mounted Substation

* these Substations are erected for mounting distribution transformers of Capacity upto 300 KVA.
* these are of outdoor type. these distribution t/formers are mounted on double pole & 4 pole structure based on transformers ratings.

transformers rating upto 125 KVA double structure is preferred & if above rating 125 KVA 4 pole structure is preferred. A mechanically operated switch is used for switching on & off transmission line.
* Substations are earthed at 2 or more places.
* these are preferred in thickly densly populated areas.

It is a simple & cheaper substation & also maintainence cost of substations is low.

foundation - mounted substations

* These are of outdoor type
* Here all Components are assembled into one unit for safety purpose.
* Substations for Primary & 2ndary transmission, for 2ndary & distribution above 300KVA prefers foundation mounted substations.
* Such substations are almost nearer to transport

factors selecting such substation

* Must be near to load
* Must accessible to transport
* land availability
* Reasonable Cost to purchased the land
* Spare land availability must to further extension
* It must be in local laws.

Advantages & disadvantages of outdoor substations

Advantages: It takes less time to Construct

* Cost of Construction is easier
* Installation Cost of switch gears etc is less
* All equippments is properly viewed, fault location is identified easily
* Spacing b/w the equippments is more, this will reduce the faults
* Replacement & extension is easier.

Disadvantages:

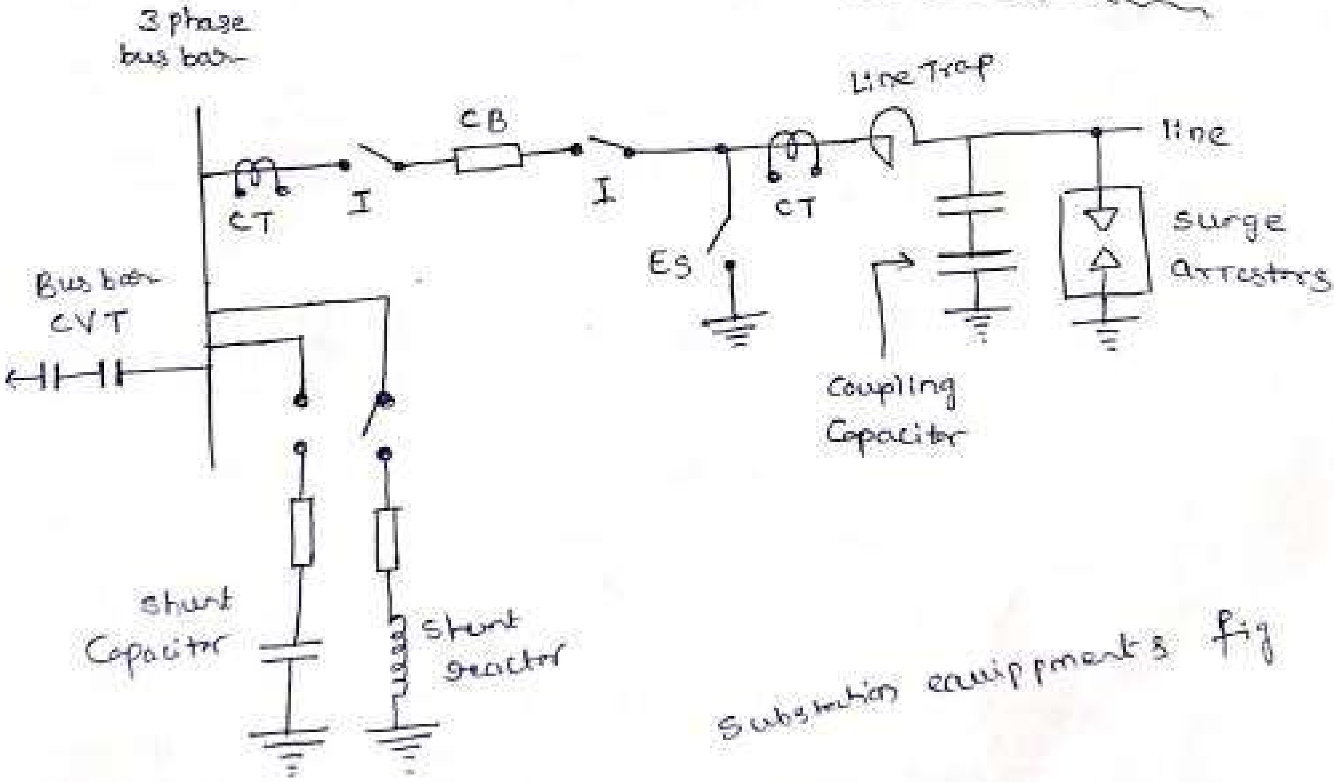
* Requires more space to install Components
* size of equippments is big it occupies more place
* It is exposed to environment so directly dirt & dust deposited on equippments, Proper maintainence is required.

* switching should be difficult during rainy seasons.

Comparison b/w outdoor & indoor substations

	outdoor	indoor
space required	more	less
Time required to erect	less	more
further extension	easy	difficult
fault location	easy, every equipment is open view	difficult
Capital Cost	low	High
operation	tough	easier
fault occurance	less	more

substation layout with location of all equipments



substation equipments fig

CT → Current Transformer
CB → Circuit breaker
I → Isolator

Main Components in substation are

① **Bus-bars** These are current carrying conductors directly connected to substation. Bus bars are copper or aluminimum bars, operating at constant voltage. All incoming & outgoing lines are connected to bus bars.

(2) **Incoming & outgoing lines**

These lines are connected to bus bars. Incoming lines supplies from source i.e either from generation or transmission lines at high voltage. After step up or step down the voltage levels these lines leaves the substation. These lines are outgoing lines.

(3) **lightning arresters** → These are provided at both incoming & outgoing lines which are used to protect the main electrical apparatus from sudden surges & lighting discharges.

(4) **Insulators** These are used to support the conductors & also confine the current to conductors. Serveral types of insulators such as post insulator, Pin type, suspension type etc.

(5) **Isolators** isolators are provided in both incoming & outgoing lines which are used to disconnect the line & equippment from the bus bar. The isolators are off load type switches. Before operating an isolator, it is must & should keep the load off. An isolator under normal condition acts a closed circuit.

⑥ **circuit breakers**

It is used to open or close a circuit under normal as well as fault conditions. Various types of circuit breakers are (I) air OBW circuit breaker (II) Vaccum circuit breaker (III) Oil circuit breaker (IV) Air blast circuit breaker (V) SF_6 circuit breaker

(7) Fuses : A fuse is a protective device which can protect the circuit during overcurrents. It is metal fuse element consists of a set of contacts. It isolate the circuit during short circuits or faults.

(8) Power transformer

It is main equipment in substation which is used to change the voltage levels based on step up & step down transformers. The power transformers are either a 2 winding transformer or auto transformer. The usage of transformer depends on its transformation ratio. if transformation is less than unity auto transformers are used if greater than unity 2 winding transformer is used.

(9) Instrument transformers these are of current transformer & potential transformers.

Current transformers are used for measuring as well as protecting the equipments from overcurrents, earth faults etc. The secondary of CT is standardised as 5 & 1 amp. these CT measures load current in amps, kwh, mw flow & power factor.

Potential transformers are used for measuring voltage in KWH, mw flow, power factor etc & also it can protect the equipment from over voltages etc. The secondary voltage of potential transformer is standardised as 110V.

(10) Metering & indicating equipments

The metering & indicating equipments in substation is used to monitor the circuit parameters. Examples are voltmeters, ammeters, energy meters, wattmeters p.f meters etc.

(i) Protective relays

A relay is fault sensing device & activate the circuit breaker contacts to open their by it isolates the faulty system. transformers, busbars, lines etc are protected by using protective relays.

Other equippments

(i) Carrier Current equippment

Such an equippment is installed in special room known as Carrier room. These are used for Communication, relaying, telemetering & also for supervisory Control. This Carrier Circuit Connected to high voltage circuit.

(ii) auxillary power supply

AC supply in substation used for Lighting, battery charging etc. DC supply is essential for working of Control & Protection equippments. Some times DC supply is used as emergency back up i.e Inverter.

(ii) Earthing Also known as grounding. It is used in substation so as to provide safety to operators as well as for equippments due to induced Currents during high voltages.

An substation earthing is provided for the following

(i) neutral point of transformers
(ii) Lightning Protection s/m
(iii) Equippment frame work & non-current Carrying metal part associated with substation.

(iii) Reactors & Capacitors

Reactors are used to the limit line charging Currents in lines Connected to the high voltage. Each end of line i.e sending & receiving end of line is provided with reactors. Reactors are of bus reactors & tertiary reactors. Bus reactors connected at the substation bus, whereas the tertiary reactor are connected to tertiary winding of the transformer.

Ferranti effect in the line is reduced by using reactors.

Bus bar arrangements in substations

Bus bars are very important in substations. These are used to carry high amount of energy in confined space. Theirfore failure of bus bars leads to the interruption of electric supply.

Types of bus bars

(I) **Enclosed bus bars**: These are rigid conductors of either alluminium or copper supporting on insulators. The assembly is supported on fabricated steel rolls & is enclosed by sheet steel or alluminium sheets.

(II) **Non-Segregated bus ducts**: Here all phases of conductors (3 phases) are placed in a common metal enclosure without any barriers.

(III) **Segregated bus ducts**: Conductors of all phase are placed in common metal enclosure by providing insulator barriers b/w them

(IV) **Isolated phase s/m**: Conductor of each phase is separately enclosed in metal enclosure

(V) **Tabular alluminium rigid bars**: It is preferred for outdoor substation. Tube sections are welded or bolted with clamps.

(VI) **flexible (ACSR) or strain bus bar**:

It is an alternate to the tabular bus bars, it is mostly preffered in Indoor substations. Strain bus bars is made up of Alluminium Conductor Steel Reinforced. It is supported by strain insulators.

Rigid bus bar	Strain bus bars
* used for low & medium voltage bus bars	* used for High Voltage bus bars
* It is made up of either aluminium or copper bars or tube	* It is made up of alluminium Conductor steel Reinforcement.
* Rigid bus bars are supported to pedestal type insulator	* It is supported to strain insulator
* These bus bars are used below EHV Voltage levels.	* these bus bars are used in substations have EHV & UHV class voltage levels.

Advantages of rigid bus bars Compared to strain bus bar

* Rigid bus designs employs less steel
* It is used for low level structures
* Bus bars are supported to pedestal type insulator so maintainence & cleaning are very easy
* these bus bars easily visible
* Due to larger dia-meter, corona loss is less

Disadvantages of Rigid bus bars Compared to strain bus

* It is expensive in terms of tubing & Connection
* It requires more supports & also requires more insulators
* It is more sensitive to deflections in structure
* It requires more space than strain type bus bar

Choice of bus bar s/m

the function of bus bar s/m depends on the following requirements

* Degree of flexibility: Higher degree of flexibility mains reduces the power outages in desired substation. It is obtained by providing alternate supply from another route

(2) importance of load & local Condition: Based on local load Condition they have a choice to total shut down or partial shut down the substation.

(3) no: of outages frequently occured in circuits during faults

(4) Maintainance, safety, quality, reliability must be Considered

(5) switching sequence: Minimum outage under normal or emergency or fault operation.

(6) Location of circuit breakers & isolators is decided by switching sequence

(7) Protective Zones: only faulty zone is switched off & isolated without disturbing to the other zones.

(8) Providing enough extension

substation bus arrangement scheme

(1) single bus scheme

(2) " " " with sectionalise scheme

(3) Double or duplicate with single breaker scheme

(4) " " " double breaker scheme

(5) Main & Transfer bus scheme

(6) Ring bus scheme

(7) Breaker & half with 2 main bus schemes

(8) Double bus bar with bypass isolator scheme.

Substation arrangement with single bus scheme

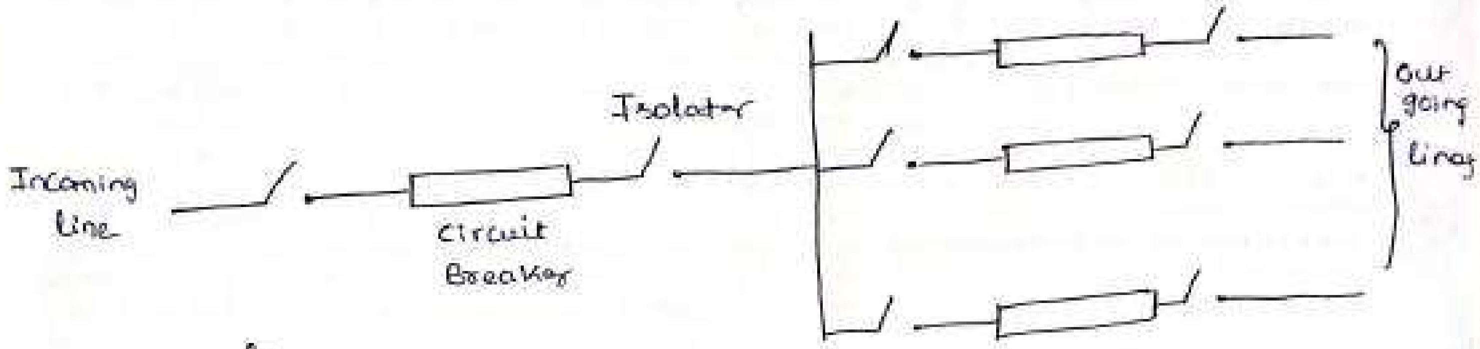


fig single bus bar scheme

* It is used in outdoor substation
* It is used where voltage levels less than or equal to 33 KV. * The scheme of cost is low
* It is also preferred if a substation have less no: of incoming & outgoing feeders.

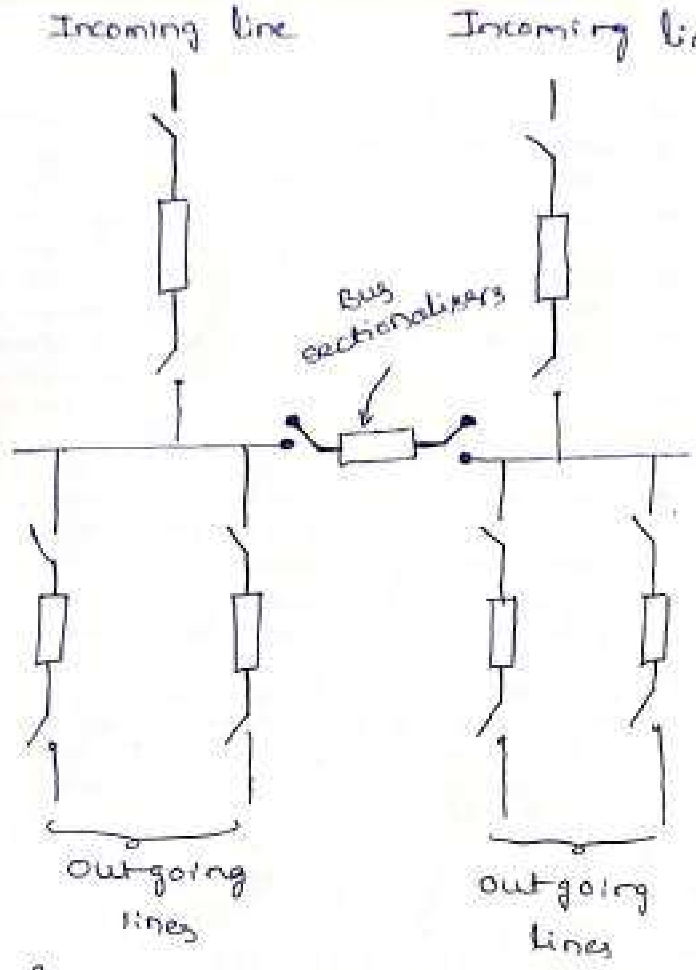
Disadvantages

* A substation with single bus arrangement can cause power outage during bus failure
* Regular monitoring & frequent maintainence is required
* Bus cannot be extended without de-energising the substation
* this scheme is employed in substation having other alternative supply is required. or provided.

Single Bus with sectionalizer scheme

In this scheme, Bus bar is normally divided into 2 sections with help of breaker & isolators. The incoming or outgoing lines are evenly distributed. If the s/m fed to single load, only one circuit is in normal operation. Here each section behaves as a separate bus.

* Differential Protection scheme is employed to trip the faulty section.



Advantages

* Bus failure in s/m cannot create power outages
* Power is exerted from other bus
* possibility of extending the bus without interrupting the supply.

fig shows single Bus with Bus sectionaliser

Double or Duplicate bus with Breaker Arrangement

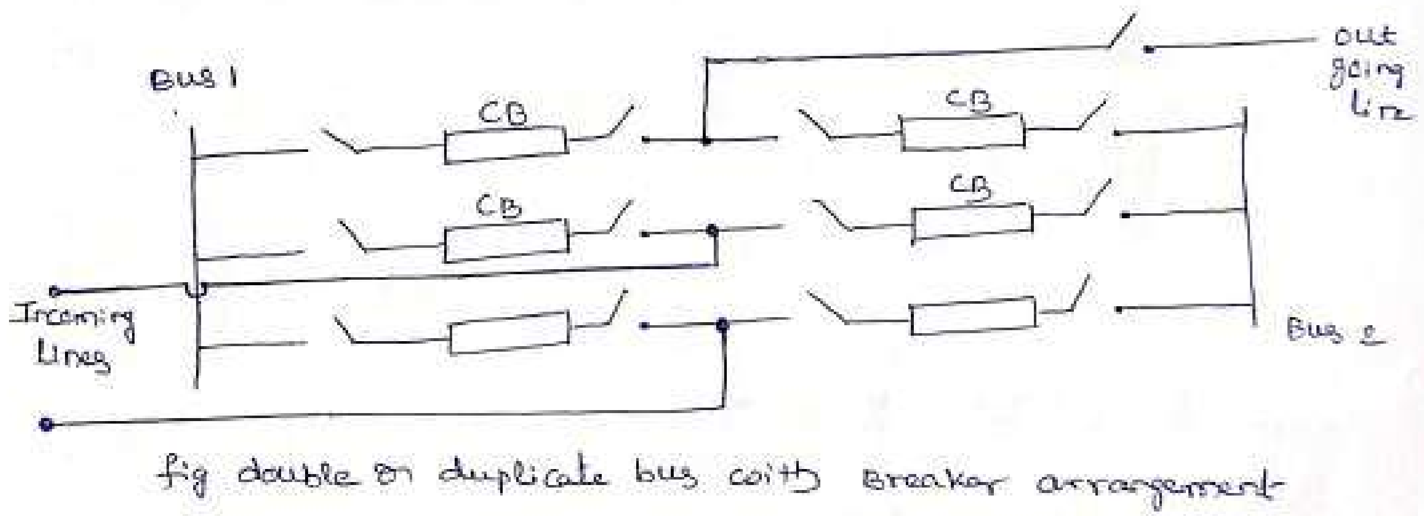


fig double or duplicate bus with Breaker arrangement

This scheme is used where continuity of power needed & and also connects an extra load to the existing bus.

The main advantages are

1. Each circuit has 2 breakers
2. flexibility of connecting feed circuits to any of either bus
3. Maintainence is easy without interrupting the supply
4. More reliable than single bus scheme

Drawback

* It is expensive
* failure in breaker can provide half of the power to the existing bus

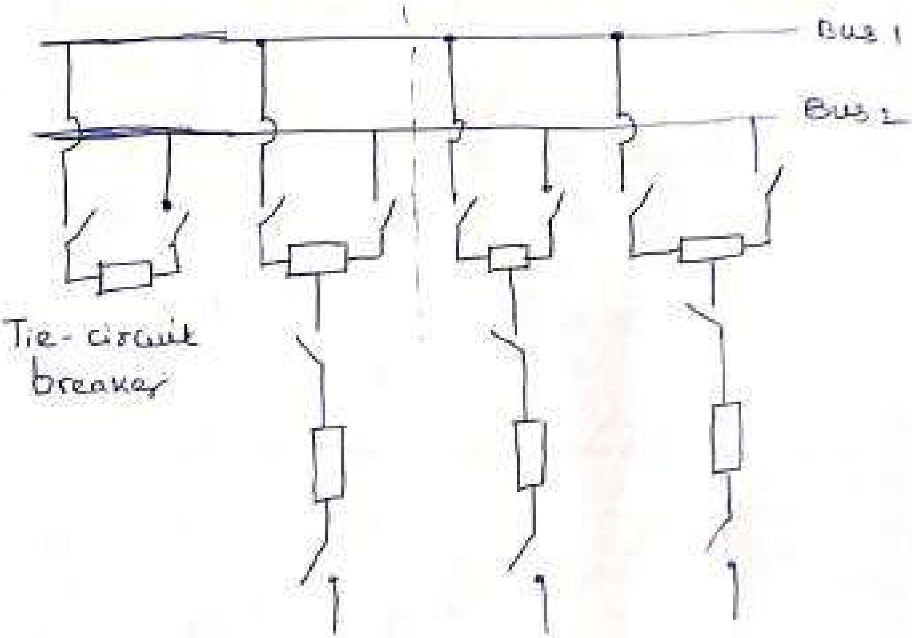
Double or duplicate bus with single breaker arrangement

In this scheme 2 main buses is connected with 2 disconnecting switches. This disconnecting switches are Tie circuit breaker or bus coupler.

This scheme allows to change the load from one bus to another bus.

Advantages

* flexibility to operate 2 buses at a time
* bus 1 & bus 2 isolated for maintainence
* Load can be transferred from one bus to another bus by using tie bus breaker & isolators



Drawbacks

* requires extra breaker for one circuit
* 4 isolators are required for each circuit
* when all circuits are operated are connected to bus, the protection becomes complex.

Main and Transfer bus arrangement

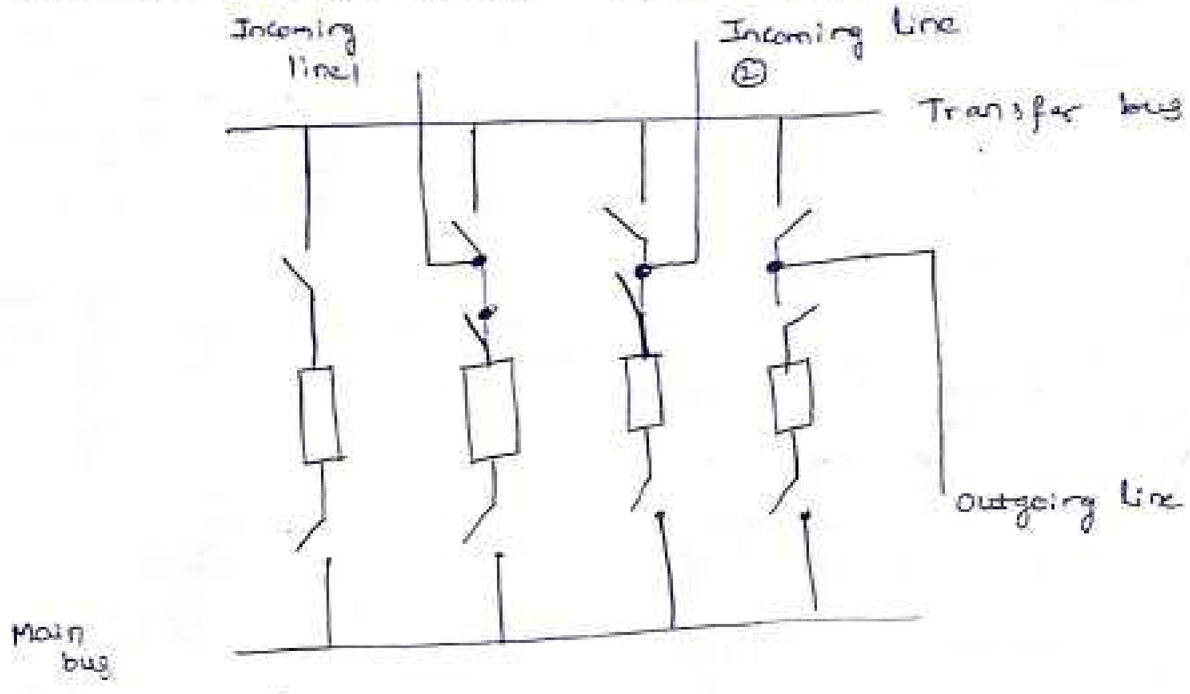


fig: Main & Transfer bus

In this scheme of arrangement 2 bus are required. Those are ① Main bus ② Transfer bus. these 2 buses are tie connected with one extra breaker.
Here transfer bus is always in standby & used in emergency case. The advantages of this scheme is it saves the usage of several circuit breakers. Also inital cost of this scheme is less. Any breaker can be taken out for maintainence without power interruption via transfer bus.

The drawback of this schemes are
① All circuit breakers are operated, switching becomes complicated
② Any circuit breaker failure results shut down entire substation.
③ Requires an extra breaker i.e provided b/w main & transfer bus to isolate the faulty breaker.

Ring bus arrangement

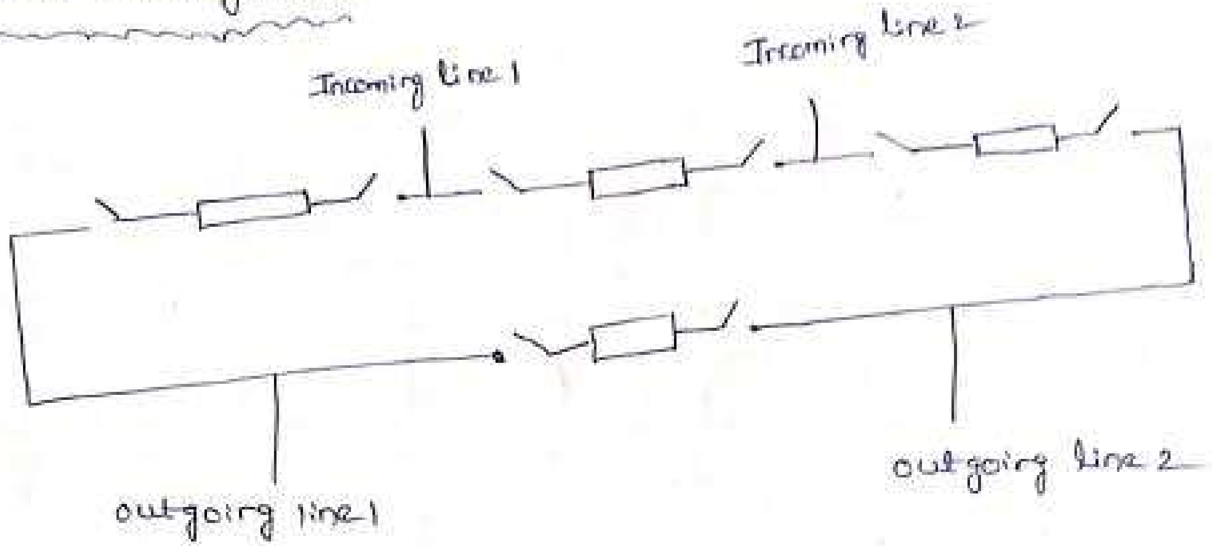


fig: Ring bus or mesh scheme

(1) This is also known as mesh scheme
(2) It uses one circuit breaker per circuit
(3) Each outgoing line has 2 sources of supply.
(4) The advantages of this scheme is
* Initial cost is low
* Breaker maintainence is easy
* Any Breaker can be removed during maintainence without interrupting load.
* Each circuit uses one circuit breaker only
* Switching is done using circuit breaker

Disadvantages

(1) During breaker maintainence, any fault occurs, ring will be divided into 2 sections
(II) Automatic reclosing & relay protection is complex
(III) It requires potential devices on all circuits for synchronisation of line voltage.
(IV) Any fault in breaker of one circuit causes a loss of one additional circuit

One and Half breaker with Two main Buses Arrangement:

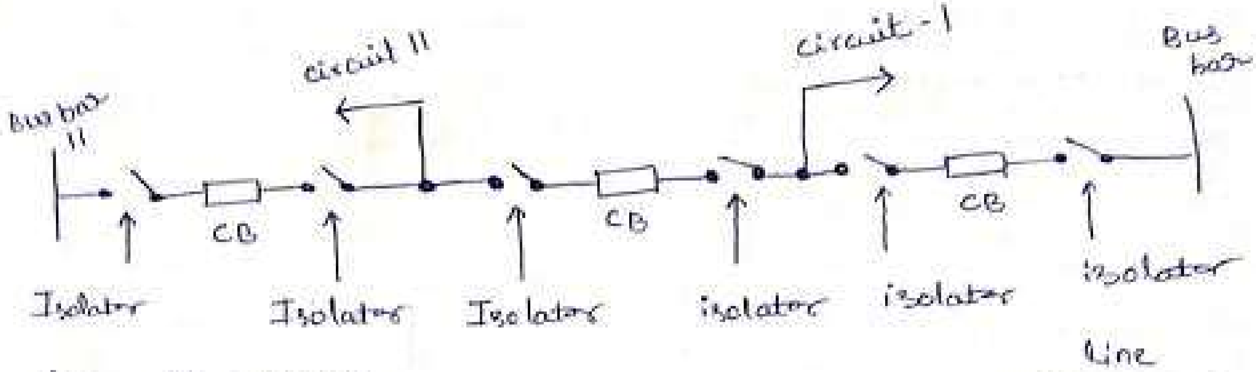


fig (a) principle

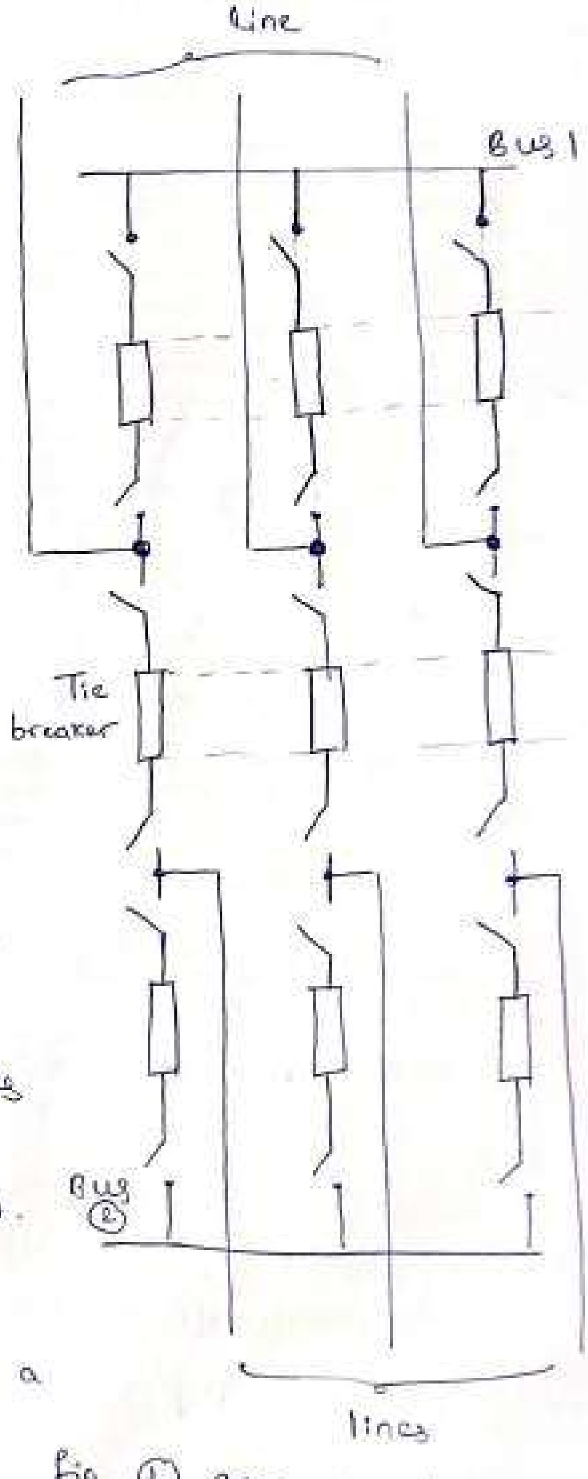


fig (b) arrangement

* For 2 circuits, it uses 3 circuit breakers
* Any breaker can removed or switched off during maintainence without interrupting the supply
* The circuit uses one & half circuit breakers hence the name is obtained

It is an improvement of double bus double breaker scheme, to save the cost of breakers.

3 breakers are connected in series b/w the main buses. shown in fig a & b.

Under normal operating conditions all breakers are closed and the main buses are energised. To trip the circuit, 2 associated circuit breakers must be opened.

Advantages

* It has flexible in operation & also a reliable one
* Breaker failure of bus side cannot interrupt the bus service. only failure part of bus circuit is remove & other circuit provides service
* switching is done with breakers.
* Bus failure does not remove any feeder ckt from service.

Double bus bar with Bypass Isolators Arrangement

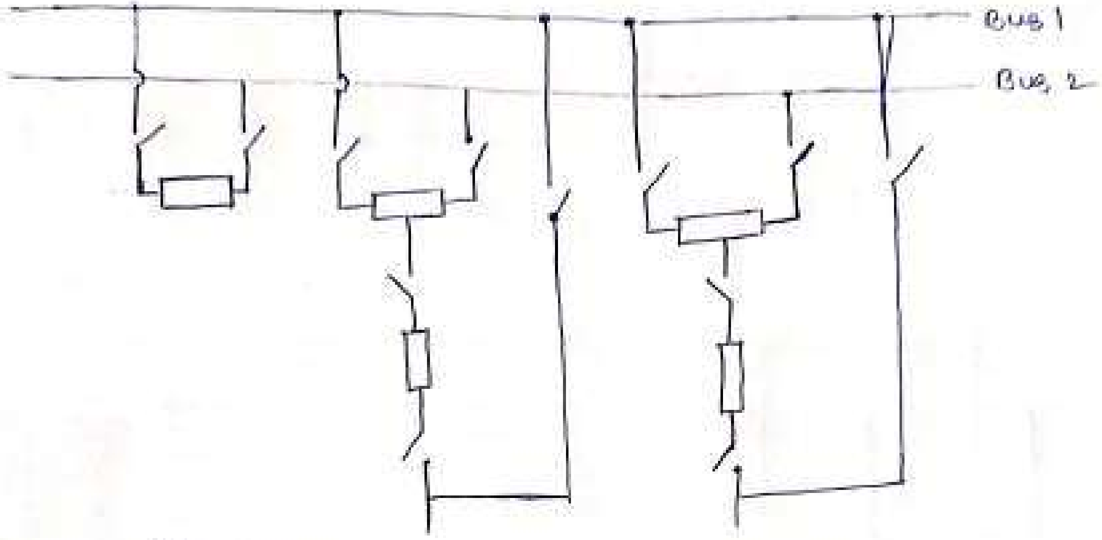


fig double bus with bypass isolators

This scheme is similar to main & Transfer bus. Here transfer bus in this scheme treated as main bus. Here transfer of bus 1 from to bus 2 is done through isolators.

The advantage of this scheme is

(i) Any bus can act as a main bus

(ii) Any breaker taken out of service without interrupting the feeder supply.

(iii) It is simple & more economically.

Layout of substation

Equipments used in substation are

* Incoming & outgoing lines
* Isolators, circuit breakers, PT's, CT's, Protective equipments like lightning arrestors, relays etc
* Power transformer
* Bus bars
* Metering, Controlling equipments located inside the control room
* DC & AC supply distribution for substation, battery room
* Carrier room for Communication
* Earthing etc

factors Consider for layout of substation

① numbers of equippments choosen for required load should be minimum, no: of circuit breakers & no: of circuits should be minimum for a given load.

② substation layout should provide with proper protection to avoid consequective damage of next equippments

③ Easy of inspection & maintainence should be minimum

④ Provision should be fire proof & also explosion proof

⑤ For High voltage distribution, all equippments is locate at outdoor. All monitoring & Control equippments are located at inside the room.

⑥ Maintaining Proper clearance for each equippment to visualise the status of equippment during faults

⑦ If it is small substation, the layout is Compact.

——— X END X ———

GIS - substation

→ It is a high voltage substation in which majority of conducting materials are contained within a sealed enclosure filled with a di-electric gas known as SF_6 as an insulating medium.

In comparison AIS (Air insulated substation) uses air as dielectric medium most of the AIS are of outdoor type.

GIS technology is developed in 1960 by japan & now 20% of new substations in countries with severe space limitations. In US about 2-5% of new substations are of GIS type.

The main advantage of GIS is clearance needed for phase to phase or phase-ground for all equipment is much less than that of GIS.

Also space required for GIS is 1/10th of AIS facility. AIS requires several feet of air insulation to isolate the conductor where GIS facility to fit into smaller areas. Expansion of existing AIS with new GIS possible known as Hybrid GIS. This design uses GIS breakers, switches & t/formers.

Advantages of GIS

① Space saving: GIS saves 90% of space compared to AIS. This can be installed in single or multi storey buildings also

② Safety: GIS enhance the personal safety & equipment. It eliminates exposure of live parts & arc flash hazards. GIS reduces the risk of fire accidents.

③ Reliability: Mechanical components in GIS are very few, no component is directly exposed to environment so life span GIS is high & more reliable.

④ Maintenance: Due to less mechanical parts, GIS maintenance is less just like AIS, no frequent testing is needed to estimate the life. GIS has self diagnostic features that can detect the faults & alerts the operators.

Constructional aspects of GIS design

① Modular design :

GIS substations are built from standard equippment modules. All GIS equippments like breakers, CT & PT, disconnectors, bus bars etc all are housed in modular metal enclosures.

② SF_6 Gas insulation :

The enclosures are filled with sulpher hexafluroide (SF_6) gas which provides superior insulation & arc quenching capabilities.

③ Compact design

The design of GIS have significantly smaller area compared to air insulated substation.

④ space location & foundation:

GIS is preferred where space limitation is raises. Also site selection focuses on accessibility, Proximity to power lines, it should be follow the land regulations.

GIS are high voltage substation so every equippment must have to withstand on concrete foundation.

⑤ Gas monitoring & sealing

Continous monitoring of temperature, pressure & purity is necessary to ensure the good insulation.

⑥ Cable Design

In
GIS is off ~~dis~~door design. Maximum of indoor substations prefer underground cables.

Gas Insulated Substations

→ SF_6 gas is used as a insulation, which is 5 times heavier than air.
→ It offers an excellent arc extinction behaviour.
→ It is preferred for 12KV, 36KV, 72.5KV, 145KV, 420KV & above.
→ An GIS all electrical equipments like CB's, busbars, Isolators, CT's, PT's etc are housed in a separate metal enclosure filled with SF_6.
→ As di-electric strength of SF_6 gas is higher than air space b/w the electrical apparatus reduces.
→ these are pre-assembled as a modules & are already filled with SF_6 gas & final bring to the installation site area.
→ It is widely preferred in heavily polluted areas & also where frequent flash overs occurs.
→ GIS requires a less number of lightning arresters.

Advantages

→ Compact in size
→ Protection from pollution
→ Reduced switching over voltages
→ Reduces the installation time
→ Superior Arc Interruption
→ Possibility of less accidents to live parts.

Drawbacks

→ High cost of equipments
→ once internal fault occurs, excessive damage occurs
→ Repair of damaged part at site is difficult & also long time to restore the supply.
→ Procurement & adequate gas stock is maintained.

Air-insulated Substations

Air insulation substation is a metal clad system. It is also known as outdoor substation.
→ Here all equipments like switchgears, busbars are installed outside
→ It is extensively used in power distribution including residentials, industrial areas uses air insulated substations.

→ Maximum of Air insulated substations are outdoor type which requires large space to accomdate the equipments

→ Losses also will be High

→ Low reliability

Maintainence

Maintainence of Air insulated substation is easy but life span of AIS is less due to the equipments directly exposed to climate.

outage cost

failure rate is High.

Safety In conventional open terminal AIS more safety is taken to work on live parts.

Differences in AIS & GIS

	AIS	GIS
Land requirement	High	Low
Initial cost	Low	High
civil cost	Low	High
flexibility	High	Limited
Safety	Low	High
Reliability	Low	High
Maintenance cost	High	Low
Restoration time	Low	High
losses	High	Low

Classification of Distribution S/m

Introduction

The function of Transmission & distribution S/m is to transfer Power from generation to load as economical & as Convenient as possible. The choice of voltage transmission depends on the Distance of transmission & amount of Power transmitted. In case of Subtransmission S/m, S/m Voltages will be reduced to distribution voltage level.

Power from Subtransmission S/m to distribution substation by means of Primary distribution or feeders. The distribution transformers located at distribution substations to change Primary distribution Voltage to secondary distribution voltage.

Distribution S/ms may be divided into 2 parts

(a) Primary (High voltage) Distribution S/m

High voltage transmission lines having voltage ranging from 33KV to 220KV Voltage is stepped down to 11KV or 33KV or 6.6KV. This Power is transferred to Various substations for distribution & to the bulk Consumers. Such a S/m is known as Primary or High Voltage distribution System.

(b) Secondary (Low voltage) Distribution S/m

At distribution substations, Primary high voltage distribution is steppdown to 440V. This step down voltage is fed to the Consumers in form of 3 phase i.e 415V or Single phase 230V. Such a S/m is known as Secondary or low voltage distribution S/m.

Elements of distribution s/ms

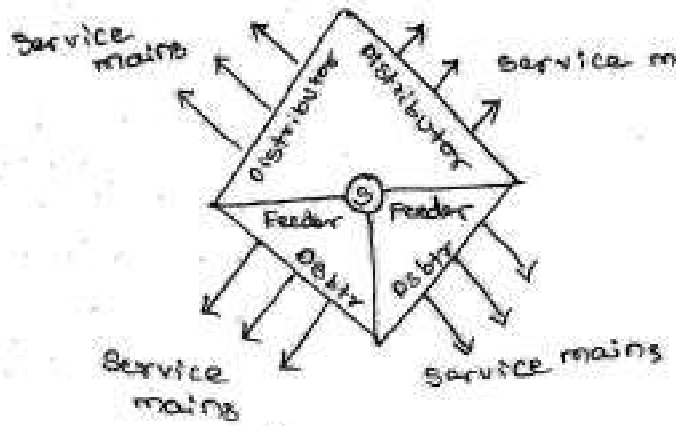


fig Typical distribution s/m

A distribution s/m has subdivided into

(i) feeders (ii) Distributors (iii) service mains

A feeder is a conductor which Connects the substation where power is to be distributed. A feeder doesn't have any tappings so Current in feeder remains same. Its purpose is to Carry current.

(ii) Distributors : Distributor is also a Conductor but it has provided with some tappings. so Current is not Constant in Distributor. These tappings are arranged at Certain lengths. In case of Distributor voltage drop along the length is Considered. Various of voltage levels ± 5 at the Consumer terminals.

(iii) Service mains It is a small Conductor that Connects the distributor & the Consumer terminals.

Requirements of Distribution s/m

followings are requirements for good distribution s/m

(i) Proper voltage : Main thing is to provided a proper voltage to the Consumers terminals.

* Minimise the voltage distortions at Consumers side
* Low voltages makes revenue loss, operating the machines at low efficiency.
* High voltages Causes Permanent damage to lamps, burning of motors

This necessiates that various in voltage must be allowable ±5% of rated value.

(2) Enough Power during demand: Based on the Consumers demand Enough Power should be maintain to avoid the interruptions. This is done by Continously monitoring the given load patterns. & estimate the future demand to maintain sufficient Power.

(3) Reliability: Reliability of s/m depends on the operation of distribution s/m. This can be improved by
① Interconnecting existing s/ms ② Provides the automatic Control s/ms (3) Maintaining the additional reserves.

Classification of Distribution systems

③

Its classification mainly depends on
① According to Current, ② Construction type, ③ Type of Connection
④ no. of wires employed.

① According to nature of Current: It is classified as
ⓐ DC Distribution s/m: It is more Preferred during transmission purpose but in case of distribution s/m it is not recomonded
ⓑ AC Distribution s/m: It is universly adpoted for distribution of electric power because it is simple, economical than cost wise cheap way of distributing AC power. In case of DC Cost of Conversion equippment is more cost.

② According to Construction type

As per the Construction, distribution system is classified as ⓐ overhead system: It is cheaper & more economical than under ground s/m.
ⓑ underground system: Under ground s/m is Preferrable where overhead Construction is not possible, specially highly populated area there underground s/m is Preferrable.

iii) According to the type of Connection: These are classified as

① Ring main connection s/m ② Radial type connection

③ Integrated & InterConnected s/m

Connection schemes of distribution system

(4)

① Radial type distribution s/m

* Here distributors are fed at one end.
* It is suitable when power generated at low voltage
* Here substation is located at nearer to load or located at the Center of load.

Advantages * simplest distribution s/m
* Initial cost is very low.

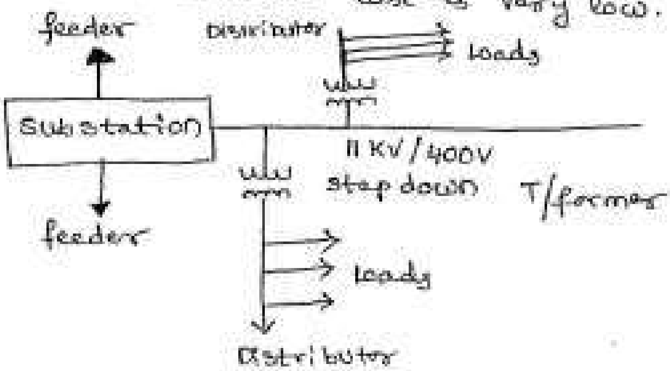


fig: Radial distribution system

Drawbacks of Radial s/m

* distributor nearer to the feeding point is heavily load.
* fault on feeder or fault on distributor results power interruption
* this s/m is used for short distances only because consumer at the end of distributor under voltage fluctuations.

② Ring main distribution system

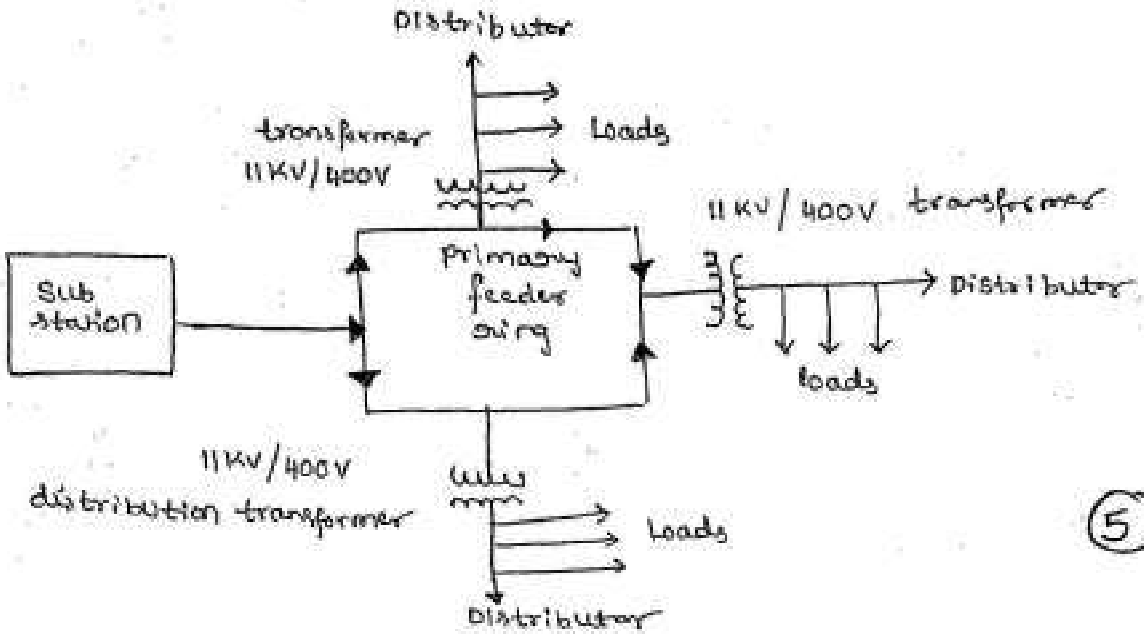
* Primaries of all distribution transformers form as a loop. It is starting from substation & returns to the substation as a loop.

* In given figure ② substation suplies a closed loop ring main feeder. Here distributors are located at the different points is provided with tapping through distribution transformers,

Advantages * Voltages fluctuations at end of consumer will be very low.

* Here each distributor are formed as a loop, any fault on any distributor, Continuity of power supply goes on

* This type of s/m uses less copper conductors because ring main s/m carries less current.

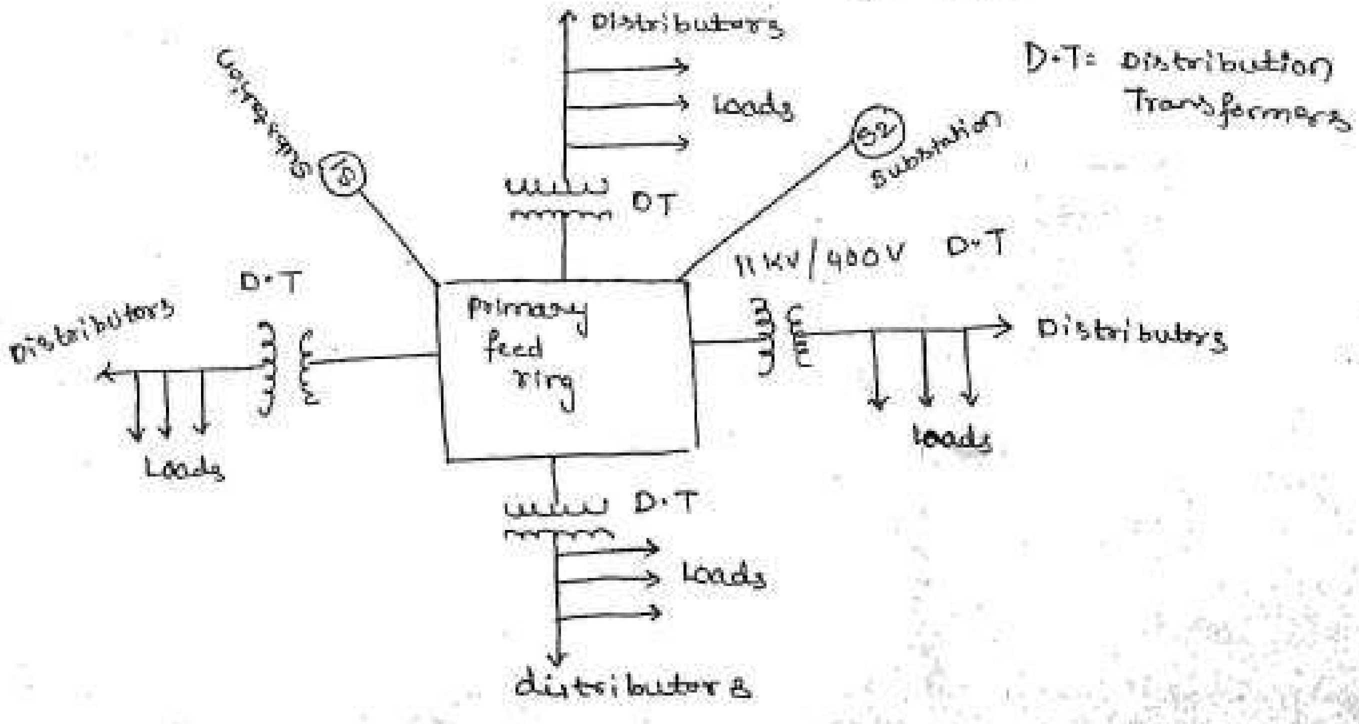


(5).

fig(2) shows Ring main distribution system.

③ Interconnected Distribution System

* Here primary feeder ring is energised by 2 or more generating stations or substations then it is called interconnected s/m.
* Fig③ shows a closed primary feeder ring is energised by 2 substations S1 & S2. The distributors are connected to feeder ring through distribution transformers.



Fig③ : InterConnected distribution s/m.

Advantages

* increases service reliability
* Reduces the reserve power capacity
* During peak load demand, other generating station supplies peak load.
* this system utilises the full efficiency, increases the efficiency of s/m.

(IV) According to the number of wires employed ⑥

These are classified as

ⓐ Three wire s/m : these s/m is employed in both AC & DC distribution s/m. In case AC system with balanced loads 3 phase 3 wire system is used. For unbalanced loads 3 phase 4 wire system is used.

ⓑ Two-wire s/m : In case of AC system single phase AC 2 wire system is used for lighting & other purposes is used. Again Two-wire system is also used in DC distribution but it is not economical.

ⓒ Four wire s/m : For unbalanced loads in AC distribution s/m 3 phase 4 wire system is preferrable.

Comparison of DC & AC Distribution System

DC-system advantages

* More power transmitted with same conductors used in AC system
* Power can be transmitted over a long distances by over head lines but AC power can not be transmitted over distances
* Ground return is possible *
* Reversibility & Controllability of power flow possible
* Voltage regulation problem is not serious sine IX drop is nil
* No inductance & Capacitance Problem
* There is no skin effect, as result conductor can carry maximum current, theirfore conductor is fully utilised.

* Corona effect & telephone interference is very less
* allows synchronous as well as asynchronous connections
* No need to synchronisation
* For same amount of power in AC, DC power requires less insulation than AC power.

Disadvantages of DC system

(7)

* installation cost is very high
* Cost of Conversion equipments like Converters, DC switch gears are very high
* Converter operation requires reative power.
* filters are required to reduce dc harmonics.
* Magnitudes of voltages cannot be step up & step down
* Commutation failures in Converters Causes the malfunctioning of s/m.

AC Systems

Advantages

* Present day electrical power generated, transmitted & distributed in AC
* Power can be generated at high voltages
* Installation of substations is requires less cost
* Magnitudes of Voltages can be stepped up & steppdown by the use of transformers.

Disadvantages

* Construction of transmission lines is very difficult
* More amount of Copper requires
* Insulation & Capacitance of 2 Conductors must be large.
* Spacing b/w 2 Conductors requires more space
* Synchronisation is mandatory to put any s/m in parallel with other s/m
* Corona & skin effect is severe
* Continous Power loss when line opens

Comparison between overhead & under ground s/m

Electric power transmitted from one to another place by using overhead or underground s/ms.

For overhead distribution s/m Inductance is the main problem & for under ground distribution s/m Capacitance is the main problem.

(8)

① large charging Current on very high voltage Cable limits the use of underground s/m.

For long distance transmission overhead transmission is Preferable

② Conductor size & cost of overhead Cable is less compared to underground Cable.

③ Insulation Cost is more in case of underground Cables

④ Installation Cost is much less than the underground Cable

⑤ under ground Cables greater safety to public, less Interference with other amenities.

⑥ For submarine Crossing under ground Cables is more Convenient.

Advantages of overhead lines

* Transmission & Distribution of power is much cheaper than underground Cables.
* Detection & location of faults in overhead lines is very easy. It is easily repaired & put into service
* As transmission voltage increases, Cost of overhead lines increases by small amount.
* Capacity of transmission Can be increases easily by replacing the old one by new.

Disadvantages of overhead lines

* It is not suitable for thick & densly population areas.
* Laying of new lines in small streets, lanes is difficult.
* overhead lines are easily subjected to interruptions due to lightnings, birds fault etc.
* Due to higher inductance in ~~conductors~~ conductors, voltage & power factor loss is high.
* maintinence cost is very high (9)
* these lines interferance with Communication circuits

Under ground Cables advantages

① free from external interruptions like lightning, falling objects
② more safe to public
③ No disturbance to Communication circuits
④ Surge effect is minimised.

Disadvantages of under ground Cables

① under ground Cable s/m is very costly
② locating & detecting faults is difficult
③ Repairs & extension is not easy
④ on no load, s/m draws more charging Current result more Copper loss.
⑤ Also sheath loss and dielectric loss will be very high.

Design of substations

For designing substations following points shall be remember

① **Service Conditions**: This involve a load study like type of load, no. of Consummers, points of electrical distribution lines, length of lines on roads, streets & street layouts. The main loads in distribution s/m has divided into domestic, Commercial, industrial, muncipal load, traction load etc..

② **Electrical design**: Electrical design involves choosing voltage for primaries, size, location of substations, type of distribution s/ms for primaries & sndaries, allocwable voltage regulation on load, length of lines, adding of Controll devices at proper location. Also Protecting eauippments, arresters, grounding methods, spacing of Conductors, insulation levels to be used for lines should be properly choosen.

③ **Mechanical design**: It involves, size of Conductors, spacing of wires, loading structures, selecting pole height, span length hardware support, guying and clamping arrangements.

④ **cost of Comparison**:

Different possible distribution plans including subtransmission, distribution & secondary distribution s/ms shall be Compared & the most economical plan should be adopted.

Design Considerations of Distribution feeders

AC distribution s/m

Electrical Power Generated, transmitted, distributed & utilized in AC. 3 phase 3 wire is for transmission purpose & 3 phase 3 phase 4 wires is used for utilization purpose.

Various Components are

(I) Generating station where Power is generated by 11 KV or 33 KV generators.

(II) Primary transmission: electric Power from generating station is step up to 66, 132, 220, or 400 KV & is transmitted by 3 phase 3 wire over head system.

(III) 2ndary transmission: At end of Primary transmission at the receiving station, voltage is reduced to 33 KV by step down transformers. Here 33 KV power is transmitted to extremely large Consumers by 3 phase 3 wire overhead s/m is 2ndary transmission

(IV) Primary distribution: Voltage of 33KV from 2ndary transmission is reduced to 11KV at substation is Primary distribution. 3 phase 3 wire of 33 KV lines reduced to 11 KV lines find on road sides of city.

(V) secondary distribution: 11 KV from Primary distribution is reduced to 415V 3 phase 4 wire 2ndary distribution. Here in 2ndary distribution Single phase is given to residential & 3 phase supply is given to 3 phase loads. There are mainly Consists of feeders, Distributors and service mains

(1) feeders: It is a line Conductors which can Carry current from substations to feeding areas (load). Normally feeders don't have tappings

(2) Distributors: these are also a Conductors which can distribute Power to loads. It Consists of several tappings

(iii) service mains:

There are also a conductors that connects b/w the distributor & consumer terminals. Here from the distributor voltage can be stepdown to 400V & finally distributed to ultimate consumers. These are distributed as

(a) 3 phase 3 wire AC is used for balanced loads, show in fig ① a
(b) 3 phase 4 wire AC is used for unbalanced loads. shown in fig ⓑ
(c) single phase, 2 wire AC is used for lighting & small drives shown in fig ① c

fig ① ⓐ 3 phase 3 wire distributor

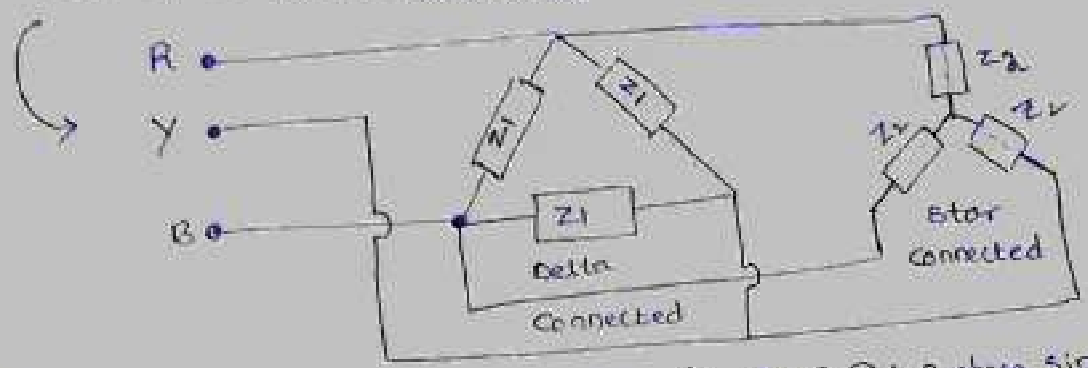


fig ① ⓑ 3 phase 4 wire distributor

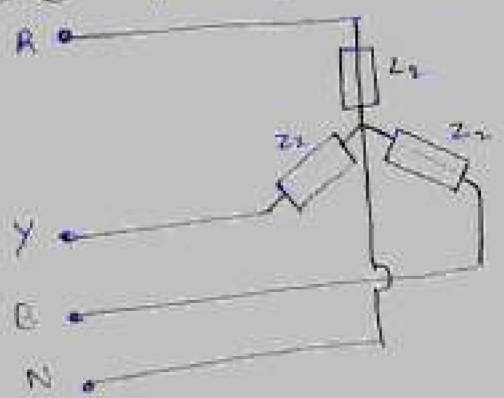
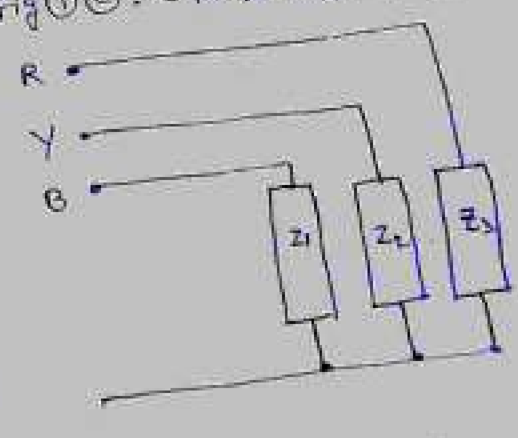


fig ① ⓒ: 3 phase single phase



Design Conditions or Considerations of Primary feeders or Primary distribution s/m

The s/m lies between the distribution substation & the distribution transformers is called Primary system or primary distribution feeder s/m.

A feeder which is usually 3 phase 4 wire or single phase or 3 phase circuits which does not have tappings.

(a) factors affecting the selection of feeders

→ nature or Type of load
→ Capacity of load served to given area
→ incerement rate of load.
→ Providing reserve Capacity for emergency operations
→ Type & Cost of circuit
→ Design & Capacity of Substation involved.
→ type of regulating equippment used
→ quality & Continuity of service

(13)

(b) Voltage Improvement on primary feeders

Voltage improvement on distribution system is done by using series & shunt Capacitors. shunt Capacitors are Connected at the load side, this shunt Capacitors reduces voltage drops & also reduces Current losses. Series Capacitors is also used to improve the voltage Conditions but it fails to reduce the Current losses so its applications is limited. Capacitors in distribution s/m should also improves the power factor also.

Types of Primary feeders

① Radial type primary feeder

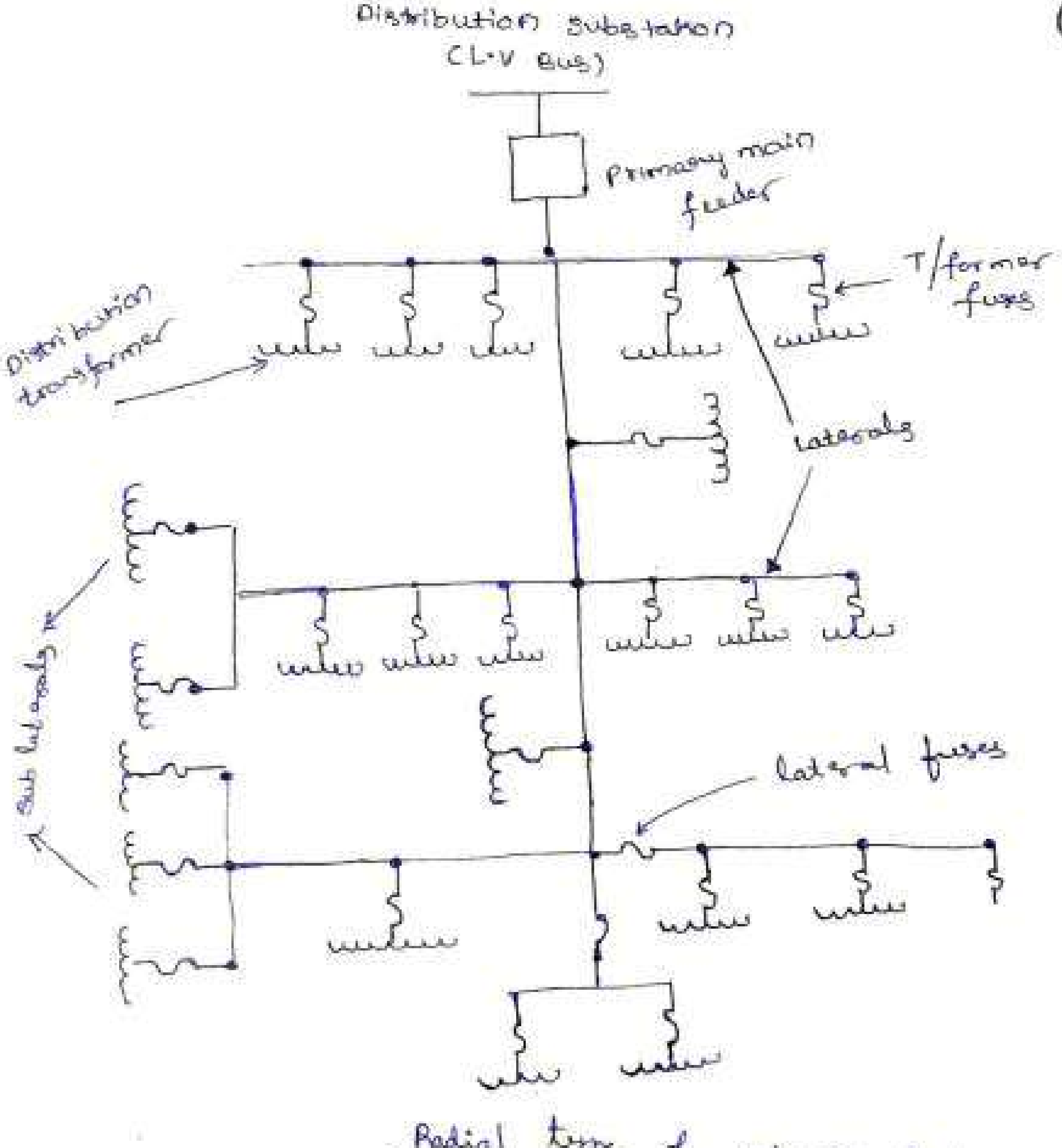
the simplest & cheap cost of primary feeder is radial type of feeder. Here main primary feeder branches is divided into various primary laterals & again primary laterals is sub divided into various sub laterals which can serve all distribution transformers.

* Main feeder and subfeeders are either 3 phase 3 wire or 3 phase 4 wire but laterals are 3 phase or single phase. At end of feeder magnitude of Current reduces & sublaterals are topped of. The permissible voltage of any feeder depends on thermal Capability & Current Carrying Capacity.

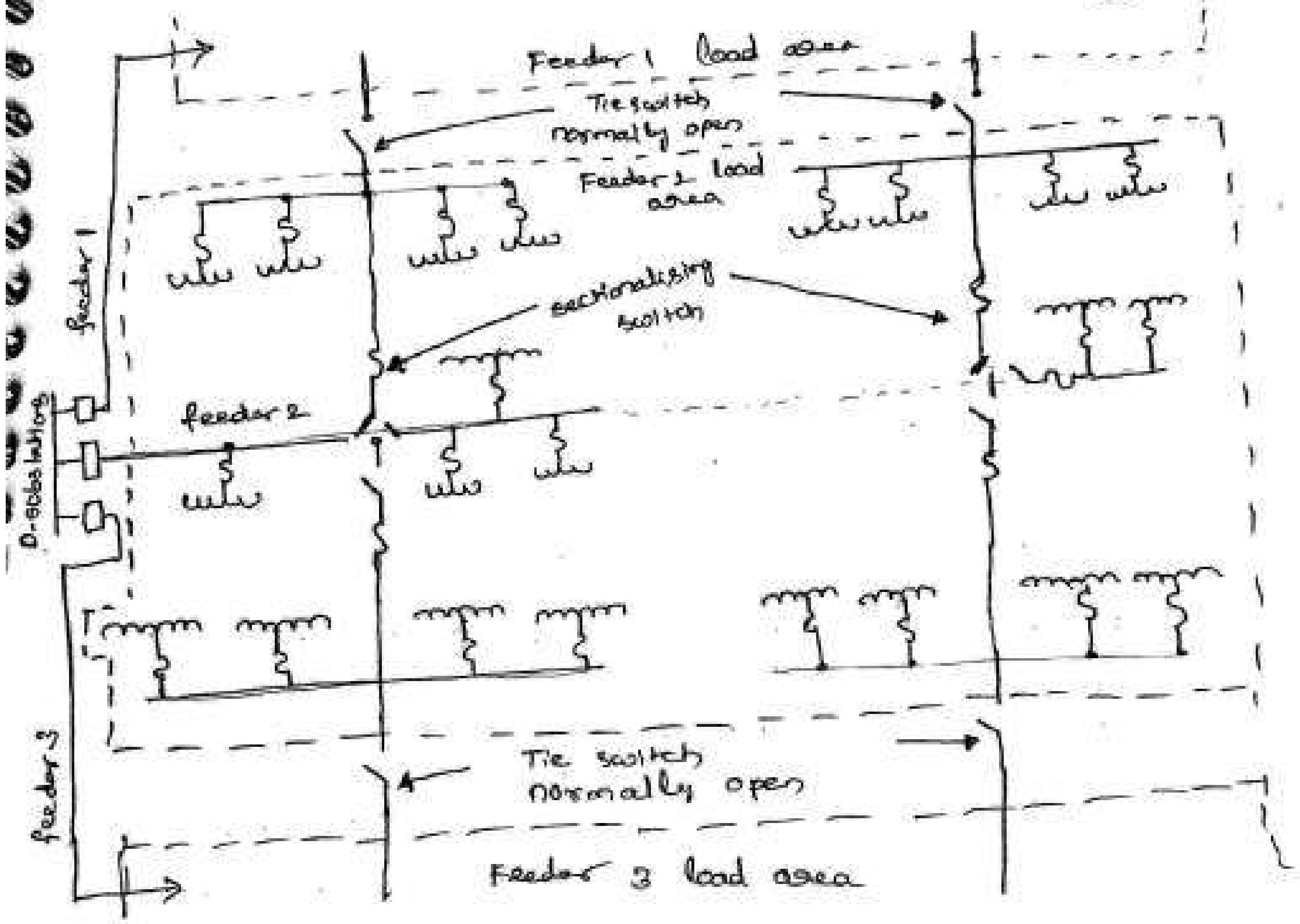
Drawback of radial feeder

* reliability is very low
* fault occur at any location on feeder causes a power outage.
* During fault conditions feeder should be disconnected from source.

(14)



Radial type of primary feeder



fig(1)(b) Radial type feeder with tie & sectionlizing switches

fig(1)(b) has modified Radial feeder Providing with tie & Sectionlizing switches. During fault Condition the circuit Can be isolated by opening these switches & also to the provide fast restoration of electrical Power to consumers by closing the health section of feeder.

(2) Another type of Radial Primary feeder is expressed feeder and backfed feeder. Express feeder lies b/w the L.V side of the substation and the load Centre is express feeder. Here no tappings are not allowed.

A Subfeeder is allowed to provide backfeed towards the substation from the load Center

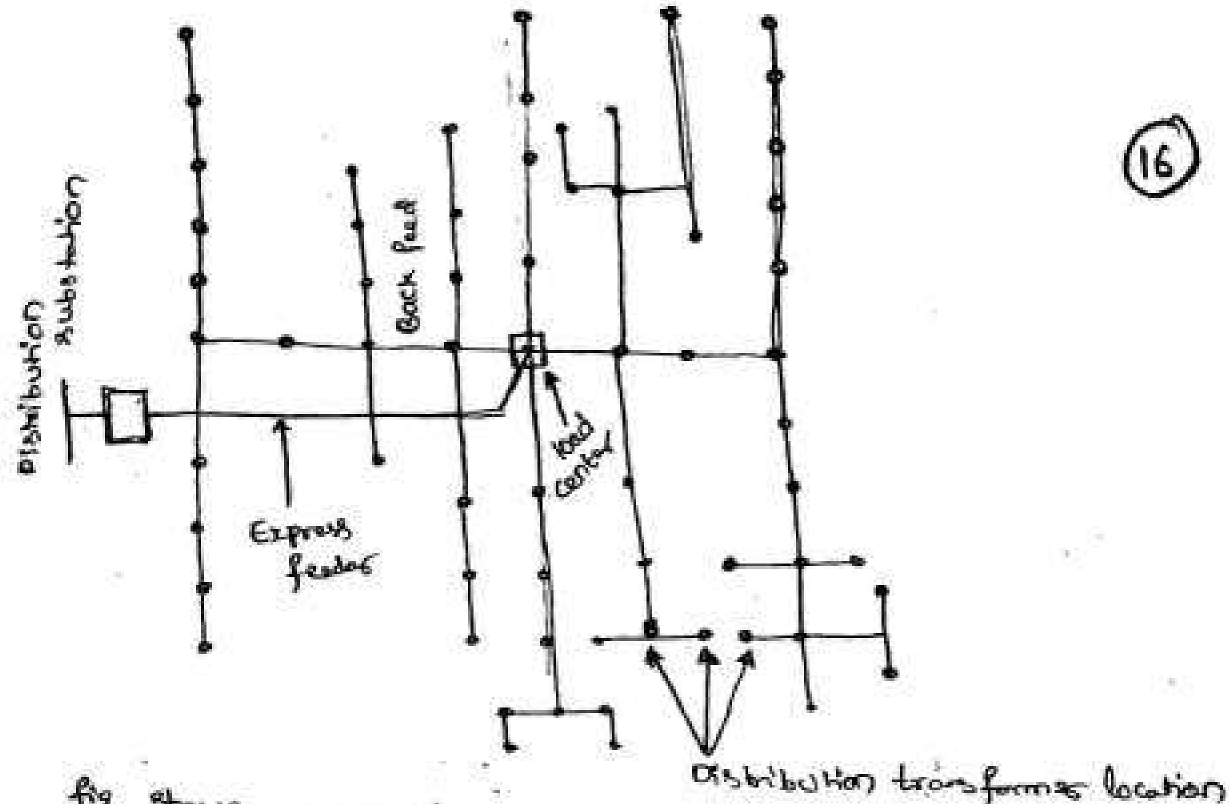
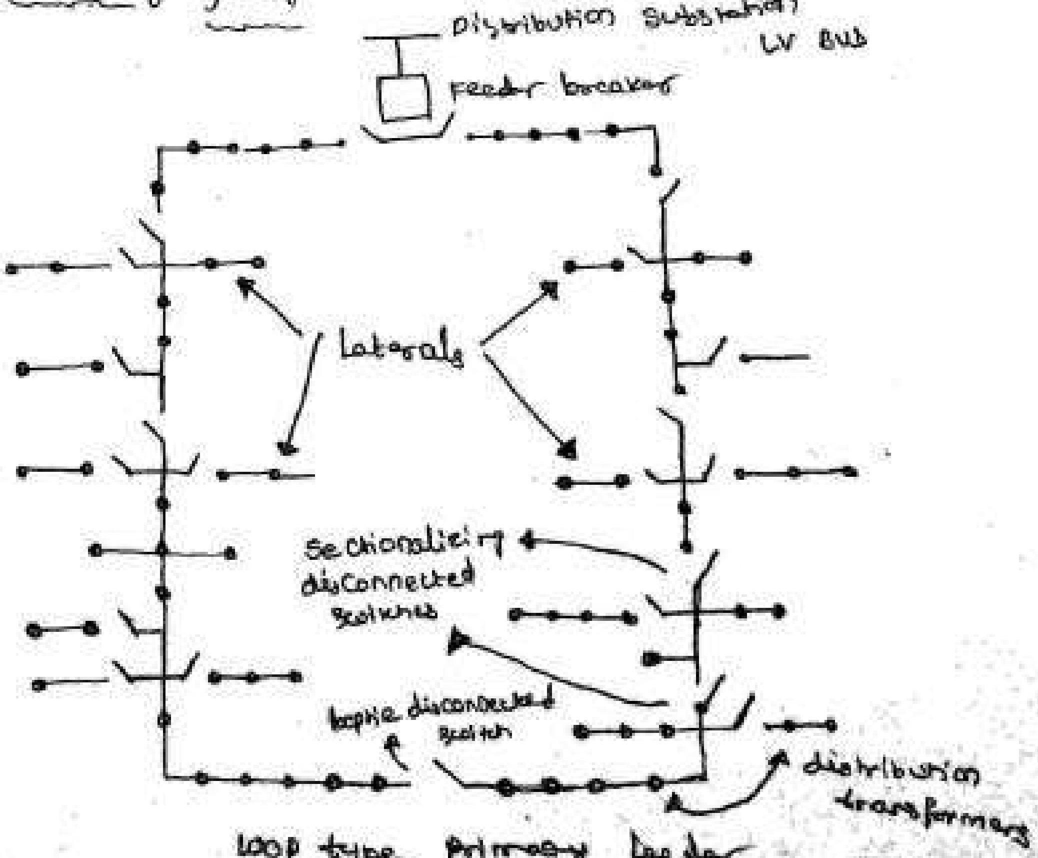


fig shows Radial type feeder with express feeder & Back feed.

(3) Another type is phase area feeder arrangement in which each phase of 3 phase feeder serves its own service area. Dots represent a balanced 3 phase load lumped at the service.

(b) Loop- Type Primary feeder



Loop type Primary feeder

fig shows loop-type primary feeder which has loop through the feeder load area & to the bus. Here loop tie disconnected switch is replaced by loop tie breaker. During loading conditions this switch or breaker normally open or close.

feeder Conductor Carry its normal load plus load of other half of the loop. When loop is operated with normally open tie breakers it has 2 parallel paths from substation to load.

If a fault occurs in s/m Primary feeder breaker opens until the fault is isolated from both directions. Normally open lateral loops are also used particularly in underground s/ms.

Primary network (17)

It is an interconnection of feeders supplied from a number of substations. Primary network system supplies load from several directions. By properly locating the transformers & properly regulating feeders at substation an adequate voltage levels is maintained at utilisation point.

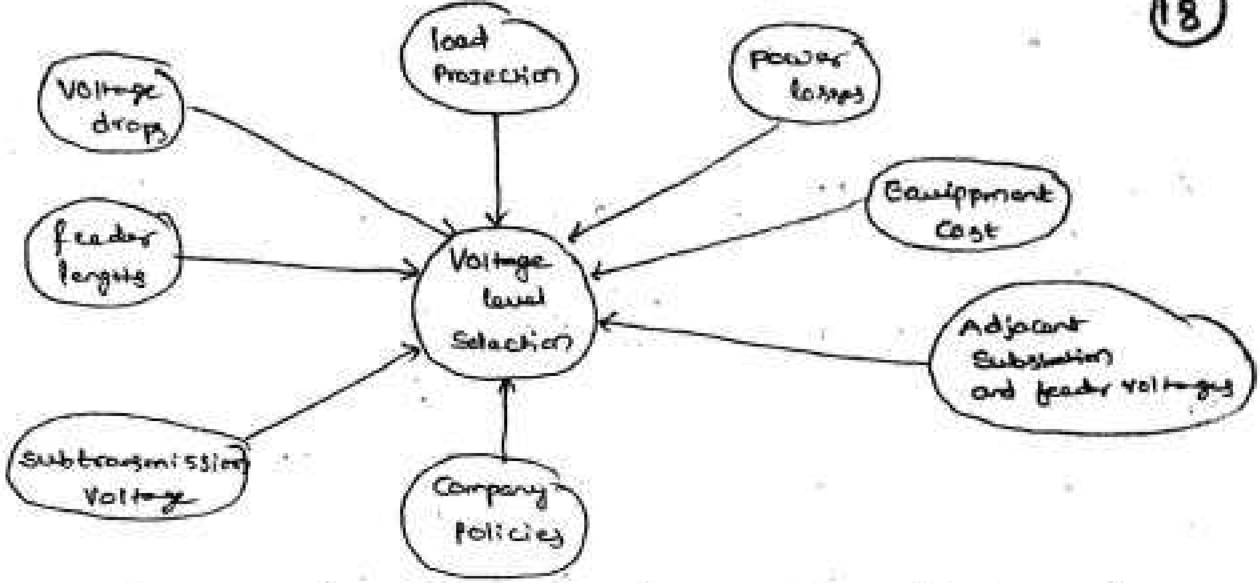
the reliability & quality of service of Primary n/w arrangement is much higher than the radial & loop arrangements.

<u>Primary feeder voltage levels</u>

This is the most important factor affecting the design cost & operation.

1. Length & loading of primary feeder
2. number of locations & ratings of distribution substation
3. Number of subtransmission lines & distribution lines serves the load area
4. Route plan, number of poles, section
5. number of Consumers & type of loads.

additional factors affecting Primary feeder voltage levels are



Voltage levels in primary distribution feeders are 33 KV or 11 KV & all Primary feeders are 3 phase 3 wire. Usually primary feeder located in high load areas i.e industrial & Commercial areas.

Selection of Voltage levels

(1) Voltage square law

feeder Voltage levels depends on % Voltage drop & feeder length.

If feeder voltage level doubles, it can supply same power over four times the distance

$$\boxed{V = d^2}$$ d = distance

(2) Voltage square factor rule (VSF)

$$V_{sf} = \left[\frac{V_{L-N}\ new}{V_{L-N}\ Old}\right]^2, \quad \text{feeder distance ratio} = \frac{\text{New distance}}{\text{old distance}}$$

$$\text{feeder load ratio} = \frac{\text{New feeder loading}}{\text{old feeder loading}}$$

If % of voltage drop is same then relationship is

$$VSF = \left(\text{feeder distance ratio}\right) * \left(\text{feeder load ratio}\right)$$

explaination

case ① $V_{L-N} = 1$ Per unit VD = 1, Area served = 1, load served = 1

It is formal for normal voltage (19)

case ② $V_{L-N} = 2$ Per unit VD = 1, Area served = 2, load served = 2

Case ③ $V_{L-N} = 2$, Per unit VD = 1, Area served = 2.52, load served = 2.52

Case 2 & Case ③ is for Twice the normal voltage

If new feeder voltage level is increased twice the previous voltage level, new load & area served with % VD is

$$\left[\left(\frac{V_{L-N}\ new}{V_{L-N}\ old}\right)^2\right]^{2/3} = \left[\left(\frac{2}{1}\right)^2\right]^{2/3} = 2.52$$

Similarly for new feeder voltage level is increased to 3 times these normal voltage level then

$$\left[\left(\frac{V_{L-N}\ new}{V_{L-N}\ old}\right)^2\right]^{2/3} = \left(\left(\frac{3}{1}\right)^2\right)^{2/3} = 4.32$$

times the original load & area served.

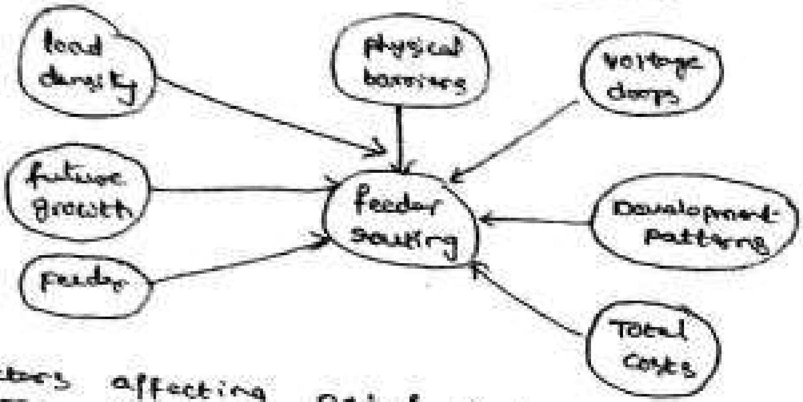
Primary feeder loading

It is defined as loading of feeder during peak load & is measured in substation

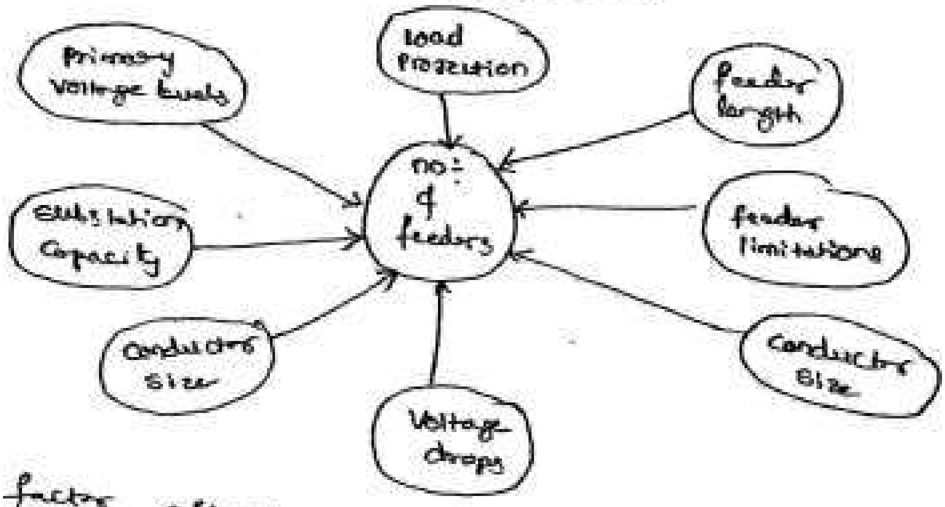
factors affecting the design of feeder loading are

* Nature & density of loads
* Growth rate & reserve Capacity during emergency
* continuity, reliability & quality of service
* location & Capacity of distribution substation
* Type, cost of Construction & operating
* alternate supply

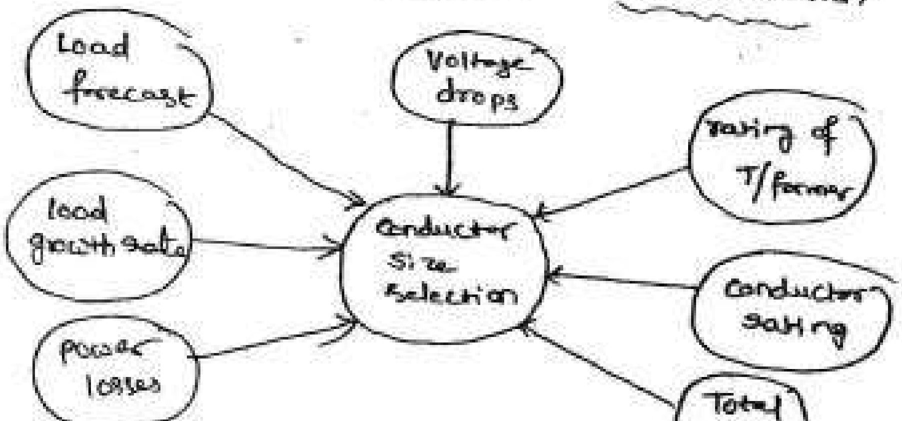
Factors Affecting Routing decisions



factors affecting no: of feeders



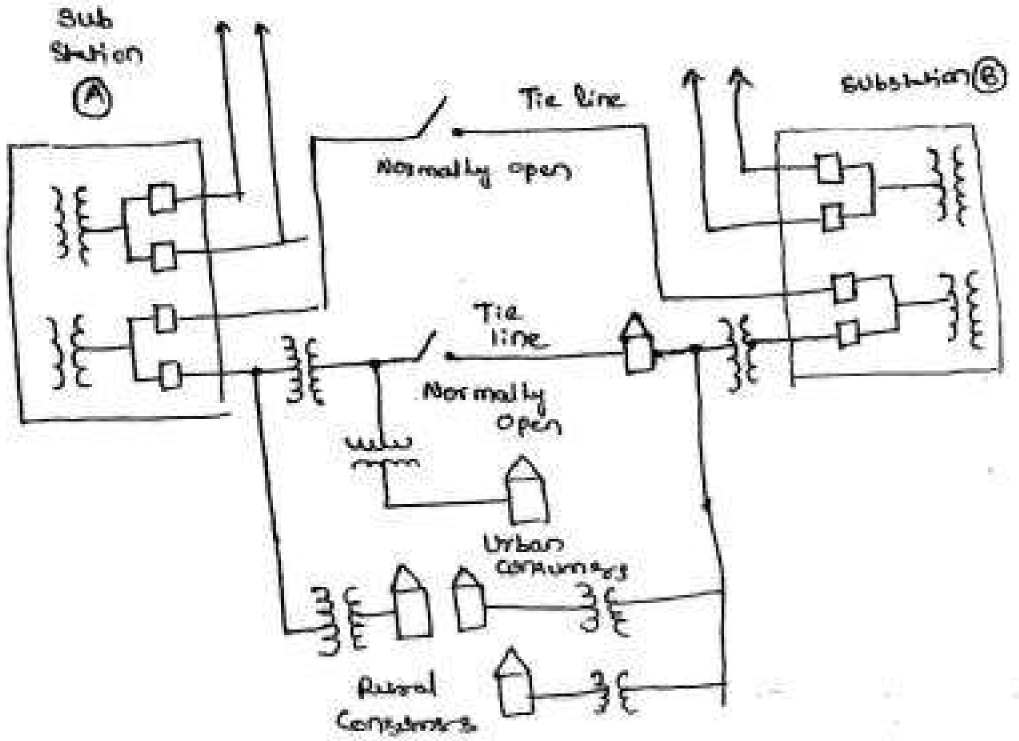
factor affecting Conductor size selection



Tie lines

It is a lines that connects 2 supply s/ms. It provides emergency service to fault service areas.

this also necessitates by eliminating emergency back up supply at service substation. This is needed more than one substation is required to serve the load area.



Singline diagram of typical 2 substation area with tie lines

Secondary distribution systems

The s/m lies b/w the Primary s/m & the load area is called 2ndary distribution s/m. This s/m supply energy to the Consumers based on area, number of Consumers & load requirements.

Secondary Consists of
(i) step-down transformers
(ii) 2ndary mains
(iii) Consumer services
(iv) metering equipments to measure the energy Consumption

Secondary distribution voltage levels
(a) H.V distribution s/m 11 kV or 33 kV
(b) L.V distribution s/m 415 V, 3 phase or 230 V single phase s/m

Requirements of 2ndary distribution s/m
(i) Maximize the utilization of electrical Power in economical way
(ii) Minimize the circuit length, voltage drop & power losses
(iii) Easy route location, maintainence of transformer managements.

design Practice of 2ndary distribution s/m

these designed are in 2 ways ① single phase designed used for residential Consumers & ② 3 phase for industrial as well as Commercial Consumers with high load densities.

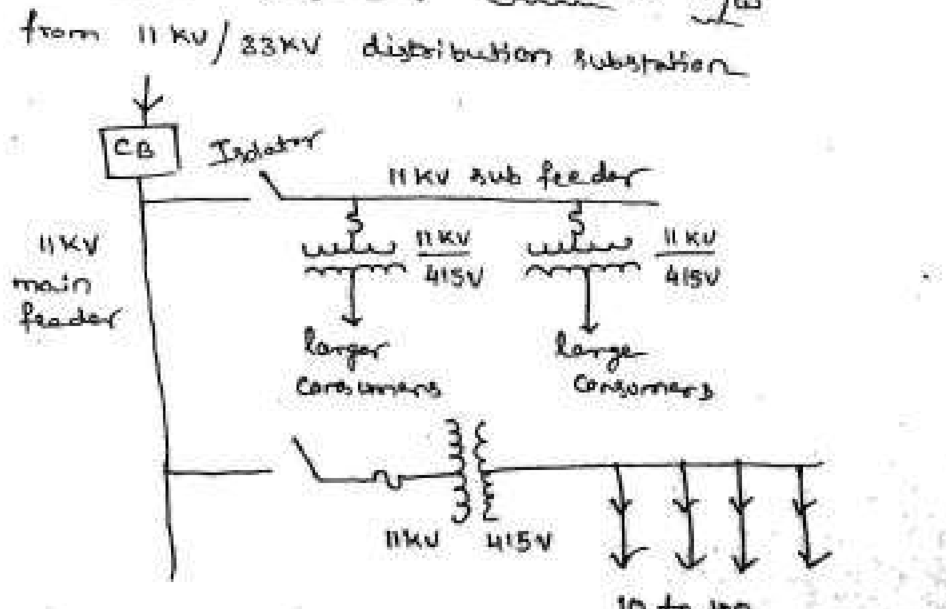
Some of design practices adopted in 2ndary distribution s/m is

* a separate Connection is provided for each individual Consumer
* group of Consumers like Commercial loads, small industries requires a separate transformer with radial feeder lines.
* loads greater than or equal to 25KVA must use their own transformer & substation directly Connected to high voltage distribution. Ex: Commercial Complexes, hospitals, institutions etc
* Interconnect the 2ndary networks with Common 2ndary mains called 2ndary banking. this 2ndary is needed during Uninterrupted power supply.

2ndary mains should provide the following

① division of loads based on feeder & transformers
② maintains good voltage regulation & proper voltage levels at Consumer points.
③ Separating the fault lines without interrupting the mains & supply.

Typical H.V & L.V secondary distribution n/w



AC Distribution Calculations

① Voltage drop in A.C distribution are due to combines effects of resistance, inductance & capacitance.

② In D.C s/m voltage calculations are done arithmetically but in case AC, these are vectorially calculated.

③ In A.C s/m power factor has taken into account. These are of referring in 2 ways

ⓐ Referring to supply or receiving end voltage

ⓑ Referred to voltage at load

Single phase AC distribution s/m

Power factors of various load currents are considered since currents in distributors will be vector sum of load currents. The powerfactor of load currents may be given with

ⓐ Respect to recieving end voltage

ⓑ with respect of load voltage itself

ⓐ Power factor of load refer to recieving end voltage

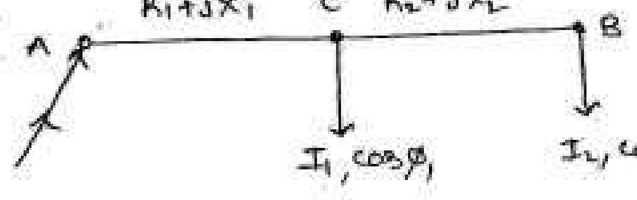


fig AC distributor fed at one end

Let I_1 & I_2 are load currents tapped off at point C & point B. V_R is the recieving end voltage as reference voltage. Let $\cos\phi_1$, $\cos\phi_2$ be the lagging power factors at points C & D.

Let $R_1 X_1$ & $R_2 X_2$ are resistance & reactance of AC & CB

Impedance of $Z_{AC} = R_1+jX_1$, $Z_{CB} = R_2+jX_2$

load current at point C is

$$I_1 = |I_1| \angle -\phi_1 = I_1(\cos\phi_1 - j\sin\phi_1)$$

load current at point B is

$$I_2 = |I_2| \angle -\phi_2 = I_2(\cos\phi_2 - j\sin\phi_2)$$

Current in section CB

$$I_{CB} = I_2 = I_2(\cos\phi_2 - j\sin\phi_2)$$

Current in section AC

$$I_{AC} = I + I_2$$

$$I_{AC} = I_1(\cos\phi_1 - j\sin\phi_1) + I_2(\cos\phi_2 - j\sin\phi_2)$$

Voltage drop in section BC

$$V_{CB} = I_{BC} * Z_{BC}$$

$$= I_2(\cos\phi_2 - j\sin\phi_2) * (R_2 + jX_2)$$

Voltage drop in AC

$$V_{AC} = I_{AC} \cdot Z_{AC}$$

$$= (I_1 + I_2)(R_1 + jX_1)$$

$$= \left[I_1(\cos\phi_1 - j\sin\phi_1) + I_2(\cos\phi_2 - j\sin\phi_2)\right](R_1 + jX_1)$$

Sending end voltage

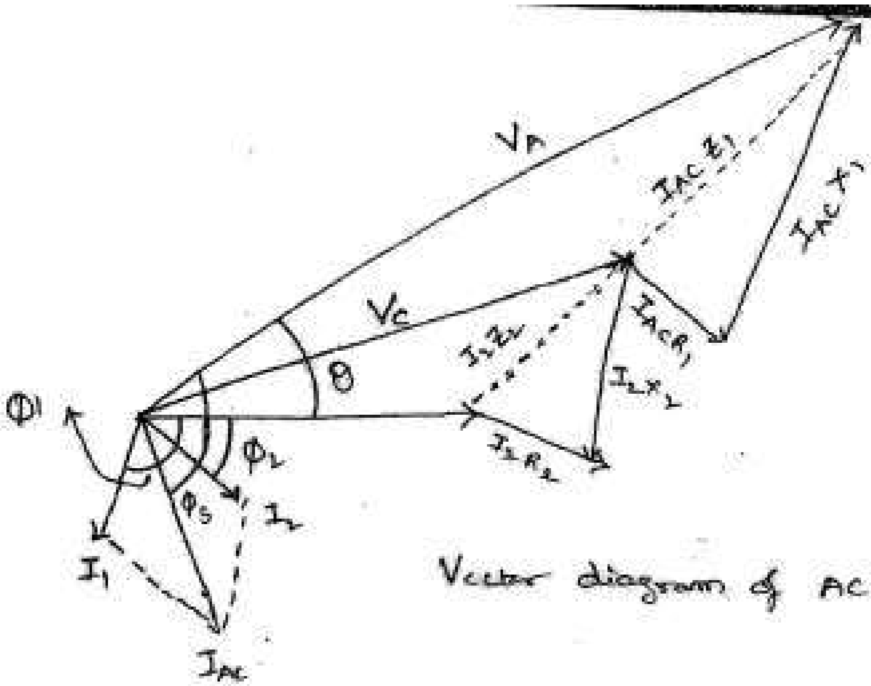
$$V_A = V_B + V_{BC} + V_{AC}$$

Sending end Current

$$I_{AC} = I_1 + I_2$$

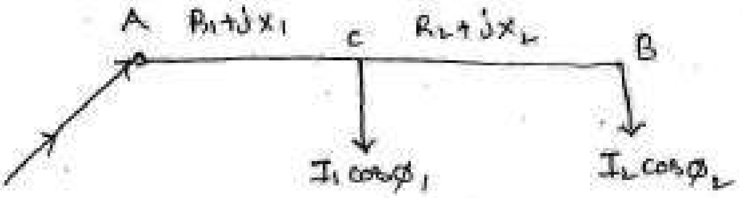
$$= I_1(\cos\phi_1 - j\sin\phi_1) + I_2(\cos\phi_2 - j\sin\phi_2)$$

In given phasor diagram at receiving end p.f of loads with respect of V_B & therefore I_1 & I_2 lag behind by ϕ_1 & ϕ_2.



Vector diagram of AC distributor

Power factor of loads referred to Respective load voltage

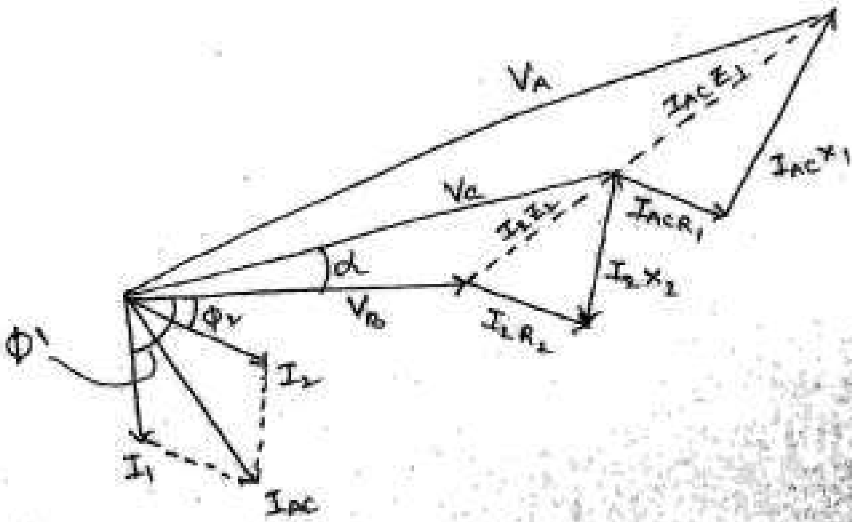


AC distributor feeder at one end

Considered a distributor AB have I_1 & I_2 are tapped off at point C & B.

$φ_1$ is angle b/w V_C & I_1

$φ_2$ is angle b/w V_B & I_2



$V_{CB} = I_2 Z_{CB}$

$= I_2(\cos\phi_2 - j\sin\phi_2)(R_2 + jX_2)$

Voltage at point c

$V_C = V_B + V_{BC} = V_C \angle \alpha$

Now $I_1 = I_1 \angle -\phi_1$ with respect to ϕ_1 of voltage V_C

$I_1 = I_1 \angle -(\phi_1 - \alpha)$ with respect to voltage V_B

$I_1 = I_1 [\cos(\phi_1 - \alpha) - j\sin(\phi_1 - \alpha)]$

Now $I_{AC} = I_1 + I_2$

$= I_1[\cos(\phi_1 - \alpha) - j\sin(\phi_1 - \alpha)] + I_2(\cos\phi_2 - j\sin\phi_2)$

Voltage drop in section AC

$V_{AC} = I_{AC} \cdot Z_{AC}$

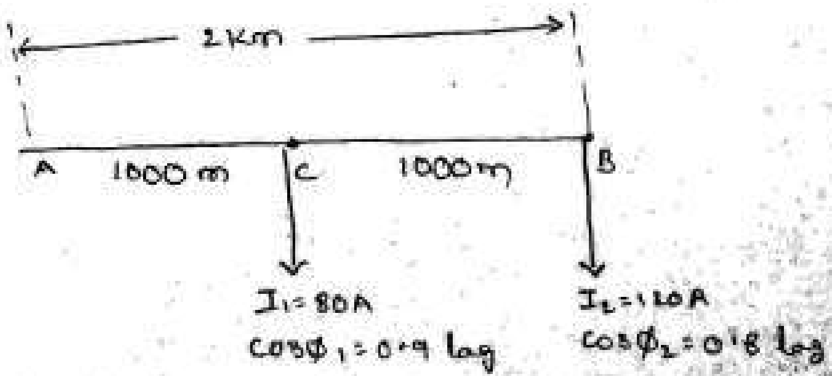
$V_A = V_B + V_{BC} + V_{AC}$

Problems

A single phase distributor has 2km long supplies load of 120 A at 0.8 p.f lagging at its far end & load of 80A at 0.9 p.f lagging at its midpoint. Both Powerfactors are referred to voltage at far end. Resistance R = 0.05 Ω, reactance X = 0.1 Ω per km. If voltage at far end is maintained at 230V. Calculate

(i) Voltage at sending end (ii) phase angle b/w voltages at 2 ends.

Sol



Impedance of distributor AB

$Z_{AB} = 0.05 + j0.1$

Impedance of section AC | Impedance of section CB

$Z_{AC} = 0.05 + j0.1$ | $Z_{BC} = 0.05 + j0.1$

Let V_B is taken as reference at point B

$V_B = V_B \angle 0 = 230 \angle 0° = 230 + j0°$

(i) load Current at point B

[illegible]

$I_2 = I_2 [\cos\phi_2 - j\sin\phi_2]$

$= 120 [0.8 - j0.6] = 96 - j72$

(ii) load Current at point C

$I_1 = I_1 [\cos\phi_1 - j\sin\phi_1] = 80 [0.9 - j0.436] = 72 - j34.88$

Current in section CB

$I_{CB} = I_2 = 96 - j72$

Current in section AC

$I_{AC} = I_1 + I_2 = (72 - j34.88) + (96 - j72) = 168 - j106.88$

(iii) Voltage drop in section CB

$V_{BC} = I_{BC} \cdot Z_{BC}$

$= (96 - j72)(0.05 + j0.1) = 12 + j6$

Voltage drop in section AC

$V_{AC} = I_{AC} \cdot Z_{AC} = I_{AC} Z_{AC} = (168 - j106.88)(0.05 + j0.1)$

$V_{AC} = 19.08 + j11.45$

∴ Sending end voltage

$V_A = V_B + V_{BC} + V_{AC}$

$= 230 + 12 + j6 + 190.08 + j11.45 = 261.08 + j17.45$ for V_A

$|V_A| = \sqrt{(261.08)^2 + (17.45)^2} = 261.57 V$

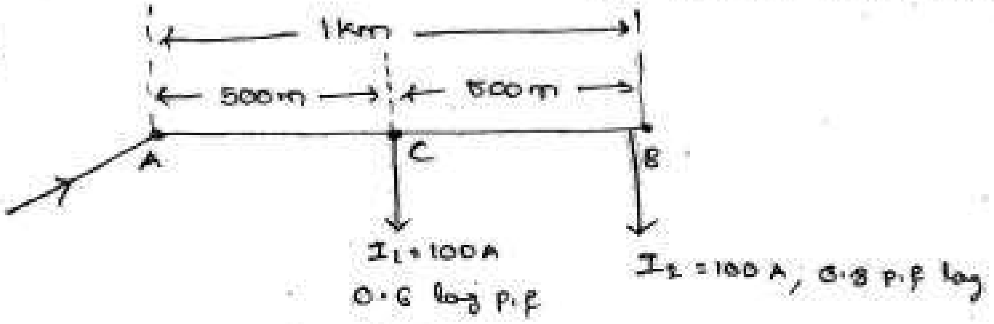
(V) phase angle b/w V_A & V_B

$\tan\theta = \tan^{-1}\left(\frac{17.45}{261.08}\right) = 0.0668$

$\theta = 3^{\circ}49$

(11) Distributor length AB = 1 km long, R = 0.1Ω & X = 0.15Ω. At far end B Voltage V_B = 200 V & Current at tapped is 100A, 0.8 p.f lag. At midpoint C of distributor, a current 100A, tapped of 0.6 lag with reference to the voltage V_C at the mid point

Sol



$Z_{AB} = 2(0.1 + j0.15) = 0.2 + j0.3$

Impedance at section AC

$Z_{AC} = 0.1 + j0.15$

Impedance at section CB

$Z_{CB} = 0.1 + j0.15$

let V_B is voltage at point B is taken as reference then

$V_B = 200\angle 0 = 200 + j0$ V

(1) Load Current at point B

$I_2 = 100(\cos\phi_2 - j\sin\phi_2)$

$= 100(0.8 - j0.6)$

$\cos\phi_2 = 0.8$

$\phi_2 = \cos^{-1}(0.8)$

$\sin\phi_2 = 0.6$

Current in section BC

$I_{BC} = I_2 = 100(0.8 - j0.6) = 80 + j60$

Voltage in drop CB, V_{CB} =

$V_{CB} = I_{CB} * Z_{BC} = (80 + j60)(0.1 + j0.15) = 17 + j6$

Voltage at point c

$V_c = V_B + V_{BC}$

$= 200 + 17 + j6 = 217 + j6$ (R + jX)

$|V_c| = \sqrt{(217)^2 + (6)^2} = 217.1\ V$

phase angle b/w V_c & V_B

$\alpha = \tan^{-1}\left(\frac{X}{R}\right) = \tan^{-1}\left(\frac{6}{217}\right) = 1^\circ 315$

(ii) load current I_1 has 0.6 p.f lagging with respect to c.

$\phi_1 = \cos^{-1}(0.6) = 53^\circ 130$.

phase angle b/w I_1 & V_B

$\phi_1' = \phi_1 - \alpha = 53.7 - 1.35$

⇒ load current at point C

$I_1 = I_1 \angle -\phi_1' = I_1[\cos(51.32) - j\sin(51.32)]$

$I_1 = (62.2 - j78.3)\ A$

Current in section AC

⇒ $I_{AC} = I_1 + I_2 = 142.2 - j138.3$

Voltage drop in section AC

$V_{AC} = I_{AC} \cdot Z_{AC}$

$= (142.2 - j138.3) + (0.14 + j0.15) = (34.06 + j7.5)$

Sending end voltage

$V_A = V_c + V_{AC} = (217 + j6) + (34.96 + j7.5) = 251.96 + j13.5$

$|V_A| = \sqrt{(251.96)^2 + (13.5)^2} = 252.32\ V$

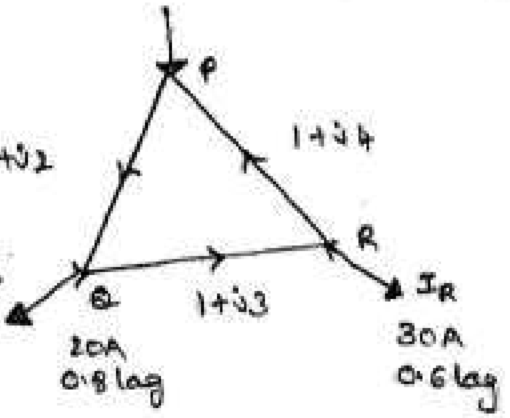
(iii) phase difference θ b/w V_A & V_B is

$\tan\theta = \frac{X}{R} = \frac{13.5}{251.96} = 0.05358$

$\theta = \tan^{-1}(0.05358) = 3^\circ 4$

V_B leads by $3^\circ 4$

A single phase ring distributor PQR is fed at P. Two loads at Q & R are 20A at 0.8 p.f lagging & 30A at 0.6 p.f lagging. Both are referred to voltage at P. Determine the total current fed at P & the current in each section if the total impedance of 3 sections PQ, QR & RP are (1+j2), (1+j3) & (1+j4) Ω. The ring distributor is shown below



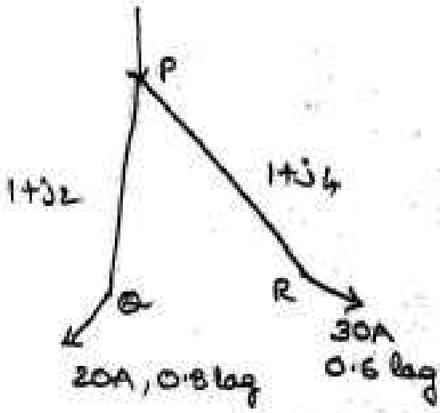
$I_Q = I_{PQ} - I_{QR}$

$\boxed{I_{PQ} = I_Q + I_{QR}}$

$I_R = -I_{PR} + I_{QR}$

$\boxed{I_{PR} = I_{QR} - I_R}$

Sol: Open the circuit QR then above ckt is



$I_{PQ} = I_Q = 20(\cos\phi - j\sin\phi)$

$= 20(0.8 - j0.6) = (16 - j12)$

$I_{PR} = I_R = 30(0.6 - j0.8) = (18 - j24)$

* Voltage drop in PQ

$V_{PQ} = I_{PQ} \cdot Z_{PQ} = (16 - j12)(1 + j2) = 40 + 20j\ V$

Voltage drop in PR

$V_{PR} = I_{PR} * Z_{PR} = (18 - j24)(1 + j4) = 114 + j48 = 123.69\angle 22.8$

* Open circuit voltage $V_{QR} = V_{PR} - V_{PQ} = (114 + j48) - (40 + j20)$

$V_{QR} = +74 + j28 = 79.12\angle 20.72°\ V$

* Open circuit impedance $Z_{oQR} = Z_{PQ} + Z_{PR} = (1+j2) + (1+j4) = 2 + j6$

short circuit impedance $Z_{SQR} = 1 + j3$

Total impedance in QR ⇒ $Z_{TQR} = Z_{OQR} + Z_{SQR}$

$Z_{TQR} = (2+j6)+(1+j2) = 3+j9 = 9.5\angle 71.6°$

* Current passing through section QR

$$I_{QR} = \frac{V_{QR}}{Z_{TQR}} = \frac{79.12\angle 20.72}{9.5\angle 71.6} = 8.33\angle -50.8$$

$= 5.26 - j6.46$

* Current passing through section PQ = $I_Q + I_{QR}$

$I_{PQ} = (16-j12)+(5.26-j6.46) = 21.26 - j18.26$

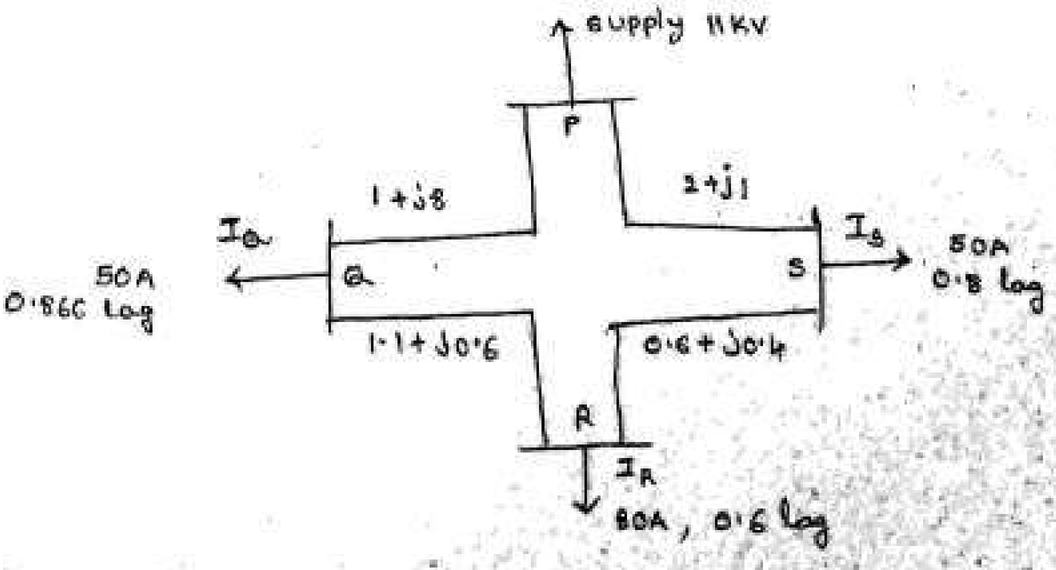
Current passing through section PR = $I_R - I_{QR}$

$I_{PR} = 12.74 - j17.34$

Current fed at (P) ⇒ $I_P = I_{PQ} + I_{PR} = (21.26 - j18.46) + (12.74 - j17.34)$

$= 34 - j35.8$

⑥ 3 phase ring main s/m ABCD fed at 11 KV supplies balanced load shown below. Impedances of various sections are shown in figure. All load currents referred to supply voltage at P, determine station bus voltages at Q & R & currents various sections.



let $I_{PQ} = a + jb$

apply KCL to QR => $I_Q = I_{QR} + I_{PQ}$

$I_{QR} = I_{PQ} - I_Q = (a+jb) - 50[\cos\theta - j\sin\theta] = (a+jb) - 50[0.866 - j0.5]$

$I_{QR} = (a+jb) - (43.3 + j25) = (a-43.3) + j(b+j25)$

=> Current in section RS

$I_R = I_{QR} + I_{RS} \Rightarrow I_{RS} = I_{QR} - I_R = [(a-43.3)+jb(+25)] + [80(0.6-j0.8)]$

$I_{RS} = (a-91.3) + j(b+89)$

=> Current in section SP

$I_S = I_{PS} + I_{RS}$

$I_{PS} = I_{RS} - I_S = [(a-91.3)+j(b+89)] - [50(0.8-j0.6)] = (a-131.3) + j(b+119)$

=> Voltage in PQ

$V_{PQ} = I_{PQ} * Z_{PQ}$

$= (a+jb)(1+j0.8)$

$= [(a-0.8b) + j(b+0.8a)]$

=> Voltage in QR

$V_{QR} = I_{QR} \cdot Z_{QR} = [(a-43.3)+j(b+25)] * [(1.1+j0.6)]$

$= [(1.1a - 0.6b - 62.63) + j(1.52 + 0.6a - 1.1b)]$

=> Voltage in RS

$V_{RS} = I_{RS} \cdot Z_{RS} = [(a-91.3)+j(b+89)] * [0.6+j0.4]$

$V_{RS} = [(0.6a - 0.4b - 90.38)] + j(0.4a + 0.6b + 16.88)$

=> Voltage in V_{SP}

$V_{SP} = I_{SP} * Z_{SP} = [(a-131.3)+j(b+119)] * (2+j1) = [(2a-b-381.6)+j(a+2b+100.87)]$

$V_{PQ} + V_{QR} + V_{RS} + V_{SP} = 0$

$[(a-0.8b)+j(b+0.8a)] + [(1.1a-0.6b-62.63)+j(1.52+0.6a-1.1b)] +$
$[(0.6a-0.4b-90.38)+j(0.4a+0.6b+16.88)] + [(2a-b-381.6)+j(a+2b+100.8)]$

$(4.7a - 2.8b - 191.17) + j(2.8a + 2.5b + 125.27) = 0$

Split above equation as real & imaginary part make equal to zero

$4.7a - 2.8b - 191.17 = 0 \Rightarrow 4.7a - 2.8b = 191.17 \rightarrow (1)$

$2.8a + 2.5b = -125.27 \rightarrow (2)$

Solving 3 & 4

$$Det = \begin{vmatrix} 4.7 & -2.8 \\ 2.8 & 2.5 \end{vmatrix} = (4.7 * 2.5) - (-2.8 * 2.8) =$$

$$a \Rightarrow \begin{vmatrix} 4.7 & -2.8 \\ 2.8 & 2.5 \end{vmatrix} = \begin{vmatrix} 191.17 \\ -125.27 \end{vmatrix}$$

$$a = \frac{\begin{vmatrix} 191.17 & -2.8 \\ -125.27 & 2.5 \end{vmatrix}}{\begin{vmatrix} 4.7 & -2.8 \\ 2.8 & 2.5 \end{vmatrix}} \Rightarrow 42.3 \qquad b = \frac{\begin{vmatrix} 4.7 & 191.17 \\ 2.8 & -125.27 \end{vmatrix}}{\begin{vmatrix} 4.7 & -2.8 \\ 2.8 & 2.5 \end{vmatrix}} = -57.4$$

$\Rightarrow I_{PQ} = (a + jb) = 42.3 - j57.4$

$I_{QR} = (a - 43.3) + j(b + 25) = -1 - j32.4$

$I_{RS} = (a - 91.3) + j(b + 89) = -49 + j31.6$

$I_{SP} = (a - 131.3) + j(b + 119) = 89 - j61.6$

$\Rightarrow V_{PQ} = I_{PQ} * Z_{PQ} = (a - 0.8b) + j(b + 0.8a) = 88.22 - j23.56$

$V_{QR} = I_{QR} * Z_{QR} = (1.1a - 0.6b - 62.63) + j(1.52 + 0.6a - 1.1b)$

$= 18.24 + j90.04$ V

$V_{RS} = [(0.6a - 0.4b - 90.038) + j(0.42 + 0.6a - 16.88b)] = -87.96 - j0.66$

$V_{SP} = [(2a - b - 301.6)] + j[a + 2b + j106.7]$

$= -239.6 + j34.2$

$V_R = \frac{11 KV}{\sqrt{3}} = \frac{11000}{\sqrt{3}} = 6351 V$

$V_Q = V_{PQ} + V_{QR}$

$V_{PQ} = V_P - V_Q$

$V_{QR} = V_Q - V_R$

$V_{RS} = V_R - V_S$

⇒ voltage at bus 'Q'

$V_Q = V_P - V_{PQ} = 6351 - (88.22 - j23.56)$

$= 6262.78 + j23.56$

⇒ Voltage at bus 'R'

$V_R = V_Q - V_{QR} = 6262.78 + j23.56 - [18.34 + j90.4]$

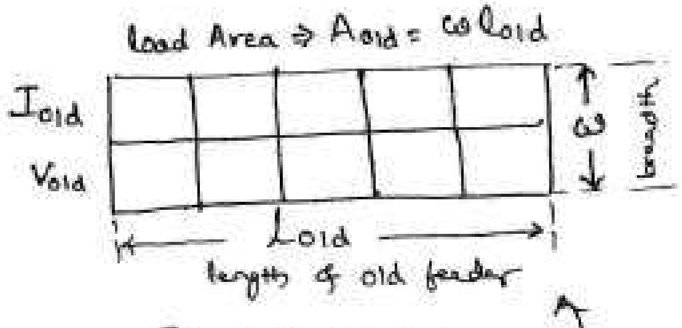
$= 4244.44 + j113.6$

⇒ voltage at bus 'S'

$V_S = V_R - V_{SR} = 6244.44 + j113.6 - [-87.96 - j0.64]$

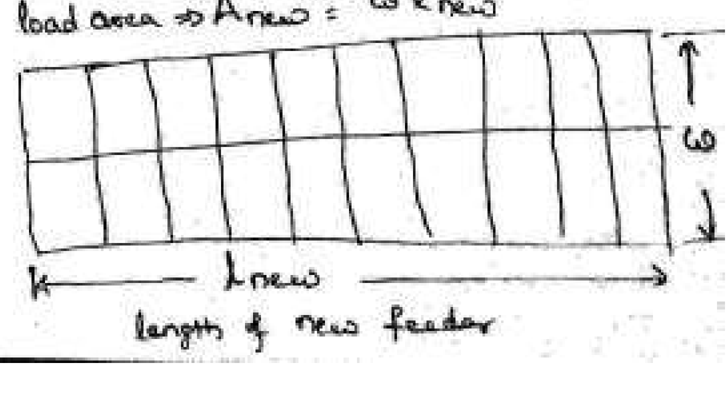
$V_S = 6334.4 + j114.24 V$

(8) assume service area of feeder is increasing to new residential development. Determine new load area & area that can be served with same % voltage drop. If the new feeder voltage level is increased to 34.5KV from previous voltage level of 12.47KV



(a) old feeder

(b) New feeder.



$V_{PQ} = V_Q - V_P$

Assume feeder is uniformly loaded with constant load density. Hence i is the load density for old & new feeder

old feeder density $= i * A_{old}$ New feeder density $= i * A_{new}$

let I be the loading of both old & new feeder

loading I on old feeder is	Loading of I on new feeder is
$I_{old} = i * A_{old}$	$I_{new} = i * A_{new}$
$= i * \omega * l_{old}$	$I_{new} = i * \omega * l_{new}$

let Z be the impedance of both old & new feeder

impedance Z on old feeder is	impedance Z on new feeder is
$Z_{old} = Z \cdot A_{old}$	$Z_{new} = Z \cdot A_{new}$
$Z_{old} = Z \cdot \omega \cdot l_{old}$	$Z_{new} = Z \cdot \omega \cdot l_{new}$

let V be the voltage on old & new feeder

$V_{old} = 12.47\,KV$	$V_{new} = 34.5\,KV$

The percentage voltage drop in old & new feeder remains unchanged

$$\% \text{ voltage in old feeder} = \frac{I_{old} * Z_{old}}{V_{old}} * 100$$

$$\% \text{ voltage in new feeder} = \frac{I_{new} * Z_{new}}{V_{new}} * 100$$

$$\frac{I_{old} \cdot Z_{old}}{V_{old}} * 100 = \frac{I_{new} * Z_{new}}{V_{new}} * 100$$

$$\frac{i * \omega * l_{old} * Z * \omega * l_{old}}{12.47} = \frac{i * \omega * l_{new} * Z * \omega * l_{new}}{34.5\,KV}$$

$$\frac{(l_{old})^2}{12.47} = \frac{(l_{new})^2}{34.5}$$

$$\frac{(l_{old})^2}{(l_{new})^2} = \frac{12.47}{34.5} \text{ or } \frac{(l_{new})^2}{(l_{old})^2} = \frac{34.5}{12.47} = 2.766$$

$$\left(\frac{l_{new}}{l_{old}}\right)^2 = 2.766 \Rightarrow \frac{l_{new}}{l_{old}} = 1.663$$

feeder service area is proportional to $\left[\left(\frac{V_{L,new}}{V_{L,old}}\right)^2\right]^{2/3} = \left[\left(\frac{34.5}{12.47}\right)^2\right]^{2/3}$

$= 3.883$

feeder service area & load of new feeder is 3 times the values of old feeder

Important terms used

	old feeder	new feeder
Load density A/Km^2	i	i
Loading A	I_{old}	I_{new}
Service Area length in Km	l_{old}	l_{new}
Service area width in Km	ω_{old}	ω_{new}
Service area in Km	A_{old}	A_{new}
Impedance	Z	Z
Total impedance	$Z_{old} = Z \cdot l_{old}$	$Z_{new} = Z \cdot l_{new}$
Voltage applied	V_{old}	V_{new}
% Voltage drop	$\frac{I_{old} \cdot Z_{old}}{V_{old}} \times 100$	$\frac{I_{new} Z_{new}}{V_{new}} \times 100$

(8) assume feeder length is 2 km, new feeder loading is increased to 3 times the old feeder loading. Determine the new maximum length of feeder with same % voltage drop. If new feeder voltage is increased to 34.5 kV from previous voltage level of 12.47 kV.

Sol

$V_{old} = 12.47\,kV$, $Z_{old} = Z * l_{old}$

$\rightarrow I_{old}$

$V_{new} = 34.5\,kV$, $Z_{new} = Z * l_{new}$

$I_{new} = 3 * I_{old}$

Z = impedance in km, l_{old} = length of old feeder = 2

$$\%\text{ voltage drop} = \frac{I \cdot Z}{V} * 100 = \frac{I \cdot Z \cdot l}{V} * 100$$

$$\%\text{ voltage drop for old feeder} = \frac{(I_{old}) \cdot (Z_{old})}{V_{old}} * 100$$

$$= \frac{(I_{old}) * (Z \cdot l_{old})}{12.47} * 100 \rightarrow (1)$$

similarly for % voltage drop for new feeder

$$= \frac{(I_{new}) * (Z_{new})}{V_{new}} * 100 = \frac{(3 * I_{old}) \cdot (l_{new} * Z)}{34.5} \rightarrow (2)$$

equating (1) & (2)

$$\frac{I_{old} * Z * l_{old}}{12.47} = \frac{3 * I_{old} \cdot l_{new} \cdot Z}{34.5}$$

$$\frac{3 * l_{new}}{34.5} = \frac{l_{old}}{12.47} \Rightarrow \frac{l_{old} * 34.5}{12.47 * 3} \Rightarrow l_{new} \Rightarrow 0.95$$

$$l_{new} = \frac{2 * 34.5}{3 * 12.47} = 1.884\,km$$

With increased of 34.5 V in new feeder, length of new feeder increases to 1.884 times of old feeder length.

UNIT-4
UNDER GROUND CABLES

II EEE II-SEM- POWER SYSTEMS-1

Presented By
V AMARNATH REDDY
Dept- of EEE

INTRODUCTION

- Cable: Simply a metallic conductor designed to carry current.
- These are classified as-over head cable & under ground cables
- Under ground cables: Cables which are used in underground to transfer data. It consists of 2 or more conductors provided with strong insulation & is surrounded by a cover.
- Why under ground cables?
- ✓ Less chances of faults,
- ✓ more safety at very high voltages,
- ✓ long life

Requirements of Cables

- Cables must high conductivity, made of stranded copper or alluminium.
- Carries desired current without over heating with less voltage drop
- Thick insulation to provide better safety & high reliable
- Good mechanical strength in design
- Materials used should with stand chemical & physical changes

Construction of Cables

- ***Cores or Conductors:-*** *A cable may have one or more than one* tinned copper or aluminum *(conductor) depending* upon the type of service and are usually stranded in order to provide flexibility to the cable.
- ***Insulation.:-*** *Each core or conductor is provided with a suitable thickness of insulation,* The commonly used materials for insulation are impregnated paper, varnished cambric or rubber mineral

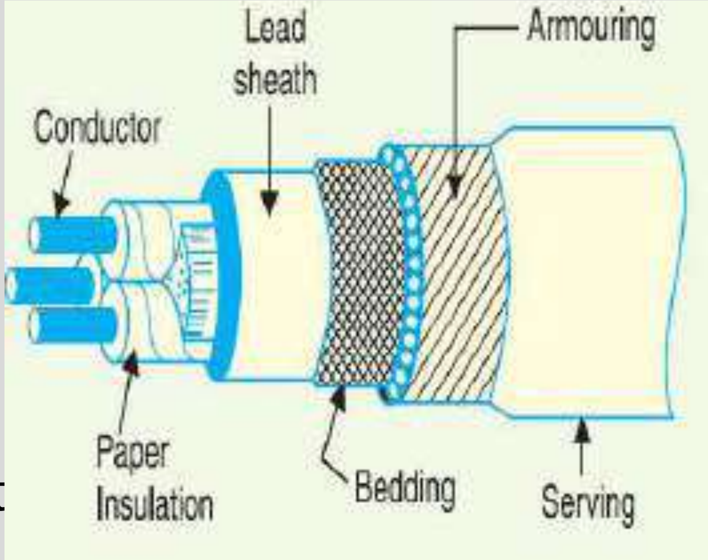
compound.

Metallic sheat :-*. Protect* the

cable from moisture which is usually made lead or aluminium

provided over the insulation

Bedding :- fibrous material like j
 or hessian tape. Used to protect
Cable from mechanical damage



Construction of Cables

- ***Armoring:-*** *Over the bedding, armouring is provided which consists of one or two layers of* galvanised steel wire or steel tape used to protect the cable from mechanical damage.
- ***Serving:-*** *In order to protect armouring from atmospheric conditions, a layer of fibrous* material (like jute) similar to bedding

Classification of Cables

- Three ways based on (*i)* the type of insulating material

  ii) voltage

  iii) Type of service
- cables can be divided into the following groups based on voltage :
- (i) Low-tension (L.T.) cables — upto 1000 V
- (ii) High-tension (H.T.) cables — upto 11,000 V
- (iii) Super-tension (S.T.) cables — from 22 kV to 33 kV
- (iv) Extra high-tension (E.H.T.) cables — from 33 kV to 66 kV
- (v) Extra super voltage cables — beyond 132 kV

Classification of Cables

- Type of service & load demand.

It may be (*i)* single-core (*ii) two-core (iii) three-core (iv) four-core etc.*

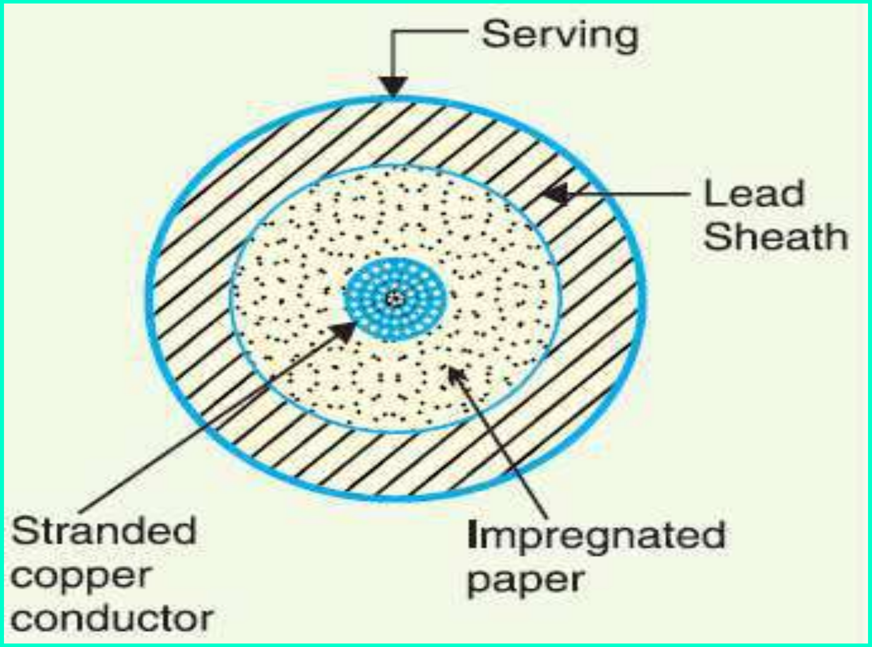


Fig shows construction view of single core cable

Classification of Cables

- **Cables for 3-Phase Service**
- For voltages upto 66 kV, 3-core cable voltages
- beyond 66 kV, 3-core-cables become too large single-core cables are

  used

TYPES OF CABLE FOR 3 PHASE SERVICE

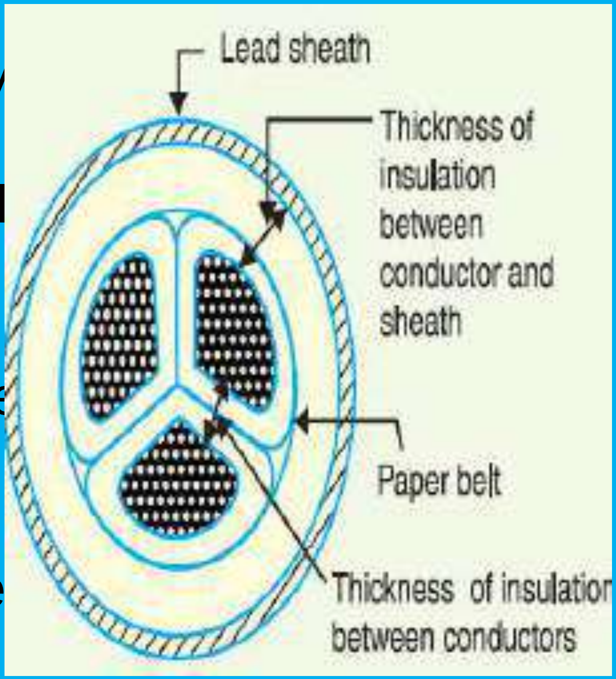
- 1. Belted cables — upto 11 kV
- 2. Screened cables — from 22 kV to 66 kV
- 3. Pressure cables — beyond 66 kV.

Classification of Cables

TYPES OF CABLE FOR 3 PHASE SERVICE

Belted cables:-

- cables are used for voltages upto 11kV
- Insulation used is impregnated paper.
- Gap between the insulated cores is fil with fibrous insulating material.
- lead sheath to protect the cable against moisture and mechanical damage



Draw back:

Leakage current causes heating of cable results damage of insulation

Classification of Cables

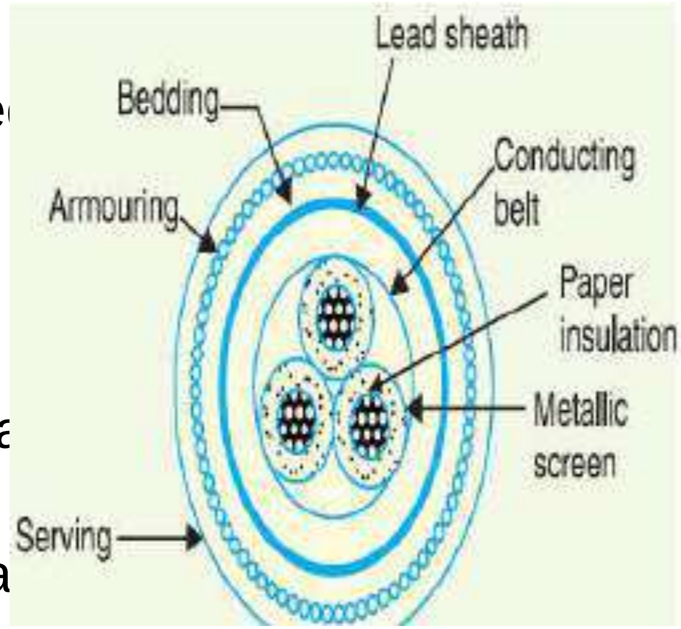
TYPES OF CABLE FOR 3 PHASE SERVICE

2. SCREENED CABLES :-

- It is used where leakage currents are conducted to earth.
- used upto 33 kV
- These are H type cables and S.L. type cables.

- ***(i) H-type cables:-***
- ✓ Insulation used is layers of impregnate paper.
- ✓ Each core covered with aluminum foil called metallic screens contact with each core.
- ✓ conducting belt (copper woven fabric ta wrapped round the three cores.
- ✓ The electrical stresses are purely radia

and consequently dielectric losses are reduced.



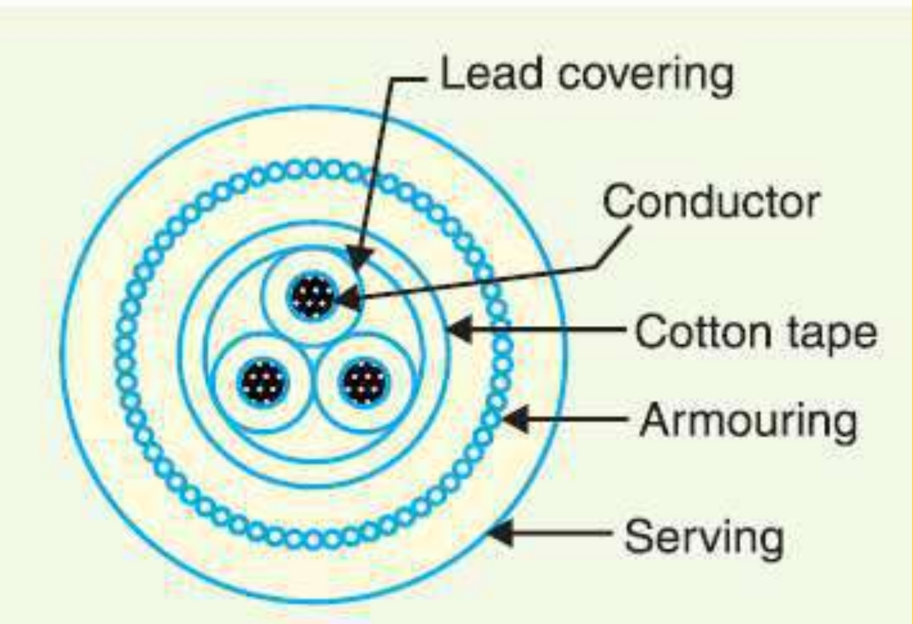
Classification of Cables

TYPES OF CABLE FOR 3 PHASE SERVICE

2. SCREENED CABLES :-

ii) S.L. type cables: It is also called as separate lead cables. Each core insulation is covered by its own lead sheath.

- No over all lead sheath only armouring and serving are provided.



TYPES OF CABLE FOR 3 PHASE SERVICE

- **Advantages of S.L. type cables :-**

i) separate sheaths minimize the possibility of core-to-core breakdown

ii) bending of cables becomes easy due to the elimination of overall lead sheath

- **Dis-Advantages of S.L. type cables :-**

S.L. cable are much thinner than the single sheath of *H-cable*

3. Pressure cables

- voltages beyond 66 kV, solid type cables are unreliable due to insulation problems. So Pressure cables is needed.
- Two types of pressure cables

  i) Oil-filled cables and ii) gas pressure cables

i) Oil-filled cables: channels or ducts are provided in the cable for oil circulation at constant pressure.

- Oil compresses the insulation to

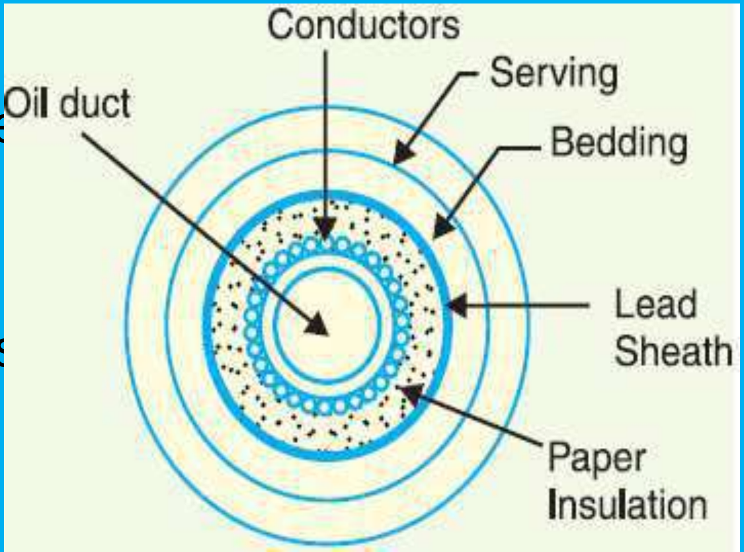
  Minimizes the gaps(voids) betwee

  the paper.

  Due to the elimination of voids,

  oil-filled cables for higher voltages

  from 66 kV upto 230 kV.



(ii) Gas pressure cables.

- The voltage required to set up ionization inside a void increases as the pressure is increased.
- The construction of the cable is similar to that of an ordinary solid type except that it is of triangular shape and thickness of lead sheath is 75% that of solid cable.
- The sheath is protected by a thin metal tape. The cable is laid in a gas-tight steel pipe. The pipe is filled with dry nitrogen gas at 12 to 15 atmosphere which acts as quenching the flame
- The gas pressure produces radial compression and closes the voids.
- disadvantage that the overall cost is very high.

Fig shows Gas pressure cables.

Types of insulating materials for cables

- insulating materials used in cables should have the following properties.
- High insulation resistance to avoid leakage currents
- High dielectric strength to avoid electrical breakdown
- High mechanical strength
- Non-hygroscopic- not absorb any moisture
- Non-inflammable
- Unaffected by acids and alkalies to avoid any chemical action

Types of insulating materials for cables

- Rubber. It has relative permittivity varying between 2 and 3, dielectric strength is about 30 kV/mm and resistivity of insulation is 1017Ω cm
- it suffers form some major drawbacks viz., readily absorbs moisture, maximum safe temperature is low (about 38ºC), soft and liable to damage due to rough handling and ages when exposed to light. Therefore, pure rubber cannot be used as an insulating material.
- **Vulcanized India Rubber (V.I.R.):-**It is prepared by mixing pure rubber with mineral matter such as zinc oxide, red lead etc., and 3 to 5% of sulphur, operating temperature is 150 degree centigrade.
- Advantage : greater mechanical strength, durability and wear resistant property than pure rubber .
- Draw back sulphur reacts very quickly with copper, used for low & moderate voltages.

TYPES OF INSULATION MATERIALS

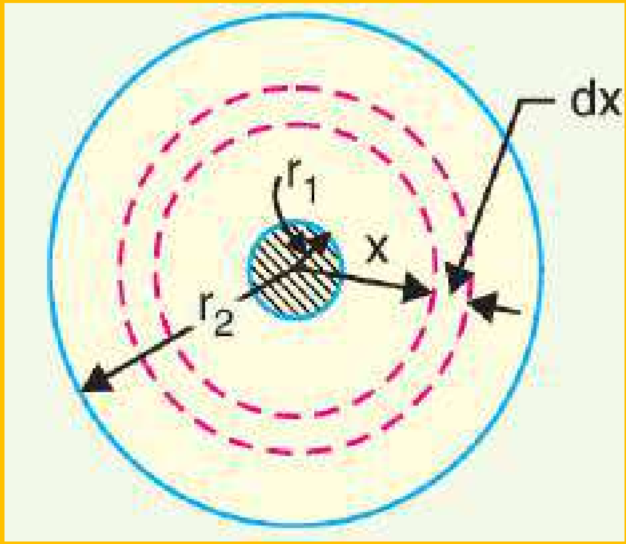
- **IMPREGNATED PAPER:-** It consists of chemically pulped paper made from wood chippings and impregnated with some compound such as paraffinic or naphthenic material.
- Advantages:- low cost, low capacitance, high dielectric strength and high insulation resistance.
- disadvantage is that paper is hygroscopic able to absorb moisture.

- **VARNISHED CAMBRIC:** It is a cotton cloth impregnated and coated with petroleum jelly varnish. This type of insulation is also known as *empire tape.*
- varnished cambric is hygroscopic, therefore, such cables are always provided with metallic sheath. Its dielectric strength is about 4 kV/mm and permittivity is 2.5 to 3.8.

- **Polyvinyl chloride (*PVC*).** This insulating material is a synthetic compound. It is obtained from the polymerisation of acetylene For obtaining this material as a cable insulation, it is compounded with certain materials known as plasticizers which are liquids with high boiling point over desired range of temperature.
- Polyvinyl chloride has high insulation resistance, good dielectric strength and mechanical toughness over a wide range of temperatures. It is inert to oxygen and almost inert to many alkalies and acids. Therefore, this type of insulation is preferred over *VIR in extreme enviormental conditions* such as in cement factory or chemical factory. As the mechanical properties (*i.e., elasticity etc.) of PVC are not so good as those of rubber, therefore, PVC insulated cables are generally used for low* and medium domestic lights and power installations.

Insulation Resistance of a Single-Core Cable

- Insulating material used in cable is to prevent leakage currents
- path for leakage current is radial & is opposed by some resistance is called insulation resistance.
- Consider a single-core



Let **r1** = conductor radius

***r*2** = internal sheet radius

l = length of cable, ρ be the resistivity

dx = thickness of insulation of X radius

Leakage current flows through out length is dx

Area of X-section A = $2\pi x l$

Insulation resistance $R = \rho \frac{dx}{2 \prod x l}$

$$R = \int_{r_1}^{r_2} \rho \frac{dx}{2\pi x l}$$

Insulation resistance of the whole cable is

$$\frac{\rho}{2\pi l} \int_{r_1}^{r_2} \frac{1}{x} dx \qquad R = \frac{\rho}{2\pi l} \log_e \frac{r_2}{r_1}$$

A single-core cable has a conductor diameter of 1cm and insulation thickness of 0·4 cm. If the specific resistance of insulation is 5×10^{14} Ω-cm, calculate the insulation resistance for a 2 km length of the cable.

Solution:-

Conductor radius, r1 = 1/2 = 0·5 cm

Length of cable, *l* = 2 km = 2000 m

Resistivity of insulation, ρ = 5 × 1014 Ω-cm = 5×10^{12} Ω-m

Internal sheath radius, r2 = 0·5 + 0·4 = 0·9 cm

Insulation resistance of cable is $\boldsymbol{R} = \ \rho \frac{dx}{2\prod xl}$

$$R = \frac{\rho}{2\pi l}\log_e \frac{r_2}{r_1} = \frac{5\times 10^{12}}{2\pi \times 2000}\log_e \frac{0\cdot 9}{0\cdot 5}$$

$= 0{\cdot}234 \times 10^9\ \Omega$

Example 2: The insulation resistance of a single-core cable is 495 MΩ per km. If the core diameter is 2·5 cm and resistivity of insulation is $4·5 \times 10^{14}$ Ω-cm, find the insulation thickness.

Solution:

Length of cable, l = 1 km = 1000 m

Cable insulation resistance, R = 495 MΩ = 495×10^{6}Ω

Conductor radius, r1 = 2·5/2 = 1·25 cm

Resistivity of insulation, ρ = $4·5 \times 10^{14}$ Ω-cm = $4·5 \times 10^{12}$Ωm

Let r2 cm be the internal sheath radius.

$$R = \frac{\rho}{2\pi l} \log_e \frac{r_2}{r_1}$$

$$\log_e \frac{r_2}{r_1} = \frac{2\pi l R}{\rho} = \frac{2\pi \times 1000 \times 495 \times 10^{6}}{4 \cdot 5 \times 10^{12}} = 0{\cdot}69$$

single core cable 5 km long has an insulation resistance of 0·4 MΩ. The core diameter is 20 mm and the diameter of the cable over the insulation is 50 mm. Calculate the resistivity of the insulating material.

Solution:-

Length of cable, l = 5 km = 5000 m

Cable insulation resistance, R = 0·4 MΩ = $0{\cdot}4 \times 10^6 \Omega$

Conductor radius, r1 = 20/2 = 10 mm

Internal sheath radius, r2 = 50/2 = 25 mm

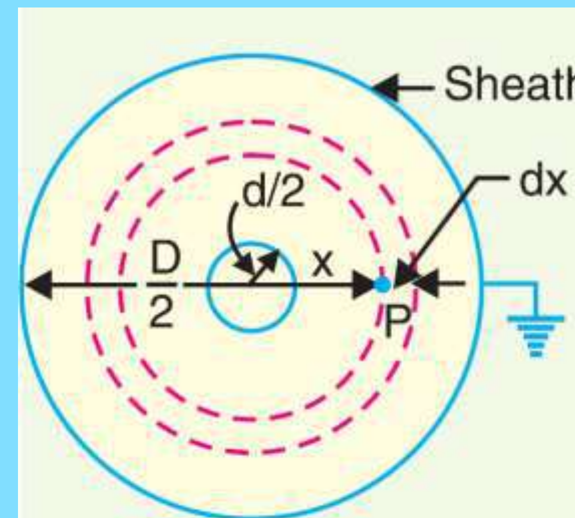
∴ Insulation resistance of the cables is

$$R = \frac{\rho}{2\pi l} \log_e \frac{r_2}{r_1}$$

$$0{\cdot}4 \times 10^6 = \frac{\rho}{2\pi \times 5000} \times \log_e \frac{25}{10}$$

Capacitance of a Single-Core Cable

- The conductor (or core) of the cable is the inner cylinder while the outer cylinder is represented by lead sheath which is at earth potential.
- Consider a single core cable



Let conductor diameter = *d*

inner sheath diameter = *D*

charge per metre axial length = *Q*

permittivity of the insulation material between core and lead sheath = ε, $\varepsilon = \varepsilon_o \varepsilon_r$

- Consider a cylinder of radius *x* metres and axial length 1 metre
- surface area of this cylinder is = $2\pi x * 1 = 2\pi x m^2$
- Electric flux density at any point *P*

$$D_x = \frac{Q}{2\pi x} \text{ C/m}^2$$

Electric intensity at point *P*, $E_x = \frac{D_x}{\varepsilon} = \frac{Q}{2\pi x \varepsilon} = \frac{Q}{2\pi x \varepsilon_0 \varepsilon_r}$ volts/m

- work done in moving a unit positive charge from conductor to sheath,

$$V = \int_{d/2}^{D/2} E_x \, dx = \int_{d/2}^{D/2} \frac{Q}{2\pi x \varepsilon_0 \varepsilon_r} dx = \frac{Q}{2\pi \varepsilon_0 \varepsilon_r} \log_e \frac{D}{d}$$

Capacitance of the cable is

$$C = \frac{Q}{V} = \frac{Q}{\frac{Q}{2\pi\,\varepsilon_0\varepsilon_r}\log_e\frac{D}{d}}\ \text{F/m}$$

$$= \frac{2\pi\,\varepsilon_o\varepsilon_r}{\log_e(D/d)}\ \text{F/m}$$

$$= \frac{2\pi\times 8\cdot 854\times 10^{-12}\times\varepsilon_r}{2\cdot 303\,\log_{10}(D/d)}\ \text{F/m}$$

$$= \frac{\varepsilon_r}{41\cdot 4\,\log_{10}(D/d)}\times 10^{-9}\ \text{F/m}$$

If the cable has a length of l metres, then capacitance of the cable is

$$C = \frac{\varepsilon_r\ l}{41\cdot 4\,\log_{10}\frac{D}{d}}\times 10^{-9}\ \text{F}$$

Unit - I

Load characteristics

The characteristics are drawn b/w load in W & time in hours is load characteristics. This curves provides a variation of load during the specified interval of time.

Here minimum capacity of generator such that it can meet maximum demand.

① Demand : Power required over a specified interval time is averaged. or

Average power required over a specified interval of time. It is given in watts, KW, KVA

② Demand interval

It is the period where load is averaged within the specified interval of time. It is obtained from load curves or daily demand curves. It is denoted as Δt.

③ Connected load

Sum of total continous rating of all equipments connected to the s/m.

④ Maximum demand

maximum load drawn by the s/m during the specified period of time. this can be daily, weekly, monthly or yearly. It is mainly used for billing purpose in india on monthly basis. Maximum demand is always less than the connected load

Maximum demand = load connected.

Demand factor (D_f)

Ratio of maximum demand to the total load connected to the s/m.

$$\text{Demand factor} = \frac{\text{Maximum load}}{\text{total connected load}}$$

It varies b/w 0.5 & 0.8

Coincident maximum demand (D_g)

Any demand that occurs simultaneously with any other demand & also the sum of any set of coincident demand. or highest electrical demand that occurs simultaneously across a group of consumers

Non coincident demand

The sum of demands of a group of loads with no restrictions on the interval to each demand is applicable. or Highest electrical demand of individual or group of consumers which may not occur at the same time.

Diversity factor (F_D)

It is the ratio of sum of individual maximum demand to the coincident maximum demand of all consumers

$$F_D = \frac{\text{sum of individual maximum demand}}{\text{coincident maximum demand}} = \frac{\sum_{i=1}^{n} D_i}{\sum D_g}$$

D_i = individual maximum demand

$$\boxed{D_g = C_f D_i}$$

D_g = coincident maximum demand

C_f = coincidence factor

Coincidence factor (C_f)

It is the ratio of coincident maximum demand of consumers group to the sum of individual maximum demand

It is the reciprocal of diversity factor (2)

Coincident factor (C_f) = $\frac{\text{coincident maximum demand}}{\text{sum of individual max. demand}}$

Load Diversity

The difference b/w the sum of peaks of 2 or more individual loads & the peak of combined loads.

Load Diversity = $\sum_i D_i - D_g$

D_i = individual maximum demand

D_g = Coincident factor. = maximum demand among the individual loads

Contribution factor C

This is a factor usually referred in distribution s/m regarding its weights & effect of particular load.

if $C_1, C_2, C_3 \dots C_n$ are Contribution factors of n individual loads.

$D_1, D_2, D_3 \dots D_n$: individual maximum demand

D_g = coincident maximum demand is taken as

$$D_g = C_1D_1 + C_2D_2 \dots C_nD_n = \sum_{i=1}^{n} C_iD_i =$$

$$\text{coincidance factor} = \frac{\sum_{i=1}^{n} C_iD_i}{\sum_{i=1}^{n} D_i} = \frac{\sum_{i=1}^{n} D_g}{\sum_{i=1}^{n} D_i}$$

Loss factor

It is ratio of average power loss to the peak load power loss during a specified period of time is known as 'loss factor'.

$$\text{Loss factor} = \frac{\text{Average power loss}}{\text{peak load power loss}}$$

This is considered only for copper loss.

Load factor

It is the ratio of average load demand to the peak load demand for a certain period time.

$$\text{Load factor} = \frac{\text{Average load demand}}{\text{Maximum load demand}}$$

$$= \frac{\text{Energy generated in a given period}}{\text{Maximum demand} * \text{No. of hours operating in given period}}$$

Load factor is always less than unity.

$$\text{Annual load factor} = \frac{\text{Total annual energy}}{\text{Anual peak load} * 8760}$$

1 day * 365

24 * 365 = 8760 hrs.

Utilisation factor (Fu)

Ratio of maximum demand of a s/m to the rated s/m capacity. It is denoted as Fu

$$F_u = \frac{\text{Maximum demand}}{\text{rated s/m capacity}}$$

(3)

Plant factor

Also known as Capacity factor.

It is the ratio of total actual energy produced during a specified time to the energy produced by the plant when operating at maximum rating.

$$\text{Plant factor} = \frac{\text{actual energy produced} * T}{\text{maximum rating of plant} * T}$$

$$\text{Annual plant factor} = \frac{\text{actual energy produced annually}}{\text{maximum plant rating}}$$

(or)

$$= \frac{\text{actual annual energy produced}}{\text{maximum plant rating} * 8760}$$

Problems

Load Curve

This curve represents the variations in load with respect to time. Also called as daily load curve or monthly load curve. The load curve is not similar in all days.

Daily load curves following information

1. Area under the curves gives actual units generated during the period
2. The maximum peak value in curve gives maximum demand
3. Area under the curve divided by number of hours gives average demand

Course Objectives:

- To inculcate the basic knowledge of microeconomics and ...
- To make the students learn how ...

(4) This curve helps in deciding & selecting the number of generating units

(5) Average load = $\frac{\text{Energy generated during period}}{\text{Time in hours (24 hr)}}$

Energy is represented as kWh

(6) Load factor = $\frac{\text{average load}}{\text{maximum demand}}$

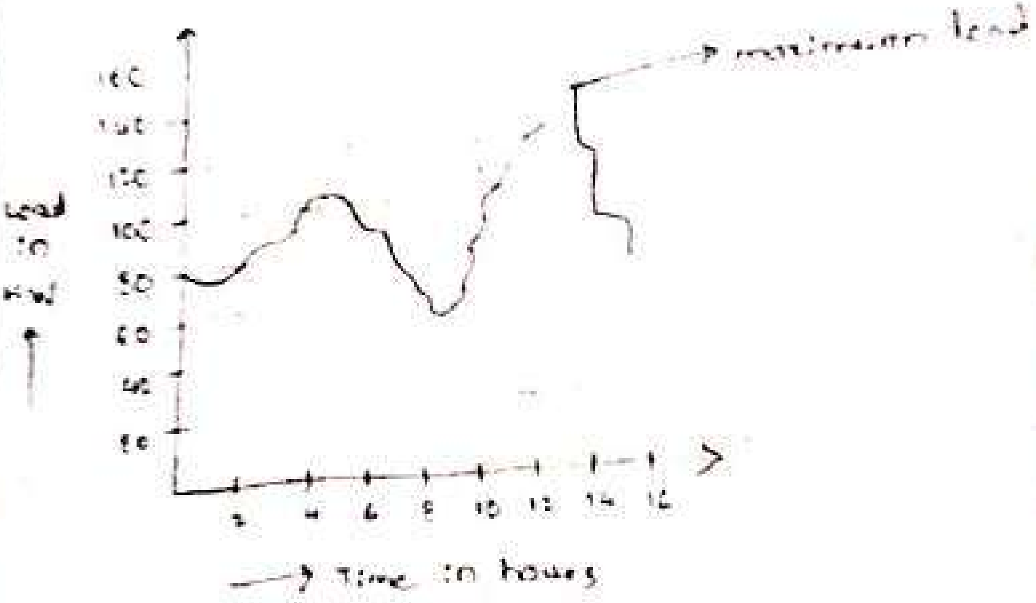


figure shows load curve

<u>Load duration Curve</u>

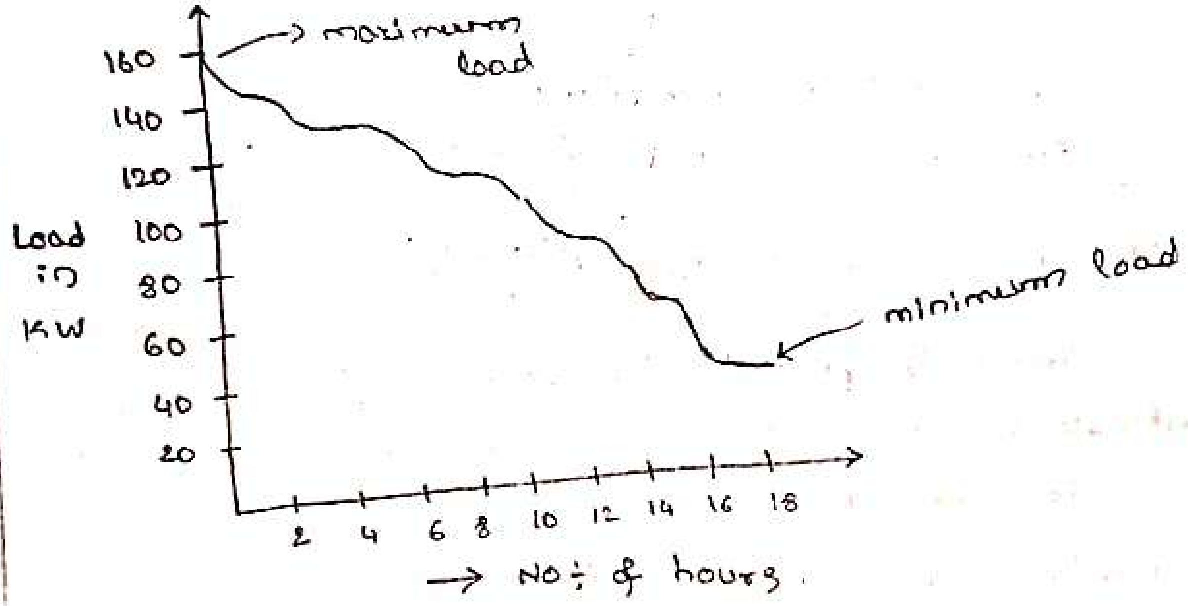
If load elements of a load curve are arranged in descending order magnitudes then curve obtained is called as load duration curve

The curve is plotted load demand with time

Ordinates (Y-axis) of load duration Curve are arranged in descending order magnitude.

Here maximum load is taken on left & lesser load demand is taken at a right side.

The abscissa (X-axis) gives the number of hours for which a particular load.



Integrated load duration Curve (Energy-load Curve)

This Curves gives information about total number of units generated for the given demand.

In ordinate (Y-axis) represents the demand in KW & the abscissa (X-axis) represents energy generated in KW-h.

Integrated load duration Curve starting from zero load to maximum load.

If energy & load are plotted in terms of percentage than it Called as Peak percentage Curve

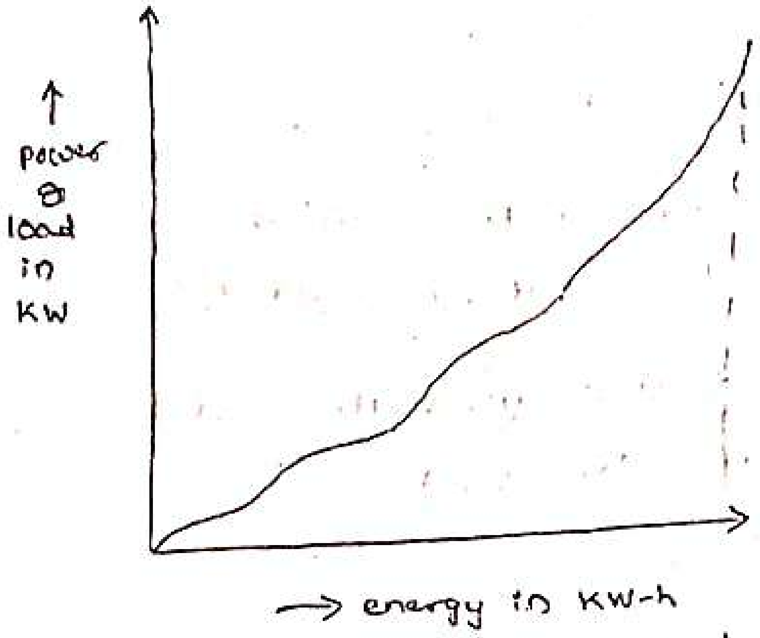


fig shows integrated load duration curve.

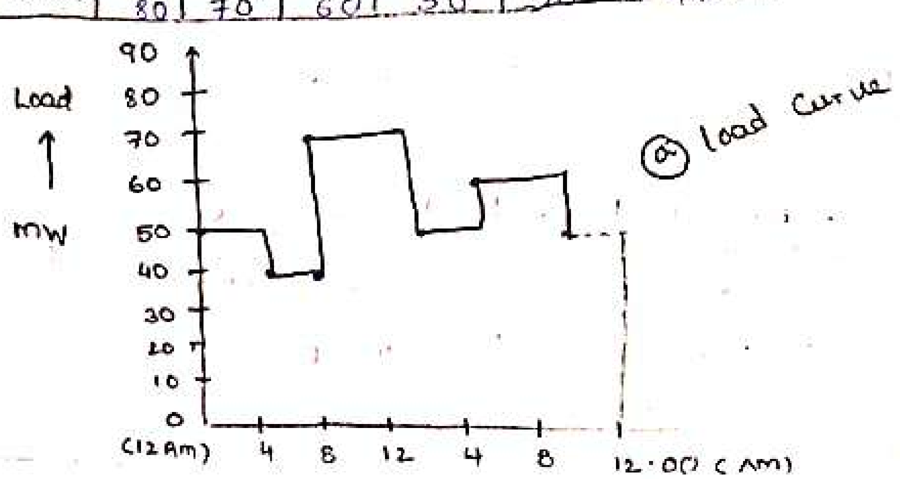
Mass Curve (Energy - Time Curve)

Curve is plotted b/w energy in KW-h as ordinate (y-axis) & time as in abscissa (x-axis)

It gives total energy consumed by load at a particular time in a day.

Example for Constructing load duration Curve

Time	AM			PM		
HOURS	12-6	6-8	8-12	2-6	6-9	9-12
Load MW	50 80	40 70	70 60	50 50	60 50	80 40



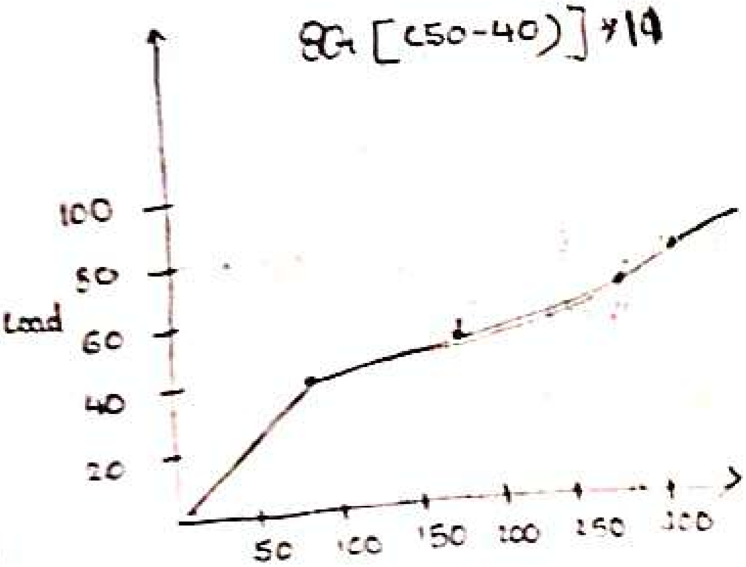
integrating load duration Curve

Load mw	0	40	50	60	70	80
Period in hrs	0	2	11	4	4	3
Energy in mw-h	0	? 40*2 80W	? 80+(50-40) *11=190	? 230	? 270	? 300

we know that energy = Power * time

Load	40	50		
0	40*2 80W	(50-40) = 10 (80+10)*11 190	190+[(60-40)*4] 230	230+[(70- ... = 270
0				

80+[(50-40)]*11



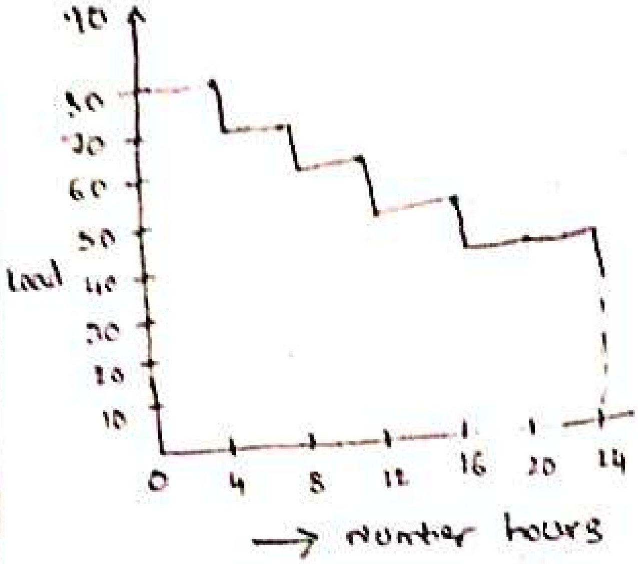
→ energy in kw-h

Y-axis Load mw	X-axis Energy mw-h
40	80
50	190
60	230
70	270
80	300

$$E = PE_{in\ wh} + [(PP - PreP) * time]$$

mass - Curve

Time		A.m			P.m			
Hours	0	6hrs 12-6	2hrs 6-8	4hrs 8-12	2hr 12-2	4hr 2-6	3hr 6-9	3hr 9-12
Load mw	50	50	40	70	50	60	50	50
Energy generated in mw-h	0	? 300	? 380	? 660	? 760	? 1000	? 1240	? 1390



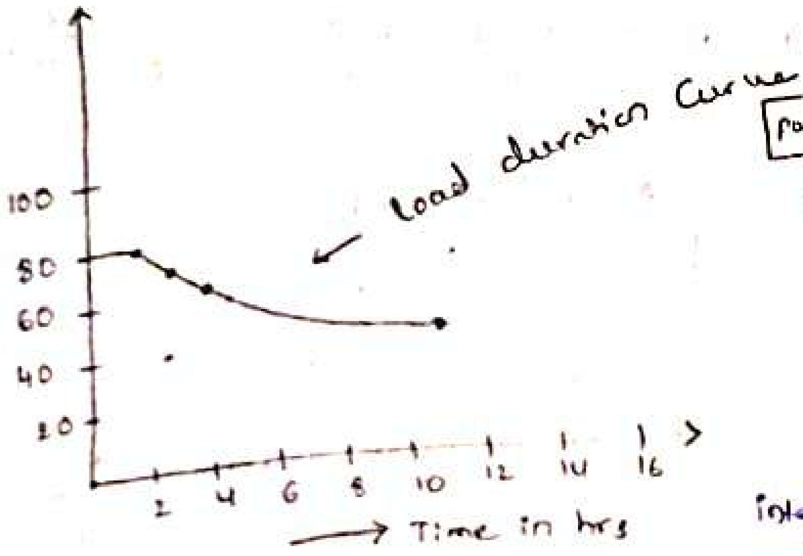
load duration Curve

Example for integrated load duration Curve

Load mw		40	50	60	70	80
Period in hrs		2	11	4	4	3
Total period in hrs		24	22	11	7	3

From load Curve 40mw for 2 hrs, 50mw for 11 hrs 60mw for 4 hrs, 70mw for 4hrs, 80mw for 3 hrs.

Load duration Curve Can be plotted as descending loads



period	load hrs
2	80
3	70
4	60
4	50
11	40

integration load duration Curve

Energy in wh = (Previous Energy demand in wh) + [(Present load in w - previous load demand in w) * no: of hrs]

⑥

A.M

For 6hrs load is 50mw (12-6)

Energy = 6*50 = 300 mw-h

For 2 hrs load is 40 mw (6-8)

300+(40*2) = 380 mw-h (8-12)

For 4 hrs load is 70mw (8-12)

energy => 380+(70*4) = 660 mw-h

P.M

For 2hrs load is 50mw (12-2)

660+(50*2) = 760 mwh

For 4hrs load is 60w (2-6)

energy = 760+(60*4)

= 1000 mw-h

For 3hrs load is 80mw (6-9)

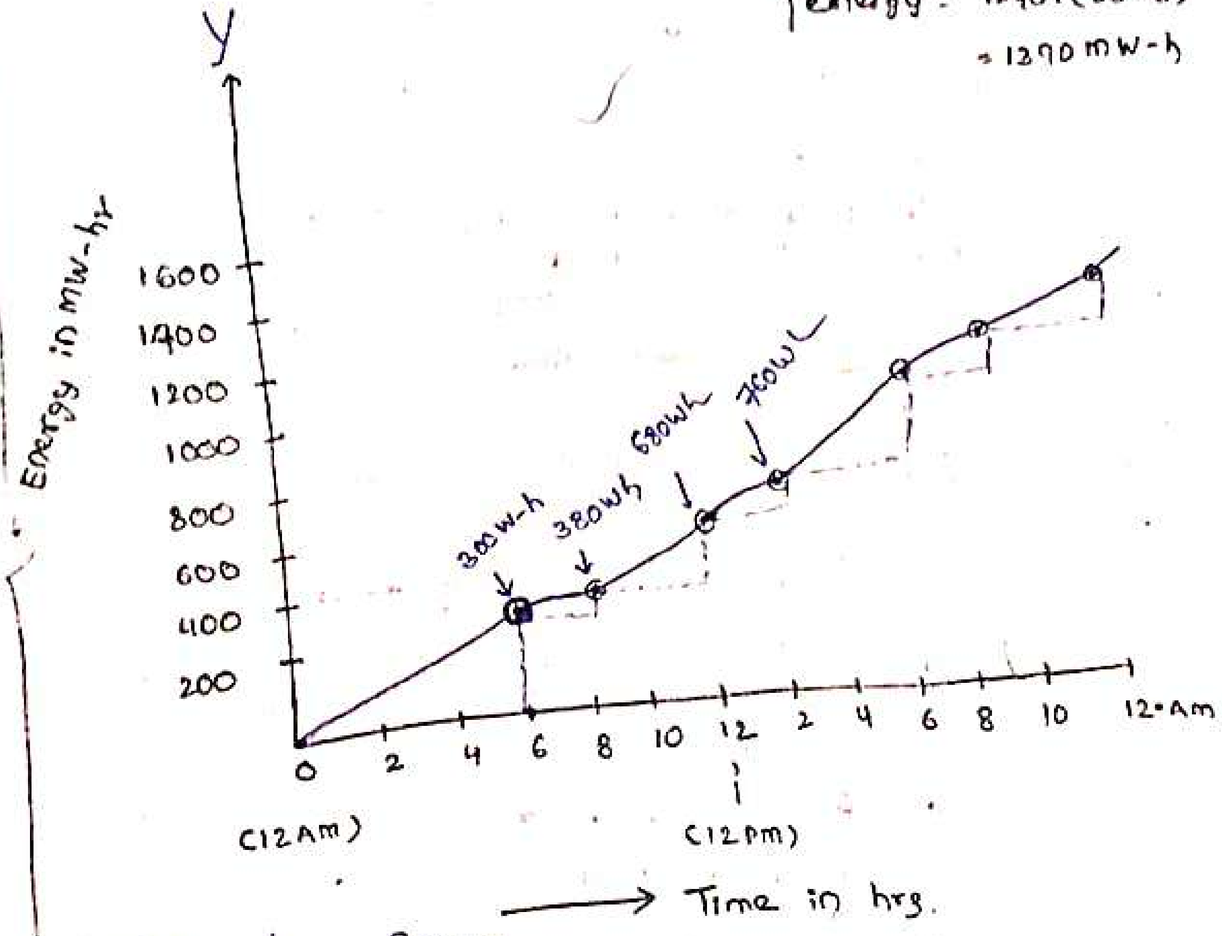
energy = 1000+(80*3)

= 1240 mw-h

For 3hr load is 50mw (9-12)

energy = 1240+(50*3)

= 1390 mw-h

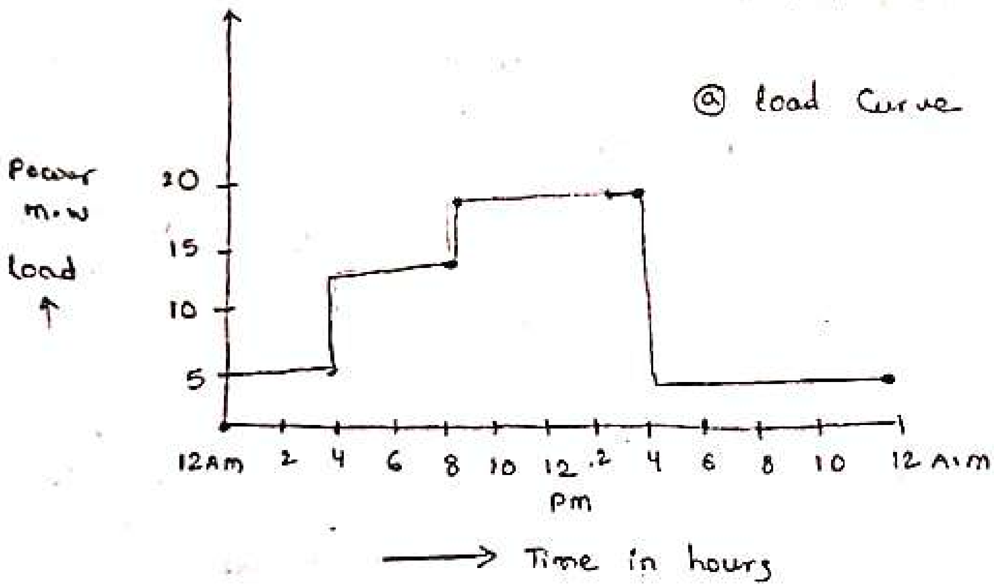


	Time x-axis	Energy y-axis
am	12-6	300 MW-h
	6-8	380 MW-h
	8-12 PM	660 MW-h
PM	12-2	760 MW-h
	2-6	1000 MW-h
	6-9	1240 MW-h
	9-12 am	1390 MW-h

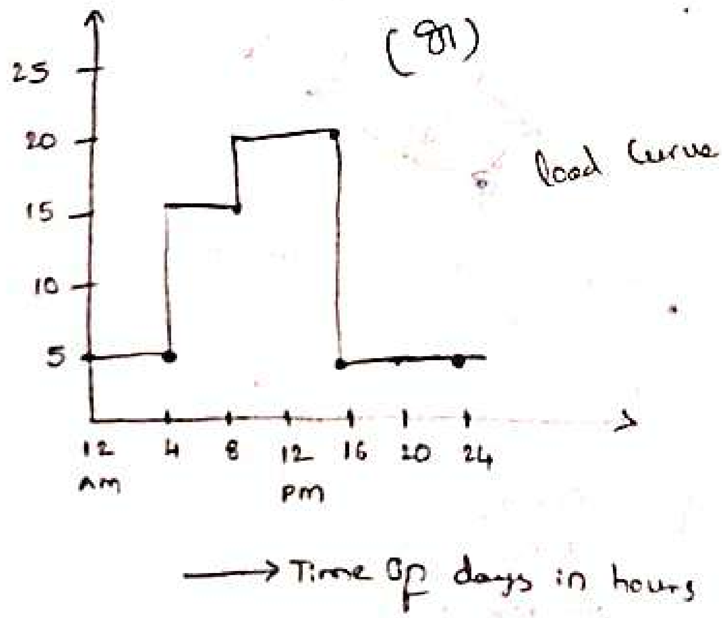
Example ②

Time in hrs	12 AM - 4 AM	4AM - 8 AM	8 AM - 4PM	4PM - 12 AM
Load MW	5	15	20	5
	20	15	5	5

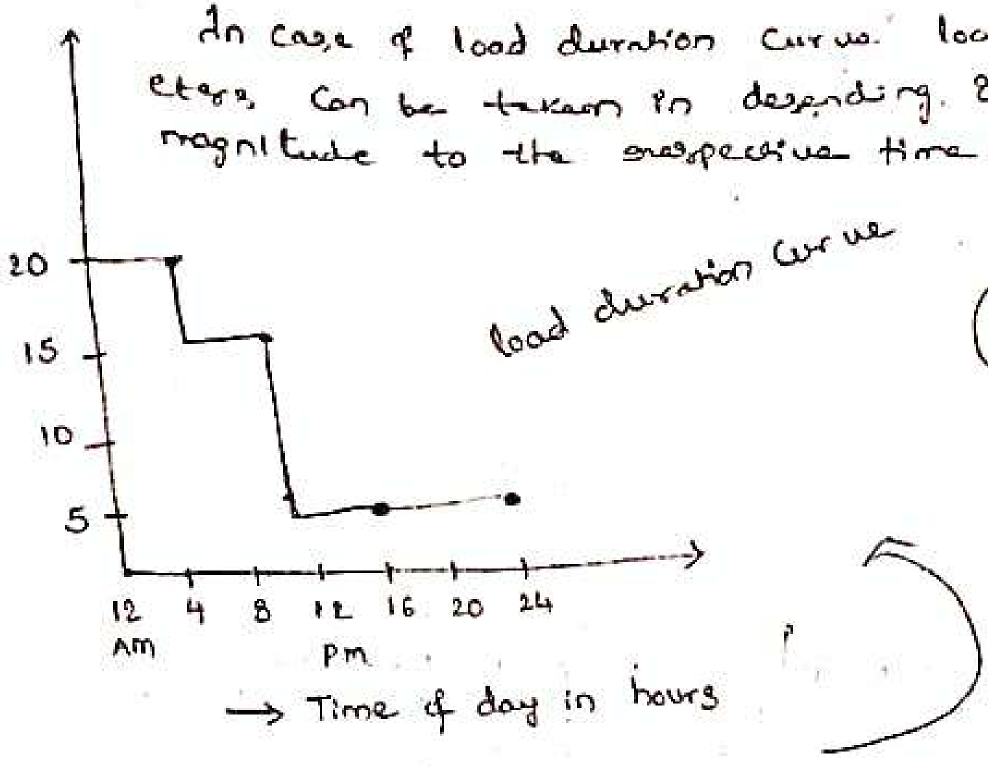
Plote ⓐ Load curve ⓑ load duration Curve



(or)



In case of load duration curve load parameters can be taken in descending order magnitude to the respective time periods



7

Time in hrs	12AM - 4AM	4AM - 8AM	8AM - 16 or 8AM - 4PM	16 - 24 or 4PM - 12 AM
load in descending order	20	15	5	5

Example Residential consumer has connected 10 lamps each of 100watts. His demand as

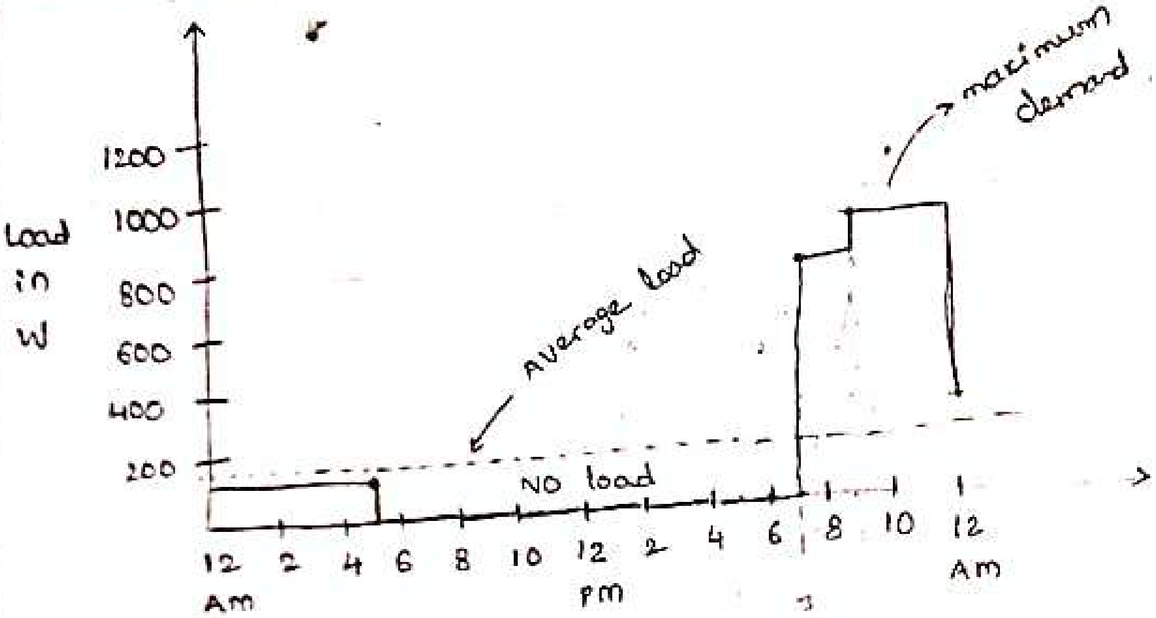
Time	12 A.M - 5AM	5AM - 6PM	6PM - 7PM	7PM - 9PM	9PM - 12AM
Load in W	100W	No load 0W	800W	900	400W

(a) Plot load curve

(b) Determine demand factor, average demand, maximum demand & load factor

• To inculcate the basic knowledge of microeconomics

ⓐ load Curve



ⓑ Energy Consumption during 24 hours

			Energy Consumption
12AM - 5am		= 100W	(5*100) = 500Wh
5am - 6PM	= 13hrs	= 0W	= 0*13 = 0Wh
6PM - 7PM :	1 hr	= 800W	= 800*1 = 800 Wh
7PM - 9PM =	2 hr	= 900 W	= 900*2 = 1800Wh
9PM - 12 AM :	3 hr	= 400 W	= 400*3 = 1200 Wh

Total energy consumption during 24 hrs

= 500 + 0 + 800 + 1800 + 1200 = 43,00Wh

From data maximum demand is 900W occurs at a time 7PM - 9PM.

Maximum demand = 900W

Total Connected load = 10*100 = 1000W

① Demand factor = $\frac{\text{Maximum demand}}{\text{total Connected load}} = \frac{900}{1000} = 0.9$

= 90%.

Average demand = $\frac{\text{Energy Consumed in 24 hrs.}}{24 \text{ hrs}}$ (8)

$= \frac{4300}{24} = 179 W$

load factor : $\frac{\text{Average demand}}{\text{maximum demand}} = \frac{179}{900} = 0.199$

Example (2) A power station has following power demand

Group	Time	Demand
(A)	8AM - 6PM	200 KW
(B)	6AM - 10am	100 KW
(C)	6AM - 10AM	50 KW
(D)	10AM - 12AM	100 KW
		12 AM - 6AM

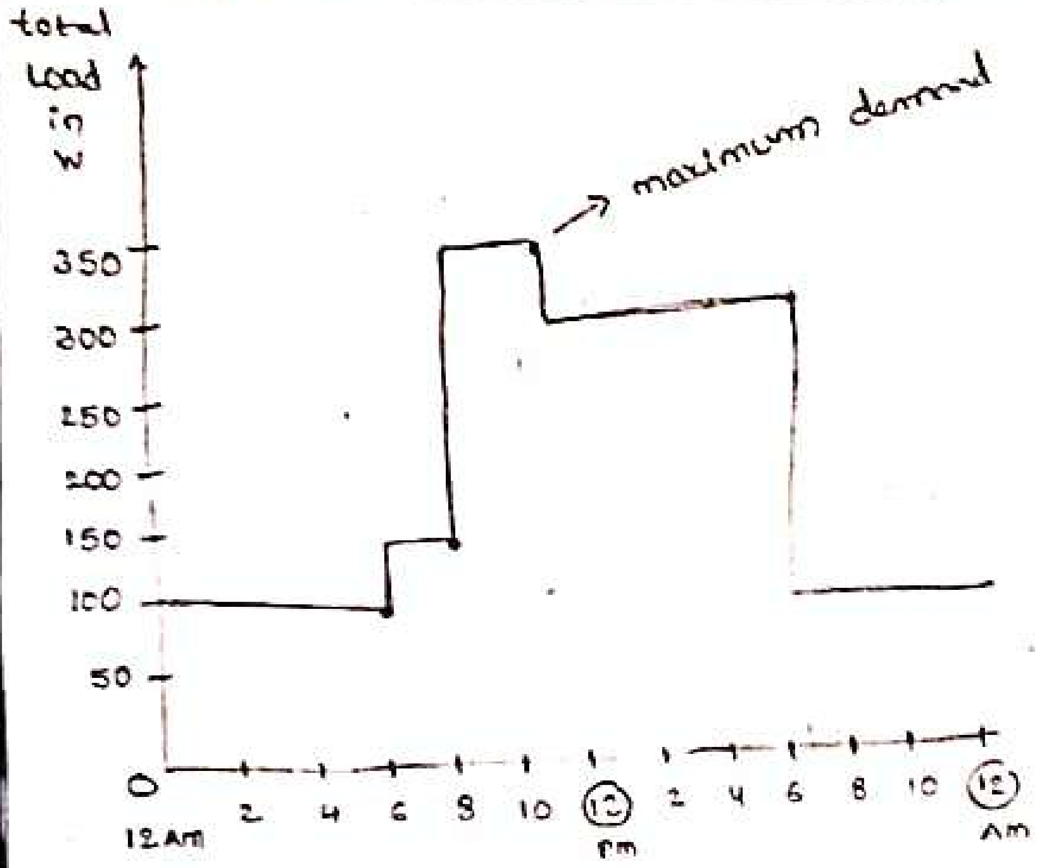
Rough:
0 12AM
6 AM
8 AM
10 AM
18 → 6PM
24 → 12 AM

(a) plot daily load curve (b) Diversity factor, units generated per day and load factor

Sol

Load demand in kW

Time (hrs)	(0 - 6am) 12am - 6am	(6am - 8am)	(8am - 10AM)	(10AM - 18) 10Am - 6pm	18 - 24 6pm - 12 Am
			200	200	
Group A		100	100		
Group B		50	50		
Group C				100	100
Group D	100				
Total load on Station	100	150	350	300	100



sum of individual load demand

$= 200+100+50+100 = 450\ KW$

(i) Diversity factor $= \dfrac{\text{sum of individual load demand}}{\text{maximum demand}}$

$= \dfrac{450\ KW}{350\ KW} = 1.286$

(ii) No. of units generated per day

= Area (in kWh) under load curve

$= (100*6)+(150*2)+(350*2)+(300*8)+(100*6)$

$= 4{,}600\ KW\text{-}h$

(iii) Average load $= \dfrac{\text{energy or no. of units generated}}{24\ hrs}$

$= \dfrac{4{,}600}{24} = 191.7\ KW$

Load factor $= \dfrac{\text{Average load demand}}{\text{maximum demand}} = \dfrac{191.7}{350} = 0.545$

Example

(7)

Annual peak load on primary feeder is 2000 kW. Power loss or total Cu loss is 80 kW for 3 phases. assume annual loss factor 0.15. Determine

(a) Average annual power loss (b) total annual energy loss due to Copper loss

Sol

Average power loss = Power loss at feeder * annual loss factor

= 80 * 1000 * 0.15 = 12 KW

(b) Total annual energy loss = average power loss * No. of hours in a year

= 12 * 1000 * 8760 = 105,120 kWh

(8) 6 Consumer Connected to transformer. Assume load is 9 kW per house & diversity factor for group of six houses have 0.65 & 1.10 respectively. Determine diversified demand of six houses.

Sol

$$\text{Diversity factor} = \frac{\left(\begin{array}{c}\text{Total connect load}\\ \text{in a group } i\end{array}\right) * \left(\begin{array}{c}\text{Demand factor}\\ \text{of group } i\end{array}\right)}{\text{sum of maximum demand of group } i}$$

$$F_D = \frac{\sum_{i=1}^{n} (TCD_i) * (DF_i)}{D_g}$$

D_g = diversified demand of six houses

$$D_g = \frac{\left(\sum_{i=1}^{6} 9KW\right)(0.65)}{1.1}$$

DF : demand factor

F_D : diversity factor

$$= \frac{6 \times 9KW \times 0.65}{1.1} = 31.9\ KW$$

Example assume there are 2 feeders by one of 3 t/formers located at distribution substation.

one feeder supplies industrial load primarly occurs b/w 8AM & 11PM, with peak load 2000KW at 5PM.

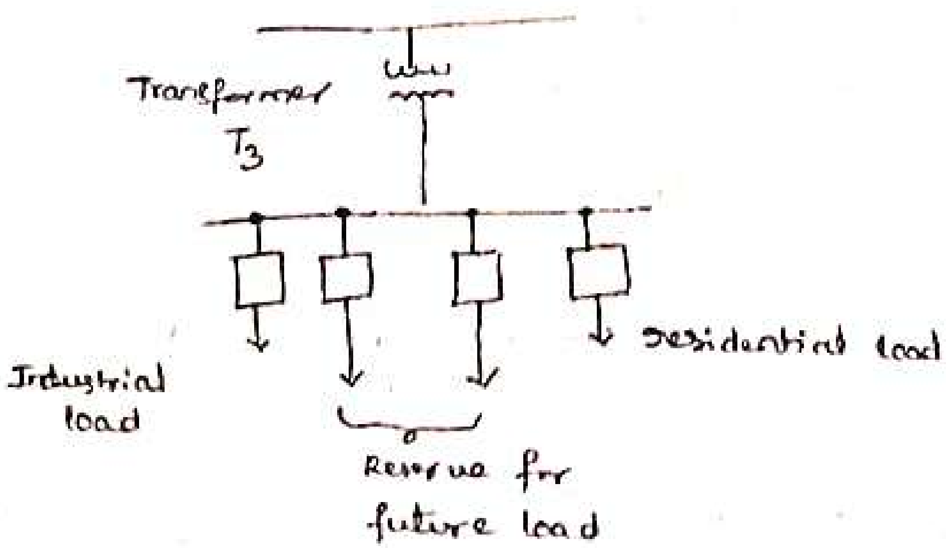
Another feeder supplies residential load occurs b/w 6AM & 12PM with peak load 3000KW at 9PM

Determine

(a) Diversity factor (F_D) Connected to T/f (3)

(b) Load diversity (LD) of load Connected to T/f (3)

(c) Coincidence factor of load Connected to T/f (3)



(a) Diversity factor F_D = $\frac{\text{Sum of individual demand}}{\text{Coincident maximum demand}}$

$$F_D = \sum_{i=1}^{n} D_i \Big/ D_g$$

$$F_D = \frac{2000+2000}{3000} = 1.333$$

(ii) load diversity

$$LD = \sum_{i=1}^{n} D_i - D_g$$

$$= 5000 - 3000 = 2000 \text{ KW}$$

(iii) Coincidence factor

$$F_c = \frac{1}{F_D} = \frac{\text{Coincident max. demand}}{\text{sum of individual demand}}$$

$$F_c = \frac{1}{1.33} = 0.752$$

Example

Time	Street lighting	Residential	Commercial	Total
12 A.m	100	200	200	500
1	100	200	200	500
2	100	200	200	500
3	100	200	200	500
4	100	200	200	500
5	100	200	200	500
6	100	200	200	500
7	100	300	200	600
8		400	300	700
9		500	500	1000
10		500	1000	1500
11		500	1000	1500
12 p.m		500	1000	1500
1		500	1200	1700
2		500	1200	1700
3		500	1200	1700
4		500	1200	1500
5	0 (Maximum demand)	600	1200	1500
		700	800	1600
6	100	800	400	1300
7	100	1000	1100	1500
8	100	1000	400	1500
9	100	900	700	1100
10	100	600	300	900
11	100	300	200	600
12	100			

from above load data for given period is shown table.

From this table maximum load demand occurs at 5pm are 1800 W. Determine the following

(a) Class contribution factor for each of 3 loads
(b) Diversity factor for the primary feeder
(c) Diversified maximum demand of the load group
(d) Coincidence factor of load group.

sol class contribution

coincidence factor C_i = coincident maximum demand / sum individual load demand

$$C_i = \frac{\sum_{i=1}^{n} D_g}{\sum_{i=1}^{n} D_i} = \frac{\sum_{i=1}^{n} C_i D_i}{\sum_{i=1}^{n} D_i}$$

we know that $D_g = C_i * D_i$

we know that maximum demand mainly occurs at 5pm

$$C_1 \quad C_{street} = \frac{0}{\text{individual maximum demand}} = \frac{0}{100} = 0$$

$$C_2 = C_{residential} = \frac{\text{Maximum demand at 5pm}}{\text{individual maximum demand}} = \frac{600}{1000} = 0.6$$

$$C_3 = C_{commercial} = \frac{\text{maximum demand at 5pm}}{\text{individual max: demand}} = \frac{1200}{1200} = 1$$

(ii) Diversity factor $F_D = \frac{\sum_{i=1}^{n} D_i}{\sum_{i=1}^{n} D_g} = \frac{\sum_{i=1}^{3} D_i}{\sum_{i=1}^{3} C_i D_i}$

$C_i D_i = C_1 D_1 + C_2 D_2 + C_3$

$= (0 \times 100) + (0.6 \times 1000) + (1.0 \times 1200)$

$$F_D = \frac{100 + 1000 + 1200}{(0 \times 100) + (0.6 \times 1000) + (1.0 \times 1200)} = 1.278$$

(c) Diversified maximum demand

Diversity factor $F_D = \dfrac{\sum_{i=1}^{n} D_i}{D_g}$

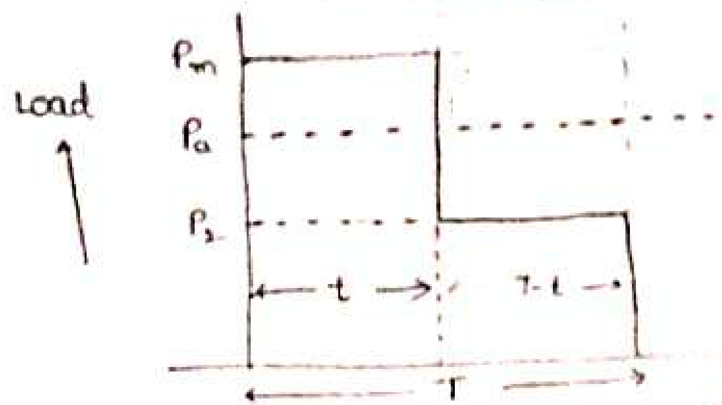
$D_g \rightarrow$ maximum diversified demand $= \dfrac{\sum_{i=1}^{n} D_i}{F_D}$

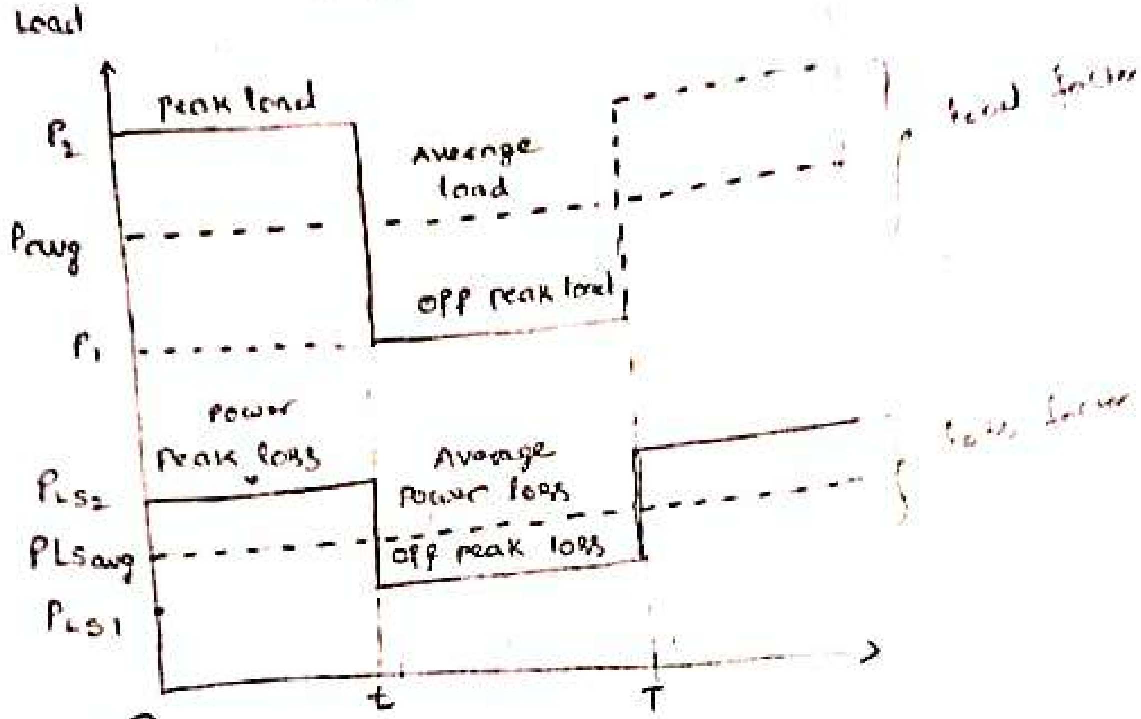
$$D_g = \frac{100 + 1000 + 1200}{1.278} = 1800\,KW$$

(d) coincidence factor $C_f = \dfrac{1}{F_D} = \dfrac{1}{1.278} = 0.7825$

Relationship b/w load & loss factor

load demand Continuously changes for any type of load on any feeder can be idealised by using idealised load pattern curve





fig① shows arbitrary & idealised load curve

Fig① does not represent daily load curve. Assume off peak loss is P_{LS1} at some off peak load P_1. similarly peak loss is P_{LS2} at peak load P_2.

Load factor $F_{LD} = \dfrac{\text{average demand of power}}{\text{maximum demand of power}} = \dfrac{P_{av}}{P_{max}}$

$$F_{LD} = \frac{P_{av}}{P_{max}} = \frac{P_{av}}{P_2} \rightarrow ①$$

$$P_{av} = \frac{P_2(t-0) + P_1(T-t)}{T} \rightarrow ②$$

$$F_{LD} = \frac{P_2 * t + P_1(T-t)}{T P_2} \Rightarrow \frac{t}{T} + \frac{P_1}{P_2} * \frac{(T-t)}{T} \rightarrow ③$$

loss factor $\rightarrow F_{LS} = \dfrac{P_{LSav}}{P_{LSmax}} = \dfrac{P_{LSav}}{P_{LS2}} \rightarrow ④$

$$\left(\frac{P_1}{P_2}\right)\times\left(\frac{T-t}{t}\right) = \left(\frac{P_1}{P_2}\right)^2\times\left(\frac{T-t}{t}\right)$$

$$\frac{P_1}{P_2} = \left(\frac{P_1}{P_2}\right)^2$$

$$F_{LS} = (F_{LD})^2$$

loss factor is square of the load factor

Case ③ Load steady

Here $t \rightarrow T$

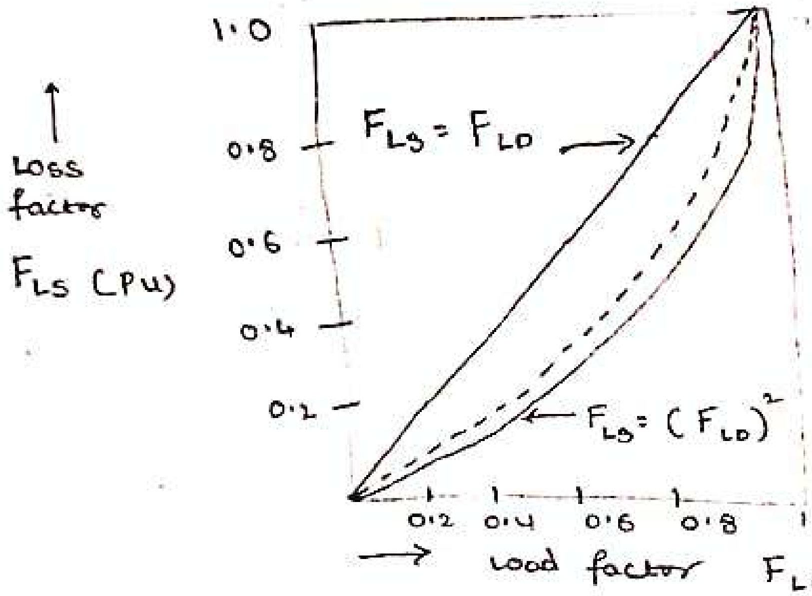
$$F_{LS} = F_{LD} = 1$$

Loss factor approaches the value of load factor. Loss factor is determined from the losses as a function of time.

$$(F_{LD})^2 < F_{LS} < F_{LD}$$

— x — x — x — x — x — x —

Approximate formula is developed by Buller & Woodrow then loss factor related to load factor is



where $P_{LS\,av}$ is average power loss, $P_{LS\,max}$ is maximum power loss, $P_{LS2} \rightarrow$ peak power loss at peak load

(12)

$$P_{LS\,av} = \frac{P_{LS2} * t + P_{LS1}(T-t)}{T * P_{LS2}} \rightarrow (5)$$

$$F_{LS} = \frac{P_{LS2} * t + P_{LS1}(T-t)}{T * P_{LS2}} \rightarrow (6)$$

where P_{LS1} = off peak loss at off peak load of P_1

t = peak load duration from 0 - t

$T-t$ = off peak load duration

$\therefore P_{LS1} = K * P_1^2$, $P_{LS2} = K * P_2^2 \rightarrow (8)$

↳ (7)

substitute 7 & 8 in equation (6)

$$F_{LS} = \frac{(K * P_2^2) * t + (K * P_1^2) * (T-t)}{(K * P_2^2) * T} \rightarrow (9)$$

$$F_{LS} = \frac{t}{T} + \left(\frac{P_1}{P_2}\right)^2 * \frac{T-t}{T} \rightarrow (10)$$

Case (1) off peak load is zero

off peak load P_1 is zero , off peak loss $P_{LS1} = 0$

$F_{LD} = F_{LS} = \frac{t}{T}$ Load factor = Loss factor = $\frac{t}{T}$

Case (11) very short lasting peak

$t \rightarrow 0$ equation (3) & equation 10

$F_{LD} = F_{LS}$

for urban area loss factor

$$F_{LS} = 0.3 F_{LD} + 0.7 (F_{LD})^2$$

for rural areas loss factor:

$$F_{LS} = 0.16 F_{LD} + 0.84 (F_{LD})^2$$

Example

annual peak load = 3500 KW, total annual energy supplied by feeder = 10,000,000 kWh. Peak demand occurs in july or August due to air conditioners loads. Find (a) Annual average Power demand
(b) annual load factor.

sol

(a) Annual average Power = $\frac{\text{Total annual energy}}{\text{Year in hours}}$

$$\text{Annual } P_{avg} = \frac{1 * 10^7}{8760} = 1141 \text{ KW}$$

(b) Annual load factor =

$$F_{LD} = \frac{\text{Annual average}}{\text{annual maximum or Peak load}} = \frac{1141}{3500}$$

$$F_{LD} = 0.326$$

or

Annual load factor

$$\text{Annual } F_{LD} = \frac{\text{Total annual energy supplied}}{\text{Annual Peak load} * \text{Years in hrs}}$$

$$= \frac{10^7}{3500 * 8760} = 0.326$$

Example annual peak i/p to feeder is 2000 kW. voltage drop and I^2R losses where total copper loss at a time of peak load $\sum I^2R$ = 100 kW. Total annual energy supplied to sending end of feeder 5.6 * 10^6 kWh

(a) Determine annual loss factor

(b) Calculate total annual copper loss & its value 2.00/kWh

Sol annual power loss $F_{LS} = 0.3 F_{LD} + 0.7 (F_{LD})^2$

$$F_{LD} = \frac{\text{Total annual energy}}{\text{annual peak power} * \text{year, in hrs}}$$

$$= \frac{5.6 * 10^6}{2000 * 8760} = 0.32$$

annual Power loss $F_{LS} = (0.3)(0.32) + 0.7(0.32)^2$

$= 0.1667$.

(b) Loss factor = $\frac{\text{Average Power loss}}{\text{Peak load power loss}}$

Average Power loss = loss factor * Peak load power loss

= 0.1667 * 100 = 16.77 kW .

Total annual Copper loss = Average Power loss * year in hrs

= 16.77 * 8760 = 1,46,905 kWh

cost of total annual Copper loss = 1,46,905 * 2.00

= 2,93,810 Rs

Load modelling

(14) ③

Generally the loads in the electrical s/m are classified as ① Industrial & commercial loads which have 2 peak load period (2) agricultural loads have seasonal loads ③ Residential like lighting loads are constant loads.

As per the classification of loads load modelling can be performed. Load modelling depends on 2 important factor ⓐ static application which is a voltage dependent load (b) voltage & frequency dependent load.

Static load modelling generally modelled in substations by load versus duration. The 2nd factor is evaluated using load window.

Incandescent light	Tube lights, CFL, LED	room AC's	Heater	fridge washing machine	TV others

Table shows load window for distribution s/m

Construction of load winding

Based on the available load data a load window can be constructed. It requires
① among all what is the maximum load
(2) Duration of maximum load demand of all components
(3) diversity (4) % of load among all the total load percentage (5) operating at which full load, a part etc

In case of frequency dependent loads apparent power is splitted into 2 components S = P & Q
P → active power, Q = reactive power

$P = P(V)\left[1 + D_p \Delta f\right]$ ↳ ① $Q = Q(V)\left[1 + D_Q \Delta f\right]$ ↳ ②

P(V), Q(V) depends on voltage in distribution s/m
Δf is change in frequency, D_P, D_Q are factors that correct loads during frequency variation.

Load models for 3 phase, 3 wire and 4 wire s/m

loads in distribution network are

① 3 phase loads connected b/w 3 lines
② 1-phase loads connected b/w phase & neutral wire
these is an unbalanced one
③ Other loads such as combination loads

modelling is done to take as

① constant current, impedance & constant power loads.
(2) In constant power loads both real & reactive power is taken as constant
(3) In load flow analysis constant power per phase either phase to neutral, line to line voltage is defined for computation.

Classification of loads

load requirement mainly depends on area, population, living standards, etc. Loads are not all constant one. There are of different types. Generally loads are classified as

(a) Domestic loads: Fans, mixies, heaters, lighting s/ms, refridegrators, AC, small motors etc.
Demand factor = 70 - 100%.
diversity factor = 1.2 - 1.3, load factor = 10 - 15%.

(b) Commericial loads: Decorative lights, fans, AC, heating s/ms, elevators etc used in shops, restaurants, shopping malls etc
Demand factor = 90 - 100%, diversity factor = 1.1 - 1.2
load factor = 25 - 30%.

(c) Industrial load: These are classified as low, medium, heavy & Extreme industrial loads. above 5KW power consumption are come under industrial loads. The loads on s/m is constant throughout a day.

(d) Municipal loads: The loads are mainly street lighting & practically constant throughout the night. Demand factor is 100%. Diversity factor is taken as 1. Also some amount of load used in water supply.

(e) Agricultural loads: These are seasonal loads used for supplying water to crops. Induction motors are major part as loads. load factor 20 - 25%, diversity factor 1 - 1.5, demand factor is 90 - 100%.

characteristics of loads

(a) Nature of load: It is characterised by the demand factor, load factor, diversity factor, utilisation factor & power factor

System power factor Except synchronous motors, most of the loads are operating at lagging power factor. Induction motors widely used in industries constitute a major load. Overall power factor is lagging in nature i.e. below 0.7. So P.f must be improve

ⓒ System load diversity

It is very important to plan for peak demand power during some seasonal condition like winter & summer. It is desirable to evaluate diversity of load to get the better load management.

ⓓ Feeder load characteristics

The load composition is known by the type of feeder. Categories like domestic, commercial, industrial, agricultural etc are expressed as percentage of total load. Each category of load may be a function of time, voltage, frequency etc.

ⓔ System load

Electric load itself changes as function of consumers. As the number of consumers in a group is increased, the system peak of each consumer is decreased.

system power factor except synchronous ~~machine~~ motors, most of the loads are operating at lagging power factor. Ind... the loads are operating at lagging power factor. Induction motors, widely used in industries, constitute a major load. Overall power factor is lagging in nature i.e. below 0.7. So p.f must be improve

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Problems

load	Max: demand	load factor	Diversity of group
Residential	1000 kw	20 %	1.2
Commercial	2000 kw	25 %	1.1
industrial	10,000 kw	80 %	1.25

overall s/m diversity factor = 1.3

find ① Maximum demand ② Daily energy Consumption
iii) Load factor

sol sum of all loads maximum demand = 1000 + 2000 + 10,000 = 13000 kw

① Diversity factor = $\frac{\text{sum of all loads maximum demand}}{\text{maximum demand}}$

maximum demand = $\frac{13000}{1.3}$ = 10,000 kw

(ii) load factor = $\frac{\text{Average load}}{\text{maximum demand}}$

Average load = (load factor) * maximum demand

Average Residential load : 0.2 * 1000 = 200 kw
Average Commercial load : 0.25 * 2000 = 500 kw
" industrial load : 0.8 * 10,000 = 8000 kw

Average of all Types of load = 200 + 500 + 8000 = 8700

ii) Daily energy Consumption = (Average of Total load) * 24 hrs

= 8700 * 24 = 2,08,800 kwh

iii) Load factor = $\frac{\text{Average maximum load}}{\text{maximum demand}}$ = $\frac{8000}{10,000}$ = 0.8 %

Tarrif

the Consumers Can afford the use of electrical energy if it is available at reasonable cost.

Tarrif is defined as rate at which the electrical energy is supplied not only recovers total cost of producing electrical energy but also earns profit.

Cost of producing electrical energy depends on magnitude & type of load used. This tariff

objectives of tariff

It must recovers not only the returns but also earns profit. A tarrif must include the following terms

① Recovers cost of producing electrical energy

② Recovers the Investment on transmission & distribution

③ Recovers the cost of operation & maintenance through billing.

characteristics of tarrif

① proper return: total returns from Consumers must be equal to cost of producing & supplying electrical energy plus profit earning.

(ii) fairness : Rate at which energy supplied must be satisfied for different types of consumers. Even a big consumer should be charged at lowest rate like a small consumer.

(iii) simplicity : A tarrif should be simple & it must be understandable to normal consumer.

(iv) Reasonable profit : Electric supply company is a public utility company. Here profit is to restricted to 8% per annum.

(v) Attractive : Tarrif should be fair & attractive so that more number of consumers utilizes the electrical supply.

Cost of generation :

Total cost of producing electrical energy including cost of equippment, fuel, operation & maintenance.

Cost of generation also includes

* Capital costs : includes cost of equippment, land, grid connection, initial investment

* fuel cost : Cost of fuel required for power generation like fossil fuel say coal, gas, diesel or nuclear fuel.

operation & maintenance cost

It includes labour, cost of materials, insurance, rent etc.

Depreciation: Aging of equipment over the usage time.

* Taxes & duties: cost of govt taxes, Custom duties taxes on importing electrical equipments.

Besides above classifications, there are some classification have been divided into 3 parts these are namely
(I) fixed cost (II) semi-fixed cost (III) Running or operating cost

(I) fixed cost It is independent on maximum demand & units generated. The fixed cost is due to interest on Capital cost of land, salaries of higher officials payment of insurance etc. Here the plant has high or low maximum demand or it generates less or more.

semi fixed cost it depends on maximum demand but independent on units generated Maximum demand on power station determines its size & cost of installation. Greater the maximum demand, greater its size & greater its installation.

(iii) Running cost: depends on no. of units generated. Running cost on account of annual fuel, maintenance, repairs & salaries of operating staff. Running cost is directly propotional to no. of generated by station.

Types of Tariff

① Simple Tariff: fixed rate per unit consumed then it is called a simple tariff. Also called as uniform rate tariff. The consumption of electrical is recorded by means of energy meter.

Disadvantages:

* No discrimination b/w other type of consumers due to fixed charges.
* Cost per unit delivered very high
* It does not encourage the use of electricity

Advantages

* cost does not varying with increase or decrease in number of units consumed.
* Due to simplicity, it is easily understood by consumers.
* Transparency in collecting charges

② Flat rate tariff

Different types of consumers are charged at different fixed charges per unit.

In this types of tariff, consumers are splitted into different class or groups are charged at different fixed charges per unit.

The different classes of consumers are made taking into account their diversity & load factors.

advantages

* easy to understand
* predictability makes the budgeting easier
* Cost saving in stable energy usage patterns.

disadvantages

* No discrimination b/w other type of consumers
* Cost per unit is charged very high
* Separate meters are required for different types of loads.

③ Block rate tariff

A particular block of energy ~~kWh~~ is charged at specific rate or fixed rate & next (succeeding). block of energy are charged at reduced rates

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In this type, energy consumption is divided into some blocks & each block is provided with fixed rate.

The first block price per unit is high & its price for next following blocks is charged at reduced rates.

Example: first 30 units charged at 60p say per unit & next 25 - 55 units is charged at 55p per unit, then next 55 - 100 units is charged at 30p per unit.

Advantages

① Consumer gets incentives during consumption of more electrical energy

② Increases load factor on s/m, cost of generation is reduced.

Disadvantages

* prediction of consumer demand is typical
* widely used in residential & small commercial consumers

Two part tariff

→ Rate at which electrical energy is fixed based on consumer maximum demand & no. of units consumed.

→ total charged on consumer is split into fixed & running charges

* fixed charges depends on maximum demand
* Running " " " no. of units consumed

total charge = Maximum demand in KW + no. of units (energy)

total charge = KW + KWh

no. of units Consumed = energy = KWh

total charges = cost per KW + cost per KWh energy Consumed

Advantages

* tariff is easily understandable
* recovers fixed charges based maximum demand
* mostly suitable industrial Consumers.

Disadvantages

* Consumer has to pay fixed charges whether consumed or not Consumed the electrical energy.
* error in assessing maximum demand

Maximum demand tariff

It is similar to two part tariff s/m only difference is, a maximum demand meter is installed in Consumer premises.

This tariff mostly suitable to big Consumers but not for small Consumer. The main disadvantages is it requires a separate meter to read the maximum demand.

Three part tariff

Total charge on Consumer is splitted into 3 parts

① fixed charged → based on billing

② semi fixed charges, ③ running charges

Total charge = (a) + (b * KW) + (c * KWh)

a = fixed charge during billing period
b = charge per KW of maximum demand
c = charge per KWh of energy Consumed

→ simply adding fixed charges to 2 part tariff becomes 3 part tariff.

Disadvantages

* charges are splitted into 3 components
* this type of tariff suitable to big Consumer.

Power factor tariff

This tariff is fixed based on power factor of Consumer load.

At low power factor increases size & rating of equipment & also increases line losses

Consumer who are operating at low power factor must be penalised.

Here are some important types of tariff those are

(i) KVA maximum demand tariff

It is a modified from of 2 part tariff. Here fixed charges are made based on maximum demand in KVA not in KW.

$$KVA \propto \frac{1}{\text{power factor}}$$

KVA demand is high means power factor is very low, has to pay more fixed charges.

(ii) Sliding scale tariff

Also known as average power factor. Here 0.8 p.f is taking as reference. If this value below, an additional charges are. If power factor above 0.8 discount is provided above reference

(iii) KW & KVAR tariff

In this type both active & reactive power charges are fixed separately.

A Consumer having low power factor will draw more reactive power shall pay more additional charges.

Time of Day (ToD) → Tariff → reduction of peak demand

Here pricing mechanism of electricity is based on time of Consumption.

The main intension is to encourage Consumers to shift their energy use during peak off demand.

ToD rates have separate rates.
→ during peak hours, tariff's are higher than normal tariff
→ during solar hours, tariff's are lower than tariffs

→ Advantages
* improves s/m load factor
* optimise the power purchase costs

→ drawbacks
* during working off hours, bills might increase. (day in office, night in home)
* smart meters is needed to record

TOU (Time of use) → Tariff

A fixed rate tariff does not provide any incentive to consumers. For example a person going to charge electric vehicle after sunset (during peak demand) or charge the vehicle during peak off demand will incur same cost.

Tou is an alternative to fixed rate tariff, here pricing of electricity varies according to time like peak off & peak demand.

Tou tariff's are 2 types
(i) static Tou & (ii) Dynamic tou

In this tariff total time of day is splitted into 3 block as hours

Normal hours : Tariff is set at fixed rate here Consumer neither get incentive nor penalised for Consuming electricity.

Mid night (12am) to day break (6am)

Solar hours :- typically span 8hrs a day, throughout this time tariff is ~~lower~~ lower than normal tariff. since solar power is generated can reduces the 10-20% of Conventional power.

peak hours :- Tariff is higher than normal. During peak hours, tariff is 10-20% higher than solar power.

Dynamic TOU

Rates are determined in real time based on actual s/m conditions like Company's stock price & investors demand.

Advantages of TOU

* saving on electricity bills
* faster energy transistions.

disadvantages

* Consumers are not aware of tariff & energy usage
* Smart meters are needed
* Continous synchronisation is needed with smart meter & user.