20/9/10

Power Systems.

– Seshaiah

Syllabus :-

– Power generation < Steam (or) Thermal, hydel, Nuclear

– Power Transmission – ac – overhead

- Basic concepts in Transmission lines
- Transmission line constants – Evaluation of L.C
- Steady state performance of Tx lines < Short, medium, long
- Wave propogation phenomina in Tx lines
- Voltage control and Power factor correction
- Overhead line insulators
- Concept of corona
- Under ground cables

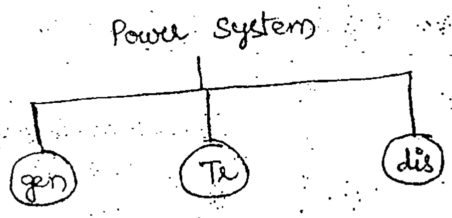
– Distribution system

- Per unit system
- Symmetrical components
- Fault analysis
- Power system stability analysis
- Relays and C.B's
- Load flow studies (YBus)
- Economic aspects and economic load dispatch
- HVDC transmission

P.S < generation, transmission, distribution

Power System :-

It is the system which can deal with power generation, transmission and distribution.



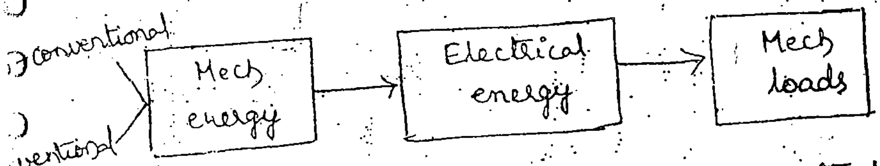
(or)

It is the system which can able to deliver the electrical energy to the consumer on economical basis ie the cost of energy should be minimum.

Electrical energy = power x time

Electrical energy → To produce the artificial illumination in order to see the objects clearly on the assigned task. (10%)

→ To drive the mechanical loads effectively (90%)



→ The efficiency of the system is high with elec energy as medium.

→ The mechanical energy used for driving the mech loads will result as ineffective energy transformation so that the loss in the s/m will be high and the η of the system is less.

→ If the electrical energy used to drive the mech load, there will be effective energy transformation, so that the loss in the system will be less and the efficiency will be high.

POWER SYSTEM

→ It Consists of Generation, Transmission and Distribution

Gen → Tr → Dis → } Consumers

→ It Consists of almost all electrical equipments which are placed at different locations and working together to supply the Electrical Energy to the consumer on Economic basis

→ What is the need to have Electrical Energy?

Electrical Energy: 1) To have an artificial illumination so that the objects can be seen very clearly (10% used)

2) To drive the mechanical loads (90% utilized)

The above ① & ② can be done by using some Non-Electrical energy

But to go for electrical energy is because of following advantages

I) Efficiency is high (II) Reliability is high (III) Cost is Less (IV) Easy control (V) No pollution

→ Mech Energy → Electrical Energy → Mechanical Load

Since both are in same form we call it as ineffective energy transformation then efficiency is Less.

→ But Mech → Elec → Mech is effective energy transformation then efficiency is more

→ Mechanical energy is obtained from two forms (or) Sources

Conventional, Non-Conventional → Electrical Energy

NON-CONVENTIONAL	CONVENTIONAL
1. Small capacity power generation for short interval of time	1. Bulk capacity of power generation for a longer time continuously
2. Range of only KW	2. Range of 5MW [illegible]

3. 'KW' can be generated with 220 V, 615 V and 1.1 KV

Ex: Solar, Tidal, Geothermal, Biomass Diesel and MHD (Magneto Hydro Dynamo generator)

4. Reliability is less

5. No Geographical constraints to install these plants

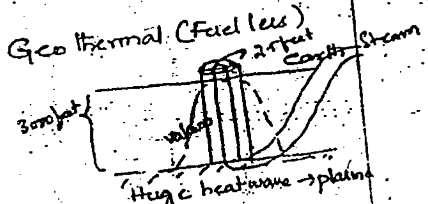
6. Running of plant is based on atmospheric conditions

7. Cost Analysis: Fixed + Running
Rs ₹/KW + Rs ₹/Kwhr.

Fixed cost is less
Running cost is high.

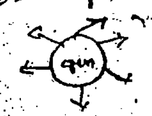
8. Application: Except Geothermal remaining are suitable for Peak load

9. Geothermal (Fuel less)



10. Generators used are Asynchronous generators i.e. Variable speed Ex: Induction generator

11. Used for nearly distributed areas



Distribution & Transmission avoided

3. Generation levels are of 3.3 KV 6.6 KV, 11 KV, 13.2 KV, 18.6 KV and 22 KV

Ex: Steam (or) thermal, Hydel, Nuclear and Gas.

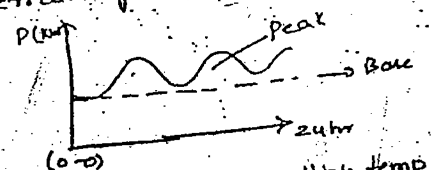
4. Reliability is High

5. Installation of these plants based on Geographical constraints

6. The running of plant doesnot depend on atmospheric conditions

7. Fixed cost / KW is high.
Running cost is less

8. Appln: Except Gas plants the remaining suitable to base load.



9. High pressure and high temp steam

10. Generators used are of Constant speed type Ex: Synchronous generator (or) alternator

11. Bulk capacity power generation is made at remote place. So it is necessary to carry over along to the populated area which is known as power transmission and then followed by power distribution.

→ 1,30,000 MW total power generation in India from 1.63 ... formed

+ 32 Hydel +

STEAM (OR) THERMAL STATIONS

The high pressure and high temperature steam (mechanical energy) is converted in to an Electrical Energy

→ Thermal plants based on capacity

1. Industrial plants — (5MW – 10MW) – 1.5 kg/cm² (Pressure)
2. Commercial Plants — (10 MW – 500 MW) – 160 kg/cm²

→ Selection of site :

(i) Large capacity thermal plants are proposed to locate near the pit head

(ii) Available of ample water

(iii) Land requirement at less cost

(iv) Accessible to road and rail.

→ The principle of operation of Thermal plants is based on RANKIN CYCLE

→ Capacities of Plants in APGENCO

VTPS → 210 × 6 MW

RTPP → 210 × 4 MW

KTPS → 60 × 4 → I & II Stages
110 × 4 → III & IV Stages
250 × 2 → V stage

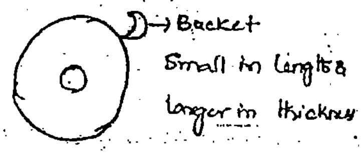
RTPS → 66.5 MW

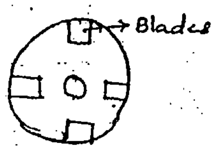
NTPC → 1000 MW (Vizag)

NTPC → 2600 MW (Ramagundam)

→ For effective utilization of the steam at higher pressure and higher temperature, allow the steam for expansion at more than one stage.

→ Impulse turbine | Reaction turbine





→ The purpose of the turbine is to rotate the alternator by using the mechanical energy (steam)

→ The generator which is placed at the thermal station is synchronous Generator (Alternator) with cylindrical Rotor

→ For 2-pole machine the maximum speed is 3000 rpm for a cylindrical rotor at f = 50Hz.

→ Cylindrical Alternator is also called as Turbo alternator

→ Cooling of the Alternator Rotor

(i) For ≤ 100MW plant → Natural cool

(ii) For > 100 MW plant → Natural cool + Hydrogen gas (lightest gas)

*pressure is 0.035 Kg/cm²

→ At present the turbo alternator available are with a capacity of 500MW

→ CONDENSER: The purpose of the condenser is to provide vacuum to the turbine so that the steam will be expanded over a larger area which will result that the output of steam will come out with 0.04 Kg/cm² and 40°C

→ P^H Value of the D.M water is slightly greater than 7.

→ The pressure of steam in steam drum is 110 – 160 Kg/cm² with a temperature of 300°C

→ SUPER HEATER: The purpose of the super heater is to increase the temperature of the steam without changing the pressure with the help of the temperature of the FLUE GAS

→ The maximum temperature at which thermal station is working is 540°c and maximum pressure is 160 Kg/cm²

→ The super heater consisting of series of tubes in which the amount of steam is allowed and over the surface of the tubes, the flue gases are allowed to flow so that the amount of temperature of the flue gases is extracted by the steam in the tubes of the economizer

→ Range of temperature of flue gases is 240°c

→ The purpose of the steam valve is to control the amount of steam based on the loading conditions on the alternator

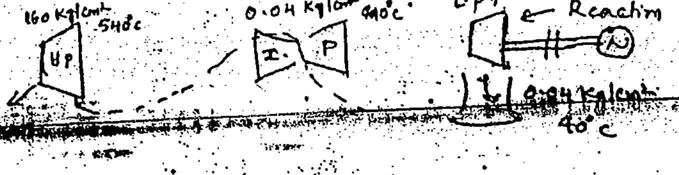
→ TURBINE (PRIME MOVER):

→ Based on Principle of Operation

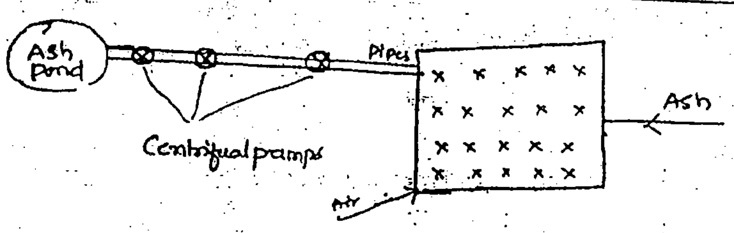
1. Impulse turbine Ex: Pelton wheel
2. Reaction turbine Ex: Franchis, Kaplan, propellar

→ The turbine used in Thermal power plant is

a) Impulse (b) Reaction © Either Impulse or Reaction (d) Impulse-Reaction



→ Most common way of handling ash is called is Hydraulic system



⟹ **BOILER:** The purpose of the boiler is to generate the amount of steam required with sufficient pressure as well as temperature [Boiler is a series of tubes]

→ TYPES OF BOILERS :

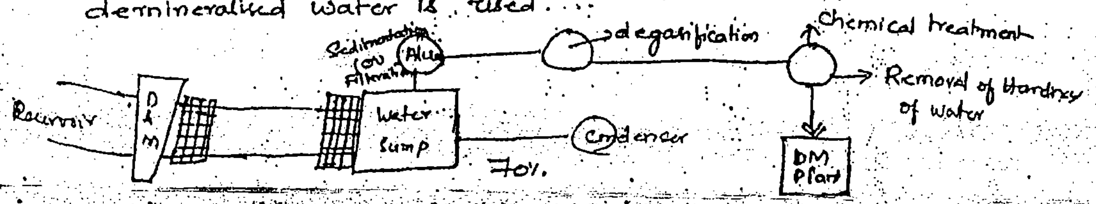
Recommended 1. Water tube Boilers : Water in tubes and heat is surrounded

Not recommended 2. Fire tube Boilers : Fire in tubes and water is surrounded.

→ Water is used in the boiler tubes to get an amount of steam is Demineralised water (D.M water)

→ Scaling [deposits of sodium & calcium] is formed in the tubes if we use mineral water

→ In order to avoid the scale formation inside the boiler tubes demineralised water is used.



→ FUELS

(i) Liquid fuels → low grade petroleum < for normal Starting / Sudden

(ii) Coal → Semi bitiminous coal is used in all the thermal Stations in India

→ The liquid fuels are normally used during the normal Start up and also variation of the load

→ The ash content in Indian coal is 20 – 40 %

→ Coal → 1) peat → Lignite → Bitminous → Semi Bitiminous → Anthracite

1) Coal is unloaded by wagon tippler

2) Coal transportation is done from open yard to boiler is by using Belt Conveyers.

3) Coal preparation → 1) Crushers
2) Dryers
3) Seperators

→ Coal used in furnace is pulverized Coal (fine powder) which is done in "Ball mills"

→ The purpose of the pulverized coal is to increase the heating and burning properties of the coal.

→ The Ash in Thermal power plants is of two types

(i) Heavy ash (or) bottom ash

(ii) Fly ash

→ Ash handling ways

1) Mechanical System

2) Jet of Steam → Injected water

3) Pneumatic System → Air injected

→ The pressure and temperature is very low at condenser.

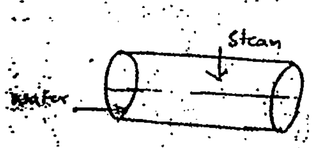
→ TYPES OF CONDENSERS:

(i) Jet type (ii) Surface type

(i) Jet type: In jet type condenser, a jet of water is mixed with the steam and the combination is discharged into the down stream canal may be utilized for irrigation purpose

In this method, there is no recollection of water from the expanded stream.

(ii) Surface type:



In the surface type condenser, one side the expanded steam is allowed and the other side the water is allowed so that the temperature of the steam is extracted by the water.

→ The purpose of the condensated extraction pump is to collect the water from the expanded steam, which is not sufficient as the feed water to the boiler due to some amount of loss of steam during the expansion

→ The feed water is a combination of condensated extraction water as well as make up water from the D.M plant

→ The purpose of the cooling tower is to send the vapour particles into the atmosphere, so that the normal water will be collected at the bottom of the cooling tower which can be reutilised for the purpose of the condenser again.

→ There are two types of draughts in the Thermal Stations

~~1) Natural draught → pressure difference [Ex: chimney)~~

2) Artificial draught → Fan — Induced draught fan (I.D) [-ve pressure]
— Forced draught Fan (F.D) (+ve pressure]

→ The cooling towers are attached with Forced draught so that the air is blowing on the vapour particles inorder to send them in to the atmosphere

→ The purpose of the I.D fan at the chimney is to collect the flue gases and send it in to the atmosphere.

→ The purpose of the low pressure heater and high pressure heater is to increase the pressure and temperature of feed water.

→ The Economizer consisting of series of tubes in which the feed water is allowed and over the surface of the tubes the flue gases are flowing. The amount of temperature of flue gases are extracted by the feed water in the economiser tubes.

→ The purpose of the economizer is to supply the feed water to the boiler tubes with certain temperature and pressure so that the actual amount of coal required in the boiler furnace is less. Hence the boiler efficiency is increased. So the economiser is one of the acciary (Auxilary equipment) for the boiler.

→ Economizers are normally employed if the pressure of the steam which is required is more than 70 kg/cm²

→ The another auxilary equipment for the boiler is Airpreheater. The purpose of the airpreheater is to supply the hot air to the boiler furnace for effective conversion of the coal.

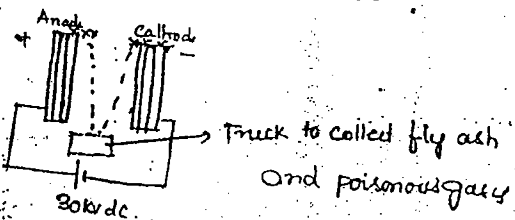
→ The air to the boiler surface is supplied through chimney as well as F.D fan which is placed near to the Air-preheater. (APH)

→ The temperature of the flue gases is extracted by the air in the Airpreheater, so that the air supplied to the boiler furnace will attain certain temperature

→ **ELECTRO STATIC PRECIPITATOR**: The flue gas consisting of the ash particles as well as the poisonous gases like CO CO_2 and SO_2. The purpose of the ESP is to collect the flyash particles as well as the poisonous gases

→ Efficiency of ESP is from 99.5% to 99.8%.

→ It consists of few plates



→ Fly ash is used in brick Industries & Cement Industries otherwise it is send to heavy air and disposed through Hydraulic system.

EFFICIENCY:

The overall efficiency of a thermal station is

$$\eta_o = \underbrace{\eta_b \times \eta_t}_{\eta_T} \times \underset{0.95}{\eta_e}$$

η_b → 90% (0.9)

η_b → boiler efficiency

η_t → turbine efficiency

η_e → Electrical efficiency

$$\boxed{\eta_o = \frac{\text{Heat equivalent of Electrical output (KWh)}}{\text{Heat of combustion of coal (Kcal)}}}$$

→ $\boxed{1 \text{ KWhr} = 860 \text{ Kcal}}$, $\boxed{1 \text{ KWH} = 36 \times 10^5 \text{ Joules}}$

$$\boxed{\therefore \eta_o \doteq 30\%}$$

→ Life of thermal station is 20 years

→ 1 MW of generation in T.S requires 10 tonnes of coal perday

1 ton → 1000 kg

$$\therefore \boxed{\eta_o = \eta_T \times \eta_e} \quad \eta_T \rightarrow \text{Thermal efficiency}$$

→ Without A.P.H and Economiser the boiler efficiency is 70% only

η_{APH} → 8%, $\eta_{Economiser}$ → 12%

→ The efficiency of the Thermal plant is less because

(i) There is a huge loss in pressure & temperature of the steam at condenser.

(ii) The Auxiliary consumption of the station is high because of more auxiliary equipment.

(2) HYDEL PLANTS:

It is also a conventional source of electrical energy

→ Working principle: The potential energy of a stored water is first converted into high velocity and high pressure kinetic energy which is later converted into Electrical Energy

→ Selection of site:

(i) Ample quantity of water is available with specific head
(ii) Storage facility
(iii) Accessible to road
(iv) Near to Load Centres

→ Capacities of Hydel plants in Andhrapradesh.

1. Nagarjuna Sagar → 110 × 1 → 110 MW (BHEL); → 100 × 7 → 700 MW (Stator) } 810 MW

2) Srisailam → R → 100×7 = 700 MW; L → 150×6 = 900 MW } 1600 MW

3) Upper Sileru → 60×4 = 240 MW; Down Sileru → 110×4 = 440 MW } 680 MW

→ HYDROLOGY:

1. Precipitation (P): It is the amount of water which is available on the earth's surface due to melting of the Ice (or) direct rains

2. Run off (R): It is the amount of water which is flowing through valleys in the form of a stream of water from the available precipitation after infilteration by the soil

3) EVAPORATION (E): It is the amount of water which got evapdated to atmosphere during summer

$$\boxed{\begin{aligned} P &= R+E \\ R &= P-E \end{aligned}}$$

4) HYDROGRAPH: It is electrically called as load curve

→ It gives the variation of the discharge in the m^3/sec with respect to time. It is an equivalent of load curve

(1) The area of the curve upto this specified area will provide the volume of water which got discharged

(2) The peak point will indicate maximum discharge

(3) It provides the discharge in m^3/sec at any particular point of time

(4) It can also provide the average discharge

(5) FLOW DURATION CURVE: It gives the variation of discharge in m^3/sec w.r.t percentage of time and the discharges are rearranged in descending order.

→ From the given flow duration curve, it can estimate the total available power.

→ Cu-sec → discharge, TMC → volume of water

Cu-sec: cubic feet; TMC: Thousand million cu-sec's

6) MASS CURVE: It gives the cumulative amount of water which got stored in the reservoir w.r.t percentage of time over a specified period

→ Mass curve is expressed as Day - sec - meter

→ The amount of power that can be generated is

$$P = \frac{9.81 \times W Q H \times \eta}{1000} \text{ KW}$$

$W \rightarrow$ Density of the water $= 1000 \text{ kg/m}^3$

$Q \rightarrow$ Discharge $\rightarrow m^3/sec$

$H \rightarrow$ available Head $\rightarrow m$

$\eta \rightarrow$ efficiency $= 0.85$

Q: The amount of power generated in KW in a mass curve of day - sec - m and η is 100%.

Sol:

Day - sec - m $\rightarrow$ $24 \times 3600 \times 1$

144
72
86400 m^3

$\therefore$ Volume $\rightarrow 86400 \text{ m}^3$

$\therefore$ Discharge/sec $\rightarrow \frac{86400}{24 \times 3600} = 1 \text{ m}^3/sec$

$$\therefore P = \frac{9.81 \times 1000 \times 1 \times 1 \times 1.0}{1000} = 9.81 \text{ KW}$$

→ If 10 day - sec - m $= 10 \times 24 \times 3600 \times 1 = 8,64,000 \text{ m}^3$

$$\text{Discharge} = \frac{8,64000}{24 \times 3600} = 9.81 \text{ kw}$$

→ If Day - sec - 10m $= 24 \times 3600 \times 10 = 8,64,000 \text{ m}^3$

$$\text{Discharge} = \frac{8,64,000}{24 \times 3600} = 10 \text{ m}^3$$

→ If 100m $\rightarrow 100 \text{ m}^3/sec$

But if 10 days $\rightarrow 1 \text{ m}^3/sec$

$\therefore$ For $10 \text{ m}^3/sec$

$$P = \frac{9.81 \times W \times Q \times H \times \eta}{1000} = \frac{9.81 \times 1000 \times 1 \times 10 \times 10 \times 1}{1000}$$

$= 981 \text{ kw}$

CLASSIFICATION OF THE HYDEL PLANTS

1) Based on the installed capacity

(i) Micro → ≤ 5 MW
(ii) Medium → 5 to 100 MW
(iii) Large → 100 to 1000 MW → In general preferred
(iv) Super → above 1000 MW

2) Based on the available head

(i) Low head plants → < 70 MW
(ii) Medium head → 70 to 300 MW
(iii) High head → > 300 MW

3) Based on the availability of water

Base load (i) Run off river without pondage
Peak load (ii) Run off river with pondage → temporary storage of water with small capacity
B load (iii) Reservoir type → Most common type in India
P.L (iv) pumped storage plant

(i) RUN OFF RIVER WITHOUT PONDAGE:

If the water is available with natural head then the available water in the river can be directly utilized for power generation, however the reliability of this plant is very less.

(ii) RUN OFF RIVER WITH PONDAGE:

It is expected to run if there are floods in the river During the dry season the stream of water in the river is very very low and it can be stored continuously over ~~a period of time~~. The stored water can be utilized to generate the power to meet the peak load demand. So

→ CLASSIFICATION OF DISTRIBUTORS

(1) Based on Construction
- → OHL
- → U.G. (highly populated areas)

(2) Based on nature of current
- → a.c (I.Z) (vector calculation) Time required ↑
- → d.c → IR (Arithmetic calculation)

→ The voltage drop calculations will be taking much time in case of a.c distribution when compared to d.c distribution. Hence the distributor performance can be carried out for most of examples with d.c currents.

(3) Based on no. of wires
- → dc
  - → 2 wire ✓
  - → 3 wire (rare)
- → ac
  - → 1 − φ 2 wire
  - → 3 − φ 4 wire ✓ → (1 − φ, 2 wire Calculations)
  - → 1 − φ, 3 wire (rare)

(4) Based on the service (or) scheme

(i) Radial distributor fed from one end with concentrated load (or) uniform loading

(ii) Radial distributor fed from both the ends with concentrated load (or) uniform loading, with equal voltages (or) unequal voltages.

(iii) Ring main distributor

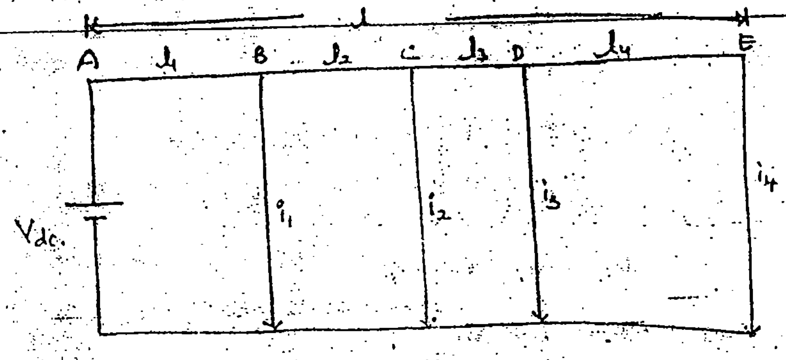
(iv) Interconnected ring main distributor.

→ In rural areas, Radial distribution scheme's are employed

→ In urban areas, Ring main distribution scheme's are employed

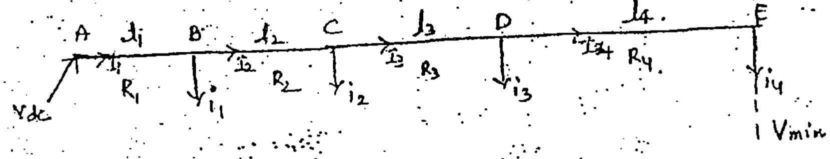
DC 2 wire

→ Radial distributor fed from one end with concentrated load:



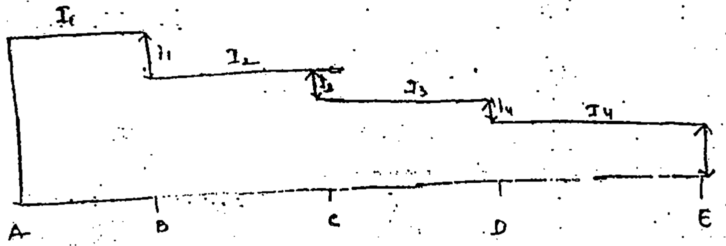
$r' \rightarrow$ be the resistance of conductor in Ω/m

$r = 2r' \rightarrow$ resistance of distributor in Ω/m



$R_1 = r \times l_1$	$I_1 = i_1 + i_2 + i_3 + i_4$
$R_2 = r \times l_2$	$I_2 = i_2 + i_3 + i_4$
$R_3 = r \times l_3$	$I_3 = i_3 + i_4$
$R_4 = r \times l_4$	$I_4 = i_4$

→



→ Current diagram

Voltage drop at A $= 0$

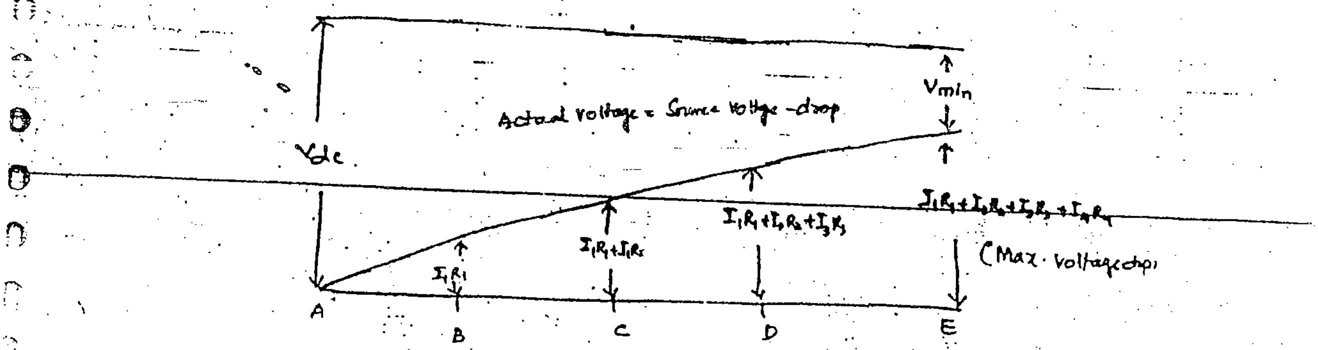
$B = I_1 R_1$

$C = I_1 R_1 + I_2 R_2$

$D = I_1 R_1 + I_2 R_2 + I_3 R_3$

$E = I_1 R_1 + I_2 R_2 + I_3 R_3 + I_4 R_4 \Rightarrow$ Max voltage drop

Power loss $= I_1^2 R_1 + I_2^2 R_2 + I_3^2 R_3 + I_4^2 R_4$

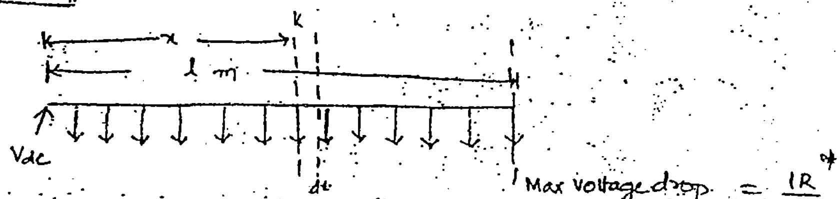


→ A radial distributor fed from one end is having a maximum voltage drop at the tail end of the consumer so that there will be a minimum voltage for that consumer.

→ In general the voltage at a distance of 'x'

$$\boxed{V_x = V_{dc} - \Sigma IR}$$

→ UNIFORM LOADING



i = uniform current Amp/m

r = resistance of distributor in Ω/m

→ In practical case, the loads on the distribution are the concentrated loads. The uniform loading is the special case.

→ The leakage current of the U.G.C under no load condition is called as uniform loading.

$$\boxed{\text{Max voltage drop} = \frac{IR}{2}}$$

Voltage drop in 'dx' $= i(l-x).r.dx$

Drop upto 'x' $= \int_0^x i(l-x)\, r.dx$

Drop at 'x' $= ir\left[lx - \frac{x^2}{2}\right]_0^x$

$= ir\left[lx - \frac{x^2}{2}\right]$

If $x = l$, Maximum Voltage drop.

MVD $= ir\left[l^2 - \frac{l^2}{2}\right]$

$= \frac{irl^2}{2}$

$= \frac{(i \times l)(r \times l)}{2} = \frac{I \cdot R}{2}$

$$\boxed{V_{min} = V_{dc} - \frac{IR}{2}}$$

→ Power loss $= \frac{I^2R}{3}$

↓

Loss in $dx = \left[i(l-x)\right]^2 r\,dx$

Loss up to 'x' $= \int_0^x i^2(l-x)^2 r\,dx$

$= i^2 r \int_0^x (l^2 + x^2 - 2lx)\,dx$

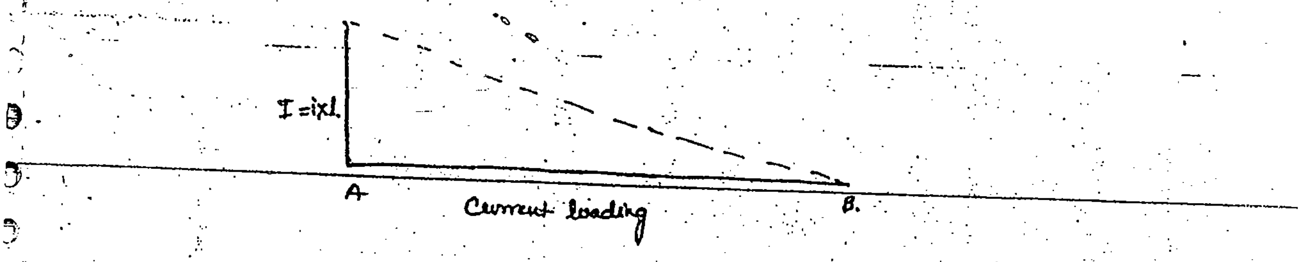
$= i^2 r \left[l^2 x + \frac{x^3}{3} - 2l \cdot \frac{x^2}{2}\right]_0^x$

Loss up to 'x' $= i^2 r \left[l^2 x + \frac{x^3}{3} - lx^2\right]$

Total loss $(x = l)$ $= i^2 r \left[\cancel{l^3} + \frac{l^3}{3} - \cancel{l^3}\right]$

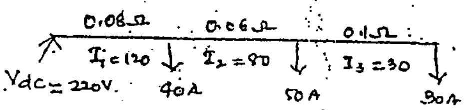
$= \frac{(il)^2 (r \times l)}{3}$

$$\boxed{\text{Total power loss} = \frac{I^2R}{3}}$$



→ voltage profile

(Q)



A dc 2-wire distributor along with concentrated loading is as shown above. The minimum voltage drop of the Distributor in volts is

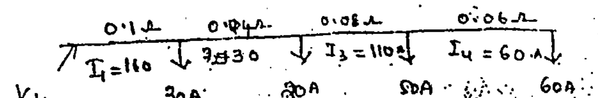
Sol

$$V_{min} = V_{dc} - (I_1 R_1 + I_2 R_2 + I_3 R_3)$$

$$= 220 - (120 \times 0.08 + 80 \times 0.06 + 30 \times 0.1)$$

$$= 202.6 \text{ volts}$$

(Q)

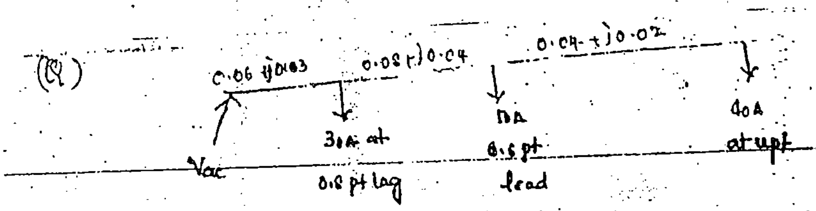


The V_{max} drop of the distributor is

$$V_{max} \text{ Drop} = 160 \times 0.1 + 130 \times 0.04 + 110 \times 0.08 \times 60 \times 0.06$$

$$= 33.6 \text{ volts}$$

(Q)



Calculate MVD of a.c. ae 2-wire distributor

Sol

Max Voltage drop $= I_1 Z_1 + I_2 Z_2 + I_3 Z_3$

$I_1 = (30 \times 0.8 - j30 \times 0.6) + 50(0.6 + j50 \times 0.8 + 40$

$= 24 - 18j + 30 + 40j + 40$

$= 94 + j22$

$I_2 = 30 + 40j + 40$

$\Rightarrow 70 + 40j$

$I_3 = 40$

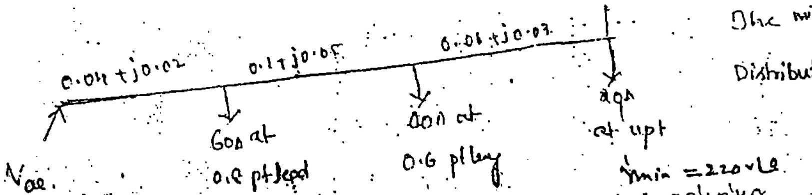
$MVD_{ae} = (0.06 + j0.03)(94 + j22) + (70 + 40j)(0.08 + j0.04)$

$+ 40(0.04 + j0.02)$

$= 4.98 + j4.14 + 4 + 6i + 32 + j1.6$

$MVD_{ae} = 12.18 + j\,11.74$

(Q)



The min voltage of Distributor is 220V.

The voltage at which the distributor is supplying.

Sol

$V_{ac} = 220\angle 0 + (I_1 Z_1 + I_2 Z_2 + I_3 Z_3)$

$I_1 = (60 \times 0.8 + j60 \times 0.6) + (40 \times 0.6 - j40 \times 0.8)$

$+ 20(\cancel{0+j0})$

$= (48 + j36) + 24 - j32 + 20$

$I_1 = 48 + 24 + 20 + j(36 - 32)$

(Q) A DC 2WIRE DISTRIBUTOR IS HAVING A LENGTH OF 1200m. The resistance of the distributor is 0.2Ω/Km. The uniform loading of the distributor is 0.1 A/m.. The max voltage drop of the distributor.

Sol

$$MVD = \frac{IR}{2}$$

$$= \frac{0.1 \times 1200 \times 0.2 \times 1.2}{2}$$

$$= \frac{28.8}{2} = \underline{14.4V}$$

(Q). A radial dc-2wire distributor is having a uniform loading of 0.1A/m. The length of the distributor is 800m. The resistance of each wire is 10^{-4} Ω/m. The distributor is fed at 220V. The min. Voltage on the distributor is:

Sol

$$V_{min} = V_{dc} - MVD.$$

resistance of distributor $= 2 \times 10^{-4}$.

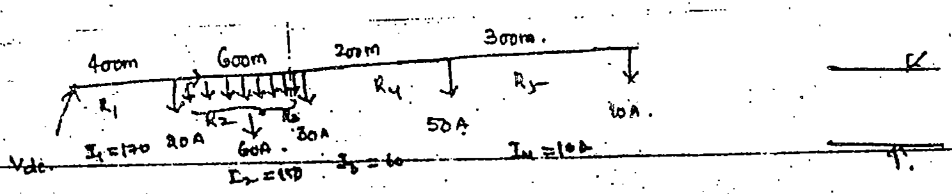
$$MVD = \frac{I \cdot R}{2}$$

$$= \frac{(0.1 \times 800)(2 \times 10^{-4} \times 800)}{2}$$

$$= \frac{12.8}{2} = 6.4V.$$

$$V_{min} = 220 - MVD$$

$$= 220 - 6.4$$

(Q) 

$i = 0.8$ A/m.

The resistance of the each wire is $1.5\times10^{-4}\ \Omega/m$. The max voltage drop of the distributor is.

Sol

$$I_1 = 20+30+50+10+60 = 170.$$

$$R_1 = 2\times1.5\times10^{-4}\times400 = 0.12$$

$$R_2 = 2\times1.5\times10^{-4}\times300 = 0.09.$$

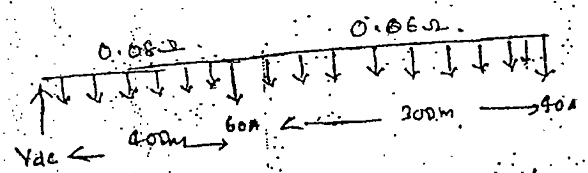
$$R_3 = 0.09.$$

$$R_4 = 2\times1.5\times10^{-4}\times200 = 0.06$$

$$R_5 = 2\times10^{-4}\times1.5\times300 = 0.09.$$

$$MVD = 170\times0.12+150\times0.09+\overset{90\times0.09}{60\times0.09}++10\times0.09$$

$$= \underline{48.3\ V.}$$

(Q) 

uniform loading $= 0.1$ A/m.

Resistance of the distributor $= 2\times10^{-4}\ \Omega/m$. MVD =?

The length of the distributor $= 700$ m.

Sol

$$MVD = I_1R_1 + I_2R_2 + \frac{IR}{2}$$

$$= \cancel{\frac{(i\times x)(r\times x)}{2}}$$

$$= 100\times0.08+40\times0.06+\frac{(0.1\times100)\times\ldots}{2}$$

$= 10.4 + 70.14$

$= \underline{80.54}$

→ **Disadvantages of Radial distributor fed from one end.**

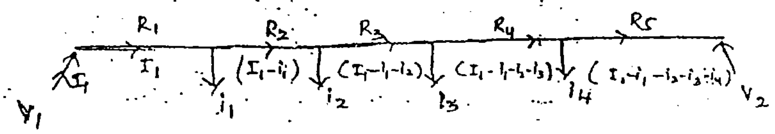
(1) It will provide low voltages for the consumers who will be far away from the source.

(2) As it is fed from only one supply, the reliability of the scheme is less.

(3) In effective utilization of the size of the conductor over a given length

→ In order to overcome the disadvantages it is proposed that the distributor can be fed from both ends.

→ **RADIAL DISTRIBUTOR FED FROM BOTH ENDS WITH CONCENTRATED LOADS** (DC-2wire



→ The minimum voltage will occur at one of the load point to which the current can be supplied by both the sources

→ To locate the minimum potential point it is required to calculate the magnitude of any one of the source current.

$$V_2 = V_1 - \text{Drop}$$

$$V_2 = V_1 - [I_1R_1 + (I_1 - i_1)R_2 + (I_1 - i_1 - i_2)R_3 + (I_1 - i_1 - i_2 - i_3)R_4$$

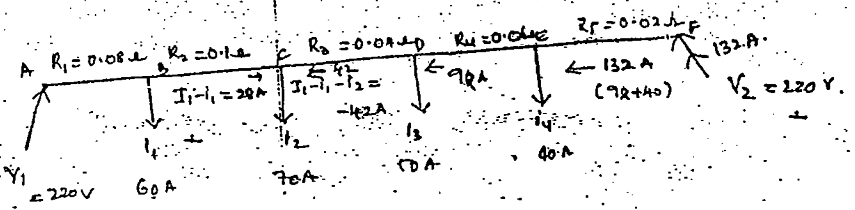
$$+ (I_1 - i_1 - i_2 - i_3 - i_4)R_5$$

$$I_1\left[R_1+R_2+R_3+R_4+R_5\right] = V_1 - V_2 + i_1R_2 + (i_1+i_2)R_3 + (i_1+i_2+i_3)R_4 + (i_1+i_2+i_3+i_4)R_5$$

$$I_1 = \frac{V_1 - V_2 + i_1R_2 + (i_1+i_2)R_3 + (i_1+i_2+i_3)R_4 + (i_1+i_2+i_3+i_4)R_5}{R_1+R_2+R_3+R_4+R_5} \rightarrow (1)$$

eq (1) hold good for both equal & unequal voltages.

(Q)



The V_{min} on distributor in volts is

Sol

$R_1+R_2+R_3+R_4+R_5 = 0.3\Omega$

$$I_1 = \frac{0 + 60\times(0.1) + (130)(0.04) + (180)(0.06) + 220\times0.02}{0.3}$$

$$= \frac{26.4}{0.3} = 88A$$

$I_1 = 88A$

$I_2 = 132A$ (from fig).

$\therefore V_{min} = V_1 - M.V.D$

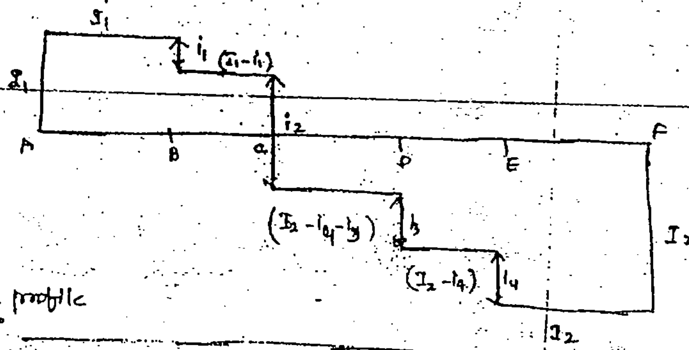
$= V_2 - M.V.D$

$V_{min} = 220 - (88\times0.08 - 28\times0.1) = 210.16V$

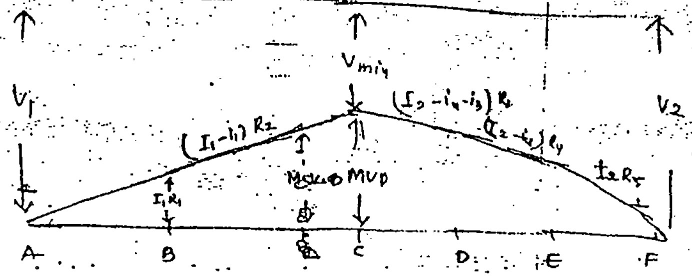
$= 220 - (132\times0.06 - 92\times0.06 - 92\times0.04) = 210.16V$

$V_{min} = 210.16V$

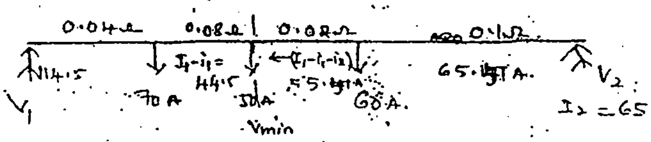
→ Current diagram



→ Voltage profile



(Q)



The min Voltage on the distributor is 218.5V. The distributor is fed in such away that $V_1 - V_2 = 1.5V$. The magnitude of the same voltages of the distributor i.e. $V_1 = ?$ $V_2 = ?$

Sol

$$I_1 = \frac{V_1 - V_2 + i_1R_2 + (i_1+i_2)R_3 + (i_1+i_2+i_3)R_4}{R_1+R_2+R_3+R_4}$$

$$= \frac{1.5 + 70(0.08) + (120 \times 0.02) + (180 \times 0.1)}{0.04 + 0.08 + 0.02}$$

$$= \frac{27.5}{0.24}$$

$$= 114.58A$$

$$I_2 = 65.5A$$

$$V_{min} = 218.5 = V_1 - M.V.D$$

$$V_1 = V_{min} + \ldots$$

$$V_2 = V_{min} + V.D$$

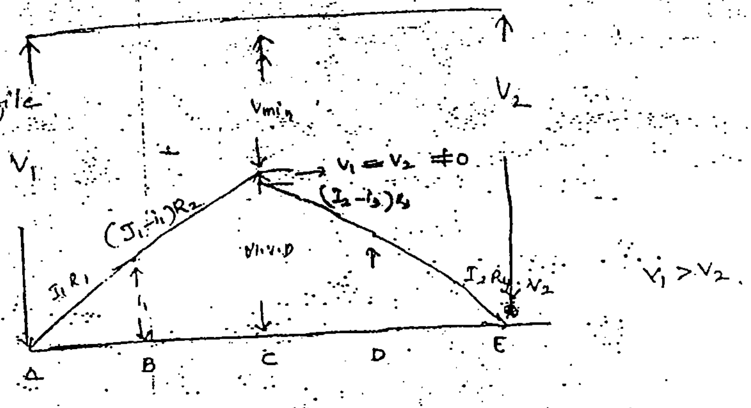
$$V_1 = 218.5 + (114.5 \times 0.04) + (44.5 \cdot 0.08)$$

$$= \underline{226.64V.}$$

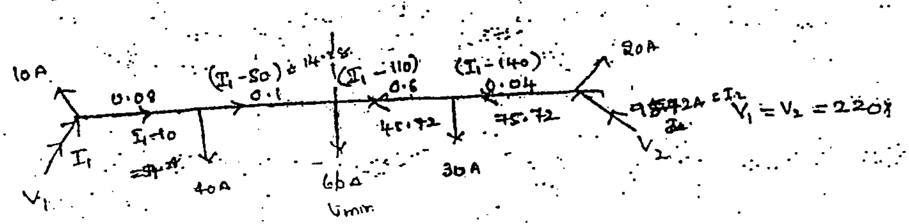
$$V_2 = 218.5 + (65.5 \times 0.1) + (5.5 \times 0.02)$$

$$= \underline{\underline{225.14\ V}}$$

→ Voltage profile



(Q) →



The min voltage of the distributor is

Sol

$$\therefore V_1 - V_2 = \text{Drop}$$

$$(I_1 - 10) \times 0.08 + (I_1 - 50) \times 0.1 + (I_1 - 110) \times 0.06 + (I_1 - I_{40}) \times 0.04 = 0$$

$$\Rightarrow I_1 [0.08 + 0.1 + 0.06 + 0.04] = 10 \times 0.08 + 50 \times 0.1 + 110 \times 0.06 + 140 \times 0.04$$

$$\Rightarrow I_1 = \frac{18}{0.28}$$

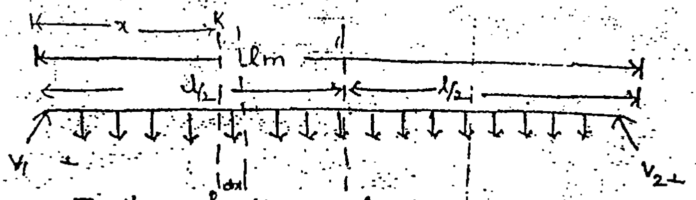
$$I_1 = 64.28A.$$

$$V_{min} = 220 - (\overset{(I_1-10)}{54.28 \times 0.08} + \overset{(I_1-60)}{14.28 \times 0.1})$$

$$= 220 - (75.72 \times 0.04 + 45.72 \times 0.06)$$

$$= \underline{214.42\ V}$$

→ **DC- 2WIRE RADIAL DISTRIBUTOR FED FROM BOTH ENDS WITH UNIFORM LOADING**



uniform loading of i A/m.

Min voltage point ≠ Max voltage drop $= \frac{IR}{8}$

Resistance of the distributor $= r\ \Omega/m$. r = resistance of wire Ω/m.

<u>Case(i)</u> Equal voltages

→ If $V_1 = V_2$ then the minimum potential will get exactly at the middle of the distributor so that the distributor is symmetric on both sides with respect to the middle of the distributor.

$$\text{Drop in the "dx"} = (i \times l/2) - (ix)\, r\,dx$$

$$\text{Drop upto 'x'} = \int_0^x (i\,l/2 - ix)\, r\,dx$$

$$= ir \int_0^x (l/2 - x)\, dx$$

$$= ir \left[l/2\, x - \frac{x^2}{2} \right]_0^x$$

$$= ir \left[l/2\, x - x^2/2 \right]$$

Max Voltage drop will be at $x = l/2$

$$= ir \left(l/2 \cdot l/2 - 1/2\, (l/2)^2 \right)$$

$$= ir \left[l^2/4 - l^2/8 \right]$$

$$\text{Max Voltage drop} = ir \left[l^2/8 \right] = \frac{(i \times l)(r \times l)}{8} = \frac{I \times R}{8}.$$

$$\text{Total power loss} = \frac{I^2R}{12}$$

→ ~~The maximum voltage drop and the total power loss of a~~ The maximum voltage drop and the total power loss of a radial distributor fed from both the ends having uniform loading will be $\frac{1}{4}$th to that of the max voltage drop and the total power loss of a radial distributor fed from one end.

$$M.V.D = \frac{1}{4}\left(\frac{I.R}{2}\right), \quad P.\text{loss} = \frac{1}{4}\left(\frac{I^2R}{3}\right)$$

(Q) A dc 2wire radial distributor fed from both ends with equal voltages of 220V, the uniform loading is 0.1 A/m and resistance of each wire is 0.1 Ω/Km. The length of the distributor is 1600m. The min voltage of the distributor is.

Sol

$$V_{min} = V_1 - \text{Drop}$$
(or)
$$= V_2 - \text{Drop}$$

$$V_{min} = 220 - \frac{(IR)}{8}$$

$$= 220 - \frac{(0.1 \times 1600)(2 \times 0.1 \times 1.6)}{8}$$

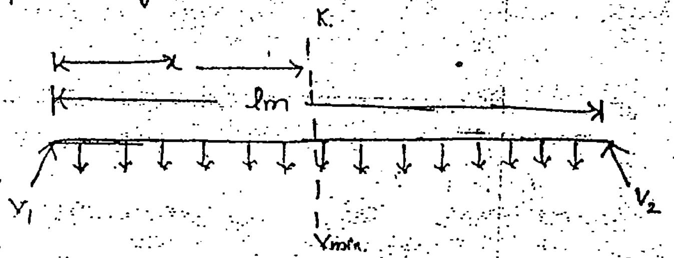
(Q) The max voltage drop and the total power loss of a radial distributor fed from both the ends having uniform loading is 2.5V and 5W. The max voltage drop and the total power loss of radial distributor fed from one end with uniform loading is.

Sol $\frac{IR}{8} = 2.5V$, $\frac{IR^2}{12} = 5W$ → both ends

$\Rightarrow \frac{IR}{2} = 2.5 \times 4 = 10V$

$\Rightarrow \frac{IR^2}{12} = \cancel{5\times4} = 20W$ } on one end.

Case (ii) Unequal voltages:



Uniform loading $= i$ A/m

Resistance of distributor $= r\ \Omega/m$

$V_1 \neq V_2$

→ In order to locate the minimum potential point can be assumed at point 'K' having a distance 'x' from any one of the source.

$V_{min} = V_1 - \text{Drop}$

(or)

$V_2 - \text{Drop}$

$$V_1 - ir\frac{x^2}{2} = V_2 - ir\frac{(l-x)^2}{2}$$

$$= V_2 - ir\left(\frac{l^2+x^2-2lx}{2}\right)$$

$$V_1 - \cancel{\frac{irx^2}{2}} = V_2 - \frac{irl^2}{2} - \cancel{\frac{irx^2}{2}} - irlx$$

$$V_1 = V_2 - \frac{irl^2}{2} - irlx$$

$$irlx = V_1 - V_2 + \frac{irl^2}{2}$$

$$x = \frac{V_1 - V_2}{irl} + \frac{l}{2}$$

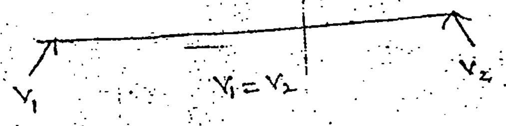
$$\boxed{x = \frac{l}{2} + \frac{V_1 - V_2}{irl}}$$

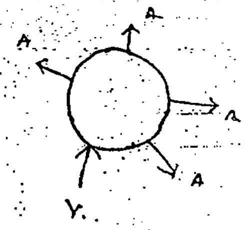
9/2/2010

- RINGMAIN DISTRIBUTOR:

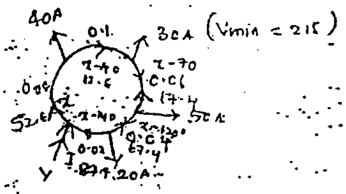
It consists of one or more sources and form a closed circuit (or) loop

- Radial distributor fed from both ends with equal voltages can also treated as ring main distributor with single equivalent source.





(Q) The minimum voltage of the distributor is 215 V. The magnitude of the source voltage.



Sol In order to locate the minimum voltage point consider the sum of the voltage drop in the distributor will be zero.

$$x \times 0.08 + (x-40)\times 0.1 + (x-70)\times 0.06 + (x-120)\times 0.04 + (x-140)\times 0.02 = 0$$

$$x = \frac{40\times 0.1 + 70\times 0.06 + 120\times 0.04 + 140\times 0.02}{0.08 + 0.1 + 0.06 + 0.04 + 0.02}$$

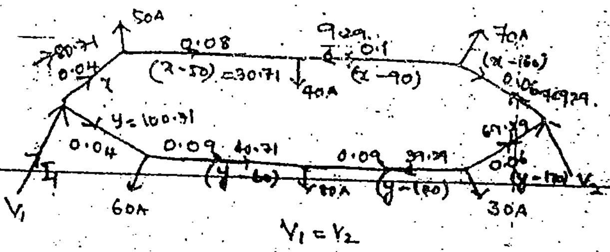
$$= \frac{\cancel{15.8}}{0.3} = 52.6\,A$$

$$V = 215 + 12.6\times 0.1 + 52.6\times 0.08$$

$$= 215 + 5.468$$

$$= 220.468\,V$$

(Q)



$V_1 = V_2$

(or)

$V_1 \neq V_2$

⇓

(Q) $V_1 = V_2 = 220\,V$.

Calculate the minimum voltages of the distributor.

→ If the ring main distributor is fed from n-sources then it will be resolved as n-radial distributors fed from both ends so that it consisting of n-minimum voltages.

$$x \times 0.04 + (x-50)\,0.08 + (x-90) \times 0.1 + (x-160) \times 0.06 = 0$$

$$x = \frac{50\times0.08 + 90\times0.1 + 160\times0.06}{0.04+0.08+0.1+0.06} = \frac{22.6}{0.28} = 80.71\,A$$

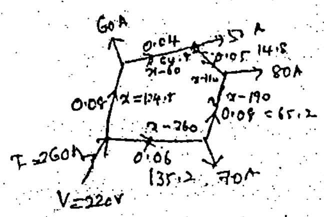
$$y \times 0.04 + (y-60)\,0.09 + (y-140) \times 0.09 + (y-190) \times 0.06$$

$$y = \frac{60\times0.09 + 140\times0.09 + 170\times0.06}{0.04+0.09+0.09+0.06} = \frac{28.2}{0.28} = 100.71\,A$$

$$V_{min} = 220 - 80.71\times0.04 - 30.71\times0.08 = 214.32\,V$$

$$220 - 100.71\times0.04 - 40.71\times0.09 = 212.3077\,V$$

(Q)



The new voltage of the distributor.

Sol

$$x\times0.08 + (x-60)\,0.04 + (x-110)\times0.05 + (x-190)\times0.08 + (x-260)\times0.06$$

$$x = \frac{60\times0.04 + 110\times0.08 + 190\times0.05 + 260\times0.06}{0.08+0.04+0.05+0.09+0.06} = \frac{...}{...} = 124.8\,A$$

$$V_{min} = 220 - 135.2\times0.06 - 65.2\times0.08$$

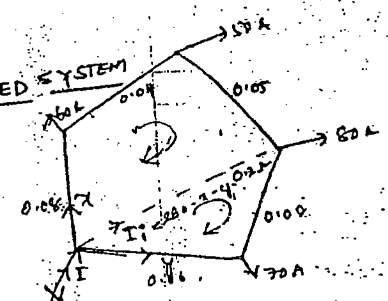
$$= 206.67\,V$$

(8)

$$V_{min} = 220 - (124.8\times0.08 + 64.8\times0.04 + 14.8\times0.05)$$

$$=$$

→ INTERCONNETED SYSTEM



If a ring main distributor is having only one source then there is a possibility to have a low voltage at the minimum potential and inorder to increase the min potential voltage, it is proposed to have an interconnector between the source and the minimum potential point so that certain amount of current will be carried out by the interconnector directly to the min potential point which will reduce the magnitude of the current in the distributor so that the voltage drops will be reduces.

→ In general the size of the ~~distributor~~ interconnector will be 50% to that of the size of the original distributor.

$$x\times0.08 - (x-60)\,0.04 + (x-110)\,0.05 - (260-x-y)\times0.20$$

$$= x\times0.08 - (x-60)\,0.04 + (x-110)\,0.05 - 52 + 0.2y$$

$$x(0.08+0.04+0.05+0.2) = 60\times0.04 + 110\times0.05 - 52 + 0.2y$$

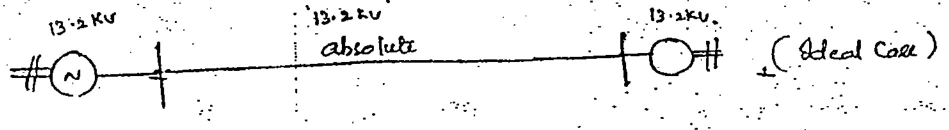
$$0.37x - 0.2y + 44.1 = 0.$$

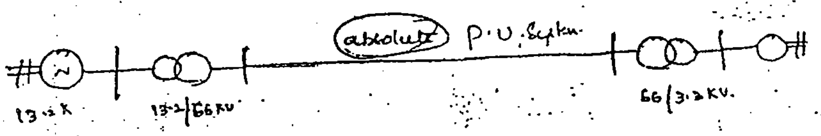
$$260 - x - y - (y - 70)\,0.08 - y \times 0.06 = 0.$$

→ PER UNIT SYSTEM, SYMMETRICAL COMPONENTS AND FAULT ANALYSIS.

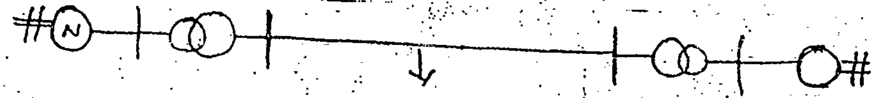
→ The fault analysis on the existing system can be carried out by using symmetrical components and they are expressed in per-unit values.

→ Electrical quantities
- absolute — associated with units
- per-unit — doesn't associated with units





ABSOLUTE SYSTEM	PER UNIT SYSTEM
1. If the given single line diagram is dealing with more than one operating voltage then the above single line diagram can be represented electrically with more than one electrical n/w so that there are more than one n/w equation to be solved. Hence the time taking is high, inorder to analyse the performance of the single line diagram.	1. The given single line diagram is dealing with more than one operating voltage then the above single line diagram can be represented electrically with only one network. Hence there is only one n/w equation to be solved. Hence the time taking is less inorder to analyse the performance of the given single line diagram.
2. The absolute impedance of the t/f in primary and secondary are not same so that it will be represented electrically as two circuits	2. In the per-unit system the impedance of the transformer will be same either on primary or secondary so it can be represented electrically as a single ckt only

→ 

↓

SLD

↓

Electrical Simulation — Imp/Reactance diagram in p.u.

(or)

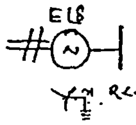
Machine Modelling (Electrically)

→ In the p.u system the given single line diagram can be represented as an electrical simulation diagram in a phase manner under the assumption of the load is balanced.

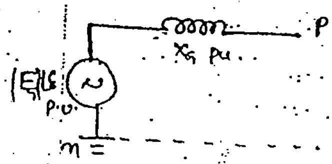
Ex: Syn machine → Voltage source in series with Impedance / Reactance.

T/f, Tr.line and Induction motors — Imp / Reactance.

SLD	SIMULATION

1) 

(Syn.m/c → Gen)

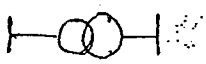


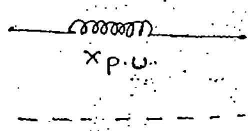
per phase — phase to neutral / phase to ground.

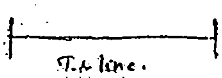
Balanced load ⇒ $I_n = 0$

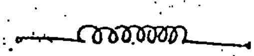
only Magnitude of Voltage is p.u.

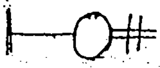
2) T/f.



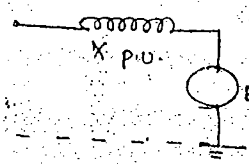


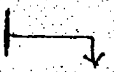
3) 



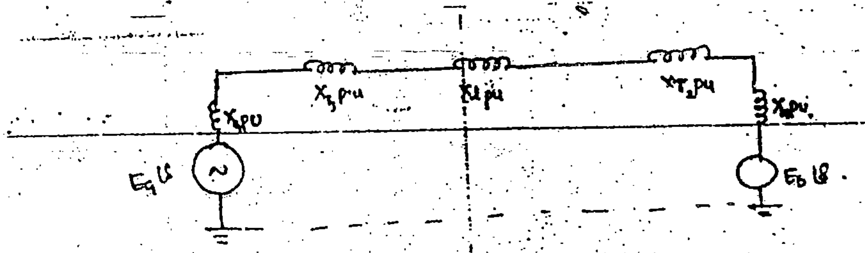
(4) 

(Syn. load)



(5) 

Asyn. load



Simulation diagram for SLD

The above simulation diagram is having the voltages and the reactances. These values needs to be represented in p.u manner. It is very easy to represent the voltage in p.u because the voltage is one of the rating, however a mathematical equation to be developed to represent the reactance in per unit in terms of the ratings of the equipment i.e.

(1) Voltage & current (or) voltage and its capacity in V.A.

→ **PER UNIT QUANTITY (OR) VALUE:**

$$\text{P.U Value} = \frac{\text{Actual (or) absolute quantity in the units}}{\text{Base or reference quantity in the same unit}}$$

→ The magnitude of the p.u quantity does depends on the Base value and the selection of the Base value is optional.

Ex:

	absolute	P.U	absolute	P.U
Gen-1	V_1	$V_1\,p.u = \frac{V_1}{V_{1b}}$	I_1	$I_1\,pu = \frac{I_1}{I_{1b}}$
Gen-2	$(V_2)_b$	$V_2\,pu = \frac{V_2}{V_{2b}}$	$(I_2)_b$	$I_2\,pu = \frac{I_2}{I_{2b}}$

same m/c

– In addition to the voltage, if the equipment is rated interms of current

– Select the current base from the same m/c if it is dealing with more than one electrical quantity as the rating.

<u>absolute</u>

$X_1 = \frac{V_1}{I_1}$

$X_2 = \frac{V_1}{I_2}$

<u>p.u</u>

$$X_1\,p.u = \frac{X_{1\Omega}}{X_{2b}} = \frac{X_{1\Omega}}{\frac{V_{2b}}{I_{2b}}} = X_{1\Omega}\cdot\frac{I_b}{V_{2b}} \qquad \frac{V_{2b}}{I_{2b}} = X_b\ \Omega$$

$$X_2\,p.u = \frac{X_{2\Omega}}{X_{2b}} = \frac{X_{2\Omega}}{\frac{V_{2b}}{I_{2b}}} = X_{2\Omega}\cdot\frac{I_b}{V_{2b}}$$

The ratio of two base values will give another base value but it will have a different unit.

∴ In general, $$\boxed{X_{p.u} = X_{\Omega}\,\frac{I_b}{V_b}} \longrightarrow (1)$$

If the equipment is having the rating in terms of the voltage and current.

However most of the equipments have their rating in terms of <u>Voltage</u> and its capacity in <u>Volt Ampere</u> rather than <u>voltage</u> & <u>current</u>

<u>absolute</u>

VA_1

$(VA_2)_b$

<u>p.u (x)</u>

$$X_1\,p.u = X_{1\Omega}\cdot\frac{I_{2b}}{V_{2b}} = X_{1\Omega}\cdot\frac{VA_{2b}}{\frac{V_{2b}}{V_{2b}}} = X_{1\Omega}\frac{VA_{2b}}{(V_{2b})^2} \qquad \frac{VA_{(b)}}{V_{2(b)}} = I_{2(b)}\,A.$$

$$X_2\,p.u = X_{2\Omega}\cdot\frac{I_{2b}}{V_{2b}} = X_{2\Omega}\cdot\frac{VA_{2b}}{V_{2b}/V_{2b}} = X_{2\Omega}\frac{VA_{2b}}{(V_{2b})^2}$$

∴ In General.

$$X_{p.u} = X_{\Omega}\,\frac{VA_b}{(V_b)^2}$$

$$= X_{\Omega}\,\frac{\frac{VA_b}{10^6}}{\left(\frac{V_b}{10^3}\right)^2}$$

$$\boxed{X_{p.u} = X_{\Omega}\,\frac{MVA_b}{(KV_b)^2}} \longrightarrow (2)$$

lly

$$\boxed{Z_{p.u} = Z_{\Omega}\,\frac{MVA_b}{(KV_b)^2}}$$

The p.u. Impedance/reactance is directly proportional to its capacity and inversely proportional to square of the operating voltage.

$Z_{p.u} \times 100 = Z\%$

phase value: $X_{p.u} \times 100 = X\%$

3-φ 3-W

MVA – 3-φ

KV – L-L

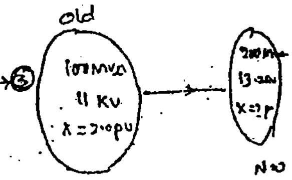
but "X" in phase

(Q) Alternator rated at 6.6 KV, 5 MVA and $X = 5\,\Omega$

$$X_{p.u} = 5 \times \frac{5}{(6.6)^2}$$

(Q) Alternator rates a 11 KV, 100 MVA having $X = 2.0$ p.u. The p.u reactance of the alternator for the rating of 200 MVA, 13.2 KV is.

$$\boxed{X_{p.u\,New} = X_{pu\,old} \times \frac{MVA_{new}}{MVA_{old}} \times \left(\frac{KV_{old}}{KV_{new}}\right)^2}$$



$$= 2 \times \frac{200}{100} \times \left(\frac{11}{13.2}\right)^2$$

$= $

Ily
$$\boxed{Z_{pu\,New} = Z_{pu\,old} \times \frac{MVA_{new}}{MVA_{old}} \times \left(\frac{KV_{old}}{KV_{new}}\right)^2}$$

(Q) What is the p.u reactance of the capacity & voltage are double.

$$X_{pu(new)} = 1 \times \frac{2}{1}\left(\tfrac{1}{2}\right)^2 = \frac{1}{2}$$

(Q) capacity ½, voltage = ½ $X_{pu} = ?$

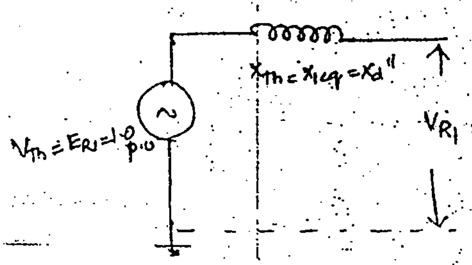
$$X_{pu(new)} = 1 \times \frac{1/2}{1} \times \left(\frac{1}{1/2}\right)^2 = 2 \text{ p.u. or } 200\%$$

(Q) Capacity = ¼ Voltage = 4 times $X_{p.u} = ?$

$$X_{pu\,new} = 1 \times \frac{1/4}{1} \times \left(\frac{1}{1/4}\right)^2$$

$$= 1 \times \frac{1}{4} \times \frac{16}{1} = 4\,pu = 400\%$$

to loaded alternator. Hence, the fault analysis can be carried out generally on a no load system rather than loaded system.

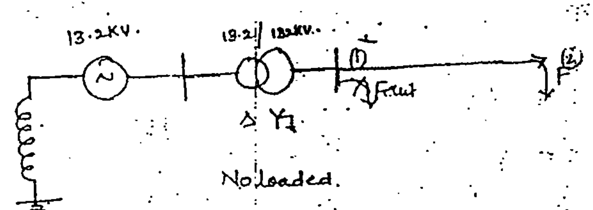


$V_{R1} = E_{R1} - I_{R1} X_{eq}$.

(+ve sequence subtransient terminal voltage)

+ve sequence sub-transient network.

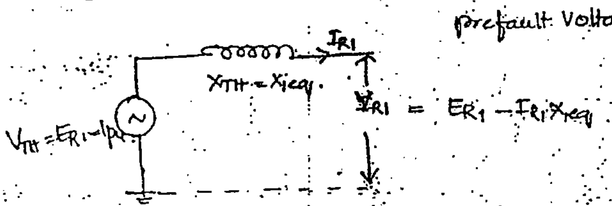
→



No loaded.

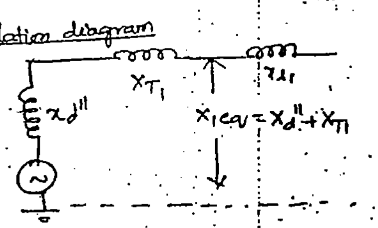
prefault voltage $V_{TH} = E_{R1} = 1.0 \rightarrow \left(\frac{132K}{132K}\right)$

Sol



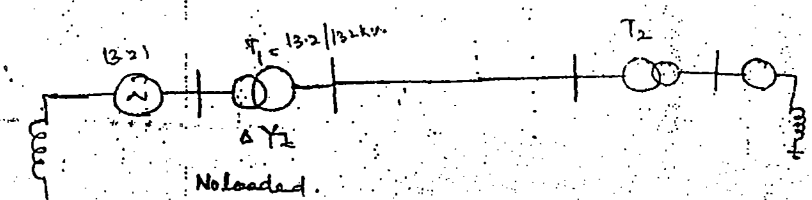
$V_{R1} = E_{R1} - I_{R1} X_{1eq}$.

(1) Simulation diagram



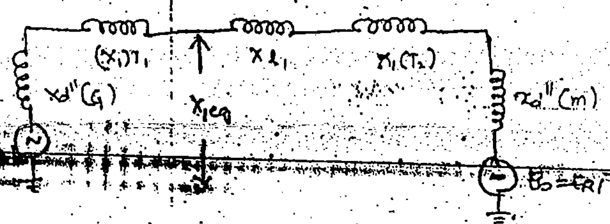
(2) $X_{1eq} = X_d'' + X_{T_1} + X_{l}$.

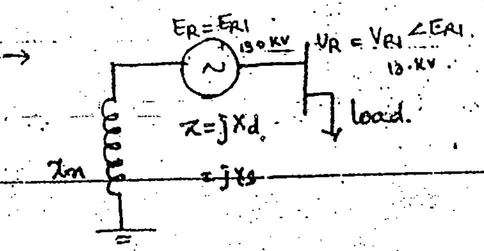
→ Special case:

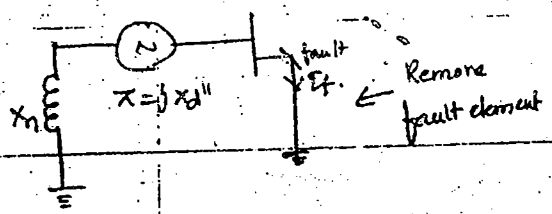


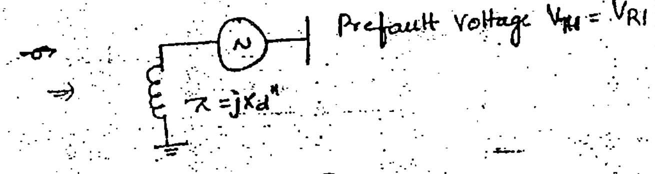
No loaded.

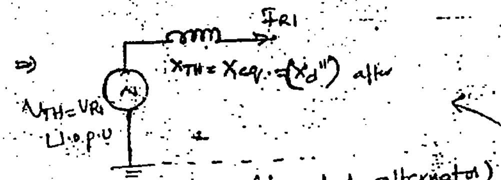
Since, two active sources on both sides.





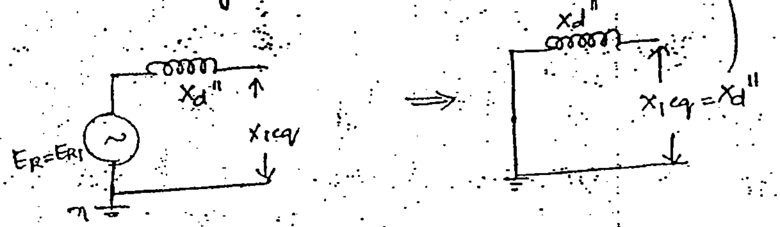


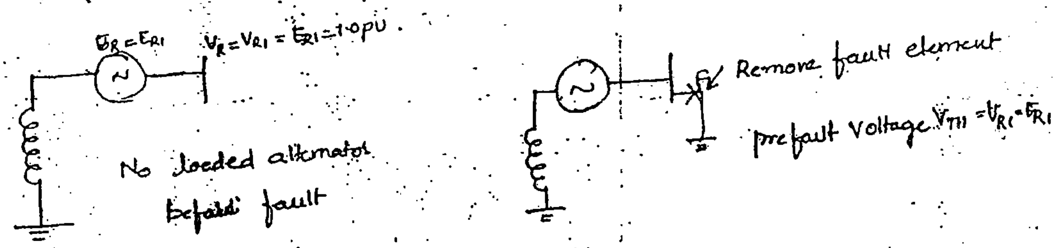


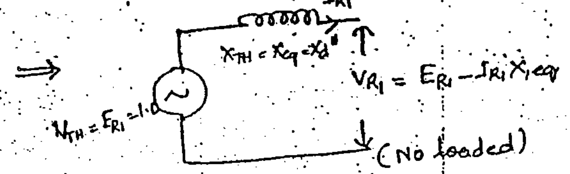


(Loaded alternator)

→ In order to evaluate reactance w.r.t fault point, draw the simulation diagram for the given SLD







There is no change in the equivalent reactance if the alternator is working under no load condition (or) loaded condition, however prefault voltages are different. In case of no loaded alternator the +ve sequence subtransient current delivered will be high compared

→ The Sequence Components are associated with their Sequence Networks:

(or) Subtransient Imp/Reactance n/w's

Balanced Components ⟶ per-phase.

→ In case of +ve and −ve sequence n/w's the reference is neutral where as in case of zero sequence n/w's the reference is ground. So include the neutral grounding effect ~~by~~ while drawing the zero sequence and ignore the neutral grounding effect while drawing +ve & −ve sequence n/w's

$$I_n = I_R + I_Y + I_B = 0 \quad \text{Balanced System}$$

$$\neq 0 \quad \text{Unbalanced System}$$

$$I_n = I_{R0} + I_{R1} + I_{R2} + I_{Y0} + I_{Y1} + I_{Y2} + I_{B0} + I_{B1} + I_{B2}$$

$$= I_{R0} + I_{R1} + I_{R2} + I_{R0} + K^2 I_{R1} + K I_{R2} + I_{R0} + K I_{R1} + K^2 I_{R2}$$

$$= 3 I_{R0} + I_{R1}(1 + K^2 + K) + I_{R2}(1 + K + K^2)$$

$$= 3 I_{R0} + 0 + 0$$

$$\boxed{I_n = 3 I_{R0}}$$

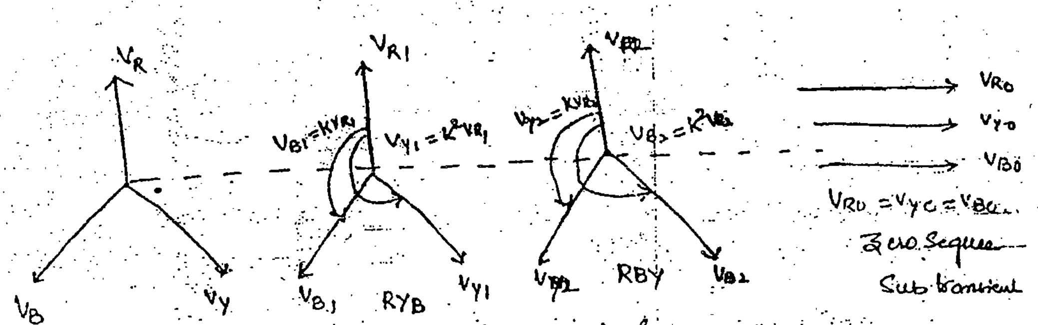
→ SEQUENCE NETWORKS:

→ Any sequence network consists of prefault voltage at the fault point in series with equivalent subtransient reactance which is evaluated with respect to fault point by replacing all the active sources with their internal reactances.

→ The sequence n/ws are also called as an Electrical equivalent of thevenin's theorem.

→ The single line diagram of the power system n/w may consisting of voltage sources because of the syn. m/c and they can be replaced as short circuit while evaluating equivalent reactance.

→ From the above, we can ~~udderstand~~ that the +ve and −ve sequence components are refferred to the phases where as the zero sequence components are referred to the ground.



Unbalanced Voltages RYB

+ve sequence Sub-transient

−ve sequence Sub-transient

$$V_R = V_{R0} + V_{R1} + V_{R2}$$

$$V_Y = V_{R0} + K^2V_{R1} + KV_{R2}$$

$$V_B = V_{R0} + KV_{R1} + K^2V_{R2}$$

$$\Rightarrow \begin{bmatrix} V_R \\ V_Y \\ V_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & K^2 & K \\ 1 & K & K^2 \end{bmatrix} \begin{bmatrix} V_{R0} \\ V_{R1} \\ V_{R2} \end{bmatrix}$$

Illy

$$\begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & K^2 & K \\ 1 & K & K^2 \end{bmatrix} \begin{bmatrix} I_{R0} \\ I_{R1} \\ I_{R2} \end{bmatrix} \Rightarrow \begin{bmatrix} I_{R0} \\ I_{R1} \\ I_{R2} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & K^2 & K \\ 1 & K & K^2 \end{bmatrix}^{-1} \begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix}$$

Unknown unbalanced

Known balanced Sequence Components.

$$A^{-1} = \frac{\text{Adj } A}{\det A}.$$

$$\begin{bmatrix} I_{R0} \\ I_{R1} \\ I_{R2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & K & K^2 \\ 1 & K^2 & K \end{bmatrix} \begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix}$$

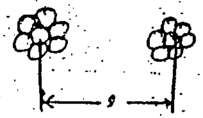
Unknown

Known.

Ex: Solid | Hallow | Stranded

Solid	Hallow	Stranded
m=1 (Smooth surface)	m=1 (Smooth surface)	m is less than one, $V_d \downarrow$
* → ρ less	→ ρ is least	⇒ Corona is high.
		⇒ ρ is high

→ Bunde Conductor.



Self GMD

* Corona loss

$\boxed{\text{Hallow} < \text{Solid} < \text{Stranded}}$

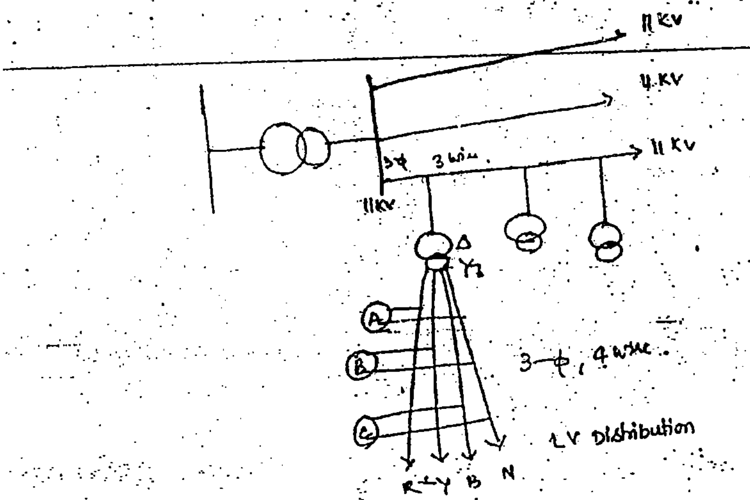
$\rho \uparrow V_d \propto \text{Self GMD} \uparrow$

$V_d \propto m$

$\therefore \rho \downarrow$

→ For the same amount of Current, the radius of the hallow conductor will be slightly high when compared to Solid, Hence V_d is high and Corona loss is less.

DISTRIBUTION SYSTEM:



(i) Feeder.
(ii) Distributor.
(iii) Service wires.

— Feeder is rarely used in distribution.

→ A Feeder is the one in which the magnitude of the ~~length~~ current throughout the length is same and in distribution system it is very rarely used.

→ Distributor is an element in which the magnitude of current varies throughout its length and in D-system it is the most common word.

— The selection of the size of the conductor for distributor is based on voltage drop, and if the operating voltage is increased by 'n' times then the area of c/s of distributor will reduced by $\frac{1}{n^2}$ times.

→ A Service wires are the completely insulated wires and they can connect the distributor to the consumer terminals.

→ The guard ring will protect the string of the insulator against direct lightening stroke in which the peak magnitude of the lightening surge will be discharged to the ground from the guard ring through the cross arm.

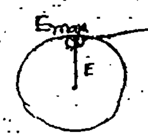
⇒ CONCEPT OF CORONA

– The ionisation of insulating material (air) near the surface of the power conductor at certain points is called as CORONA.

(OR)

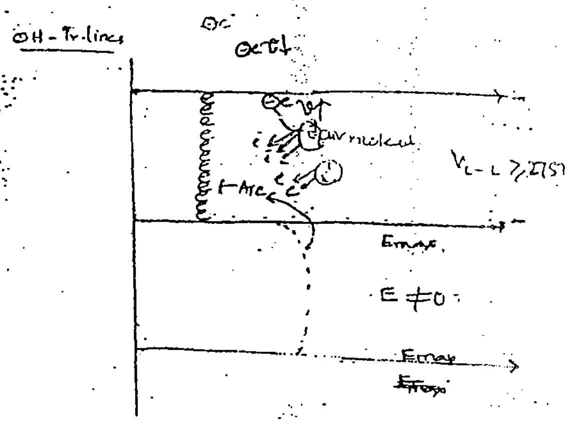
– The complete disruption of the dielectric strength of air near the surface of the power conductor at certain point is called as CORONA

→ Because of radioactivity in the space there are certain free electrons which are scattered.



$\uparrow E \propto v \uparrow$

$v \rightarrow$ Mobility of the electron.



→ As the operating voltage between the two conductors will increase then the electric field intensity at the surface of the conductor will increase which intern will increase the mobility of the electron near the surface of the conductor.

→ When the operating voltage b/w the two conductor has become $\geq 275K$ There will be huge electric field intensity at the surface of the conductor, so that the mobility of electron is very ~~and~~ high ~~and it will collide with any other air molecules so that some~~

Electrons can be released from those molecules.

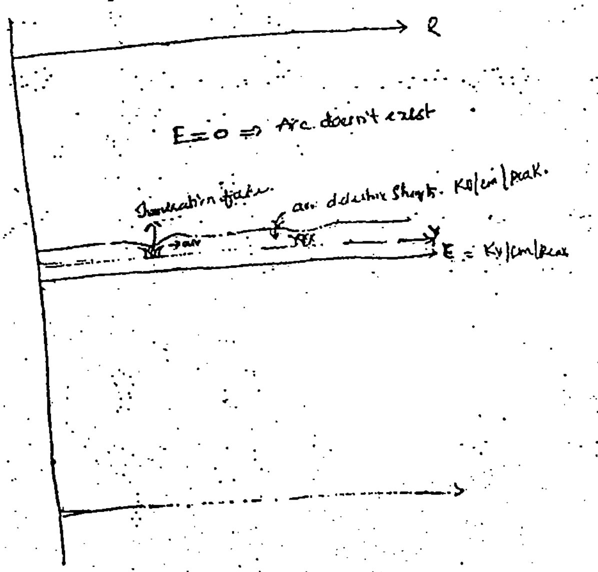
→ The released electrons will further collide with the other air molecules so that few more electrons are released ~~and it will be~~ continuous and after certain time, there will be an electron avalanche will taken place i.e., the distance b/w the two conductor is having ~~high~~ electron density and finally it will leads to the occurance of the arc b/w the two conductors.

— Arc is an ionized body. so that it will be treated as L-L fault.

→ There fore the reliability of the supply is reduced.

→ In order to eliminate the occurance of the arc at higher and higher operating voltages, then the tr. line is designed in such a way that the $\left(\frac{d}{r}\right)$ ratio >15 (d → dis b/w separation, r → rad of conductor)

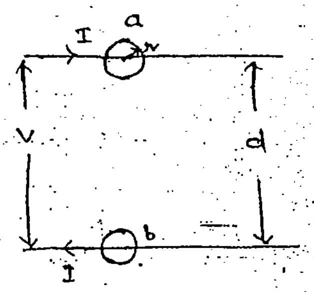
→ Even though the arc can be eliminated but there is a possibility to get the ionisation of air near the surface of the power conductor, at certain locations, because in those locations, the dielectric strength of air is expected to be less than the electric field intensity.



→ The voltage at which the ionisation of air takes place is called as CRITICAL DISRUPTIVE VOLTAGE (V_d)

→ The Ionisation of the air is the field intensified ionisation at Certain locations.

→ Critical Disruptive Voltage (V_d): (1-φ, 2-wire OHTL)



$$E_{max} = \frac{V}{r \ln(d/r)}$$

$$\boxed{V = \frac{E_{max}}{\sqrt{2}} \cdot r \ln(d/r)} \text{ KV/rms.}$$

g_0 = Dielectric strength of air KV/cm/peak.

$$\therefore \boxed{V_d = g_0 \cdot r \ln(d/r)} \quad \text{KV/rms.}$$

$g_0 = 30$ KV/cm/peak at NTP ⇒ 25°c and 76 cm Hg.

$\Rightarrow g_0 = \frac{30}{\sqrt{2}} = 21.1$ KV/cm/rms at NTP

$\therefore V_d = 21.1 \, r \ln(d/r)$ KV/rms.

— In a practical case it is difficult to maintain NTP. So at any temperature and pressure the critical disruptive voltage "V_d"

$$V_d = g' r \ln(d/r) \text{ KV/rms.}$$

g' = dielectric strength of air at any temperature & pressure.

$$g' = g_0 \cdot \delta$$

$\delta \rightarrow$ Air density factor (little less than 1)

$\delta = \frac{3.92 \times h}{273 + t} < 1$; h = actual pressure in cm of Hg.

t = actual temp in °c

$\Rightarrow \boxed{g' < g_0}$

$\therefore V_d = 21.1\ \delta\ r \ln(d/r)$ Kv/rms.

∴ Consider the surface irregularity factor i.e "m"

$\therefore \boxed{V_d = 21.1\ \delta\ m\ r \ln(d/r)}$ Kv/rms. → Calculated Value.

→ $m = 1$ → of surface is smooth (solid conductor)

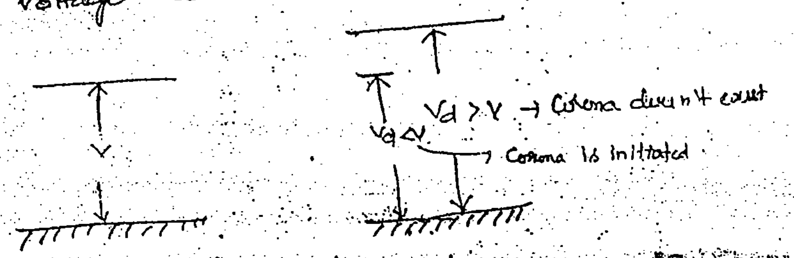
** → $m = 0.93 - 0.98$ → For rough surface (stranded conductor)

** → $m = 0.83 - 0.87$ → Underground cable

→ In Underground Cables, there is a possibility for the ionisation of the insulating material at higher operating voltages due to the temperature gradient.

→ * $\boxed{V_d \propto \delta,\ m,\ r,\ \ln(d)}$

→ In order to avoid the ionisation of the air, then the calculated critical disruptive voltage must be more than the operating voltage of the transmission system, for which the transmission line designed with maximum distance of seperation. However due to bad weather conditions which are prevailed in the atmosphere, the calculated critical disruptive voltage is appears to be less than the operating voltage so that the CORONA will be initiated.



For 3-ϕ OHTL

$$\boxed{V_d = 21.1\, \delta\, m\, r \ln\left(\frac{GMD}{r}\right)} \text{ KV/rms/phase}$$

$GMD = \sqrt[3]{xyz}$ → un symmetrical configurat

$GMD = d$ → symmetrical configuratio

For Bundle conductor (or) double circuit:

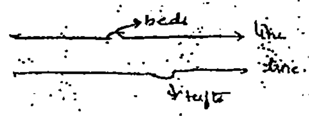
$$\boxed{V_d = 21.1\, \delta\, m\, \ln\left(\frac{GMD}{Self\ GMD}\right)} \text{ KV/rms/phase.}$$

→ Identification of the initiation of Corona on tr. line:

(1) Occurance of hissing noise

(2) Releasing of ozone gas.

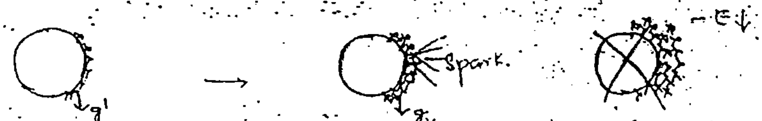
(3) Occuriance of beds and tufts at certain locations which can be seen through a "Stroboscope"



** ⇒ $r\uparrow$, $L\downarrow$, $C\uparrow$

8/2/10

→ VISUAL CRITICAL DISRUPTIVE VOLTAGE:



Corona is initiated

1. Corona is extended
2. The electron density will increase

not possible to extend over larger thickness of air.

→ As the corona is initiated then it will be extended near the surface of the conductor over a smaller thickness of the air. So that the density will increase, The increased electron density will result as the occurance of the spark near the surface of the conductor in the form of WHITE BLUISH GLOW COLOUR and the Voltage which corresponding to the occurrance of the spark is called as VISUAL CRITICAL DISRUPTIVE VOLTAGE.

$$\boxed{V_v = g_v\, m\, r \ln(d/r)} \quad \text{KV/rms.}$$

→ The occurance of the spark will takes place if there is a gradient for the dielectric strengths of air between the occurance of the spark and the corona is initiated.

$$g_v = g'\left(1+\frac{0.3}{\sqrt{r\delta}}\right)$$

$$\text{But } g' = g_0\delta = \frac{30}{\sqrt{2}}\delta = 21.1\,\delta \quad \text{KV/rms}$$

$$\boxed{V_v = 21.1\,\delta\, m\left(1+\frac{0.3}{\sqrt{r\delta}}\right) r \ln(d/r)} \quad \text{KV/rms.}$$

and

$$\boxed{V_d = 21.1\,\delta\, m\, r \ln(d/r)} \quad \text{KV/rms.}$$

$$\boxed{V_v > V_d}$$

→ For any t/line the occurance of the spark will take place at higher voltages when compared to the voltage at the which the CORONA is initiated.

→ Result of Corona: When the Corona is initiated then there will be certain amount of real power loss which will be converted into heat, so the insulating material will be slowly heated up. The loss due to occurance of the initiation of Corona is a real power loss which will be named as Corona loss apart from the ohmic loss of the system.

operating voltage/phase

critical disruptive voltage/phase.

Empherical formula, Corona loss $\boxed{P = 241\times10^{-5}\left(\frac{f+25}{\delta}\right)\sqrt{\frac{r}{d}}\,(V_p - V_d)^2}$ KW/phase/Km.

→ The Corona may not be initiated in all the three wires at the same time. So that the Corona loss will be expressed in phase manner

(Q) If $f = 50Hz$, $\delta = 0.95$, $r = 2.5\,cm$, $d = 8m$ $V_p = 292.45$, $V_d = 294.65$ kV/p.

$p = ?$

Sol) Here $V_p = 292.45$ kV/phase.

$V_d = 294.65$ kV/phase

** If $\boxed{V_d > V_p}$ → Corona does not exists

$\Rightarrow p = 0$

If $V_p = 292.45$ kV/phase

$V_d = 290.25$ kV/phase

* $\boxed{V_d < V_p}$ → Corona exists.

→ FACTORS INFLUENCING THE CORONA LOSS:

(1) Electrical factors

(i) Supply Frequency:

In ac system $p \propto (f+25)$

In dc system $p \propto 25$ $(f=0)$

∴ As the frequency ↑ ⇒ p_{ac} increases.

(Q) A 50Hz. tr-line $p = 1.2\,kW$, for 60Hz. $p = ?$

a) 1.2
b) 1.1
c) 1.26
d) 1.36.

$$\frac{P_1}{P_2} = \frac{(f_1+25)}{(f_2+25)} = \frac{1.2}{P_2} = \frac{75}{85}$$

$$P_2 = \frac{\cancel{85}\,17}{\cancel{75}\,15} \times 1.2 =$$

→ For the same operating voltage the Corona loss in d.c system is less when compared to a.c system.

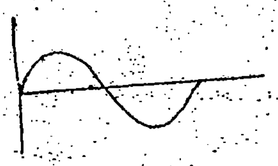
(Q) If 400 kV a.c tr. line; $p = 3$ kW, 400 kV dc tr.line. $p = ?$

a) 3 b) 6 c) 1 d) 2

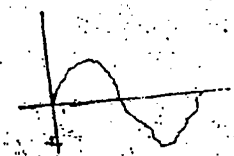
$3 \propto 75$

$p \propto 25 \Rightarrow p = 1$

(ii) Nature of Supply wave form: (a.c)



Sinusoidal wave

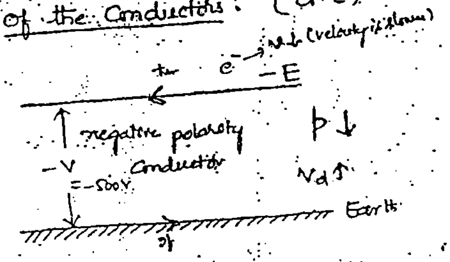


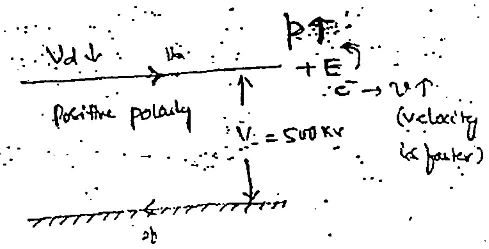
distorted wave

If 5th harmonic exists

$\downarrow p \propto (f+25)$ $\uparrow p \propto (f+5f+25)$

(iii) Polarity of the Conductors: (d.c)





As $p \propto (V_p - V_d)^2$

$\therefore p \propto \frac{1}{V_d}$ (V_d is −ve) $\Rightarrow$ As $V_d \downarrow \Rightarrow p \uparrow$

→ If the voltage at which the Corona occurs will be less then the Corona loss will be high.

→ In HVdc transmission we prefer negative polarity conductors to get less Corona loss.

(iv) Distance of Seperation between two Conductors:

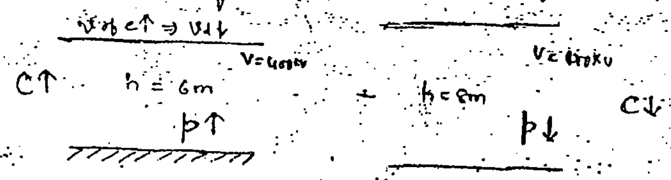
(i) $p \propto \frac{1}{\sqrt{d}}$ (from emphirical formula for Corona loss)

$\Rightarrow$ As $d \uparrow$ then $p \downarrow$

(or) (ii) $V_d \propto \ln(d)$

As $d \uparrow \Rightarrow V_d \uparrow \Rightarrow p \downarrow$

(iii) The height of the conductor from the ground



— If the height of the conductor from the ground is less then the Capacitance effect is high so that there will be better voltage profile throughout the length of the conductor which inturn maintains high electric field intensity, so that the mobility of electron is high. The critical disruptive voltage is less and the Corona loss is high.

(v) Configuration of the conductors:

— In case of unsymmetrical configuration the Corona loss will be high for the middle conductor when compared to outer conductors where as in case of symmetrical configuration the Corona loss will be same for all the three conductors.

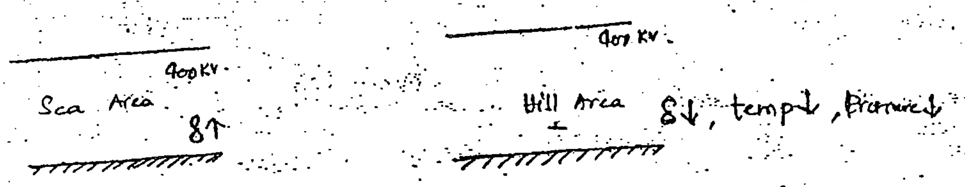
(2) ATMOSPHERIC FACTORS:

(i) ~~Temperature and~~ Pressure

Air density factor, $\delta = \dfrac{3.92 \times h}{273 + t}$

$$\downarrow P \propto \frac{1}{\delta \uparrow} \quad (\text{or}) \quad \uparrow V_d \propto \delta \uparrow (\delta) \Rightarrow P \downarrow$$

(Q)



Ans:

- The Corona loss in hill area will be high when compared to the corona loss in sea area.
- The fall in pressure is predominant when compared to fall in temperature at the hill areas so, that the air density factor will be low and the corona loss will be high.

(ii) Deposition of dust, Snow, Ice and fog on the surface of the Conductor

Bad weather condition

'm' is low (Surface irregularity factor)

$$\Rightarrow V_d \downarrow \Rightarrow P \uparrow$$

(3) Factors related to the size of the Conductor:

1 or 2M (i) To reduce the Corona loss, use larger radius of the Conductor.

$$P \propto 241 \times 10^{-5} \left(\frac{f+25}{\delta}\right) \sqrt{\frac{r}{d}} \left(V_p - V_d\right)^2$$

As 'r' of Conductor ↑

$$P \propto \sqrt{r}$$

However $P \propto (V_p - V_d)^2$

We know that $V_d' \propto r$

$\Rightarrow$ as $r\uparrow \Rightarrow V_d\uparrow$

and $V_d \uparrow \Rightarrow (V_p - V_d)^2 \downarrow$

$\therefore p \propto (V_p - V_d)^2$

$\Rightarrow$ As $(V_p - V_d)^2 \downarrow \Rightarrow p\downarrow$

Hence $(V_p - V_d)^2$ is more predominant than $\sqrt{r}$

As the radius $\uparrow \Rightarrow p\downarrow$

(ii) Employ more than one sub conductor per phase (Bundle Conductors)

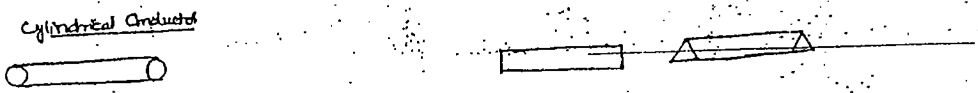
In Bundle conductors $\rightarrow$ Self GMD

As Self GMD $\uparrow \Rightarrow V_d\uparrow$

$\Rightarrow p\downarrow$

(iii) Profile of the Conductor (or) Shape of the Conductor

Cylindrical Conductor



1) uniform distribution of field intensity

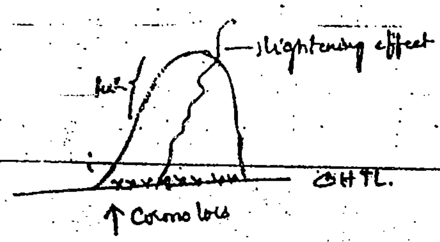
$\Rightarrow V_d\uparrow \Rightarrow p\downarrow$.

$V_d\downarrow$ $p\downarrow$

non-uniform 'E'

$\longrightarrow$ ADVANTAGES OF CORONA

1) The Corona will acts as safety valve to the transmission line conductor against direct lightening stroke, in which the peak magnitude of the lightening surge will be dissipated in the form of Corona loss.

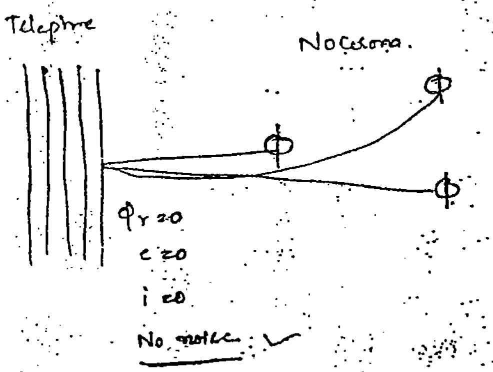


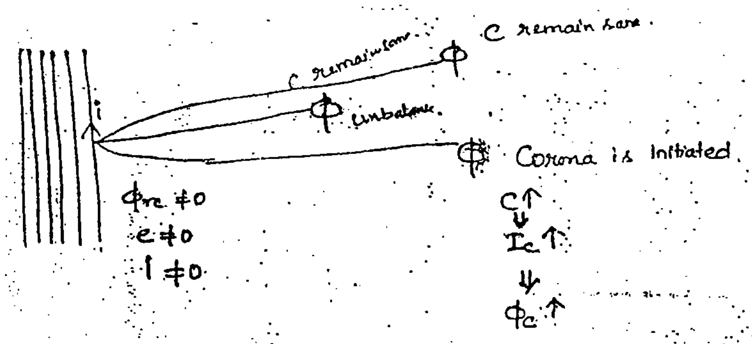
* Ground wire to protect the line a low insulation level.

→ **Disadvantages of Corona:**

(1) There is certain real power loss in the form of Corona loss.

(2) The Corona cause an interference with the neighbouring communication line because the net charging flux that can be linked with communication line is not zero.





→ **Methods to reduce the Corona loss:**

(1) Use larger size of the conductor

(2) Use hallow conductor

(3) Use bundle conductor (most practical)

$$3C_1' = c'$$

$$\boxed{C_1' = \frac{c'}{3}}$$

→ $I_2'' = I_2'$

$$(V_3 + V_4)\omega C_2' = (V_1 + V_2)\omega c'$$

$$2C_2' = 2c'$$

$$\boxed{C_2' = c'}$$

→ $I_3'' = I_3'$

$$V_4 \omega C_3' = (V_1 + V_2 + V_3)\omega c'$$

$$\boxed{C_3' = 3c'}$$

→ In general, the static capacitance at the required 'Kth' disc is

** $$\boxed{C_K' = \frac{Kc'}{n-K}}$$ where $K \neq n$ always.

$$C_1' = \frac{c'}{3}$$

$$C_2' = \frac{2c'}{4-2} = \frac{2c'}{2} = c'$$

$$C_3' = \frac{3c'}{4-1} = 3c'$$

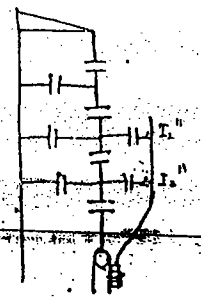
→ The 'K' is considered from the cross arm to the power conductor and it is not exactly equal to the no. of discs.

→ Gaurd ring is partially effective:

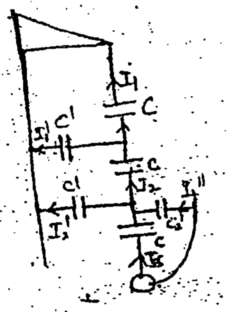
If the G.R is not fully effective

$\% \eta < 100\%$

$V_4 = V_3 = V_2 = V_1$



(Q) In a 3-disc string insulator, the Gaurd ring is effective only for a disc near to the power conductor. The shunt capacitance is $\frac{1}{10}$th of the self capacitance. The peak voltage of the disc is 10 kV. Calculate the voltage of the string, string efficiency and the static capacitance.



Sol

$$V_3 = V_2 \neq V_1.$$

$$\Rightarrow \quad V_3 = 10\ \text{kV}$$

$$V_2 = 10\ \text{kV}.$$

$$V_2 = V_1(1+K)$$

$$V_1 = \frac{10}{1.1}$$

$$V_1 = 9.09\ \text{kV}.$$

$$V = V_1 + V_2 + V_3$$

$$= \underline{29.09}\ \text{kV}.$$

$$\%\eta = \frac{29.09}{3 \times 10} \times 100 = \underline{\underline{96.76\%}}$$

For C_2'

$$\rightarrow \quad I_2'' = I_2'$$

$$V_3 \omega C_2' = (V_1 + V_2)\omega C'$$

$$10 C_2' = 19.09 C'$$

$$C_2' = \frac{19.09}{10} C'$$

$$\boxed{\frac{C_2'}{C'} = 1.909}$$

Advantages of Multishell Pin Insulator

(1) Due to the multishells the paths for leakage current will increase so that the magnitude of the leakage current is less.

(2) During bad weather conditions the top shell will become wet and the bottom shells are dry, so that there will be more resistance for leakage current. Hence the magnitude of leakage current is reduced.

(3) It can withstand the lightening voltages by splitting the lightening magnitude across each shell.

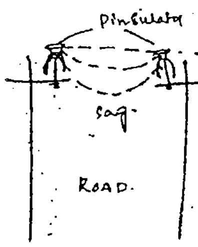
→ Multishells are also called as Rainsheds.

→ The multishell pin insulator will become uneconomical for the voltage 66KV and above so that the String (or) Suspension Insulator is used.

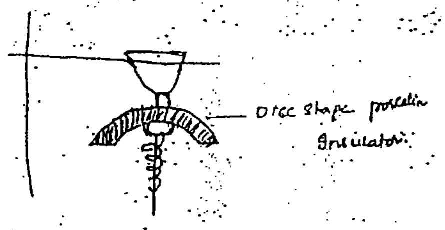
* Cost of insulator $\propto V^x$, $x > 2.0$

5/02/10

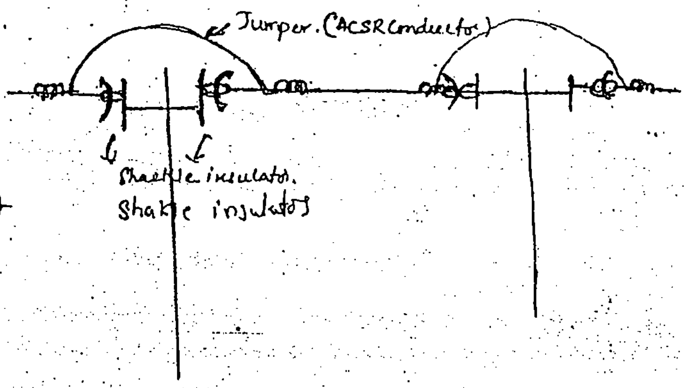
(2) SHACKLE INSULATOR:



As temp ↑, Sag increases which is unwanted. Hence going for Shackle Insulator.

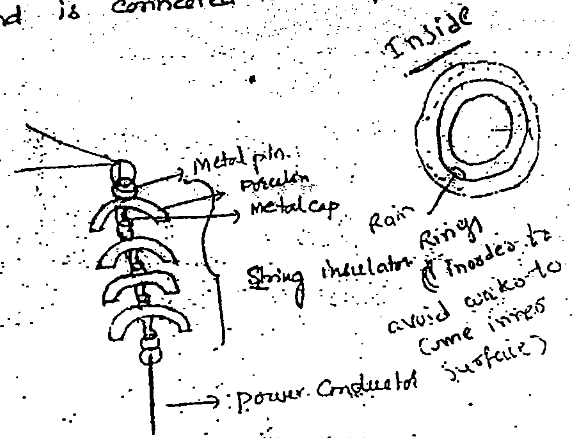


→ The no. of shackle insulators which are required are normally "double" that of no. of pin insulators.

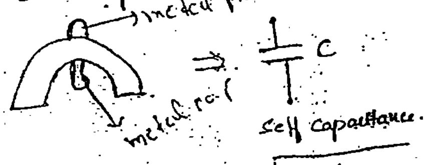


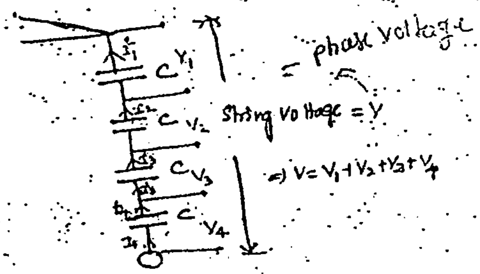
(4) STRING OR SUSPENSION INSULATOR:

It consists of two or more larger disc shape porcelain insulator which are connected each other in a flexible manner in order to form a string. One end of the string is connected to the cross arm and the other end is connected to the power conductor.



→ A disc is a mechanical concept can be represented electrically as a capacitor





→ $V_4 = I_4 X_C$

$V_3 = I_3 X_C$

$V_2 = I_2 X_C$

$V_1 = I_1 X_C$

→ In general $V_4 > V_3 > V_2 > V_1$ since $I_4 > I_3 > I_2 > I_1$

→ The utilization of the insulating material of a given string can be analysed by defining the concept of "String efficiency"

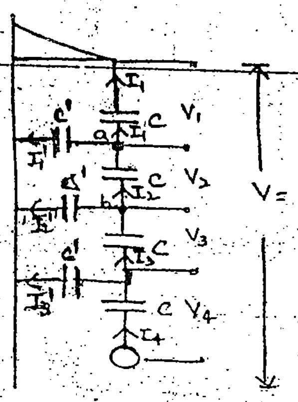
→ String efficiency:

$$\% \text{ String efficiency} = \frac{\text{Voltage across the string}}{\text{no. of discs} \times \text{Voltage of a disc near to power Conductor}} \times 100$$

$$\eta = \frac{V_1 + V_2 + V_3 + V_4}{4\,V_4} \times 100 \quad \text{(Four Insulators}$$

In a.c system, the string efficiency is less than 100%, because

(i) The occurance of shunt capacitance (c')



$$\boxed{\frac{\text{Shunt cap}}{\text{Self cap}} = \frac{c'}{c} = K} \text{ (Multiplication factor)} \quad c' < c$$

$$K < 1$$

At 'a', $I_2 = I_1 + I_1'$ ($\because$ All are charging unit and not expressed with angle)

$$V_2 \omega C = V_1 \omega C + V_1 \omega C'$$

$$V_2 \omega c = V_1 \omega c + V_1 \omega Kc$$

$$\boxed{V_2 = V_1(1+K)}$$

Voltages across each discs are unequal i.e string efficiency is less than 100%. is due to effect of shunt capacitance

At 'b', $I_3 = I_2 + I_2'$

$$V_3 \omega c = V_2 \omega c + (V_1+V_2)\omega c'$$

$$V_3 \omega c = V_2 \omega c + (V_1+V_2)\omega Kc$$

$$V_3 \omega c = V_2 \omega c + V_1 \omega Kc + V_2 \omega Kc$$

$$V_3 \omega c = V_2 \omega c(1+K) + V_1 \omega Kc$$

$$V_3 \omega c = \omega c(V_1(1+K))(1+K) + V_1 \omega Kc$$

$$V_3 \omega c = V_1(1+K)^2 \omega c + V_1 \omega Kc$$

$$V_3 = V_1(1+K^2+2K) + V_1 K$$

$$\boxed{V_3 = V_1(1+3K+K^2)}$$

At 'c'

$$I_4 = I_3 + I_3'$$

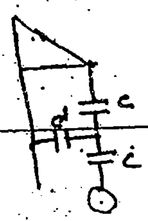
$$V_4 \omega c = V_3 \omega c + \cancel{V_3 \omega c'}(V_1+V_2+V_3)\omega c'$$

$$V_4 \omega c = V_3 \omega c + \cancel{V_3 \omega Kc}\, V_1 \omega c' + V_2 \omega c' + V_3 \omega c'$$

$$= V_3 c$$

$$\boxed{V_4 = V_1(1+6K+5K^2+K^3)}$$

(Q) What is the string efficiency of the system if $c' = \frac{1}{2} c$



Sol

$$\% \eta = \frac{V_1 + V_2}{2V_2} \times 100$$

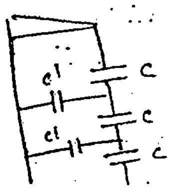
$$= \frac{V_1 + V_1(1+K)}{2(1+K)V_1} \times 100 \qquad K = \frac{c'}{c} = 0.5$$

$$= \frac{\cancel{V_1}(1 + 1(1+K))}{\cancel{V_1}(2(1+K))} \times 100$$

$$= \frac{(1 + (1+0.5))}{2(1+0.5)}$$

$$\% \eta = \frac{1 + 1.5}{2(1.5)} = \frac{2.5}{3} \times 100 = 83.3\%$$

(Q) $\% \eta = ?$ if



$c' = \frac{1}{10} c$

Sol

$$\% \eta = \frac{V_1 + V_2 + V_3}{3 \times V_3} \times 100$$

$$= \frac{V_1 + V_1(1+K) + V_1(1+3K+K^2)}{3(1+3K+K^2)} \times 100$$

$$= \frac{3 + 4K + K^2}{3(1+3K+K^2)} \times 100 \qquad K = \frac{c'}{c} = \frac{1}{10} = 0.1$$

$$= \frac{3 + 4(0.1) + (0.1)^2}{3(1 + 3(0.1) + (0.1)^2} \times 100$$

$$= \frac{3 + 0.4 + 0.01}{3(1.3) + (0.01)} \times 100$$

$$\% \eta = 86.76\%$$

(Q) A 3-φ, 3wire 33KV system is Having a string of 3 disc insulators. the shunt capacitance is $\frac{1}{10}$th of the self capacitance. What are the voltage drops across each disc

Sol

$$V_1 + V_2 + V_3 = \text{String Voltage}$$

$$V_1 + V_2 + V_3 = \frac{33 \times 10^3}{\sqrt{3}}$$

$$V_1 + V_1(1+K) + V_1(1+3K+K^2) = \frac{33 \times 10^3}{\sqrt{3}}$$

$$V_1 (3+4K+K^2) = \frac{33 \times 10^3}{\sqrt{3}}$$

$$V_1 = \frac{33 \times 10^3}{\sqrt{3}(3+4K+K^2)}$$

$$V_1 = \frac{33\,K}{\sqrt{3}(3+0.4+0.01)} \qquad K = \frac{1}{10} = 0.1$$

$$V_1 = 5.56\,KV.$$

$$V_2 = V_1(1+K)$$
$$= 5.56(1+0.1)$$
$$= 5.165\,V$$

$$V_3 = V_1(1+3K+K^2)$$
$$= 5.56(1+3(0.1)+(0.01)^2)$$
$$= 7.2836\,KV.$$

(Q) In a 3-disc string insulator, the peak voltage of the disc is 9KV the shunt capacitance of the string is $\frac{1}{10}$ of self capacitance. The Voltage across the string in KV is ____

Sol

Given $V_3 = 9KV.$

$$\frac{C'}{C} = K = \frac{1}{10} = 0.1$$

$$V_3 = V_1(1+3K+K^2)$$

$$V_1 = \frac{V_3}{1+3K+K^2} = \frac{9}{1+3(0.1)+(0.01)} = 6.87\,KV$$

$V_2 = V_1(1+K)$

$= 6.87(1+0.1)$

$= 7.55\ KV.$

Voltage across string, $V = V_1 + V_2 + V_3$

$= 6.87 + 7.55 + 9$

$= \underline{23.42\ KV}$

(Q) In a 2-disc string insulator, the voltages across the discs are 10KV and 8KV. The ratio of the self capacitance the shunt capacity is.

Sol

$V_2 = 10$

$V_1 = 8$

$V_2 = V_1(1+K)$

$\cancel{10}^{5} = \cancel{8}^{4}(1+K)$

$4 + 4K = 5$

$4K = 1$

$K = \frac{1}{4} = \frac{c'}{c}$

$\therefore \frac{c}{c'} = \frac{1}{K} = \underline{4}$

(Q) In a 4-disc string insulator the peak voltage of the disc is 30% to that of string voltage, ~~voltage~~. The string efficiency of the system is

Sol

$\%\eta = \frac{V}{n V_4}$

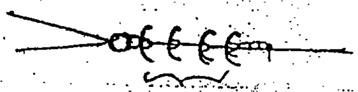
$= \frac{\cancel{V}}{4 \times 0.3 \times \cancel{V}} \times 100$

$= \frac{100}{1.2}$

$\%\eta = \underline{83.33\%}$

→ For the Same operating voltage the string efficiency for the dc system is 100% because the shunt capacitance effect can be ignored. (little less than 100% for practical case)

→ When ever the road crossing, we have Strain (or) tension insulator.



Strain Insulator

The efficiency of Strain (or) tension Insulator = 100%. Since there is no shunt capacitance effect

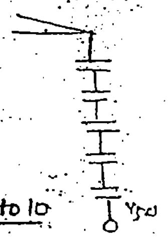
→ Advantages of String (or) Suspension Insulators:

(1) Each disc is normally rated for 11KV, so that the operating voltage can be increased by adding the extra required no. of discs only.

→ For 66KV → $\frac{66}{\sqrt{3}} = \frac{38.105}{11} = 3.46 \simeq \cancel{4}\ \boxed{5}$

→ but no. of disc required are $\boxed{5}$ since of unequal voltages across each disc.

* The Extra disc is for the safety purpose.



→ For 132KV → $\frac{132}{\sqrt{3}} = \frac{76.22}{11} = 6.9 \simeq 7+1 = 8$ to 10

→ For 220KV = $\frac{220}{\sqrt{3}} = \frac{127.3}{11} = 11.5 \simeq 12+1 = 13$ to 16

→ For 400KV = $\frac{400}{\sqrt{3}} = \frac{230.9}{11} \simeq 20.9 \simeq 21+1 = 23$ to 28

S. Cut

66 → $\frac{66}{11} = 6 - 1 =$

132 → $\frac{132}{11} = 12 - 2 =$

220 → $\frac{220}{11} = 20 - 4 =$

400 → $\frac{400}{11} = 36 - 8 =$

(2) It requires the replacement of failed disc only.

~~(3) The string is flexibly connected so that it can make the~~ oscillations horizontally inorder to supress the wind effect. However it requires the longer length of cross arms.

→ **METHODS TO IMPROVE STRING EFFICIENCY:**

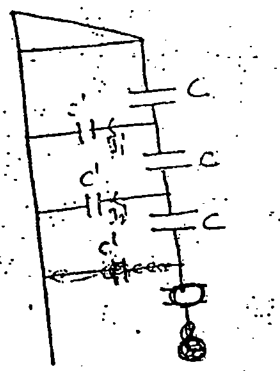
The method which suggests is make equal voltage drop across each disc so that the efficiency will almost 100%

(1) Selection of 'K' value → Similar discs. (Most practical one) ≃100%

(2) Grading of insulators → Dissimilar discs ≈ 100%

(3) Static sheilding or Gaurd ring → Similar disc's = 100%

(1) Selection of 'K' Value: (longer cross arm)



$$K = \frac{C'}{C}$$

$V_3 \neq V_2 \neq V_1$

$I_3 \neq I_2 \neq I_1$

$I_2' = I_1' = 0$ Un practical

because the l

$$\boxed{C' = \frac{1}{10} C}$$

→ If the length of the cross arm is reduced then the shunt capacitance will increase so that the charging current of the shunt capicator which will reduce the currents in self capacitance

So that the string efficiency ~~is reduced.~~

→ In order to make the voltage drops are almost equal, there should be optimum length of cross arm. So that $c' = \frac{1}{10}c$ can be recommended.

$$\boxed{K = \frac{c'}{c} = \frac{1}{10}}$$

(ii) <u>Grading of the Insulators:</u> (Dissimilar disc) (Equal voltages) = 100% efficiency

→ In the capacitance grading of the Insulator, the disc which is having less capacitance will be placed near to the cross arm and the disc which is having highest capacitance will be placed near to the power conductor.

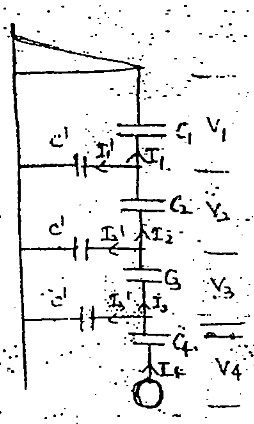
$V_4 = V_3 = V_2 = V_1$

$I_4 \times X_{C4} = I_3 \times X_{C3} = I_2 \times X_{C2} = I_1 \times X_{C1}$

$I_4 > I_3 > I_2 > I_1$

$\boxed{X_{C4} < X_{C3} < X_{C2} < X_{C1}}$

$\boxed{C_4 > C_3 > C_2 > C_1}$



<u>The calculation of the capacitance of the disc if c' & C_1 are given.</u>

→ $I_2 = I_1 + I_1'$

$V_2 \omega C_2 = V_1 \omega C_1 + V_1 \omega c'$

$\boxed{C_2 = C_1 + c'}$ $(\because V_2 = V_1)$

→ $I_3 = I_2 + I_2'$

$V_3 \omega C_3 = V_2 \omega C_2 + (V_1 + V_2)\omega c'$

$\boxed{C_3 = C_2 + 2c'}$

$\boxed{\cancel{C_3 = C_2 + 2c'}}$

→ $I_4 = I_3 + I_3'$

$$V_4 \omega C_4 = V_3 \omega C_3 + (V_1 + V_2 + V_3)\omega C'$$

$$\boxed{C_4 = C_3 + 3C'}$$

** ∴ For n-disc, n^{th} disc placed at cross arm

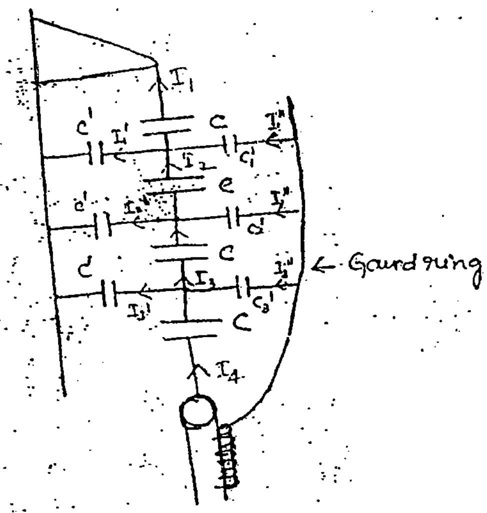
$$\boxed{C_n = C_{n-1} + (n-1)C'}$$

(3) Gaurd Ring (or) Static shielding method:

$V_4 = V_3 = V_2 = V_1$

$I_4 = I_3 = I_2 = I_1$

$I_4 X_C = I_3 X_C = I_2 X_C = I_1 X_C$



→ Due to Gaurd ring the static capacitance is formed between the insulator disc and the gaurd ring

→ The charging current of the shunt capacitance will be supplied by the charging current of the static capacitance, so that there will be equal currents in each disc, which will result as equal voltage drops.

$$\% \eta = 100\%$$

→ Calculation of Static capacitance. $V_1 = V_2 = V_3 = V_4$

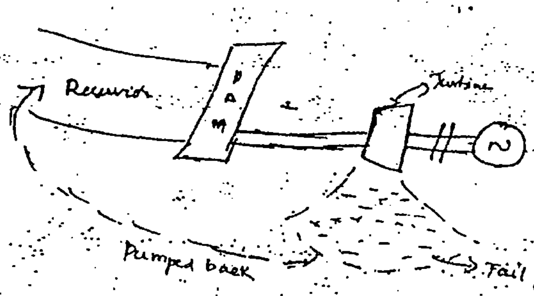
$I_1'' = I'$

$(V_4 + V_2 + V_3)\omega C' = V_1 \omega C'$

that the efficiency of runoff river without pondage will improve.

(iii) Reservoir type: In the reservoir type huge volume of water can be stored by constructing dam across the river during floods and the stored water can be utilized to generate the power over a specified period.

(iv) PUMPED STORAGE PLANT:



In this type the water is drawn from the dam for the generation purpose and the utilized water will be stored temporarily at the tail pond and during light load condition on the network the stored water will be fed back to the reservoir.

→ **Efficiency is only of 60% because some of the units are re-utilized for pump mode.

→ The turbine which is used in pumped storage plant is Reversible turbine.

(4) BASED ON APPLICATION

1) Base load plant

2) Peak load plant

→ CLASSIFICATION OF TURBINES:

(1) BASED ON HEAD:

(i.) 2-15m → Propellar (or) Kaplan turbine

(ii) 15-70m → Kaplan (or) Francis

(iii) 70-500m → Francis or pelton wheel

*(iv) above 500m → Pelton wheel

**(v) upto 300m → Deriaz turbine

(2) DIRECTION OF FLOW:

(i) Tangential flow → Pelton wheel

(ii) Mixed flow (Radial inflow + Axial outflow) → Franchis turbine

(iii) Axial flow → Kaplan (or) propellar

*(iv) Diagonal flow → Deriaz turbine → upto 300m

→ The preferrable turbine used for revousible mode of operation is Deriaz turbine

(3) BASED ON SPECIFIC SPEEDS:

Specific speed: It is the speed of the turbine which is working with a head of 1m and 1 metric horse power

** $\boxed{N_s = \frac{N(P)^{1/2}}{H^{5/4}}}$

$\Rightarrow N \propto \sqrt{P}$

$\Rightarrow \boxed{N_s = \frac{1.15\, N.\, P^{1/2}}{h^{5/4}}}$ P is in KW

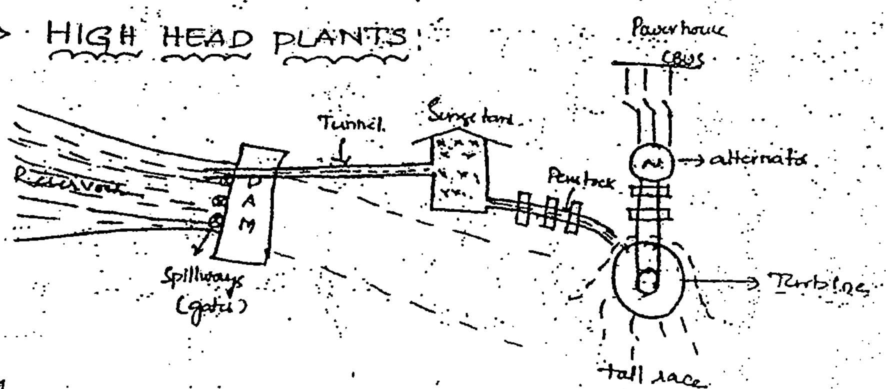
→ SPECIFIC SPEEDS:

discharge
(i) Low speed → 4 - 70 rpm → Pelton wheel
(ii) Medium speed → 70-420 rpm → Francis
(iii) High speed → 350 - 910 rpm → Kaplan (or) Propellar

→ ** Francis turbine can give maximum power with available head and discharge

✓ F → $P \propto (Q h)$ Medium
✓ P → $P \propto \uparrow Q \; h \downarrow$
✓ K → $P \propto \downarrow Q \; h \uparrow$

→ HIGH HEAD PLANTS:



In case of high head plants the power house is normally located away from the dam to reduce the pressure of water

Dam: It is the big R.C.C structure developed b/w the two natural hills in order to develop an amount of head as well as to provide storage facility

Reservoir: It is the catchment area of the dam in which the water is stored.

Spillways (gates): The spill ways acting as safety devices to the dam in order to discharge the excess amount of water directly into the tail race during the floods

→ TUNNEL! The power house is away from the main dam so the required water is first taken from the dam to the surge tank by a closed canal or open canal which is known as tunnel. It is also made by R.C.C.

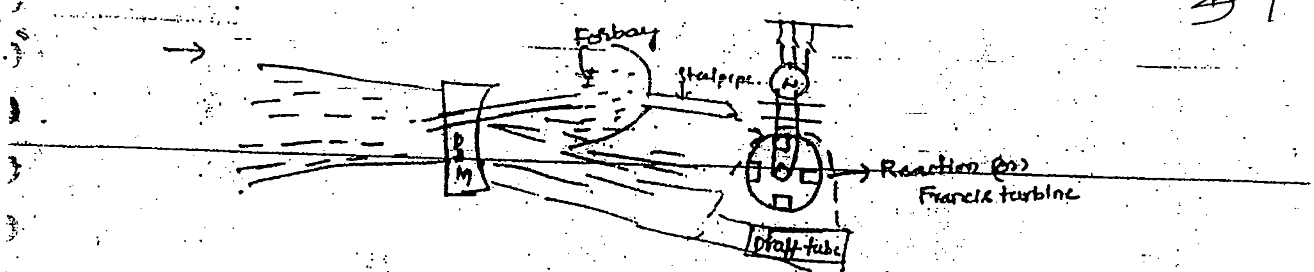
→ Surge tank: It is located near the turbine and the purpose of this is to store the water temperarily from which the water is allowed to the turbine. It will acts as temporarily regulating reservoir also.

→ Penstock: The turbine runner and the surge tank is connected through a steel pipes in case of medium and high head plants which are known as penstocks. The purpose of the penstock is to supply the water to the turbine from a surge tank.

→ If any sudden increase in the load on the alternator then the nozzle of the penstock will be open widely inorder to admit -ve pressure, so that the water should be sent to the penstock

→ If the load on the alternator is suddenly reduced the nozzle is closed, so that the excess should be sent back from the penstocks where the penstock are developed with +ve pressure. The development of +ve and -ve pressure in the penstock is called "Water Hammer effect"

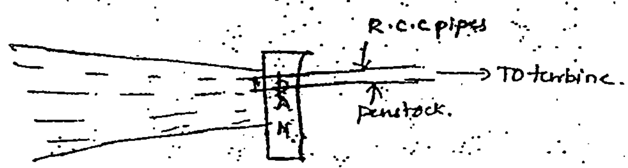
→ The purpose of the surge tank is to supress the



→ Surge tank is also a temporarily water storage device from which the water is supplied to the turbine through penstocks. However from FORBAY, it can plan with more no. of penstocks.

→ The Draft tube is associate with reaction turbines, which will connect the runner outlet to the tail race with a gradually increased in diameter of the tube.

→ LOW HEAD PLANTS:



→ In case of low head plants the power house is located near the dam, so that the water is directly taken from the tank through penstocks which are made by R.C.C pipes

→ The velocity of water in penstocks is of

1.) low head → 2 m/sec

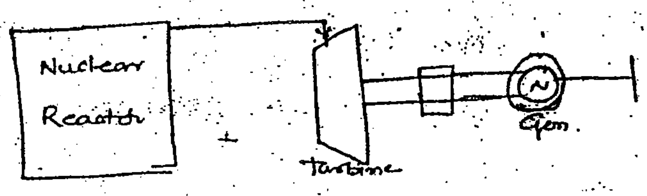
2.) Medium head → 4 m/sec

3.) High head → 8 m/sec.

3) NUCLEAR PLANTS

The high pressure and temperature steam is Converted into Electrical energy

→ High temperature and pressure steam can be obtained by the heat released from Radio active materials



* 1.2 Kg of Uranium is sufficient to generate 1 MW for 1 year

→ Selection of site:

1. Availability of water
2. It should be near to load centres but away from populated areas.
3. Facility to dispose the waste material
4. Easy accesible to road and Rail.

→ Plants in India:

(i) Tarapur → Trombay → 2 × 210 MW (Maharashtra)

✓FUEL: U^{238} → called as Enriched Uranium

→ 99.3% of Uranium

✓TYPE OF REACTOR: Boiling water Reactor (BWR)

(ii) Rana Pratap Sagar → Rajastan → 2 × 220 MW

✓FUEL: U^{235} → natural Uranium → 0.7%

✓Type of Reactor: CANDU reactor

(iii) Kalpakkam → 2 X 235 MW (Tamil Nadu)

FUEL: U^{235} → Natural Uranium (0.7%)

TYPE OF REACTOR: CANDU TYPE

(iv) NORARA → 2 X 235 MW (Uttar pradesh)

FUEL: U^{235}

REACTOR: CANDU

(v) KAKPARA → 2 X 235 MW (Gujarat)

FUEL: U^{235}

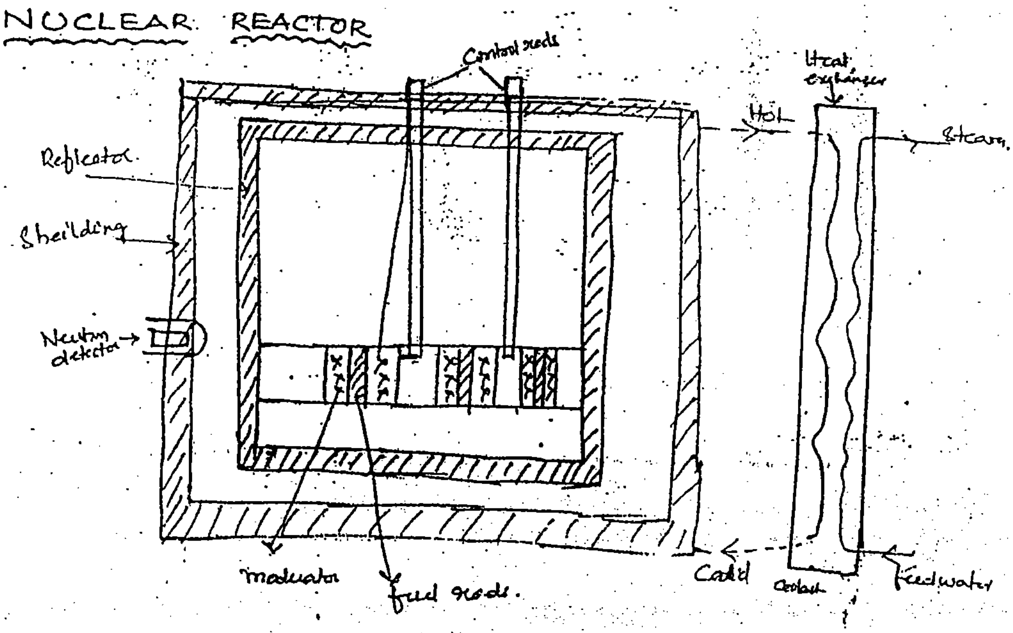
REACTOR: CANDU

(vi) KAIGA → 2 X 235 (Karnataka)

FUEL: U^{235}

REACTOR: CANDU

→ NUCLEAR REACTOR



→ Reactors are classified based on the speed of Neutrons

(i) Thermal Reactors → Speed less than 2000 m/sec

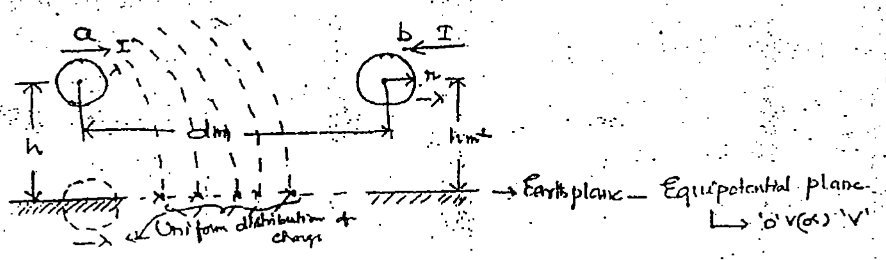
(ii) Fast Breeder Reactors → Speed more than 2000 m/sec

∴ Charging current, I_c/phase = $V_{phase}\,\omega\,C$/phase

$$V_{phase} = \frac{V_{L-L}}{\sqrt{3}}.$$

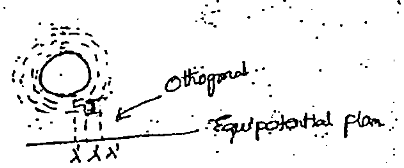
→ CAPACITANCE OF A 1-φ 2-WIRE TRANSLINE — FINITE EARTH PLANE

↳ By using Kelvin's Images law.



→ The No. of electric flux lines that can be generated from the surface of the conductor are equal to the amount of charge deposited on the surface of the conductor.

No. of flux lines = λ .



— Electric flux lines are orthogonal to equipotential plane

— Each flux will induced an amount of charge depending upon no. of flux lines.

Eg: $\lambda' \to -\lambda$

$\lambda' \to -\lambda/2$ for '2' flux line

$\lambda' \to -\lambda/3$ for '3' "

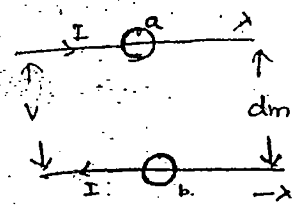
→ Due to more no. of electric fluxlines which can cut the Equipotential plane in an orthogonal manner, there will be uniform distribution of charges throughout the equipotential plane.

→ It is very difficult to calculate the capacitance b/w charge 'λ' and the uniform distribution of charges. So that the conjugu

— The Earth plane is also running in parallel to the tr. line conductors and this is an effect of Earth on capacitor calculations and the effect of the earth is not considered for inductance and resistance calculations.

→ By Assuming Earth as isolated i.e. infinite plane.

→ 1-ϕ 2-wire — Isolated Earth



$$C_{ab} = \frac{\lambda}{V} = \frac{\pi \epsilon_0 \epsilon_r}{\ln(d/r)} \text{ F/m.}$$

$$\therefore C_{ab} = \frac{\pi \epsilon_0}{\ln(d/r)} \text{ F/m} \quad (\because \epsilon_r = 1.0)$$

$$\Rightarrow C_{ab} = \frac{3.14 \times 8.854 \times 10^{-12}}{\ln(d/r)} \text{ F/m}$$

$$= \frac{3.14 \times 8.854 \times 10^{-9}}{\ln(d/r)} \text{ F/Km}$$

$$C_{ab} = \frac{3.14 \times 8.854 \times 10^{-3}}{\ln(d/r)} \text{ µF/Km.}$$

$$\Rightarrow C_{ab} \propto \frac{1}{\ln(d/r)}$$

As d is metres, and r is cm.

$$C_{ab} \propto \frac{1}{\ln(d)}$$

As the d ↑ ⇒ C_{ab} ↓

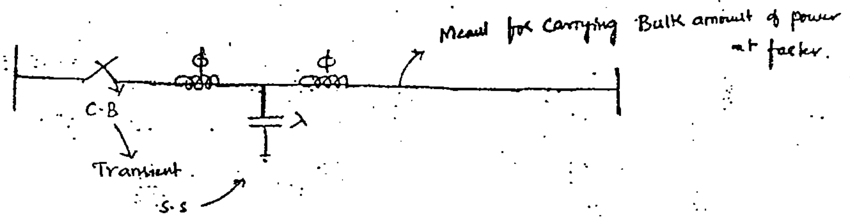
→ For Bundle conductors (or) Double circuit lines

the Inductance, $\boxed{L/\text{phase} = 0.2 \ln\left(\frac{GMD}{\text{self } GMD}\right)}$

⟹ CAPACITANCE:

1) 1-φ 2 wire

→ A 1-φ 2wire over head transmission line will act as a capacitor and the value of the capacitance will be increases as the length of the tr. lines increases.

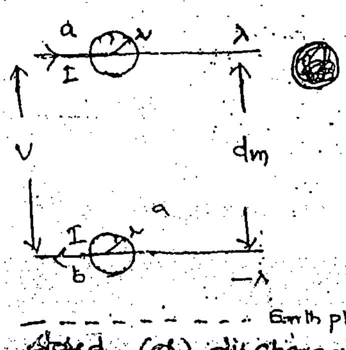


→ The Shunt capacitance of the Tr. line will be useful for

(1) Bulk amount of power carrier at a faster rate when the switch is closed

(2) In order to compensate the voltage drop of the inductive reactance

→ 1-φ-2wire

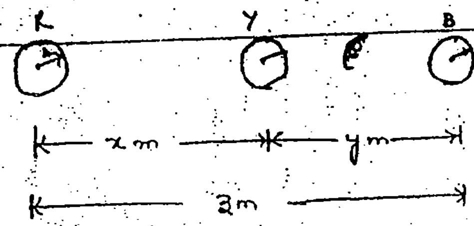


$$\text{Capacitance} = \frac{\text{Charge}}{\text{Voltage}}$$

→ It will build up the static field.

→ The instantaneous energy that can be stored (or) discharged by the capacitor $= \frac{1}{2} CV^2$ KVAR or MVAR

INDUCTANCE - 3-PHASE - 3 WIRE



Use the transposition of transmission line to get the equal inductance per phase.

We know $L_a = 0.2 \ln (d/r')$

$$\therefore \boxed{L/\text{phase} = 0.2 \ln \left(\frac{GMD}{GMR}\right)} \text{ mH/Km.}$$

where $GMD = \sqrt[3]{xyz}$

$GMR = r'$

If $x = y = z = d \Rightarrow$ Symmetrical Configuration.

$$\therefore L/\text{phase} = 0.2 \ln \left(\frac{GMD}{GMR}\right) \text{ mH/Km.}$$

where $GMD = d$

$GMR = r'$

Since GMD in metres

& GMR in cm.

$$\therefore \boxed{L \propto \ln (GMD)}$$

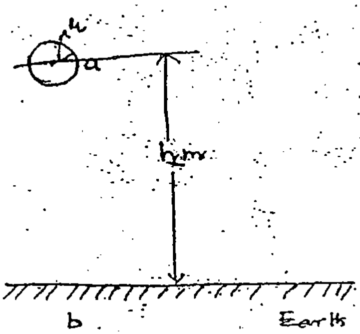
→ The inductance/Km in an unsymmetrical configuration will be slightly high when compared to the Inductance/Km of a Symmetrical Configuration.

$r_1 r_2$ distantance of separation

$$\boxed{\frac{X}{R} < 1.0}$$ $\longrightarrow$ For distribution system.

⇒ Resistance is predominant in distribution system where as Inductive Reactance is predominant in Transmission system.

→



$\therefore L_{ab} = L_a + L_b$

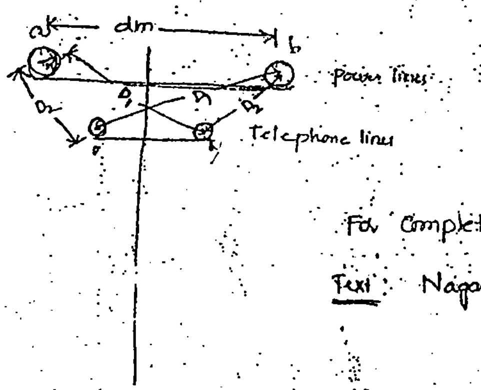
$\simeq L_a$

$$\boxed{L_a = 0.2 \ln\left(\frac{h}{r'}\right)} \text{ mH/Km.}$$

For all copper strands →

$$\boxed{L_a = 0.05\mu_r + 0.2\ln\left(h/r\right)} \text{ mH/Km}$$

→



For complete derivation go for

Text: Nagarath & Kotari

$\therefore M_c + M_d = 2M_c$

$$= 2 \times 0.2 \ln\left(\frac{D_1}{D_2}\right)$$ max distance / min distance

$$\boxed{M_c + M_d = 0.4 \ln\left(\frac{D_1}{D_2}\right)} \text{ mH/Km.}$$

$$\Rightarrow L_a = 2\times10^{-7}\left[\ln e^{1/4} + \ln(d/r)\right] \qquad \left(\because \ln e^{1/4} = \tfrac{1}{4}\right)$$

$$= 2\times10^{-7}\left[\ln\left(\frac{d e^{1/4}}{r}\right)\right]$$

$$= 2\times10^{-7}\ln\left(\frac{d}{e^{-1/4} r}\right)$$

$$= 2\times10^{-7}\ln\left[\frac{d}{0.7788\, r}\right]$$

$$\boxed{L_a = 2\times10^{-7}\ln\left[d/r'\right]}$$

where r' = Imaginary radius = $0.7788\, r$ because of internal flux linkages

$$\therefore L_a = 2\times10^{-4}\ln(d/r') \quad H/Km.$$

$$L_a = 2\times10^{-1}\ln(d/r') \quad mH/Km.$$

$$\boxed{L_a = 0.2\ln(d/r')} \quad mH/Km.$$

and

$$\boxed{L_{ab} = 2L_a = 0.4\ln(d/r')} \quad mH/Km.$$

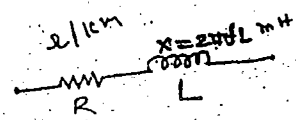
$$\Rightarrow L \propto \ln(d/r') \qquad d \to \text{metres}, \; r' \to cm.$$

$$\boxed{L \propto \ln(d)}$$

$$\Rightarrow \text{As } d\uparrow \longrightarrow L\uparrow$$

=> in Tr lines the line to line distance is high & it is in 'm' whereas the radius of the conductor is small & it is in 'cm' so we can neglect 'r'

$\longleftrightarrow$



$\uparrow X = 2\pi f L\uparrow$

$$\downarrow R \propto \frac{1}{a}, \quad \uparrow L \propto \ln(d)$$

=> If distance of separation is high ie 'd' is high X will be high so

$$\boxed{X > R}$$

$$\boxed{\frac{X}{R} > 1}$$ ~~For any trans line~~

=> if area of cross section of loop is high (ie d↑) then inductance of the conductors will be high

From (2)

$R_{ab} = R_a + R_b$

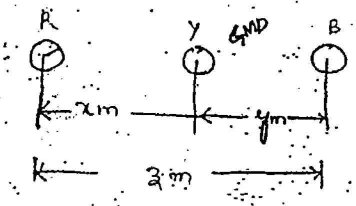
$\neq 2R_a$

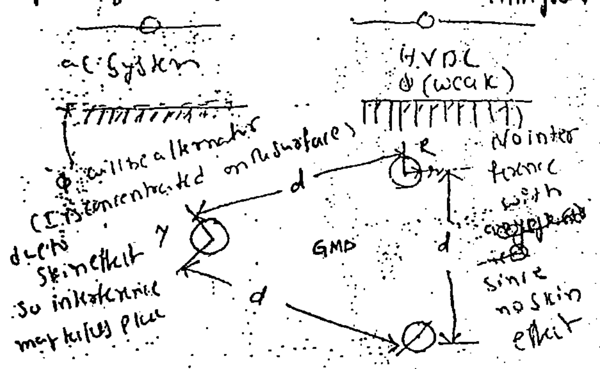
$\therefore \boxed{R_{ab} \simeq R_a}$

→ If in 1-φ 2wire if earth is one of the conductor then weight of the conductor is Reduced

→ In case of a.c trans system, Earth is not preferred as one of the conductor because it can produce an interference with the any other grounding system. Where as It can be recomended as one of the conductor for HVDC transmission because there is no concept of interference (noise due to alternator flux interface)

→ Bulk power 3-phase - 3wire;





Unsymmetrical, $R/phase = \frac{\rho l}{a}\ \Omega/Km$

Symmetrical. $R/ph = \frac{\rho l}{a}\ \Omega/Km$.

→ The current will be carried out by each phase for 120° Phase displacement

→ The vector sum of the currents at any point of time will be ZERO so that there will not be any seperate return path for each phase and the trans.line constants are calculated in a phase manner having a reference of neutral.

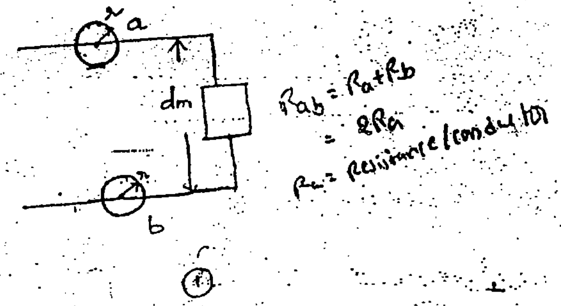
→ For the same operating voltage the resistance/Km in both the configuration will be same because it doesnot depends up on GMD

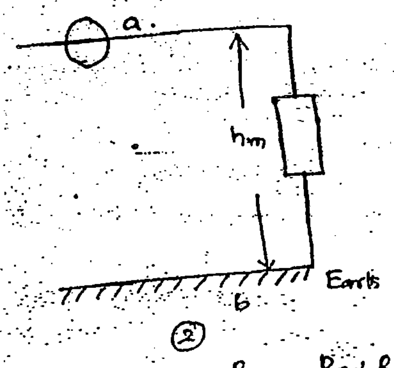
23-01-10

→ RESISTANCE CALCULATION 1-PHASE 2 WIRE

Transmission lines are normally of 'Km' lengths

All the line constants are evaluated based on per-unit length i.e. per Km





② $R_{ab} = R_a + R_b$
$\neq 2R_a$.

→ The Purpose of the second wire

(1) To show the potential difference

(2) To provide the closed path for the Load current ~~load current~~.

① Circuit Resistance (or) Loop Resistance $R_{ab} = R_a + R_b$

$R_{ab} = 2R_a$.

R_a = Resistance / conductor

$$\boxed{R_a = \frac{\rho l}{a}} \ \Omega/\text{Km}.$$

ρ = Specific Resistance Ω-Km

l = length of one Km

a = Area of c/s in Km^2

In transmission lines the distance of seperation between the two conductors is high and also the size of the conductor is larger. However the resistance does only depends on the size of the conductors and it will be less in tr. lines when compared to the distribution system.

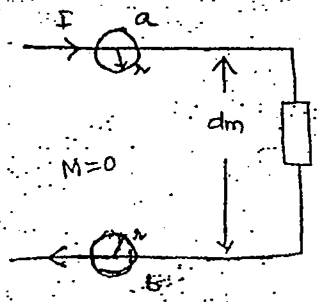
→ INDUCTANCE OF 1-phase 2 Wire Tr. line

$$\text{Inductance} = \frac{\text{Flux linkages}}{\text{Current}}$$

— It will build up the magnetic field i.e. called Flux.

— The instantaneous energy that can be stored or discharge by the inductor at any point of time 'dt' is

$$E = \frac{1}{2} L I^2 \quad \text{KVAR (or) MVAR}$$



According to skin effect

$L_{ab} = L_a + L_b$ → Circuit (or) Loop inductance

$L_{ab} = 2L_a$

L_a = Inductance / conductor

$\Rightarrow L_a = L_{int} + L_{ext}$

→ In overhead Trans. line the role of Mutual Inductance is ZERO since the distance of seperation of conductor is very high

→ L_{int} and L_{ext} are to be called as the self inductances of the conductor due to internal flux linkage of inner strands and external flux linkages of outer strands.

$$\therefore \boxed{L_a = L_{int} + L_{ext}} \Rightarrow \text{self inductance}$$

$$L_a = \frac{\mu_0 \mu_r}{8\pi} + \frac{\mu_0 \mu_r}{2\pi} \ln d/r \quad H/m.$$

$$= \frac{\mu_0 \mu_r}{8\pi} + \frac{\mu_0 1.0}{2\pi} \ln(d/r)$$

$\mu_r > 1.0 \qquad \mu_r = 1$ air

inductance that can be offered due to internal flux ~~does not depends on the distance of seperation and~~ the radius. Where as the self inductance that could be offered due to external flux linkages depends on the distance of seperation and radius.

$$\therefore La = \frac{4\pi\times10^{-7}\mu_r}{8\pi} + \frac{4\pi\times10^{-7}}{2\pi}\ln(d/r) \quad H/m$$

$$= \frac{10^{-7}}{2}\mu_r + 2\times10^{-7}\ln(d/r) \quad H/m$$

$$= \frac{10^{-4}}{2}\mu_r + 2\times10^{-4}\ln(d/r) \quad H/Km.$$

$$= \frac{10^{-1}}{2}\mu_r + 2\times10^{-1}\ln(d/r) \quad mH/Km.$$

$$\therefore \boxed{La = 0.05\mu_r + 0.2\ln(d/r)} \quad mH/Km$$

and $\boxed{L_{ab} = 2La = 0.1\mu_r + 0.4\ln(d/r)}$ mH/Km.

→ If all the strands are made of Copper (if μ_r is not given we should take $\mu_r=1$)

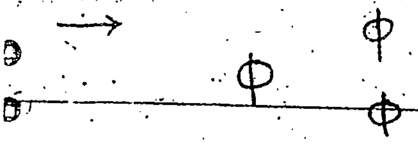
$$La = \frac{\mu_0\mu_r}{8\pi} + \frac{\mu_0\mu_r}{2\pi}\ln(d/r)$$

$$= \frac{\mu_0}{8\pi} + \frac{\mu_0}{2\pi}\ln(d/r) \quad (\because \mu_r = 1.0)$$

$$\therefore La = \frac{4\pi\times10^{-7}}{8\pi} + \frac{4\pi\times10^{-7}}{2\pi}\ln(d/r)$$

$$= \frac{10^{-7}}{2} + 2\times10^{-7}\ln(d/r) \quad H/m.$$

$$= 2\times10^{-7}\left[\frac{1}{4} + \ln(d/r)\right] \quad H/m.$$

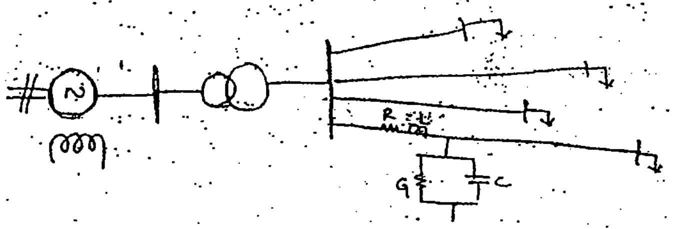
→ 

$\Rightarrow$ Performance of the line is in phase manner.

$\phi \quad \phi \quad \phi \Rightarrow$ per phase under the assumption that the inductance and capacitance are almost equal.

→ The Inductance & Capacitance per phase can be equal under the assumption of the transposition of tr. line or the average inductance or capacitance.

⇒ TRANSMISSION LINE CONSTANTS:



— A Tr. line is a bulk amount of power carrier between the remote generating station to the load.

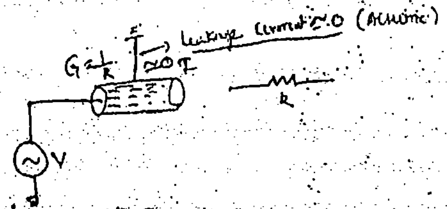
— It will be represented electrically as

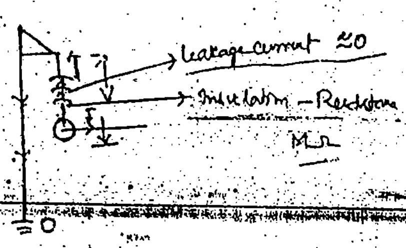
(1) A Series combination of resistance & Inductance

(2) A parallel combination of Conductance & capacitance

However the conductance of tr. line is assumed as ZERO ($G \simeq 0$)

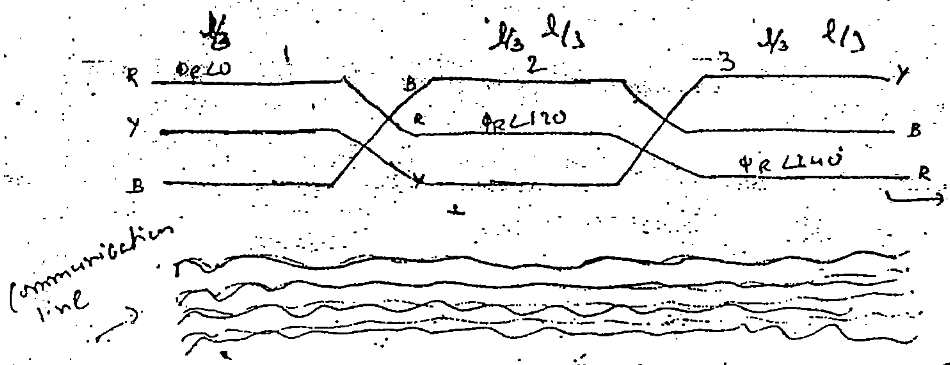
$\Rightarrow G \simeq 0 \Rightarrow$ Current is '0'

→ 



— To eliminate the communication interference the Transposition of Tr.lines is employed.

— Change the position of power conductor at regular intervals by maintaining equal distance so that the position of the original phase conductor will be replaced by its successive phase conductor.



Transposed — Unsymmetrical → Symmetrical

$$\therefore GMD_R = \sqrt[3]{GMD_{R_1}\, GMD_{R_2}\, GMD_{R_3}}$$

$$GMD_{R_1} = \sqrt{6\times 12}$$

$$GMD_{R_2} = \sqrt{6\times 1}$$

$$GMD_{R_3} = \sqrt{6\times 12}$$

GMD is equal.
L/ph is equal.
I/ph is equal.
ϕ/ph is equal.
$\phi_r = 0$

Voltage drop/phase is equal.
Balanced Receiving end Voltages

$(\phi_R\angle 0 + \phi_R\angle 120 + \phi_R\angle 240 + \phi_Y\angle 0 + \phi_Y\angle 120 + \phi_Y\angle 240 + \phi_B\angle 0 + \phi_B\angle 120 + \phi_B\angle 240)$

$$\therefore GMD_R = \sqrt[3]{6\sqrt{2}\times 6\times 6\sqrt{2}}$$

$$\therefore \boxed{GMD_Y = GMD_B = GMD_R}$$

→ There are certain difficulties that are experienced to do the transposition of tr.lines in a modern p.s. because it is a very thick n/w. However the transposition of tr. lines can be recommended in older days because the n/w is a thin n/w.

→ The interference can be avoided either by having max distance ~~b/w the two ckts are any one of the circuits employed~~ with the insulated system.

$\therefore$ Self GMD $= \sqrt[3]{\text{Self GMD}_{R_1}\ \text{Self GMD}_{Y_1}\ \text{Self GMD}_{B_1}} = 15.50$ cm.

$\therefore \; GMD = \sqrt[3]{GMD_R \; GMD_Y \; GMD_B}$

$GMD_R = \sqrt{GMD_{R_1} \, GMD_{R_2}} = GMD_{R_1}$

$= \sqrt[4]{6.08 \times 12 \times 10.8 \times 14.42} = 10.32$

$GMD_B = GMD_R$

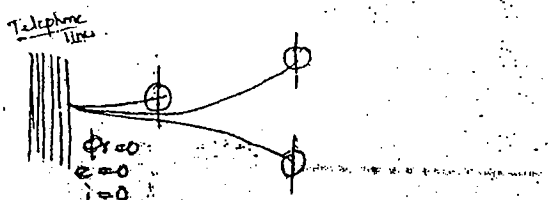
$GMD_Y = \sqrt[4]{6.08 \times 6.08 \times 10.8 \times 10.8} = \sqrt{6.08 \times 10.8} = 8.1$

$\therefore \; GMD = \sqrt[3]{10.32 \times 10.32 \times 8.1}$

$=$

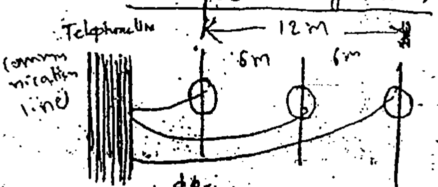
→ TRANSPOSITION OF TRANSMISSION LINES:

Whenever an unsymmetrical tr. line is running neighbour to the Communication line then the tr. line will produce an interference in the communication line. In order to eliminate the Communication interference the transposition of tr. lines are employed.



No noise, No interference
→ No need of TRANSPOSITION
Untransposed & Symmetrical

un-transposed — unsymmetrical



$e = \frac{d\phi_r}{dt} \neq 0 \Rightarrow i \neq 0$

⇒ Interference → called Magnetic effect in Communication

GMD is equal L/ph is equal I/ph is equal ϕ/ph is equal $\phi_r = 0$	Voltage drop/phase is equal. Balanced Receiving end Voltage.	GMD is unequal L/ph is unequal I/ph is unequal ϕ/ph is unequal $\phi_r \neq 0$	Voltage drop/phase is unequal. Unbalanced Receiving end Voltage.

- The double ckt configuration is more preferred to enhance the power transfer capacity at a given voltage, when compared to a single ckt with larger radius of the conductor, becos the double ckt line will having self GMD which is more than GMR, so that L/phase is reduced — x —

(P.T.O) → $\therefore GMD_R = \sqrt{GMD_{R_1} \, GMD_{R_2}}$

$= GMD_{R_1} = \sqrt[4]{6 \times 12 \times 10 \times 14.42}$

$= 10.09\,m = GMD_{R_2}$ (since both are same)

$GMD_B = \sqrt{GMD_{B1} \, GMD_{B2}}$

$= GMD_{B_1} = 10.09m$

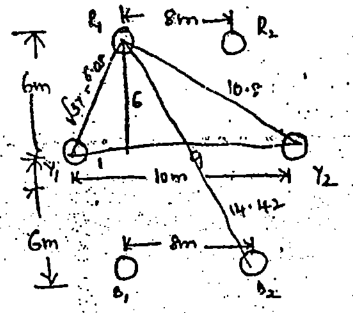
$GMD_Y = \sqrt{GMD_{Y_1} \, GMD_{Y_2}}$

$= GMD_{Y_1} = \sqrt[4]{6 \times 6 \times 10 \times 10}$

$= \sqrt[4]{60} \; 7.74m$

$\therefore GMD = \sqrt[3]{10.09 \times 7.74 \times 10.09} = 9.23m$

→ Eg:



Self GMD = $\sqrt[3]{\text{self } GMD_R \; \text{Self} GMD_Y \; \text{Self} GMD_B}$

Self GMD_R = Self GMD_{R_1}

$= \sqrt{0.7788 \times 1.5 \times 800} = 30.57$

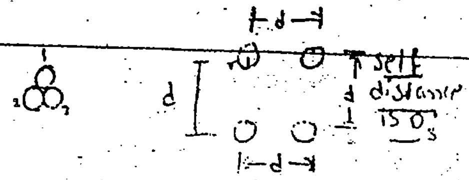
self GMD_B = self GMD_R

$= \sqrt{0.7788 \times 1.5 \times 800} = 30.5$

Self GMD_Y = Self GMD_{Y_1}

$= \sqrt{0.7788 \times 1.5 \times 1000} = 34.17$

Q) There are 3 sub conductors in each phase and they are touching each other. The radius of each sub conductor is r, the self GMD of ~~sub conductor configuration is~~



Sol

$\therefore$ Self GMD = Self GMD$_1$

$$= \sqrt[3]{0.7788 \times r \times 2r \times 2r}$$

$$= r(0.7788)^{1/3} \cdot 2^{2/3}$$

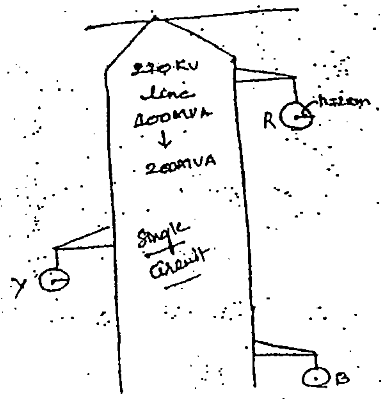
Self GMD = Self GMD R_1

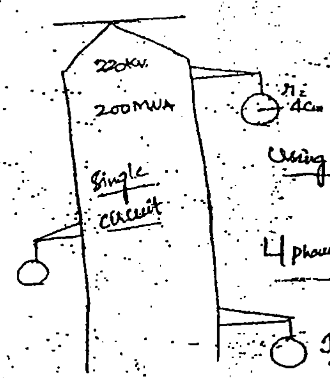
$$= \sqrt[4]{D_s \times d \times d \times \sqrt{2}d}$$

$$= (D_s)^{1/4}\, d^{3/4}\, 2^{1/8}$$

DOUBLE CKT TR LINE :

→ ENHANCEMENT OF POWER TRANSFER CAPACITY AT A GIVEN VOLTAGE





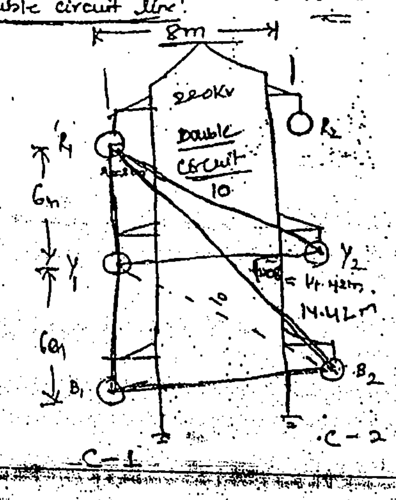
Using larger conductors.

$$L/\text{phase} = 2\times10^{-7} \ln\left(\frac{GMD}{GMR}\right) \text{ H/m.}$$

Inductance is reduced because GMR is increased.

The inductance is further reduced by using 'double circuit line'

→ Double circuit line: double ckt :



$$L/\text{phase} = 2\times10^{-7} \ln\left(\frac{GMD}{\text{Self GMD}}\right) \text{ H/m.}$$

Self GMD = Self GMD$_R$ = Self GMD R_1

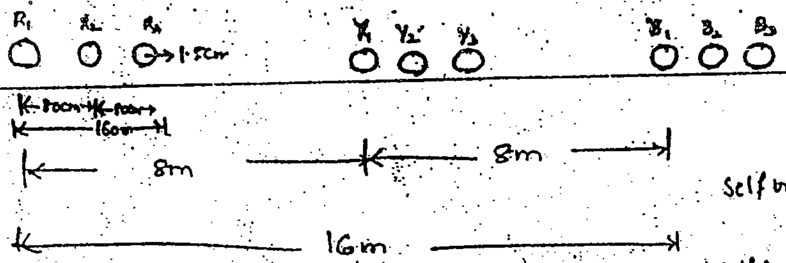
$$\sqrt{r' \times b} = \sqrt{0.7788 \times 2 \times 800} \text{ cm.}$$

$= 35.299$ cm.

$$GMD = \sqrt[3]{GMD_R\, GMD_Y\, GMD_B}$$

→ (P.T.O).

Eq:



$\text{Self GMD} = \sqrt[3]{\text{Self GMD}_{R_1}\ \text{Self GMD}_{R_2}\ \text{Self GMD}_{R_3}}$

$\text{Self GMD}_{R_1} = \sqrt[3]{0.7788 \times 80 \times 160 \times 2r \times 4r}$

$$\text{Self GMD} = \text{Self GMD}_R = \sqrt[3]{\text{Self GMD}_{R_1}\ \text{Self GMD}_{R_2}\ \text{Self GMD}_{R_3}}$$

Since the sub conductors are unsymmetric

$$\therefore \text{Self GMD}_{R_1} = \sqrt[3]{0.7788 \times 1.5 \times 80 \times 160}$$

$\text{Self GMD}_1 = \sqrt[5]{0.7788 \times r \times 2r \times 4r \times 2\sqrt{2}r \times 2\sqrt{2}r}$

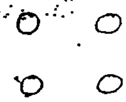
$$\text{Self GMD}_{R_3} = \text{Self GMD}_{R_1}$$

$= \text{Self GMD}_2 = \text{SG}_3 = \text{SG}$

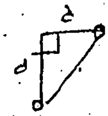
$$\text{Self GMD}_{R_2} = \sqrt[3]{0.7788 \times 1.5 \times 80 \times 80}$$

$\text{Self GMD}_5 = \sqrt[5]{0.7788 \times r \times r \times r \times 2r \times 2r}$

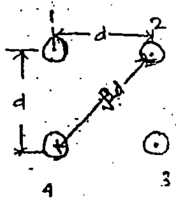
Q) * The self distance of each subconductor (D_s) r' and the adjacent distance between any two sub conductor (d), the sub conductors are arranged as shown below. The self GMD of the subconductor configuration is



fig



Sol



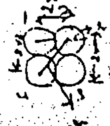
$\therefore$ Self GMD = Self GMD_1 (Symmetric Sub Conductor)

$$= \sqrt[4]{D_s \times d \times d \times \sqrt{2}d}.$$

($\because$ given that $r' = 0.7788r = D_s$)

$$= \boxed{(D_s)^{1/4}\ d^{3/4} \cdot 2^{1/8}}$$

(Q)

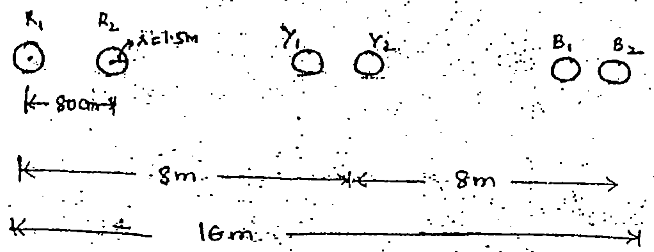


$\Rightarrow$ Self GMD = Self GMD_1

$$= \sqrt[4]{0.7788 r \times 2r \times 2r \times 2\sqrt{2}r} = \boxed{r(0.7788)^{1/4}\ 2^{7/8}}$$

— In case of bundle conductors consider the sub-conductor effect for calculation of Self GMD and ignore the sub conductor effect for calculation of GMD.

→ **Eg:**

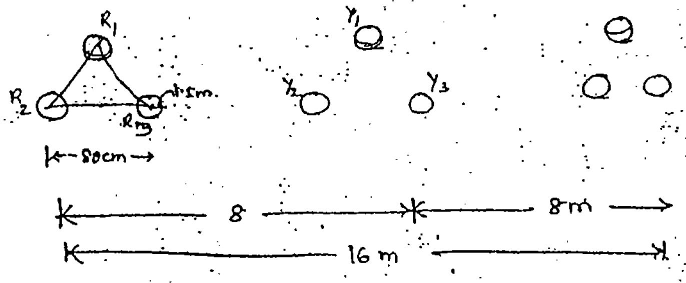


Self GMD = Self GMD_{R_1}

$$= \sqrt{0.7788 \times 1.5 \times 80}$$

$\therefore$ GMD $= \sqrt[3]{xyz} = \sqrt[3]{8 \times 8 \times 16}$ m. (Un symmetric)

→ Eg:



Self GMD = Self GMD_{R_1}

$$= \sqrt[3]{0.7788 \times 1.5 \times 80 \times 80}$$ (Equilateral spacing)

GMD $= \sqrt[3]{8 \times 8 \times 16}$. m.

(6) If the tr. line is a long line then the impedance of the line is represented as characteristic impedance.

$$\Rightarrow \downarrow Z_c = \sqrt{\frac{L}{C\uparrow}}$$

→ The Relation b/w 'r' and "r_1" is

By considering the same aggregate cross sectional area.

$$\Rightarrow \pi r^2 = 2\pi r_1^2$$

$$\boxed{r_1 = \frac{r}{\sqrt{2}}}$$

For Three sub conductors

$$\boxed{r_1 = \frac{r}{\sqrt{3}}}$$

For 'n' sub conductors

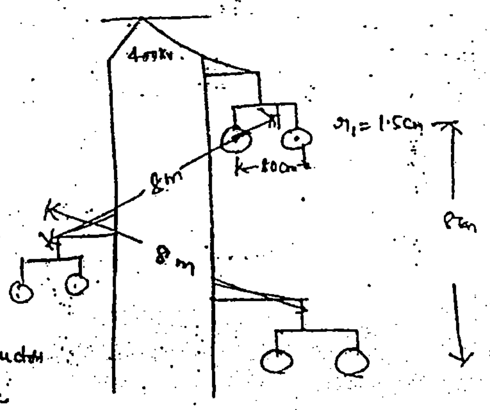
$$\boxed{r_1 = \frac{r}{\sqrt{n}}}$$

Q
Eg Self GMD = ?

S) GMR = GMR_R

$\Rightarrow$ Self GMD = Self GMD_R

$= \sqrt{\text{Self } GMD_{R_1} \cdot \text{Self } GMD_{R_2}}$

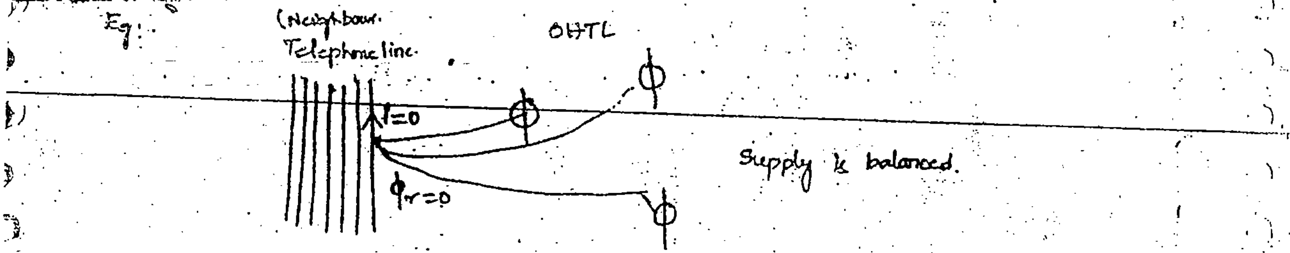


$\boxed{\text{Self GMD} = \text{Self } GMD_{R_1}}$ (since, sub conductors are symmetric

$\therefore$ Self GMD = Self $GMD_{R_1} = \sqrt{0.7788 \times 1.5 \times 80}$

$\therefore$ GMD = d = 8m (since voltage is same)

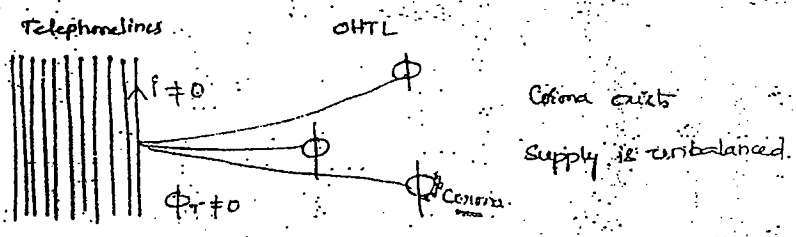
Eg:



$$\therefore \frac{d\phi_r}{dt} = e = 0$$

since $\phi_r=0$, $e=0$, $i=0 \Rightarrow$ No noise in the communication system $\Rightarrow$ No interference.

Eg: If corona exists there



$\Rightarrow$ Noise $\Longleftarrow \frac{d\phi_r}{dt} = e \neq 0$ Corona may not take place in every conductor at the same time.

$\Rightarrow$ Inference (Telephone)

(or) Radio interference.

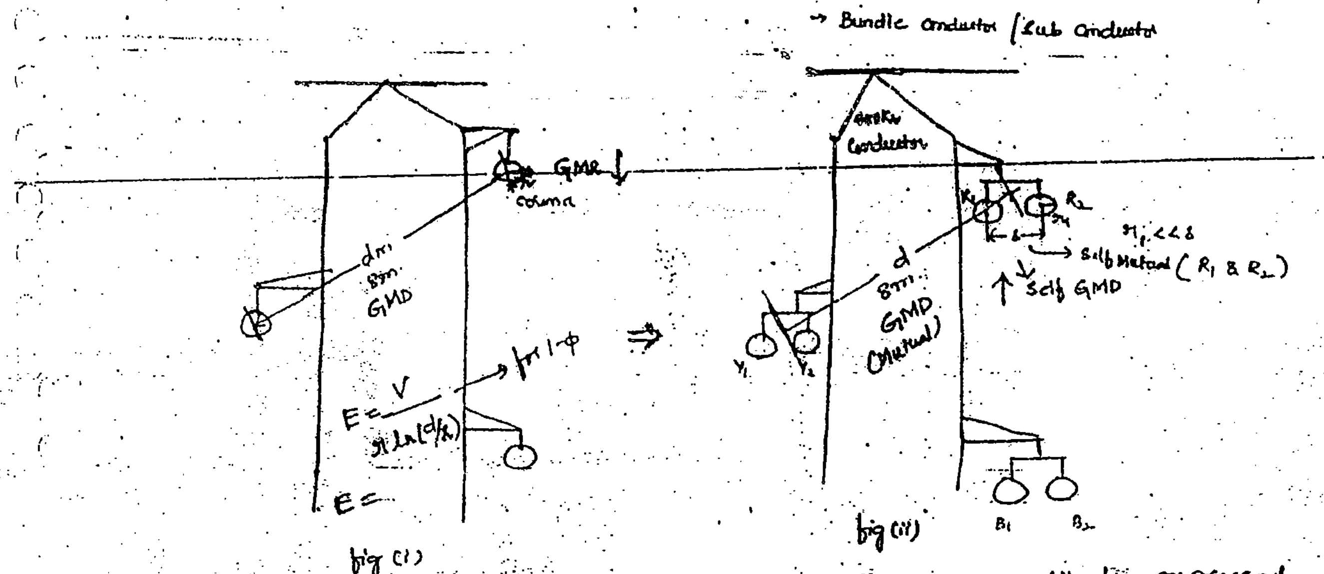
(4) $L/\text{phase} = 2\times10^{-7} \ln\left(\frac{GMD}{\text{self GMD}}\right)$ H/m $\xrightarrow{\text{in}}$ Bundle, is reduced, so that the inductive per phase is also reduced $(X = 2\pi f L)$.

$L/\text{phase} = 2\times10^{-7} \ln\left(\frac{GMD}{GMR}\right)$ H/m $\longrightarrow$ Normal Condu.

and $C/\text{phase} = \frac{2\pi\epsilon_0}{\ln\left(\frac{GMD}{\text{Self GMD}}\right)}$ is increased.

(5) The power system stability will increase because a.c transmission is synchronous transmission and by using bundle conductor the reactance per phase is reduced

$\Rightarrow P = \frac{EV}{X\downarrow} \sin\delta$ ↑



→ In case of Bundle Conductors, the self distance will be expressed mathematically as "SELF GMD"

∴ From fig (ii)

$$\text{Self GMD}_{R1} = \sqrt{r_1' \times s}$$

— The Bundle Conductor will result as increased self GMD without changing GMD since the voltages are same in either case.

$$E = \frac{V}{r\ln(d/r)} \rightarrow 1\text{-}\phi$$

$$E = \frac{V}{GMR\ln\left(\frac{GMD}{GMR}\right)}$$

$$\downarrow E = \frac{V}{\uparrow \text{Self GMD}\ln\left(\frac{GMD}{\text{Self GMD}}\right)}$$

Advantages of B.C:

1) The electric field intensity at the surface of each sub conductor is reduced

2) The corona loss is reduced because E↓ and ionisation of air ↓

3) The communication interference with the neighbouring communication line is reduced.

— The GMD depends upon the configuration of the conductors

→ The selection of size of the conductor for (i) EHV line — Carrying capacity

(ii) Distributor — Voltage drop

(iii) Modern EHV line — Based on the concept of Corona.

(iv) UHV — Based on the concept of Corona

→ The selection of the insulation level for Modern EHV line is "Switching voltage"

→ BUNDLE CONDUCTORS

As the operating voltages are increasing the electric field intensity at the surface of the conductor will also increases which will be result as the ionisation of air near the surface of the conductor and it is known as the concept of CORONA. The result of the CORONA is in the form of corona loss which is a real power loss apart from I^2R loss. In order to avoid the concept of CORONA at higher operating voltage the BUNDLE CONDUCTORS are employed.

→ Bundle conductor consists of two or more sub conductors per phase where the sub conductor spacing is more than the radius of each subconductor and the subconductors are running in parallel in order to ↑ the current capacity

→ ~~In order to increase the~~

→ Each sub conductor is once again a combination of steel & Al in stranded manner

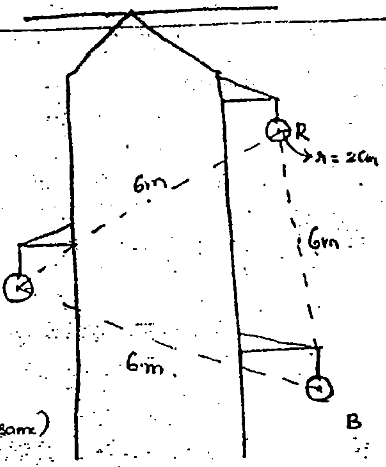
(1) Symmetrical Configuration

(i) GMR

$GMR_R = r'$

$GMR_y = r'$

$GMR_B = r'$



$\therefore GMR_s = \sqrt[3]{GMR_R \cdot GMR_y \cdot GMR_B}$

$= GMR_R$ ($\because$ r's same)

$\Rightarrow \boxed{GMR = GMR_R}$ ($\because$ self distance of all conductor is same)

$= 0.7788 \times 2cm$

(ii) GMD

$GMD_R = \sqrt{6 \times 6} = 6$, $GMD_y = \sqrt{6 \times 6} = 6$, $GMD_B = \sqrt{6 \times 6} = 6$

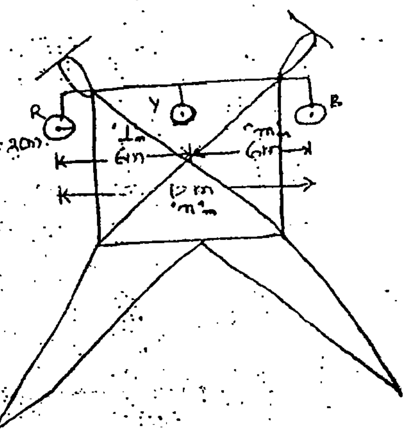
$\therefore GMD = \sqrt[3]{GMD_R \, GMD_y \, GMD_B} = \sqrt[3]{6 \times 6 \times 6} = 6m.$

$\boxed{GMD = d}$ $\Rightarrow$ Equilateral Spacing.

(2) Un symmetrical Configuration.

(i) GMR

$GMR_s = GMR_R = GMR_y = GMR_B = r'$



$\Rightarrow GMR = GMR_R = 0.7788 \times 2cm$ ($\because$ r = 2cm)

(ii) GMD

$GMD_R = \sqrt{6 \times 12} = 6\sqrt{2}$

$GMD_y = \sqrt{6 \times 6} = 6$

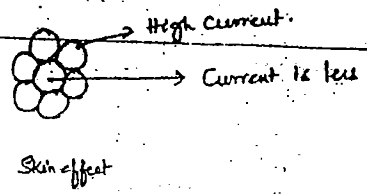
$GMD_B = \sqrt{6 \times 12} = 6\sqrt{2}$

$\therefore GMD = \sqrt[3]{6\sqrt{2} \times 6 \times 6\sqrt{2}}$

$= \sqrt[3]{6 \times 6 \times 12} = \sqrt[3]{xyz} = \sqrt[3]{lmn} \Rightarrow \boxed{GMD = \sqrt[3]{xyz}}$

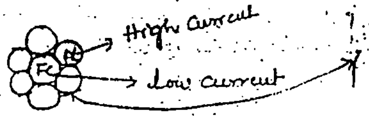
* The GMR only depends on the radius of conductor and it is independent of line to line distance.

→ To reduce the sag, the mechanical strength should increase



~~Because of skin effect, the current~~ is less in the inner strand.

Hence inner 'Al' is replaced by 'Fe'



→ Composite Stranded Conductor.

→ The purpose of the steel is to increase the mechanical strength and the purpose of 'Al' is to carry more amount of current.

→ Example for composite stranded conductor is ACSR Conductor.

→ The No. of steel strands $<$ No. of 'Al' strands.

Arranging of strands for different layers $1+6+12+18+24+30$

→ In case of comp. stranded conductor the skin effect is further reduced because the effective area that could be utilized will be high in composite stranded conductor.

→ In case of comp. stranded conductor, the conductivity of the steel as well as the conductivity of 'Al' are properly utilized so that the total area is considered for calculation of a.c resistance.

→ ACSR → 'Al' conductor and steel reinforced (or) steel reinforced 'Al' conductor

→ ACSR is represented mathematically as $\frac{x}{y}$ ratio

x → either 'Al' (or) Fe strands

y ← either 'Al' or Fe strands.

Ex: An ACSR conductor consisting of 30 Al and 7 Fe strands then it is represented by $30/7$.

→ As the skin effect is high, then R_{ac} is high because d' is less.

→ Skin effect

$L_{in}\uparrow$, $L_{ext}\downarrow$

$\uparrow L = L_{in} + L_{ext}$

→ As the area of c/s of conductor increase for same amount of current then, the effective area utilized is less. Then skin effect is High

As $a\uparrow \Rightarrow a'\downarrow \Rightarrow R_{ac}\uparrow$ according to skin effect

∴ ~~Rac ∝ a~~

$\boxed{\text{Skin effect} \propto a}$ $a \rightarrow$ Area.

$\boxed{\text{Skin effect} \propto d^2}$ d – diameter

→

$a'\downarrow$	a'
$R_{ac}\uparrow$	$R_{ac}\downarrow$
Skin effect ↑	Skin effect ↓

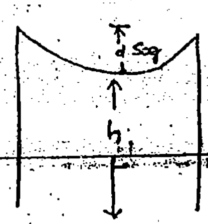
→ Hence Stranded conductors are preffered than Solid Conductors.

→ And the Stranded conductors are replaced by Composite Stranded Conduct

 Copper Stranded Conductor → Cost is high → Uneconomical.

 → Al. Str. Conductor → Cost is less – but → Mechanical Strength is less

As Mech. strength is less → Sag ↑ and ground clearance decreases.

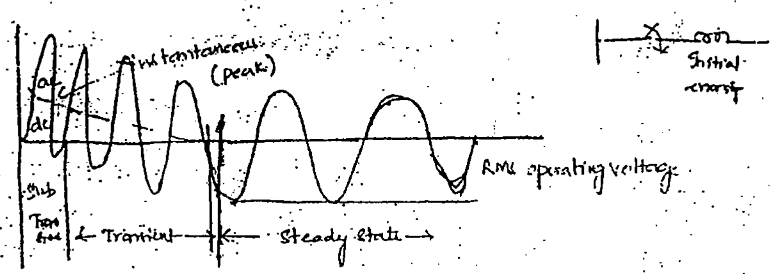


which is an external wire so that the magnitude of the lightening wave is directed to the ground.

→ Ground wire is normally made up of Galvanised steel material.

→ The lightening voltage can be diverted by using Surge diversion Technique.

→ When the switch is closed, because of inductance effect of the H line the wave form is as below.

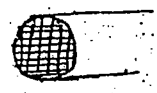


→ Hence the insulation level selection is based on the Peak Values of the switching voltages.

→ DIFFERENT TYPES OF CONDUCTORS

- Solid conductors
- Stranded conductors
- Composite stranded conductors ⟶ for $V \leq 220kV$
- Bundle conductors ⟶ for $V \geq 275KV$.

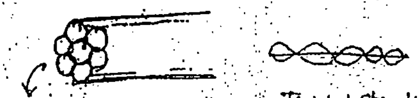
SOLID CONDUCTOR (Copper)



→ It made of a solid copper.

→ High electrical conductivity.

STRANDED CONDUCTOR (Copper)



- It consists of two or more smaller c/s strands and they are twisted together to get the required more elements

→ The Selection of Insulation level for EHV line (or) Distribution → Switching Voltage

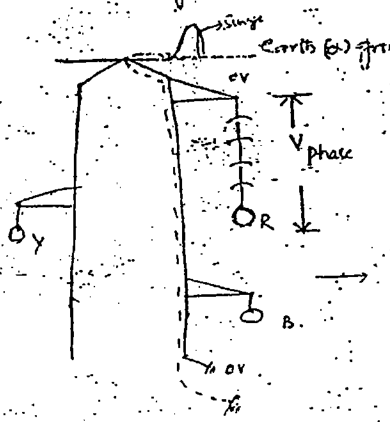
— The Selection of Insulation level for EHV line (or) Distribution is based on the switching voltage (or) Switching Surge (or) Internal Voltage. (or) Internal surge

→ The operating voltages of a 3-φ, 3-wire tr. line will be Line to line Rms

Power is 3-φ always.

$\Rightarrow S = \sqrt{3} V_L I_L \Rightarrow 3-\phi$

→ Operating voltage: A voltage at which the system is working stable and the generator working in synchronous speed.



220 kV (L-L)

$\frac{220}{\sqrt{3}}$ = phase Voltage

→ (Surge diversion technique)

→ Overvoltages on the tr. line because of 1) Direct lightening effect (External)
(2) Switching effect (Internal), These are called as "Surge"

— Any uneven wave form is called "Surge"

— For any given t/line the magnitude of the lightening voltages are high when compared to the magnitude of switching voltages.
If the lightening is allowed the insulation can be selected for lightening voltages, so that amount of insulation is high, Cost of is high

→ In order to reduce cost of insulation the lightening voltages can be diverted by running a ground (or) earth wire on the top of the tower

— Hence most of the current is concentrated on the outer surface of the stranded conductor.

(S.Stat)

$$R_{a.c} = \frac{\rho l}{a'} \quad \text{(Rms Resistance)}$$

where a' → Effective area that is Utilized.

$\boxed{a' < a}$

$R_{ac} > R_{dc}$

$\therefore R_{a.c} = K \cdot R_{dc}$ | Skin effect.

$K = 1.6$

→ When the switch is closed, then the instantaneous currents in the strands will produce the corresponding fluxes. The flux produced by the outer strand will link with inner strand in addition to it own strand. The flux produced by inner strand does only link with it own strand so that the total fluxes linkages for inner strands is high and for outer strands is low. The amount of ϕ linkages produces will offer an inductance to the strands.

→ As the internal flux linkages are high, then the inductance offered for inner strands is high, where as for outer strands is low.

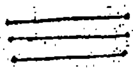
— The Inductance is the one which can oppose initially the flow of current through the strands. so that most of the current is concentrated on the outer strands. If the current can carry in such manner for a period of 't', then the resistance which is offered is called as a.c resistance.

$$R_{ac} = \frac{\rho l}{a'}$$ where a' → effective area that is utilized.

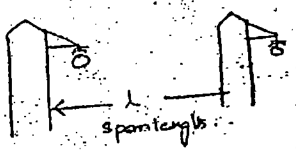
$R_{ac} \propto$ Skin effect.

→ High mechanical strength

→ These are in the form of rods (small)



→ It is difficult to connect continuously by stringing solid conductor. and difficult to transport



$l = 300m \rightarrow$ for 132kV

$l = 350m \rightarrow$ for 220kV.

$l = 400m \rightarrow$ for 400kV.

→* In ac system it deals with high skin effect

→ All the strands are twisted in parallel inorder to increase the current carrying capacity.

→ High electrical conductivity

→ Required mechanical strength

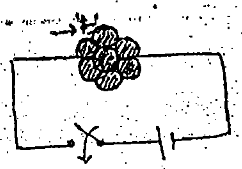
→ It can wound like a ring

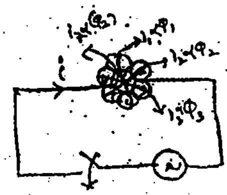
→ It is easy to transport and stringing of the conductor.

*→ In a.c system it will offer a low skin effect.

→ SKIN EFFECT: If the conductor carries an alternating current then most of the current will be concentrated through an outer surface of the conductor, hence the current distribution is non-uniform in the conductor, because of the non uniform distribution of flux linkages

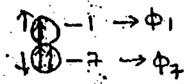
Stranded conductor





1—6 Outer strands
7 — Inner strand

Reluctance of air is high
← air



Dc resistance (or) Ohmic resistance.

$$R_{dc} = \frac{\rho l}{a}$$

a = total area of cs.

$\phi_7 \rightarrow$ flux linkages are high.

Since flux linkages are high then the inductance is high.

— The tr.line having one conductor in each phase with the ~~radius of 'r'. The self distance of the conductor w.r.t the~~ same conductor is "radius" 'r' and the mean of which is also called as "Radius"

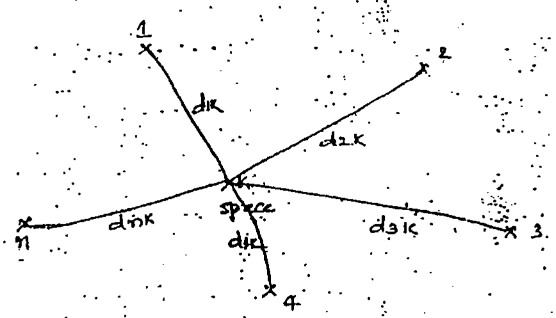
→ lin + lint

$\boxed{GMR = r} = r'$ $r' \to$ Imaginary radius

$r' = 0.7788 r$ because of Skin effect of the conductor.

$\boxed{GMR = r'}$

GMD:



A point 'K' in the space is surrounded by 'n' other points. The Equivalent distance of 'K' w.r.t 'n' other points will be the Geometric mean of the individual distance between the reference point and each individual point

$$\boxed{GMD_K = \sqrt[n]{d_{1K}\, d_{2K}\, d_{3K} \, ---- \, d_{nK}}}$$

→ The tr. line ~~of~~ will be two configurations physically as

(1.) Symmetrical Configuration → Equilateral spacing

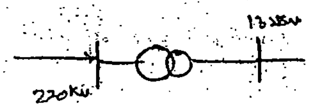
~~(2.) Asymmetrical Configuration → Flat/Unequal spacing~~

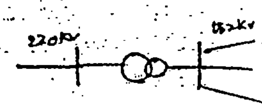
Ex: If conductor (ACSR) consists of '7' steel and 30 'Al' then it is represented as $\frac{7}{30}$

→ ACSR represented as $\frac{54}{7}$ then, 54 — Al, 7 → Fe.

→ $7/30$ Al → 132KV, $7/54$ Al → 220KV.

→





→ Hence for all practical purposes the ~~pow~~ size of the conductor increases as the power handling capacity increases.

22/01/10

→ **MATHEMATICAL CONCEPTS**

GMR — Geometric Mean Radius → self Distance

GMD — Geometric Mean (or) Mutual Distance → Mutual distance.

— Transmission lines are normally 3-φ, 3-wire and it requires the calculation of the line constants in a phase manner, the GMR & GMD are useful to calculate the inductance per phase and capacitance per phase at a faster rate.

→ Arithmatic Mean → plane co-ordinates

→ Geometric Mean — Space Co-ordinate

GMR: The self distance of a point is the distance from the centre towards the circumference w.r.t same point in the space.

$$a \propto \frac{1}{V^2\cos^2\phi}$$

If p.f. is constant.

$$a = \frac{k'}{V^2}$$

$$\therefore \frac{a_1}{a_2} = \frac{V_2^2}{V_1^2} = \frac{n^2V_1^2}{V_1^2}$$

$$\Rightarrow \frac{a_1}{a_2} = \frac{n^2}{1}$$

$$\Rightarrow \boxed{a_2 = \frac{1}{n^2}a_1}$$ (for same efficiency also)

→ For the same power, same material, and same length if the operating voltage of a distributor increased by 'n' times, the area of c/s of distributor is $a_2 = \frac{1}{n^2}a_1$

* The selection of size of conductor in Distribution system is "Voltage drop" ie "% voltage drop" criteria.

V_1, I_1 and R_1	V_2, I_2 and R_2
$\frac{I_1R_1}{V_1}\times 100$	$\frac{I_2R_2}{V_2}\times 100$
$\frac{I_1R_1}{V_1}\times 100$	$= \frac{\frac{I_1}{n}\times R_2}{nV_1}\times 100$

$V_2 = nV_1$, $I_2 = I_1/n$

$$\Rightarrow \boxed{R_2 = n^2R_1}$$

$$\therefore \boxed{a_2 = \frac{1}{n^2}a_1}$$

~~→ For same material, same length, same power, same power loss of the voltage is increased by n times then area of c/s of conductor is ______~~

Power loss:

$$P_2 = \frac{1}{n} P_1$$

$$P_1 = I_1^2 R_1$$

$$P_2 = I_2^2 R_2 = \left(\frac{I_1}{n}\right)^2 \cdot n R_1 = \frac{I_1^2}{n^2} n R_1 = \frac{I_1^2 R_1}{n} = \frac{P}{n}$$

As loss is reduced, the efficiency is increased.

$$\text{Since } \uparrow\eta = 1 - \frac{K \leftarrow \text{Constant}}{\uparrow V\cos\phi}\downarrow$$

$$\%\,\eta = \left(1 - \frac{K}{V\cos\phi}\right) \times 100.$$

— As the operating voltage and the power factor are high, then the η is high.

→ For same power, same length, same material, same loss of the operating voltage of EHV is increased by 'n' times then the area of c/s of the conductor is $\underline{a_2 = \frac{1}{n^2} a_1}$

$$P = VI\cos\phi$$

$$I = \frac{P}{V\cos\phi}$$

$$\text{Loss, } p = I^2 R = \frac{I^2 \rho l}{a} \Rightarrow a = \frac{I^2 \rho l}{p}$$

$$\Rightarrow a = \left(\frac{P}{V\cos\phi}\right)^2 \cdot \frac{\rho l}{p}$$

$$= \frac{P^2}{V^2\cos^2\phi} \cdot \frac{\rho l}{p} = \frac{K}{V^2\cos^2\phi}$$

→ In an element where the magnitude of the current varies through out its length is called electrically a **DISTRIBUTOR**, where the current density is variable

→ The Selection of size of the Conductor for EHV line:

→ The Selection of size of the conductor for EHV line is based on the CURRENT CARRYING CAPACITY ($\because V = \text{const}, P = V \cdot I$)

→ Current carrying capacity is nothing but "Const. Current density"

For Distributor:

→ The Selection of size of the conductor for Distributor is based on "Voltage drop".

→ For same power, same material and same length, if the operating Voltage of EHV line (OR) feeder is increased by 'n' times then area of the c/s of the conductor is ____ $a_2 = \frac{1}{n} a_1$

Expl

$$P = V_1 I_1 \cos\phi$$

$$P = V_2 I_2 \cos\phi \qquad V_2 = n V_1$$

$$I_2 = I_1/n$$

$$\Rightarrow \quad = \cancel{n} V_1 \cdot \frac{I_1}{\cancel{n}} \cos\phi$$

$$P = VI \cos\phi$$

→ The Selection of size of Conductor in EHV line is based on Current Carrying capacity

$$\Rightarrow I \propto a$$

$$I_1 \propto a_1 \qquad I_2 = \frac{I_1}{n}$$

$$I_2 \propto a_2$$

$$\Rightarrow \boxed{a_2 = \frac{1}{n} a_1}$$

→ As the line side of tf is always STAR with Neutral grounding so that the tr. lines are always electrically 3-φ Y. So, that

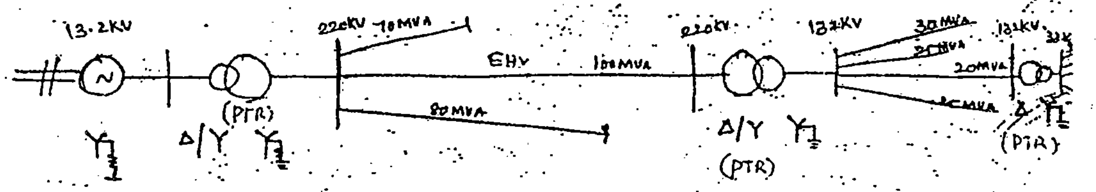
$V_{phase} = \frac{V_L}{\sqrt{3}}$ and $I_{ph} = I_L$

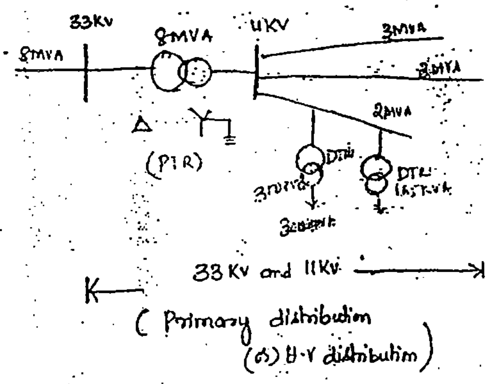
→ For the length of the line > 500 Km we prefer HVDC transmission

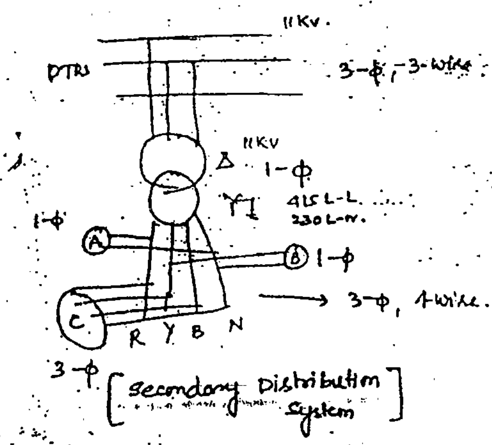
→ In India max HVDC transmission is ±500 kV DC.

→ For the length of the line < 500 Km A.C transmission is preferred for economical reasons.

→ According to protection system, the source end of the tr. line will be provided with neutral grounding.

→ 





→ If the magnitude of the current that could be carried out through out its length is same then such a current carrying element is called FEEDER, Hence EHV lines are called FEEDERS.

$I \propto a$

$I = Ja$

$J = I/a$ → A Feeder is also called as Constant current density element

→ If there is any 3-φ fault in a single tr. line then

$$P = P_s - P_e$$

$$P = P_s - 0$$

$$P = P_s$$

= (accelerated because of +ve power) ↑

Illy if there is any 3-φ fault in any one of the parallel tr-line

then $P = P_s - P_e \downarrow$

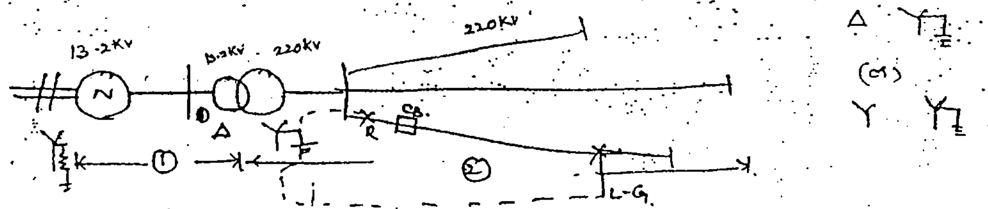
= +ve

= acceleration ↓

→ The a.c power transmission from the syn. m/c to the load is asynchronous transmission i.e. it is associated with the stability.

→ In order to maintain the s.state stability and also the transient stability, the Tr. lines are proposed with parallel lines.

→ By using parallel lines the net reactance of the system is reduced and also the acceleration property is reduced during the fault condition.

→ 

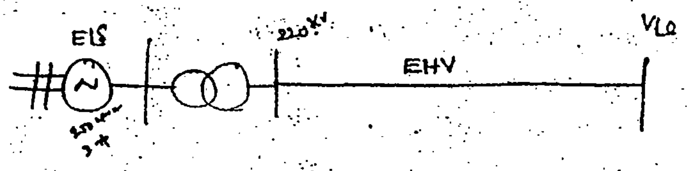
→ While selecting the t/f wdg it should ensure that the fault in one electrical n/w should not reflect in another electrical n/w so that the line side of the t/f must be Star with grounding where as the Source side of the t/f is isolated grounding.

H.V ⟶ Modern EHV ⟶ 400kV. (Ap transco)

H.V ⟶ UHV ⟶ 765 kV and above. (PGCIL)

⟶ Maximum transmission in India is 765KV (PGCIL)

⟶ Based on the distance of transmission, the selection of the transmission Voltage is Considered.



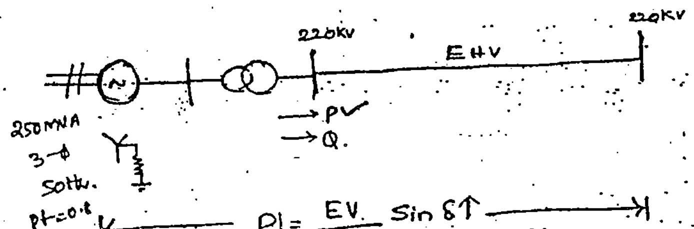
$S = \sqrt{3} V_L I_L$

$I_L = \dfrac{250 \times 10^6}{\sqrt{3} \times 220 \times 10^3} \Rightarrow I_{phase} \downarrow \Rightarrow I_L \downarrow \Rightarrow a \downarrow \Rightarrow w \downarrow$

Therefore
(i) Cost is less.
(ii) $P_L = 3I^2R \downarrow$
(iii) $\%\eta \uparrow$

12/01/10

⟶



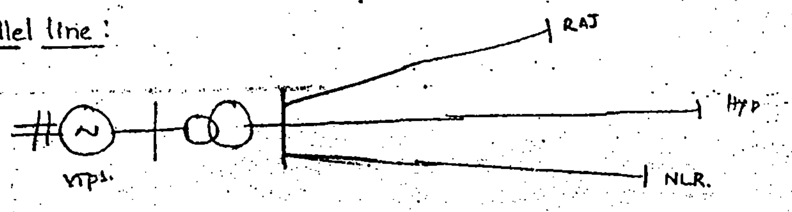
⟶ Single Tr. line

$\longleftarrow P\downarrow = \dfrac{EV}{X_{eq}\uparrow} \sin\delta\uparrow \longrightarrow \quad \delta\uparrow$

(R<<X) [loss less]

$= 250 \times 0.8$

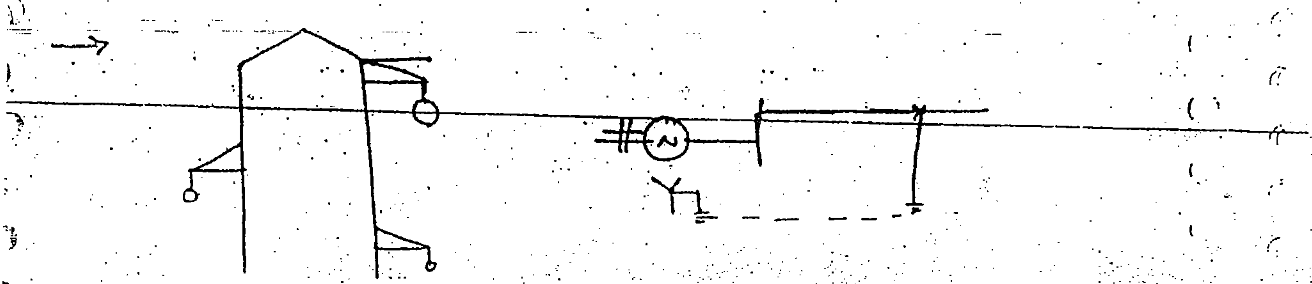
⟶ Parallel line:



$\longleftarrow P = 250 \times 0.8 \longrightarrow$

$P = \dfrac{EV}{X_{eq}\downarrow} \sin\delta \downarrow \Rightarrow \delta\downarrow \leq 70^\circ$

The Reactance X_{eq} reduce in parallel tr. line decreases. Hence the power transmission the same.



→ The t/lines are not having any neutral grounding but the grounded fault in t/lines will be closed through the neutral grounding of the generator. Hence if gen — $Y_{\bar{\pm}}$ then t/l is also "Y"

<u>Disadvantages of HV Tx system</u>

→ (i) $I_{phase} = I_L$

$\Rightarrow I \propto a$

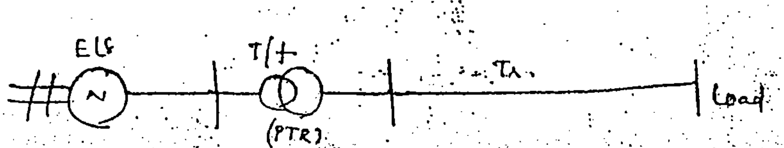
$\Rightarrow a\uparrow \longrightarrow \text{weight}\uparrow \Rightarrow a \times l.$

$\Rightarrow \text{Cost} \uparrow$

(ii) Power loss $= 3I^2R \uparrow$

(iii) $\%\eta \downarrow$

→ In order to overcome all the disadvantages, we have to change the electrical quantities V, I without changing power. Hence a t/f is connected.



→ Power transformers (PTR) → 1 MVA and above

Distribution t/f → ≤ 500 KVA

→ To change electrical characteristics H.V < 66 KV, 132 KV, 220 KV

— ~~A syn m/c is a dilevery character m/c~~

→ A Syn m/c ⟶ Speed Regulation

→ For a system to be stable the angle is $0 \le \delta \le 90^\circ$

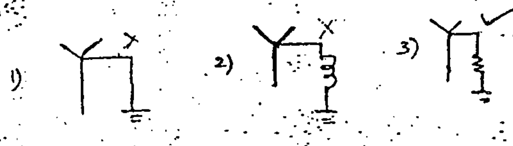
As δ changes ⟶ speed changes ⟶ Frequency changes.

→ "'Y' grounding" is required because of Grounded faults taken into considered.

→ L-G faults are frequently occuring faults in the system.

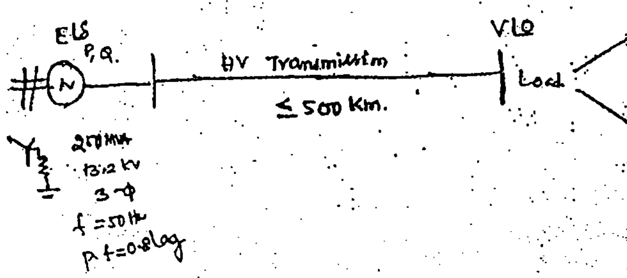
→ The system is dealing with Grounded faults and also with isolated grounded faults, in order to provide a closed path for fault current in case of ground faults, it is necessary to employ neutral grounding.

(Resistance grounding)



→ It improves the stability of the syn m/c during fault condition and also provide closed paths

→ The Resistance grounding can be employed to provide the closed paths and also to improve the stability of the system.



Asynchronous loads ✓

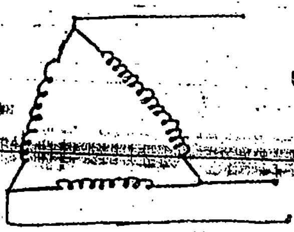
Syn load ✗ (practical problems)

→ Disadvantages of HV transmission

(i) $S = \sqrt{3}\, V_L I_L$

$I_L = \dfrac{250 \times 10^6}{\sqrt{3} \times 13.2 \times 10^3}$

$I_{ph} = I_L$ (Y system)



L-L 3-ϕ Δ (or) closed (or) Shunt wdg

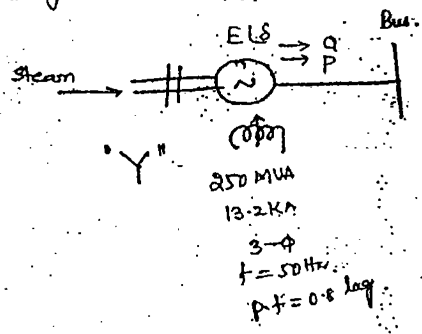
→ Voltage and current are per phase values and Power is always a 3-ϕ since, size of Conductor & Insulation is decided.

$S=\sqrt{3}V_LI_L$ 'Y' → $V_{phase} = \frac{V_L}{\sqrt{3}}$, $I_{ph} = I_L$ ⇒ More weight of Conductor is required

$S=\sqrt{3}V_LI_L$ Δ → $V_{phase} = V_L$, $I_{ph} = \frac{I_L}{\sqrt{3}}$ ⇒ More amount of Insulation is required.

→ Cost of the equipment = Conductor cost + Insulation cost

→ Single Line Diagram (SLD)



→ When there is unbalance in the load because of faults, the electrical quantities becomes more than the rated values hence there are changes failure of Insulation and results in damage of equipment.

→ To employ effective protection system in a phase manner, the alternator stator wdg is preferred as a 3-ϕ Y-winding

→ Power Generation — Electrically ⟨ 1-phase / 3-phase (Bulk amount of power)

(Rotor) + ϕ + (Stator) → 3-ϕ power.

Electrical.

→ Three phase is nothing but '3- Single phases' are suitable connected as Y or Δ

→ The physical appearance of Electric equipment

(i) Conductor → Carry the current

(ii) Insulation → To provide electrical isolation with other surfaces, so that the leakage current is prevented.

→ The selection of the size of the ~~current~~ conductor is based on current carrying capacity ⇒ $\boxed{I \propto a}$ ✓

→ The insulation is based on the voltage. ~~through~~.

⇒ $\boxed{\text{Insulation} \propto \text{voltage}}$ ✓

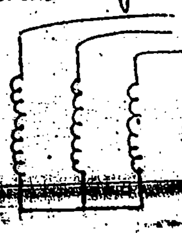
⇒ $E \propto V \propto$ Insulation → Dielectric strength (kV/cm

Dielectric strength ↑ ⇒ thickness of Insulation ↑.

⇒ Voltage ↑ ⇒ thickness of Insulation ↑.

→ Voltage and Current are called Basic electrical quantities which are useful to design the electrical equipment.

→ For a 3-ϕ phase system.

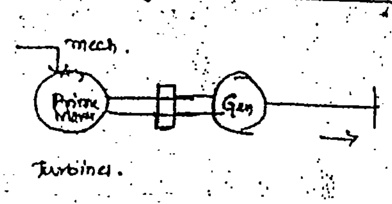


L-L

3-ϕ, Y (or) Open (or) Series winding

→ The Nature of current in MHD is dc currents

→ Most of the power is generated based on Rotational principles



→ Normally for generation, synchronous generator (or) alternators are used.

→ For Non-Conventional Sources: Generators used are

1) Asynchronous Generators

Ex: Induction generator.

→ Most of the Conventional plants are located at Remote places by fullfiling the geographical conditions.

→ Where as for N.C plants are located near the load points.

→ Application:

Conventional

- Except gas plants, the remaining are suitable for base loads plants.

→ Generation — Transmission
↓
Distribution.

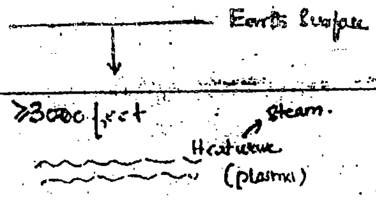
→ The Bulk amount of power is generated at remote place and it is needs to be carried over a longer distance through Transmission and then followed by Distribution comes.

N.C.

→ Except Geothermal plants, the remaining are suitable for Peak loads

→ The amount of power generation is very less so that the available power can only distributed from the generation to the nearer load points by using D

Ex:



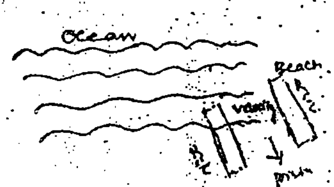
* Heat wave can be identified where there are frequent eruption of valcano's

→ Wind Mill: pressure of the ~~air~~ wind (Mech) is converted into electrical energy

→ Latest Range is 1MW plant each.

→ Started with 20KW

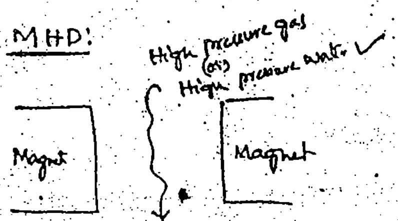
→ TIDAL plant: The velocity of the tide in the ocean (Mech) is converted into Electrical energy.



Turbine used: "Bulb Turbine" which is Kaplan turbine

→ Solar: Fuel: Sun light.

→ MHD:



1) Steam or Thermal: The high pressure and High temperature steam (Mech energy) will be converted into Electrical Energy

- pressure → 100 to 160 Kg/cm^2
- Temperature → 540°C

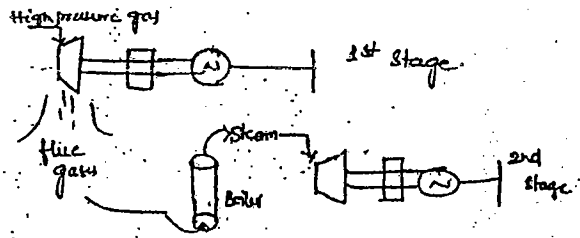
For captive plants: 7 Kg/cm^2 (<10MW)
↳ (For self purposes)

(2) Hydel: Most of the Hydel plants are of Reservoir type.

- The potential energy of the stored water is first converted into kinetic energy and then later into electrical energy.

(3) Nuclear: steam (or) Thermal plant but in place of boiler, a Nuclear reactor is placed.

(4) Gas: The high pressure gas is converted into electrical energy → 1st stage.



Called as Combined cycle (or) two stage.

→ If the high temperature is allowed to flow b/w the two Magnets the emf is induced in the magnets which is connected to the load (EMF

5) No atmospheric pollution.

→ Non Conventional / Conventional → Mechanical Energy → Electrical Energy → Mech load

— Mechanical energy can be obtained by (1) Conv (2) Non-Conv.

Non Conventional

1) Small capacity power generation for a short interval of time

EX: Solar, wind, Tidel, Biomass Geothermal and Magneto Hydro Dynamo generator. (MHD)

→ KW — Few (MW) with Voltages of 230V, 650V and 11KV.

→ Hence low voltage Category.

→ Bio mass plants: generation is based on steam

→ ~~Gauther~~ Fuel: pulp of the sugar-canes, wastematerial of paddy, ground nut. e.t.c

→ Recently huge no. of plants are in demand

→ Geothermal: It is also based on steam plants principle

Fuel: No Fuel (Fuel less)

CONVENTIONAL

1. Bulk amount of power generation over a longer period

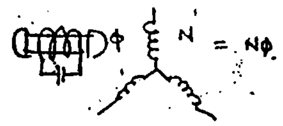
EX: Steam (or) Thermal, Hydel, Nuclear and Gas.

→ With Few MW to 500 MW with range of Voltages 3.3KV, 6.6KV 11KV, 13.2KV, and 22KV. Hence Comes under High Voltage upto 33KV

→ Max voltage generation levels in India is 22KV

$\uparrow E \propto N \uparrow \phi \uparrow$

EX: (1) For 15 MW



(2) For 100 MW the size of rotor field and Stator increase.

→ 62% of power is by Steam
33% " from Hydel.
5% from Nuclear, Gas and

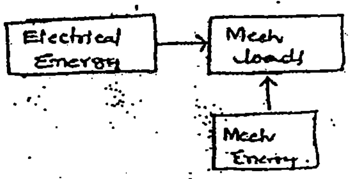
→ POWER SYSTEM: It is the system which deals with the almost all electrical equipment which are placed at different locations depends on the requirement and they are all working together to deliver electrical energy to the consumer on Economical basis

— Electrical Energy: Electrical power over a period of time.

The need of Electrical energy is —

1) To have an artificial illumination in order to see the objects very clearly (10%)

2) To drive the mechanical loads (90%)



EX: Traction system

→(1) The Transformation of Electrical energy into a mechanical energy will be more effective so that the energy loss in the system is less and finally the efficiency is high.

(2) If the power can be generated in a bulk manner then it is more economical.

(3) By employing effective monitoring system then the interruptions to the system are less so that the reliability of the supply is high.

(4) Easy control over the electrical energy in the form of switches.

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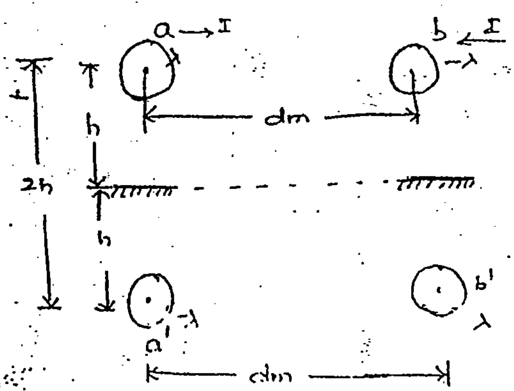
distribution of charges can be replaced by single equivalent charge for the calculation of capacitance.

→ Zero potential plane means → Potential is "ZERO" always.

→ Equipotential plane can be Zero potential but converse is not true.

→ For the safety of the electrical system it is preffered to consider the Earth as ZERO potential plane.

By considering a conductor at a depth of a 'h' from earth to calculate the earth effect.



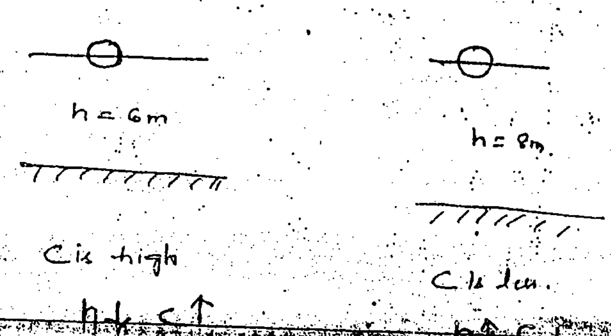
$$\uparrow C_{ab} = \frac{\pi\epsilon_0}{\downarrow \ln\left[\dfrac{d}{r\left(\left(1+\dfrac{d^2}{4h^2}\right)\right)^{1/2}}\right]} \text{ F/m} \longrightarrow \text{Effect of Earth}$$

>1.0

$$C_{ab} = \frac{\pi\epsilon_0}{\ln\left(\frac{d}{r}\right)} \text{ F/m} \longrightarrow \text{Isolated Earth}$$

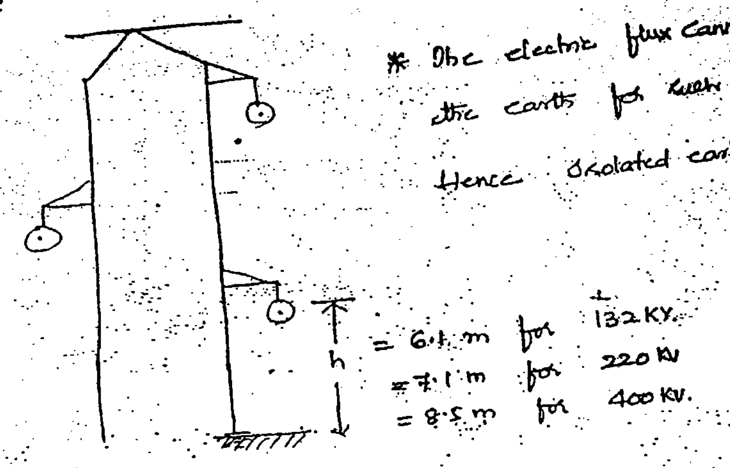
→ If the effect of earth is considered the value of capacitance will increase when compared to isolated earth.

Eg:



→ In General, In all practical case, the Calculation of Capacitance is by Isolated Earth Concept

Reason:



* The electric flux cannot reach the earth for such ~~large~~ more heights. Hence Isolated earth is considered.

⟹ R L X_L C B (Suscepta.) $\left(X_c = \frac{1}{B}\right)$

l. length ↑ ↑ ↑ ↑ ↑ ↑, $X_c \downarrow$ $\left(X_c \propto \frac{1}{l}\right)$

Eg: A 100 Km tr.line having a charging reactance of 50Ω. What is the charging reactance if the length of the line is 200 Km.

$$X_c \propto \frac{1}{l}$$

$$\frac{l_2}{l_1} = \frac{X_{c_1}}{X_{c_2}} = \frac{200}{100} = \frac{50}{X_{c_2}}$$

$$X_{c_2} = 25$$

$$X_{c_2} = 25$$

24/01/10

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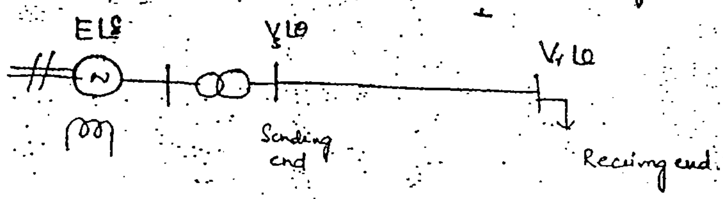
→ PERFORMANCE OF TRANSMISSION LINES:

→ The performance of any electrical equipment can analysed by taking efficiency and Regulation of that equipment.

Regulation — Speed (Rotating equipment)
— Voltage (static equipment)

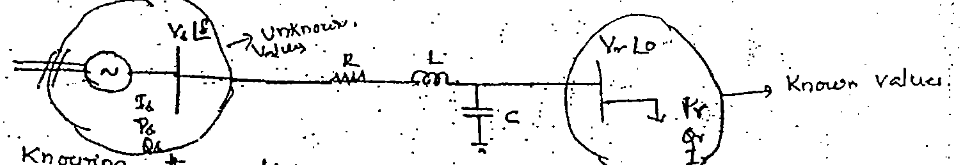
→ Hence for Transmission lines — efficiency
— Voltage Regulation.

→ 

$$\boxed{\theta \simeq \delta}$$

Since $Z_T << Z_L$

∴ Trans. line can be represented as follows.



— By Knowing the efficiency of the tr. line, It can be understood the amount of energy loss in the form of heat which is not recovered

→ If the efficiency of the t/line is high then the energy loss is less so that the performance of the tr.line will be satisfactory.

$$\therefore \% \eta = \frac{P_r}{P_r + 3I^2R} \times 100$$

→ The trans. line 'η' as well as the voltage Regulation can be calculated by knowing the sending end voltage & sending end current with the help of the receiving end voltage and the receiving end current along with tr. line constants.

→ Generally the Tr. lines are more efficient because

$$\% \eta \uparrow = \frac{P_r}{P_r + 3I^2 R \downarrow}$$ → very less (by default)

→ According to Indian Standards the power loss is (2 - 5)%
↓ by
CEA (Central Electricity Authority) → [Indian Electricity Rules]
↳ CPRI → Central power Research Institute
↓
BIS → Bureau of Indian Standards.

→ The loss in the Distribution network is (8 - 10)%

→ The Tr. & Dr loss is (10 - 15)% i.e. Ohmic loss (Tech. loss) (I^2R + Mech)

In addition to that commercial loss.

∴ loss = Tech loss + Commercial loss { ① Meter loss, i.e. meter which is not working consumption ② Unauthorized tapping of energy }

→ VOLTAGE REGULATION:

It is the change in the voltage of the receiving end from no load to full load while keeping the sending end voltage constant and also the supply frequency is made as constant.

$|V_{ro}|$ = No load voltage.

$|V_r|$ = Full load voltage

P = Pm − Pe
= 0
$N = N_s \rightarrow f = 50\,Hz$
by keeping excitation constant

volts (or) K.V.

% Regulation $$\boxed{\%\epsilon = \frac{|V_{ro}| - |V_r|}{|V_r|} \times 100}$$

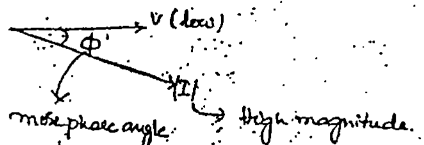
→ Regulation is expressed in $1-\phi$ where as the efficiency in $3-\phi$ since power is in $3-\phi$ and Voltage is in $1-\phi$.

→ If the Regulation of tr. line is low then there will be a better voltage at the load point so that the performance of the load is satisfactory, which in turn the performance of the tr. line is satisfactory.

→ Quality of the supply to the consumer is in the form of VOLTAGE

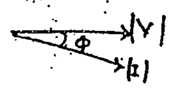
→ The Regulation of a tr. line is decided by L & C of the line.

→ Eg: If the magnitude of voltage is low.



$$S = VI\cos\phi + jVI\sin\phi$$
$$P + jQ$$
$$P\downarrow \Rightarrow \text{poor quality.}$$

② If voltage is high



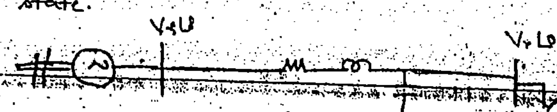
$$S = VI\cos\phi + jVI\sin\phi$$
$$= P\uparrow + jQ$$

High quality.

In General

→ Regulation of the tr. line is not exactly same as the voltage drop on the tr. line

For all the above cases the tr. line is considered as steady state.



→ The performance of the tr. lines can be analysed by representing the line electrically based on the physical length of the line.

(i) Short tr. lines → ≤ 80 km → Line constants represented in lumped (S.S) manner

Not possible to analyse transient behavior because of length

(ii) Medium tr. lines → 80 – 160 km → Lumped manner (S.S)

(iii) Long tr. lines → > 160 km → Uniformly distributed (Transient) (or) lumped (S.S)

↳ transient + S.S

C.B closed → wave travelling

→ If the lines are represented in lumped manner — then we can use KCL and KVL for analysis

→ If the line is distributed uniformly the Mathematical approach is used for analysis

→ lumped — R — L — Uniformly distributed

→ A lumped element is one which can be identified in physical manner and also separated electrically.

→ Uniformly distributed is the one which cannot be identified physically and also not possible to separate electrically.

→ In general any tr. line consisting of a stranded conductor and it is represented in a uniformly distributed manner.

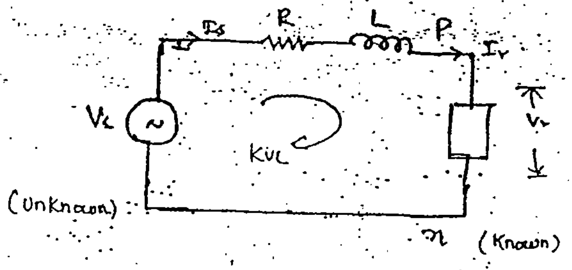
Regulation of lines & Efficiency
1) STL → %ε = ±6%, η = 95%
2) MTL → %ε = ±9%, η = 97%
3) LTL → %ε = ±12%, η = 98%

→ In STL, $C \simeq 0$ since Cap/km is negligible (ZERO) (Assumed) because of length is short. (∵ R. & L are considered

→ As the length of the line is short, so that the shunt Capacitance can be assumed as ZERO $(C \simeq 0)$

→ For medium line, R, L, & C
→ For Long line, ∵ R, L & C
} are considered.

→ SHORT LINE:

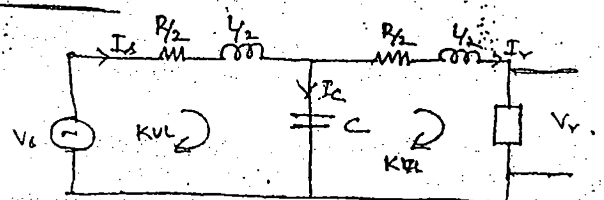


→ Medium Line: This is of '4' network models based on the shunt capacitance placement

Most commonly employed because these are of symmetrical representation
1) Nominal — T: → shunt capacitance is at the middle of the line
2) Nominal — π: → Shunt capacitance is placed on both sides of the t/line with equal magnitude

Unsymmetrical representation.
3) Load End Capacitance: Shunt cap is placed at load end.
4) Sending End Capacitance: Shunt Cap is placed at source end.

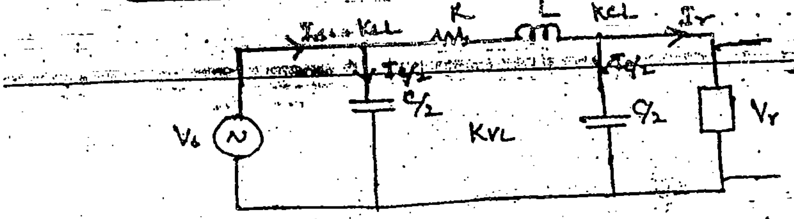
1) Nominal — T:



③ equations to solve for V_s & I_s.

I_c is upto middle of the line.

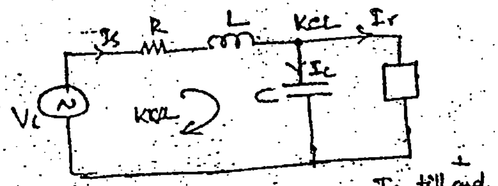
(2) Nominal – π



(2) equations to solve for V_s & I_s.

I_c is half at S.E & L.E

(3) LEC:

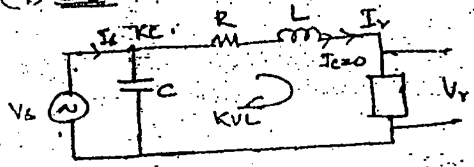


I_c till end.

Unsymmetrical

(2) equations for V_s & I_s

(4) SEC



Unsymmetrical.

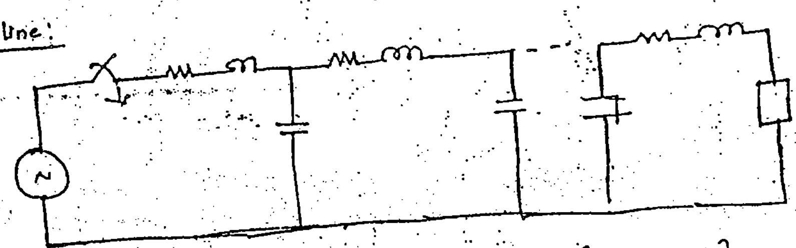
$I_c = 0$ at end.

(2) equations for V_s & I_s

→ For a given rated voltage & rated current ~~at~~ the receiving end, the voltage & current which is calculated at the sending end are called as Nominal Voltage & Nominal Current i.e. why we call Nominal – π & Nominal – T

→ In order to reduce the no. of the network equations, so that the time taking will be less to calculate V_s and I_s is by representing the tr. line in a two port n/w model rather than RLC model

3) Long line:

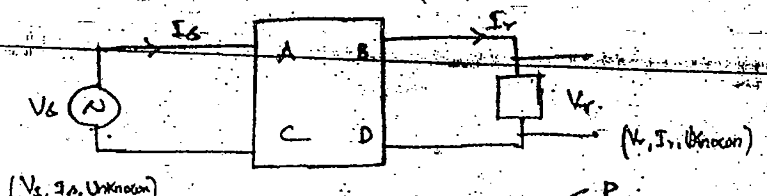


✓ Mathematical approach (transient)

✓ Steady state → lumped < Equivalent – T, Equivalent – π } models

~~for analysis by using KCL & KVL~~

→ TWO PORT NETWORK MODEL



Port – A pair of terminals < P, N.

Two ports < Sending end, Receiving end.

→ The Unknown electrical quantities are evaluated by using the Known electrical quantities along with certain parameters. Those parameters are called ABCD parameters (or) Transmission line parameters.

$$V_s = AV_r + BI_r \longrightarrow (1) \quad \text{KV/phase}$$

$$I_s = CV_r + DI_r \longrightarrow (2) \quad \text{KA/phase.}$$

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix} \qquad \begin{bmatrix} V_r \\ I_r \end{bmatrix} = \frac{1}{AD-BC} \begin{bmatrix} D & -B \\ -C & A \end{bmatrix} \begin{bmatrix} V_s \\ I_s \end{bmatrix}$$

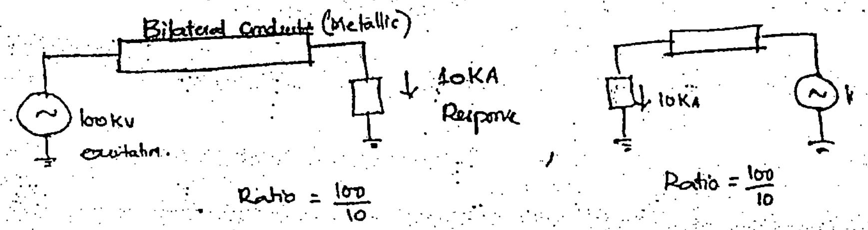
If $A = D \Rightarrow$ Symmetric Network model.

and

If $AD - BC = 1 \Rightarrow$ A Reciprocal network model.

Reciprocal network: The ratio of excitation to the response is same even though the positions are interchanged.

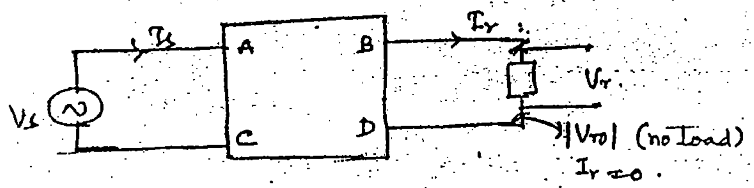
Ex:



Electronic element → hybrid parameters
Electric(al) metallic → ABCD parameters

→ Any electrical n/w may or may not symmetric but always Reciprocal.

→ Units of ABCD values:



Case(i) No load condition at receiving end

$$V_s = A V_{ro} \longrightarrow (3)$$

$$I_s = C V_{ro} \longrightarrow (4)$$

$$\boxed{\frac{V_s}{I_s} = \frac{A}{C}} \longrightarrow (5)$$

$$A = \frac{V_s}{V_{ro}}\bigg|_{I_r=0} \quad \text{Unitless}$$

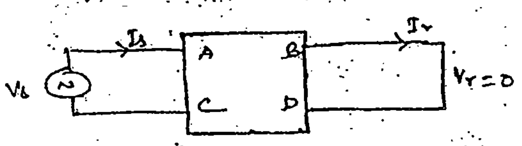
$$C = \frac{I_s}{V_{ro}}\bigg|_{I_r=0} \quad \text{O.C admittance (or) Mhos (or) siemens}$$

mho's

$$\%\epsilon = \frac{|V_{ro}| - |V_r|}{|V_r|} \times 100$$

$$\%\epsilon = \frac{\frac{V_s}{A} - |V_r|}{|V_r|} \times 100$$

Case(ii) Assuming short circuit at the receiving end.



$$V_s = B \cdot I_r \longrightarrow (6)$$

$$I_s = D \cdot I_r \longrightarrow (7)$$

$$\boxed{\frac{V_s}{I_s} = \frac{B}{D}} \longrightarrow (8)$$

ohms

$$B = \frac{V_s}{I_r}\bigg|_{V_r=0} \quad \text{S.C Impedance — ohms.}$$

$$D = \frac{I_s}{I_r}\bigg|_{V_r=0} \quad \text{Unitless}$$

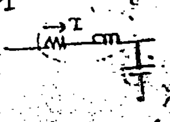
From eq's (5) & (8) $(B = Z \quad C = Y)$

$$\frac{V_s}{I_s} = \frac{V_s}{I_s} = \frac{A}{C} = \frac{B}{D}.$$

$$\Rightarrow \frac{V_s}{I_s} = \sqrt{\frac{A}{C}\cdot\frac{B}{D}} = \sqrt{\frac{B}{C}} = \sqrt{\frac{Z_{sc}}{Y_{oc}}}$$

$$\therefore \boxed{\frac{V_s}{I_s} = \sqrt{Z_{oc}\,Z_{sc}} = Z_c} \rightarrow \text{Characteristic Impedance.}$$

$\frac{V}{I} = Z$



→ A tr. line is having a series representation of Impedance and parallel representation of admittance, the ratio of Voltage to the current any where in the line is called as the "CHARECTERISTIC IMPEDANCE" of the line.

→ ABCD Values with magnitude & Angles.

$A = |A|\angle\alpha$

$B = |B|\angle\beta$

$C = |C|\angle\gamma$

$D = |D|\angle\alpha$

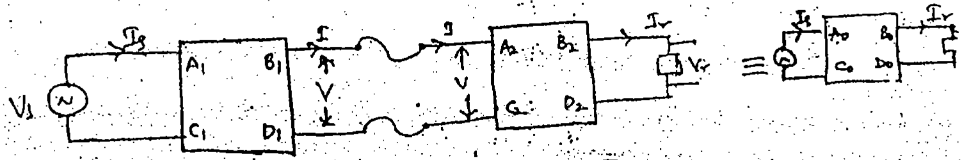
Max value of A is 1.

⇒ generally long lines are assumed as lossless since R is very less

(since $C \neq 0$, x_c)

STL $C \simeq 0$	MTL $C \neq 0$	LTL $C \neq 0$
$\boxed{\lvert A\rvert = 1.0}$	$\boxed{\lvert A\rvert = 0.95 - 0.98}$	$\boxed{\lvert A\rvert = 0.9 - 0.95}$
$\boxed{\alpha = 0}$	$\boxed{\alpha = 1-2^\circ}$	$\boxed{\alpha = 2\text{-}5^\circ}$
$\boxed{\lvert B\rvert = \sqrt{R^2+X^2}}$ does depends on the length of the line	$\lvert B\rvert = \sqrt{R^2+X^2}$ depends on line length	$\lvert B\rvert = \sqrt{R^2+X^2}$ depends on length of the line
β = Impedance angle $\beta = \tan^{-1}(\frac{X}{R})$	$\beta = \tan^{-1}(X/R)$	$\beta = \tan^{-1}(\frac{X}{R})$
$\boxed{\beta = 60^\circ}$	$\boxed{\beta = 70^\circ}$	$\boxed{\beta = 87^\circ}$
$\lvert C\rvert = \lvert wc\rvert = 0$	$\lvert C\rvert = \lvert wC\rvert$ depends on line length	$\lvert C\rvert = \lvert wc\rvert$ depends on line length
$Y = G + jB$		
$\boxed{\gamma = 0}$	$\boxed{\gamma = 90^\circ}$ ($G=0$)	$\boxed{\gamma = 90^\circ}$
$\boxed{D = A}$	$\boxed{D = A}$	$\boxed{D = A}$

→ Two trans. lines are Connected in Cascade (or) Tandom



$$\begin{bmatrix} A_0 & B_0 \\ C_0 & D_0 \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix}\begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix}$$

→ If two tr. lines are connected in cascade then the equivalent tr. line matrix is nothing but the matrix multiplication of the individual tr. line matrices.

$$\Rightarrow \begin{bmatrix} A_0 & B_0 \\ C_0 & D_0 \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix}$$

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} V \\ I \end{bmatrix}, \quad \begin{bmatrix} V \\ I \end{bmatrix} = \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

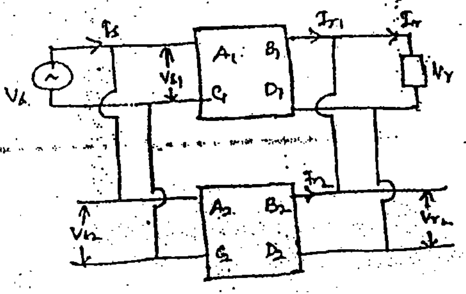
$$\Rightarrow \begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A_0 & B_0 \\ C_0 & D_0 \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

→ For two similar lines

$$A_1 = A_2 = A$$
$$B_1 = B_2 = B, \quad \Rightarrow \begin{bmatrix} A_0 & B_0 \\ C_0 & D_0 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} A & B \\ C & D \end{bmatrix}$$
$$C_1 = C_2 = C$$
$$D_1 = D_2 = D$$

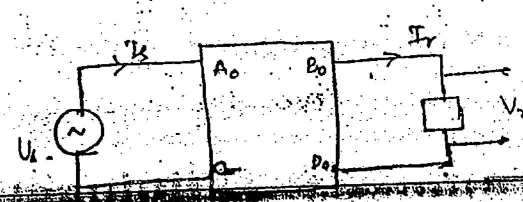
→ Two Transmission lines in parallel:



$V_{s1} = V_{s2} = V_s$

$V_{r1} = V_{r2} = V_r$.

$I_s = I_{s1} + I_{s2}$



$$A_0 = \frac{A_1 B_2 + A_2 B_1}{B_1 + B_2}$$

$$B_0 = \frac{B_1 B_2}{B_1 + B_2}$$

$$C_0 = C_1 + C_2 + \frac{(A_1 - A_2)(D_2 - D_1)}{B_1 + B_2}$$

$$D_0 = \frac{D_1 B_2 + D_2 B_1}{B_1 + B_2}$$

For Similar lines

$A_1 = A_2 = A$ $\quad\quad$ $A_0 = A$

$B_1 = B_2 = B$ $\quad\quad$ $B_0 = B/2$ (Impedance)

$C_1 = C_2 = C$ $\quad\quad$ $C_0 = 2C$ (Admittance)

$D_1 = D_2 = D$ $\quad\quad$ $D_0 = D$

1st line

$$V_{s_1} = A V_{r_1} + B_1 I_{r_1} \longrightarrow (1)$$

V_s, V_r

$$I_{s_1} = C_1 V_{r_1} + D_1 I_{r_1} \longrightarrow (2)$$

2nd line

$$V_{s_2} = A_2 V_{r_2} + B_2 I_{r_2} \longrightarrow (3)$$

V_s, V_r

$$I_{s_2} = C_2 V_{r_2} + D_2 I_{r_2} \longrightarrow (4)$$

$(1) \times B_2 + (3) \times B_1$

$$V_s (B_1 + B_2) = (A_1 B_2 + A_2 B_1) V_r + B_1 B_2 \underbrace{(I_{r_1} + I_{r_2})}_{I_r}$$

$$\therefore V_s = \left(\frac{A_1 B_2 + A_2 B_1}{B_1 + B_2}\right) V_r + \left(\frac{B_1 B_2}{B_1 + B_2}\right) I_r \longrightarrow (5)$$

$$V_s = A_0 V_r + B_0 I_r \longrightarrow (6)$$

Comparing Eq's (5) and (6)

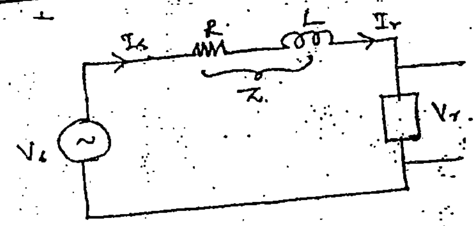
we get A_0, B_0, and $A = D$

and C_0 can be calculated by $A_0D_0 - B_0C_0 = 1.0$

$$\Rightarrow C_0 = \frac{1 - A_0D_0}{B_0}$$

$$C_0 = \frac{1 - \left(\frac{A_1B_2 + A_2B_1}{B_1+B_2}\right)\left(\frac{D_1B_2+D_2B_1}{B_1+B_2}\right)}{\frac{B_1B_2}{B_1+B_2}}$$

→ SHORT TRANSMISSION LINES:



$$V_s = AV_r + BI_r \rightarrow ①$$

$$I_s = CV_r + DI_r \rightarrow ②$$

$$V_s = 1.0 \times V_r\angle 0 + Z.I_r \rightarrow ③$$

$$I_s = 0 \times V_r\angle 0 + 1.0 \times I_r \rightarrow ④$$

Comparing ①, ② with ③ & 4

$$\boxed{A = 1.0, \quad B = Z, \quad C = 0, \quad D = 1.0}$$

$A = D$ and $AD - BC = 1.0$

Regulation of the line

$$\% \epsilon = \frac{|V_{ro}| - |V_r|}{|V_r|} \times 100 \rightarrow \text{Any line.}$$

For No load
$|V_{ro}| = V_s$
$C \approx 0$
$I_s = I_r$

$$\rightarrow \boxed{\% \epsilon = \frac{|V_s| - |V_r|}{|V_r|} \times 100} \longleftrightarrow \text{STL}$$

→ In STL ~~the~~ Regulation of the line is equal to VOLTAGE DROP

$$\therefore \ \% \epsilon = \frac{V_r + I_r \cdot Z - V_r}{V_r} \times 100$$

$$\boxed{\% \epsilon = \frac{I_r \cdot Z}{V_r} \times 100}$$

Another method

$$\% \epsilon = \frac{|V_{r0}| - |V_r|}{|V_r|} \times 100$$

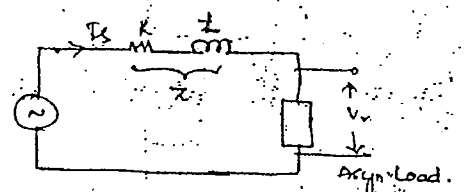
$$\% \epsilon = \frac{|\frac{V_s}{A}| - |V_r|}{|V_r|} \times 100$$

$$\% \epsilon = \frac{|V_s| - |V_r|}{|V_r|} \times 100$$

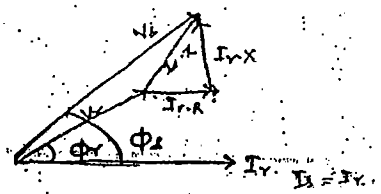
$$\% \epsilon = \frac{\cancel{V_r} + I_r \cdot Z - \cancel{V_r}}{V_r} \times 100$$

$$\boxed{\% \epsilon = \frac{I_r \cdot Z}{V_r} \times 100}$$

→ Alternative method



Use the vector diagram

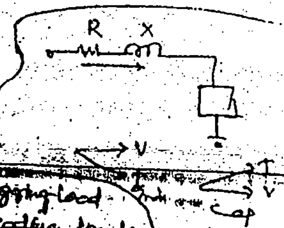


$$\boxed{\cos\phi_s = \frac{V_r \cos\phi_r + I_r R}{V_s}}$$

$$V_s \cos\phi_s = V_r \cos\phi_r + I_r R \longrightarrow (1)$$

$$V_s \sin\phi_s = V_r \sin\phi_r + I_r X \longrightarrow (2)$$

Square and Add eq's (1) & (2)



$$V_s \simeq V_r \angle 0 + I_r R \cos\phi_r \pm I_r X \sin\phi_r$$

$$I_s = I_r$$

+ for lagging load

− for leading loads

$$\% \epsilon = \frac{|V_{ro}| - |V_{r}|}{|V_r|} \times 100$$

For Noload

$|V_{ro}| = |V_s|$

$$\% \epsilon = \frac{|V_s| - |V_r|}{V_r} \times 100$$

$$\% \epsilon = \frac{\cancel{V_r} + I_r R \cos\phi_r \pm I_r X \sin\phi_r - \cancel{V_r}}{V_r} \times 100$$

$$\% \epsilon = \frac{I_r \cdot R}{V_r} \times 100 \cos\phi_r \pm \frac{I_r \cdot X}{V_r} \times 100 \times \sin\phi_r$$

$$\% \epsilon = \% V_r \cos\phi_r \pm \% V_x \sin\phi_r$$

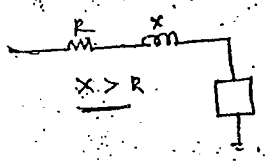
$\% V_r$ = % resistance drop $= \frac{I_r R}{V_r} \times 100$

$\% V_x$ = % Reactance drop $= \frac{I_r X}{V_r} \times 100$.

% ϵ will be maximum, if the load is Inductive load.

% ϵ will be negative, if the load is Capacitive load.

Expl ↳



$|V_r| > |V_{ro}|$

Special case $\cancel{\% \epsilon = 0}$

$$\% \epsilon = \% V_r \cos\phi_r - \% V_x \sin\phi_r$$

since $(X > R)$

Drop in 'X' is more than drop in 'R'

→ Under loaded condition $|V_{ro}|$ is less than $|V_r|$

Hence Negative Regulation and more voltage at receiving end load

→ Special Case

$\% \epsilon = 0$ $\boxed{X = R}$ and 0.707 p.f lead.

~~(practically not possible)~~

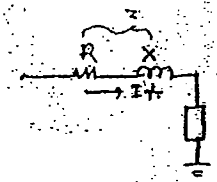
→ The phase angle at which the regulation is maximum

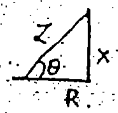
$$\cancel{\%\epsilon = \%V_R\cos\phi_r + \%V_x\sin\phi_r}$$

$$\frac{d\,\%\epsilon}{d\phi_r} = -\%V_R\sin\phi_r + \%V_x\cos\phi_r = 0$$

$$\tan\phi_r = \frac{\%V_x}{\%V_R} = \frac{\frac{I_r \cdot X}{V_r}\times 100}{\frac{I_r \cdot R}{V_r}\times 100} = \frac{X}{R}$$

$$\therefore \boxed{\phi_r = \tan^{-1}\left(\frac{X}{R}\right)}$$





$$\tan\theta = \frac{X}{R}$$

$$\Rightarrow \tan\phi_r = \frac{X}{R} = \tan\theta$$

$$* \boxed{\phi_r = \theta}$$

→ The phase angle at which the regulation is ZERO.

$$\%\epsilon = \%V_R\cos\phi_r - \%V_x\sin\phi_r = 0$$

$$\tan\phi_r = \frac{\%V_R}{\%V_x} = \frac{\frac{\cancel{I_r}\cdot R}{\cancel{V_r}}\times\cancel{100}}{\frac{\cancel{I_r}\cdot X}{\cancel{V_r}}\times\cancel{100}} = \frac{R}{X}$$

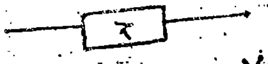
$$\tan\phi_r = \frac{R}{X}$$

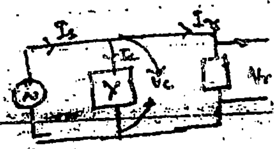
$$\boxed{\phi_r = \tan^{-1}\left(\frac{R}{X}\right)}$$

$$\tan\phi_r = \cot\theta = \tan\left(\pi/2 - \theta\right)$$

$$\phi_r = \pi/2 - \theta$$

$$* \boxed{\phi_r + \theta = \pi/2}$$





$A = 1.0$
$B = Z$
$C = 0$
$D = 1.0$

$A = 1.0$
$B = 0$
$C = Y$
$D = 1.0$

$V_s = V_c = V_r + 0 \times I_r$

$V_s = AV_r + BI_r$

$A = 1.0$

$B = 0.$

$I_s = I_c + I_r.$

$= V_c \omega C + I_r$

$I_s = YV_r + I_r$

$I_s = CV_r + DI_r$

$C = Y$

$D = 1.0$

⟹ MEDIUM TRANSMISSION LINE

⟶ Nominal – T

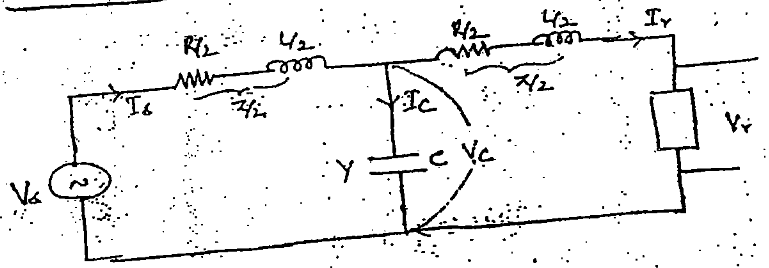


fig (1)

$V_s = AV_r + BI_r$

$I_s = CV_r + DI_r$

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & Z/2 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} \begin{bmatrix} 1 & Z/2 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 + \frac{ZY}{2} & Z\left(1 + \frac{ZY}{4}\right) \\ Y & 1 + \frac{ZY}{2} \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

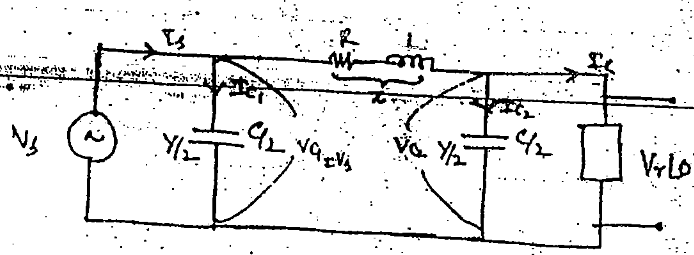
$A = 1 + \frac{ZY}{2}$ $\quad$ $A = D$ and $AD - BC = 1.0$

$B = Z\left(1 + \frac{ZY}{4}\right)$ $\quad$ Symmetric and Reciprocal.

$C = Y$

$D = 1 + \frac{ZY}{2}$

NOMINAL – π



$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y/2 & 1 \end{bmatrix} \begin{bmatrix} 1 & z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y/2 & 1 \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 + \frac{ZY}{2} & Z \\ Y\left(1 + \frac{ZY}{4}\right) & 1 + \frac{ZY}{2} \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

$A = 1 + \frac{ZY}{2}$

$B = Z$

$C = Y\left(1 + \frac{ZY}{4}\right)$

$D = 1 + \frac{ZY}{2}$

$A = D$ and $AD - BC = 1$, Symmetric & Reciprocal

→ Nominal – T

→ Regulation, % ε for fig (i) $= \frac{|V_{r0}| - |V_r|}{|V_r|} \times 100$

Under No Load Condition

$V_r = |V_{r0}| = |V_C|$

$I_r = 0$.

$$|V_{r0}| = \frac{|V_s| \left|\frac{1}{j\omega C}\right|}{\left|\frac{R}{2} + \frac{j\omega L}{2} + \frac{1}{j\omega C}\right|}$$ (By potential divider Rule)

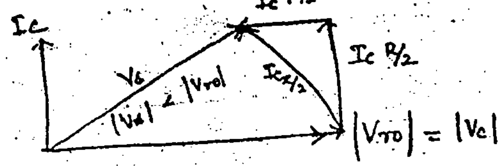
$|V_{r0}| > |V_s|$ ⟶ Ferranti Effect

F.E: If the tr. line is working at no load or light load condition then the receiving end voltage is more than the sending end voltage which is known as the FERRANTI EFFECT.

~~There is no Ferranti effect~~ will be much severe in LTL when compared MTL

Vector diagram

(opposite to V_{ro} because negative X drop)



Another method

$$|V_{ro}| = \left|\frac{V_s}{A}\right|$$

$$|V_{ro}| > |V_s|$$

$|A| < 1.0$ because of Shunt Capacitance

$$A = 1 + \frac{ZY}{2}$$

$$|A| = \left|1 + \frac{ZY}{2}\right|$$

$$= \left|1 + \frac{|Z|\angle\theta\,|Y|\angle\gamma}{2}\right|$$

$$= \left|1 + \frac{|Z||Y|}{2}\cos(\theta+\gamma) + j\frac{|Z||Y|}{2}\sin(\theta+\gamma)\right|$$

$(70+90)$ MTL $\qquad$ $(90+90)$

$-ve$ ↑ than 1 $\qquad$ $+ve$ ↓

(vectorial addition)

$$= |a + jb|$$

$$< \underline{\underline{1.0}}$$

→ Nominal-π

For no load condition

$$\%\,\epsilon = \frac{|V_{ro}| - |V_r|}{|V_r|} \times 100$$

$$|V_{ro}| = |V_{ca}| = \frac{|V_s|\left|\frac{1}{jwc}\right|}{\left|R + jwL + \frac{1}{jwc}\right|}$$

$|V_{ro}| > |V_s|$

$$|V_{ro}| = \left|\frac{V_s}{A}\right|$$

$$|A| < 1.0$$

$$\Rightarrow |V_{ro}| > |V_s|$$

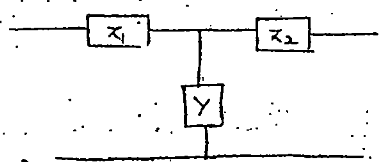
→ For a given receiving end voltage, the sending end voltage which is calculated will be slightly high for nominal-π configuration, so that the regulation will be slightly HIGH ~~when~~ in Nominal-π when compared to nominal-T
(since shunt capacitance is on load end side)

Q) Which is the most practical network model in Medium line

(i) N-T (ii) N-π (iii) either N-T (or) N-π (iv) None

Expl: In a practical case there is a better voltage at the load point, For a fixed sending end voltage if the transmission line is modelled in the nominal-π configuration rather than nominal-T.

(Q)



$(Z_1 \neq Z_2)$ Unsymmetric But Reciprocal.

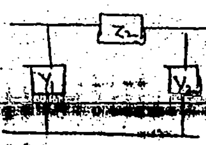
⇓

Y is not placed exactly at the middle of the line

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & Z_1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} \begin{bmatrix} 1 & Z_2 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

$$A \neq D, \quad \text{But } AD - BC = 1.$$

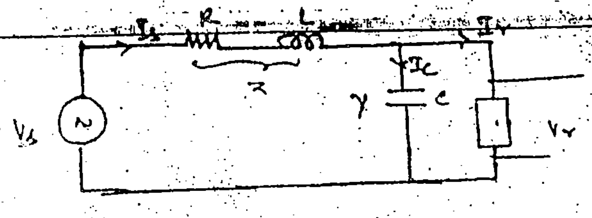
(Q)



$Y_1 \neq Y_2$, Unsymmetric but Reciprocal

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y_1 & 1 \end{bmatrix} \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y_2 & 1 \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

(3) Load end capacitance:



$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

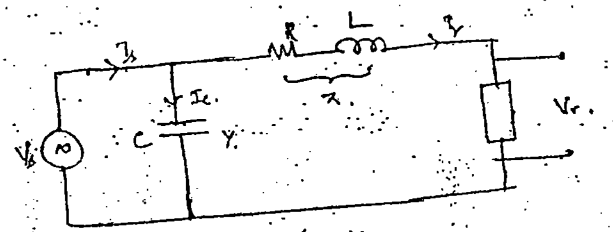
$A = 1 + ZY$

$B = Z$ unsymmetric

$C = Y$

$D = 1.0$, $A \neq D$, But $AD - BC = 1.0$

(4) Source End Capacitance:



$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y & 0 \end{bmatrix} \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

$\therefore$ $A = 1.0$

$B = Z$

$C = Y$

$D = 1 + YZ$

$AD - BC = 1$

Unsymmetrical but Reciprocal.

**

		A	B	C	D
1)	Distance b/w the ~~Conductor increases~~	Remain Same	↑	↓	Remain Same
2)	Radius increases	Remain Same	↓	↑	Remain Same
** 3)	Length Increases	↓	↑	↑	↓

Eg: Nominal - T (for above, Expl)

$A = 1 + \frac{ZY}{2}$ ⟹ Remain same

$B = Z\left(1 + \frac{ZY}{4}\right)$ ⟹ ↑

$C = Y$ ⟹ ↓

$D = 1 + \frac{ZY}{2}$ ⟹ Remain same.

As $d\uparrow \Rightarrow L\uparrow,\ Z\uparrow$

$C\downarrow\ Y\downarrow$

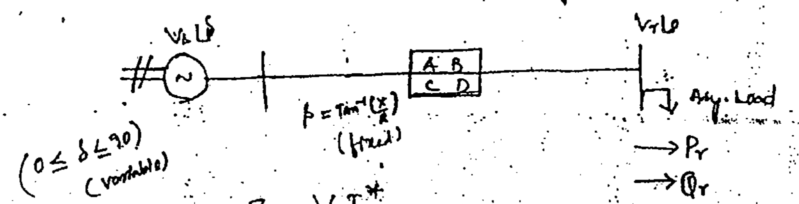
~~As length~~ ⟹

As $r\uparrow \Rightarrow L\downarrow\ Z\downarrow$

$C\uparrow\ Y\uparrow$

28/01/10

→ POWER TRANSFER EQUATIONS : (Receiving end)



$$S = VI^*$$
$$= V^*I$$

P always +ve if it is motor side & gen side

The purpose of the Conjugate is to ensure that the real power is always positive and also to provide the sign for the reactive power.

In AC system (Conjugate requirement explanation)

$S = VI$

$S = |V|\angle\alpha \; |I|\angle+\beta$

$= |V||I|\angle\alpha+\beta$

$S = |V||I|\cos(\alpha+\beta) + j\,|V||I|\sin(\alpha+\beta)$

$\alpha+\beta > 90$

$\Rightarrow$ P will be $-ve$ (no meaning for $-ve$ Real power)

$\therefore$ Conjugate

$S = VI^*$

$= |V|\angle\alpha \; |I|\angle-\beta$

$= |V||I|\angle\alpha-\beta$

$S = |V||I|\cos(\alpha-\beta) + j|V||I|\sin(\alpha-\beta)$

If $\boxed{\alpha > \beta} \Rightarrow$ Voltage leading w.r.t current.

$\alpha-\beta < 90$ ($+ve$)

$S = P+JQ$ (For Inductive load ~~…~~ P +ve, Q = +ve)

If $\boxed{\alpha < \beta} \Rightarrow$ Voltage is lagging w.r.t current

$\alpha-\beta < 90°$ ($-ve$)

$\therefore \; S = P-JQ$ (For Capacitive load ~~…~~ P is +ve, $Q = -ve$)

* Hence the Real power is always "positive"

$\therefore \; S_r = V_r I_r^*$

$$S_r = |V_r|\angle 0 \left[\frac{|V_s|\angle\delta - |A|\angle\alpha |V_r|\angle 0}{|B|\angle\beta}\right]^*$$

Since $V_s = AV_r + BI_r$

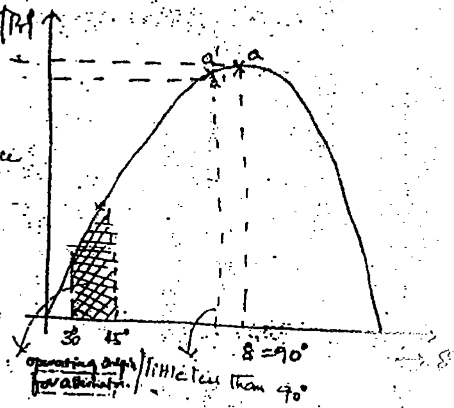
$I_r = \frac{V_s - AV_r}{B}$

$$S_r = \frac{|V_s||V_r|}{|B|}\angle\beta-\delta - \frac{|A|}{|B|}|V_r|^2\angle\beta-\alpha$$

$$\therefore P_r = \frac{|V_s||V_r|}{|B|}\cos(\beta-\delta) - \left|\frac{A}{B}\right||V_r|^2\cos(\beta-\alpha) \longrightarrow (1)$$

$$Q_r = \frac{|V_s||V_r|}{|B|_{(phase)}}\sin(\beta-\delta) - \left|\frac{A}{B}\right|V_r^2\sin(\beta-\alpha) \longrightarrow (2)$$

$P_r = P_{max}$ = Steady state stability limit



a' → stability angle.

$\delta \neq 90°$ because there is some resistance in the line

Hence δ = 85° — 87° to deliver max power at "a"

$\rightarrow \boxed{\delta = \beta}$

$$\therefore P_{max} = \frac{|V_s||V_r|}{|B|} - \frac{|A|}{|B|}|V_r|^2\cos(\beta-\alpha)\ \text{MW.}$$

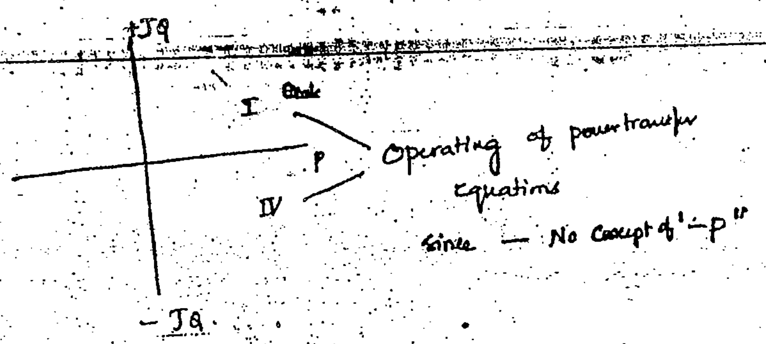
$$Q_r = -\frac{|A|}{|B|}(V_r)^2\sin(\beta-\alpha)\ \text{MVAR}$$

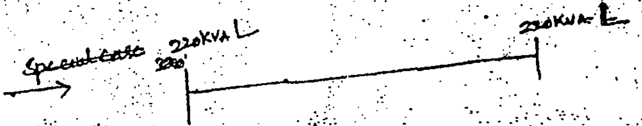
Capacitive load (or) Synchronous load — electrically

— To deliver the max amount of real power to the load, the load at the load end must be a synchronous load

→ Due to practical limitations of the synchronous motors, it is not preferrable to replace the induction motors with synchronous motors. If the load at the load end is induction motor then the real power to be +ve and also the reactive power to be "+ve" which can possible by allowing the alternator to deliver the required real power and reactive power with the operating angles rather than stability angle i.e 30° to 45°

→ The locus of the power transfer equations is a **CIRCLE**.



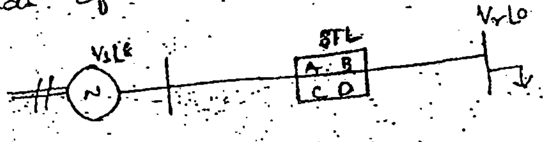


→ Special case

To prove

In the given transmission line the amount of real power transfer does depends upon the difference of the angle b/w two ends and the amount of reactive power transfer of the trans line and the amount of reactive power transfer does depends upon the difference in the magnitude of the voltage on both ends of the transmission line.

→ Special case ①



$C \simeq 0, \quad |A| = 1.0, \quad |B| = (X)$

$|\alpha| = 0, \quad |\beta| = \theta$

$$P_r = \frac{|V_s||V_r|}{|X|}\cos(\theta-\delta) - \frac{1.0}{|X|}|V_r|^2\cos\theta \rightarrow ①$$

$$Q_r = \frac{|V_s||V_r|}{|X|}\sin(\theta-\delta) - \frac{1.0}{|X|}|V_r|^2\sin\theta \rightarrow ②$$

$P_r = P_{max}$ = Steady State Stability

$\Rightarrow \delta = \theta$

$$\left.\begin{aligned} P_{max} &= \frac{|V_s||V_r|}{|X|} - \frac{1.0}{|X|}|V_r|^2\cos\theta \\ Q_r &= \frac{-1.0}{|X|}|V_r|^2\sin\theta \end{aligned}\right\} \text{For Synchronous load}$$

→ The maximum power transfer is possible provided that the load at the load end must be a synchronous load irrespective of transmission line. ~~However it is more preferred to have~~ motors at the load end and the alternator is able to operate with operating angle of 5° to 10° only if it is connected to short line.

→ (2) STL and loss less

$C \simeq 0, \quad R \simeq 0.$

$|A| = 1.0, \; \alpha = 0.$

$|B| = |X|$

$\beta = \theta = 90°$

From eq(1) & (2)

$$P_r = \frac{|V_s||V_r|}{|X|} \sin\delta \qquad (\because \cos 90° = 0)$$

$$Q_r = \frac{|V_s||V_r|}{|X|} \cos\delta - \frac{1.0}{|X|} |V_s|^2 \underbrace{(\sin(90° - 0))}_{=1}$$

loss-less Short line.

If $\delta = \beta = 90°$

$$P_r = P_{max} = \frac{|V_s||V_r|}{|X|}$$

$$Q_r = \frac{-1.0}{|X|} |V_s^2| \rightarrow (-ve) \Longrightarrow \text{Syn load.}$$

∴ Even for loss less line the P_{max} will be possible for syn load only

$$\therefore P_r = \frac{|V_s||V_r|}{|X|} \sin\delta$$

$$P_r = P_{max} \sin\delta$$

$$P_r = K \sin\delta \quad \left[\because K = P_{max} = \frac{|V_s||V_r|}{|X|}\right]$$

$$\Rightarrow \boxed{P_r \propto \sin\delta} \Longrightarrow ~~As\ \delta \uparrow \sin\delta \uparrow\ (\delta \le 90°)~~$$

$$\therefore \boxed{P_r \propto (\delta - 0)} \quad \left(\text{Real power transfer depends on angle}\right)$$

$$Q_r = \frac{|V_s||V_r|}{|X|}\cos\delta - \frac{1.0}{|X|}|V_r|^2$$

$$Q_r = \frac{|V_r|}{|X|}\left[|V_s|\cos\delta - |V_r|\right]$$

δ is small as δ 5° to 10°

$\cos\delta \simeq 1.0$

$$Q_r = \frac{|V_r|}{|X|}\left[|V_s| - |V_r|\right]$$

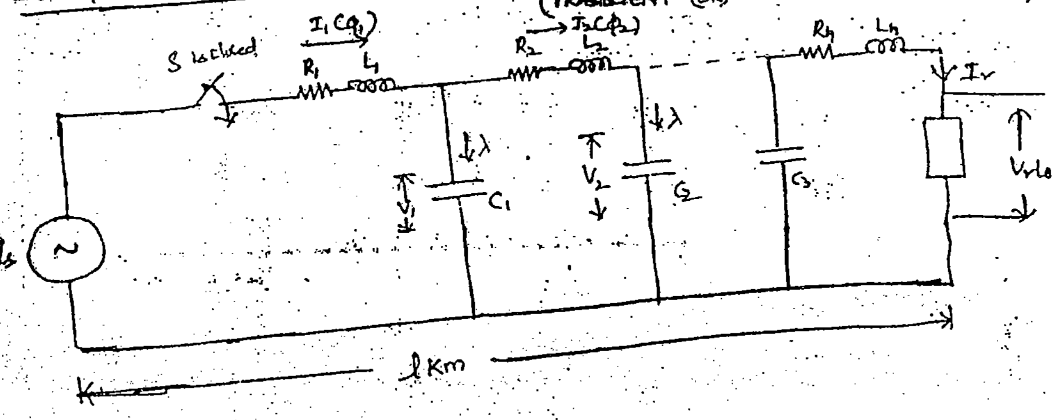
$$\doteq \frac{|V_r|}{|X|}\left[\text{Line Voltage drop}\right]$$

$Q_r \propto$ (line voltage drop) [Hence Reactive power depends on line voltages.]

→ POWER TRANSFER EQUATIONS (Sending end)

$S_s = V_s I_s^*$ (Refers Text book)

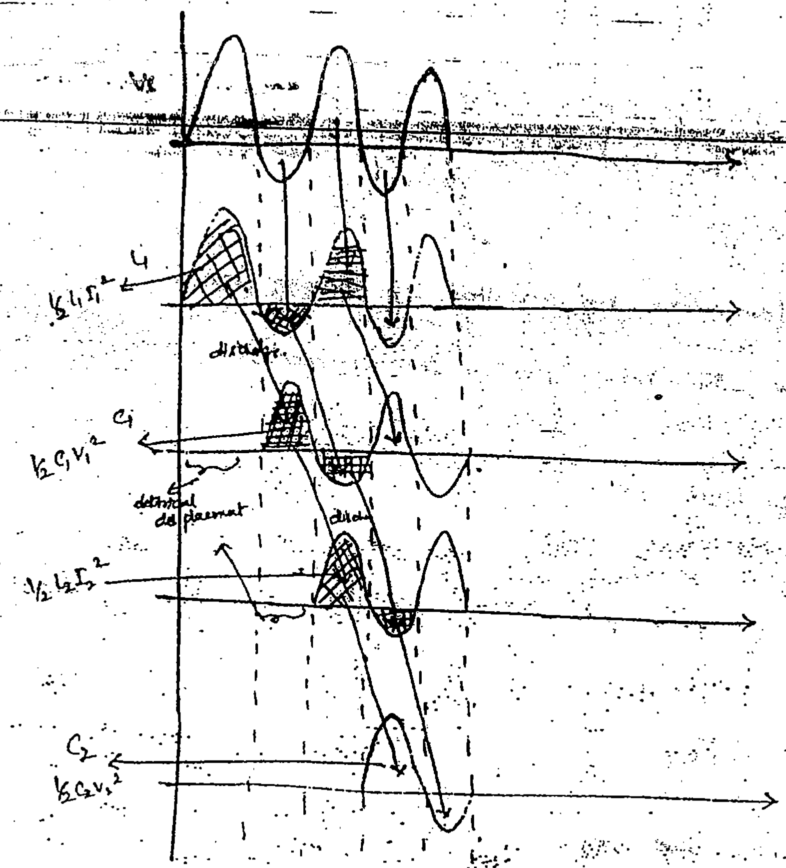
→ LONG TRANSMISSION LINE CONSTANTS (Uniformly distributed Line Constants)
(TRANSIENT (OR) SWITCHING WAVE TRAVELLING)



$R_1 = R_2 = R$ Ω/Km

$L_1 = L_2 = L$ H/Km

$C_1 = C_2 = C$ F/Km.



- The transmission line is represented with uniformly distributed line constants so that the time constants of these elements are negligible
- When the switch is closed then the switching voltage will be opposed by the resistance and inductance which are in series.
- The time constant of these elements is negligible so that the current will be allowed to flow immediately through the inductor and it can develop the magnetic field.
- The magnitude of the switching voltage will be converted into the current and it will be stored in the inductor in an instantaneous manner.
- The switching voltage waveform is a continuous so that the inductor has to discharge the energy stored previously.

- The stored energy of the inductor will discharge to the capacitor so that the capacitor will be slowly charging and it can develop the static field. The energy stored in the static field is $\frac{1}{2} C_1 V_1^2$

- The switching waveform will be travelled by having an electrical displacement between the inductor and the capacitor.

- At the end of first Km.

Energy balance

$$\frac{1}{2} L_1 I_1^2 = \frac{1}{2} C_1 V_1^2 \longrightarrow (1)$$

$$Q_{net} = 0.$$

$$\Rightarrow \boxed{V_1 = V_s} \quad (R \simeq 0)$$

⇒ The travelling wave doesnot having any attenuation.

⟶ if $Q_{net} = 0$, but $R \neq 0$

$$\Rightarrow \boxed{V_1 \neq V_s}$$

⇒ The travelling wave dees experience an attenuation

- From eq (1) $\frac{V_1}{I_1} = \sqrt{\frac{L_1}{C_1}} = \sqrt{\frac{L}{C}} = Z_c$ Char. Impedance (or) Surge Impedance

- The ratio of voltage to the current at any distance is called as the characteristic impedance (or) The Surge Impedance.

- When the switch is closed the tr.line will experience high frequency surges so that the impedance offered is called a surge impedance

⟶ At the end of 2nd Km, Energy balance

$$\frac{1}{2} L_2 I_2^2 = \frac{1}{2} C_2 V_2^2$$

$$Q_{net} = 0$$

$\boxed{V_2 = V_1}$ $(R \simeq 0)$

→ The travelling wave does not having any attenuation

If $Q_{net} = 0$ but $R \neq 0$

→ $(V_2 \neq V_1)$

∴ The travelling wave does experience any attenuation

∴ From eq (5)

$$\frac{V_2}{I_2} = \sqrt{\frac{L_2}{C_2}} = \sqrt{\frac{L}{C}} = Z_C \text{ (or) } Z_S$$

From the above, It can be understand that the switching wave will be travelled by gradually building up of the magnetic field in the inductor and the static field across the capacitor so that the concept of wave travelling is in terms of the reactive power balance.

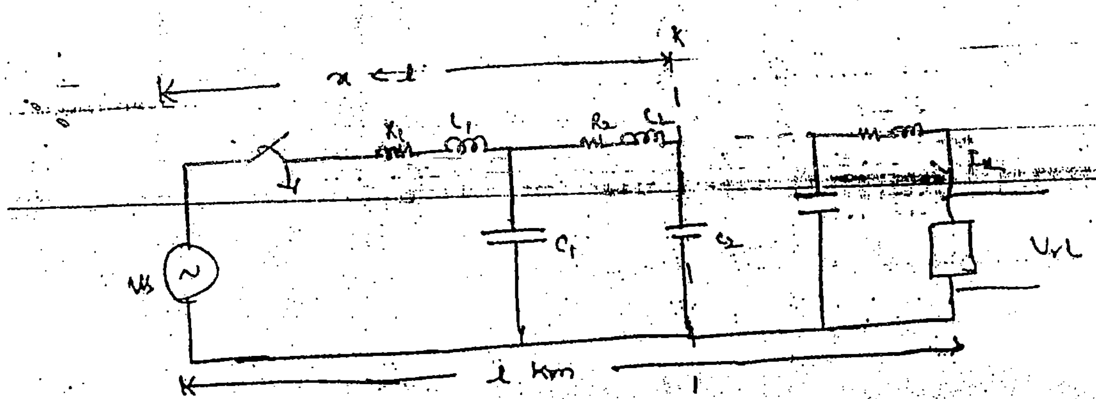
— The ratio of voltage to the current at any distance is called as Characteristic impedance or Surge Impedance. If the resistance is assumed as ZERO the travelling wave form ~~doesnot experience~~ doesnot experience any attenuation.

→ In case of OHTL the switching wave form will be travelled exactly at light velocity i.e. 3×10^8 m/s or 3×10^5 km/sec.

→ The tr. line is represented with uniformly distributed line constants so that consider the mathematical solution to know the velocity of wave travelling

→ Mathematical Approach is.

Consider a point 'K' at a distance of 'x' where $(x < l)$ from the source.



The total magnetic field deposited upto 'x'

$$\therefore \phi = Lx \cdot I \quad [I_1 = I_2 = I,\ R \approx 0]$$

$$\frac{d\phi}{dt} = V = LI \cdot \frac{dx}{dt} = LIv \longrightarrow (1)$$

$v \to$ Velocity of wave travelling.

The total static field upto 'x'

$$\lambda = CxV$$

$$\frac{d\lambda}{dt} = I = CV\frac{dx}{dt} = CVv \longrightarrow (2)$$

Multiplying (1) & (2)

$$VI = VILCv^2$$

$$\boxed{v = \frac{1}{\sqrt{LC}}} \longrightarrow \text{velocity of wave travelling}$$

$$v = \frac{1}{\sqrt{\underbrace{2\times10^{-4}\ln(d/r)}_{\substack{H/Km \\ L_{ext} \\ (\text{Skin effect})}} \times \frac{2\times3.14\times8.854\times10^{-9}\times\epsilon_r}{\ln(d/r)}}} \quad (F/Km)$$

For OHTL $\quad \epsilon_r = 1$

$$\therefore v = 3\times10^5 \text{ Km/sec} \quad (R=0)$$

$$v = 3\times10^8 \text{ m/sec}$$

} light velocity.

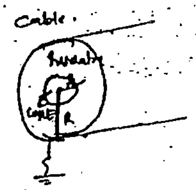
→ If Resistance is Considered then the velocity of wave is

$V = 2.5\times10^{8} - 2.8\times10^{8}$ m/sec $(R \neq 0)$

$V \rightarrow$ Attenuation velocity

Resistance can provide the attenuation for the velocity of the wave form and also the magnitude of the wave form

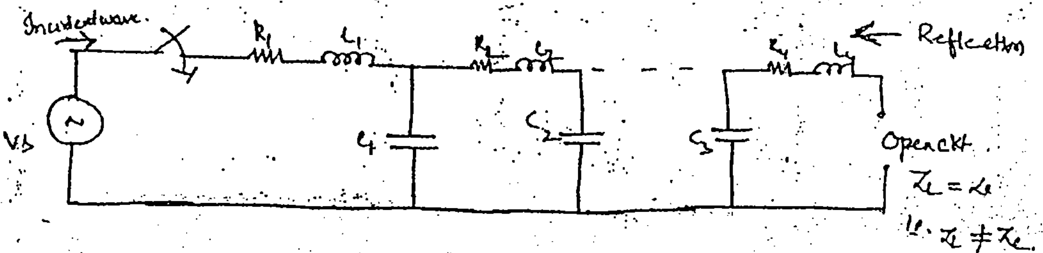
→ For undergcable, the velocity of wave travelling is



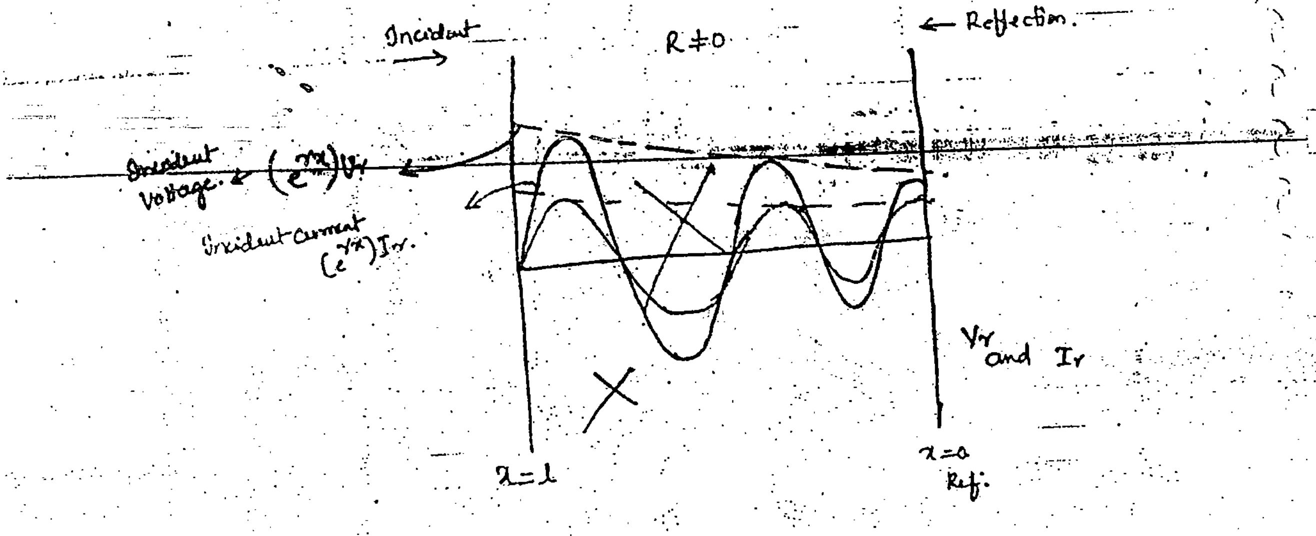
$$V = \frac{1}{\sqrt{2\times10^{-4}\ln(R/r) \times \frac{2\times3.14\times8.854\times10^{-7}\times \epsilon_r}{\ln(R/r)}}} = \frac{3\times10^{8}\ \text{m/s}}{\sqrt{\epsilon_r}}$$

The velocity of wave travelling in Underground Cable will be less than light velocity

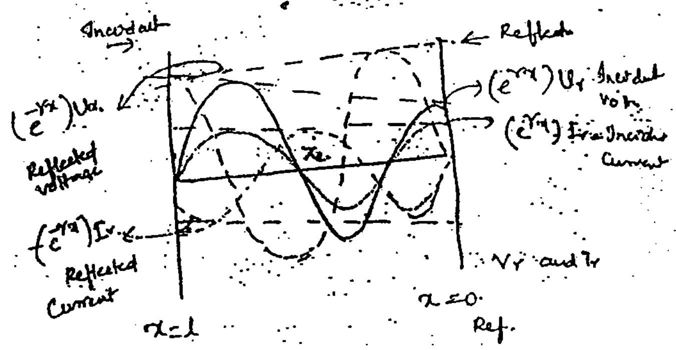
→ The lumped inductive load will become open circuit when the switching wave reaches the load end. So that the load impedance is not matched with the characteristic impedance.



— When the $Z_L \neq Z_c$, then There will be a reflection wave form which is travelled in the transmission line by offering the characteristic impedance. Hence the tr.line will experience the incident waveform and also the reflected wave form and they have expressed their magnitude in terms of receiving end voltage and receiving end current (because V_r, I_r are always known values)



— The sign of the incident current will be same as that of the sign of incident voltage



— The average of these two waveforms at any distance in the transmission line are called transmitted voltage and transmitted current

$$\therefore \quad V_x = \left(\frac{e^{\gamma x}+e^{-\gamma x}}{2}\right)V_r + Z_c\left(\frac{e^{\gamma x}-e^{-\gamma x}}{2}\right)I_r$$

$$I_x = \frac{1}{Z_c}\left(\frac{e^{\gamma x}-e^{-\gamma x}}{2}\right)V_r + \left(\frac{e^{\gamma x}+e^{-\gamma x}}{2}\right)I_r$$

If $x = l$.

$$V_s = \left(\frac{e^{\gamma l}+e^{-\gamma l}}{2}\right)V_r + Z_c\left(\frac{e^{\gamma l}-e^{-\gamma l}}{2}\right)I_r$$

$$I_s = \frac{1}{Z_c}\left(\frac{e^{\gamma l}-e^{-\gamma l}}{2}\right)V_r + \left(\frac{e^{\gamma x}+e^{-\gamma x}}{2}\right)I_r$$

$\Rightarrow \quad V_s = \cosh\gamma l \, V_r + Z_c \sinh\gamma l \, I_r$

$I_s = \frac{1}{Z_c} \sinh\gamma l \, V_r + \cosh\gamma l \, I_r$

Comparing with

$V_s = A V_r + B I_r$

$I_s = C V_r + D I_r .$

$$\therefore \boxed{\begin{aligned} A &= \cosh\gamma l \, , \quad B = Z_c \sinh\gamma l . \\ C &= \frac{1}{Z_c} \sinh\gamma l \, , \quad D = \cosh\gamma l . \end{aligned}}$$

$A = D$ & $AD - BC = 1.0$ $\Rightarrow$ Symmetric & Reciprocal.

Whenever a line constants are represented T and π sections then the line is said to be symmetric and Reciprocal.

29/01/10

$V_s = \cosh\gamma l \, V_r + Z_c \sinh\gamma l \cdot I_r$

$I_s = \frac{1}{Z_c} \sinh\gamma l \cdot V_r + \cosh\gamma l \, I_r .$

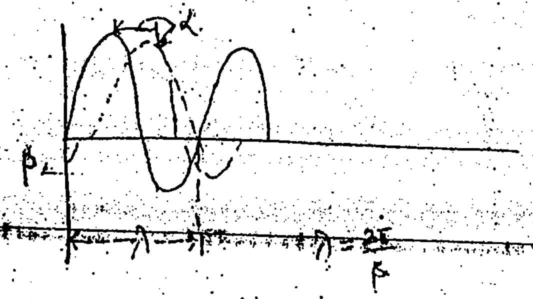
Where.

γ = propagation constant $= \sqrt{zy} = \sqrt{\text{Imp/Km} \cdot \text{Adm/Km}}$

$= \sqrt{(R+j\omega L)(G+j\omega C)} = \alpha + j\beta$

Where α = Real part = Attenuation Constant (Neper / Km)

β = phase component (or) quadrature component (rad / Km)



A travelling wave is having a propagation Constant

$\gamma = \alpha \pm j\beta$

For one complete sinusoidal variation, the wavelength in which the wave is travelled,

For loss less line, $R=0$ & $G=0$

$\rightarrow \gamma = \sqrt{(j\omega L)(j\omega C)} = j\omega\sqrt{LC} = j\beta$

(Q) A 300 Km, Tr-line is having quadrature component of 0.0027 rad/Km. What is the % of the physical length of a Tr-line to be wavelength of the line?

Phy length $l = 300$ km.

Wave length $\lambda = \dfrac{2\pi}{\beta}$

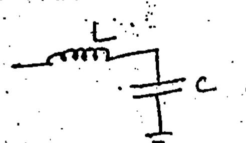
$\dfrac{l}{\lambda} = \left(\dfrac{300}{\frac{2\pi}{0.027}} \times 100\right)$ Ans

$\rightarrow Z_c$ (or) $Z_s = \sqrt{\dfrac{B}{C}} = \sqrt{\dfrac{Z}{Y}} = \sqrt{\dfrac{R+j\omega L}{G+j\omega C}} \rightarrow 400\angle -\theta \ \Omega$

(θ is -ve) why $G \simeq 0$

For long Tr. line $R=0$, $G=0$

Z_c (or) $Z_s = \sqrt{\dfrac{L}{C}} = \sqrt{\dfrac{\text{Ind}/\text{Km}}{\text{Adm}/\text{Km}}} = 400\angle 0^\circ \ \Omega = 400\ \Omega.$



$Q_{net} = 0$

In a lossless Tr-line, the net reactive power of system is zero so that the Tr. line can be neither Inductor or capacitor hence it will be a resistive nature. It is Independent on line length

for 300 Km, $Z_c = 400\Omega$.

for 400 Km $Z_c = 400\Omega$ (same since) Z_c = 400Ω

- At a frequency of 50Hz, Z_s = 400 ohms, of f = 100Hz then

Z_s = 400 Ω

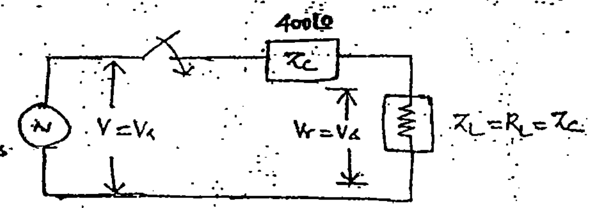
→ For 132KV, 220KV, 400KV, 765KV the Z_s is same but for 400KV and 765KV will be less but about $\simeq 380\,\Omega$ (for...

→ SURGE IMPEDANCE LOADING / CHARACTERISTIC IMPEDANCE LOADING

In a loss less transmission line it is the loading of the transmission line where the load impedance is equal the characteristic impedance of the transmission line.

(OR)

Whenever the transmission line is terminated by a load having the load impedance is equal to the characteristic impedance of the line then such loading on the transmission line is called as Characteristic impedance loading



→ If the line is operating with SIL then such a trans. line is called a FLAT LINE. A Flat line is the one in which the magnitude of voltage throughout its length will be same

→ A transmission line is a Flat line provided that it is of an infinite line length.
$R=0$

→ If the tr. line is of infinite length then the travelling wave does not experience any attenuation

$\therefore$ $SIL = \frac{V_s V_r}{Z_c}$

$SIL = \frac{V^2}{Z_c}$ $[\because V_s = V_r = V]$ MW.

Units of SIL = MW. ($\because$ system is working under unity pf

$\therefore$ $SIL \propto V^2$

$\propto \frac{1}{Z_c}$

Eg: A 400KV tr. line SIL = ?

$\Rightarrow$ $SIL = \frac{V^2}{Z_c}$

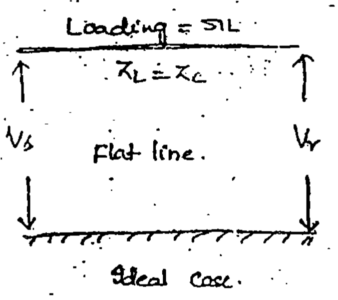
$= \frac{400 \times 400\text{ M}}{400}$

$= 400$ MW

For a 220KV tr. line, then SIL = ?

$\Rightarrow SIL = \frac{220 \times 220}{400} = \frac{22 \times 22}{4} = 121$ MW

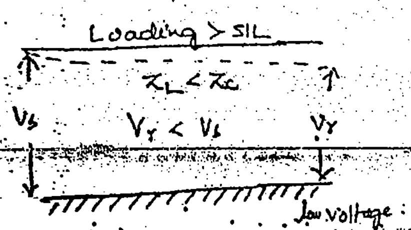
→ SIL is also known as Ideal capacity (or) the Natural Capacity



(1) Loading > SIL (MVA capacity)

$\Rightarrow Z_L < Z_c$ ($\because$ loads are parallel, $Z_{eq} \downarrow$)

since the current is more, $\Rightarrow |I| \uparrow$



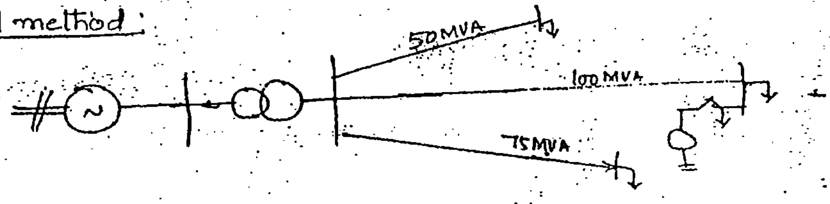
$\frac{1}{2} LI^2 > \frac{1}{2} CV^2$

Q_{net} = Inductive nature

→ In parallel trans. network it is impractical to work with full load conditions by all the lines at the same point of time.

→ In order to improve the voltage at any one of the load point by increasing the excitation of the alternator then it will also increase the voltages at other parallel loads, which is not required. hence the excitation is not recommended

(2) External method:



— In external method, install a suitable voltage control device and control the voltage at that particular point without effecting the voltage of other parallel transmission lines. Hence the location for the voltage control device is the Receiving end.

— The various devices that can be used for voltage control are

(1) Shunt capacitor
(2) Shunt Inductor
(3) Series Capacitor
(4) Synchronous Capacitor
(5) Synchronous Inductor
(6) Synchronous phase modifier

— All most all voltage control devices are of purely capacitive nature or inductive nature and the rating of those devices are expressed in terms of reactive power

$$S = \sqrt{P^2+Q^2}$$

$$= Q \quad [\because P=0]$$

KVA (or) MVAR.

$$Q_r = \frac{V_r}{|X|}\left[|V_s| - |V_r|\right]$$

→ For a fixed sending end voltage, the voltage at the receiving end will be controlled by controlling the net reactive power at the load point i.e. either by injecting the reactive power or by absorbing the reactive power hence the concept of voltage control is also called as the concept of reactive power control

→ Some times we call the voltage control device as Compensating devices.

Rating of voltage control | compensating device = MVAR (Reactive power)

→ The amount of the reactive power of the system is

$$Q_r + Q_c = Q_d$$

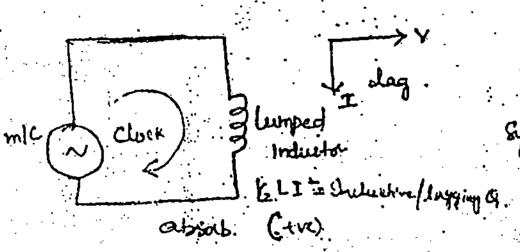
$$(or)\quad Q_c = Q_d - Q_r$$

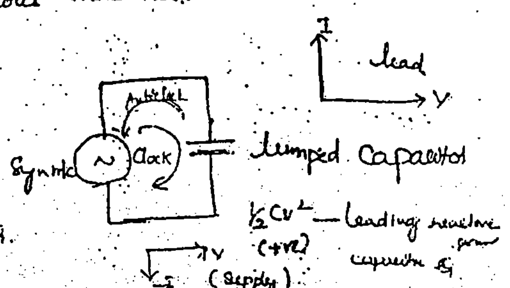
Q_r → Reactive power tr. line.

Q_d → load reactive.

Q_c → Compensative reactive power

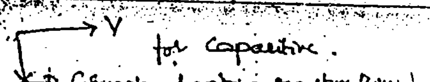
→ The sign property for the reactive powers of the lumped elements and also the synchronous machines.





→ In the above n/w the synchronous m/c will deliver the required reactive power required by the lumped elements.

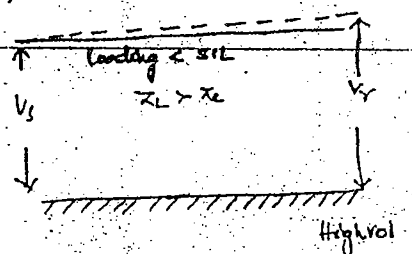
→ Inorder to get the conventional sign:



for capacitive.

(ii) Loading < SIL (MVA Capacity)

$\Rightarrow Z_L > Z_c$ ($\because$ light loads)



$\Rightarrow |I| \downarrow$

$\Rightarrow \frac{1}{2} LI^2 < \frac{1}{2} CV^2$

$\Rightarrow$ Q_{net} = Capacitive nature

$\Rightarrow$ leading power factor

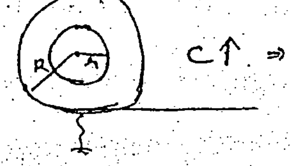
i.e. $V_r > V_s$ i.e. Ferranti Effect

→ Whenever the actual receiving end voltage has become divergent with its limits of the voltages then it will be declared as either low voltage or high voltage. The result of low voltage is the poor performance of the system, The result of high voltage will be failure of the insulation suddenly.

$(V \pm \% E)$ → poor performance [Low voltage]

High voltage → Failure of insulation

→ In order to improve the performance of the system or to prevent the failure of the insulation it is neccessary to have a suitable control over the load voltage which is known as the concept of voltage control.



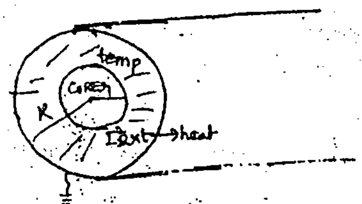
$C \uparrow \Rightarrow Z_c = \frac{1}{10} Z_c$ (OHTL)

$\Rightarrow Z_c = 40$ ohms

→ The most economical loading on over head tr. line is the loading more than SIL

→ The most economical loading in an underground cable is the loading ≤ SIL

because



Sheath (heat) = 0

Core (heat) = high.

⇒ High temperature gradient — Ineffective heat dissipation.

⇒ Insulation life decrease.

→ Due to the improper heat dissipation there will be a temperature gradient at the surface of the core and it will increase if the loading is more than SIL, so that the insulation failure will take place.

→ If the loading is < SIL, the cable will experience severe over voltage if the length of the cable is high because the capacitance / km is high. In order to limit the over voltages the cables are not recommended beyond 50km to transmit the bulk amount of power.

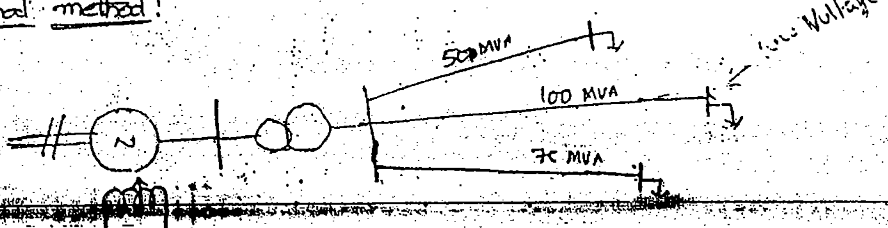
⇒ VOLTAGE CONTROL

Voltage Control can be done by 2 methods.

(1) Internal method — Excitation Control

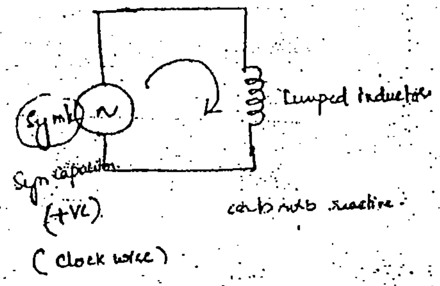
(2) External method — Install any suitable device.

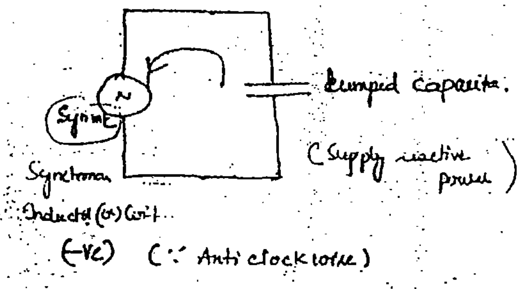
(1) Internal method:



$\Rightarrow$ $\frac{1}{2} L I^2 \rightarrow +ve$ (absorbing the reactive power) (C.W. current direction.

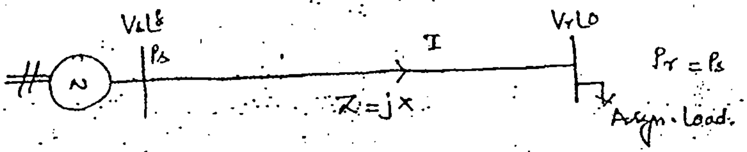
~~$\frac{1}{2} C V^2 \rightarrow -ve$ (Supply the reactive power) (c.c.w current direction~~





→ The sign of the reactive power of the lumped elements are opposite to that of the sign of the reactive power of synchronous elements.

→ APPROXIMATE MATHEMATICAL RELATION FOR LUMPED ELEMENTS:



$$|V_r| = |V_s| - jXI \quad \longrightarrow (1)$$

— The voltage control device doesnot change the real power

$$\therefore P_r = P_s$$

$$V_r I^* = V_s I^* = P + jQ.$$

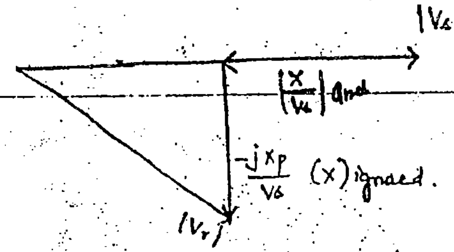
$$I^* = \frac{P+jQ}{|V_s|}$$

$$(I^*)^* = I = \frac{P-jQ}{|V_s|^*} = \frac{P-jQ}{|V_s|}$$

From (1)

$$\therefore |V_r| = |V_s| - jX\left[\frac{P-jQ}{|V_s|}\right]$$

$$\boxed{|V_r| = |V_s| - \frac{jXP}{|V_s|} - \frac{X}{|V_s|} Q_{net}}$$

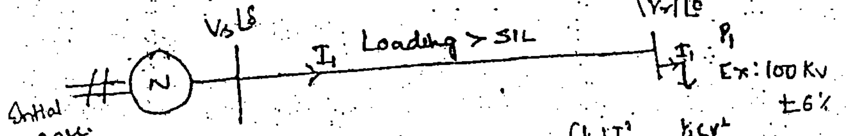


$$|V_r| \simeq |V_s| - \frac{|X|}{|V_s|} Q_{net}$$

→ In case of the shunt capacitor and shunt inductor, the voltage is controlled by controlling the net reactive power at the load point for fixed sending voltage & fixed line reactance

(1) <u>SHUNT</u> <u>CAPACITOR</u>: (power factor improvement/correction device)

If the transmission line is experiencing the loading more than surge impedance loading, then the inductive reactive power of the system is more than the capacitive reactive power so that the receiving end voltage is less than V_s and if it is a low voltage, a suitable shunt capacitor is placed at the load end in order to inject capacitive reactive power to compensate the excess inductive reactive power of the system. So that the voltage at the receiving end will be improved.



$$|V_{r1}| = |V_s| - \frac{X}{V_s}\underbrace{\left[\overset{(\frac{1}{2}LI^2)}{Q_{ab}} - \overset{\frac{1}{2}CV^2}{q_{gen}}\right]}_{Q_1} \rightarrow (i)$$

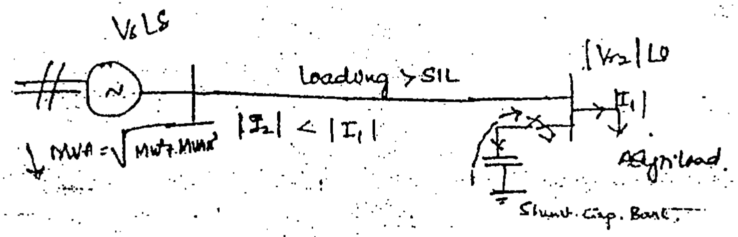
$$\Rightarrow |V_{r1}| < |V_s|$$

If it is low voltage then it needs to improve

$$|V_{r1}| < (V - \%\epsilon)$$

~~For ex: 100 kV ± 6% ≃ Regulation limit (94 – 106 kV)~~

low voltage



$$|V_{r2}| = |V_s| - \frac{X}{|V_s|}\left[Q_{ab} - Q_{Gen} - Q_{sh.Cap}\right]$$

$$|V_{r2}| = |V_s| - \frac{X}{|V_s|}\left[Q_{ab} - \underbrace{(Q_{Gen} + Q_{sh.Cap})}_{Q_2}\right] \rightarrow (2)$$

$\therefore$ $|V_{r2}| < |V_s|$; But $|V_{r2}| > |V_{r1}|$ $\Rightarrow$ $|V_{r2}| > (V - \%\epsilon)$

$\therefore$ Voltage of the system is improved

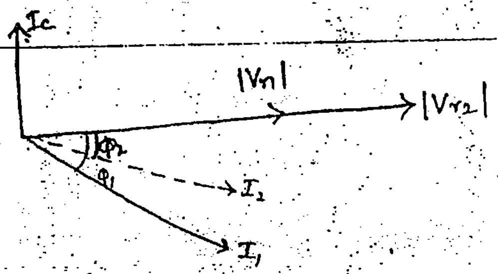
→ If $|V_{r2}| = |V_s|$ → Flat voltage

$$Q_{net} = 0$$

$$Q_{sh.cap} = Q_{ab} - Q_{Gen}$$

$\therefore$ The rating of the shunt capacitor is high so that the extra cost of the shunt capacitor is also high. Hence the supply system is uneconomical.

→ If the voltage is improved the rating of the capacitor required is less so that the extra cost of capacitor is less and finally the total cost of the supply system is economical.



$|V_{r2}| > |V_{r1}|$ — improvement in Voltage.

$\phi_2 < \phi_1$

$\cos\phi_2 > \cos\phi_1$ — Improvement in p.f of the load

$S_1 = \frac{P_1}{\cos\phi_1}$, $S_2 = \frac{P_2}{\cos\phi_2}$ ↑ $(P_2 = P_1)$

→ In case of shunt capacitor, the improvement in the power factor of the load is predominant compared to the improvement in voltage because the improvement in the power factor of the load will result as there is saving in annual bill paid by the consumer.

→ Consumers are 1) Domestic, 2) Non-domestic] Flat rate tariff.

3) Industrial → Two part tariff.

$$\text{Bill} = \underbrace{Rs.\,x/KVA}_{F.C} + \underbrace{Rs.\,y/Kwhr.}_{R.C}$$

→ Some of the voltage control devices are preferred as power factor correction devices rather than voltage control devices because the existing power system will experience low power factor due to the following reasons and it is necessary to improve the p.f of the system.

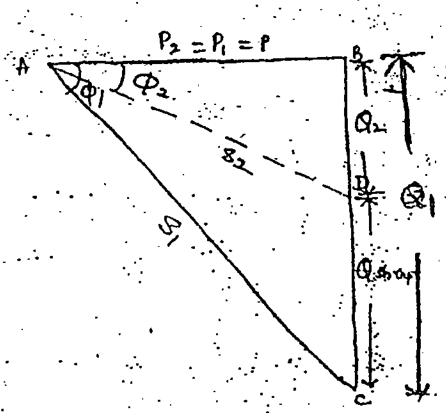
→ Reasons for low power factor.

(1) Most of the loads are driven by Induction motor.

→ (ii) The Heating and welding in the industry is done by using induction principle.

(iii) Due to no load current of the transformer, the powerfactor at the full load will also be reduced.

→ The amount of reactive power supplied by the shunt capacitor by using the power triangle can be obtained.



$$Q_{sh.Cap} = Q_1 - Q_2$$

$$= S_1 \sin\phi_1 - S_2 \sin\phi_2$$

$$= \frac{P_1}{\cos\phi_1}\sin\phi_1 - \frac{P_2}{\cos\phi_2}\sin\phi_2$$

$$\therefore Q_{sh.Cap} = P(\tan\phi_1 - \tan\phi_2) \longrightarrow 3\text{-}\phi.$$

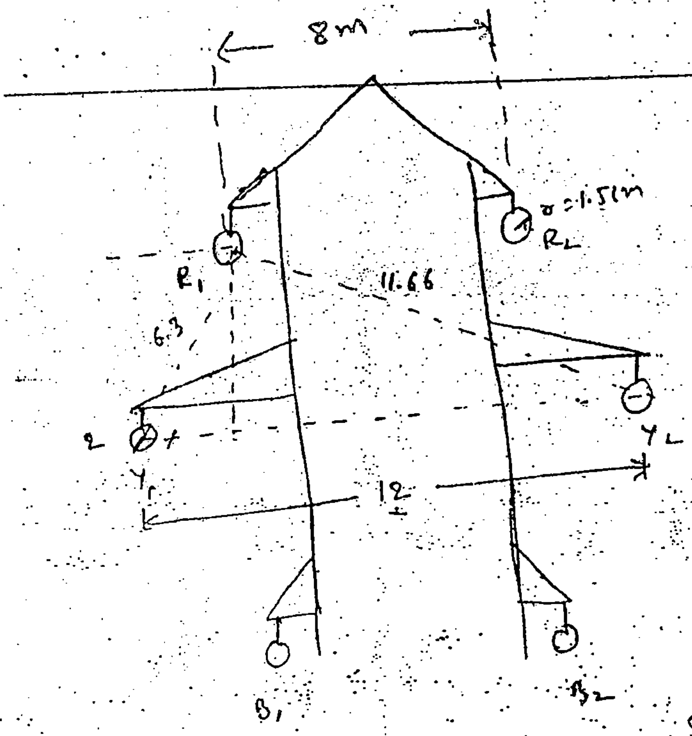
$$Q.\,sh\,cap/ph = \frac{P(\tan\phi_1 - \tan\phi_2)}{3}$$

$\boxed{Q_{sh.cap} \propto V^2 f}$

$$Q.\,sh.\,cap/phase = V_{phase} \cdot I_c/phase \cdot \sin 90^\circ$$

$$= V_{phase} \cdot \frac{V_{phase}}{X_c} = V^2_{phase}\,\omega C/phase$$

$$\boxed{\therefore C/phase = \frac{Q_{sh}/phase}{V^2_{phase}\,\omega}}\quad F\ (\text{or})\ \mu F$$



$= \sqrt[3]{\text{Self}GMD_R \; \text{self}GMD_y \; \text{Self}GMD_B}$

$\text{self}GMD_R = \sqrt{\text{Self}GMD_{R_1} \; \text{Self}GMD_{R_2}}$

$= \text{self}GMD_{R_1}$

$= \sqrt{0.7788 \times 1.5 \times 800}$ cm

$\text{self}GMD_B = \text{self}GMD_R$

$\text{self}GMD_y = \text{self}GMD_{Y_1}$

$= \sqrt{0.7788 \times 1.5 \times 2 \times 1200}$

$GMD = \sqrt[3]{GMD_R \; GMD_y \; GMD_B}$

$GMD_R = GMD_{R_1} = \sqrt[4]{6.3 \times 12 \times 11.66 \times 14.4}$

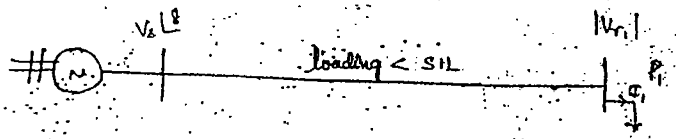
$GMD_B = GMD_R = GMD_{R_1}$

$GMD_y = GMD_{y_1} = \sqrt[4]{6.3 \times 6.3 \times 11.66}$

11/Feb/2010

→ **SHUNT INDUCTOR:** Whenever the tr. line is experiencing the loading less than SIL then the capacitive reactive power of the system is more than inductor reactive power. So that the receiving end voltage is more than sending end. If it is a high voltage a suitable shunt inductor is placed in a receiving end in order to absorb the excess capacitive reactive power so that the receiving end voltage will reduce which will prevent the failure of insulation.

Initial case:

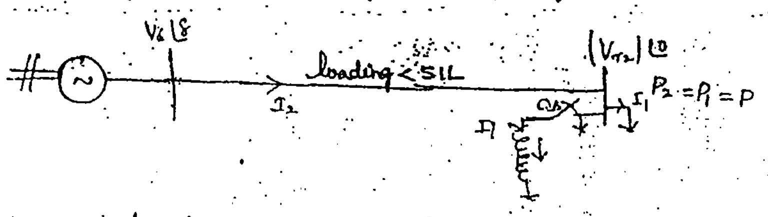


$$|V_{r1}| = |V_s| - \frac{X}{|V_s|}\left[\underset{\downarrow}{Q_{ab}} - \underset{\uparrow}{Q_{gen}}\right]$$

$|V_{r1}| > |V_s|$ → If it is a high voltage

i.e. $|V_{r1}| > (V + \%\in)$

It requires to reduce the voltage.



$$|V_{r2}| = |V_s| - \frac{X}{V_s}\left[\underbrace{Q_{ab} + Q_{sh.Ind}}_{\downarrow} - \underset{\uparrow}{Q_{Gen}}\right]$$

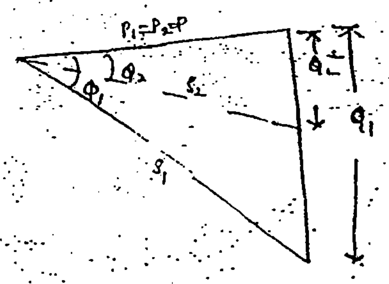
$|V_{r2}| > |V_s|$

But $|V_{r2}| < |V_{r1}|$

$$\Rightarrow \boxed{|V_{r2}| < |V_{r1}|}$$

— The shunt inductors are installed when the loading on the tr. line is a light load inorder to limit the ferranti effect of the tr. line. ~~rather than the powerfactor of the load. Hence it will be~~ treated as the voltage control device rather than power factor correction device.

— As similar to that of the shunt capacitor, the amount of reactive power absorbed will be calculated by using the power triangle.



$$Q_{sh.Ind} = P(\tan\phi_1 - \tan\phi_2) \quad (3\text{-}\phi)$$

$$Q_{sh\,Ind}|_{phase} = \frac{P(\tan\phi_1 - \tan\phi_2)}{3.0}$$

$$= V_{phase}\, I_i|_{phase} \sin 90^\circ$$

$$Q_{sh.Ind}|_{phase} = V_{phase} \cdot \frac{V_{phase}}{X_L} = \frac{V^2_{phase}}{\omega L|_{phase}}$$

$$\boxed{L|_{phase} = \frac{V^2_{phase}}{\omega\, Q_{sh.Ind}|_{phase}}}$$

$$\Rightarrow \boxed{Q_{sh.Ind}|_{phase} \propto \frac{V^2}{f}}$$

(Q) What are the percentage increases in the reactive power of the shunt capacitor and the shunt inductor if the operating voltage and frequency are increased by 10%.

Sol

$$Q_{sh.Cap} \propto V^2 f$$

$$Q_1 \propto V_1^2 f_1$$

$$Q_2 \propto V_2^2 f_2$$

$$\Rightarrow Q_2 \propto (1.1V_1)^2 \times 1.1 f_1$$

$Q_2 \propto 1.331\, V_2^2 f_1$

$\Rightarrow \frac{Q_2 - Q_1}{Q_1} \times 100 = 33\%$

(ii) $Q_{sh\ Indu} \propto \frac{V_1^2}{f}$

$Q_1 \propto \frac{V_1^2}{f_1}$

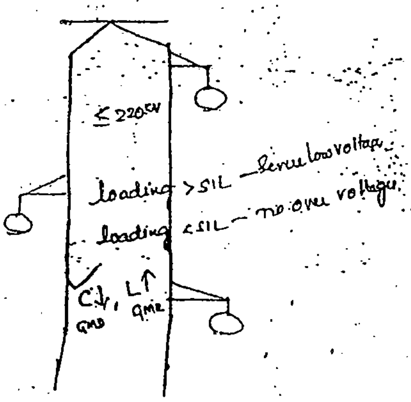
$Q_2 \propto \frac{V_2^2}{f_2}$

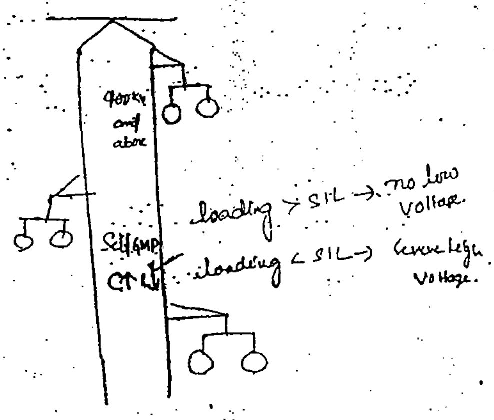
$\Rightarrow Q_2 = \frac{(1.1 V_1)^2}{(1.1) f_1}$

$Q_2 = \frac{1.21 V_1^2}{1.1 f_1} = \frac{1.1 V_1^2}{f_1}$

$\therefore Q_2 - Q_1 = 0.1 \Rightarrow 10\%$

→ System study





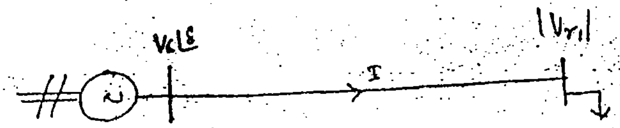
→ In EHV line the shunt compensation is shunt capacitor, resulting powerfactor correction

→ In modern EHV line the shunt compensation is shunt Inductor resulting in reduction of voltage.

→ The shunt compensation does not effect the power system stability since the reactance of the line is not effected by shunt cap & shunt Indu.

→ SERIES CAPACITOR: In this case the voltage at the end of the tr. line will be controlled by controlling the product of the reactance and the net reactive power of the line i.e. controlling the voltage drop

(i) Initial case:

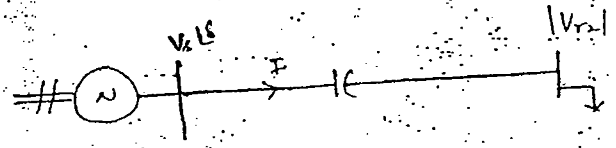


$$|V_{r1}| = |V_s| - |\Delta V_1|$$

$$|\Delta V_1| = |IR\cos\phi_r \pm IX_L \sin\phi_r|$$

ϕ_r → phase angle of the load.

(ii) final case:



$$\uparrow |V_{r2}| = |V_s| - |\Delta V_2|$$

$$\downarrow |\Delta V_2| = |IR\cos\phi_r + I(\underbrace{X_L - X_C}_{\downarrow})\sin\phi_r|$$

$|V_{r2}| > |V_{r1}|$ → improvement in voltage.

The improvement in the voltage by the series capacitor will be

$$|\Delta V_C| = |IX_C \sin\phi_r| \Rightarrow \text{Booster in the voltage}$$

Hence the series capacitors are also called as <u>BOOSTER</u>

→ As the capacitor is connected in series, the % compensation given to the line reactance $= \frac{X_C}{X_L} \times 100$

→ In tr. line

$$P_{max1} = \frac{V_s V_{r1}}{X_L}$$

$$\uparrow P_{max2} = \frac{V_s V_{r2}}{(X_L - X_C)}$$

steady state stability limit.

$$\Rightarrow \frac{Q_{sh \cdot cap}}{Q_{se \cdot cap}} = \frac{\sin\phi_r \cdot V}{IX} = \frac{\sin\phi_r}{\frac{IX}{V}} = \frac{\sin\phi_r}{\epsilon}$$

Since p.f of the load $\cos\phi_r = 0.8$ (generally)

$\sin\phi_r = 0.6$

$$\therefore \frac{Q_{sh \cdot cap}}{Q_{se\ cap}} = \frac{0.6}{\epsilon} > 1.0$$

$\because$ For STL — $\epsilon = 0.06$

MTL — $\epsilon = 0.09$

LTL $\rightarrow$ $\epsilon = 0.12$

Hence Q_{sh} cap > Q_{se} cap for the same voltage.

→ SYNCHRONOUS CAPACITOR & ~~SYN~~ INDUCTOR

$R << X \Rightarrow |Z| = |X|$

$\Rightarrow \theta = 90°$

Reactive Power of trans. line is.

$$Q_r = \frac{|V_s||V_r|}{|B|}\sin(\beta - \delta) - \left|\frac{A}{B}\right| |V_r|^2 \sin(\beta - \delta)$$

δ = Torque angle (or) load angle.

Assume $C \simeq 0$ [No shunt element connected] ↓ Short link.

$$Q = \frac{|E||V|}{|X|}\cos\delta - \frac{1.0}{|X|}|V|^2 \xrightarrow{\text{Since}}$$

$\Rightarrow A = 1.0$

$\alpha = 0$.

→ No loaded ($\delta = 0$) ($\because$ It is not connected to any load and also not meant any thing to drive)

$$\Rightarrow Q = \frac{|E||V|}{|X|} - \frac{1.0}{|X|}|V|^2$$

$$Q = \frac{|V|}{|X|}\left[|E| - |V|\right]$$

Case(1) : If $Q > 0$ provided $|E| > |V|$ ⇒
(iff)

⇒ ~~Reactive power flowing from load to Bus.~~

⇒ Synchronous Capacitor (or) Condenser.

→ A No loaded syn. m/c working with over excitation is called Syn. capacitor / condenser.

→ Since loading > SIL Hence the syn. capacitor is called as powerfactor correction device rather than Voltage control device.

→ Hydel plants can be operated as syn. capacitor / condenser due dry season to increase p.f (or) voltage control by supplying reactive power (in olden days)

Case(2) : $Q < 0$, $|E| < |V|$ → syn. Inductor (or) syn. coil.

— A noloaded syn. m/c. working with under excitation is called as syn. Inductor (or) syn. coil.

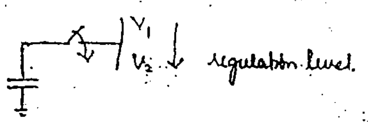
→ syn m/c can be worked as syn. Inductor provided that

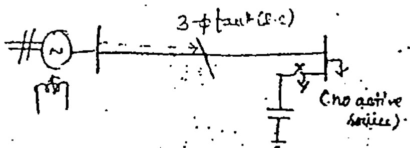
$\boxed{\text{loading} < \text{SIL}}$

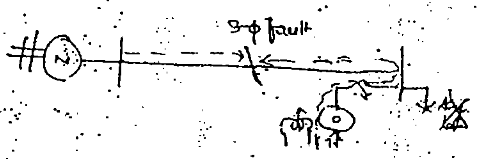
→ The syn m/c having a specific design that is it has the voltage rating as same as that of the bus voltage and the size of the rotor is smaller because it is working under no load condition.

→ In modern p.s system n/w the shunt capacitors are more preferred when compared to syn. m/c, due to the following Comparisons.

SHUNT CAPACITOR	SYNCHRONOUS CAPACITOR
(i) The Control of Voltage (or) Reactive Power is in step nature	(i) The control of voltage (or) reactive power smooth over a wide range due to change of excitation.
(ii) $P_2 = P_1 = P$	(ii) P_2 is slightly more than P_1 due to mechanical losses of syn. m/c.
(iii) There is no starting method	(iii) It requires certain starting methods
(iv) For the same operating voltage the cost of the capacitor is less	(iv) For the same operating voltage the cost of the m/c is high.
(v) It will not raise the fault level during fault conditions	(v) It will raise the fault level during the fault conditions.
Ex: $I_f = I_G$. (Since, cap (or) ind doesn't supply any current to the fault.)	Ex: $I_f = I_G + I_{sy\,m/c}$.
(vi) It does not associated with stability	(vi) It is associated with stability since it is of syn. m/c. with some excitation.







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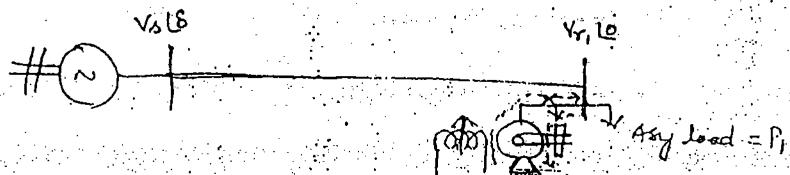
→ SYNCHRONOUS PHASE MODIFIER (Power factor Correction device)

Any loaded synchronous machine working with over excitation is called as syn phase modifier.

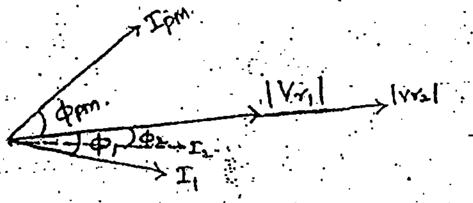


local load $= p << P_1$

Over all load $P_2 = P_1 + p$

$$Q = \frac{V}{X}\left[E\cos\delta - V\right]$$

$Q > 0$, $\boxed{E\cos\delta > V}$ → Synchronous phase modifier



$|V_{r_2}| > |V_{r_1}|$

$\phi_2 < \phi_1$

$\boxed{\cos\phi_2 > \cos\phi_1}$ ⇒ Powerfactor correction device.

3-09

(Q) Match the following

A. Shunt capacitor (4)

B. Shunt Inductor (3)

C. Series capacitor (2)

D. Series Inductor (1)

1. To reduce fault level

2. To improve the stability

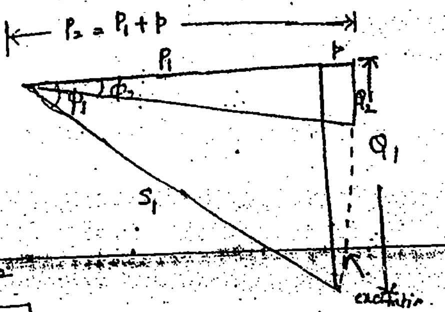
3. To limit the Ferranti effect

4. To improve p.f of the load.

→ Rating of the synchronous phase modifier $= \sqrt{P^2 + Q_{pm}^2}$ KVA

$$\cos\phi_{PM} = \frac{P}{S} \text{ leading}$$

→ The amount of reactive power supplied by the synchronous phase modifier



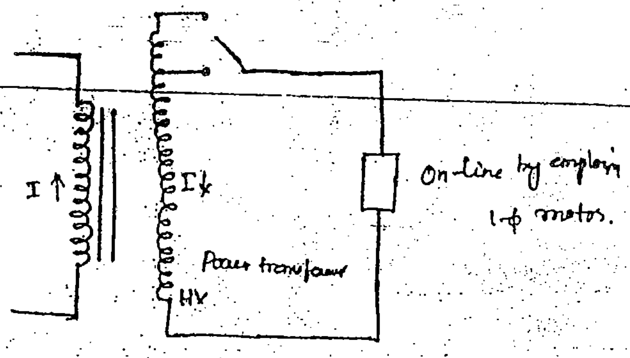
$$Q_{PM} = Q_1 - Q_2$$

$$= S_1\sin\phi_1 - S_2\sin\phi_2$$

$$= \frac{P_1}{\cos\phi_1}\sin\phi_1 - \frac{P_2}{\cos\phi_2}\sin\phi_2$$

$$\boxed{Q_{pm} = P_1\tan\phi_1 - P_2\tan\phi_2}$$

→ TAP CHANGING TRANSFORMER



→ ~~The voltage of the load can~~ also be controlled either by increasing the no. of turns or decreasing the no. of turns by providing the tap changer of the transformer which is known as tap changing transformer

→ The tap changing can be done on online mechanism by employing single phase motor.

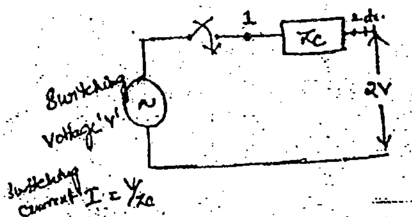
→ For all power transformers the facility of tap changing is provided.

→ In addition As the loads are the most inductive loads then the improvement in voltage given by the tap changing transformer will not bring the voltage into the regulation level so the other Voltage control device which are discussed are also to be installed along with tap changing of the transformer.

→ In high voltage side the magnitude of the current is less so that the intensity of the spark That could be taken by place while Changing the tapping is less.

→ WAVE TRAVELLING – UNIFORMLY DISTRIBUTED LINE CONSTANTS ($R \simeq 0$)

Case(i) Line is open circuited



This can be under stood by (i) Energy balance *(ii) Wave shaping

(i) Energy Balance

At '1'

$$\frac{1}{2} L I^2 = \frac{1}{2} C V^2$$

$$\frac{V}{I} = \sqrt{\frac{L}{C}} = x_c$$

$$\boxed{V = I \cdot x_c}$$

At '2'

$$\frac{1}{2} L I^2 = \frac{1}{2} C V^2$$

$$\frac{V}{I} = \sqrt{\frac{L}{C}} = x_c$$

$$\boxed{V = I \cdot x_c}$$

In dx

$$\frac{1}{2} L dx I^2 = \frac{1}{2} C dx V^2$$

$$\frac{V}{I} = \sqrt{\frac{L}{C}} = x_c$$

$$\boxed{V = I \cdot x_c}$$

→ At the end of the tr. line the energy stored in the Inductor will give away an instantaneous voltage to the capacitor where as the capacitor is unable to discharge the previous energy that was stored.

$$\therefore \frac{1}{2} L I^2 dx = \frac{1}{2} C e^2 dx \qquad e = \text{Inst. voltage}$$

$$\frac{e}{I} = \sqrt{\frac{L}{C}} = x_c$$

$$e = I \cdot x_c = V$$

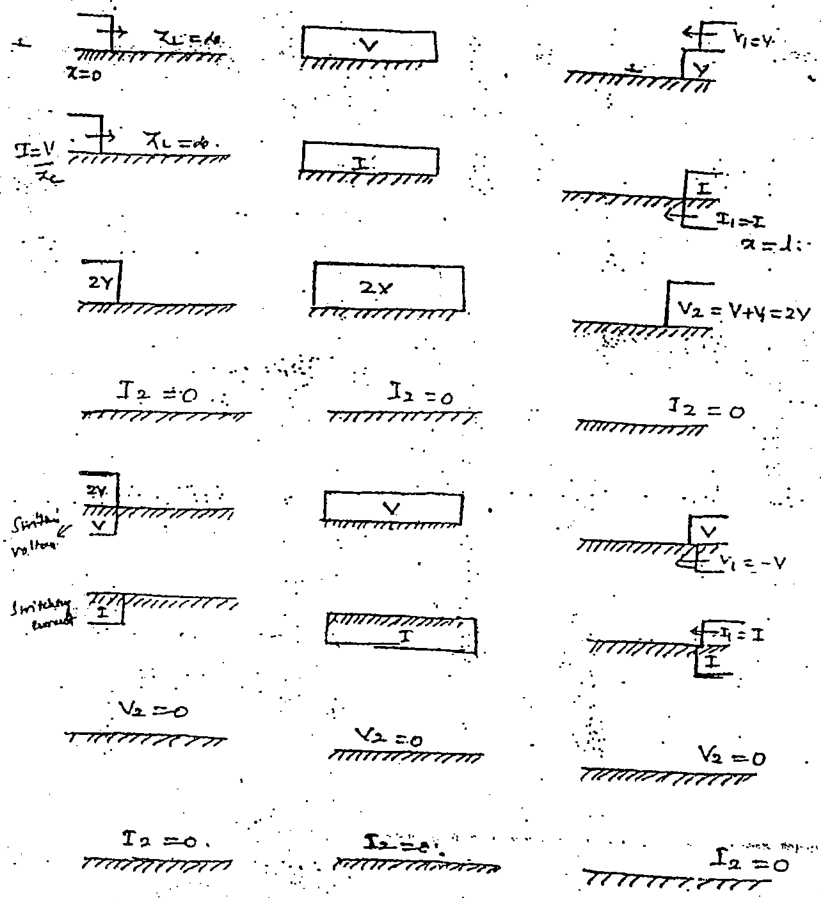
$$\therefore V_c = V + e = V + V = 2V$$

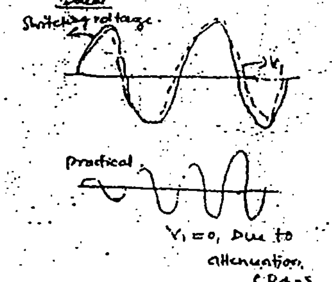
$$\therefore V_c = 2V$$

→ When the switch is closed then there will be current waveform and the voltage waveform that will be travelled in the tr. line. However at the end of the line the current has to become zero and according to energy balance principle, the energy cannot be destroyed but it can be converted into another form i.e. static field so that the voltage across the capacitor become 2V.

(ii) Wave Shaping:

The sign of the switching voltage and switching current are assumed as zero.





$V_1 = V$ = Reflected Voltage.

$I_1 = -I$ = Reflected Current

$\frac{V_1}{V} = 1.0$ Coefficient of reflection for voltage of o.c line.

$\frac{I_1}{I} = -1.0$ C. of reflection of o.c line

→ (P.T.O) for Explanation.

→ At the end of the tr. line the load Impedance is not matched with the characteristic Impedance there will be a concept of reflection to the switching wave form.

- The reflection current can be choden in opposite to that of switching current because at the end of the line the current has to become Zero

$V_1 = V$ = reflected voltage.

$I_1 = -I$ = reflected current

→ $\frac{V_1}{V} = 1.0$; Coefficient of reflection for voltage of O.C line.

→ $\frac{I_1}{I} = -1.0$; Coefficient of reflection for current of O.C line

$V_2 = 2V$; Refracted voltage.

→ $\frac{V_2}{V} = 2$; Coefficient of refraction for voltage of O.C line

$I_2 = 0$; Refracted current

→ $\frac{I_2}{I} = 0$, Coefficient of refraction for current of O.C line.

→ The voltage has become 2V at the source point which is an ideal case where as in a practical case voltage is not more than V, however under any circumstances the voltage at source should not be more than V

→ In order to make the voltage V at the source point, the wave travelling can be continued further under the assumption that the supply terminals are interchanged. So the switching voltage & switching current have become negative.

Sub-sequent wave travelling (from fig) (Interchanging of supply terminals)

$V_1 = -V$

$I_1 = I$

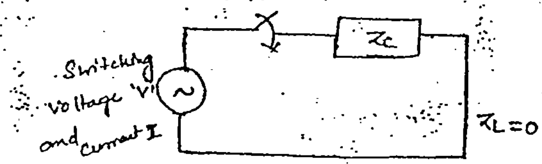
$\frac{V_1}{V} = -1$, $\frac{I_1}{I} = 1$,

$V_2 = 0$ $\frac{V_2}{V} = 0$,

$I_2 = 0$, $\frac{I_2}{I} = 0$.

→ As the Voltage has become zero and in order to maintain V the wave travelling can be continued in a repetition manner.

Case (ii) Line is short circuited.



→ At the end of the line the load impedance is not matched with the characteristic impedance so that there will be a reflection wave form and inorder to make the voltage zero in a s.c line. It can be assumed that the voltage reflection is negative

$V_1 = -V$ Reflected Voltage.

$I_1 = I$ Reflected current

$\frac{V_1}{V} = -1.0$ coefficient of reflected voltage for s.c line

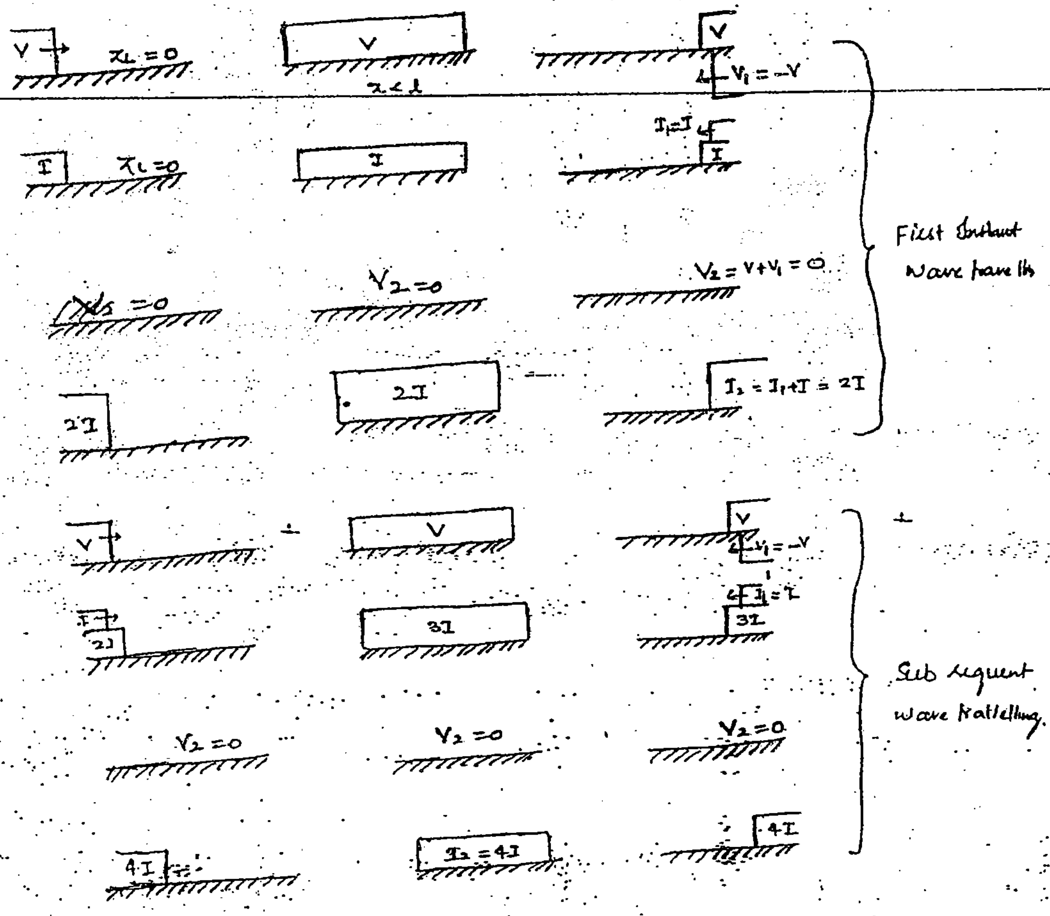
$\frac{I_1}{I} = 1.0$ " " current for s.c line.

$V_2 = 0$ → Refracted voltage

$\frac{V_2}{V} = 0$ → Coefficient of Refracted V for s.c.

$I_2 = 2I$ Refracted current

$\frac{I_2}{I} = 2$. Coef of Refracted cnt of s.c line.



→ Due to the resistance of tr. line the reflected current will be gradually attenuated and become zero over a long tr. line. so that the current is not more than I. but the voltage has become zero.

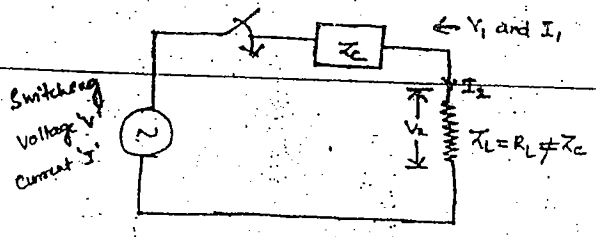
— It is necessary to maintain voltage 'V' at the source point so that the switching wave travelling is carried out further

→ Subsequent wave travelling.

$V_1 = -V, \quad I_1 = I, \quad \frac{V_1}{V} = 1.0, \quad \frac{I_1}{I} = 1.0$

$V_2 = 0, \quad I_2 = 4I \quad \frac{V_2}{V} = 0, \quad \frac{I_2}{I} = 4.0.$

Case (iii) Line terminated by an Impedance



$V, I \rightarrow$ Switching value

$V_1, I_1 \rightarrow$ Reflected value

$V_2, I_2 \rightarrow$ Refracted value

According to open circuit behavior,

$$V_2 = V + V_1 \longrightarrow (1)$$

According to S.C behavior

$$I_2 = I + I_1 \longrightarrow (2)$$

$$\Rightarrow \frac{V_2}{Z_L} = \frac{V}{Z_c} - \frac{V_1}{Z_c} \longrightarrow (3)$$

To know V_2, replace; $V_1 = V_2 - V$

$$\frac{V_2}{Z_L} = \frac{V}{Z_c} - \frac{V_2 - V}{Z_c}$$

$$\boxed{V_2 = 2V \frac{Z_L}{Z_L + Z_c}} \text{ KV}$$

$$\boxed{\frac{V_2}{V} = \frac{2 Z_L}{Z_L + Z_c}}$$ ✓ Coefficient of refraction for Voltage.

$$\boxed{\frac{V_2}{V} = \frac{\cancel{2} Z_L}{Z_L + Z_c}}$$ × → Steady state nature of wave.

$$\therefore I_2 = \frac{V_2}{Z_L} = \frac{2V \frac{Z_L}{Z_L + Z_c}}{Z_L}$$

$$\boxed{I_2 = 2I \frac{Z_c}{Z_L + Z_c}} \text{ KA}$$

$$\boxed{\frac{I_2}{I} = \frac{2 \cdot Z_c}{Z_L + Z_c}}$$ → Coefficient of refraction for Current

To know V_1 Replace $V_2 = V + V_1$

$$\frac{V_1 + V}{Z_L} = \frac{V}{Z_C} - \frac{V_1}{Z_C}$$

$$V_1 = V\left[\frac{Z_L - Z_C}{Z_L + Z_C}\right] \quad KY$$

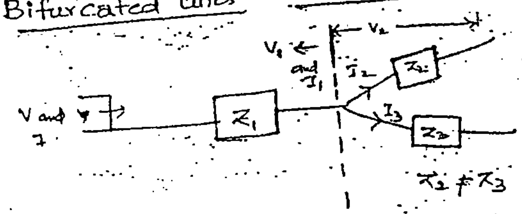
$$\frac{V_1}{V} = \left[\frac{Z_L - Z_C}{Z_L + Z_C}\right]$$ coefficient of reflection for voltage.

$$I_1 = \frac{-V_1}{Z_C} = \frac{-V\left[\frac{Z_L - Z_C}{Z_L + Z_C}\right]}{Z_C} = \frac{-I\cancel{Z_C}\left[\frac{Z_L - Z_C}{Z_L + Z_C}\right]}{\cancel{Z_C}}$$

$$\boxed{I_1 = -I\left[\frac{Z_L - Z_C}{Z_L + Z_C}\right]} \quad KX$$

$$\boxed{\frac{I_1}{I} = -\left[\frac{Z_L - Z_C}{Z_L + Z_C}\right]} \longrightarrow$$ Coefficient of reflection for Current

Case(iv) Bifurcated lines - T-network



$Z_2 \neq Z_3$

$$V_2 = V + V_1 \longrightarrow (1)$$

$$I_2 + I_3 = I + I_1 \longrightarrow (2)$$

$$\frac{V_2}{Z_2} + \frac{V_2}{Z_3} = \frac{V}{Z_1} - \frac{V_1}{Z_1} \longrightarrow (3)$$

To know V_2, Replace $V_1 = V_2 - V$.

$$\frac{V_2}{Z_2} + \frac{V_2}{Z_3} = \frac{V}{Z_1} - \frac{V_2 - V}{Z_1}$$

$$V_2 = 2V \cdot \frac{Z_2 Z_3}{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1}$$

$$\boxed{\frac{V_2}{V} = 2 \cdot \frac{Z_2 Z_3}{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1}}$$

$$I_2 = \frac{V_2}{Z_2} = \frac{\dfrac{2V \cdot \cancel{Z_2} Z_3}{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1}}{\cancel{Z_2}}$$

$$\boxed{I_2 = \frac{2 I Z_1 Z_3}{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1}}$$ KA

$$I_3 = \frac{V_2}{Z_3}$$

$$= \frac{\dfrac{2V \cdot Z_2 \cancel{Z_3}}{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1}}{\cancel{Z_3}}$$

$$\boxed{I_3 = \frac{2 I Z_1 Z_2}{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1}}$$

To know V_1 Replace $V_2 = V + V_1$

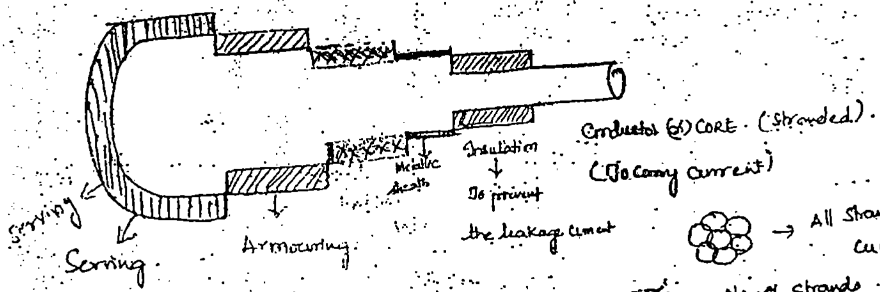
$$V + V_1 \left[\frac{1}{Z_2} + \frac{1}{Z_3}\right] = \frac{V}{Z_1} - \frac{V}{Z_1}$$

$$V_1 = V\left(\frac{Z_2 Z_3 - Z_1 Z_2 - Z_1 Z_3}{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1}\right)$$

$$\boxed{\frac{V_1}{V} = \left[\frac{Z_2 Z_3 - Z_1 Z_2 - Z_1 Z_3}{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1}\right]}$$

→ UNDER GROUND CABLES

OHTL	UGC
(i) Conductor	electrical characteristics: (i) Conductor; (ii) Insulation throughout the length; (iii) Metallic sheath
(ii) Line supports (Galvanised steel structure)	(iv) Bedding
(iii) Insulation at line supports (porcelin)	(v) Armouring
	(vi) Searving — Mechanical Characteristics



→ All strands are cu (or) Al.

$\frac{x}{y}$ = No. of strands / Size of each strand in mm of dia

Ex: $\frac{7}{1.25}$, $\frac{19}{1.5}$

→ Heavy duty cable → Copper.

→ In general UGC → of Aluminium.

→ Insulation prevents the leakage current from the surface of the conductor to the ground or earth surface.

Ex: Vulcanised rubber, Impregnated paper } used for Multistoryed building for distribution ≤ 1.1 KV (low voltage)

latest ≤ 33 KV: PVC (Poly Vinyle Chloride), polythene → XLPE [Cross linked polyethylene] → 66 KV and above

As the operating voltages are increased, & power handling capabilities increases, due to the thickness of insulation is high there is a improper dissipation heat dissipation in cable so we should go for high temp withstanding materials (i.e. PVC, polythene)

→ Basic Characteristics:

(i) High dielectric strength — KV/cm.

so that the thickness of insulation required for a given voltage.

(2) High insulation resistance: To prevent the leakage current.

It is in MΩ.

(3) Non Hygroscopic → To prevent corrosiveness due to moisture.
(not to observe moisture from earth)

(4) Free from impurities

(5) It should not be chemically (or) electrically active.

→ Metallic Sheath: To prevent the entry of moisture from the earth surface into the insulating material

Metals used → Aluminium (or) Lead foils. (Pb foils)

→ Bedding: To prevent the mechanical stress from electrical field in the core.

Ex: Jute

It is a low grade insulating material.

→ ARMOURING: To prevent the damage of bedding or insulation of the cable while laying or transposting.

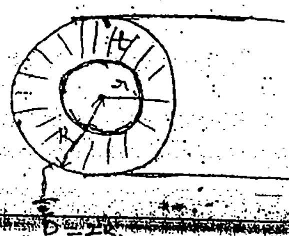
— It is for the protection against mechanical damage.

Ex: Galvonized steel foils.

→ SERVING:

The purpose of the serving is to prevent the occurance of the corrosion on the armouring. Normally Fiber materials are employed as Serving.

→ Normally the cable represented as



r = radius of conductor or core

$d = 2r$

t = thickness of Insulation

R = Radius of the cable $= r+t$

→ Classification of Cables:

1. Based on operating voltage. — for the same amount of power & same ~~operating~~ voltage the area of cross section of the conductor of cable is

(i) Low voltage ⟶ 1 KV

(ii) High voltage ⟶ 11 KV

(iii) Super voltage ⟶ 22 KV – 33 KV

(iv) Extra ~~High voltage~~ ⟶ 66 KV

(v) Extra Super voltage ⟶ 132 KV and above

⇒ H.V and above called as power cables. } Field nomenclature
→ L.V cables called Distribution cables

2. Based on the insulating material.

(i) Vulcanised Rubber.

(ii) Impregnated paper

(iii) PVC

(iv) XLPE

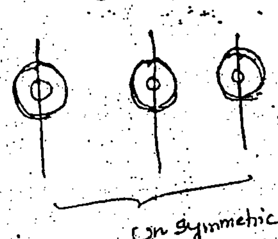
3. Based on no. of Cores

(i) Single Core ≥ 66 KV

(ii) Three Core ≤ 33 KV

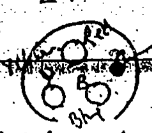
→ Symmetrical shape of core.

↳ Since the insulation requires high for high voltages the cables become bulky.



⇒ 3 - Single core Cable. ⇒ for high voltages

(iii) Three and half → for L.V distribution system.



* Size of neutral = 50% c/s of any phase.

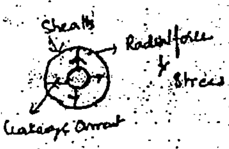
3/2/2010

→ 3-Core Cables — (i) Belted cables ⟶ 11KV

(ii) Screened cables ⟶ 22KV – 66KV

(iii) oil (or) Gas filled cables → 132KV and above.

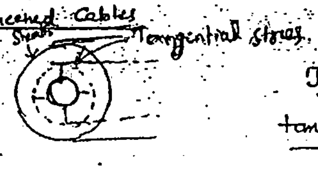
(i) Belted Cable



Stress on cable because of leakage current

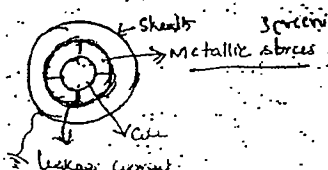
– If there will be a radial stress in the insulating material then the insulating material may not damage. So the radial stress can be allowed.

(ii) Screened Cables



The insulating material will get damaged because of tangential stress.

to avoid this one more metallic screen b/w core and sheath

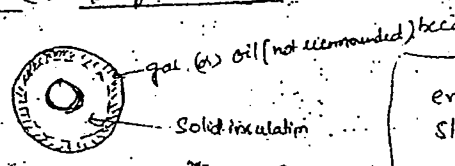


Metallic stress → eliminates the tangential stress.

all practical cases we go for 3 single core cables for above 66 KV

(iii) Oil (or) Gas filled Cables

because H_2 is released during heat-up of cable



a 3-core cable can also be employed for voltages 66 kV & above with a slight changes in the cable insulation but the cost of the cable is high hence for voltages 66 kV & above single core cables are preferred rather than 3 core cables

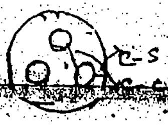
Gas – SF_6 – Pressure: 14 kg/cm² (in C.B also)

→ FAULTS IN CABLES:

(i) Open circuit Fault → If cable joints fail the o.c problem occur
↳ measurement of insulation resistance b/w core & core & core-sheath to identify the o.c fault

(ii) Short circuit Fault

↳ (i) If the insulation b/w core and sheath fails then it called Core – Sheath.



(ii) Core – sheath, Core – core faults.

⇒ we can identify ~~s.c fault by measuring~~ core-core & core-sheath to identify s.c fault

→ To detect the open circuit faults, to insulation resistance is calculated or measured by using Megger.

→ To detect the S.C faults, by using the measurement of capacitance by using Bridges. (b/w Core – Core, Core – Sheath)

→ Limitations:

(1) For the same power, same operating voltage the area of cross section of the conductor of the cable will be larger when compared to the area of C/S of the conductor of the OHTL so, that the cost of conductor of cable increases.

$$a = \frac{1.5}{V^2\cos^2\phi} K \rightarrow \text{for } 3\text{-}\phi \text{ 3 core cable}$$

$$a = \frac{0.5}{V^2\cos^2\phi} K \rightarrow 3\text{-}\phi \text{ 3-w OHTL}$$

K → Area of C/s of the DC – 2 wire supply which is the reference supply.

(2) The amount of insulation required through out the length of the conductor hence the total amount of insulation required will be high. Hence the cost of insulation is high.

(3) Due to the nearness of the two plates the capacitance per Km is high hence the charging current per Km is high. If the length of the cable increases, the total charging current increases which will result as severe over voltages in the cable. In order to limit the over voltages the cable is not recommended beyond 50 Km

(4) As the cable is placed in the ground then it is very difficult to locate the location of the fault.

Advantages of Cables:

1) The frequency of occurance of faults are less hence the reliability of the supply is high.

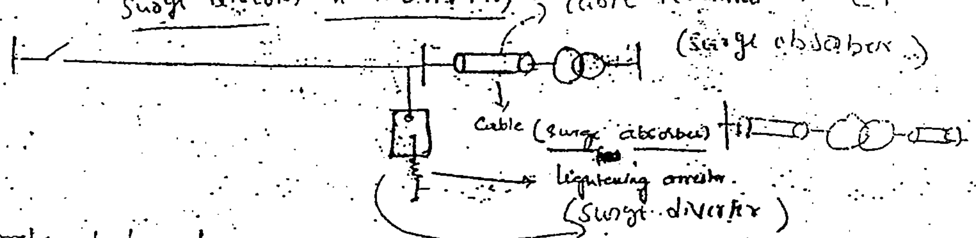
2) As the fixed cost of cable is high then the maintainance cost is less compared to O.H.T.L

— Applications of UGC:

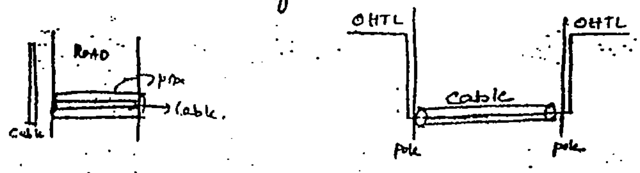
1) It is well suited for a distributed system in a high populated area so that area will become electrically more beautiful

2) The deadend of OHTL will be connected to the substation (Transformer) through a Cable joint

Surge absorber used in distribution systems
Surge diverters " " EHV lines



3) It is preferred to have a cable joint at road crossing or railway crossing or river crossings.

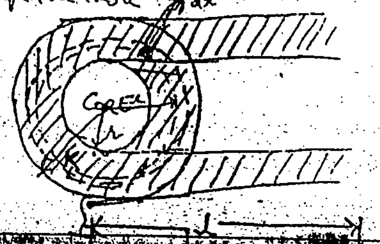


(4) For all submarine applications the cables are preferred.

→ CALCULATION OF INSULATION RESISTANCE OF THE CABLE: (1-core cable)

⇒ The electrical characteristics of the cable can be analysed in single core cable because the bulk amount of power in longer distance can be done at 66 kV & above

Resistance of the Conductor (or) Core $= \frac{\rho l}{a}$



— The insulating material is distributed more uniformly from the surface of the core towards the sheath and in order to know the insulation resistance we the mathematical solution.

Consider a point 'K' a distance from the centre.

Consider 'x' in the insulation and an elementary width dx

$$\therefore \; dR_{in} = \frac{\rho\,dx}{2\pi x\,l} \quad (\text{circum of cylinder})$$

$$R_{in} = \int_r^R \frac{\rho\,dx}{2\pi x l}$$

$$\boxed{R_{in} = \frac{\rho}{2\pi l}\ln(R/r)\ M\Omega}$$

$$\Rightarrow \boxed{R_{in} \propto \frac{1}{l}}$$

*** (Q) A 10 km length of cable having a insulation resistance of 20 MΩ. What is the insulation resistance of a cable having a length of 5 km.

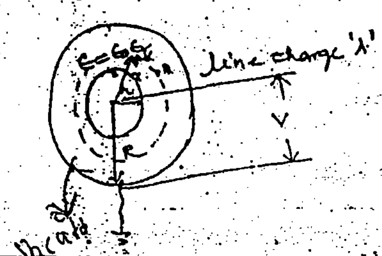
Sol

$$\frac{R_1}{R_2} = \frac{l_2}{l_1} \Rightarrow \frac{20}{R_2} = \frac{5}{10}$$

$$R_2 = 40\ M\Omega.$$

→ As temperature ↑ ⇒ R↑ further ↑ of Temp ⇒ R↓

→ ELECTROSTATIC STRESSES IN THE CABLE:



To know the electrostatic stress consider point 'x' at distance of 'x' from the Centre.

~~The electrostatic stress at a distance of 'x' will be~~

$$E_x = \frac{\lambda}{2\pi\epsilon x}$$

Replace the line charge 'λ' in terms of the operating voltage of the cable.

$$\text{Operating voltage } V = -\int_R^r E_x\,dx.$$

$$= \int_r^R E_x\,dx$$

$$= \int_r^R \frac{\lambda}{2\pi\epsilon x}\,dx$$

$$\boxed{V = \frac{\lambda}{2\pi\epsilon}\ln(R/r)}$$

$$\boxed{\lambda = V\frac{2\pi\epsilon}{\ln(R/r)}}$$

$$E_x = \frac{\lambda}{2\pi\epsilon x}.$$

$$= \frac{\frac{V.\cancel{2\pi\epsilon}}{\ln(R/r)}}{\cancel{2\pi\epsilon} x}$$

$$E_x = \frac{V \times \sqrt{2}^{\text{ peak}}}{x\ln(R/r)} \quad KV/Cm/peak.$$

If $x = r$, then

$$E_r = \underline{E_{max}} = \frac{V}{r\ln(R/r)} \quad KV/cm/peak.$$

If $x = R$ then

$$E_R = \underline{E_{min}} = \frac{V}{R\ln(R/r)} \quad KV/cm/peak.$$

$$\boxed{r < R}$$

→ In a given single core cable, the electrostatic stress is maximum at the surface of the core and it will be minimum at the surface of the sheath.

→ For a 3-core cable

$$E_{max} = \frac{V}{r \ln(R/r)} \text{ kV/cm/peak/phase}$$

$$\boxed{V = \frac{V}{\sqrt{3}} \times \sqrt{2}}$$

Ex: for 33 KV

$$V = \frac{33}{\sqrt{3}} \times \sqrt{2}$$

for 1-core

$$\boxed{V = \sqrt{2} V}$$

→ In order to increase the life of cable, then the electrostatic stress at the surface of the core should be reduced for the same operating voltage and also the same size of the cable i.e. 'R'

$$E_r = E_{max} = \frac{V}{r \ln(R/r)} \text{ kV/cm/peak}$$

$$\therefore f(r) = r \ln(R/r) \rightarrow \text{Maximize.}$$

$$\frac{d f(r)}{dr} = 0 \; ; \Rightarrow \boxed{\frac{R}{r} = e \text{ (or) } \frac{D}{d} = e} = 2.71$$

Most economical size of the cable so that the stress at the surface of the core is minimized.

$$\boxed{\frac{r}{R} = \frac{1}{e}} = \frac{1}{2.71}$$

→ For stability operation of the cable.

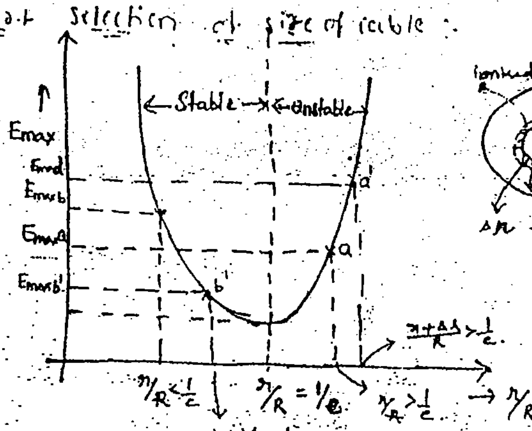
$$\boxed{R/r > 1} \quad \boxed{\frac{r}{R} < \frac{1}{e}} \quad \boxed{\frac{r}{R} < 0.369}$$

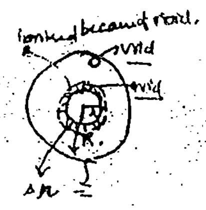
Apart from the electrostatic stress the insulating material of the cable (Heat → I^2R current) will also experience the thermal stresses due to small and gradual variation of the load which is known as the steady state stability of the cable.

Variation of Electrostatic stress w.r.t selection of size of cable :

Case (i) Initially the cable is selected as

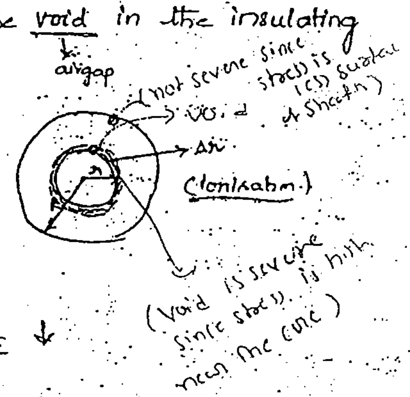
$$\frac{r}{R} > \frac{1}{e} \downarrow$$





Most of the reasons for the failure of the cable is the occurance of the void (airgap) in the insulating material.

$$\frac{r+\Delta r}{R} > \frac{1}{e} \uparrow$$



Case (ii) Initially the cable is selected as $\frac{r}{R} < \frac{1}{e} \downarrow$

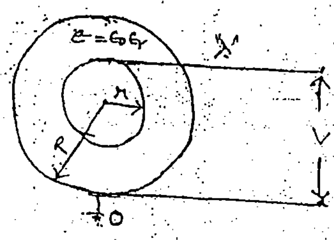
$$\frac{r+\Delta r}{R} < \frac{1}{e} \uparrow$$

∴ Case (ii) is the more suitable for the stable operation of the cable.

→ CAPACITANCE OF SINGLE CORE CABLE :

A single core cable will physically acts as a capacitor.

$$C = \frac{\lambda}{V} = \frac{\lambda}{\left(\frac{2\pi\epsilon\lambda}{\ln(R/r)}\right)^{-1}}$$



$\epsilon_r > 1$

$$\Rightarrow \boxed{C = \frac{2\pi\epsilon_0\epsilon_r}{\ln R/r}} \text{ F/m}$$

In OHTL $\epsilon_r \leftarrow 1.0$

$$C = \frac{2\pi\epsilon_0\epsilon_r}{\ln(d/r)} \text{ F/m}$$

But in cable, (i) $\epsilon_r > 1.0$

(ii) R is distance between the two plates is on.

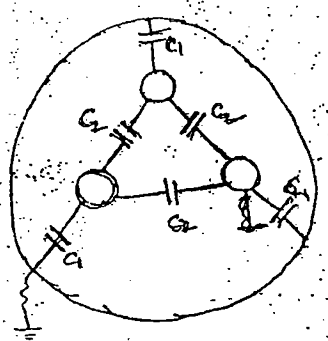
so The capacitance in UGC is high as compared to 'C' in OHTL.
due to $\epsilon_r > 1$ & due to nature of the plates

Char. Impedance, $Z_c = \sqrt{\frac{L}{C}} = 40$ ohms → For cable
(Z_c for UGC is less i.e. $\frac{1}{10}$ th of Z_c in OHTL since 'C' is more)

It is independent of cable length

Charging Current, $\boxed{I_c = V\omega C}$ A/m.

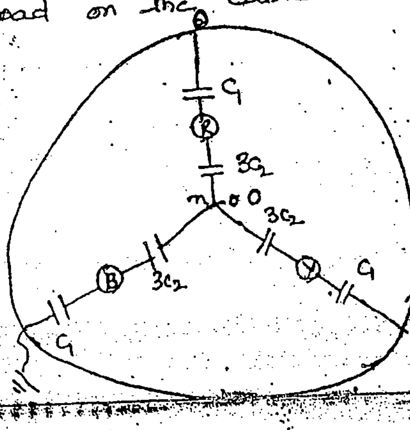
→ CAPACITANCE OF 3-CORE CABLE:



C_1 = Core to sheath capacitance → Sheath Capacitance

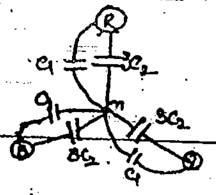
C_2 = Core to Core capacitance → Core Cap.

To get the capacitance / phase convert the Δ-connected core configuration into an equivalent of Y-configuration and assuming that the potential of the neutral is zero because the load on the cable is balanced.



Δ	Y
R	R/3
X	X/3
L	L/3
C	3C ($\because X \propto \frac{1}{C}$)

$\therefore C|\text{phase} = C_1 + 3C_2$



(∵ potential of neutral = 0, Potential of Sheath = 0.)

$I_c|\text{phase} = V_{phase}\,\omega C|\text{phase}$ Ampls.

$V_{phase} = \frac{V_{L-L}}{\sqrt{3}}$.

Q) In a 3-φ core cable the sheath capacitance 0.1 μF and core capacitance 0.3 μF. The cable is operated at 3-φ 11 KV, 3-φ, 50Hz. The Charging current/phase in amperes is

Sol

$$C|\text{phase} = C_1 + 3C_2$$

$$= 0.1 + 3(0.3)$$

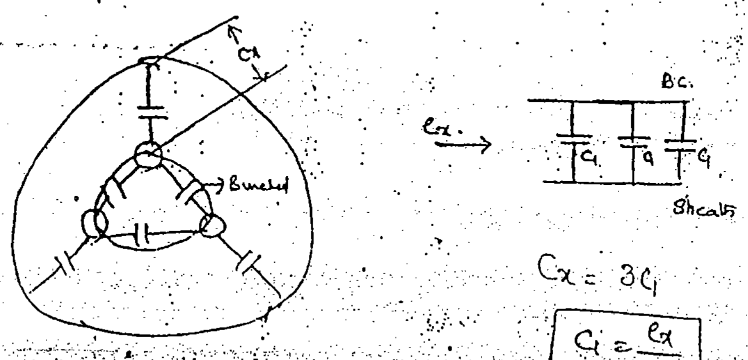
$$C|\text{ph.} = 0.1 + 0.9 = 1.0\ \mu F$$

$$I_c|\text{phase} = \frac{11\times10^3}{\sqrt{3}} \times 314 \times 10^{-6}$$

$$= 1.995\ A.$$

→ If C_1, C_2 are not directly given then the following assumptions are made to calculate C_1 and C_2

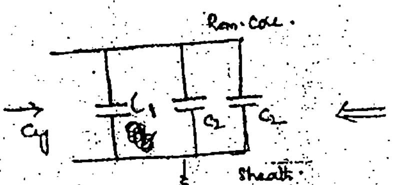
(i) Bunch all the 3-cores and measure the capacitance between bunched core and the sheath

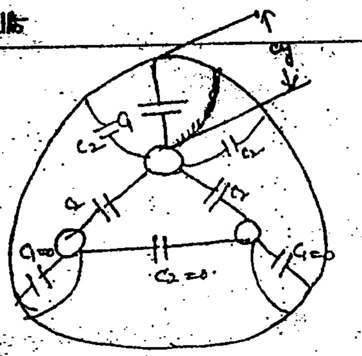


$C_x = 3C_1$

$$\boxed{C_1 = \frac{C_x}{3}}$$

(ii) Connect any two cores to the sheath and measure the capacitance b/w the core and the sheath





$$C_y = C_1 + 2C_2$$

$$C_2 = \frac{C_y - C_1}{2}$$

$$C_2 = \frac{C_y - \frac{C_x}{3}}{2}$$

$$\therefore \quad C_2 = \frac{3C_y - C_1}{6}$$

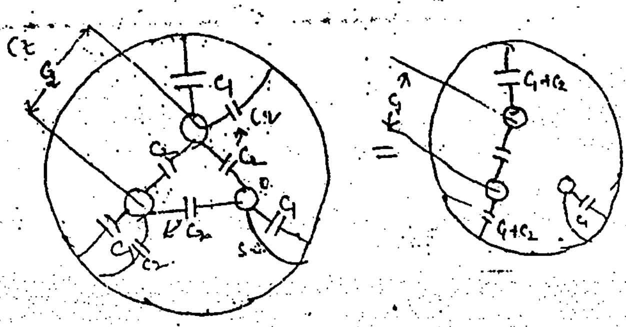
$$\therefore C \text{ phase}, \quad C_n = C_1 + 3C_2$$

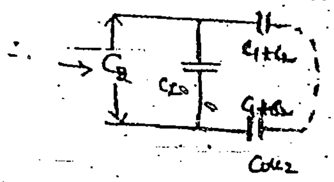
$$= \frac{C_x}{3} + 3\left[\frac{3C_y - C_x}{6}\right]$$

$$= \frac{3}{2} C_y + \frac{C_x}{3} - \frac{C_x}{2}$$

$$\boxed{C_n = \frac{3}{2} C_y - \frac{C_x}{6}}$$

(iii) Connect any one of the core to sheath and measure the capacitance between the two cores.





$$C_3 = C_2 + \frac{C_1+C_2}{2}$$

$$= \frac{2C_2 + C_1 + C_2}{2}$$

$$C_3 = \frac{C_1+3C_2}{2}$$

$$C_3 = \frac{C_n}{2}$$

$$\therefore \boxed{C_n = 2C_3}$$

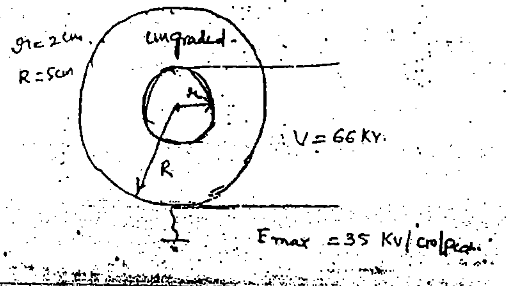
(Q) In a 3-core cable the capacitance b/w the two cores is 0.25 μF when the other core is connected to sheath. The capacitance to neutral in μF is

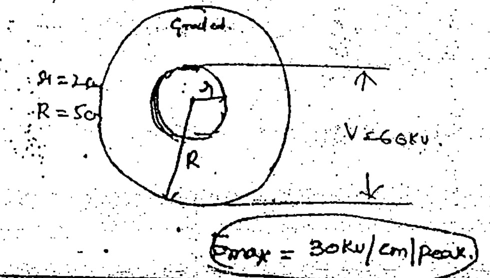
Sol

$$C_3 = 0.25\,\mu F$$

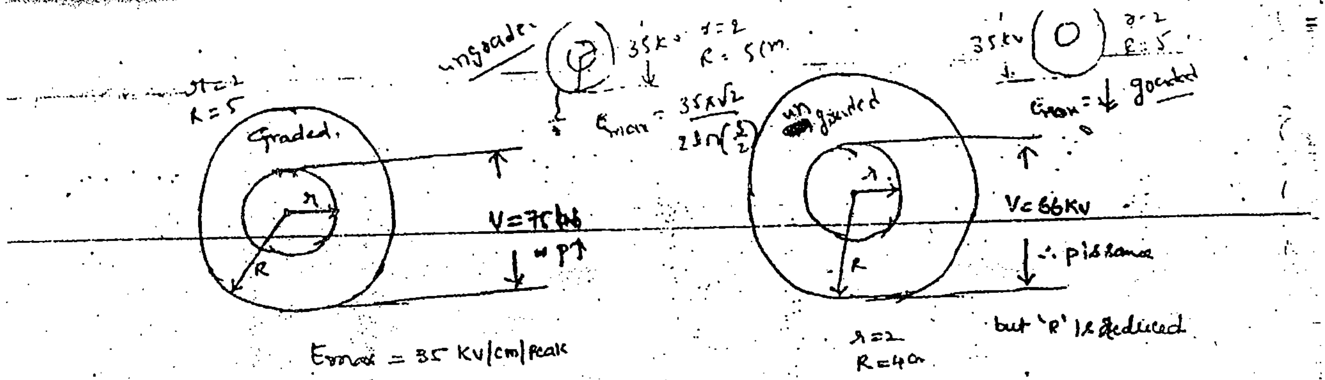
$$C_n = 2\times0.25 = \underline{0.5\,\mu F}$$

→ **GRADING OF THE CABLES:-** The grading of the cable means reduce the difference between the maximum electrostatic stress to the minimum electrostatic stress by way of reducing the maximum stress so that the same size of the cable can be employed at higher voltages, which will increase the power handling capacity (or) for the same operating voltage, the size of the cable will reduced so that the cost of the cable will be reduced.





If Emax = 35 KV/cm/peak in liquid



The grading principle can be obtained by using

(i) Capacitance grading → Use more than one insulating material

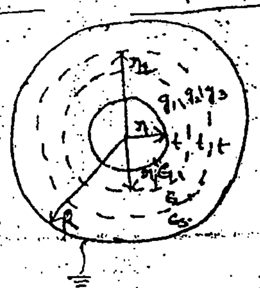
(ii) Intersheath grading → Use more than one intersheaths, but same insulating material.

(i) Capacitance grading:

Use more than one insulating material.

Three materials of permittivity ϵ_1, ϵ_2 and ϵ_3

Case(i) If the cable is operating with non uniform maximum electrostatic stresses then the insulating material which is having the highest product of the dielectric strength and the permittivity is placed near the core where as the lowest product will be placed near the sheath.



g_1 = dielectric strength kV/cm

g_2 = kV/cm

g_3 = kV/cm.

$g_1 \neq g_2 \neq g_3$.

$$\left.\begin{aligned} G_1 &= g_1 \times t \\ G_2 &= g_2 \times t \\ G_3 &= g_3 \times t \end{aligned}\right\} \Rightarrow G_1 \neq G_2 \neq G_3 \Rightarrow \text{Ultimate dielectric strength.}$$

Max Working stress, $E_{max1} = \frac{\lambda}{2\pi\epsilon_1 r}$, $E_{max2} = \frac{\lambda}{2\pi\epsilon_2 r_1}$, $E_{max3} = \frac{\lambda}{2\pi\epsilon_3 r_2}$

Working stress or atention $= \dfrac{\text{Ultimate Stress}}{\text{Factor of Safety}}$ → is same for all dielectric material.

$$\therefore \; E_{max1} = \frac{\lambda}{2\pi\epsilon_1 r} = \frac{G_1}{f}$$

$$E_{max2} = \frac{\lambda}{2\pi\epsilon_2 r_1} = \frac{G_2}{f}$$

$$E_{max3} = \frac{\lambda}{2\pi\epsilon_3 r_2} = \frac{G_3}{f}$$

$$\therefore \lambda = \cancel{2\pi}\epsilon_1 r \frac{G_1}{\cancel{f}} = \cancel{2\pi}\epsilon_2 r_1 \frac{G_2}{\cancel{f}} = \cancel{2\pi}\epsilon_3 r_2 \frac{G_3}{\cancel{f}}$$

$$\epsilon_1 r G_1 = \epsilon_2 r_1 G_2 = \epsilon_3 r_2 G_3$$

$$\boxed{r < r_1 < r_2}$$

$$\boxed{\epsilon_1 G_1 > \epsilon_2 G_2 > \epsilon_3 G_3}$$

**

(Q) A Capacitance grading is employed in cable by using 3 materials 3 insulating materials having the permittivities of 2, 3 and 4. The dielectric strengths of the materials are 20 KV/cm, 30 KV/cm and 15 KV/cm. The materials which are arranged w.r.t the core of the cable is

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$\epsilon_1 = 2, \quad \epsilon_2 = 3, \quad \epsilon_3 = 4$

$G_1 = 20, \quad G_2 = 30, \quad G_3 = 15$

$\therefore \; \epsilon_1 G_1 = 2\times 20 = 40, \quad \epsilon_2 G_2 = 3\times 30 = 90, \quad \epsilon_3 G_3 = 4\times 15 = 60$

$\therefore$ * Arrangement is <u>3, 4, 2.</u> (core)

** Arrangement w.r.t sheath ; <u>2, 4, 3</u>

—x—

→ The operating Voltage of the cable if the stress is given.

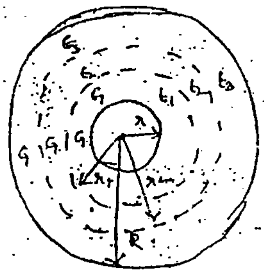
$$E_{max} = \frac{V}{r \ln(R/r)}$$

~~$\therefore V = \frac{E_{max}}{\sqrt{2}} r \ln(R/r)$ KV/rms ; $V = \frac{E_{min}}{\sqrt{2}} R \ln(R/r)$ KV/rms~~

operating Voltage

$$\therefore \boxed{V = \frac{E_{max1}}{\sqrt{2}} r \ln\left(\frac{r_1}{r}\right) + \frac{E_{max2}}{\sqrt{2}} r_1 \ln\left(\frac{r_2}{r_1}\right) + \frac{E_{max3}}{\sqrt{2}} r_2 \ln\left(\frac{R}{r_2}\right)}$$ Kv/cm. Kv/rms

Case(ii) The cable is working with uniform working stress then the material which is having highest permittivity will be placed near the core and the material which is having lowest permittivity will be placed near the sheath



$g_1 =$ Kv/cm.

$g_2 =$ Kv/cm

$g_3 =$ Kv/cm.

$g_1 \neq g_2 \neq g_3$

$\Rightarrow G_1 = g_1 \times t_1, \quad G_2 = g_2 \times t_2, \quad G_3 = g_3 \times t_3.$

$$\Rightarrow G_1 = G_2 = G_3 = G.$$

$$E_{max} = \frac{\lambda}{2\pi\epsilon_1 r}$$

$$E_{max} = \frac{\lambda}{2\pi\epsilon_2 r_1}$$

$$E_{max} = \frac{\lambda}{2\pi\epsilon_3 r_2}$$

$$\therefore \lambda = 2\pi\epsilon_1 r = 2\pi\epsilon_2 r_1 = 2\pi\epsilon_3 r_2$$

$$\epsilon_1 r = \epsilon_2 r_1 = \epsilon_3 r_2$$

$$r < r_1 < r_2$$

$$* \boxed{\epsilon_1 > \epsilon_2 > \epsilon_3} **$$

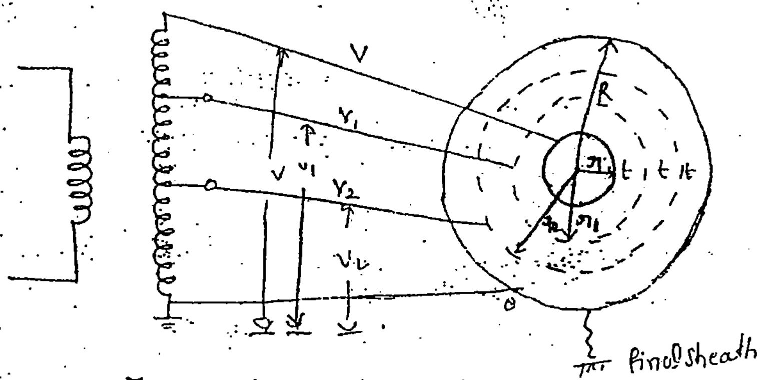
Since the stress are same the operating voltage is

$$\boxed{V = \frac{E_{max}}{\sqrt{2}}\left[r \ln\left(\frac{r_1}{r}\right) + r_1 \ln\left(\frac{r_2}{r_1}\right) + r_2 \ln\left(\frac{R}{r_2}\right)\right]} \text{ kV/rms}$$

(Q) The C-grading is employed in a 1-core cable having the permittivities of 1, 2 and 3 and they are working with uniform stress of 30 kV/cm. The arranging of the material w.r.t to core is 3, 2, 1

4/02/2010

INTER SHEATH GRADING: More than one sheath.



$$\frac{r_1}{r} = \frac{r_2}{r_1} = \frac{R}{r_2} = K$$

Maximum electrostatic stress without grading

$$\uparrow E_{max1} = \frac{V}{r \ln(R/r)} = \frac{V}{r \ln\left(\frac{R}{r_2}\cdot\frac{r_2}{r_1}\cdot\frac{r_1}{r}\right)} = \frac{V}{r \ln(K^3)} = \frac{V}{3r \ln(K)}$$

The grading principle can be obtained by maintaining the surface of the core and intersheath are at different potentials with the help of a transformer having tappings on cable side so that there will be uniform electric field intensity throughout the cable

$$\downarrow E_{max2} = \frac{V - V_1}{r \ln(r_1/r)} = \frac{V_1 - V_2}{r_1 \ln(r_2/r_1)} = \frac{V_2 - 0}{r_2 \ln(R/r_2)}$$

For the same operating voltage, Emax 2 ↓

$$\frac{V_1 - V_2}{r_1 \ln(K)} = \frac{V_2}{r_2 \ln(K)}$$

$$\boxed{V_2 = V_1 \frac{K}{1+K}}$$

$$\frac{V - V_1}{r \ln(K)} = \frac{V_1 - V_2}{r_1 \ln(K)} \Rightarrow V_1 = V \frac{K(1+K)}{1+K+K^2}$$

$$\therefore E_{max2} = \frac{V - \frac{V K(1+K)}{1+K+K^2}}{r \ln(K)} = \frac{V}{r \ln(K)\underbrace{(1+K+K^2)}_{73}}$$

∴ For the same size of the cable and operating voltage, then maximum electrostatic stress (E_{max2}) of graded cable is less than that of ungraded cable (E_{max1}).

→ The same size of the cable can be operated at the same voltage (or) to operate at the same voltage the size of the cable can be reduced in order to get equal stress.

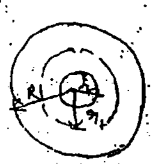
$$\boxed{\frac{E_{max1}}{E_{max2}} = \frac{1+K+K^2}{3}}$$

$$\boxed{\frac{r_1}{r} = \frac{r_2}{r_1} = \frac{R}{r_2} = e}$$

$$\boxed{\frac{E_{max1}}{E_{max2}} = \frac{1+e+e^2}{3}}$$ → For most economical size of the cable for intersheath grading.

if only one intersheath is there

→
$$\boxed{\frac{E_{max1}}{E_{max2}} = \frac{1+K}{2} = \frac{1+e}{2}}$$ → For most economical size.



$$\frac{r_1}{r} = \frac{R}{r_1} = K$$

~~The most commonly~~ employed grading in the cable is the capacitance grading which can be easily employed and also the cost of grading will be less. (Since for inkoskeeth grading transformer is req. so cost is more)

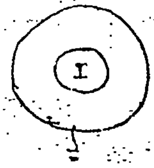
→ LOSSES IN THE CABLE:

(i) Core loss → Copper loss ↓ because of core current

(ii) Dielectric loss → leakage current in the insulating material

(iii) Sheath loss → Induced sheath current

(1) Core loss:



Core loss $= I^2R$

3-ϕ ⇒ Core loss $= 3I^2R$, I = Core current

R = Core resistance.

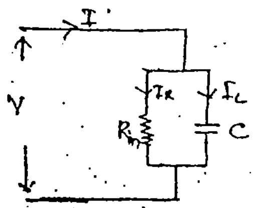
→ For the same amount of current the core loss will increase if the temperature at the surface of the core will increase because of improper heat dissipation, so that the resistance of core will increase.

(2) Dielectric loss:

For 1-core: Dielectric loss $= \frac{V^2}{R_{in}} = V\left(\frac{V}{R_{in}}\right)$; R_{in} → insulation resistance.

For 3-core-3ϕ: Dielectric loss $= \frac{3V^2}{R_{in}}$

Representation of dielectric material electrically as:



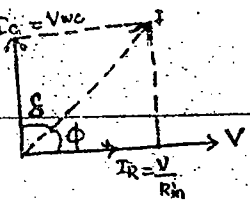
$$V\left(\frac{V}{R_{in}}\right) = V \cdot V\omega C \tan\delta$$

$$= V^2 \omega C \tan\delta. \quad , \quad \delta = \text{dielectric angle}$$

$\tan\delta$ = loss (or) dielectric tangent.

$$\boxed{\text{Dielectric loss} \propto V^2 f}$$

~~⇒ Dielectric heat ∝ $V^2 f$~~



$\phi = 90 - \delta$

$$\boxed{\cos\phi = \cos(90-\delta) = \sin\delta}$$

→ power factor of the cable = sine of dielectric angle.

If $\delta = 30°$, p.f = ⇒ $\cos\phi = \sin 30° = \frac{1}{2} = 0.5$ leading.

$$\therefore \tan\delta = \frac{I_R}{I_C} = \frac{V/R_{in}}{V\omega C}$$

$$\boxed{\frac{V}{R_{in}} = V\omega C \tan\delta}$$

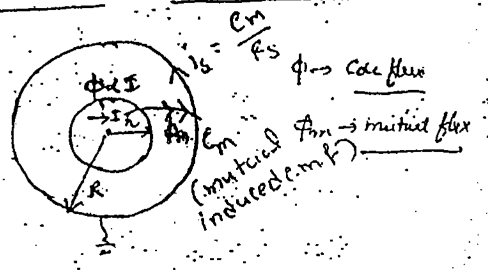
$$\boxed{\tan\delta = \frac{1}{\omega C R_{in}}}$$

(3) SHEATH LOSS: It is because of the induced sheath currents
(AC cables)

→ Sheath is near to core.

∴ Rate of change of flux (mutual) which link with sheath

$$\boxed{e_m = \frac{d\phi_m}{dt} = \omega M I}$$



Sheath current, i_s by e_m.

M → Mutual inductance b/w core & sheath
I → Core current

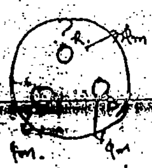
∴ Sheath loss $= i_s^2 R_s (m)$ (m) → mean resistance of the sheath because sheath it is a foil of rectangular shape

The amount of sheath loss main depends on core current

⇒ If the core current is high then the sheath loss is high because

'i_s' depends on M, depends on $\phi_m \to e_m \to I$.

→ For a 3-core cable



Sheath loss = 0 (because of balanced load because each ϕ_m is 120° apart and resultant $\phi_m = 0$ ⇒ $e_m = 0$ ⇒ $i_s = 0$ ⇒ No sheath loss)

→ In order to transmit the bulk amount of power, The single core ~~Cables are employed rather than 3-core cables, so that the Sheath loss can be Considered.~~

→ If the sheath loss is included, then the equivalent resistance of the cable will increase

i.e. $\boxed{R_{eq} = R(1+\lambda)}$

$R \rightarrow$ Core resistance

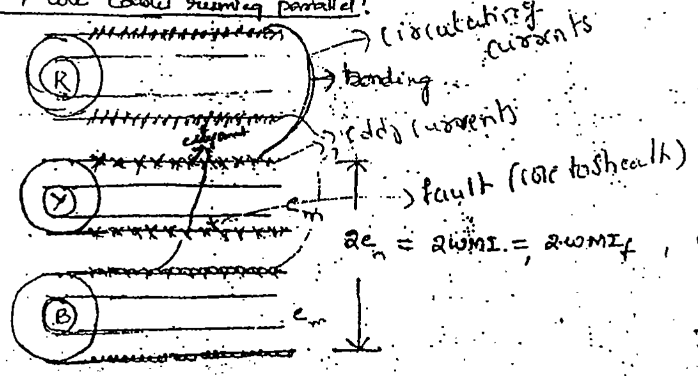
$\lambda = \dfrac{\text{Sheat loss}}{\text{Core loss}}$

→ The induced sheath currents that are produced are classified as

1) Sheath eddy currents : These are the currents which are flowing in only one particular sheath of the cable (Because of un bonding of the sheath).

(2) Sheath Circulating Currents: These are the currents which are flowing from the sheath of one cable to the sheath of another cable. (bonding of the sheaths)

3-F-core cables running parallel:



$2e_m = 2\omega MI = 2\omega MI_f$, where I_f = fault-current due to fault

$I_f > I$, I - load curt

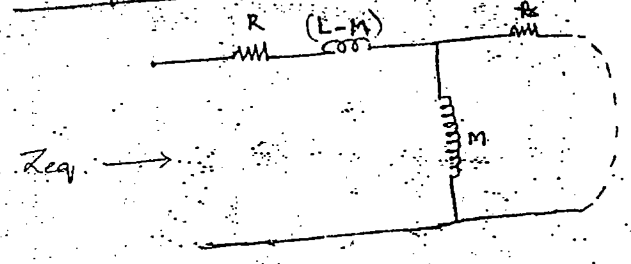
→ There will puncture of sheaths due to excessive voltage that can be developed b/w the two outer sheaths, during the fault condition if the sheath eddy current are allowed. In order to prevent the puncture of the sheaths, sheath circulating currents are ~~allowed rather than eddy currents.~~

→ If the sheaths circulating currents are allowed by making bonding of the sheaths, then there will be a sheath loss. Due to the sheath loss, the equivalent resistance of the cable will increase and the equivalent inductance will be reduced.

→ To prove $R_{eq} \uparrow$ and $L_{eq} \downarrow$.

Consider 1-core cable ⟺ 1-φ transformer, where the sheath is S.ckted

The equivalent circuit diagram (electrical equivalent of 1-φ core ⇒ 1-φ T/F)

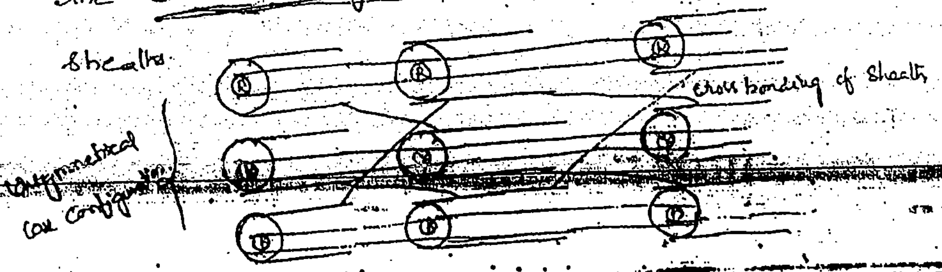


$$Z_{eq} = R + j\omega(L-M) + \frac{R_s j\omega M}{R_s + j\omega M} \times \frac{R_s - j\omega M}{R_s - j\omega M}$$

$$\Rightarrow Z_{eq} = \underbrace{\left[R + R_s \frac{\omega^2 M^2}{R_s^2 + \omega^2 M^2}\right]}_{R_{eq}\uparrow} + j\omega\underbrace{\left[L - M\frac{\omega^2 M^2}{R_s^2 + \omega^2 M^2}\right]}_{L_{eq}\downarrow}$$

Hence proved $R_{eq} = R + (\ ) \Rightarrow R_{eq} \uparrow$, $L_{eq} = L - (\ ) \Rightarrow L_{eq} \downarrow$ } in sheath loss

→ In order to eliminate the sheath loss it is preferred to have the cross bonding of the sheaths rather than bonding of the sheaths.



→ Due to unsymmetrical core configuration, the sheath loss cannot be eliminated completely even though the cross bonding of the sheaths are employed.

→ In order to eliminate the sheath loss completely, the cross bonding of the sheaths can be done along with transposition of the core.

⟹ OVERHEAD LINE INSULATORS

— Due to economical reasons, it is preferred to transmit the bulk amount of power over a longer distances the over-head system is preferred rather than UGC.

— In order to provide the ground clearance between the current carrying element and the ground the line supports are employed and inorder to provide the line to line clearance, the line support is employed with cross arms. In order to provide the electrical isolation between the cross arm and the power conductor a suitable insulation is preferred which is known as the "Over-head line insulator"

→ Basic characteristics of the insulating material.

(i) High dielectric strength

(ii) High insulation resistance

(iii) Free from impurities.

(iv) Non-Hygroscopic.

(v) High mechanical strength → to meet wind effect & carry current element

PORCELIN		TOUGHEND GLASS
→ Clay + Feldspar + Silica	(composition) →	Silica.
→ 60 Kv/cm	← (Dielectric strength) →	120 Kv/cm.
→ Non Hygroscopic		→ As the age of insulator ↑ it will become slowly hygroscopic Hence frequent replacement is required.

Porcelin	Toughent Glass
→ 415V-3ϕ to 765 KV (1-ϕ) (Capacity) and for HVDC lines. ⇒ Porcelin preffered	→ ≤ 33KV. (For distribution)

→ The Porcelin material is also used as Bushings or Covers for all most all electrical equipments.
Ex: C.B, Transformers, C.T, P.T, ... etc

→ PORCELIN INSULATIONS:

(I) Pin Insulators ⟶ ≤ 33KV (Distribution) [Most Common]

(II) Shackle insulator ⟶ ≤ 33KV
- (i) Sudden deviation of the line more than 2°
- (ii) Road crossing (iv) Canal crossings/ Rail crossing
- (iii) Dead end of the line.

(III) Stray (or) Guy insulator → In the dis. sys. a mech. support is required at junction poles in order to withstand unequal weights.

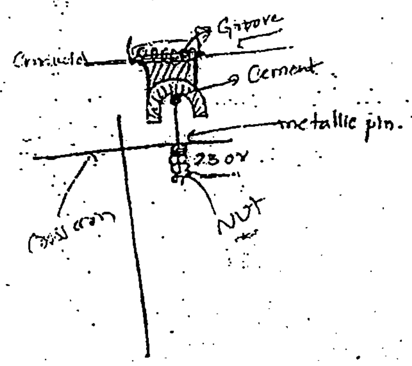
(IV) String (or) Suspension Insulator ⟶ (EHV i.e 66KV and above) (in transmission) (Most Common) in T

(V) Strain (or) Tension Insulation ⟶ The application of the shackle insulator at EHV level can be employed with strain (or) tension insulators

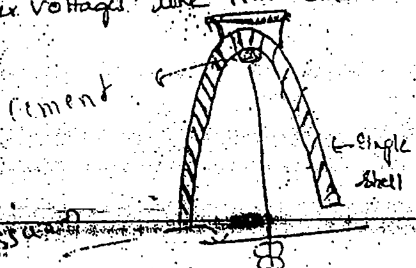
→ The insulator which can be employed at the middle of the stray wire inorder to prevent the leakage current not to allow to the ground.

(I) PIN INSULATOR:

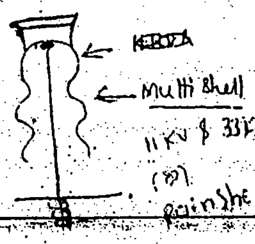
→ Purpose of the Groove is to house the conductor properly so that the position of the conductor is not disturbed due to wind effect.



→ For Higher voltages like 11KV and 33KV in distribution



(damaged)



recommended.

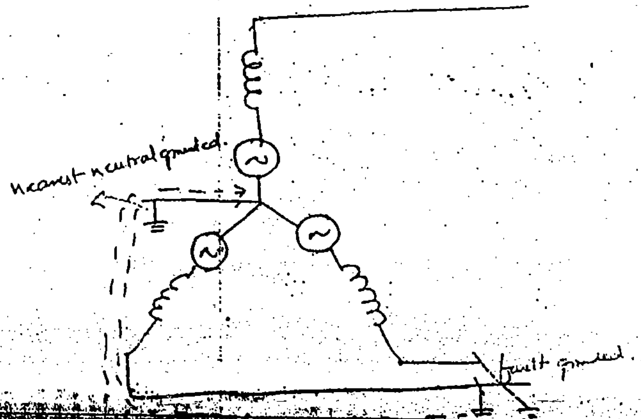
→ Physical Significance of -ve Sequence Components:

The field produced by the -ve sequence component current is opposite to that of the field produced by +ve sequence component current in the stator but it having a relative speed of double the syn. speed w.r.t rotor so that an emf is induced in the rotor wdg due to negative sequence flux, which intern produces the induced current (or) it can be also called as eddy current at double the frequency. ~~so that~~ Hence the rotor wdg will get over heated.

→ Zero Sequence Components: Zero sequence components does exists provided that (1) The fault must be grounded fault and

(2) The nearest neutral must be grounded.

→ If the fault is associated with the ground then the fault current is expected to be flowing from the fault point through ground and enter into the system through nearest neutral grounding. The earth can provide the magnitude without any phase displacement.



terms of the +ve sequence E.S component.

Ex: In case of overcurrent protection, $I_{min} = 110\%$ of I
depends on requirement.

During any type of fault, the +ve sequence subtransient current exists which is always more than the +ve sequence steady state current so that the relay will pick up.

→ The Relay can protect the existing electrical equipment for all types of faults however for line to ground fault the intensity of fault current is less and for 3-ϕ fault the intensity of the fault current is high hence the relays are set with their minimum pick up values by considering the line to ground fault.

→ Negative Sequence Components: There is no induced voltage in the stator winding due to rotor flux, however there will be a terminal voltage at the fault point so that the corresponding current is expected to be flowing from the fault point towards the stator wdg which is having opposite direction to that of the +ve sequence component current so that such components are called the "Negative sequence components" and they have a sequence of "RBY"

→ Practically the -ve sequence current cannot flow from fault point to source and it is same as +ve sequence current

Since $E_{R2} = 0$, $V_{R2} \Rightarrow$ drop.

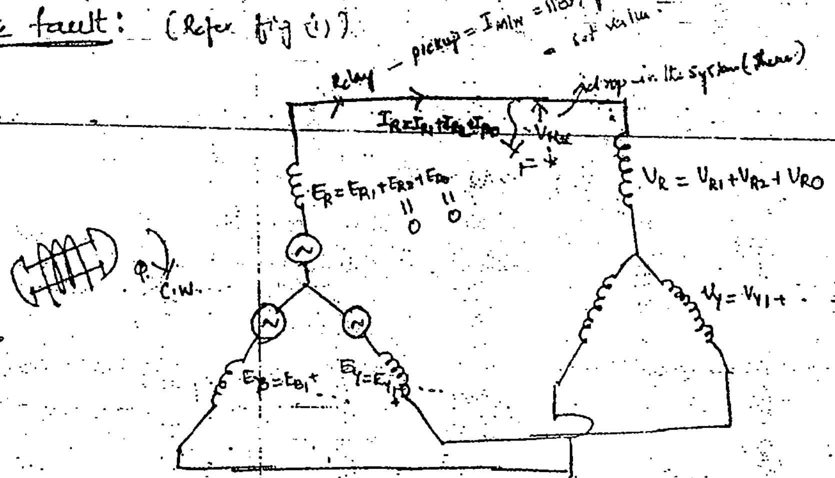
E_{R2} − drop = terminal voltage

0 − drop = terminal voltage

−ve terminal voltage.

0 is greater than +ve terminal voltage hence −ve sequence current flow from source to load.

During the fault: (Refer fig (i))



→ Even though the fault is in the stator wdg of the alternator, but there is no change in the rotation of rotor flux i.e. It will continue to rotate in the c.w direction only and the corresponding voltages are induced in the stator wdg with a sequence of RYB. The induced voltages will deliver the corresponding current to the fault point which in turn produce the corresponding field. The direction of rotation of this fld in the stator wdg is having the same direction of rotation of rotor field so that the corresponding components in phase are called as the +ve sequence sub-transient components and the Reactance (or) Impedance is called as +ve sequence sub-transient reactance or impedance.

→ Physical significance of +ve sequence components:

→ Before fault occurs the existing system is dealing with +ve sequence components in a steady state manner and during any type of fault, the +ve sequence components will exists in a subtransient manner.

→ In order to protect the electrical equipment against the faults the suitable relays are employed having the set value in

→ To know the sequence before fault occurs:

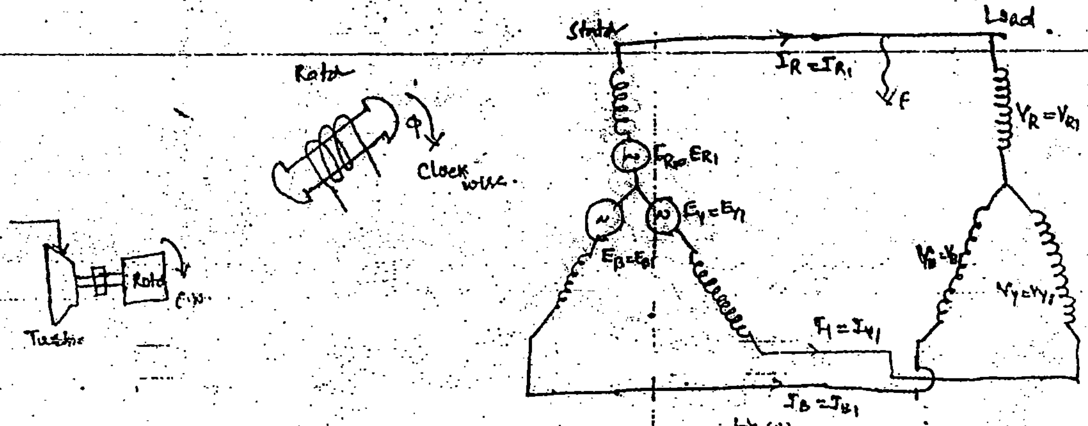
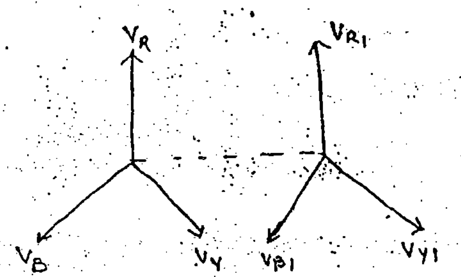


Fig (1)

→ It can be assumed as the air gap flux of the rotor is rotating in a clockwise direction so that the voltages are induced in the stator having a 3-φ winding with sequence of RYB which will able to deliver the corresponding currents to the load. Based on the magnitude of stator current there will be corresponding stator flux which can be also assumed as the direction of its rotation in clock wise with respect to the rotor of the alternator.

→ If the direction of the rotation of the stator field is same as that of the direction of the rotation of rotor field then such electrical quantities in the phasor are called as +ve sequence steady state components and the impedance or reactance that could be offered is called as +ve sequence steady state impedance or reactance.



+ve Sequence C.S. Voltages.

Will reduce the demagnetization effect.

→ ~~Refer~~ During fault condition & Next instances.

** → Faults	* Frequency of occurance	* Intensity of the fault current (I_f)
Unsymmetrical faults (or) Unbalance: L – G	70% → most common	less severe.
L – L	15%	
L – L – G	10%	
Symmetrical (or) Balanced: L – L – L, L – L – L – G	5% → least frequent	most severe.

11/9/10 ⇒ L-L-L-G is more severe compared to L-L-L (since current is more due to zero potential i.e ground)

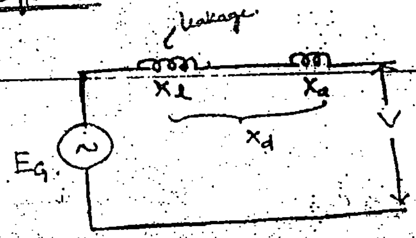
→ POSITIVE SEQUENCE COMPONENTS: These are the components having equal in magnitude and 120° phase displacement. These components having the sequence as same as that of the original phase ~~pha~~ sequence of the network

→ NEGATIVE SEQUENCE COMPONENTS: These are the components having equal in magnitude and 120° phase displacement. The phase sequence of these components is opposite to that of the original phase sequence of the network

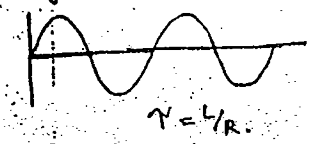
→ ZERO SEQUENCE COMPONENTS: These are the components having equal in magnitude without any phase displacement. If there is no phase displacement then there is no phase sequence to compare.

→ Sequence → Order → The direction of rotation in a 3-ϕ rotating equipment ... R B Y ...

Before fault:

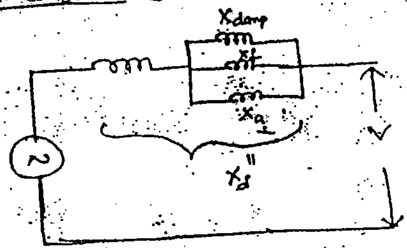


Because of steady state the wave form is symmetrical.



$X_d \rightarrow$ Steady state reactance.

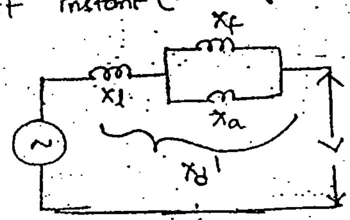
During fault condition E_G



$\longrightarrow$ During 1st cycle $\Rightarrow X_d'' = X_l + (X_{damp}) \,||\, (X_f) \,||\, X_a$

$\quad \hookrightarrow$ Sub-transient period.

$\longrightarrow$ For the next instant (2-5 cycles) X_{damp} will disappear since R is more for damper wdg i.e. time constant is less)



$X_d' = X_l + (X_f) \,||\, (X_a)$

$\hookrightarrow$ Transient Reactance. (2-5 cycles)

For a given generator ; $\boxed{X_d'' < X_d' < X_d}$

$\Rightarrow$ Sub transient current are very high than S.S. current

Expl

If a s.c. fault occurs, the armature reaction will result as severe demagnetisation of air gap flux due to dc current apart from the steady state current in the phase

~~$\longrightarrow$ It is required to maintain constant air gap flux so that the~~

Counter emf's are produced in the damper and field wdg. which

To get maximum of momentary fault current ⇒ $\alpha = 0$

i.e. $V = 0$, ⇒ dc effect high because the inductance stored energy from previous cycle

$$i_m = \frac{\sqrt{2}V}{X} + \frac{\sqrt{2}V}{X}$$

$$i_m = \frac{2\sqrt{2}V}{X} \longrightarrow \text{double effect}$$

Maximum double effect ⇒ at natural zero crossover

Expl

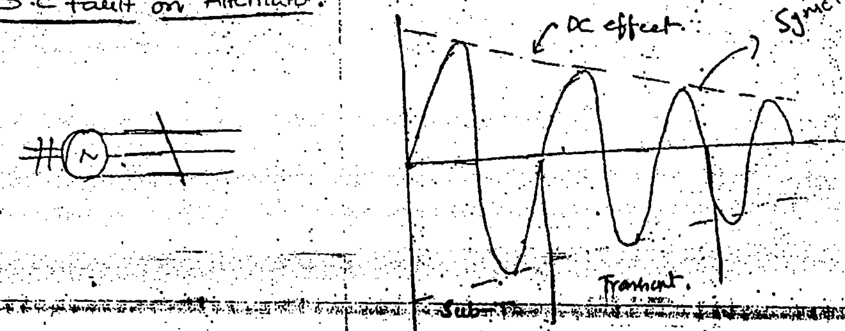
→ If a short circuit fault occurs, the currents in the phases will increase where as the voltages in the phases reduces. further the pf of the system will reduce and also the frequency of the system will slightly reduce. It is interested to calculate the fault current in the phases, becoz the increase in fault current will increase the heat that can be experience by the winding.

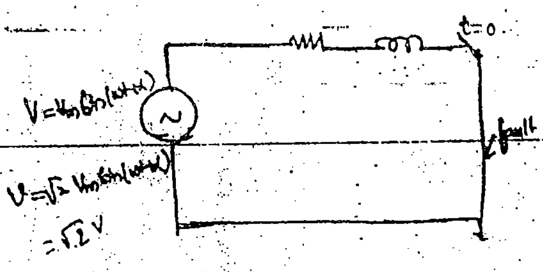
— The increase in heat may also result as the failure of the insulation.

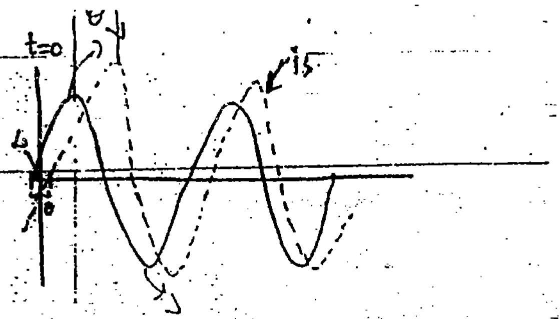
→ It is required to calculate the fault current of the phases & the subtransient currents and they are expressed in terms of rms value because the amount of heat that can be produced does depends upon the rms current.

$\boxed{i_p = i_s\,(rms)}$

→ S.C Fault on Alternator:

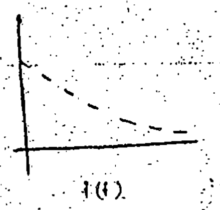






$i = i_s + i_t$ $i_s \rightarrow$ steady state current

$i_s = \frac{\sqrt{2}V}{Z} \sin(\omega t + \alpha - \theta)$ $i_t \rightarrow$ transient current



$i(t) = i(0) = i_s(0) + i_t(0)$ $\theta = \tan^{-1}\left(\frac{X}{R}\right)$

Inductor discharging

$= i_t(0) = \frac{\sqrt{2}V}{Z} \sin(\alpha - \theta)\, e^{-t/\tau}$

$\boxed{V\downarrow \; I\uparrow \; p.f\downarrow \; f\downarrow}$

For S.C fault $= \frac{\sqrt{2}V}{Z} \sin(\theta - \alpha)\, e^{-tR/L} \rightarrow$ DC effect.

→ When $i(t)$ and $i(0)$ are superimposed, then we will get an unsymmetrical wave form. Refer fig(i) (∴ dc effect + i_s)

$$\therefore \; i = \frac{\sqrt{2}V}{Z} \sin(\omega t + \alpha - \theta) + \frac{\sqrt{2}V}{Z} \sin(\theta - \alpha)\, e^{-t/\tau}$$

During the 1st cycle the maximum effect of dc current will be there.

$$\cancel{i_{max} = \frac{\sqrt{2}V}{Z} \sin(\omega t + \alpha - \theta)}$$

$$i_{max} = \frac{\sqrt{2}V}{Z} \sin(\omega t + \alpha - \theta) + \frac{\sqrt{2}V}{Z}$$

When fault occurs at $t=0$

$$i_{max} = \frac{\sqrt{2}V}{Z} \sin(\theta - \alpha) + \frac{\sqrt{2}V}{Z}$$

When $\theta = 90°$ (∵ $R \approx 0$)

$$i_{max} = \frac{\sqrt{2}V}{Z} \sin(90 - \alpha) + \frac{\sqrt{2}V}{Z}$$

$$= \frac{\sqrt{2}V}{Z} \cos\alpha + \frac{\sqrt{2}V}{Z}$$

the currents in the phases are reduced.

→ The same thing can also be understood w.r.t tr. line i.e the actual currents in the tr line will be reduced so that the inductive reactive power of the system is less than the capacitive reactive power which will increase the voltage of the phase. Hence the open ckt fault will be characterized as

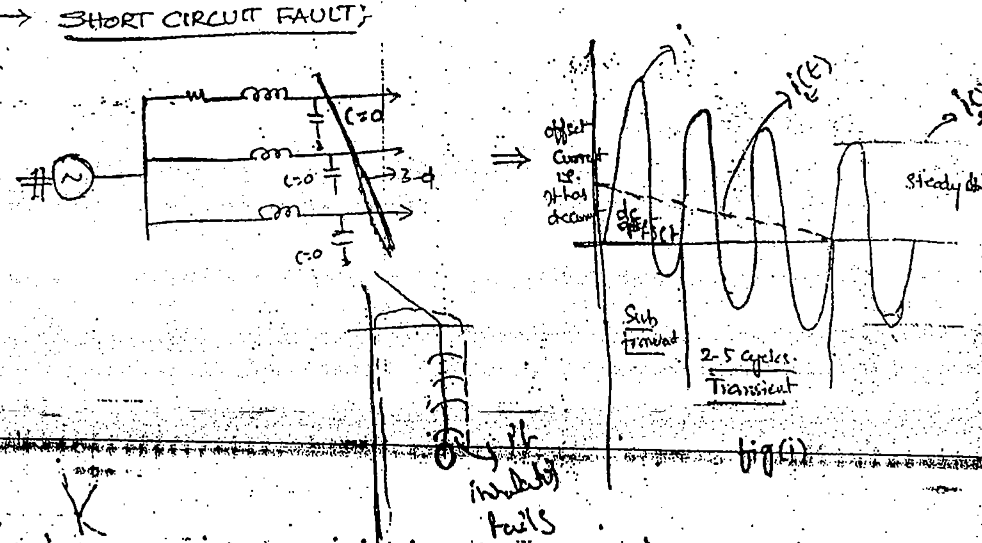
1) Increase in voltage
2) Reduce in currents
3) Slightly increase in frequency of supply
4) Slight improvement in the p.f because of Capacitance domination

$\boxed{V\uparrow \quad I\downarrow \quad p.f\uparrow \quad f\uparrow}$

O.C fault

→ The increase in voltage of phases will increase the field intensity so that there is a possibility of insulation failure because the dielectric strength of insulation may not be sufficient to withstand the field intensity. It is required to calculate the voltages of the phases and they are expressed in peak value because the system is under sub transient (or) transient period

→ SHORT CIRCUIT FAULT;



fig(1)

→ FAULTS

FAULT

Open ckt (or) Series fault

Short ckt (or) Shunt fault.

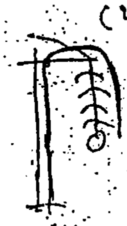
1. Melting of a fuse or conductor in onephase
2. Melting of a fuse or conductor in two phases.

} Unsymmetrical (or) unbalanced.

→ If the conductor will get melt in all the '3' phases then the system is working under no load condition where the no load voltages will be slightly more than rated voltages so that the it will not be treated as fault.

1. The S.C faults does exists due to falling of the tree branches on the wires (or).

(2) failure of the disc insulator in the string (or) failure of the mechanical fittings of the conductor with the string of the insulator.

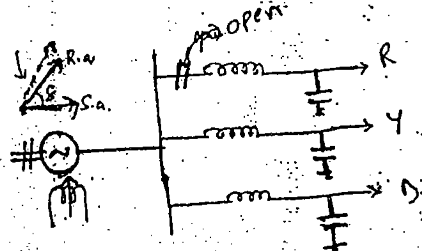


Based on above conditions fault are (1) Line - ground (L-G)

Unsymmetrical
(2) Line - line (L-L)
(3) line - line - ground (L-L-G)

Symmetrical (or) balanced
(4) line - line - line (L-L-L)
(5) line - line - line - ground (L-L-L-G)

→ Open circuit fault:



(Steady state)

$P = P_s - P_e$

$= 0$

$\rightarrow N = N_s$

→ Before fault occurs the tr. line is working in a balanced manner and the electrical quantities in the phasors are expressed in terms of r.m.s values.

→ If one of the phase gets melted then the actual loading on the alternator is reduced where as the mechanical i/p is same which will result as the syn m/c will experience an acceleration so that the actual speed is slightly more than synchronous speed. The over speed of the alternator will result as the over voltages in the phases, where as

→ The advantage of the Symmetrical Components.

1) If the unbalanced electrical quantity is expressed interms of balanced electrical components then the mathematical calculations are simple. Hence the time taking to evaluate the unbalanced electrical quantities is less.

$$I_R = I_{R0} + I_{R1} + I_{R2} \qquad Z_R = Z_{R0} + Z_{R1} + Z_{R2}$$

$$I_Y = I_{Y0} + I_{Y1} + I_{Y2} \qquad Z_Y = Z_{Y0} + Z_{Y1} + Z_{Y2}$$

$$I_B = I_{B0} + I_{B1} + I_{B2} \qquad Z_B = Z_{B0} + Z_{B1} + Z_{B2}$$

NOTE:

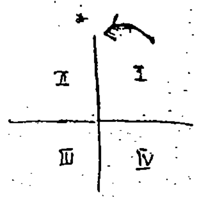
$$\left.\begin{aligned} P_R &= P_{R0} + P_{R1} + P_{R2} \\ P_Y &= P_{Y1} + P_{Y2} + P_{Y3} \\ P_B &= P_{B1} + P_{B2} + P_{B3} \end{aligned}\right\}$$

* Since power is 3-φ, there is no meaning for per phase power. And power never be calculated per phase.

→ The Symmetrical components are balanced components so the Y-phase and B-phase components can be expressed in terms of R-phase by using a suitable notation (vector notation) which is denoted by 'K'.

→ 'K' It is defined as a vector having unity magnitude and 120° phase displacement in an anti clock wise direction.

$$\rightarrow K = 1\angle 120^\circ = -0.5 + j0.8667 \rightarrow (\text{II})$$



$$\rightarrow K^2 = K \cdot K = 1\angle 120^\circ \times 1\angle 120^\circ$$

$$= 1\angle 240^\circ = -0.5 - j0.8667 \; (\text{III})$$

$$\rightarrow K^3 = K \cdot K \cdot K = 1\angle 120^\circ \cdot 1\angle 120^\circ \cdot 1\angle 120^\circ = 1\angle 360^\circ = 1\angle 0 = 1.0 + j0.0$$

$$\boxed{\begin{aligned} &\rightarrow K + K^2 + K^3 = 0 \\ &\rightarrow 1 + K + K^2 = 0 \quad (\because K^3 = 1) \end{aligned}}$$

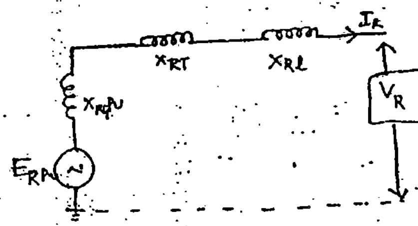
$$K^4 = K^3 \cdot K = K$$

$$K^5 = K^3 \cdot K^2 = K^2$$

(I) → External Unbalance:

→ of the existing system will experience severe unbalance due to the occurance of the fault then the electrical quantities in the phases will get severly unbalanced. The unbalanced load voltages are to be evaluated by having individual phase representation. Hence there are three electrical n/w's which will provide 3 unbalanced voltages.

→ The time taking is high to evaluate those unbalanced voltages.



$$\boxed{V_R = E_R - I_R X_{eq} R}$$

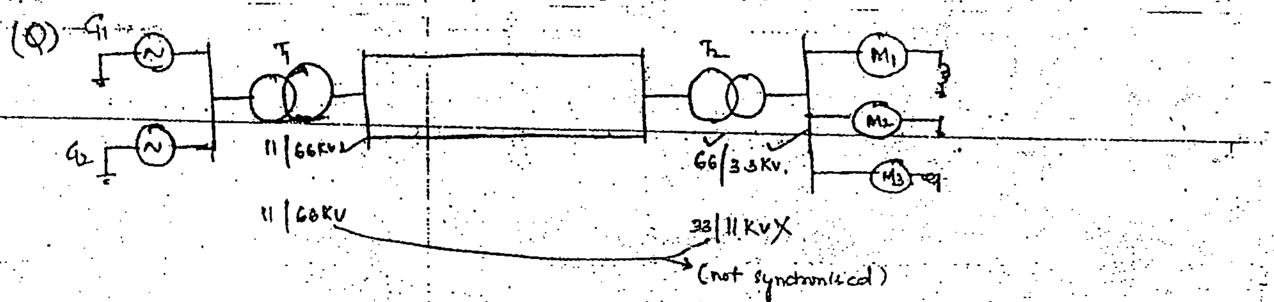
Similarly for Y-phase and B-phase.

→ In order to reduce the time taking while evaluating the unbalanced electrical quantities of the phase it is proposed to express the unbalanced phase electrical quantity by a set of 3-balanced electrical quantities.

— The set of '3' balanced electrical quantities are called as "SYMMERTRICAL QUANTITIES (OR) SYMMETRICAL COMPONENTS" which are namely

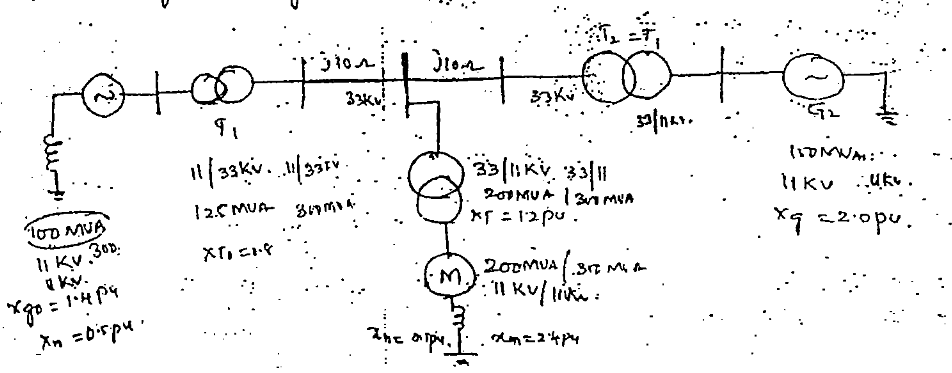
1) Positive Sequence Component — '1'
2) Negative Sequence Component — '2'
3) Zero Sequence Component — '0'

$$3\left\{\begin{aligned} V_R &= V_{R0} + V_{R1} + V_{R2} \\ V_Y &= V_{Y0} + V_{Y1} + V_{Y2} \\ V_B &= V_{B0} + V_{B1} + V_{B2} \end{aligned}\right\} 9 \Rightarrow \text{balanced} \Rightarrow 3\text{-balanced}$$



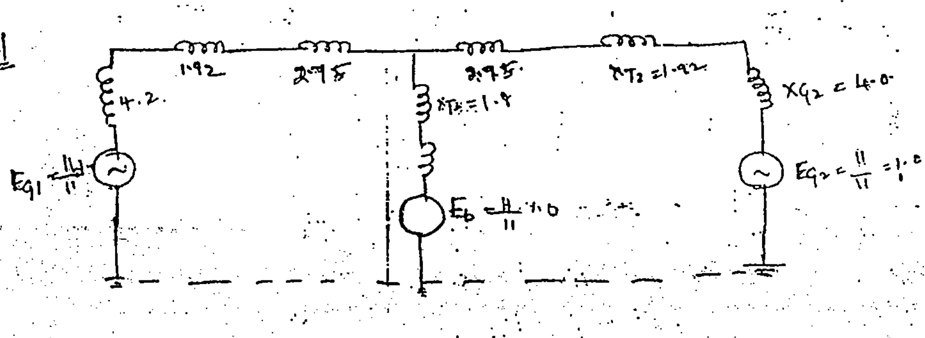
→ For the synchronization purpose it should ensure that the Voltage rating on both sides of the tr. line must be same.

(Q) For the SLD shown below draw the reactance diagram & indicate the p.u values for voltages & reactance.



Choose base as 300MVA, 11KV.

Sol

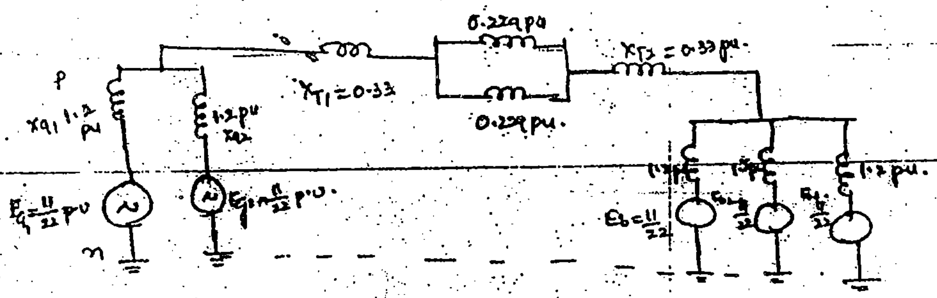


X_{G_1} pu. New $= 1.4 \times \frac{300}{100} (11/11)^2 = 4.2$

X_{T_1} P.U New (p) $= 0.8 \times \frac{300}{125}\left(\frac{11}{11}\right)^2 = 1.92$

X_{T_1} p.u New (Q) $= 0.8 \times \left(\frac{300}{125}\right)\left(\frac{33}{33}\right)^2 = 1.92$

$X_{L_1} = 10 \times \left(\frac{300}{(33)^2}\right) = 2.75$



<u>Given</u>

$X_{G1} = 1.2\,pu,$ $X_{m1} = 1.2\,pu$

$X_{G2} = 2.4\,pu,$ $X_{m2} = 1.8\,pu$

$X_n = 0.5\,pu$ $X_{m3} = 2.4\,pu.$

$T_2 = T_1$ $X_n = 0.5\,pu.$

$X_{T1} = X_{T2} = 1.0$

$X_n = 0.2$

$$X_{G1}(new) = X_{G1}\,old \times \left(\frac{MVA_{new}}{MVA_{old}}\right)\left(\frac{\cancel{KV_{old}}}{\cancel{KV_{new}}}\right)^2$$

$$= 1.2 \times \left(\frac{200}{50}\right)\left(\frac{11}{22}\right)^2$$

$$= 1.2\,pu.$$

$$X_{G2}\,new = 2.4 \times \left(\frac{200}{100}\right)\left(\frac{11}{22}\right)^2$$

$$= 1.2\,pu.$$

$$X_{T1}\,pu(new)_p = 1.0 \times \left(\frac{200}{150}\right)\left(\frac{11}{22}\right)^2 = 0.33$$

$$X_{T1}\,pu(new)_s = 1.0 \times \left(\frac{200}{150}\right)\left(\frac{66}{132}\right)^2 = 0.33\,pu$$

$$X_{pu}(l_1) = X(l_2)\,pu = 20 \times \frac{200}{(132)^2} = 0.229\,pu$$

$$X_{T2}\,pu(new)_p = 1.0 \times \left(\frac{200}{150}\right)\left(\frac{66}{132}\right)^2 = 0.33\,pu$$

$$X_{T2}\,pu(new)_s = 1.0 \times \left(\frac{200}{150}\right)\left(\frac{11}{22}\right)^2 = 0.33\,pu$$

$$X_{m1}(pu)\,new = 1.2 \times \left(\frac{200}{50}\right)\left(\frac{11}{22}\right)^2 = 1.2\,pu$$

$$X_{m2}(pu)\,new = 1.8 \times \left(\frac{200}{75}\right)\left(\frac{11}{22}\right)^2 = 1.2\,pu$$

$$X_{m3}(pu)\,new = 2.4 \times \left(\frac{200}{100}\right)\left(\frac{11}{22}\right)^2 = 1.2\,pu.$$

$$X_{G2}\ pu(new) = 2.0 \times \frac{300}{150}\left(\frac{11}{11}\right)^2 = 4.0.$$

$$\cancel{X_{T2}\ p.u\ (new)_p = 0.8 \times \left(\frac{300}{125}\right)\left(\frac{11}{11}\right)^2 = 1.92}$$

$$X_{T2}\ pu\ (new)_s = 0.8 \times \left(\frac{300}{125}\right)\left(\frac{33}{33}\right)^2 = 1.92.$$

$$X_{l2} = 10 \times \frac{300}{(33)^2} = 2.75$$

$$X_{T3}\ p.u(new)\ p = 1.2 \times \frac{300}{200}\left(\frac{33}{33}\right)^2 = 1.92$$

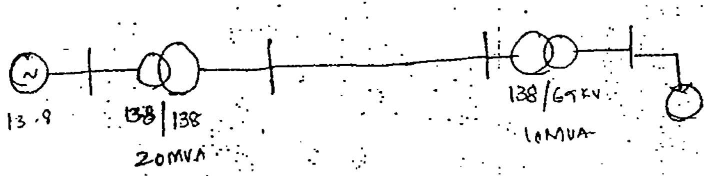
$$X_{T3}\ p.u\ (new)\ (s) = 1.2 \times \frac{300}{200}\left(\frac{11}{11}\right)^2 = 1.92$$

$$X_m\ pu\ (new) = 2.4 \times \frac{300}{200}\left(\frac{11}{11}\right)^2 = 3.6.$$

Gate-06 (2M)

Q) A syn. Generator connected to the transmission line through a step up transf. m having a rating of 13.8/138 KV, 20MVA. At the end of the tr. line the load is connected through a stepdown t/f having a rating of 138/69 KV, 10 MVA. The load reactance of 0.72 pu which is evaluated based on the load side transformer ratings. For a system base of 10MVA (old), 69 KV (old) then the p.u reactance in the generator ckt will be

Sol

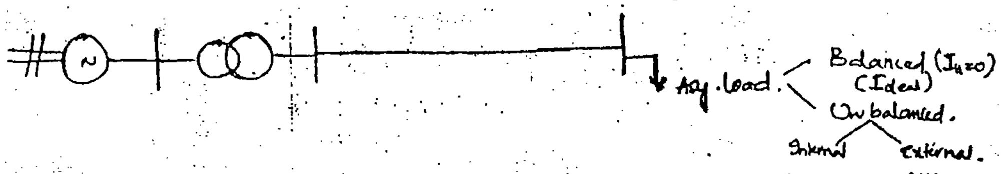


Base of 10MVA, 69 KV.

$$X_{pu}\ new = 0.72 \times \frac{20}{10}\left(\frac{69}{13.8}\right)^2$$

$$= 36.$$

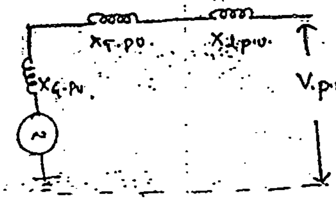
SYMMETRICAL COMPONENTS



→ When the existing system is working in a balanced load condition then the performance of the system can be evaluated by knowing the load voltage at load point for which the per phase reactance diagram along with p.u values, can be recommended.

→ There is only one n/w equation to be solved, so that the time taking will be less.

→ Whenever the load is balanced, neutral is taken as reference (Ideal case)



$$V p.u = E_G\, p.u - I p.u \cdot X p.u$$

$$X_{eq}\, p.u = (X_G + X_T + X_l)\, p.u.$$

→ Unbalanced load
- Internal (less severe) (1-ϕ loads) [$I_n \le 10\%$ Full load current]
- External (more severe) (3ϕ loads) (faults) ($I_n > 10\%$ of Full load current)

→ Even though the system is working with internal unbalance but the load voltages at the load point are with in the allowable regulation so that the perphase reactance diagram is sufficient along with p.u values inorder to evaluate the load voltages.

→ There is only n/w equation to be solved, so that the time taking will be less.

→ ~~Earthing resistance for~~ Sub station $\le 1\,\Omega$
Tr. line $\le 2\,\Omega$
Distribution $\le 5\,\Omega$

(Q) Alternator rated as 11 KV, 100 MVA, $X = 8\Omega$, what is the p.u reactance ~~for the rating of~~ 150 MVA, 13.2 KV.

Sol

$$X_{p.u} = X_{\Omega} \times \left(\frac{MVA}{(KV)^2}\right)$$

$$= 8 \times \left(\frac{150}{(13.2)^2}\right)$$

$$= 6.88\ p.u$$

(or)

$$X_{pu} = 8 \times \frac{100}{(11)^2}$$

$$= \frac{800}{121}$$

$$= 6.61 \rightarrow \text{old.}$$

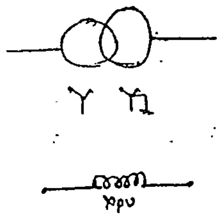
$$X_{p.u_{new}} = 6.61 \times \left(\frac{150}{100}\right)\left(\frac{11}{13.2}\right)^2$$

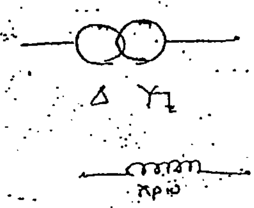
$$= 6.61 \times 1.5 \times 0.69$$

$$= 6.84\ p.u.$$

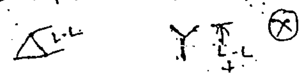
— x —

→

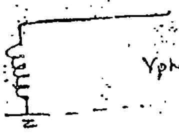




→ 3 − φ   3 − φ



but 1 − φ Y equivalent

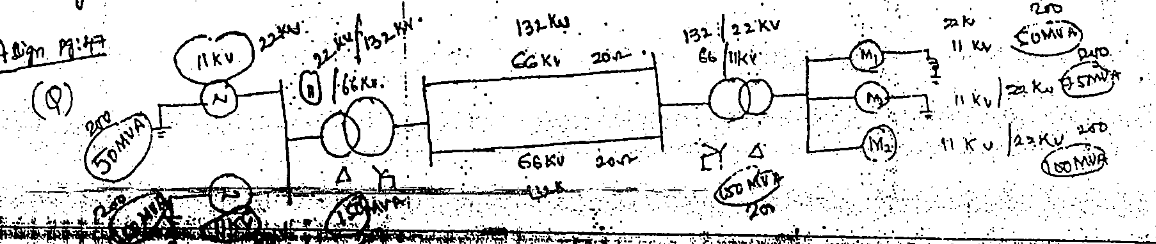


$$V_{phase} = \frac{V_{L-L}}{\sqrt{3}} \simeq V_{L-L}$$

Expl: The p.u Reactance of both sides of t/f will be same if it can be assumed as the phase voltage of the single phase Y equivalent will be same as V_{LL} of the original Δ-connected system.

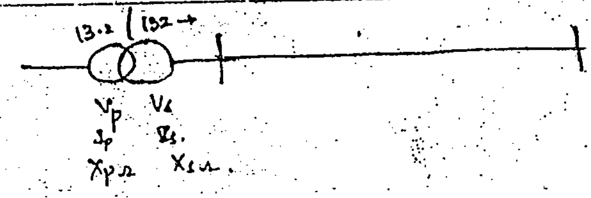
7 sign pg: 47

(Q)



Choose a base of 22 KV, 200 MVA, Draw the reactance diagram an indicate p.u values.

The p.u reactance of the transformer on both sides will be same:



$$X_{p \cdot pu} = \frac{X_{p\Omega}}{X_b}$$

While calculating the primary reactance in p.u consider, the primary ratings of the transformer as the base values.

$$X_{p \cdot pu} = \frac{X_{p\Omega}}{X_b} = \frac{X_{p\Omega}}{\frac{V_p}{I_p}} = X_{p\Omega} \cdot \frac{I_p}{V_p} = \frac{X_{s\Omega}}{K^2} \cdot \frac{I_p}{V_p}$$

$$= \frac{X_{s\Omega}}{\frac{V_s^2}{V_p^2}} \cdot \frac{I_p}{V_p} \qquad \left(\because K = \frac{V_s}{V_p}\right)$$

$$= X_{s\Omega} \cdot \frac{V_p^2}{V_s^2} \cdot \frac{I_p}{V_p}$$

$$= X_{s\Omega} \cdot \frac{V_p I_p}{V_s^2}$$

$$= X_{s\Omega} \cdot \frac{V_s I_s}{V_s^2} \qquad \left(\because \text{The product of } V \cdot I \text{ on either side of a t/f is same}\right)$$

$$= X_{s\Omega} \cdot \frac{I_s}{V_s}$$

$$= \frac{X_{s\Omega}}{\frac{V_s}{I_s}}$$

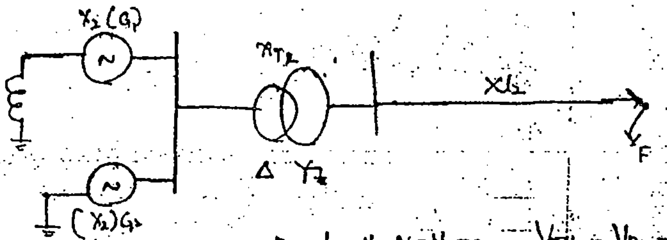
$$= \frac{X_{s\Omega}}{X_b} = X_{s \cdot PU}$$

→ In case of t/f, the base voltage of the system changes where as the capacity of the t/f is same on both sides.

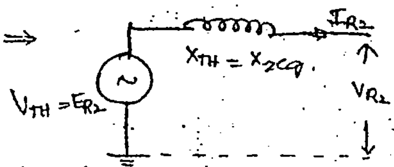
→ The t/line rating can be assumed as the transformer capacity and also the line side voltage of the transformer.

$$X_{1eq} = \left[X_d''(G) + (X_1)_{T_1}\right] \parallel \left[X_{l_1} + (X_1)_{T_2} + X_d''(M)\right]$$

→ <u>Negative Sequence Networks</u>

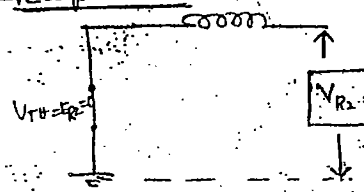
→ 

prefault voltage $V_{TH} = V_{R_2} = E_{R_2} = 0$.

⇒ 

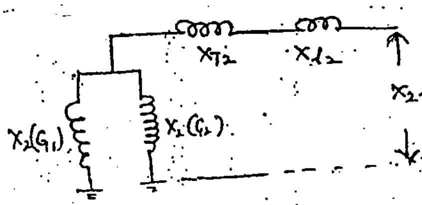
$V_{R_2} = E_{R_2} - I_{R_2} X_{2eq}$

-ve sequence n/w

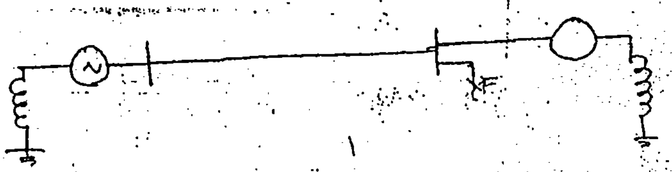
⇒ 

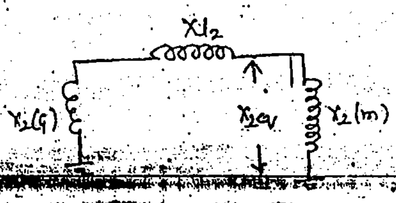
$\boxed{V_{R_2} = -I_{R_2} X_{2eq}}$ → -ve Sequence n/w terminal Voltage.

Use the Simulation diagram to calculate X_{2eq}.

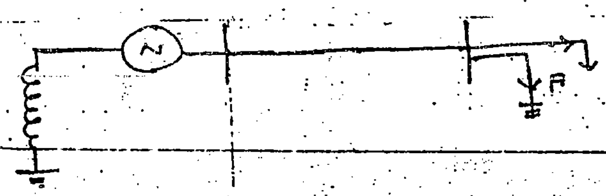


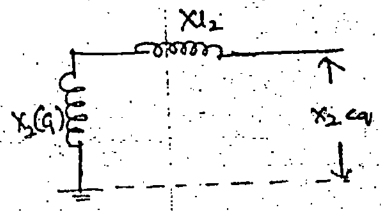
$X_{2eq} = (X_2(G_1) \parallel X_{G_2}) + (X_{T_2} + X_{l_2})$

→ 

⇒ 

$X_{2eq} = (X_2(G) + X_{l_2}) \parallel (X_m)$

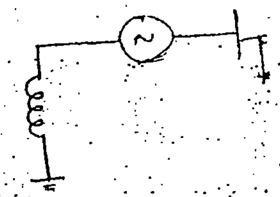




$X_{2eq} = X_2(G) + Xl_2$

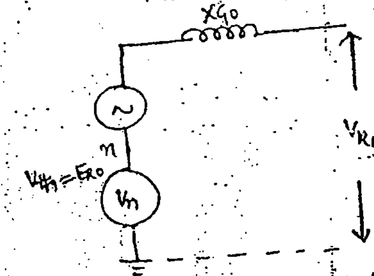
→ The –ve sequence n/w is similar to that of +ve sequence n/w except there is no prefault voltage.

→ <u>Zero Sequence Network</u>: While drawing the zero sequence n/w include the neutral grounding effect because the reference is to ground.



prefault voltage.

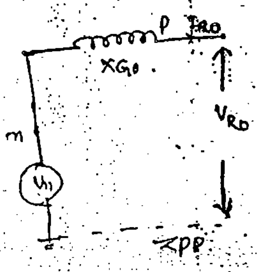
$V_{TH} = V_{R0} = E_{R0} = 0$



$V_{R0} = E_{R0} + V_n - I_{R0} X_{G0}$

zero potential plane (zpp)

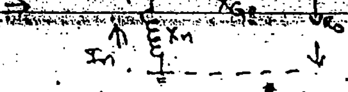
⟹



$V_{R0} = V_n - I_{R0} X_{G0}$

zpp

⟹

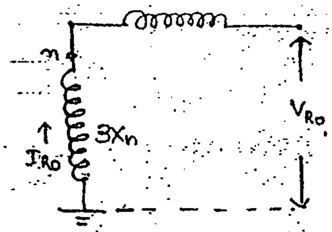


$V_{R0} = I_n X_n - I_{R0} X_{G0}$

$~~I_n~~ = -3I_{R0}$	$I_n = 3I_{R0}$
$V_n = -V_c$	$V_n = +V_c$ × (possible only under identical balance condition)

∴ Under fault condition. $I_n = -3I_{R0}$

$$\therefore V_{R0} = -3I_{R0}X_n - I_{R0}X_{G0}$$



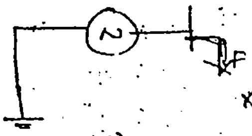
$$V_{R0} = -3I_{R0}X_n - I_{R0}X_{G0}$$
$$= -I_{R0}(3X_n + X_{G0})$$
$$= -I_{R0}(X_{0eq})$$

To ensure the current through the series is same i.e. I_{R0}

$$X_{0eq} = X_{G0} + 3X_n.$$

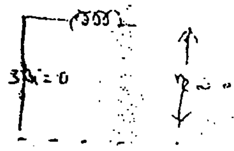
$$V_{R0} = -I_{R0} \cdot X_{0eq} \quad \text{(Zero sequence n/w terminal Voltage)}$$

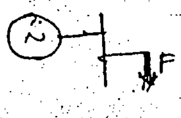
$$\rightarrow \begin{bmatrix} V_{R0} \\ V_{R1} \\ V_{R2} \end{bmatrix} = \begin{bmatrix} 0 \\ E_{R1} \\ 0 \end{bmatrix} - \begin{bmatrix} X_{0eq} & 0 & 0 \\ 0 & X_{1eq} & 0 \\ 0 & 0 & X_{2eq} \end{bmatrix} \begin{bmatrix} I_{R0} \\ I_{R1} \\ I_{R2} \end{bmatrix}$$

→ 

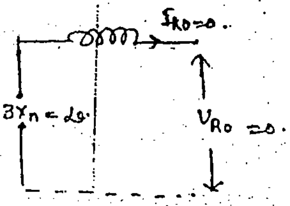
(Solid grounded)

$$X_{0eq} = X_{G0} + 3X_n$$
$$= X_{G0} + 0 = X_{G0}$$



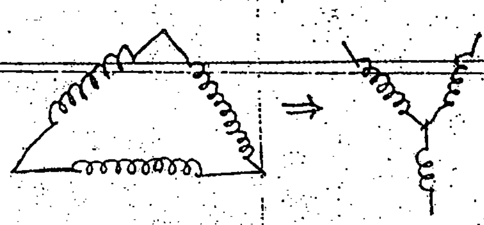
→ 

(Isolated Neutral)

⇒ 

$$X_{0eq} = X_{G0} + \infty = \infty$$

→ If the Alternator is Delta Connected

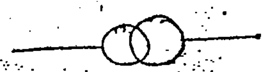


+ve and −ve Sequence Components

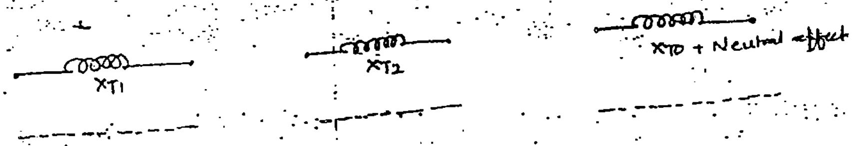
Zero sequence Component will not be there.

17/02/2010

→ ZERO SEQUENCE NETWORKS OF TRANSFORMER:



→ absolute



→ To include the neutral effect represent the t/f as a mechanical equivalent i.e. series parallel switches

→ If the winding is Y - on either side → Open operate Series switch.

→ If the winding is Δ - operate the parallel switch

→ There is Y - Isolated neutral — there is no closed path - then

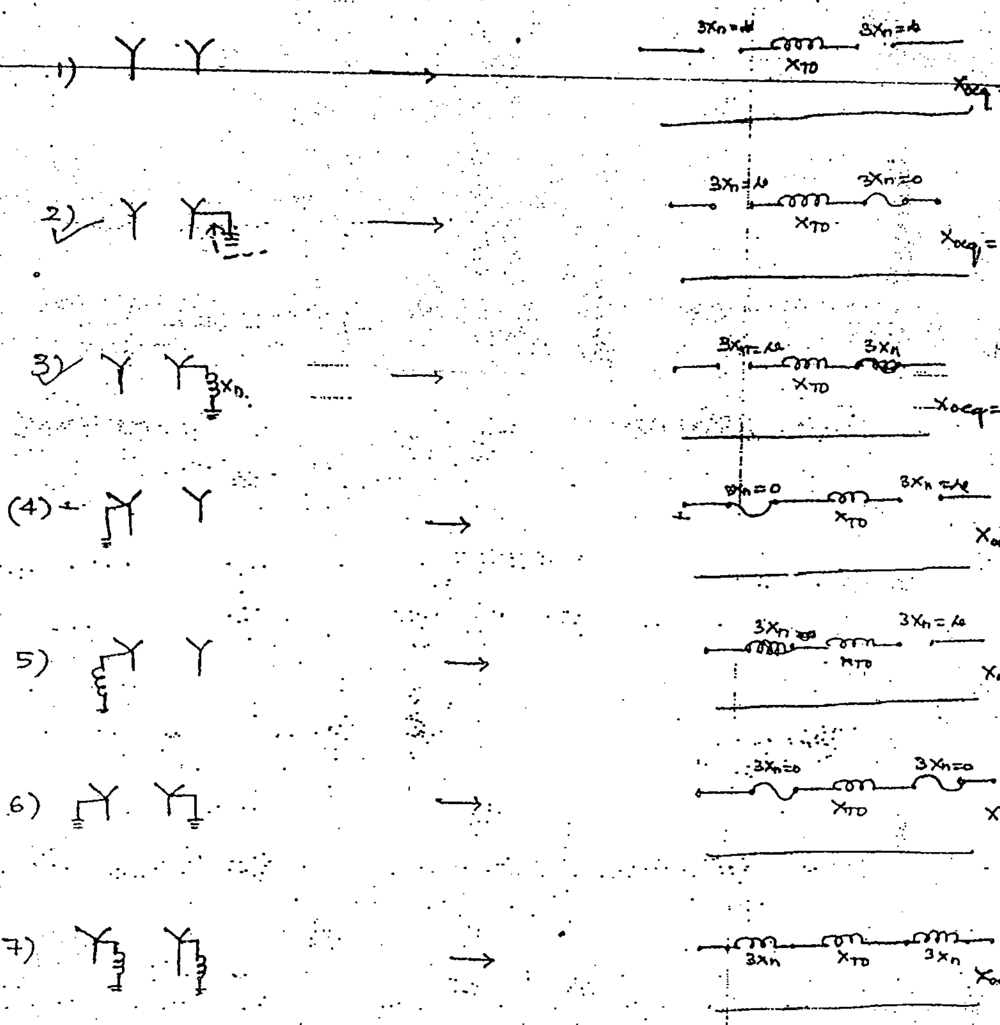
✓ open the switch ($3X_n = \infty$)

→ Y Solid neutral → Close the switch ($3X_n = 0$)

→ Y → Reactance neutral → Close the switch ($3X_n$)

→ Δ → Closed winding → Close the parallel switch ($3X_n = \infty$)

Y/Y Connection — Zero sequence n/w



1) $X_{0eq} = X_{T0} + \infty = \infty$

2) $X_{0eq} = X_{T0} + 0 = X_{T0}$

3) $X_{0eq} = X_{T0} + 3X_n$

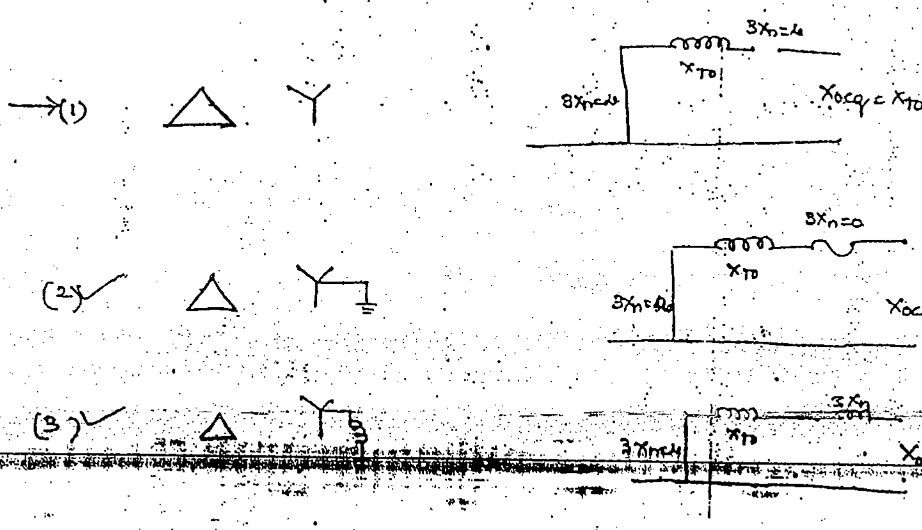
(4) $X_{0eq} = X_{T0} + 0 = X_{T0}$

5) $X_{0eq} = X_{T0} + 3X_n$

6) $X_{0eq} = X_{T0} + 0 = X_{T0}$

7) $X_{0eq} = X_{T0} + 3X_n$ (primary & secondary are same)

(2) & (6) are practical cases.

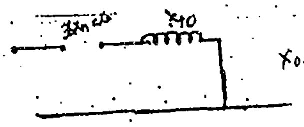


(1) $X_{0eq} = X_{T0} + \infty = \infty$

(2) $X_{0eq} = X_{T0} + 0 = X_{T0}$

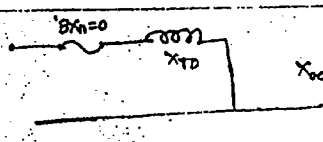
(3) $X_{0eq} = X_{T0} + 3X_n$

(4) Y − Δ



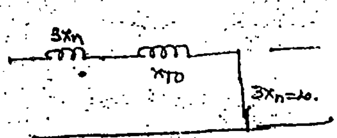
$X_{0eq} = X_{T0} + \infty + \infty$

5) Y − Δ



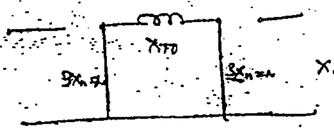
$X_{0eq} = X_{T0}$

6) Y − Δ



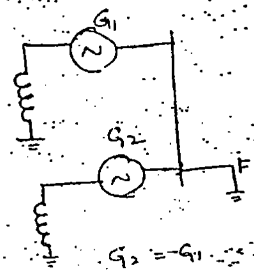
$X_{0eq} = X_{T0} + 3X_n$

7) Δ − Δ



$X_{0eq} = X_{T0} + \infty$

(Q)



$G_2 = G_1$

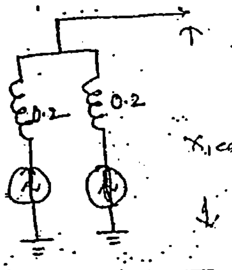
$X_d'' = 0.2$

$X_2 = 0.2$

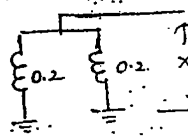
$X_{g0} = 0.1$

$X_n = 0.05$

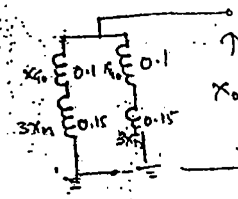
<u>Sol</u>



$X_{1eq} = 0.1$

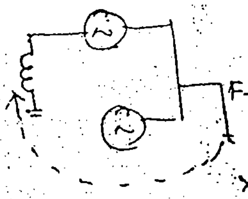


$X_{2eq} = 0.1$



$$X_{0eq} = \frac{0.25 \times 0.25}{0.5} = 0.215$$

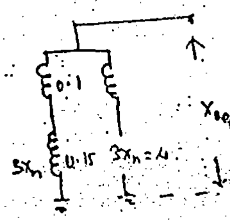
(Q)



$X_{1eq} = 0.1$

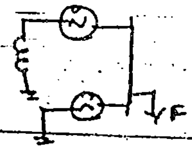
$X_{2eq} = 0.1$

$X_{0eq} = 0.25$

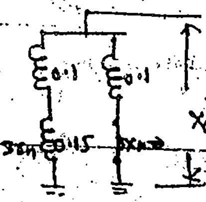


$X_{0eq} = 0.25$

(3)

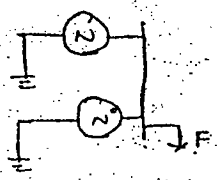


$\Rightarrow$

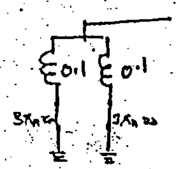


$$X_{0eq} = \frac{0.25 \times 0.1}{0.35}$$

(4)

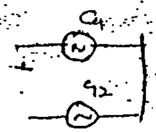


$\Rightarrow$

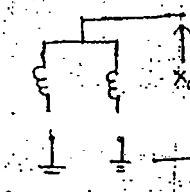


$$X_{eq} = \frac{0.1 \times 0.1}{0.2} = 0.05$$

(5)

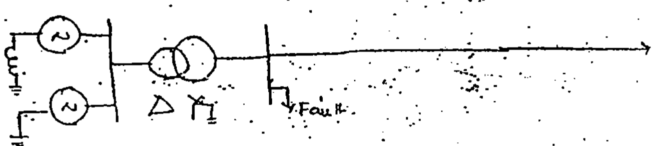


$\Rightarrow$



$$X_{0eq} = \infty$$

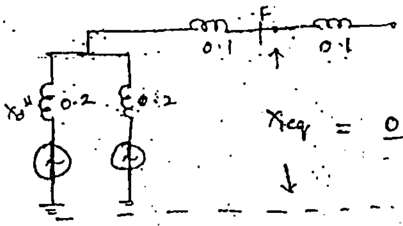
(φ)



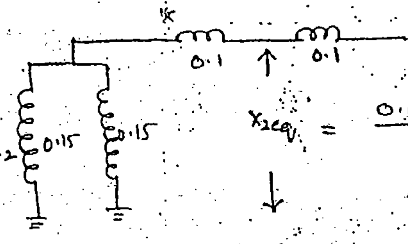
$G_2 = G_1$, $X_d'' = 0.2$, $X_2 = 0.15$, $X_{g0} = 0.08$, $X_n = 0.05$

$X_{T1} = X_{T2} = X_{T0} = 0.1$, $X_{L1} = X_{L2} = 0.1$

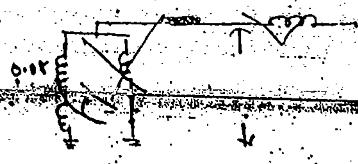
$X_{L0} = 0.3$.



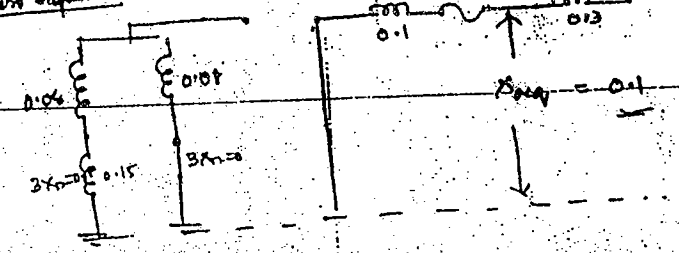
$$X_{eq} = \frac{0.2 \times 0.2}{0.4} + 0.1 = 0.2.$$



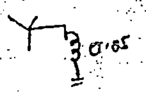
$$X_{2eq} = \frac{0.15 \times 0.15}{0.3} + 0.1 = 0.175$$



Zero Sequence



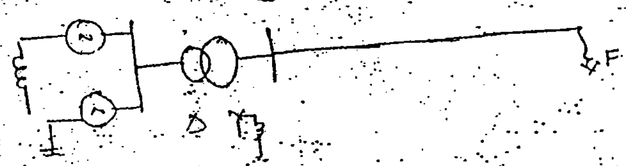
$X_{0eq} = 0.1$

If 

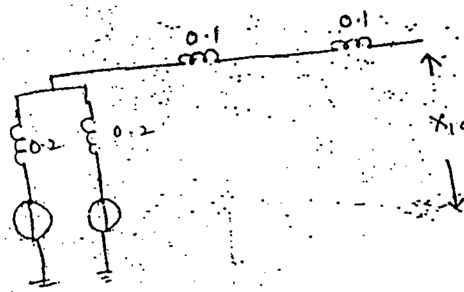
$\Rightarrow$ $3X_n = 0.15$ in above calc.

$\therefore X_{0eq} = 0.1 + 0.15 = 0.25$.

(Q)

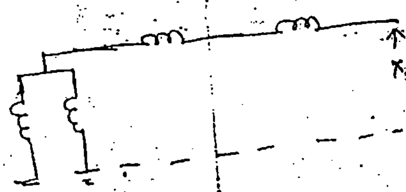


+ve seq



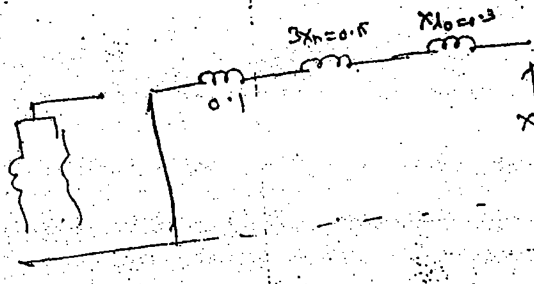
$X_{1eq} = \frac{0.2 \times 0.2}{0.4} + 0.1 + 0.1 = 0.3$

−ve seq



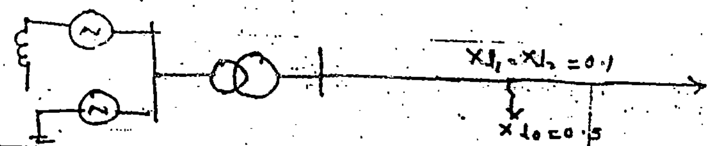
$X_{2eq} = 0.275$

Zero seq

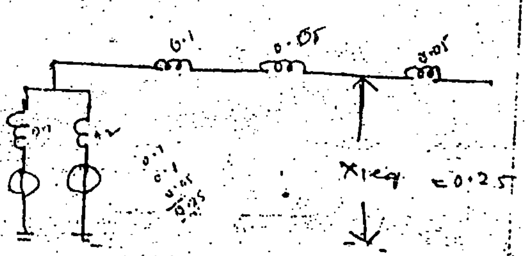


$X_{0eq} = 0.55$

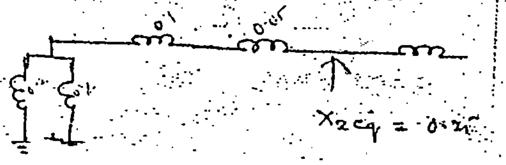
(Q)



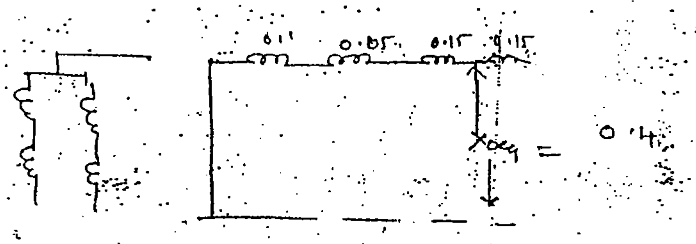
+ve eq



-ve

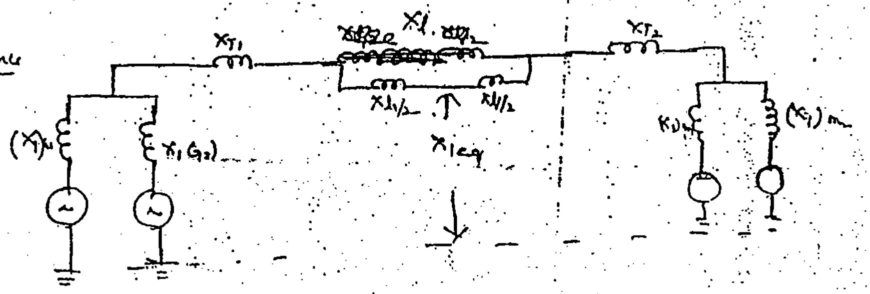


Zero

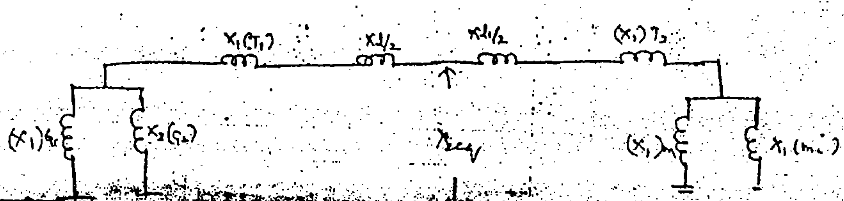


(Q)

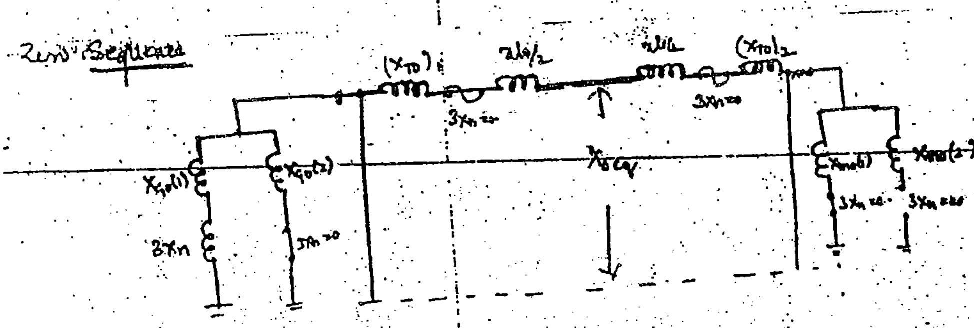
+ve sequence



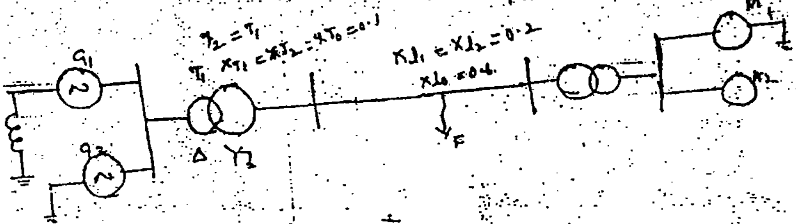
- ve sequence



Zero Sequence



(Q)



$M_2 = M_1$

$X_d'' = 0.2$

$X_2 = 0.2$

$X_{m0} = 0.1$

$G_2 = G_1$

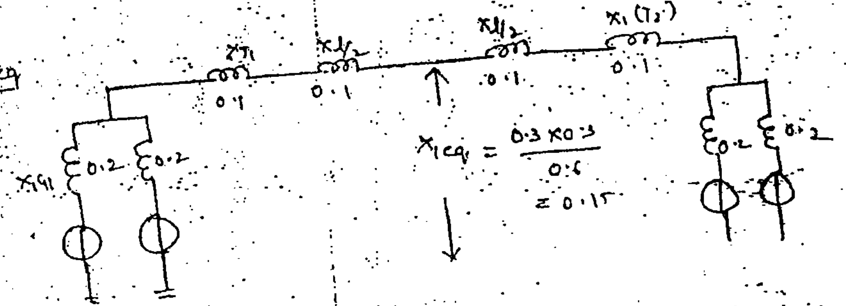
$X_d'' = 0.2$

$X_2 = 0.2$

$X_{G0} = 0.1$

$X_n = 0.05$

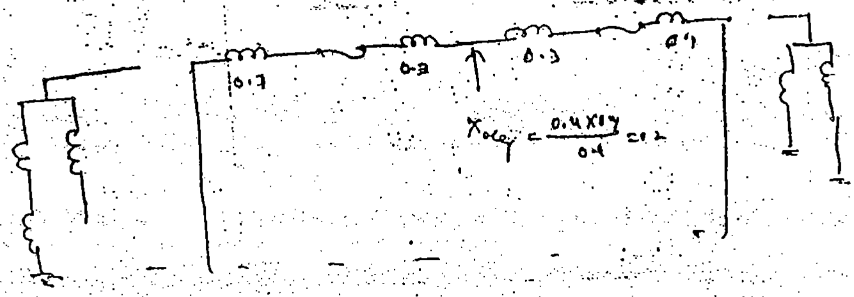
+ve seq



$$X_{1eq} = \frac{0.3 \times 0.3}{0.6} = 0.15$$

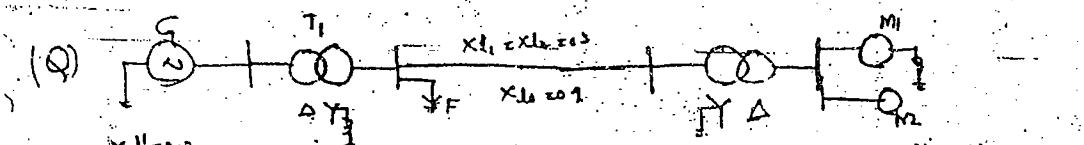
-ve seq $X_{2eq} = 0.15$

Zero seq



$$X_{0eq} = \frac{0.4 \times 0.4}{0.4} = 0.2$$

(Q)



$X_d'' = 0.2$ $\quad$ $T_2 = T_1$ $\quad$ $M_1 = M_2 = G$

$X_2 = 0.15$ $\quad$ $X_{T_1} = X_{T_2} = X_{T0} = 0.10$ $\quad$ $X_d' = 0.2$

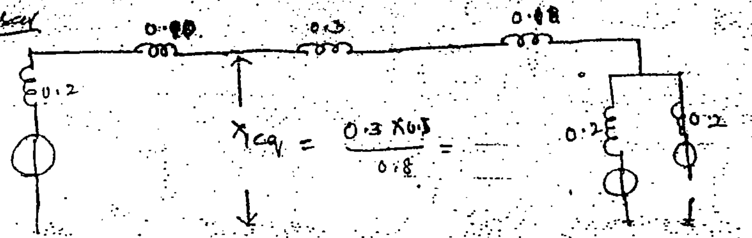
$X_{G0} = 0.08$ $\quad$ $X_n = 0.05$ $\quad$ $X_2 = 0.15$

$X_{m0} = 0.08$

$X_n = 0.05$

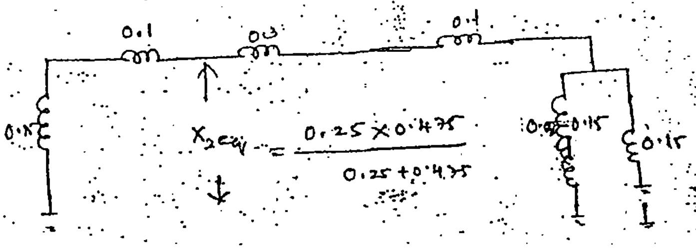
Sol.

+ve seq



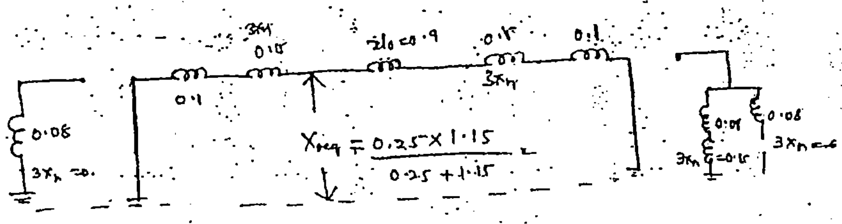
$$X_{1eq} = \frac{0.3 \times 0.5}{0.8} =$$

-ve seq



$$X_{2eq} = \frac{0.25 \times 0.475}{0.25 + 0.475}$$

Zero seq



$$X_{0eq} = \frac{0.25 \times 1.15}{0.25 + 1.15} =$$

→ RELATIONS AMONG THE SEQUENCE REACTANCES

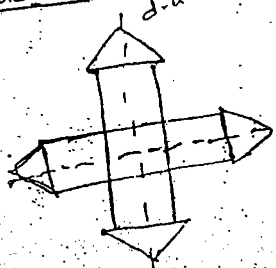
	+Ve Sequence Sub-T (1st cycle)	-Ve Sequence Sub-T	Zero Sequence Sub-T
1) Turbo gen	X_d''	$X_2 = X_d''$ (uniform airgap flux)	$X_{G0} < X_d''$ (Leakage reactance)
2) Salient pole	X_d''	$X_2 < X_d''$ (Non-uniform airgap flux)	$X_{G0} < X_d''$ (Leakage reactance)
3) Transfmr	X_{T1}	$X_{T2} = X_{T1}$	$X_{T0} = X_{T1}$
4) Tr. line	X_{l1}	$X_{l2} = X_{l1}$	* $\boxed{X_{l0} = 3X_{l}}$

→ X_d'' (Turbo) > X_d'' (Salient)

$I_{sc}\downarrow$ $\quad$ $I_{sc}\uparrow$

→ The t/f and tr. line are the static devices and they are made up of by bilateral elements so that the conductivity will be same in both the directions hence the negative sequence reactances are equal to +ve sequence reactance.

→ Salient pole Machine:



Non-uniform air gap

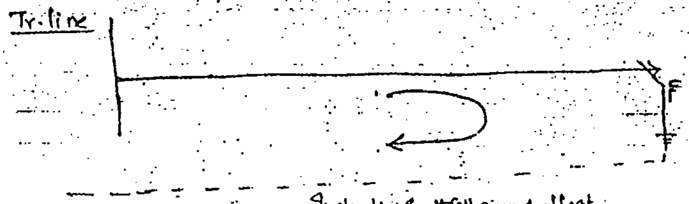
$$X_2 = \frac{X_d'' + X_q''}{2} < X_d''$$

→ In case of salient pole machine the currents that are induced due to negative sequence component flux in the stator wdg will be maxima in the direct axis ~~& quadrature axis~~ alternatively

— Hence the -ve sequence reactance is the average reactance of both the axes. $X_2 = \frac{X_d'' + X_q''}{2} < X_d''$

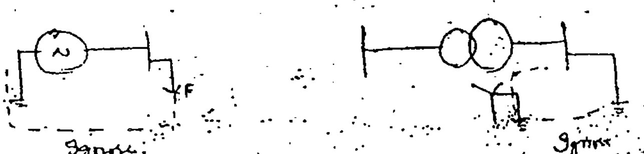
→ In case of turbo alternator there are no quadrature axis hence

$$X_2 = X_d''$$

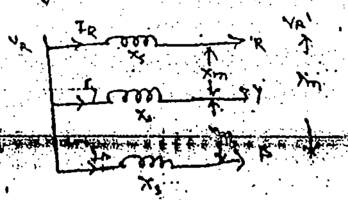
→ 

$\underbrace{2.5X_{L1} - 3.5X_{L1}}$

$X_{L0} = 3X_{L1}$



* Imp → The zero sequence components exists if the fault is associated with the ground. The fault current is expected to flow from the fault point through the ground and enters into the system from neutral grounding In case of tr.line include the earth effect while calculating the zero sequence reactance offerred and incase of alternator as well as t/f ignore the earth effect. The impedance (or) Reactance offerred by the earth will change from time to time due to dissimilar soils through out the length and different moisture levels. Hence the total zero sequence reactance to the tr.line is a variable value due to inclusion of the earth and it can varies $2.5X_1$ to $3.5X_1$. The average of this is "$3X_1$" ***

→  ⇒

$$\boxed{\begin{aligned} X_{1eq} &= X_s - X_m \\ X_{2eq} &= X_s - X_m \\ X_{0eq} &= X_s + 2X_m \end{aligned}}$$

(or)

$Z_{1eq} = Z_s - Z_m$

$Z_{2eq} = Z_s - Z_m$

$Z_{0eq} = Z_s + 2Z_m$

(b) Before fault

$$V_R = V_R' + I_R X_s + I_Y X_m + I_B X_m.$$

$$= V_R' + I_R X_s + K^2 I_R X_m + K I_R X_m$$

$$= V_R' + I_R X_s + I_R X_m (K^2 + K)$$

$$= V_R' + I_R X_s + I_R X_m (-1)$$

$$V_R = V_R' + I_R (X_s - X_m) \quad (\text{Steady state})$$

If fault occurs:

$$V_R \leftarrow V_{R0}, V_{R1}, V_{R2} \qquad V_R' \leftarrow V_{R1}', V_{R2}', V_{R0}'$$

$$I_R \leftarrow I_{R1}, I_{R2}, I_{R0} \qquad I_Y \leftarrow I_{Y1}, I_{Y2}, I_{Y0} \qquad I_B \leftarrow I_{B1}, I_{B2}, I_{B0}.$$

$$V_{R1} = V_{R1}' + I_{R1} X_s + I_{Y1} X_m + I_{B1} X_m$$

$$= V_{R1}' + I_{R1} X_s + K^2 I_{R1} X_m + K I_{R1} X_m.$$

$$= V_{R1}' + I_{R1} X_s + I_{R1} X_m (K^2 + K)$$

$$= V_{R1}' + I_{R1} X_s + I_{R1} X_m (-1)$$

$$= V_R' + I_{R1} \underbrace{(X_s - X_m)}_{X_{1eq}}.$$

$$V_{R2} = V_{R2}' + I_{R2} X_s + I_{Y2} X_m + I_{B2} X_m$$

$$= V_{R2}' + I_{R2} X_s + K^2 I_{R2} X_m + K I_{R2} X_m.$$

$$= V_{R2}' + I_{R2} X_s + I_{R2} X_m (K^2 + K)$$

$$= V_{R2}' + I_{R2} X_s + I_{R2} X_m (-1)$$

$$= V_{R2}' + I_{R2} \underbrace{(X_s - X_m)}_{X_{2eq}}$$

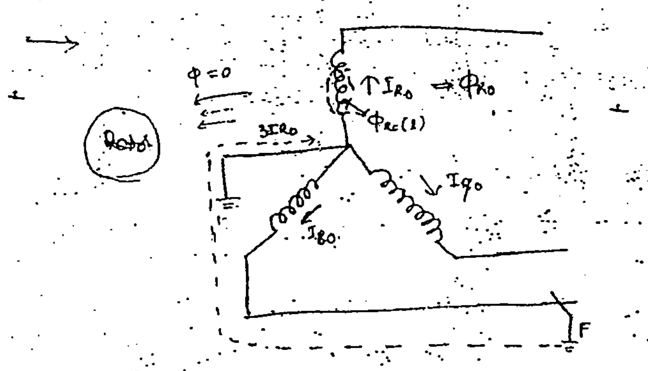
$$V_{R_0} = V_{R_0}' + I_{R_0}X_s + I_{Y_0}X_m + I_{B_0}X_m$$

$$= V_{R_0}' + I_{R_0}X_s + I_{R_0}X_m + I_{R_0}X_m$$

$$= V_{R_0}' + I_{R_0}\underbrace{(X_s + 2X_m)}_{X_{0eq}}$$

→ In case of transformer, $X_{T0} = X_{T1}$ (Zero X = +ve X) because it is a static device and also there is no ground effect. ~~hence~~

→



Expl → The field produced by the zero sequence component is having zero phase displacement w.r.t ground and 120° phase displacement in the space i.e. air gap. So the net zero sequence flux which can be linked with rotor wdg will be zero and there is no effect of zero sequence component on the rotor provided that if the stator wdg is a symmetrical wdg. (i.e completely distributed or full length wdg) However the alternator designed with unsymmetrical wdg i.e. short pitch wdg.

In case of unsymmetrical wdg there will be certain leakage flux out of the total zero sequence flux produced and the reactance offered to the leakage flux is treated as zero sequence flux which is less than the +ve sequence reactance.

18/2/2010

FAULT ANALYSIS

1) In any type of S.C faults the +ve sequence subtransient current exists

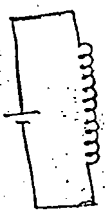
2) If the fault is associated with ground then it will be treated as unbalanced fault. The fault current will be expressed in terms of zero sequence currents however there should be a relation b/w the zero sequence current and the +ve sequence current.

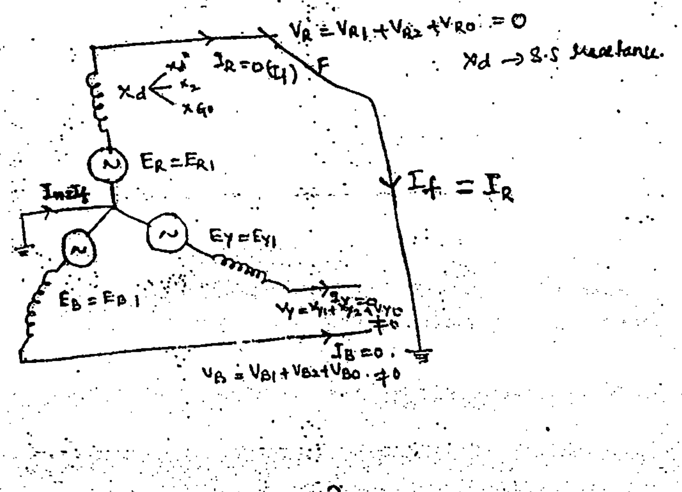
3) If the fault is not associated with ground but unbalance then the fault current will be expressed in terms of -ve sequence current. There should be a relation b/w negative sequence current and also the +ve sequence current.

4) If the fault is not associated with ground but a balanced fault then the fault current is same as +ve sequence current.

1) Line to Ground fault (L-G): Consider
* Alternator working at no load, rated voltage
and solid fault (phase to ground without reactor,
Solid neutral ⇒ I_f is high,

($X_f = 0$)





During fault

$I_f = I_R$ } unbalanced condition

$V_R = 0$; $I_Y = I_B = 0$

Using the symmetrical components

$$I_{R0} = \frac{1}{3}\left[I_{R} + I_Y + I_B\right] = I_R/3$$

$$I_{R1} = \frac{1}{3}\left[I_{R} + KI_Y + K^2 I_B\right] = I_R/3$$

$$I_{R2} = \frac{1}{3}\left[I_{R} + K^2 I_Y + K I_B\right] = I_R/3$$

$$\therefore \boxed{I_{R0} = I_{R1} = I_{R2} = \frac{I_R}{3}}$$

** i.e. In L-G fault all the sequence currents are same

$$\therefore I_R = I_f = 3I_{R0} = 3I_{R1} \text{ p.u (r.m.s)}$$

Actual fault current, $\boxed{I_{f \cdot pu} = \frac{I_f\,(\text{actual})}{I\,(\text{base})}}$

$$\therefore \boxed{I_f\,(\text{actual}) = I_f\,(\text{p.u}) \cdot I_{base}} \text{ A (or) KA}$$

In a 3-φ system

$$S = \sqrt{3}\, V_L I_L$$

$$I_L = \frac{S}{\sqrt{3} V_L}, \quad \text{For Y-system} \quad I_{phase} = I_L = \frac{S}{\sqrt{3} V_L} = I_{base}$$

→ Calculation of I_{R1}:

$$V_R = V_{R1} + V_{R2} + V_{R0} = 0$$

$$= E_{R1} - I_{R1} X_{1eq} - I_{R2} X_{2eq} - I_{R0} X_{0eq} = 0$$

$$E_{R1} = \cancel{E_{R0}} - I_{R1}(X_{1eq} + X_{2eq} + X_{0eq}) = 0$$

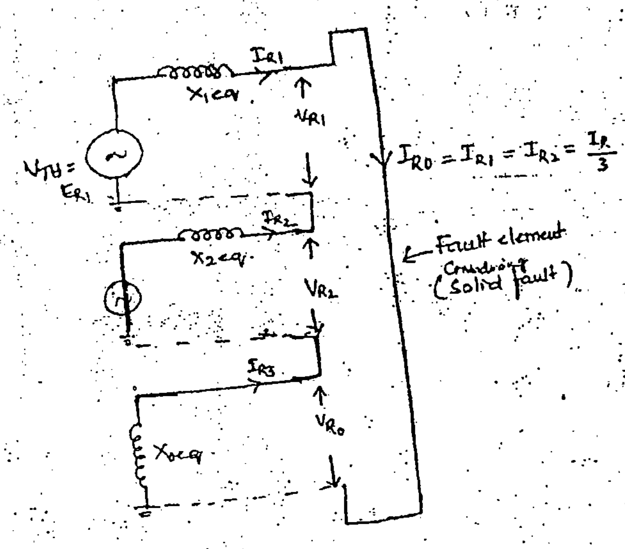
$$\boxed{I_{R1} = \frac{E_{R1}}{X_{1eq} + X_{2eq} + X_{0eq}}} \text{ p.u}$$

$$\boxed{I_f = \frac{3 \cdot E_{R1}}{X_{1eq} + X_{2eq} + X_{0eq}}} \text{ p.u.}$$

Where

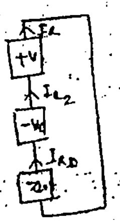
$X_{1eq} = X_1''$, $X_{2eq} = X_2$ [illegible], $X_{0eq} = X_{g0}$

* If the fault is associated with the ground so that the three sequence components are exists. The associated sequence n/w are connected in series because the ~~sequence currents are same.~~



* The thevenin equivalent have to be closed by the fault element.

(Q)



→ fault associated is L-G fault.

⇒ Potential of the Neutral during fault:

$$V_n = I_n X_n$$

$$= I_f X_n$$

$$= 3 I_{R0} X_n \quad (\text{i.e. } I_{R0} \cdot 3X_n)$$

1) $V_n = 0$ (If it is solid neutral) since $3X_n = 0$)

2) $V_n = 3 I_{R0} X_n$ (Reactance neutral

$$\boxed{V_n(\text{actual}) = V_n \text{ p.u} \times V_{base}}$$

⇒ Calculation of S.C MVA of the fault:

$$X_{p.u} = X_{\Omega} \frac{I_b}{V_b}$$

In fault condition

$$X_d'' \, p.u = X_d''\Omega \, \frac{I_b}{V_b}$$

$$X_d'' \, p.u = \frac{I_b}{\frac{V_b}{(X_d''\Omega)}} = \frac{I_b}{I_{sc}} \rightarrow \text{s.c. current.}$$

$(X_d''\Omega) \rightarrow$ s.c reactance in Ohm.

(Q) The Alternator is having p.u (or) s.c reactance = 0.2, what is s.c current

$$I_{sc} = \frac{I_b}{X_d''\Omega} = \frac{1.0}{0.2} = 5 \, p.u.$$

(A) ~~If the~~

$$X_d'' \, pu = \frac{I_b}{I_{sc}} \times \frac{3V_b}{3V_b} = \frac{\text{Base MVA}}{\text{S.C MVA}}$$

$$\Rightarrow \boxed{\text{S.C MVA} = \frac{\text{Base MVA}}{X_d'' \, p.u.}} \; P$$

∴ For L-G fault,

$$\boxed{\text{S.C. MVA} = \frac{\text{Base MVA}}{X_{1eq} + X_{2eq} + X_{0eq}}} \; p.u.$$

⇒ If the neutral is grounded with a reactance of "X_n" then,

$$X_{1eq} = X_d''$$

$$X_{2eq} = X_2$$

$$X_{0eq} = X_{G0} + 3X_n.$$

$$\therefore \boxed{I_f = \frac{3 \cdot E_{R1}}{X_{1eq} + X_{2eq} + X_{G0} + 3X_n}}$$

If the neutral is isolated, then

$$X_{1eq} = X_d'', \quad X_{2eq} = X_{2eq}, \quad X_{0eq} = X_{G0} + \infty = \infty$$

$$\boxed{\frac{3 \, E_{R1}}{X_{1eq} + X_{2eq} + \infty}} = 0 \; p.u.$$

$X_{1eq} + X_{2eq}$ X_{G0} $3X_n = \infty$ $X_{G0} + \infty = \infty \; (X_{0eq})$.

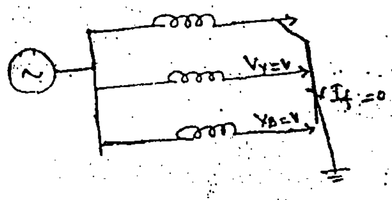
→ If the alternator is Connected to long tr.lines with isolated neutral then the fault current is ZERO. However the voltages in the healthy phases will become "$\sqrt{3}$" times of the rated voltage which is Known as "arching Grounds" = ($\sqrt{3} \times V_{rated}$). The result of the arching grounds will make the failure of insulation of healthy phase called "FLASH OVER OF INSULATION".

→ If the alternator is connected to S.line then there are no arching grounds becoz the voltages of healthy phases is same as that of rated voltages.

→ In a practical case the alternators are normally connected with long lines and it requires to eliminate the arching grounds. In order to eliminate the arching grounds the neutral of the alternator is Connected to the ground through a COIL and the type of grounding is called Resonant grounding. The value of Inductance of the coil,

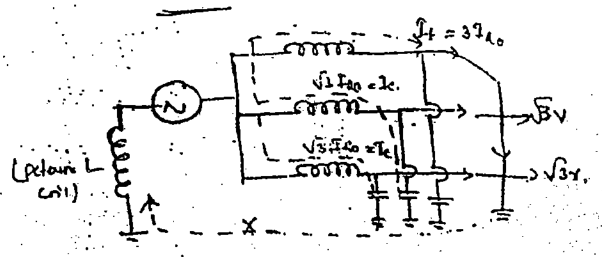
$$\boxed{L = \frac{1}{3\omega^2 C}}$$ (peterson coil)

STL



No. Shunt Capacitance.

LTL



Shunt capacitance effect.

∴ Hence Shunt capacitance is responsible for "arching grounds"

Hence the shunt capacitance effect is nullified by connecting a

Peterson coil as shown in fig (blackpu) and the charging currents are compensated.

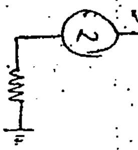
$$I_n = 3 I_{R0}$$

$$\frac{\cancel{V}}{X_L} = 3\frac{\cancel{V}}{X_C}$$

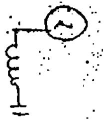
$$\frac{1}{\omega L} = 3 \times \frac{1}{1/\omega C}$$

$$\Rightarrow \boxed{L = \frac{1}{3\omega^2 C}}$$

→ Generally alternator are connected with resistance grounding in all practical cases for the purpose of stability.

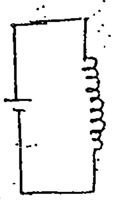


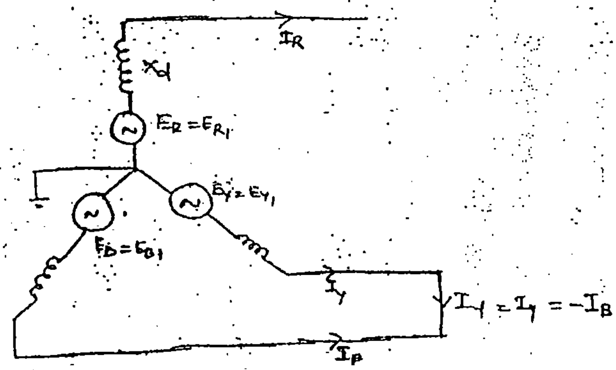
$Z_{oeq} = 3R_n + jX_{G0}$ (or)



$X_{oeq} = X_{G0} + 3X_n$

(2) Line to Line Fault (L-L fault): Consider alternator with no load, rated voltage Solid neutral & Solid fault.





During fault

$$\left.\begin{array}{l} I_f = I_Y = -I_B \\ I_R = 0, \quad I_Y + I_B = 0 \\ V_Y = V_B \end{array}\right\} \text{Unbalance Condition.}$$

Resolving by using Symmetrical Components

$$I_{R0} = \frac{1}{3}\left[I_{R} + I_{Y} + I_{B}\right] = 0$$

$$I_{R1} = \frac{1}{3}\left[I_R + K I_Y + K^2 I_B\right] = \frac{I_Y}{3}\left[K - K^2\right]$$

$$I_{R2} = \frac{1}{3}\left[I_R + K^2 I_Y + K I_B\right] = \frac{I_Y}{3}\left[K^2 - K\right]$$

$$\Rightarrow \boxed{I_{R2} = -\frac{I_Y}{3}\left[K - K^2\right] = -I_{R1}} \longrightarrow (1)$$

$$V_Y = V_B$$

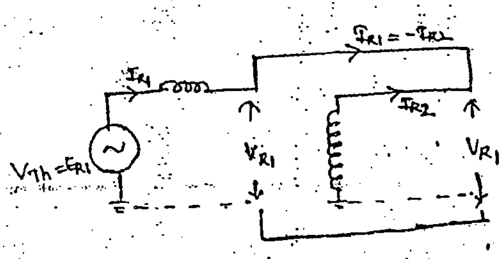
$$\cancel{V_{Y0}} + V_{Y1} + V_{Y2} = \cancel{V_{B0}} + V_{B1} + V_{B2}$$

$$K^2 V_{R1} + K V_{R2} = K V_{R1} + K^2 V_{R2}$$

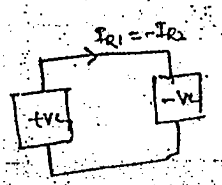
$$(K^2 - \cancel{K}) V_{R1} = (K^2 \cancel{-K}) V_{R2}$$

$$\boxed{V_{R1} = V_{R2}} \longrightarrow (2)$$

The fault is not associated with ground but un balance. So it Consisting of +ve and −ve sequence Components; the associated sequence n/w are connected in anti parallel according to eq (1) & (2)



Ex:



Form eq (2)

$$V_{R1} = V_{R2}$$

$$E_{R1} - I_{R1} X_{1eq} = -I_{R2} X_{2eq}$$

$$E_{R1} = I_{R1} X_{1eq} + I_{R1} X_{2eq}$$

$$\boxed{I_{R1} = \frac{E_{R1}}{X_{1eq} + X_{2eq}}}$$ p.u. → +ve sequence Sub-T current.

$$I_f = I_Y = I_{Y0} + I_{Y1} + I_{Y2}$$

$$= 0 + K^2 I_{R1} + K I_{R2}$$

$$I_f = I_Y = (K^2 - K) I_{R1}$$

$$I_f = I_Y = [(-0.5 - j\,0.8667) - (-0.5 + j\,0.8667)]\, I_{R1}$$

$$I_f = I_Y = -j\,1.732\, I_{R1} = j\,1.732\, I_{R2}$$

$$\therefore \boxed{I_f = \sqrt{3}\, I_{R1}}$$ (if −ve sign is neglected)

→ In case of L-G fault the unbalanced line current is 3-times the balanced phase current where as in L-L fault the unbalanced line current is $\sqrt{3}$ times the balanced phase current

$$\boxed{I_{f\,actual} = I_{f\,p.u} \times I_{base}}$$ A or KA.

$$\boxed{S.C.\ MVA = \frac{Base\ MVA}{X_{1eq} + X_{2eq}}}$$

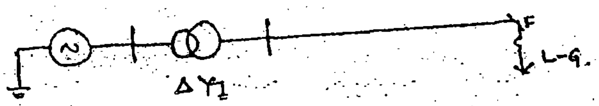
→ potential of the Neutral during fault

$$\boxed{V_n = I_n X_n = 0}$$ → For Solid-neutral & also reactance neut

[illegible] there will be zero sequence currents hence the potential of the neutral will be ZERO even in case of Reactance Neutral.

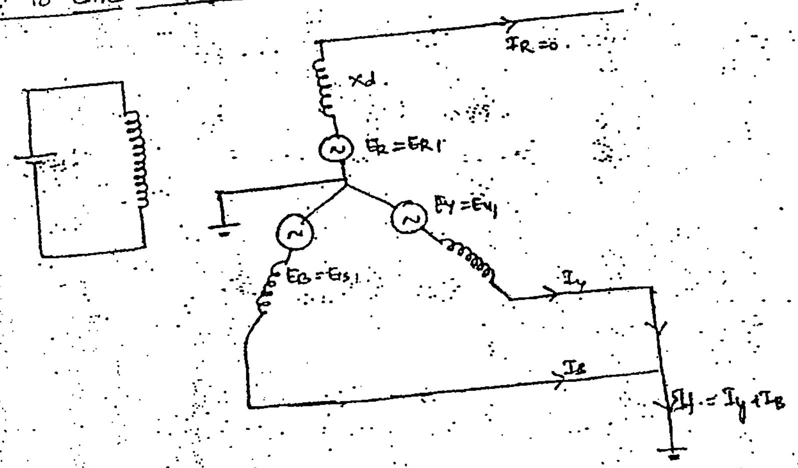
→ In case of Reactance neutral (or) Isolated Neutral, the fault current remain's same because the +ve sequence and -ve sequence n/w's doesn't depends on neutral grounding.

(repeated) (Q) imp



Ans: If the line-ground fault is referred towards the alternator side of the transformer then it will be treated as L-L fault.

3) Line to Line to Ground Fault:



During fault

$I_f = I_Y + I_B$
$I_R = 0$
$V_Y = V_B = 0$
} Unbalanced.

$I_R = I_{R0} + I_{R1} + I_{R2} = 0$

$I_{R0} = -I_{R1} - I_{R2}$

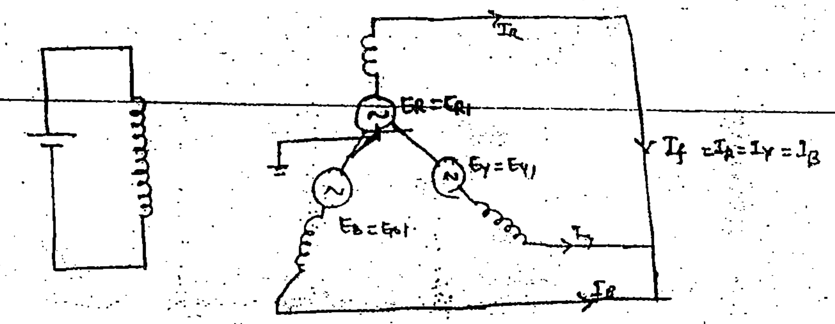
Resolving by using symmetrical components

$$V_{R0} = \frac{1}{3}\left[V_R + V_Y + V_B\right] = \frac{V_R}{3}$$

$$V_{R1} = \frac{1}{3}\left[V_R + KV_Y + K^2V_B\right] = V_R/3$$

$$V_{R2} = \frac{1}{3}\left[V_R + K^2V_Y + KV_B\right] = \frac{V_R}{3}$$

→ Line to Line to Line Fault – (Balanced Fault) Symmetrical Fault :



During Fault:

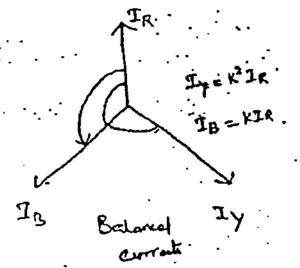
$$\left.\begin{aligned} \text{Fault Current } I_f &= I_R = I_Y = I_B \\ \text{But } I_R + I_Y + I_B &= 0 \\ V_R = V_Y &= V_B \end{aligned}\right\} \text{Balanced Fault.}$$

Resolving By using Symmetrical components

$$I_{R0} = \frac{1}{3}\left[I_R + I_Y + I_B\right] = 0.$$

$$I_{R1} = \frac{1}{3}\left[I_R + K(\overset{K^2 I_R}{I_Y}) + K^2(\overset{K I_R}{I_B})\right] = I_R.$$

$$I_{R2} = \frac{1}{3}\left[I_R + (K^2(\overset{K^2 I_R}{I_Y}) + K(\overset{K I_R}{I_B})\right] = 0.$$



$$I_{R2} = \frac{1}{3}\left[I_R + K^2 K^2 I_R + K \cdot K I_R\right] = 0$$

$$= \frac{1}{3}\left[I_R + K^3 \cdot K I_R + K^2 I_R\right] = 0.$$

$$= \frac{1}{3} I_R\left[1 + K^2 + K\right] = 0$$

$\Rightarrow I_{R2} = 0$

$\Rightarrow \boxed{I_f = I_R = I_{R1}}$ p.u.

$I_{R0} = 0, \quad V_{R0} = 0$

$I_{R2} = 0 \quad V_{R2} = 0.$

$$V_{R1} = \frac{1}{3}\left[V_R + K V_Y + K^2 V_B\right]$$

$$= \frac{V_R}{3}\left[1 + K + K^2\right]$$

$$= 0$$

$\Rightarrow \boxed{V_{R1} = 0}$

$\rightarrow$ In a 3-ϕ S.C Fault the +ve sequence n/w terminal Voltage is ZERO i.e. $V_{R1} = 0$

$$\therefore \quad E_{R1} - I_{R1} X_{1eq} = 0$$

$$\boxed{I_{R1} = \frac{E_{R1}}{X_{1eq}}} \; p.u \longrightarrow \text{+ve Sequence Sub transient Current}$$

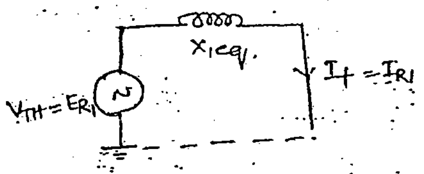
$$\therefore \boxed{I_f = I_{R1} = \frac{E_{R1}}{X_{1eq}} \; p.u}$$

$$\boxed{I_f (\text{actual}) = I_f \, p.u \cdot I_{base}}$$

$$S.C \; MVA = \frac{\text{Base MVA}}{X_{1eq}}$$

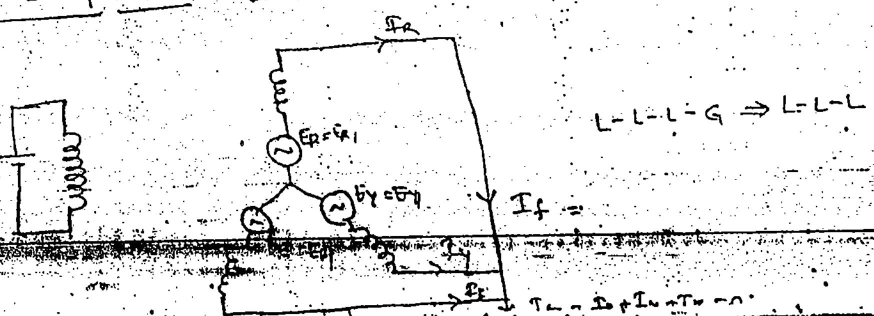
potential of the Neutral during fault

$$V_n = I_n X_n = 0 \quad (\text{for Solid and Reactance neutral grounding})$$



$\rightarrow$ In case of Isolated Neutral (or) Reactance neutral then the fault Current remains same because the +ve sequence n/w doesnot depends on neutral grounding

$\rightarrow$ L-L-L-G Fault: (3-ϕ to Ground Fault)



$$\boxed{V_{R0} = V_{R1} = V_{R2} = V_R/3} \longrightarrow (1)$$

The fault is associated with the ground so that all the ~~seque~~ three sequence components exists.

$$I_f = I_Y + I_B = I_{Y0} + I_{Y1} + I_{Y2} + I_{B0} + I_{B1} + I_{B2}$$

$$I_f = I_{R0} + K^2 I_{R1} + K I_{R2} + I_{R0} + K I_{R1} + K^2 I_{R2}$$

$$= 2 I_{R0} + (K^2 + K) I_{R1} + I_{R2} (K^2 + K)$$

$$I_f = 2 I_{R0} - I_{R1} - I_{R2}$$

$$\boxed{I_f = 2I_{R0} + I_{R0} = 3I_{R0}} \text{ p.u} \qquad (\because I_{R0} = -I_{R1} - I_{R2})$$

→ Calculation of I_{R1}

$$I_{R0} + I_{R1} + I_{R2} = 0$$

Replace I_{R0} and I_{R2} in terms of I_{R1}

$$V_{R0} = V_{R1}$$

$$-I_{R0} X_{0eq} = E_{R1} - I_{R1} X_{1eq}$$

$$I_{R0} = -\left[\frac{E_{R1} - I_{R1} X_{1eq}}{X_{0eq}}\right]$$

$$V_{R1} = V_{R2}$$

$$E_{R1} - I_{R1} X_{1eq} = -I_{R2} X_{2eq}.$$

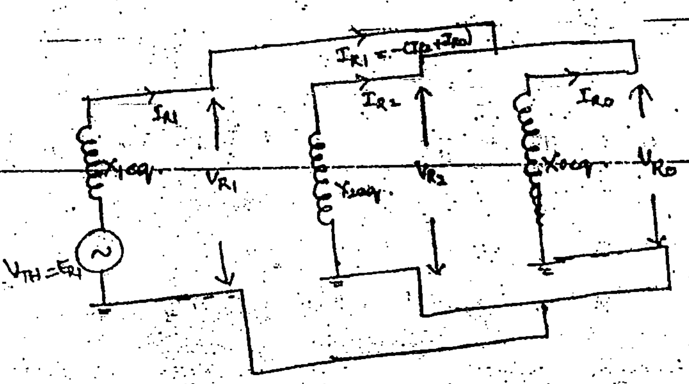
$$I_{R2} = -\left[\frac{E_{R1} - I_{R1} X_{1eq}}{X_{2eq}}\right]$$

$$I_{R0} + I_{R1} + I_{R2} = 0$$

$$\boxed{I_{R1} = \frac{E_{R1}}{X_{1eq} + \dfrac{X_{2eq} X_{0eq}}{X_{2eq} + X_{0eq}}}} \rightarrow (2)$$

+ve sequence sub-transient current.

From eq's (1) and (2) it can be observed that the parallel combination of -ve sequence and zero sequence n/w are connected in series with +ve sequence n/w.



$I_f = 3 I_{R0}$ p.u.

$$I_{R0} = -I_{R1} \frac{X_{2eq}}{X_{2eq}+X_{0eq}}$$

$$\boxed{SC\ MVA = \frac{Base\ MVA}{X_{1eq} + \frac{X_{2eq} X_{0eq}}{X_{2eq}+X_{0eq}}}}$$

→ potential of the neutral during the fault :

$V_n = I_n X_n = 0$ → Solid neutral grounding

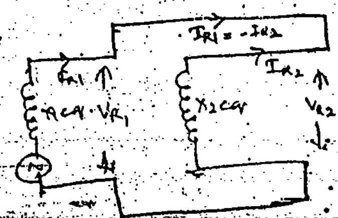
$= I_n X_n$ p.u → Reactance neutral grounding

** ⟹ Whenever there is Reactance Neutral

$$\boxed{X_{0eq} = X_{G0} + 3X_n}$$

** ⟹ Whenever there is Isolated Neutral

$$\boxed{X_{0eq} = X_{G0} + \infty = \infty}$$ $(\because 3X_n = \infty)$



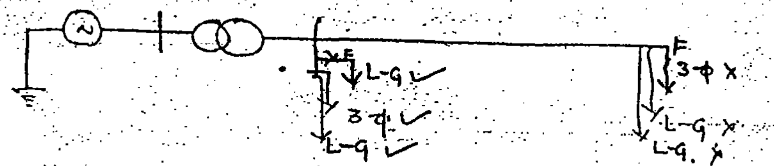
L-L-G ⟹ L-L

(No zero sequence component exists)

A L-L-L-G fault can be resolved as L-L-L fault.

$$\therefore I_{R1} = \frac{E_{R1}}{X_{1eq}}$$

(Q)



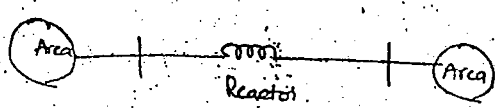
Here L-G fault is only considered. Since L-G is near to Source compared to 3-φ fault.

* Hence 3-φ fault is treated as fault in the system.

* Here only L-G fault near to the source is considered.

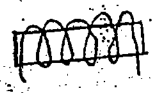
→ We know that the sub-transient reactance offered is very low so that the sub transient currents are high which will also increase the breaking of the circuit breaker so, that the rating of the C.B is high. The rating of C.B is choosen by considering a 3-φ s.c fault on the existing system. In order to reduce the SCMVA of the breaker it is proposed to have a Series REACTOR in the existing system. So that the net reactance offered will increase which will reduce the Sub-transient current as well as the SC-MVA of the breaker.

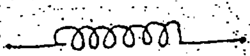
→ Another application of Reactor is



⟹ REACTORS

(1) Construction:

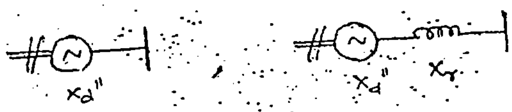
(1) Iron core  (Saturation problem) X

(2) Air core  ✓

Air core reactors are more preferred than that of Iron core becoz the Iron core reactor is having a core saturation problem.

(2) Application

(1). Generator Reactor / Alternator reactor



$$S.C\ MVA = \frac{Base\ MVA}{X_d''} \quad , \quad SC \cdot MVA = \frac{Base\ MVA}{X_d'' + X_{r_1}}$$

** → The Modern Turbo alternators doesnot require any series reactor because it has inherently high reactance i.e. 2.0 pu

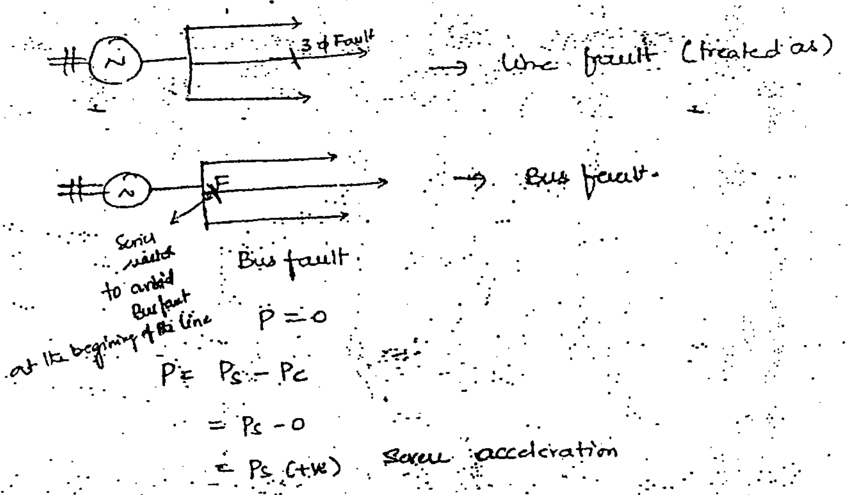
$$\rightarrow SCR = SC\ MVA = \frac{Base\ MVA}{X\,pu}$$

$$= \frac{1.0}{2.0} = \frac{1}{2} = 0.5\ pu.$$

→ The salient pole generators and also the small capacity turbo alternators require the series reactors.

(2) Feeder Reactor:

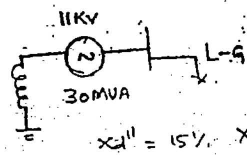
— The p.u. reactance of the feeder w.r.t its own rating is very less however w.r.t generator capacity it is very high. hence there is no need of series reactors to feeders. Some times the fault may taken place near to bus bar in the line and it is considered as Bus-Fault so there is a possibility to loss the synchronism by the syn. machine.



→ In order to prevent the stability problem a series reactor is proposed having a small reactance and it is preffered to place at the beginning of the tr. line

19/02/10

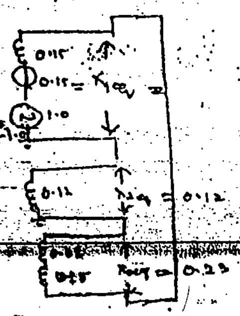
→ FAULTS (ASSIGNMENT)



(01) L-G, prefault voltage $= \frac{11}{11} = 1.0$

$x_d'' = 15\%$, $x_2 = 12\%$, $x_{g0} = 8\%$, $x_n = 5\%$ (a) I_f (p.u), I_f (kA)

V_n (p.u), V_n (kV) ?



$$I_f = I_R = \frac{3E_{R1}}{X_{1eq} + X_{2eq} + X_{0eq}}$$

$$= \frac{3 \times 1.0}{0.15 + 0.12 + 0.23}$$

$= 6.0$ pu. at 60° lag.

$$I_f(a) = 6.0 \times \frac{30}{\sqrt{3} \times 11} \text{ KA} \quad \left(\frac{MVA}{KV}\right)$$

$$V_n = I_n \cdot X_n$$

$$= I_f \cdot X_n$$

$$V_n = 6.0 \times 0.05 = \underline{0.3 \text{ pu}}$$

$$V_n = \underline{0.3 \times \frac{11}{\sqrt{3}}} \text{ KV}$$

$$\text{S.C. MVA} = \frac{30}{0.15+0.12+0.23}$$

0.15
0.12
0.23
0.50

$$= \frac{30}{0.5} = 60 \text{ MVA}$$

→ +ve sequence S-T current $I_{R1} = \frac{I_f}{3} = \frac{6.0}{3} = 2.0$ p.u. $\left(\frac{E_{R1}}{}\right.$

→ voltages of the phase during the fault

$$V_R = V_{R1} + V_{R2} + V_{R0}$$

$$V_{R1} = E_{R1} - I_{R1} X_{eq}$$

$$= 1.0 - 2\angle{-90} \times 0.15 \angle 90^\circ$$

$$= 1.0 - 2.0 \times 0.15$$

$$= \underline{0.7 \angle 0}$$

$$V_{R2} = -I_{R2} X_{2eq}$$

$$= -2\angle{-90} \times 0.12\angle 90 = \underline{-0.24\angle 0}$$

$$V_{R0} = -I_{R0} X_{0eq}$$

$$= -2\angle{-90^\circ} \times 0.23\angle 90^\circ = -0.46\angle 0$$

$$\therefore V_R = V_{R1} + V_{R2} + V_{R0}$$

$$= 0.7\angle 0 + -0.24\angle 0 - 0.46\angle 0^\circ$$

$$= \underline{0}$$

$V_Y = V_{Y0} + V_{Y1} + V_{Y2}$

$= V_{R0} + K^2 V_{R1} + K V_{R2}$

$= -0.46\angle 0 + 0.7\angle 240° + 0.24\angle 120°$

$= -0.46 + 0.7\cos 240 + j0.7\sin 240 - 0.24\cos 120° - j0.24\sin(120°)$

$= -0.69 - j0.814$

$= 1.06\angle -130°$

$V_B = V_{B0} + V_{B1} + V_{B2}$

$= V_{R0} + KV_{R1} + K^2 V_{R2}$

$= -0.46\angle 0 + 0.7\cos(120) + j0.7\sin 120 - 0.24\cos 240° - j0.24\sin 240°$

$= -0.69 + j0.398$

$= 0.796\angle 150$

(10) 3-ϕ 500 MVA, 50 Hz, V = 22 kV, $x_1 = x_2 = 0.15$, $x_0 = 0.05$

Find: Sub-transient current for 1-ϕ to ground fault in p.u.

$$I_{R1} = I_f = \frac{3 E_{R1}}{X_{1eq} + X_{2eq} + X_{0eq}}$$

$$= \frac{3 \times 1.0}{0.15 + 0.15 + 0.05}$$

$$= \frac{3}{0.035} = 8.571 \text{ p.u}$$

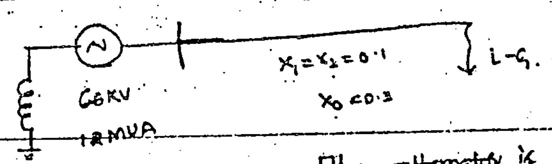
$$I_f(KA) = 8.57 \times \left(\frac{500}{\sqrt{3} \times 22}\right)$$

$$= 112.45 \text{ KA.}$$

Neutral Solid grounded, $V_n = 0$.

$$S.C \text{ MVA} = \frac{500}{0.15 + 0.15 + 0.05} = \frac{500}{0.35} = 1428.5 \text{ p.u.}$$

(Q)



$X_d'' = 0.12$

$X_2 = 0.1$

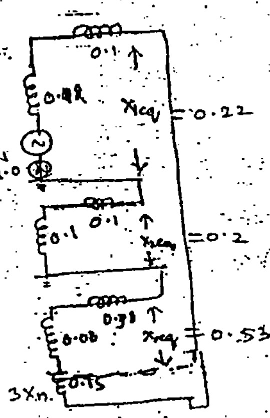
$X_{G0} = 0.08$

$X_n = 0.05$

The alternator is working under no load at rated Voltage. the tr. line is having the same rating as that of alternator. The potential of the neutral in Volts during the fault is.

Sol

Prefault Voltage $= \frac{6.6}{6.6} = 1.0$pu.



$$V_n = I_n X_n$$

$$= I_f X_n$$

$$I_f = \frac{3 \cdot E_{R1}}{X_{1eq} + X_{2eq} + X_{0eq}}$$

$$= \frac{3 \times 1}{0.22 + 0.2 + 0.53}$$

$$= 3.157 \text{ p.u}$$

$$V_n = I_n X_n$$

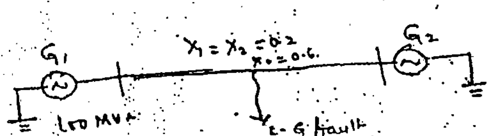
$$= 3.157 \times 0.05$$

$$= 0.157 \text{ p.u}$$

$$V_n (KV) = 0.157 \times \frac{6.6 \times 10^3}{\sqrt{3}} \text{ Volts}$$

$$= 598.25 \text{ KV}.$$

(Q)



$X_d'' = 0.2$

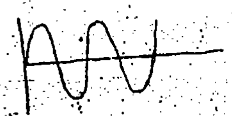
$X_d' = 0.15$

$X_{G0} = 0.08$

The initial symmetrical RMS current in KA supplied by G_1

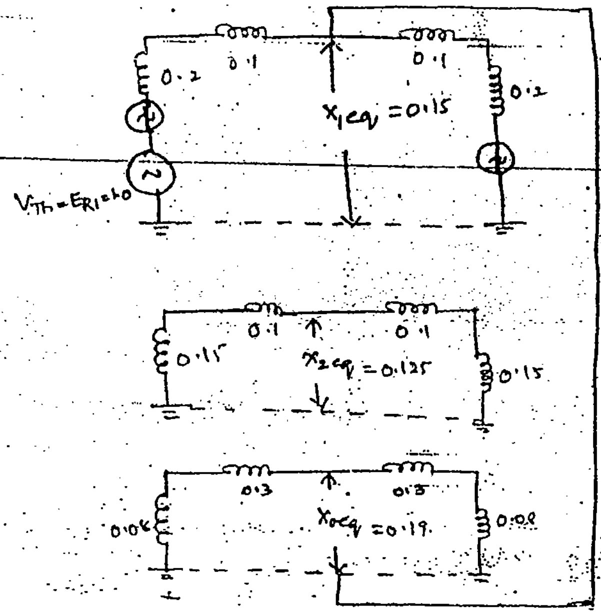
Sub-transient current.

Sol



$\Rightarrow$ Sub transient Current = Initial symmetrical rms current (a.c) component.

Prefault Voltage $= \frac{220}{220} = 1.0$ p.u.



$$I_f = \frac{3 \times 1\,pu}{0.15 + 0.125 + 0.19}$$

$$= 6.45\,p.u.$$

$$I_f(G) = \frac{6.45}{2} = 3.225\,p.u.$$

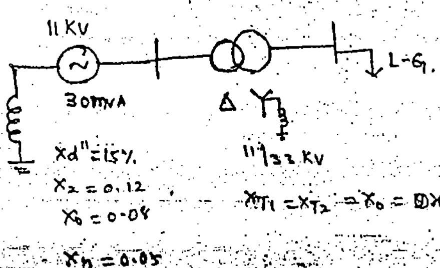
$$I_f(KA) = 3.225 \times \frac{100}{\sqrt{3} \times 220}\,KA = 0.846\,KA$$

→ The momentary fault current in KA (or) the initial symmetrical current in KA.

$$\boxed{I_m = I_f(KA) \times 1.6}$$ (Include dc. effect)

$$= 3.225 \times \frac{100}{\sqrt{3} \times 220} \times 1.6 = 1.353$$

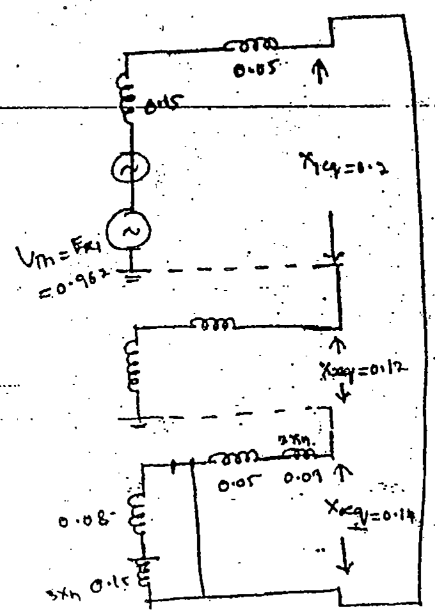
(Q2)



$X_{T1} = X_{T2} = X_0 = 0.05$, $X_n = 0.03$.

$V = 31.75\,Kv$

Prefault voltage $= \frac{31.75}{33} = 0.962\,p.u.$



$$I_f = 3 \times \frac{0.962}{0.2 + 0.17 + 0.14}$$

$$= 5.66 \text{ p.u.}$$

$$I_f(\text{KA}) = 5.66 \times \frac{30}{\sqrt{3} \times 33} \text{ KA}$$

$$= 2.970 \text{ KA}$$

$$V_n = I_n X_n$$

$$= I_f X_n$$

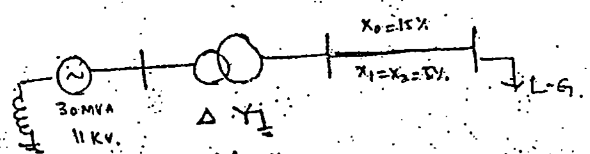
$$V_n = 5.66 \times 0.03 \text{ pu}$$

$$= 5.66 \times 0.03 \times \frac{33}{\sqrt{3}} \text{ KV} = 3.235 \text{ KV}$$

$$\text{S.C MVA} = \frac{30}{0.2 + 0.17 + 0.14} = \frac{30}{0.51} = 58.8 \text{ p.u.}$$

$$\begin{array}{r} 0.2 \\ 0.17 \\ \underline{0.14} \\ .51 \end{array}$$

(03)



$X_d'' = 15\%$

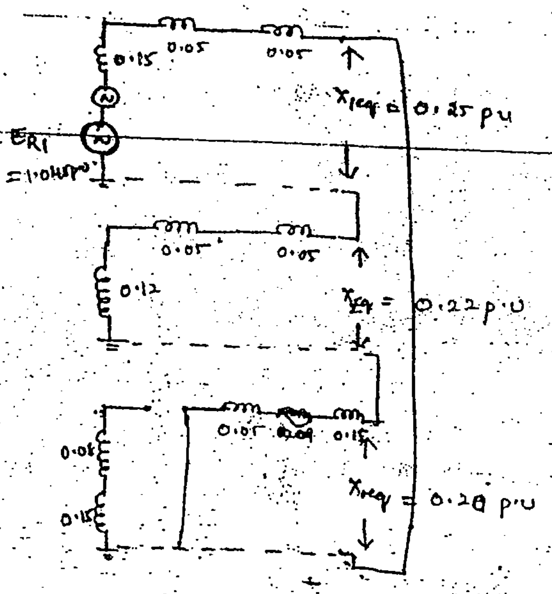
$X_2 = 12\%$

$X_0 = 8\%$

$X_n = 5\%$

$X_{T1} = X_{T2} = X_0 = 5\%$,

$$\text{Pre fault voltage} = \frac{34.5}{33} = 1.045 \text{ p.u}$$



$$I_f = \frac{3 \times 1.045}{0.25 + 0.22 + 0.20}$$

$$= \frac{3.135}{0.67} = 4.67 \text{ p.u.}$$

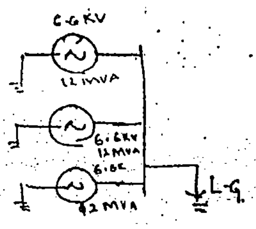
~~$I_f(E_{R1})$ =~~ $V_n = \underline{\underline{0}}$

(04) $I_{R0} = j2.4$ p.u. $\Rightarrow$ $I_f = 3I_{R0} = 7.2$ p.u.

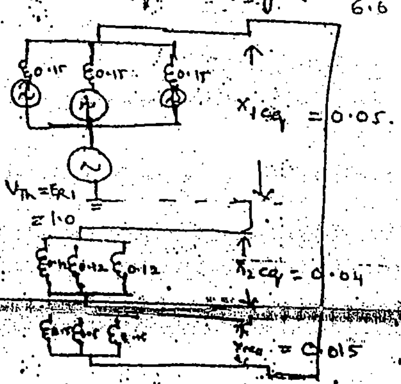
$X_n = 5\%$

$V_n = I_n X_n = I_f X_n = 7.2 \times 0.05 = 0.36$ p.u.

(06) (a)



Prefault voltage $= \frac{6.6}{6.6} = 1.0$ p.u



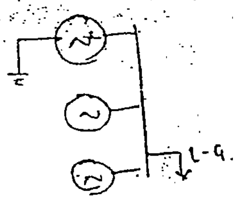
$$I_f = \frac{3 \times 1.0}{0.05 + 0.04 + 0.015}$$

$$= 28.57 \text{ p.u.}$$

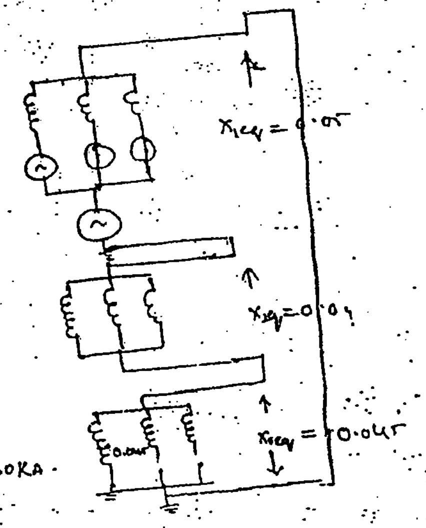
$$I_f(\text{KA}) = 28.57 \times \left(\frac{12}{\sqrt{3} \times 6.6}\right) \text{KA} \simeq 30 \text{ KA}$$

$V_n = 0$

(b) one of the neutral is grounded & the other two are isolated



⇒



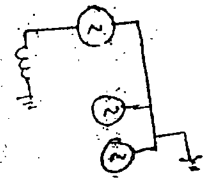
$$I_f = \frac{3 \times 1.0}{0.05 + 0.04 + 0.045}$$

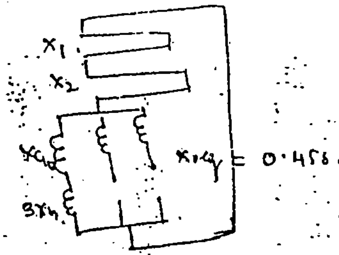
$$= 22.2 \text{ p.u.}$$

$$= 22.2 \times \frac{12}{\sqrt{3} \times 6.6} \text{ KA} = 23.30 \text{ KA}.$$

$V_n = 0.$

(c)





$$X_n \text{ p.u.} = 0.5 \times \frac{12}{(66)^2} = 0.137 \text{ pu}$$

$$3X_n = 3 \times 0.137 = 0.41$$

$$I_f = \frac{3 \times 1.0}{0.05 + 0.04 + 0.456}$$

$$= 5.47 \text{ pu} = 5.47 \times \frac{12}{\sqrt{3} \times 6.6} \text{ KA}$$

$$= 5.742 \text{ KA}$$

$$V_n = I_n X_n$$

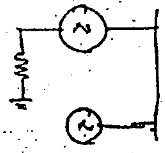
$$= 5.47 \times 0.137 \text{ pu}$$

$$= 5.47 \times 0.137 \times \frac{6.6 \times 10^3}{\sqrt{3}} \text{ V}$$

$$= 2855.55 \text{ V}$$

(Q)(d) one of the generator is grounded through a resistance of 2Ω. Calculate I_f (p.u), I_f (KA), & V_n in Volts.

Sol



$R_n = 2 \times \frac{12}{(6.6)^2}$

$= 0.55$ p.u

$3R_n = 1.65$ p.u

$I_f = \frac{3 \times 1.0}{j0.05 + j0.04 + j0.045 + 1.65}$

$= \frac{3 \times 1.0}{1.65 + j0.135}$

$= \frac{3 \times 1.0}{\sqrt{(1.65)^2 + (0.135)^2}}$

$= 1.81 \angle -4.67$ p.u.

I_f (KA) $= 1.81 \times \frac{12}{\sqrt{3} \times 6.6}$ KA $= 1.90$ KA.

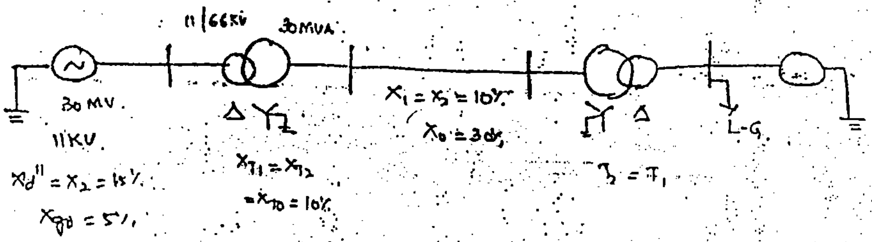
$V_n = I_n R_n$

$= 1.81 \times 0.55$ p.u

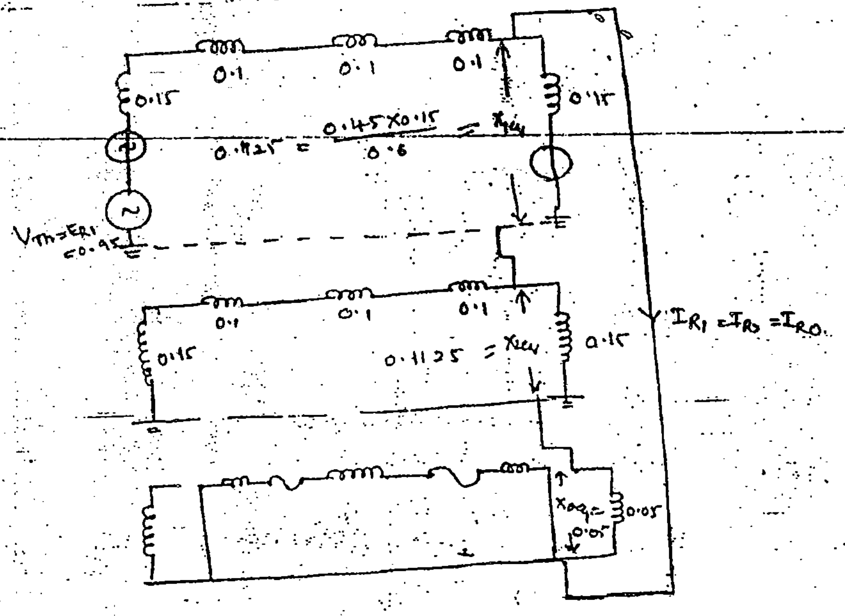
$V_n = 1.81 \times 0.55 \times \frac{6.6 \times 10^3}{\sqrt{3}}$ V $= 3793.36$

S.C MVA $= \frac{12}{1.65 + j0.135} = \frac{12}{\sqrt{(1.65)^2 + (0.135)^2}} = 7.248$ p.u.

(08)



Prefault Voltage $= \frac{10.5}{11} = 0.95$



(i) $I_{R1} = \dfrac{E_{R1}}{X_{1eq} + X_{2eq} + X_{0eq}}$

$= \dfrac{0.95}{0.1125 + 0.1125 + 0.05} = 3.45\ pu$

$I_{R1}(G) = 3.45 \times \dfrac{0.15}{0.15+0.45} = 0.8625$

$I_{R1}(M) = 3.45 \times \dfrac{0.45}{0.45+0.15} = 0.75 \times 3.45 = 2.5875$

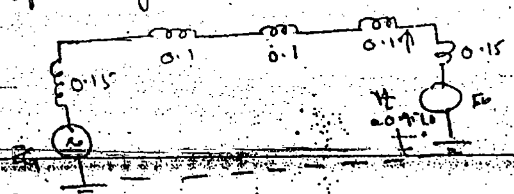
$I_{R2}(G) = 3.45 \times \dfrac{0.15}{0.15+0.45} = 0.8625$

$I_{R2}(M) = 3.45 \times \dfrac{0.45}{0.45+0.15} = 2.5875$

$I_{R0}(G) = 0$

$I_{R0}(M) = 3.45$

(ii) Calculation of voltages behind the reactances of the m/c's



$$E_G = 0.95\angle 0 + I_{p.u} \times 0.45\angle 90^\circ$$

$$E_b = 0.95\angle 0 - I_{p.u} \times 0.15\angle 90^\circ$$

$$I_{p.u} = \frac{15\times 10^6}{\sqrt{3}\times 10.5\times 10^3 \times 0.8} \text{ (actual)} \Bigg/ \frac{30\times 10^6}{\sqrt{3}\times 11\times 10^3} \text{ (base)}$$

$$= \frac{15\times 11}{30\times 10.5\times 0.8}$$

$$= 0.655\angle 36.86$$

$$E_G = 0.95\angle 0 + 0.655\angle 36.86 \times 0.45\angle 90^\circ$$

$$= 0.95\angle 0 + 0.655\times 0.45\angle 90+36.86$$

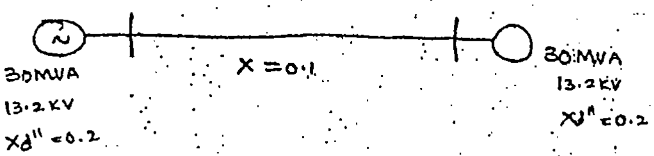
$$E_G = 0.808\angle 16.96$$

$$E_b = 0.95\angle 0 - 0.655\angle 36.86 \times 0.15\angle 90$$

$$= 0.95\angle 0 - 0.655\times 0.15\angle 90+36.86$$

$$E_b = 0.894\angle 5.04.$$

(18)

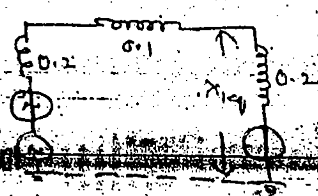


Prefault Voltage $= \frac{12.8}{13.2} = 0.96$ pu

Sol

Fault Analysis is generally based on prefault Voltage.

$$V_m = E_{R1} = 0.96\text{pu}.$$

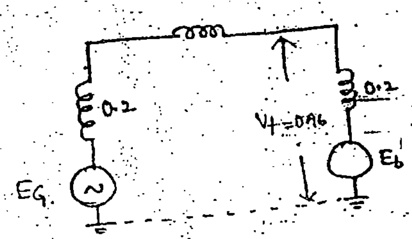


$$I_f = \frac{E_{R1}}{X_{eq}} = \frac{0.96}{\frac{0.2\times 0.2}{0.5}} = 8 \text{ p.u.}$$

$$I_{ff}(G) = 8.0 \times \frac{0.2}{0.5}$$

$$I_{ff}(M) = 8.0 \times \frac{0.3}{0.5}$$

But Calculate the internal voltages for fault Currents



$$E_G = 0.96\angle 0 + I_{p.u} \times 0.3\angle 90^\circ$$

$$E_b = 0.96\angle 0^\circ - I_{p.u} \times 0.2\angle 90^\circ$$

$$\text{But } I_{pu} = \frac{20\times10^6}{\sqrt{3}\times12.8\times10^3\times0.8} \Big/ \frac{30\times10^6}{\sqrt{3}\times13.2\times10^3}$$

$$= 0.86\angle 36.86$$

$$E_G = 0.96\angle 0 + 0.86\times0.3\angle 126.86 = 0.831\angle 14.38$$

$$E_b = 0.96\angle 0 - 0.86\times0.2\angle 126.86 = 1.07\angle -7.37$$

$$I_G = \frac{E_G}{0.3\angle 90^\circ} = \frac{0.831\angle 14.38}{0.3\angle 90} = 2.77\angle -75.62$$

$$I_M = \frac{E_b}{0.2\angle 90^\circ} = 5.35\angle -97.37$$

$$I_f = I_G + I_M = 7.989\angle -89.988$$

(11)

$V_n = I_n X_n$

$= 3I_{R0} X_n$

$= 3I_{R1} X_n$

$= 3 \times 2.0 \times 0.05$

$= 6 \times 0.05$

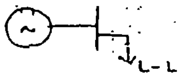
$V_n = \underline{0.3\,p.u}$

$V_n = 0.3 \times \frac{13.2\times10^3}{\sqrt{3}}$ Volts $= 2286.3$ V.

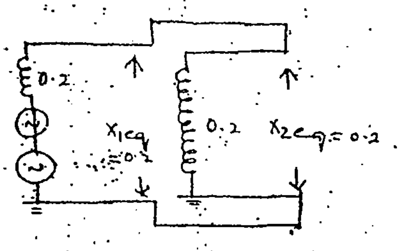
(12) $X_d'' = X_2 = 20\%$, 30 MVA, 13.2 kV,

$V_f = 13.8$

Sol



prefault Voltage $= \frac{13.8}{13.2} = 1.045$.



$I_f = \sqrt{3} I_{R1}$

$= 1.732 \times \frac{E_{R1}}{X_{1eq} + X_{2eq}}$

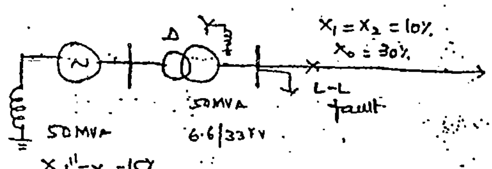
$= 1.732 \times \frac{1.045}{0.2+0.2}$

$= 4.52$ p.u

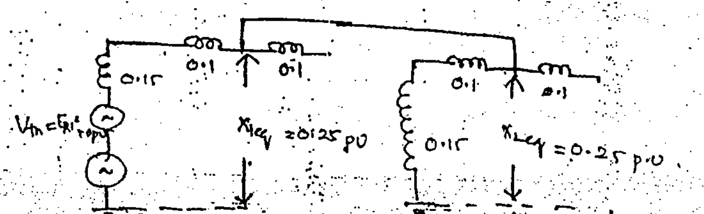
$I_f = 4.52 \times \frac{30}{\sqrt{3}\ 13.2}$ kA

$= 1033.4$ kA.

(14)



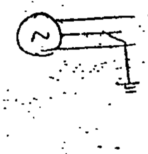
Sol prefault Voltage $= \frac{33}{33} = 1.0$ p.u.



$$I_f = 1.732 \times \frac{1}{0.25+0.25} = 3.464 \text{ p.u.}$$

$$I_f(KA) = 3.464 \times \frac{50}{\sqrt{3}\times 33} \text{ KA} = 3299.7 \text{ KA}$$

$$S.C.MVA = \frac{50}{0.25+0.25} = \frac{50}{0.5} = \frac{500}{5} = 100$$

(20)  LLG $\Rightarrow$ L-L

15 MVA, 13.2 KV,
+ve 30%,
-ve 20%,
'0' 0%

$$I_f = \frac{\sqrt{3} \cdot E_{R1}}{X_{1eq}+X_{2eq}}$$

$$= 1.732 \times \frac{1.0}{0.3+0.2}$$

$$= 3.464 \text{ p.u}$$

$$I_f(A) = 3.464 \times \frac{15\times10^3}{\sqrt{3}\times 13.2\times10^3} \text{ A} = \cancel{\ldots} = 2272.6$$

The limiting values of the currents in the phases is nothing but the max amount of current in the phases which is same as fault current

$$I_Y = I_B = I_f$$

$$\Rightarrow I_f = 3.464 \times \frac{15\times10^3}{\sqrt{3}\times 13.2\times10^3} \text{ A} = 2272.6$$

Repetitive MP Stand 97

Q) A short ckt fault on the alternator has given the following results $I_{R1} = -j8.5$ p.u. $I_{R2} = j5.5$ p.u, $I_{R0} = j3.0$ p.u and $V_{R1} = V_{R2} = V_{R0} = 0.45$ p.u. The fault is

A) L-G B) L-L-G C) L-L-L-G (D) L-L-L

$$I_{R1} = -(I_{R2} + I_{R0})$$

(Q) The voltage of healthy phase is ______ :

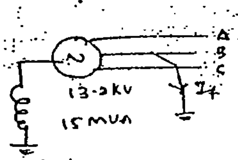
$$V_{R0} = V_{R1} = V_{R2} = V_R/3$$

$$V_{R} = 3V_{R0}$$
$$= 3 \times 0.45$$
$$= 1.35\ p.u$$

(15) A, 50Hz, 13.2K, 15MVA, $X_1 = X_2 = 20\%$, $X_{g0} = 8\%$ and $X_n = 0.5\Omega$

$V_t = 13.9V.$

Sol



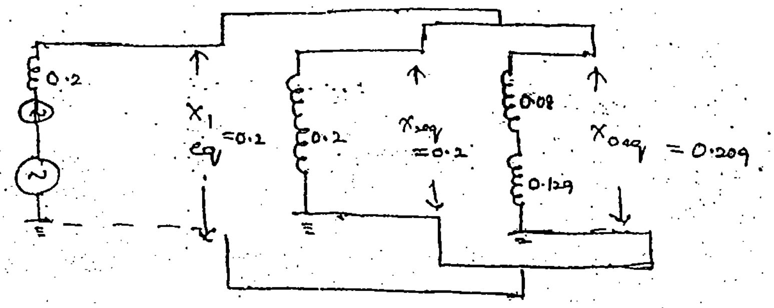
In grounded faults the current through the ground/neutral will be same as fault current

$$\text{Prefault voltage} = \frac{13.9}{13.2} = 1.05\ p.u$$

$$E_{a1} = 1.05\ pu.$$

$$X_n = 0.5 \times \frac{15}{(13.2)^2}$$
$$= 0.043$$

$$3X_n = 3 \times 0.043$$
$$= 0.129\ p.u$$



$$I_{ground} = I_f = 3I_{a0}$$

$$I_{a1} = \frac{E_{a1}}{X_{1eq} + X_{2eq} X_{0eq}/X_{2eq} + X_{0eq}}$$

$$I_{a1} = \frac{1.05}{0.2 + \frac{0.2 \times 0.209}{0.409}}$$

$$= 8.47 \angle -90^\circ$$

$$I_{a0} = -3.47 \angle -90 \times \frac{0.2}{0.409}$$

$$= 1.69 \angle 90$$

$$I_{a2} = -3.47 \angle -90 \times \frac{0.209}{0.409}$$

$$= 1.77 \angle 90^\circ$$

$$\therefore I_{ground} = 3 \times 1.69 \text{ p.u}$$

$$= 3 \times 1.69 \times \frac{15}{\sqrt{3} \times 13.2} \text{ KA (rms)} = 579.5 \text{ KA}$$

$$V_n = I_n X_n$$

$$= 3 \times 1.69 \times 0.043$$

$$V_n = 3 \times 1.69 \times 0.043 \times \frac{13.2 \times 10^3}{\sqrt{3}} \text{ Volts} = 1661.45$$

$$SC\ MVA = \frac{15}{0.2 + \frac{0.2 \times 0.209}{0.409}} = \frac{15}{0.302} = 49.63$$

Currents in phases B & C.

$$I_B = I_{B0} + I_{B1} + I_{B2}$$

$$= I_{A0} + K^2 I_{A1} + K I_{A2}$$

$$= 1.69 \angle 90 + 3.47 \angle 150 + 1.77 \angle 90 + 120^\circ$$

$$I_B = 5.2 \angle 150.76$$

$$I_B(A) = \cancel{I_{B\,pu} \times I_{base}} = 5.2 \angle 150.76 \times \left(\frac{15 \times 10^6}{\sqrt{3}\ 13.2 \times 10^3}\right)$$

$$= 5.2 \times 1136.56 \angle 150.76$$

$I_c = I_{c0} + I_{c1} + I_{c2}$

$= I_{a0} + K I_{a1} + K^2 I_{a2}$

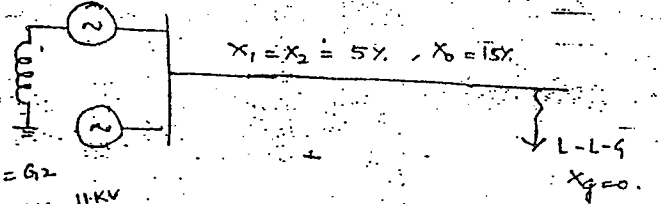
$= 1.69\angle 90^\circ + 8.47\angle -90^\circ + 120^\circ + 1.77\angle 90 + 240$

$= 5.2\angle 29.2$ p.u.

$I_c(a) = I_{c.p.u} \times I_{base} = 5.2 \times 1136.36\angle 29.2$

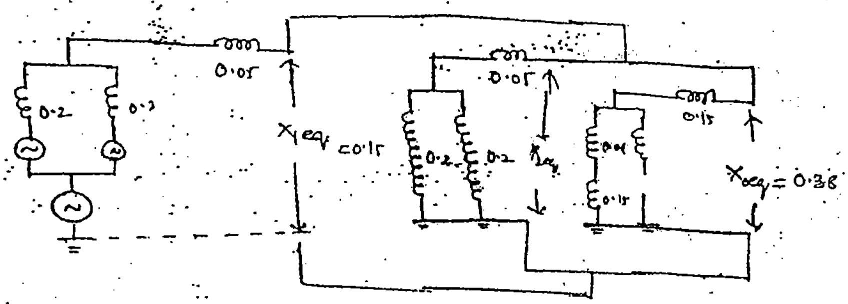
$= 5909.09\angle 29.2$

(16)



$G_1 = G_2$
7.5 MVA, 11 KV
$X_d'' = X_2 = 20\%$
$X_0 = 8\%$, $X_n = 5\%$

Prefault voltage $= \frac{11.25}{11} = 1.022$ p.u.



$I_{ground} = I_f = 3 I_{R0}$

$$I_{R1} = \frac{1.022}{0.15 + \frac{0.15 \times 0.38}{0.15 + 0.38}} = 3.968\angle -90^\circ$$

$$I_{R0} = -I_{R1} \frac{X_{2eq}}{X_{2eq} + X_{0eq}}$$

$$= 3.968\angle 90 \times \frac{0.15}{0.15 + 0.38}$$

$= 1.12$ p.u.

$I_{ground} = 3 \times 1.12$

$= 3.36$ p.u

$= 3.36 \times \frac{7.5}{\sqrt{3} \times 11}$ KA $= 160.04$ KA

$SCMVA = \frac{7.5}{0.15 + \frac{0.15 \times 0.38}{0.15 + 0.38}} = \frac{7.5}{0.15 + \frac{0.057}{0.53}} \simeq 29.12$

(17) 30 MVA, 11 KV, $X_d'' = 20\%$, $X_d' = 30\%$, $X_d = 110\%$, Balanced fault

$I_f = I_R = I_{R1} = \frac{E_{R1}}{X_d''} = \frac{1.0}{0.2} = 5.0$ p.u.

$I_f (KA) = 5 \times \frac{30}{\sqrt{3} \times 11}$ KA $= 952.62$ KA.

After 4 cycles

$I_f = 3.33$ pu

$= 3.33 \times \frac{30}{\sqrt{3} \times 11}$ KA $= 634.45$

(25) A 20 MVA, 33 KV, I_f 3-ϕ = 319 A

I_f L-G = 659 A

I_f L-L = 435 A

Sol

$I_f(a) = I_f . p.u. I_{base}$

$I_{base} = \frac{20 \times 10^6}{\sqrt{3} \times 33 \times 10^3} \simeq 350$ A.

$319 = \frac{E_{R1}}{X_1 pu} \times 350$

$X_{pu} = \frac{1.0 \times 350}{319} = 1.097$

L-L

$$I_f(a) = 1.732 \times \frac{E_{R1}}{X_1pu + X_2pu} I_{base}$$

$$\Rightarrow X_1pu + X_2pu = \frac{1.732 \times 1.0 \times 350}{435}$$

$$\Rightarrow X_2pu = \frac{1.732 \times 350 \times 1.0}{435} - X_1pu$$

$$= 1.3938 - 1.097$$

$$= 0.2966$$

L-G

$$I_f(a) = \frac{3 \cdot E_{R1}}{X_1pu + X_2pu + X_0pu} \times I_{base}$$

$$X_1pu + X_2pu + X_0pu = \frac{3 \times 1.0 \times 350}{659}$$

$$X_0pu = \frac{3 \times 350}{659} - X_1pu - X_2pu$$

$$= 1.593 - 1.097 - 0.2966$$

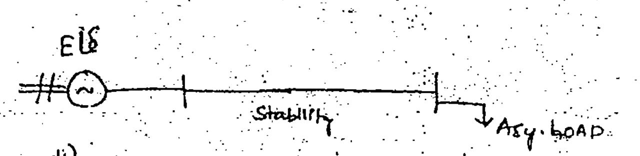
$$= 0.1997\ pu$$

23/03/10

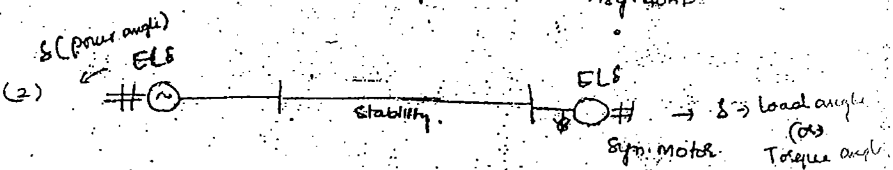
POWER SYSTEM STABILITY

→ Stability is associated with synchronous machines while delivering or receiving power ~~becoz, syn machine can acts both as generator~~ and motor

Ex: (1)

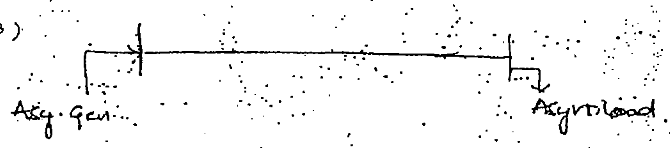


(2)



The above two cases have associated with stability because syn m/cs are involved in both cases.

(3)



not practical to generate bulk amount of power.

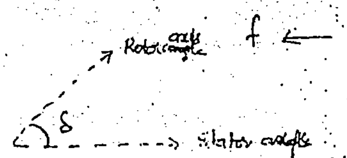
In this case the concept of stability doesn't arise.

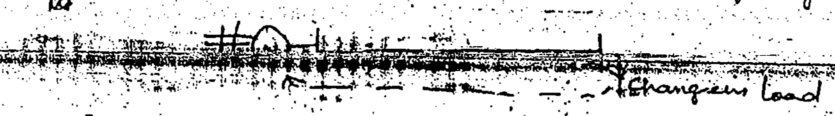
The bulk amount of power is generated by using conventional sources with the help of syn generators and the load may be asynchronous or synchronous.

STABILITY: It is the ability of the synchronous machine to deliver maximum amount of real power to the load by maintaining the synchronization with the externally connected tie line, i.e. transmission line

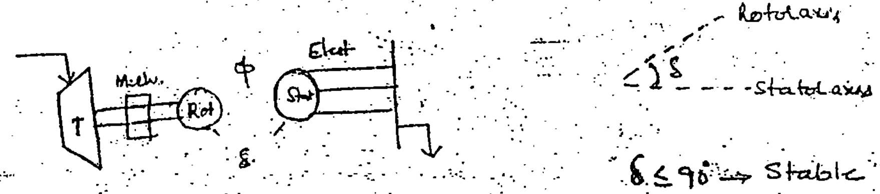
SYNCHRONIZATION: It is associated with some parameters in the system like frequency (f) and voltage (V)

$f \leftarrow N \leftarrow (\delta)$ (power angle) → generator side
(or)
Load angle
(or)
Torque angle } Motor side





→ The power system network is a dynamic network that is it will experience a continuous variation of the load. Any change of load will reflect directly on the source of generation i.e. change in the position of rotor axis with respect to the stator. Which in turn understand in terms of speed or the frequency of the system.

→ 

$\delta \le 90^\circ \rightarrow$ Stable

$\delta \le 90^\circ \rightarrow$ Magnetization of airgap flux (Stable)

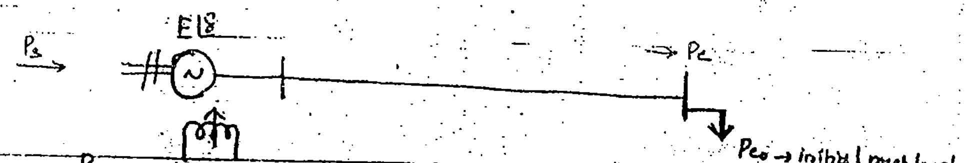
$\delta > 90^\circ \rightarrow$ DeMag

→ The Stability of the synchronous machine can also be understand in terms of the magnetization of air gap flux (or) Demagnetization of the air gap flux

→ change of load on the system is considered as

1) Small and gradual change → Steady state stability
2) Sudden and large variation → Transient Stability

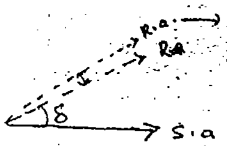
(1) STEADY STATE STABILITY : It is the ability of a syn. m/c. to deliver maximum amount of real power to the load by a synchronous machine while maintaing the synchronisation with the externally connected to line where the syn. machine is experiencing a small and gradual variation of the load. The small and gradual variation of the load means the rate of change of load is lessthan the rate of change of excitation (or) the frequency of oscillations made by the rotor are less than natural frequency of the system.



Peo → initial mech load.

Ps → Shaft power   Pe → Electrical o/p.

Peo + ΔPe
↳ small change



→ because of change in load (small) (ΔPe)

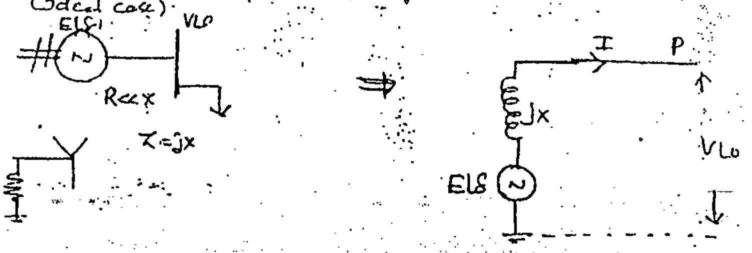
The oscillations of the rotor, ie the frequency of the oscillation of rotor is negligible small.

→ As there is no much change in the rotor position for a small and gradual variation of the load then the steady state stability analysis can be analysed by using the static ~~motor~~ model i.e. the power flow equations of the reactance diagram (per phase)

→ The change of load is considered in all the three phases so that the synchronous machine is working in a balanced manner, the current in the neutral is ZERO and the reference for the reactance diagram is neutral.

→ Steady stability analysis by using static model

(Ideal case)



The power equation at load point

$$S = VI^*$$

$$= |V|\angle 0 \left[\frac{|E|\angle\delta - |V|\angle 0}{|X|\angle 90}\right]^*$$

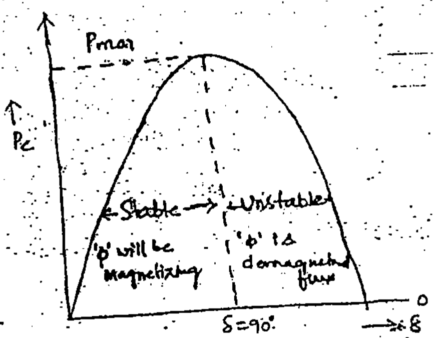
$$= \frac{EV}{X}\angle 90-\delta - \frac{|V|^2}{|X|}\angle 90^\circ$$

Real power transfer, $P_e = \frac{|E||V|}{|X|} \sin\delta$ (∵ 'Q' is be not considered in stability)

∴ $P_e = P_{max}$ = Steady state stability limit $(\delta = 90°)$

$$\therefore P_{max} = \frac{|E||V|}{|X|} \sin 90°$$

$$\Rightarrow P_{max} = \frac{|E||V|}{|X|}$$



(Power angle curve)

→ Due to change of load if $\delta > 90°$ the real power transfer P_e is reduced

→ The s.sc of the syn. m/c can also be analysed by considering the degree of magnetic coupling (or) the electrical stiffness which can be expressed in terms of synchronizing power i.e. $\frac{dP_e}{d\delta}$

$$\therefore \frac{dP_e}{d\delta} = \frac{|E||V|}{|X|} \cos\delta$$

If $\delta > 90° \Rightarrow \frac{dP_e}{d\delta} = -ve \Rightarrow$ Demagnetisation.

→ The concept of the steady state stability is the angle stability i.e. if $\delta < 90°$ before change of load, the syn.m/c is stable, otherwise it is unstable.

Ex: A syn. m/c is directly connected to the load. The internal voltage of the syn. m/c is 1.2 p.u and the load voltage 1.0 p.u. The synchronous reactance of the m/c is 1.5 p.u. The Real power transfer, the steady state stability limit of the syn. m/c synchronizing power and for an initial angle of 30°

Sol

$$P_e = \frac{EV}{X} \sin\delta$$

$$= \frac{(1.2)(1.0)}{1.5} \sin 30^\circ$$

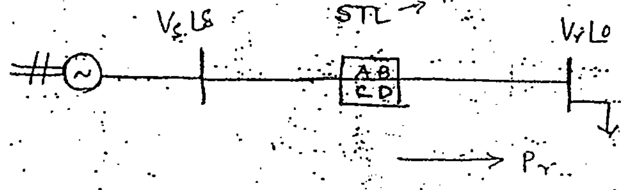
$$= \frac{1.2}{1.5} \times 0.5 = 4 \text{ p.u}$$

$$\frac{dP_e}{d\delta} = \frac{EV}{X}\cos\delta = \frac{1.2\times 1.0}{1.5}\cos 30^\circ = 0.712 \text{ p.u}$$

$$P_{max} = \frac{EV}{X} = \frac{1.2\times 1.0}{1.5} = 0.8 \text{ p.u}$$

→ <u>Practical case:</u>

STL → more stable ⇒ ($\delta = 60^\circ$)



$$^{*}P_r = P_e = \frac{|V_s||V_r|}{|B|}\cos(\beta-\delta) - \frac{|A|}{|B|}V_r^2\cos(\beta-\alpha)$$

Sending end * $P_s = \left|\frac{D}{B}\right| V_s^2 \cos(\beta-\alpha) - \frac{|V_s||V_r|}{|B|}\cos(\beta+\delta)$

For STL, $C \simeq 0$ (shunt cap)

$$|A| = 1.0 \qquad \beta = |Z|$$
$$\alpha = 0 \qquad \beta = \theta$$

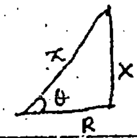
$$\therefore P_e = \frac{|V_s||V_r|}{|Z|}\cos(\theta-\delta) - \frac{1.0}{|Z|}|V_r|^2\cos(\theta-0^\circ)$$

$P_e = P_{max}$ = Steady state stability limit at $\underline{\delta = \theta}$

(Power angle = Impedance angle)

→ The stability of the syn.mc, if it is connected to the tr. line is influenced by the impedance angle of the tr. line.

$$\therefore \quad P_{max} = \frac{|V_s||V_r|}{|Z|} - \frac{1.0}{|Z|}|V_r|^2 \cos\theta$$



$$P_{max} = \frac{|V_s||V_r|}{\sqrt{R^2+X^2}} - \frac{1.0}{\sqrt{R^2+X^2}}|V_r|^2 \times \frac{R}{\sqrt{R^2+X^2}}$$

Inorder to maximize the steady state stability limit, the stability equation needs to be differentiated with respect to reactance of the n/w.

$$\frac{dP_{max}}{dX} = 0$$

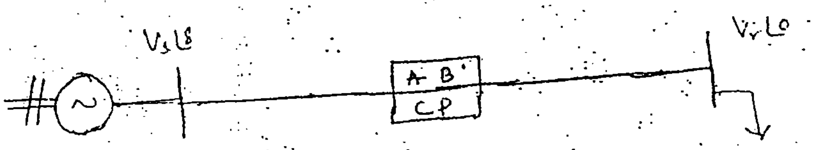
** $\boxed{X = \sqrt{3}R}$

$$\Rightarrow \boxed{\frac{X}{R} = \sqrt{3}}$$

$$\Rightarrow \boxed{\theta = \tan^{-1}(X/R) = 60^\circ}$$ → To deliver max power for STL.

$\therefore \boxed{\theta = \delta = 60^\circ}$ → more stable

→ However the alternators are normally connected with long lines.



$$P_r = P_e = \frac{|V_s||V_r|}{|B|}\cos(\beta-\delta) - \left|\frac{A}{B}\right| V_r^2 \cos(\beta-\alpha)$$

If $\delta = \beta \Rightarrow P_e = P_{max}$ = Steady State Stability limit

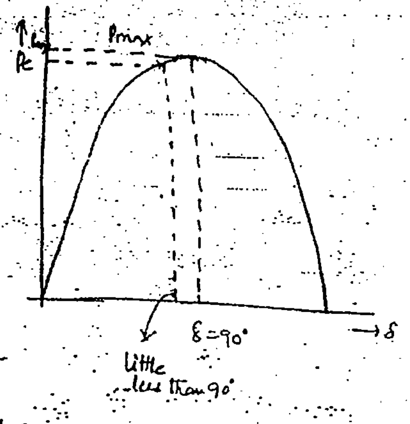
$$P_{max} = \frac{|V_s||V_r|}{|B|} - \frac{|A|}{|B|}|V_r|^2 \cos(\beta-\alpha)$$

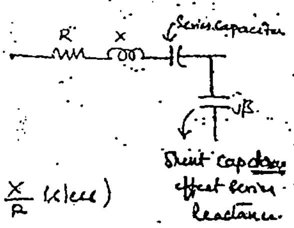
$$\delta = \beta = \tan^{-1}(X/R) = 60^\circ$$

In long lines $X\uparrow$ and $R\downarrow$ in. $\theta = \tan^{-1}\left(\frac{X}{R}\right)$

→ ~~In case of long lines the $\frac{X}{R}$ ratio is high when compared to short line~~ so that the impedance angle is almost equal to $90°$

→ If the alternator is connected to longline then it will be less stable when compared to STL and inorder to improve the stability the $\frac{X}{R}$ ratio of the long line should be reduced by having a compensation to the LTL i.e. employing a suitable series capacitor





→ A LTL is a compensated line for stability purpose where as A STL is a uncompensated line (because $\frac{X}{R}$ is less)

$$\therefore \quad P_e = \frac{|E||V|}{|X|} \sin\delta$$

$$= P_{max} \sin\delta$$

$$P_{max} = \text{Steady State stability limit} = \frac{|E||V|}{|X|}$$

→ For the given amount of power delivered if the steady state stability limit is high then the angle of the Syn. mc will be less

→ Methods to Improve the SSSL

(i) Operate the system at higher operating voltages

(2) Reduce the reactance of the system.

(a) Parallel transmission lines

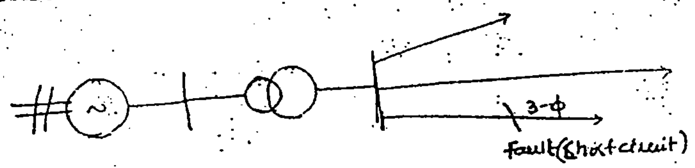
(b) Double ckt line

(c) Bundled conductors

(d) Series capacitance

⟹ TRANSIENT STABILITY : It is the ability of the Syn m/c to deliver the maximum amount of real power to the load by the synchronous machine while maintaining the ~~synchronisation with~~ the transmission line where the synchronous machine will experience a sudden and large variation of the load due to the occurrence of 3-ϕ short circuit fault on the transmission line for few cycles only.

of the fault that can exist for more no. of cycles then there are chances to lose the synchronism by the syn. m/c



Few cycles ⟹ Fault clearing time
⇓
(Relay time + C.B time) $\leq$ 5 cycles

→ Assume

P_{e1} = Power transfer before fault = $P_{m1} \sin\delta_0$

P_{e2} = Power transfer during fault = $P_{m2} \sin\delta$

✓ In general $\boxed{P_{e2} < P_{e1}}$ ⟹ $P_{m2} < P_{m1}$

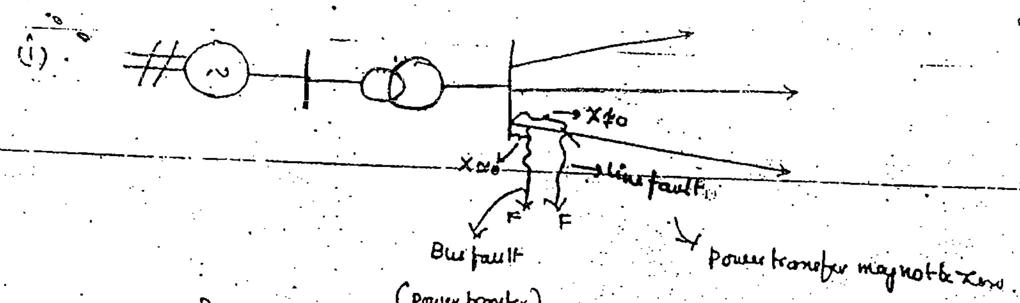
⟹ $\boxed{\text{Transient Stability Limit} < \text{Steady State Stability Limit}}$

SPECIAL CASES:

$P_{e2} = 0$, $P_{m2} = 0$

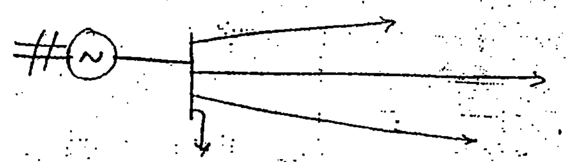
(i) Fault occurs on a line near to bus bar

(i)



$P_{e2} = 0$, $P_{m2} = 0$

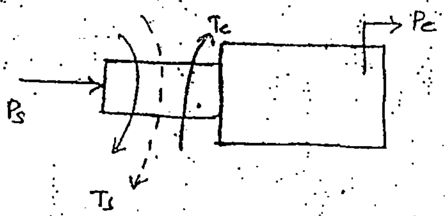
(ii)



$P_{e2} = 0$, $P_{m2} = 0$.

→ As the change of load is a sudden and large variation and it will reflect directly in changing the position of the rotor. The transient stability analysis can be made by considering the dynamic model of the rotating body i.e. the mechanical equivalent of the synchronous machine.

∴ Dynamic model: (Mech equivalent)



ω = angular velocity rad/sec

Before fault

$P = P_s - P_e = 0$

$\omega = \omega_s$

The rotor neither accelerate nor decelerate but stability with same angle.

If a fault occurs

$P = P_s - P_e \downarrow$

= +ve ⇒ Acceleration (Rotor)

$\Rightarrow \quad P_{acc} = P_s - P_e$

$\Rightarrow \quad P_{acc} = T_a \omega$ (Torque × angular ~~velocity~~ acceleration)

and $\omega \neq \omega_s$

$\omega = \frac{2\pi N}{60}$, where N is speed in rpm.

$\therefore \boxed{P_{acc} = I\alpha.\omega}$ $[T_a = I\alpha]$

where I = Inertia $Kg-m^2$

α = Angular acceleration = rad/sec^2

$\therefore \boxed{P_{acc} = M\alpha}$

where M = Moment of Inertia (or) Angularmomentum

$\downarrow$

J sec / Mech rad (Units)

But most of alternator are MVA capacity, so units of

$M = MJ\text{-}sec/Mech.rad.$

$\therefore M = MJ\text{-}sec/ P/2 \times Mech.~~deg~~ rad.$

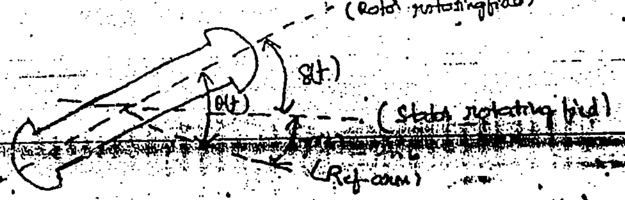
$= MJ\text{-}sec/ Elec. rad.$

$= MJ\text{-}sec/ 57.11 \times Elec.rad$

$\boxed{M = MJ\text{-}sec/ Elec.degree}$

and $\alpha = \frac{d\omega}{dt} = \frac{d^2\theta}{dt^2} = \frac{d^2\delta}{dt^2}$

But Angular displacement must be equal to Power angle



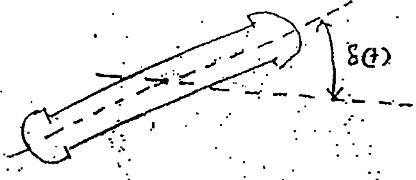
$$\therefore \theta(t) = \delta(t) + \omega_r . t$$

$$\frac{d\theta(t)}{dt} = \frac{d\delta(t)}{dt} + \omega_r$$

$$\boxed{\alpha = \frac{d^2\theta(t)}{dt^2} = \frac{d^2\delta(t)}{dt^2} + 0}$$

→ The change of load will result as the change in the position of the rotor w.r.t stator, where as the position of the stator remains same w.r.t reference axis hence the relative speed is zero

∴ No separate reference axis is required, As stator axis itself is a reference axis.



$$\therefore M\alpha = P_{acc}$$

$$M\frac{d^2\delta(t)}{dt^2} = P_s - P_e$$

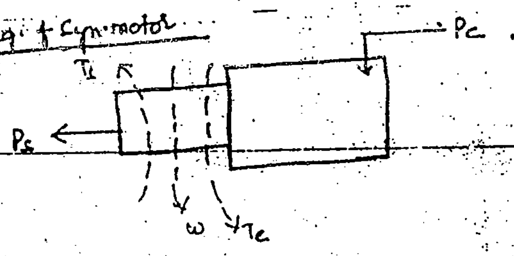
$$\Rightarrow \boxed{M\frac{d^2\delta(t)}{dt^2} = P_s - \frac{EV}{X}\sin\delta}$$ → Swing equation of the rotating body

→ The swing equation is a non-linear differential equation

→ The swing equation describes the position of the rotor w.r.t stator having the function of time for specified no. of cycles in which the syn. m/c is experiencing a disturbance.

(P.T.O)

→ Mech eq. of syn motor

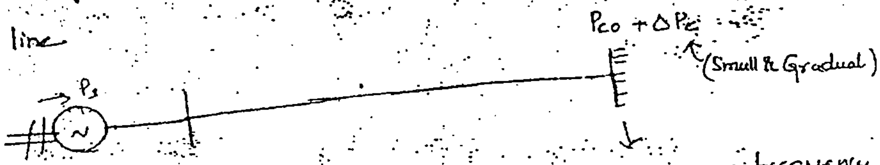


$$M\frac{d^2\delta(t)}{dt^2} = P_e - P_s$$

$$\Rightarrow \boxed{M\frac{d^2\delta(t)}{dt^2} = \frac{EV}{X}\sin\delta - P_s}$$

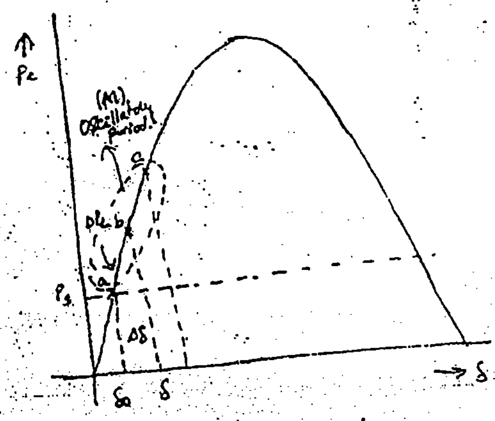
** → Inorder to know the frequency of oscillations made by the rotor for a small and gradual variation of the load, the solution of the swing equation is required.

Application: Synchronous Generator is connected to an Infinite bus through a loss less line



An infinite bus is the one at which the voltage and frequency are constant.

Convert the non-linear differential equation into a linear differential equation by using the Taylor series expansion.



At 'a', $P_s = P_{eo} = P_m \sin\delta_0$

$$\delta_0 = \sin^{-1}\left(\frac{P_s}{P_m}\right)$$

$$\therefore M\frac{d^2\delta}{dt^2} = P_a$$

$$M\frac{d^2(\delta_0+\Delta\delta)}{dt^2} = \cancel{P_s} - (\cancel{P_{eo}} + \Delta P_e)$$

$\delta = \delta_0 + \Delta\delta$

↓ Linear differential equation.

$$\therefore M\frac{d^2}{dt^2}\Delta\delta = -\Delta P_e = -\frac{\partial P_e}{\partial\delta}\bigg|_{\delta_0} \times \Delta\delta$$

$$\Rightarrow \cancel{M\frac{d^2}{dt^2}\Delta\delta + \frac{\partial P_e}{\partial\delta}\bigg|_{\delta_0}\Delta\delta = 0}$$

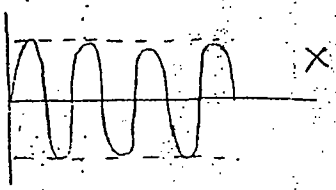
Let $\frac{d}{dt} = K$.

$$\left[MK^2 + \frac{\partial P_e}{\partial\delta}\bigg|_{\delta_0}\right] = 0$$

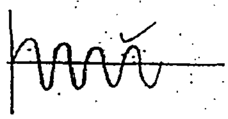
$$K = \pm\left[\frac{1}{M}\left(-\frac{\partial P_e}{\partial\delta}\bigg|_{\delta_0}\right)\right]^{1/2} \text{ rad/sec}$$

Case 1: $\frac{\partial P_e}{\partial\delta} = \frac{EV\cos\delta}{X} = +ve$; when $\delta_0 < \pi/2$

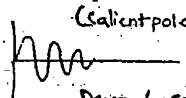
∴ The nature of the roots of the equation are imaginary but undamped oscillations.



The moment of inertia of the system is very high and the change of load is very small and the magnitude of the oscillations are very less.



→ In case of salient pole alternator, because of damper winding the ~~frequency~~ magnitude of oscillations tend to decrease after few cycles.



The system is stable

→ But in Turbo alternator, because of the large size the oscillations are negligible

∴ The system is stable.

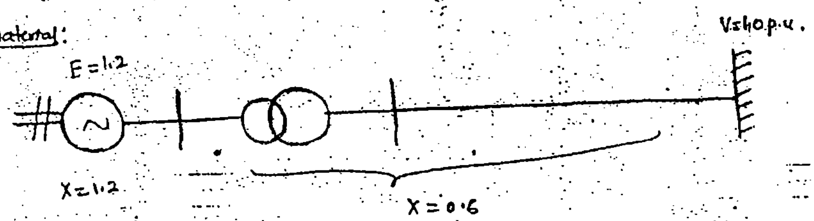
∴ The frequency of oscillations in Hz is given by

$$K = \frac{\pm\left(\frac{1}{M}\left(\frac{-\partial P_e}{\partial\delta}\bigg|_{\delta_0}\right)\right)^{1/2}}{2\pi} \text{ Hz.}$$

Case(2): $\dfrac{\partial P_e}{\partial \delta} = \dfrac{EV}{X}\cos\delta = -ve$ when $\delta_0 > \pi/2$

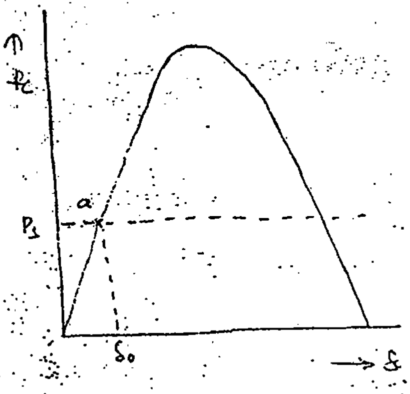
K = Real roots → The sys.mc is unstable

(Q) 14) pg: 67 material:



$H = 4$ MW-sec / MVA

$= 4$ MJ / MVA



$P_s = P_{e0} = P_m \sin\delta_0$.

$0.8 P_m = P_m \sin\delta_0$

$\delta_0 = \sin^{-1}(0.8)$

$= 53.13$

$\therefore \dfrac{\partial P_e}{\partial \delta} = \dfrac{EV}{X}\cos\delta$

$\left.\dfrac{\partial P_e}{\partial \delta}\right|_{\delta_0} = \dfrac{1.2 \times 1.0}{1.8} \times \cos(53.13)$

$= 0.4$ (Roots are imaginary)

$K = \left[\dfrac{1}{M}\left(-\left.\dfrac{\partial P_e}{\partial \delta}\right|_{\delta_0}\right)\right]^{1/2}$

$= \left[\dfrac{1}{\frac{SH}{\pi f}}(0.4)\right]^{1/2}$

$= \left[\dfrac{1}{\frac{1.0 \times 4}{3.14 \times 50}} \times 0.4\right]^{1/2}$

$= 3.96$ rad/sec

$= 0.63$ Hz.

→ **TRANSIENT STABILITY :** The stability concept can be analysed by knowing the solution for the swing equation

$$M\frac{d^2\delta}{dt^2} = P_a$$

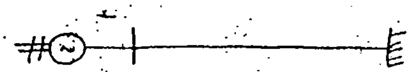
The solution for swing equation depends on no. of syn. m/c. present

(1) Single machine system

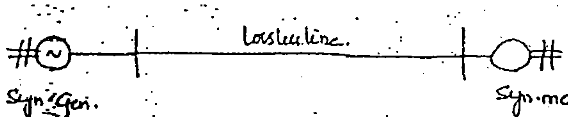
(2) Two machine system

(3) Multimachine system.

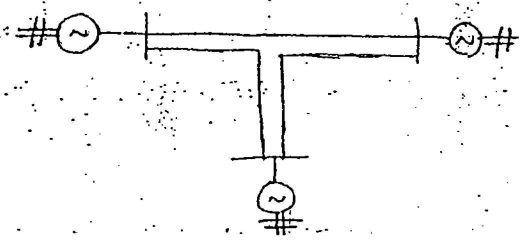
(1) Single machine system: A syn generator connected to Infinite bus is called single m/c system.



(2) Two machine system:



(3) Multimachine system:

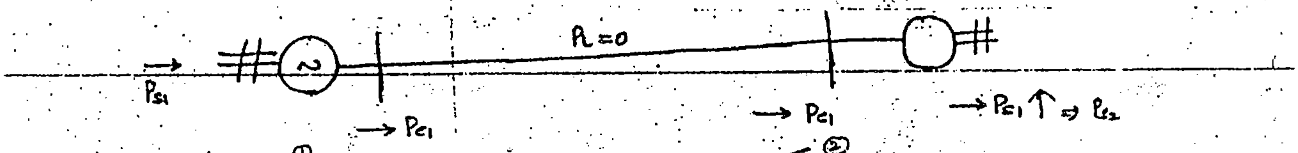


→ For Single machine system, the solution can be obtained by Elliptical Integral.

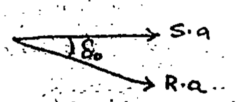
→ For Two machine system, the Graphical solution, called EQUAL AREA CRITERIA

→ For Multimachine system, the solution can be obtained by " Point by Point or " Step by step " method.

→ In a two machine system the Synchronous generator is connected to the synchronous motor through a lossless line and for the stability point of view it is equivalent to a single machine because Both the machines are stable (or) unstable at any point of time.



② Initially, $P_{e1} - P_{s1} = 0$

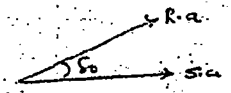


⇒ Neither acceleration nor Deceleration.

① Initially

$P_{s1} - P_{e1} = 0$

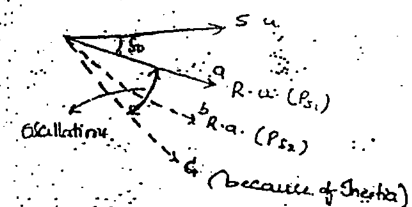
Neither acceleration nor deceleration. ⇒



(2) If there is sudden and large variation

∴ $P = P_{e1} - P_{s2}$

= −ve (Deceleration of rotor)



(2) $P = P_{s1} - 0$

⇒ accelerated.

→ Due to the acceleration of syn/Gen the frequency of oscillations are more than the natural frequency of the system, so that the syn. generator will also be pulled out.

→ If the frequency of the oscillations made by syn. motor are much more than that of natural frequency of system due to sudden and large variation of load, then the syn. motor will be pulled out from the synchronization.

→ If the motor is asynchronised then the electrical o/p delivered by Syn/Gen is ZERO. so that the generator will get accelerated.

→ The Equal area Criteria is also applicable for the synchronous generator connected to infinite bus.

→ We know that

$$M\frac{d^2\delta}{dt^2} = P_s - \frac{P_m \sin\delta}{P_e}$$

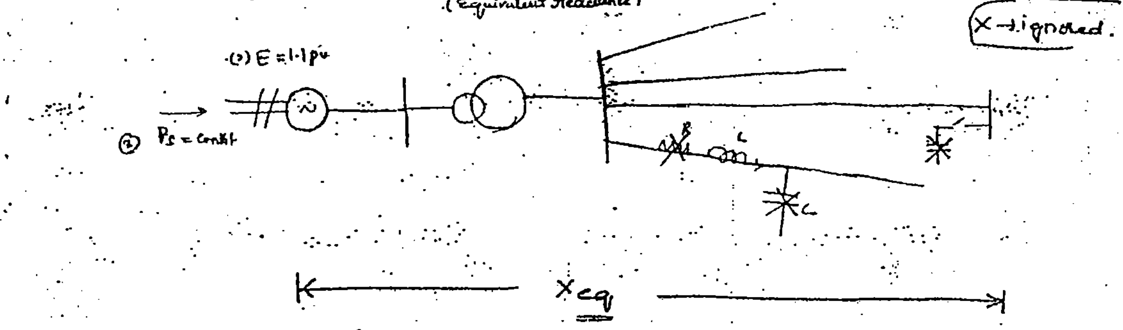
→ Calculation of the maximum power transfer (Transient stability Unit)

Which is constant during the fault condition even though the real power transfer varies

→ Consider the +ve sequence reactance n/w for the given single line diagram with the following assumptions.

(1) R<<X, Line shunt capacitance can be ignored and any external shunt elements can also be ignored, then the existing network can be modelled as the transfer reactance (Equivalent reactance) b/w the source and the load

X → ignored.

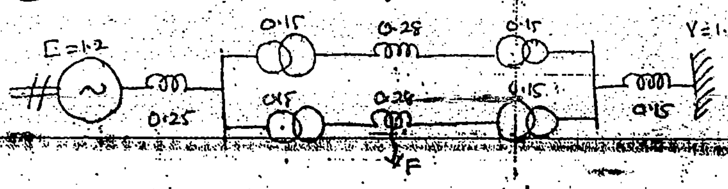


(2) The Voltages behind the reactances of the system are assumed as constant because the amount of power transfer does influence severely by the transfer reactance of the system rather than voltages.

(3) The mechanical i/p of the syn. m/c is remains same ≃ constant.

(4) The force produced by the damper wdg on the rotor can be ignored

→ Q(5) Pg: 67) Calculate the P_{max} before fault, during fault & After the fault.



Sol/ let P_{e1} = power transfer before fault $= \frac{EV}{X_1 eq}\sin\delta_0 = P_{m1}\sin\delta_0$

P_{e2} = power transfer during fault $= \frac{EV}{X_2 eq}\sin\delta = P_{m2}\sin\delta$

P_{e3} = Power transfer after fault $= \frac{EV}{X_3 eq}\sin\delta = P_{m3}\sin\delta$

where

P_{m1} = Max. power transfer before fault

P_{m2} = Max. power transfer during fault

P_{m3} = Max. power transfer after fault.

and $X_1 eq$ = transfer reactance before fault occur

$X_2 eq$ = transfer reactance during fault

$X_3 eq$ = transfer reactance after fault

But → $P_{m2} = \frac{EV}{X_2 eq} = \frac{EV}{X_1 eq}\cdot\frac{X_1 eq}{X_2 eq} = r_1 P_{m1}$

where $r_1 = \frac{X_1 eq}{X_2 eq} < 1.0$

$P_{m3} = \frac{EV}{X_3 eq} = \frac{EV}{X_1 eq}\cdot\frac{X_1 eq}{X_3 eq} = r_2 P_{m1}$

Where $r_2 = \frac{X_1 eq}{X_3 eq} < 1.0$

But $\boxed{r_2 > r_1}$

→ If the fault is considered in the line at any line length, then the relation
Middle, 20% (or) 60% (or) 80%....

is $\boxed{P_{m2} < P_{m3} < P_{m1}}$

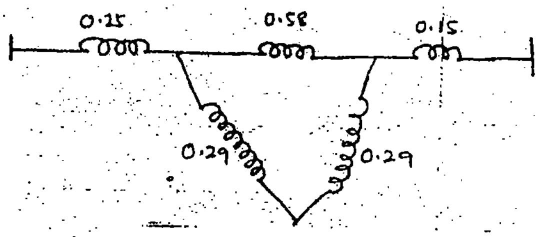
∴ $P_{m1} = \frac{EV}{X_1 eq} = \frac{1.2 \times 1.0}{0.25 + \frac{0.58}{2} + 0.15} = 1.739$ p.u

$P_{m2} = \frac{EV}{X_2 eq} = \frac{1.2 \times 1.0}{}$ $X_2 eq = ?$

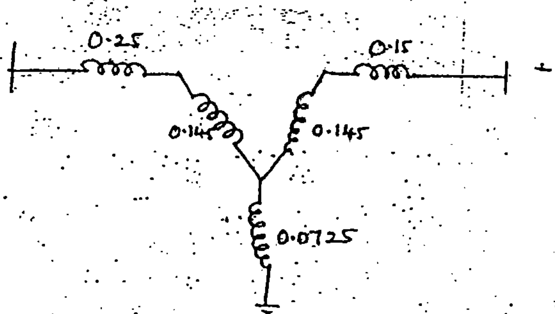
$$P_{m3} = \frac{EV}{X_3 eq} = \frac{1.2 \times 1.0}{0.25 + \frac{0.58}{2} + 0.15} = \underline{1.224 \text{ p.u.}}$$

→ **Calculation of $X_2 eq$:**

(If 'F' is at middle)



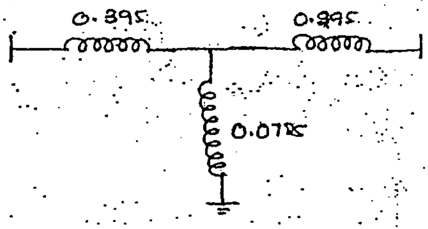
Convert Δ' in. to Y



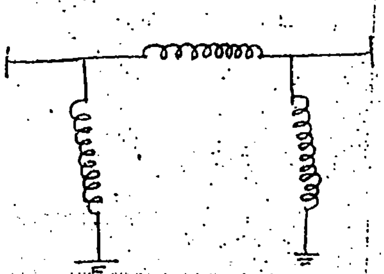
Δ − Y

$$\frac{0.58 \times 0.29}{0.58 + 0.29 + 0.29} = 0.145$$

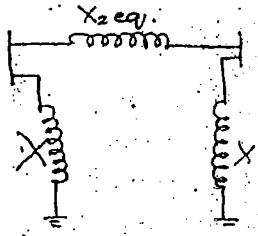
⇒



⇒



≡



× (Ignored according to assumptions)

$$\therefore X_2 eq = 0.395 + 0.295 + \frac{0.395 \times 0.295}{0.0725}$$

$$= 2.29 \text{ p.u.}$$

$$P_{m2} = \frac{EV}{X_2 eq} = \frac{1.2 \times 1.0}{2.29} = 0.52 \text{ p.u.}$$

Special Case (1) Fault occurs on a line near to Bus bar.

$$\therefore P_{m1} = \frac{EV}{X_{1eq}} = \frac{1.2 \times 1.0}{0.25 + \frac{0.58}{2} + 0.15} = 1.739 \text{ p.u}$$

$P_{m2} = 0$ (during fault max power transfer to load = 0)

$$P_{m3} = \frac{EV}{X_{3eq}} = \frac{1.2 \times 1.0}{0.25 + 0.58 + 0.15} = 1.224 \text{ p.u.}$$

(2) Fault occurs on bus bar.

$$P_{m1} = \frac{EV}{X_{1eq}} = \frac{1.2 \times 1.0}{0.25 + \frac{0.58}{2} + 0.15} = 1.739 \text{ p.u}$$

$P_{m2} = 0$, (since $P_{e2} = 0$)

$$P_{m3} = P_{m1} = \frac{1.2 \times 1.0}{0.25 + \frac{0.58}{2} + 0.15} = 1.739 \text{ p.u.}$$

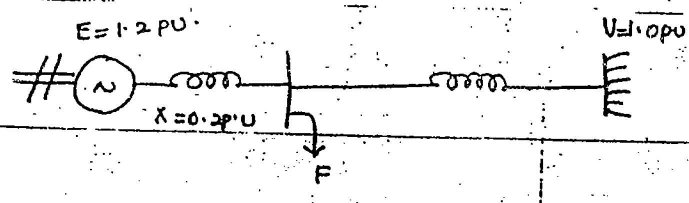
In the above two cases, the alternator is considered to be working under no load condition, which is not acceptable for more no. of cycles. Hence the C.B should be closed at faster rate. ($\because$ δ is ~~not~~ same)

$\therefore P_{m3} = P_{m1}$ but $P_{e3} \neq P_{e1}$

sie → If a fault occurs on bus bar then the alternator is isolated from the parallel tr. lines which will result as the no load operation of the alternator.

→ In order to avoid the no load operation of the alternator for more no of cycles, it can be assured that the breaker is closed at faster rate the entire n/w will be restored. Hence $P_{m3} = P_{m1}$

Ideal case

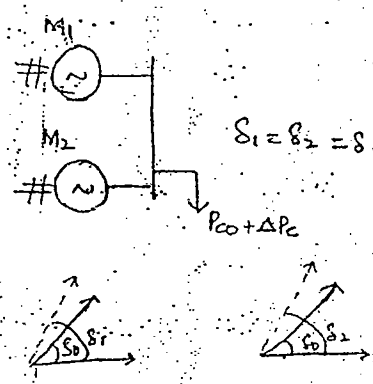


$$\therefore P_{m_1} = \frac{1.2 \times 1.0}{0.5} \text{ p.u} = 2.4 \text{ p.u}$$

$$P_{m_2} = 0 \qquad P_{e_2} = 0$$

$$P_{m_3} = P_{m_1} = \frac{1.2 \times 1.0}{0.5} = \frac{1.2 \times 1.0}{0.5} \text{ pu} = 2.4 \text{ p.u.}$$

→ SWINGING OF THE TWO MACHINES



$\delta_1 = \delta_2 = \delta$.

For any change of load, of it reflect in changing the position of rotor axes of both the machines then the two machines are swinging together

(or) For any change of load, of it will be shared by both the machines then the two machines are swinging together

$$P_{aeq} = P_{a1} + P_{a2}.$$

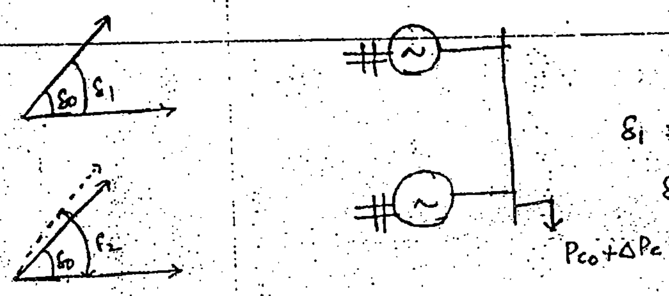
$$= M_1 \frac{d^2\delta_1}{dt^2} + M_2 \frac{d^2\delta_2}{dt^2}$$

$$M_{eq} \frac{d^2\delta}{dt^2} = (M_1 + M_2)\frac{d^2\delta}{dt^2}$$

$$\boxed{M_{eq} = M_1 + M_2}$$

For n-machine system, $M_{eq} = M_1 + M_2 + \dots + M_n$

→ TWO MACHINES DONOT SWINGING TOGETHER:



$\delta_1 \neq \delta_2$

$\delta = \delta_2 - \delta_1$

For any change of load, if it reflects in changing the position of the rotor axis of any one of the machine, then the two machines are donot swinging together.

(or)

If the change of load can only shared by only one of the machine then the two machines are donot swinging together.

$$\therefore \delta = \delta_2 - \delta_1$$

$$\frac{d^2\delta}{dt^2} = \frac{d^2\delta_2}{dt^2} - \frac{d^2\delta_1}{dt^2}$$

$$= \frac{P_{a2}}{M_2} - \frac{P_{a1}}{M_1}$$

$$\frac{d^2\delta}{dt^2} = \frac{P_{s2}-P_{e2}}{M_2} - \frac{P_{s1}-P_{e1}}{M_1} \Rightarrow (1)$$

Eq (1) has to become

$$P_{a\,eq} = P_{s\,eq} - P_{e\,eq}$$

Multiply on both sides of equation by $\frac{M_1 M_2}{M_1+M_2}$

$$\frac{M_1 M_2}{M_1+M_2}\frac{d^2\delta}{dt^2} = \frac{M_1 M_2}{M_1+M_2}\left[\frac{P_{s2}-P_{e2}}{M_2} - \frac{P_{s1}-P_{e1}}{M_1}\right]$$

$$\frac{M_1 M_2}{M_1+M_2}\frac{d^2\delta}{dt^2} = \left[\frac{M_1 P_{s2} - M_2 P_{s1}}{M_1+M_2}\right] - \left[\frac{M_1 P_{e2} - M_2 P_{e1}}{M_1+M_2}\right]$$

$$\therefore P_{aeq} = M_{eq} \frac{d^2\delta}{dt^2}$$

$$\therefore M_{eq} = \frac{M_1 M_2}{M_1 + M_2}$$

$$\therefore \boxed{\frac{1}{M_{eq}} = \frac{1}{M_1} + \frac{1}{M_2}}$$

For n-machine system.

$$\boxed{\frac{1}{M_{eq}} = \frac{1}{M_1} + \frac{1}{M_2} + \cdots + \frac{1}{M_n}}$$

→ In order to maintain the transient stability on a common bus bar where more than one synchronous machine is connected then it is preferred to allow the swinging of the two machines.

→ For a given accelerating power, there will be a slow rate of change of rotor angle if the moment of inertia will be high

$$M \frac{d^2\delta}{dt^2} = P_a$$

$$\downarrow \frac{d^2\delta}{dt^2} = \frac{P_a}{M \uparrow}$$

→ The swinging of the machines can be possible provided that the machines which are connected to common bus are of identical rating. ~~the inert~~

→ The Inertia of the synchronous m/c ~~in d~~ can also be expressed in the form of Inertia Constant.

$$\text{Inertia Constant } (H) = \frac{\text{K.E Stored in rotor}}{\text{Rating of the machine}} \quad MJ/MVA$$

$$= \frac{\frac{1}{2} I\omega^2}{S} = \frac{\frac{1}{2} I\omega \cdot \omega}{S} = \frac{\frac{1}{2} M \times 2\pi f}{S}$$

[illegible] radian

$$M = \frac{SH}{180f} \text{ degree.}$$

$$\Rightarrow \boxed{M \propto H}, \quad \boxed{H \propto \frac{1}{S}}, \quad \boxed{M \propto S}$$

* $\boxed{H_{eq} = H_1 + H_2 + \cdots + H_n}$ → Swinging together

$\boxed{\frac{1}{H_{eq}} = \frac{1}{H_1} + \frac{1}{H_2} + \cdots + \frac{1}{H_n}}$ → Donot swinging together

Ex: Gen-1 → capacity S_1 and H_1 Inertia constant = ?

Gen-2 → capacity S_2 and H_2.

Sol Inorder to maintain the swinging of the two machines, then the two machines will brought to a common base.

Let Common base → S_b

$$H_{1\,new} = \frac{H_{1\,old} S_{1\,old}}{S_b}$$

$$H_{2\,new} = \frac{H_{2\,old} S_{2\,old}}{S_b}$$

$$\therefore \boxed{H_{eq} = H_{1\,New} + H_{2\,New}}$$

EQUAL AREA CRITERIA

(i) It gives the solution for swing equation in a graphical manner

(ii) The Net area covered by the synchronous m/c during the first swing b/w the two swinging point will be ZERO (or).

The area covered during acceleration by the syn m/c will be same as the area covered during deceleration of the first swing.

Reference equation to prove (ii) is

$$M\frac{d^2\delta}{dt^2} = P_a$$

Multiply both sides with $2\frac{d\delta}{dt}$ and integrate w.r.t dt

$$\int M \frac{d^2\delta}{dt}\,\frac{2d\delta}{dt}\,dt = \int P_a \frac{2d\delta}{dt}\,dt$$

↓

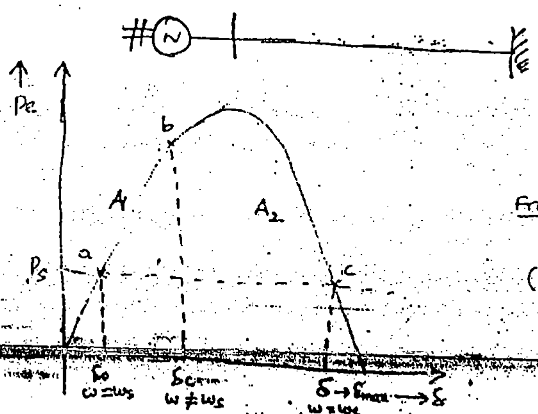
Mathematically

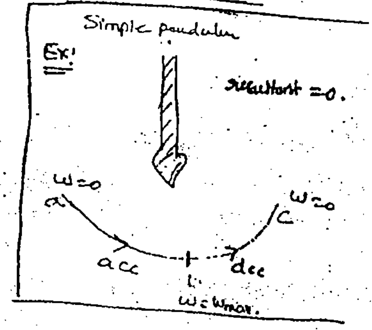
$$\int \cancel{\frac{d}{dt}} M\left(\frac{d\delta}{dt}\right)^2 = 2\int P_a \frac{d\delta}{\cancel{dt}} \times \cancel{dt} \quad \left(\because P_a = P_s - P_e = P_s - \underbrace{P_m \sin\delta}_{\text{Contour}}\right)$$

$$\frac{d\delta}{dt} = \left[\frac{2}{M}\int P_a\, d\delta\right]^{1/2}$$

The above expression should be proved, equal to ZERO

∴ For a m/c





From above eq

(a) $\left.\frac{d\delta}{dt}\right|_{\delta_0} = 0$

(b) $\left.\frac{d\delta}{dt}\right|_{\delta=\delta_{max}} = 0$

$$\therefore \frac{d\delta}{dt} = \left[\frac{2}{M}\int_{\delta_0}^{\delta} P_a \, d\delta\right]^{1/2}$$

$$\Rightarrow \int_{\delta_0}^{\delta} P_a \, d\delta = 0$$

(iii) The equal area criteria provides the critical clearing angle made by the syn m/c at the time of fault cleared by Circuit Breaker

(iv) Consider the FIRST swing for the stability analysis

A_1, A_2 (from power angle curve)

(a) If $A_1 < A_2 \rightarrow$ Stable.

(b) If $A_1 = A_2 \rightarrow$ Critically Stable

(c) If $A_1 > A_2 \rightarrow$ Unstable

(v) Even though δ_{max} is more than $90°$, inorder to get $\omega = \omega_s$ during the first swing but there are chances ~~the~~ to maintain the stability becoz it is the area comparison but not the angle comparison.

(vi) If the Synchronous m/c is stable during the first swing it could be also stable during the subsequent swings.

(vii) In Equal Area criteria it is unable to convert the critical clearing angle (δ_c) made by the breaker into critical clearing time

→ Applications:

(1) A Sudden increased mechanical i/p to the Synchronous generator

(2) A sudden increased mechanical o/p on Synchronous motor

(3) ~~Fault~~ occurs at the middle of the tr. line ~~in a~~ parallel transmission system

(4) Fault occurs on a line near to busbar, in a parallel transmission system

(5) Fault occurs on a bus bar in a parallel transmission system

(6) Fault occurs on an alternator connected to infinite bus through a lossless line

(7) Removal of one of the parallel tr. line by using fast acting circuit breaker forcebly

→ ASSUMPTIONS FOR EQUAL AREA CRITERIA

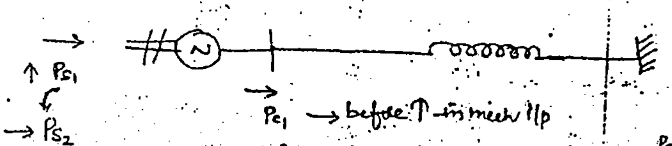
(i) $P_a = 0$ and $\omega = \omega_s$ then there is no change in the rotor angle at that position

(ii) $P_a \neq 0$ but $\omega = \omega_s$ (OR) $P_a = 0$ but $\omega \neq \omega_s$, then the rotor angle will change (↑ or ↓)

(iii) Consider the effect of moment of Inertia while explaining the Equal Area Criteria

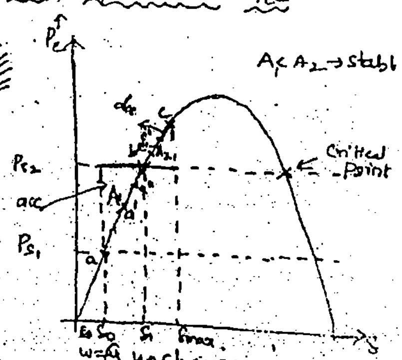
Applications

1) A Sudden increased in mechanical i/p to the synchronous m/c.



$\rightarrow P_{e_1} \rightarrow$ before ↑ in mech i/p

$\rightarrow P_{e_2} \rightarrow$ After ↑ in mech i/p



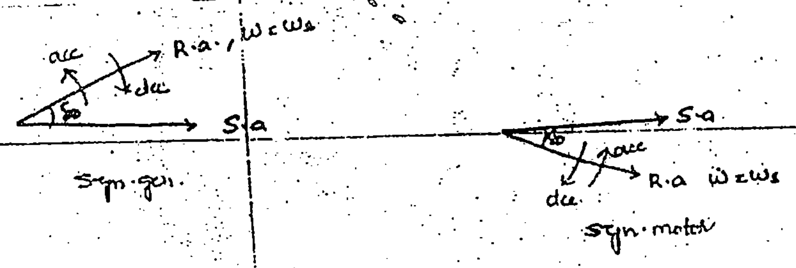
$$P_{e_1} = \frac{EV}{X_{eq}} \sin \delta_0$$

$$P_{e_2} = \frac{EV}{X_{2eq}} \sin \delta_0 = \frac{EV}{X_{eq}} \sin \delta \leftarrow$$ no change in transfer reactance

δ_0 $\omega = \omega_s$

δ_1 $\omega = \omega_{max}$ or $\omega = \omega_s$

$\delta_{max} = \omega = \omega_s$



→ Initially the Syn. generator is supplied with a mech i/p of P_{s1} and electrical o/p of P_{e1}. It is represented by Point 'a' on power angle curve.

→ If the mechanical i/p is suddenly increased from P_{s1} to P_{s2} where as there is no change in electrical o/p because the reactance of the system is same and due to large moment of inertia there is no sudden change in the rotor angle.

Hence $P = P_{s2} - P_{e1}$ (∵ Angle not changing, X not changing)

$= +ve$

$=$ acceleration $\Rightarrow \underline{\omega > \omega_s}$

→ Due to the relative speed of the synchronous m/c b/w the actual speed and the syn. speed then relatively there is change in rotor position.

⇒ Rotor angle will increase slowly.

→ The excess mech i/p will be stored in the rotor in the form of Kinetic Energy

→ The angle will ↑ beyond 'b' inorder to get $\omega = \omega_s$ in a condition that the electrical o/p must be more than mech i/p. Further it should also fulfill that the area which is covered beyond 'b' should be equal to the area which is already covered from 'a' to 'b'

→ The limiting point can be assumed as c

→ The K.E stored in the rotor will be converted into electrical i/p

	Power	Property	Speed	Remarks/obs
→ At a	$P = P_{s1} - P_{e1} = 0$	Neither acceleration nor deceleration	$\omega = \omega_s$	δ doesn't change
→ 'a' to 'b'	$P = P_{s2} - P_{e2}$ $= P_{s2} - \frac{EV}{X_{2eq}} \sin\delta$ $X_{2eq} < X_{1eq}$ and $(\delta > \delta_0)$ $= +ve$	Acceleration	$\omega > \omega_s$	δ will ↑ slowly
→ At 'b'	$P = P_{s2} - P_{e2}$ $= P_{s2} - \frac{EV}{X_{2eq}} \sin\delta_1$ $= 0$	Neither Acc. (or) Deceleration	$\omega = \omega_{max} > \omega_s$	According to (II) & (III) assumptions of equal area criteria the angle will ↑
→ 'b' to 'c'	$P = P_{s2} - P_{e2}$ $= P_{s2} - \frac{EV}{X_{2eq}} \sin\delta$ $\delta > \delta_1$	Deceleration	$\omega < \omega_{max}$ but $\omega > \omega_s$	δ will further
→ At 'c'	$P = P_{s2} - P_{e2}$ $= P_{s2} - \frac{EV}{X_{2eq}} \sin\delta_{max}$	deceleration	$\omega = \omega_s$	The angle δ starts decreasing
→ 'c' to 'b'	$P = P_{s2} - P_{e2}$ $= P_{s2} - \frac{EV}{X_{eq}} \sin\delta$ $(\delta < \delta_{max})$ $= -ve$	deceleration	$\omega < \omega_s$	The 'δ' ↓
→ At 'b'	$P = P_{s2} - P_{e2}$ $= P_{s2} - \frac{EV}{X_{2eq}} \sin\delta$ $= 0$	Neither deceleration nor acceleration	$\omega = \omega_{min} < \omega_s$	Due to 2nd & 3rd assumption of E.A.C. the rotor angle will continue ↓
→ 'b' to 'a'	$P = P_{s2} - P_{e2}$ $= P_{s2} - \frac{EV}{X_{2eq}} \sin\delta$ $+ve$ $(\delta < \delta_1)$	Acceleration	but $\omega < \omega_s$	δ further ↓

⟹ ~~Even though the synchronous m/c is swinging~~ there will be relatively change in rotor angle after completing each swinging.

For First swing taken into consideration

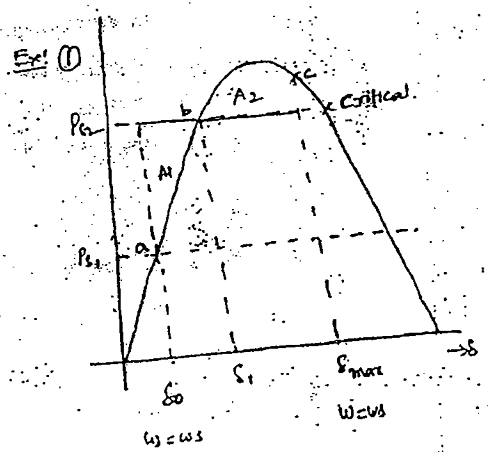
$A_1 < A_2 \longrightarrow$ Stable

$= +ve$

→ If $\omega = \omega_s$ is obtained before the critical point of the curve then the synchronous machine is stable

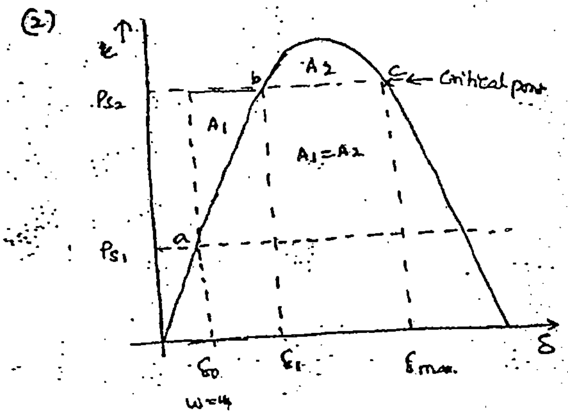
→ ** After completing the first swing the point is at 'b' the $\omega = \underline{\omega_s}$

Ex: (1)



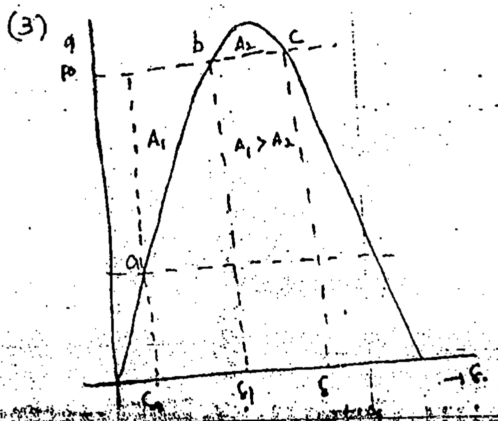
$\Rightarrow A_1 < A_2 \Rightarrow$ Stable

(2)



$\Rightarrow A_1 = A_2 \rightarrow$ Critically Stable.

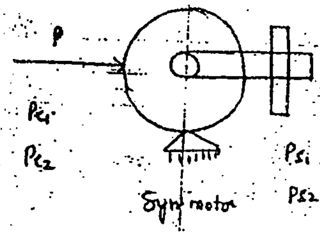
(3)



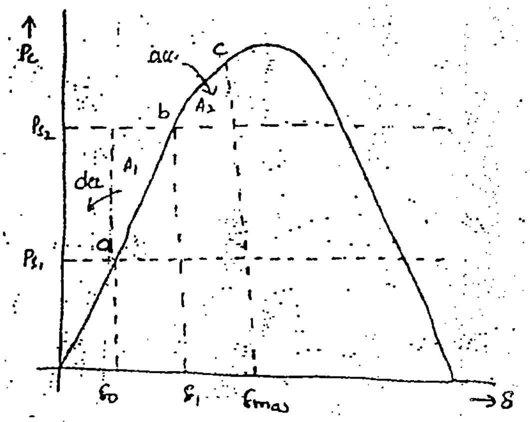
$A_1 > A_2 \Rightarrow$ Unstable.

→ The purpose of the equal area criteria is to calculate critical clearing angle made by rotor at the time of fault cleared by C.B by considering critically stable condition.

(ii) Sudden increase in the mechanical o/p of the syn. motor.



— The Equal Area Criteria of a synchronous motor is a mirror image to that of generator.



→ Initially the syn. motor is supplied with an electrical i/p P_{e_1} and the corresponding mech o/p P_{s_1}. It is represented by point 'a'

→ The mech o/p on the motor is suddenly ↑ where as there is no change in the electrical i/p because the reactance of the n/w is same and there is no sudden change in the rotor angle due to large moment of inertia.

$$P = P_{e_1} - P_{s_1}$$

$$-Ve$$

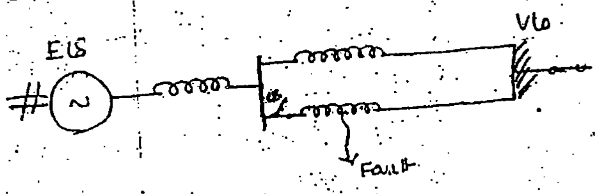
deceleration

$$\omega < \omega_s.$$

→ Due to relative speed of syn. motor the rotor angle will slowly increase

At 'a'	$P = P_{e1} - P_{s1}$ $= \frac{EV}{X_{1eq}} \sin\delta_0 - P_s$	Neither Acc nor decelerate	$\omega = \omega_s$ & does not change
'a to b'	$P = P_{e1} - P_{s1}$ $= -ve$	Deceleration	$\omega < \omega_s$
b			
b to c			
c			
c to b			
b			
b to a			

(3) Fault occurs in the middle of the tr. line in parallel Tr. system.



$P_{e1} = P_{m1} \sin\delta_0$

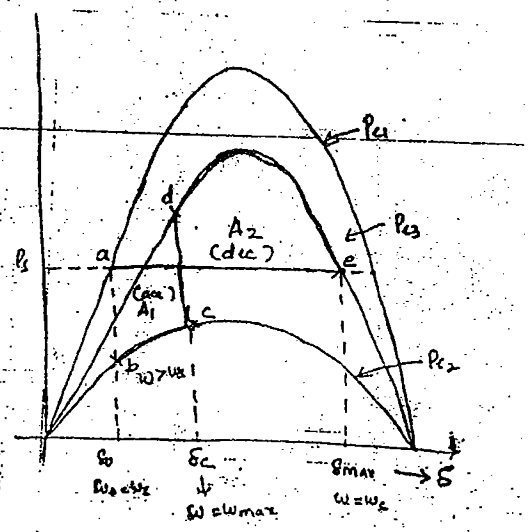
$P_{e2} = P_{m2} \sin\delta$ $\quad P_{m2} < P_{m3} < P_{m1}$

$P_{e3} = P_{m3} \sin\delta$

Initially the Syn. generator is supplied with mech I/P of P_s and the corresponding o/p of P_{e1}.

~~it is~~ represented by point 'a' on P_{e1} curve.

A 3-ϕ S-C fault has taken place at the middle of the tr. line so that the ~~electrical o/p is reduced suddenly due~~ to change in the reactance of the n/w even though there is no sudden change in the rotor angle. It is represented by point 'b' on P_{e2} curve.



However the mech i/p remain same. Hence

$$P = P_s - P_{e2}$$
$$= P_s - \frac{EV}{X_{2eq}} \sin\delta_0$$
$$= +ve \Rightarrow \text{acceleration of rotating body. and } \omega > \omega_s$$

At 'a'

$$P = P_s - P_{e1}$$
$$= P_s - \frac{EV}{X_{eq}} \sin\delta_0$$
$$= +ve$$

Acceleration $\omega = \omega_s$ δ does not change

'b' to 'c'

$$P = P_s - P_{e2}$$
$$= P_s - \frac{EV}{X_{2eq}} \sin\delta$$
$$(\delta > \delta_0)$$
$$= +ve$$

Acceleration $\omega > \omega_s$ δ will slowly ↑

'd' to 'e'

$$P = P_s - P_{e3}$$
$$= P_s - \frac{EV}{X_{3eq}} \sin\delta$$
$$(\delta > \delta_c)$$
$$= -ve$$

Deceleration $\omega < \omega_{max}$ but $\omega > \omega_s$ δ will further increase

Calculation of δ_c

$$\int_{\delta_0}^{\delta_{max}} P_a\, d\delta = 0 = \int_{\delta_0}^{\delta_c} P_a\, d\delta + \int_{\delta_c}^{\delta_{max}} P_a . d\delta = 0$$

$$= \int_{\delta_0}^{\delta_c} (P_s - P_{e2})\, d\delta + \int_{\delta_c}^{\delta_{max}} (P_e - P_{e3})\, d\delta = 0$$

$$= \int_{\delta_0}^{\delta_c} (P_s - P_{m2}\sin\delta)\, d\delta = \int_{\delta_c}^{\delta_{max}} (P_{m3}\sin\delta - P_s)\, d\delta$$

→ (Criticized after theory)

→ Due to relative speed the rotor angle will slowly increases

→ It can be assumed that the angle will ↑ slowly till the fault is cleared by the breaker after few cycles.

→ It can be assumed that the fault is cleared at 'c' and the angle corresponding to that is called "δ_c" (Critical clearing angle)

→ When the fault is cleared by the breaker, the faulty line is isolated and the alternator will deliver the electrical o/p with another healthy line. The electrical o/p is suddenly increased due to change in the reactance of the n/w even though the rotor angle is same.

– It is represented by point 'd' on P_{e3} curve. Whereas the mech i/p to the system is same. Due to moment of inertia of the rotating body the angle will ↑ further inorder to get $\omega = \omega_s$ in a critical stable manner.

$$\int_{\delta_0}^{\delta_{max}} P_a\, d\delta \Rightarrow \int_{\delta_0}^{\delta_c} (P_s - P_{m2}\sin\delta)\, d\delta = \int_{\delta_c}^{\delta_{max}} (P_{m3}\sin\delta - P_s)\, d\delta$$

$$\Rightarrow \left[P_s\delta + P_{m2}\cos\delta\right]_{\delta_0}^{\delta_c} = \left[-P_{m3}\cos\delta - P_s\delta\right]_{\delta_c}^{\delta_{max}}$$

$$\Rightarrow P_s\delta_c - P_s\delta_0 + P_{m2}\cos\delta_c - P_{m2}\cos\delta_0 = -P_{m3}\cos\delta_{max} + P_{m3}\cos\delta_c - P_s\delta_{max} + \cancel{P_s\delta_c}$$

$$\therefore P_s\delta_{max} - P_s\delta_0 + P_{m3}\cos\delta_{max} - P_{m2}\cos\delta_0 = P_{m3}\cos\delta_c - P_{m2}\cos\delta_c$$

$$\cancel{P_s(\delta_{max}-\delta_0) + P_{m3}\cos\delta_{max} - P_{m2}\cos\delta_0} = (P_{m3}-P_{m2})\cos\delta_c$$

$$\boxed{\delta_c = \cos^{-1}\left[\frac{P_s(\overset{(rad)}{\delta_{max}-\delta_0}) + P_{m3}\cos\overset{deg}{\delta_{max}} - P_{m2}\cos\delta_0}{P_{m3}-P_{m2}}\right]} \text{ elec. deg.}$$

$\therefore$ At 'a' $P_s = P_{e1} = P_{m1}\sin\delta_0$

$$\delta_0 = \sin^{-1}\left(\frac{P_s}{P_{m1}}\right) \text{ elec. deg}$$

$$\boxed{\delta_0 (rad) = \delta_0 \times \frac{3.14}{180}}$$

At 'e' $P_s = P_{e3} = P_{m3}\sin\delta_{max}$

$$\delta_{max} = \sin^{-1}\left(\frac{P_s}{P_{m3}}\right) \leq 90°$$

→ In a critically stable condition δ_{max} will be expected to be more than $90°$

$$\therefore P_s = P_{e3} = P_{m3}\sin(180-\delta_{max})$$

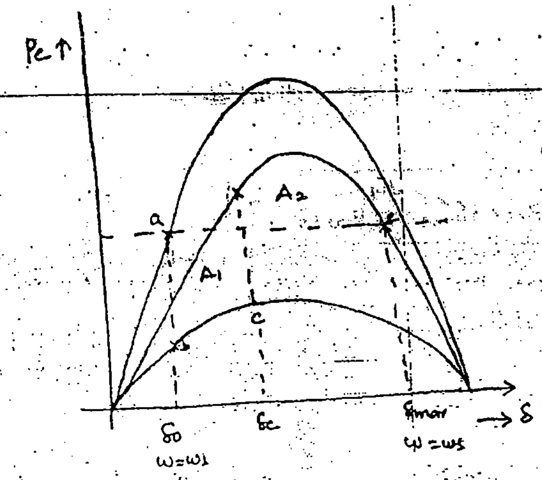
$$180 - \delta_{max} = \sin^{-1}\left(\frac{P_s}{P_{m3}}\right)$$

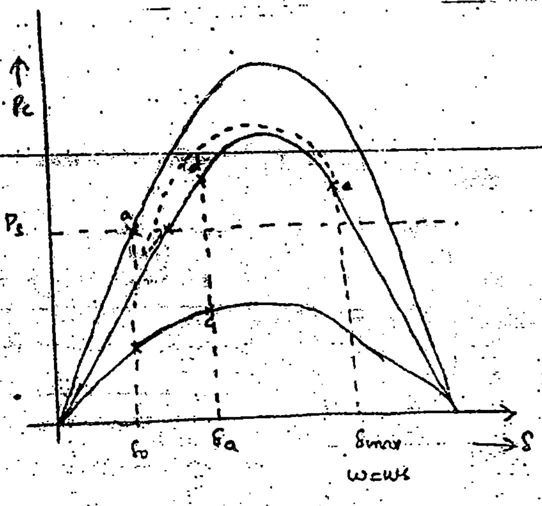
$$\therefore \delta_{max} = 180 - \sin^{-1}\left(\frac{P_s}{P_{m3}}\right) \text{ elec.}$$

$\delta_{max}(rad) = \delta_{max} \times \frac{3.14}{180}$ elc.

27/03/10

→ For any given system there will be a critical clearing angle which can be calculated by using the Equal area criteria. However the actual angle made by the breaker during the fault condition should be less than the critical clearing angle inorder to maintain the stability, otherwise





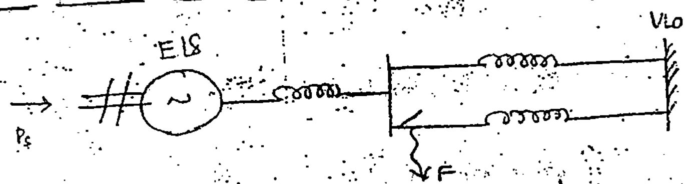
No further swings

(Critically stable)

$\delta_a < \delta_c$ Further swings

(stable)

(4) FAULT OCCURS ON A LINE NEAR THE BUSBAR

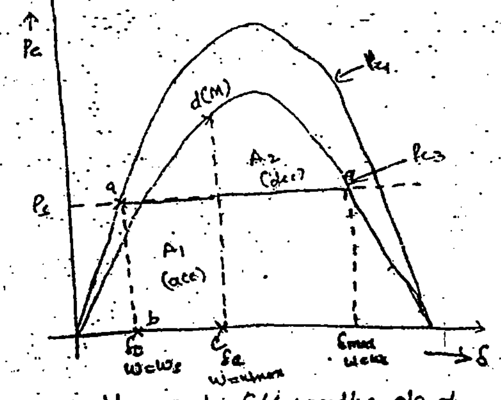


$P_{e_1} = P_{m_1} \sin \delta_0$

$P_{e_2} = 0$, $P_{m_2} = 0$

$P_{e_3} = P_{m_3} \sin \delta$

$\boxed{P_{m_3} < P_{m_1}}$



→ Initially the alternator is supplied with mech i/p and corresponding o/p of P_{e_1}. It is represented by point 'a'.

→ A 3-ϕ s.c fault is taken place on one of the parallel tr. line near to busbar and it will be assumed as fault on busbar so that the electrical o/p become zero whereas the mech i/p remains same. It is represented by point b. Hence $P_a = P_s - 0 = P_s$ ⇒ +ve (acceleration) $\omega > \omega_s$ (On)

At 'a' $P = P_s - P_{e1}$ $= P_s - P_{m1}\sin\delta_0$ $= 0$ Neither acc nor decelerate $\omega = \omega_s$ δ doesnot change

(iii) The rotor angle of the alternator will ↑ till the fault is cleared. The fault is cleared after few cycles and it can be represented by point 'c'. The angle corresponding to 'δ_c'

'b' to 'c' $P = P_s - P_{e2}$ $= P_s - 0$ $= P_s$ $= +ve$ Acceleration $\omega = \omega_s$ δ will slowly increase

→ If the fault is cleared by the breaker the faulty line is isolated and the alternator will able to deliver the electrical o/p through the healthy line which is represented by point 'd' with the same mech i/p. Due to moment of inertia the angle will increase further to get $\omega = \omega_s$ in a critically stable manner. is represented by point 'e'

d to e $P = P_s - P_{e3}$ $= P_s - P_{m3}\sin\delta$ $\Rightarrow (\delta > \delta_c)$ $= -ve$ Deceleration $\omega < \omega_{max}$ but $\omega > \omega_s$ δ will also further increase.

Calculation of δ_c

$$\int_{\delta_0}^{\delta_{max}} P_a\, d\delta = 0 = \int_{\delta_0}^{\delta_c} P_a\, d\delta + \int_{\delta_c}^{\delta_{max}} P_a\, d\delta = 0$$

$$= \int_{\delta_0}^{\delta_c} (P_s - P_{e2})\, d\delta + \int_{\delta_c}^{\delta_{max}} (P_s - P_{e3})\, d\delta = 0$$

$$\int_{\delta_0}^{\delta_c} (P_s - 0)\, d\delta = \int_{\delta_c}^{\delta_{max}} (P_{m3}\sin\delta - P_s)\, d\delta$$

$$\delta_c = \cos^{-1}\left[\frac{P_s(\delta_{max} - \delta_0) + P_{m3}\cos\delta_{max}}{P_{m3}}\right] \text{ ele. deg.}$$

→ of the accelerating power during the fault ~~is~~ constant for a special fault then the critical clearing angle which is calculated by ~~using equal area~~ criteria can be possible to convert into critical clearing time

$$M\frac{d^2\delta}{dt^2} = P_a = P_s - P_{e2} = P_s \qquad (\because \text{during fault } P_{e2} = 0)$$

$$\frac{d^2\delta}{dt^2} = \frac{P_s}{M}$$

$$\frac{d\delta}{dt} = \frac{P_s}{M}t$$

$$\delta = \frac{P_s}{M}\frac{t^2}{2} + A$$

of $t = t_c$

$$\delta_c = \frac{P_s}{M}\frac{t_c^2}{2} + A$$

Use initial condition to get a 'A' value

$t_c = 0$, before fault

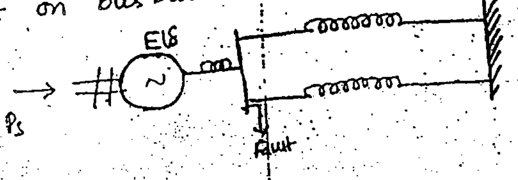
$$\delta_c = \delta_0 = 0 + A$$

$$\Rightarrow \delta_c = \frac{P_s}{M}\frac{t_c^2}{2} + \delta_0$$

$$\boxed{t_c = \sqrt{\frac{2M(\delta_c - \delta_0)}{P_s}}}$$

($M \rightarrow$ MJ-sec/rad.
$\delta_c - \delta_0 \rightarrow$ rad.
Since P_s = mech)

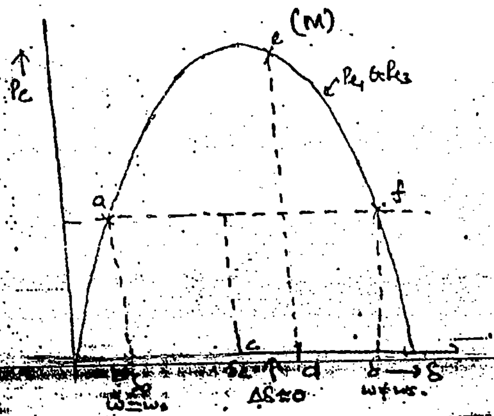
(5) Fault on bus bar



$P_{e1} = P_{m1}\sin\delta_0$

$P_{e2} = 0, \; P_{m2} = 0$

$P_{e3} = P_{m3}\sin\delta_f$



At 'a' $P = P_s - P_{e1}$
$= P_s - P_{m1}\sin\delta_0$
$= 0$

Neither acceleration nor deceleration $\omega = \omega_s$ δ doesn't change

→ A 3-φ short circuit fault occurs on the busbar so that the electrical o/p has become zero where as the mechanical i/p remains same. Hence it is represented by point 'b' hence

$$P = P_s - P_{e2}$$
$$= P_s - 0$$
$$= P_s\ (+ve)$$
acceleration
$$\omega > \omega_s$$

∴ The rotor angle of generator will slowly increase till the fault is cleared. The fault is cleared after few cycles and it can be represented by point 'c'

'b' to 'c' $P = P_s - P_{e2}$
$= P_s - 0$
$= P_s\ (+ve)$

Acceleration $\omega > \omega_s$ δ will increase slowly.

⇒ If the fault is cleared by the breaker then the alternator will be isolated from both the parallel lines so that the electrical o/p "zero". The mechanical i/p remains same. It will result that the alternator is working at no load condition and it behaves as an acceleration period. In order to avoid the no load operation of the alternator it can be assumed that the fault is cleared at a faster rate and CB is closed after few cycles so that the total n/w will be restored

→ It can be assumed that the breaker is closed at point 'd'

'c' to 'd' (No load position) $P = P_s - P_{e3}$
$= P_s - 0$
$= P_s\ (+ve)$

Acceleration $\omega > \omega_s$ δ will increase.

→ If the CB is closed, the alternator will deliver the electrical o/p by both the lines which can be represented by point 'e' and the mechanical i/p remains same. Due to moment of inertia the angle will increase further to get $\omega = \omega_s$ in a critically stable manner.

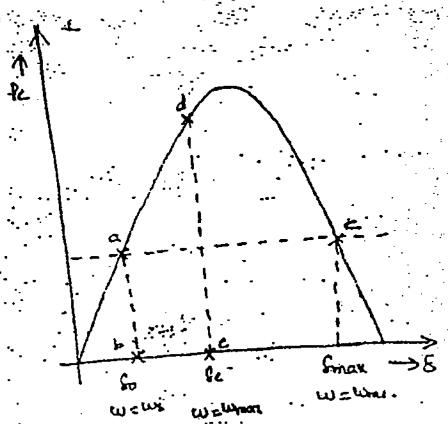
→ However the Synchronous machine will become unstable if $A_1 > A_2$ because the no load operation of the alternator will increase the acceleration region.
~~to the syn m/cs are critically stable.~~

→ The following assumptions are made

(1) The equal area criteria is a graphical solution and it can give an approximate critical clearing angle

(2) The no. of cycles during which the no load operation of the alternator are very few and the moment of inertia of the system is very high so that the change in rotor angle and the change in speed during the no load condition can be assumed as zero. (i.e. $\Delta\delta \simeq 0$, $\Delta\omega = 0$)

→ Calculation of δ_c



$$\int_{\delta_0}^{\delta_{max}} P_a \cdot d\delta = 0$$

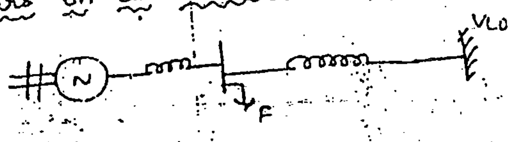
$$\int_{\delta_0}^{\delta_c} P_a \cdot d\delta + \int_{\delta_c}^{\delta_{max}} P_a \cdot d\delta = 0$$

$$\int_{\delta_0}^{\delta_c} (P_s - P_{e2})\, d\delta = \int_{\delta_c}^{\delta_{max}} (P_{e3} - P_s)\, d\delta$$

$$\therefore \quad \delta_c = \cos^{-1}\left[\frac{P_s(\delta_{max} - \delta_0) + P_{m3}\cos\delta_{max}}{P_{m3}}\right] \text{ elec-deg.}$$

$P_{m3} = P_{m1}$

(6) Fault occurs on an alternator connected to infinite bus through a loss less line.



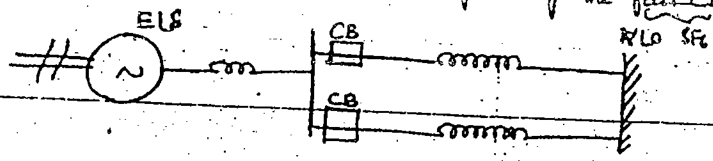
The equal area criteria of present application will be similar to that of the equal area criteria of the previous case(5)

$P_{e1} = P_{m1}\sin\delta_0$

$P_{e2} = 0,\ P_{m2} = 0$

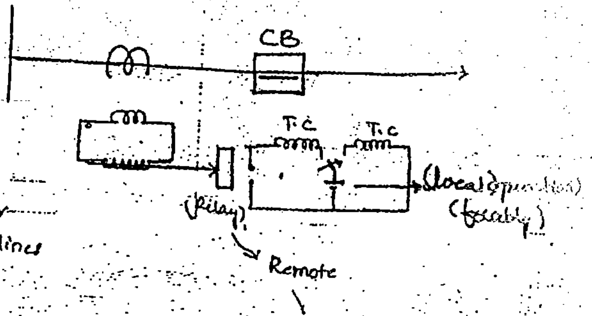
$P_{e3} = P_{m3}\sin\delta$

(7) Removal of one of the llel tr.line by using the fast CB possibly



$P_d > P_g \Rightarrow f \downarrow$ (by secondary)

up to 48.5 (tolerable)



$P_{e1} = \frac{EV}{X_{1eq}} \sin\delta_0$ Power transfer within two lines

$X_{1eq} = X_g + \frac{X_l}{2}$

$P_{m1} = \frac{EV}{X_{1eq}}$

$P_{e2} = \frac{EV}{X_{2eq}} \sin\delta_0$ → power transfer with one line.

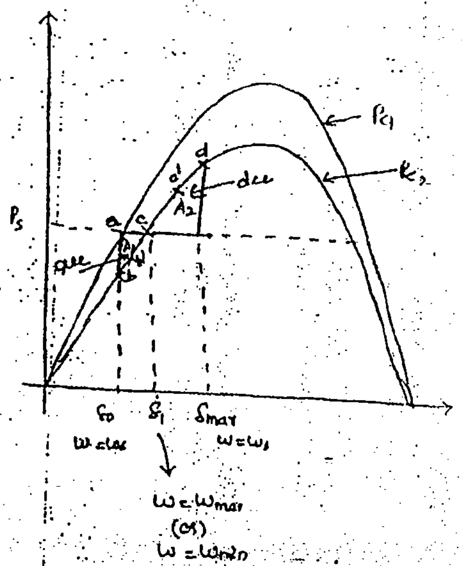
$= P_{m2} \sin\delta$

$P_{m2} = \frac{EV}{X_{2eq}}$; $X_{2eq} = X_g + X_l$.

$\boxed{P_{m2} < P_{m1}}$

→ Initially the alternator is supplied with a mean I/P of P_s and a corresponding output of P_{e1}. It is represented by point 'a' on P_{e1} curve

→ Whenever the existing load on the system is more than the available generation which can be identified by the way of falling of the system frequency, It is necessary to remove some of the existing load by way of isolating one of the connected tr. line by using Fast acting C.B's



→ At 'a' $P_a = P_s - P_{e1}$

$= P_s - \frac{EV}{X_{1eq}} \sin\delta_0$ Neither acc nor dec

$= 0$

δ doesn't change

→ The removal of the tr. line will leads to the transient stability on the syn. m/c and it can be analysed by using equal area criteria.

→ The falling of the frequency is an indication for load scheduling

→ The raising of the frequency is Backing down

→ If one of the tr. line is removed then the electrical o/p is reduced suddenly due to change in the reactance of the system where as the mech. i/p remains same

$$\therefore P = P_s - P_{e2}$$

$$= P_s - \frac{EV}{X_{2eq}} \sin \delta_0$$

$$= +ve$$

$$= \text{acceleration} \Rightarrow \omega = \omega_s$$

∴ 'δ' will slowly increases.

→ As the angle will increase the o/p power also slowly increases.

b to c	'd'	Same as 1^{st} case
c	'd' to 'c'	
c to 'd'	c 'c' to 'b'	

→ POINT – BY – POINT METHOD : (1) It gives the solution for swing equation in a mathematical manner

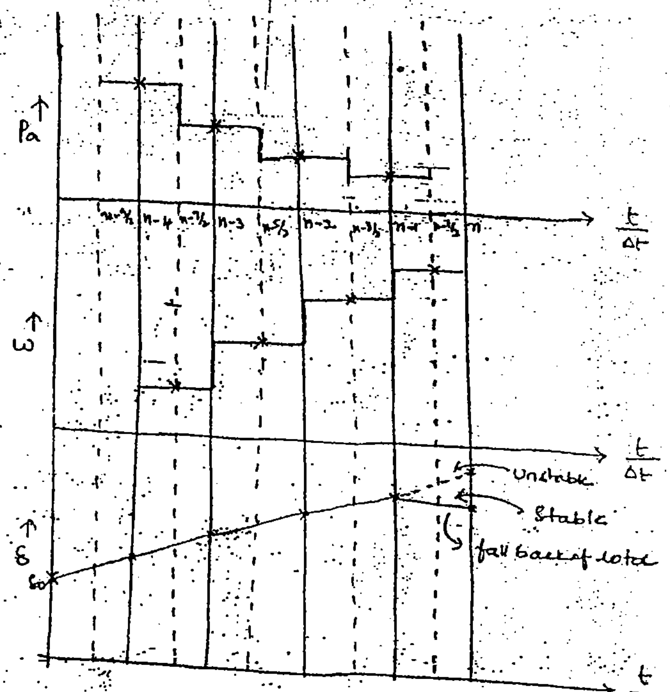
(2) The point by point method provides the change of angle made by the rotor for a smaller interval of time i.e Δt (0.05 sec by default). By knowing the change of angle then the actual angle ~~made~~ made by the rotor at the end of the interval will be calculated

→ The following assumptions are made inorder to calculate the change of angle and also the actual angle of the rotor.

(1) The accelerating power which is calculated at the begining of the interval is expected to be assumed as constant from the middle of the previous interval to the middle of the present interval.

(2) The angular velocity which is calculated at the middle of the interval is assumed to be constant through out the interval because of large moment of inertia

~~(3) The change of angle which is calculated at the beginning of the interval~~ is expected to have a smooth variation till the end of the interval.



→ In P-by-P method, the System is stable provided that the rotor angle is expected to be fall back after certain no. of intervals, then the system is stable Otherwise the system is Unstable.

Ex: After 5 cycles (F.clear):

1 - sec → 50 cycle.

? → 5 cycle.

$\frac{5}{50}$ = 0.1 & ↑ 0.15, 0.2 ... 0.5 up to 12 intervals to say the system is stable or not.

fault cleared. but continued ..

→ The change in angular velocity during the first interval $\Delta\omega_1 = \alpha . \Delta t$

Where $\alpha = \frac{Pa}{M}$;

→ The actual speed at the end of the interval. $\omega_1 = \omega_0 + \Delta\omega_1$

$\omega_0 \rightarrow$ initial speed i.e. N_s

→ The change of angle during 1st interval

$$\Delta\delta_1 = \Delta\omega_1 . \Delta t.$$
$$= (\omega_0 + \Delta\omega_1)\Delta t$$
$$= \omega_0 \Delta t + \alpha(\Delta t)^2$$
$$= \Delta\delta_0 + \alpha(\Delta t)^2$$

$$\boxed{\Delta\delta_1 = \Delta\delta_0 + \alpha(\Delta t)^2}$$

→ The actual angle at the end of 1st interval is

$$\delta_1 = \delta_0 + \Delta\delta_1$$

→ The change of angular velocity during 2nd interval is

$$\Delta\omega_2 = \alpha\Delta t \qquad \alpha = \frac{P_a}{M}$$

→ The actual speed at the end of interval $\omega_2 = \omega_1 + \Delta\omega_2$

→ The change of angle during 2nd interval. $\Delta\delta_2 = \omega_2 \Delta t$

$$= (\omega_1 + \Delta\omega_2)\Delta t$$

$$= \omega_1 \Delta t + \alpha(\Delta t)^2$$

$$\therefore \boxed{\Delta\delta_2 = \Delta\delta_1 + \alpha(\Delta t)^2}$$

→ The present change of angle not only depends on the accelerating power of present angle but also depends on the change of angle of previous interval.

→ The actual angle at the end of 2nd interval, $\delta_2 = \delta_1 + \Delta\delta_2$

∴ In general $\boxed{\Delta\delta_n = \Delta\delta_{n-1} + \alpha(\Delta t)^2}$

and

$$\boxed{\delta_n = \delta_{n-1} + \Delta\delta_n}$$

→ While calculating the change of angle consider the average accelerating power at the time of fault occur at the time of fault clear in all other intervals consider accelerating power only.

∴ <u>Fault occur</u>

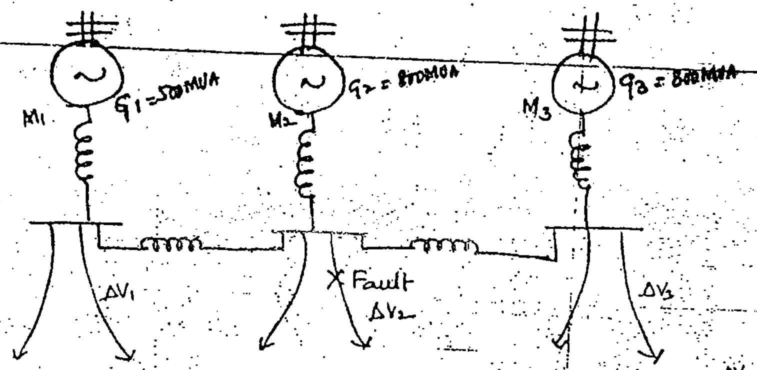
$$P_a(avg) = \frac{P_{a1} + P_{a2}}{2}$$

<u>Fault cleared</u>

$$P_a(avg) = \frac{P_{a2} + P_{a3}}{2}$$

3) Even though the synchronous m/c is stable during the 1st swing but there are chances to fall out of synchronism during the subsequent swing which cascade tripping of the syn. m/cs

→ Ex: cascade tripping of m/c's (or) grid failure.



$\Delta V_1, \Delta V_2, \Delta V_3$ are change in voltages.

1st swing — Moment of inertia & capacity — descending order

$\therefore \Delta V_2 > \Delta V_3 > \Delta V_1$

×G2, G3, G1

2nd swing
×G3, G1

3rd swing ×G1

If fault is on G1

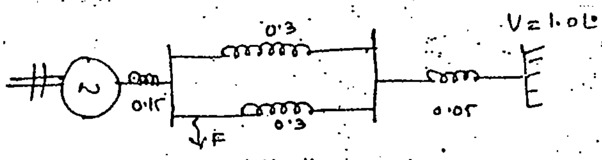
1st swing: ~~G1~~, G3, G2

2nd swing: G3, G2

3rd swing: G2

→ * If equal capacities of G's are there, then the G's which is near to the fault will swing 1st.

(Q)



The alternator is initially supplying 1.0 p.u to the infinite bus. The fault occurs on a line near to bus bar. The inertia constant is 4 p.u. Show the rotor angle by using point by point method for a time of 0.25 sec.

Sol

$$P_{m1} = \frac{EV}{X_{1eq}} = \frac{1.1 \times 1.0}{0.15 + \frac{0.3}{2} + 0.05} = 3.14\text{ p.u}$$

$$P_{m2} = 0 ; P_{e2} = 0$$

$$P_{m3} = \frac{EV}{X_{3eq}} = \frac{1.1 \times 1.0}{0.15 + 0.3 + 0.05} = 2.2\text{ p.u}$$

Time	$\Delta\delta$	δ
Initial. 0^-	0	18.57
	2.84	21.4
0.05		27.63
→ 0.1	6.23	33.74
0.15	6.1	38.57
0.2	4.83	41.32
0.25	2.75	

δ at 0^-

$P_s = P_{e1} = P_{m1}\sin\delta_0$.

$$\delta_0 = \sin^{-1}\left(\frac{P_s}{P_{m1}}\right)$$

$$= \sin^{-1}\left(\frac{1.0}{3.14}\right)$$

$$\delta_0 = 18.57$$

$$\Delta\delta_1 = \Delta\delta_0 + \alpha(\Delta t)^2$$

$$= 0 + \frac{P_a}{M}(\Delta t)^2$$

$$= \left(\frac{0.44\times10^{-3}}{0.5}\right)(0.05)^2$$

$$\Delta\delta_1 = 2.84$$

$$\therefore \delta_1 = \delta_0 + \Delta\delta_1$$

$$= 18.57 + 2.84$$

$$= 21.4.$$

$$M = \frac{SH}{180f}$$

$$= \frac{1.0\times4}{180\times50}$$

$$= 0.44\times10^{-3}$$

$$P_a = P_{avg}$$

$$= \frac{P_{a1}+P_{a2}}{2}$$

$$= \frac{0 + P_1 - P_2}{2}$$

$$= \frac{1.0-0}{2}$$

$$= 0.5$$

→ C.B. time is 5 cycles → $\frac{5}{50} = 0.1$

$$\Delta\delta_2 = \Delta\delta_1 + \alpha(\Delta t)^2$$

$$= 2.84 + \frac{P_{a(avg)}}{M}(\Delta t)^2$$

$$P_{a(avg)} = \frac{P_{a2}+P_{a3}}{2}$$

$$= \frac{P_s - P_{e2} + P_s - P_{e3}}{2}$$

$$= \frac{2P_s - P_{e3}}{2} = \frac{2P_s - P_{m3}\sin\delta_1}{2} = \frac{2(1) - 2.2\sin(21.4)}{2}$$

$$P_{a(avg)} = 0.598$$

$$\Delta\delta_2 = 2.84 + \frac{0.598}{0.44\times10^{-3}}(0.05)^2$$

$$= 6.23.$$

$\delta_2 = \Delta\delta_2 + \delta_1$

$= 6.23 + 21.4$

$= 27.63$

$\rightarrow \Delta\delta_3 = \Delta\delta_2 + \alpha(\Delta t)^2$

$= 6.23 + \frac{P_{a(avg)}}{M}(\Delta t)^2$

After fault condition, instead of taking P_{avg}.

$= 6.23 + \frac{P_s - P_{e3}}{0.44 \times 10^{-3}}(0.05)^2$

$= 6.23 + \frac{1.0 - 2.2\sin(27.63)}{0.44 \times 10^{-3}}(0.05)^2$

$= 6.1$

$\delta_3 = \delta_2 + \Delta\delta_3$

$= 27.63 + 6.1 = 33.74$

$\rightarrow \Delta\delta_4 = \Delta\delta_3 + \alpha(\Delta t)^2$

$= 6.1 + \frac{P_a}{M}(0.05)^2$

$= 6.1 + \frac{P_s - P_{e3}}{M}(0.05)^2$

$= 6.1 + \frac{1.0 - 2.2\sin(33.74)}{0.44(m)}(0.05)^2$

$= 4.83$

$\delta_4 = \Delta\delta_4 + \delta_3$

$= 4.83 + 33.74 = 38.57$

$\rightarrow \Delta\delta_5 = \Delta\delta_4 + \alpha(\Delta t)^2$

$= 4.83 + \frac{P_a}{M}(0.05)^2$

$= 4.83 + \frac{P_s - P_{e3}}{M}(0.05)^2$

$= 4.83 + \left(\frac{1.0 - 2.2\sin(38.57)}{0.44\,m}\right) \times (0.05)^2$

$= 2.73$

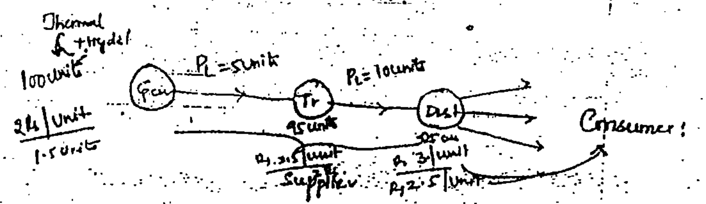
$\delta_5 = 2.75 + 38.57$

25/01/2010

→ ECONOMIC ASPECTS AND ECONOMIC LOAD DISPATCH

→ ~~ECONOMIC ASPECTS:~~

Minimize the cost/unit/annum of electrical energy generation so that the cost/unit/annum of electrical energy consumed by the consumer is minimum.



Consumer: Consumer satisfaction to the supplier. i.e.

1) Quality of the supply
2) Cost/unit is minimum

→ By proper mixing of thermal & hydel the cost of generation can be minimized so that the cost/unit for consumer is minimized.

$$\text{Unit} = 1000\ \text{Whr} = 1\ \text{KWhr.}$$

→ The cost/unit to the consumer is decided on annual basis

→ Cost: (1) fixed cost & 2) Running cost

→ Fixed Cost:

Ex: Thermal Station:

(1) Cost of the land
(2) Cost of buildings
(3) Cost of machinery
(4) Salaries of the Managers
(5) Interest & Insurance Charges
bank loan — fire hazards
(6) Depreciation charges

Organisation
→ Managers (Highly skilled)
→ Workmen (Semi skilled (or) Unskilled)

1 MW — 6 crore required.
100MW — 600 crore → go for bank loan

→ Depreciation: It is the cost in Rs/annum which is wasted, while the equipment is running.

Eg: Fan — Rs. 1000/-

Life = 10 years

Depreciation/annum = Rs 100 $\left(\frac{\text{Cost}}{\text{no. of years}}\right)$

(2) Running Cost:

(1) Cost of fuel

(2) Wages to workmen

(3) Maintainance Cost

→ Cost/unit/annum:

$$\text{Cost/unit/annum} = \frac{\text{Fixed Cost/annum} + \text{Running Cost/annum}}{\text{Total no. of units that are generated in a year}}$$

$$\text{Fixed Cost/annum} = \frac{\text{Fixed Cost}}{\text{No. of useful years (ie. life of plant)}}$$

Plant	Life
Gas station	15 years
Thermal	20 years
Nuclear	25 years
Hydel	50 years

* RCC buildings — 100 years.

$$\therefore \text{F.C/annum} = \frac{600\,\text{Cr}}{20\,\text{yrs}} = 30 \text{ Crores.}$$

Running/annum = 70 Crores (Assume)

Eg: BIKE

F.C → 50,000

F.C/an — 5,000

R.C — 365×50

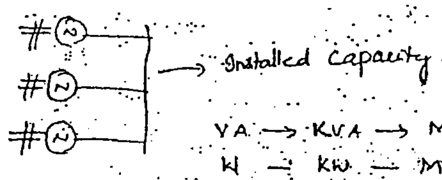
No. of Units = 500 Million Units

$\therefore$ Cost/unit/annum $= \frac{30+70}{500} = \frac{100 \times 10^7}{500 \times 10^6} = 2$ Rs/unit

→ The Cost/unit/annum can be minimised by Considering the load factor and the diversity factor.

1) Connected load (or) Installed Capacity:

→ The Arithmatic sum of the ratings of all the electrical equipments of a consumer (or) The Arithmatic sum of the ratings of the generators which are connected to a common bus is called Connected load (w.r.t consumer) or Installed Capacity (w.r.t gen. station)



VA → KVA → MVA X (Apparent power)
W → KW → MW ✓ (Real power)

→ In the Economic aspects and Economic load dispatch the rating of the equipment is in terms of the real power of the system.

→ The Connected load of the installed capacity can be considered remain same over a period of one year.

2) MAXIMUM LOAD: It is the highest amount of power being consumed by consumer or delivered by the generating station for a shorter interval of time over a specified period (24 hours)

→ For smooth functioning of the system without loosing the stability the planning is made on daily basis.

→ To maintain the Stability of the sync m/c, the M.L must be less than installed capacity.

$\boxed{M.L < I.C} \rightarrow$ Stable

$M.L = I.C \rightarrow$ Critically Stable

$M.L > I.C \rightarrow$ Unstable.

** → Reserve Capacity = Installed Capacity − Maximum Load.

$\Rightarrow$ Reserve = $I_C - M_L$

= +ve → Stable

= 0 (Critically stable)

= −ve → Unstable.

(3) Maximum Demand: The demand that can be forecasted prior to the day of

4) Average Load: It is the amount of power being consumed by the consumer or delivered by the generating station for most of the time over a specified period.

$$\text{Average load} = \frac{\text{Connected load of the Consumer}}{\text{No. of Equipments}} \quad (1 \text{ consumer})$$

(or)

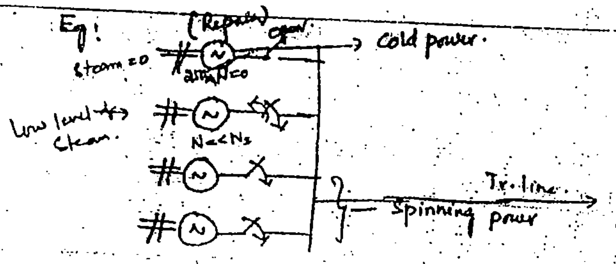
$$A.L = \frac{\text{Sum of the Connected load of the Consumer}}{\text{No. of Consumer}} \quad (\text{Consumer} > 1)$$

$\therefore \boxed{A.L < M.L < C.L}$

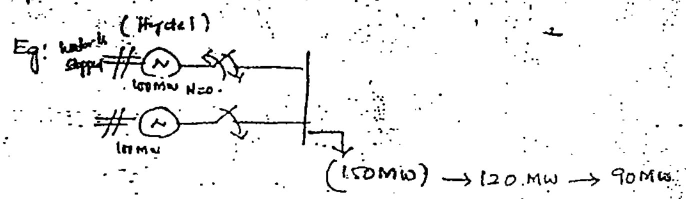
5) FIRM POWER: It is the amount of power available even during emergency condition

Eg: Diesel generators, Emergency lamps & Battery Banks.

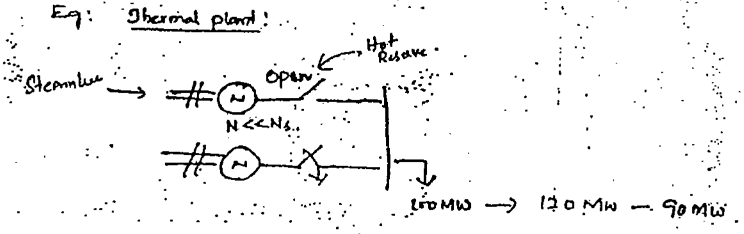
→ COLD POWER (or) COLD RESERVE: It is the amount of power available for service but not operation.
(Repairs)



→ HOT POWER or HOT RESERVE: It is the amount of power available for operation but not service.



Eg: Thermal plant:



→ The synchronization time of a gas plant for normal startup is 2 minutes.

For Hydel plants — 5 minutes, where as for thermal plant it is 8hrs. In order to reduce the syncization time the thermal units are kept under Hot reserve.

→ In case of Nuclear plant of they are exists, the variation of the load cannot be normally admitted when compared to other plants because it is very difficult to control the Nuclear reaction

→ Spinning power: (or) It is the amount of power available at the busbar due to synchronization of the units and the power is delivered to the load by using transmission lines.

→ LOAD FACTOR (or) PLANT LOAD FACTOR

$$L.F \text{ (or) } P.L.F = \frac{\text{average load}}{\text{Maximum load}} < 1.0$$

$$\text{(or)} = \frac{\text{Actual no. of units that are generated}}{\text{Maximum load} \times (\underbrace{\text{Total no. of hrs over a specified period}})}$$

Daily basis → Daily load factor → 24 (hrs)

Annual basis → Annual load factor → 8760 (hrs)

P.L.F (or) L.F is less than 100%.

→ In order to minimize the cost per unit the load factor of the system must be high

Eg PLF = 50%
PLF = 70% → prefered becoz cost is minimized compared to above.

→ If the load factor is high then the average load on the plant is almost equal to the maximum load so that there will effective utilization of the steam. The amount of fuel required is less which will reduce the fuel cost, which in turn reduces the running cost and finally the cost/unit is minimized. hence the L.F of the system will influence the Running cost.

Ex: Consumers

1) Domestic
2) Non-Domestic (or) Commercial
3) Industrial $\longrightarrow$ Bulk power (influence the simultaneous max load)
4) Agriculture
5) Public purpose.

(Q) Ex:

	C.L	M.L	Time	10-12	16-18	8-10
A	300kw	300	10-12 hrs	300	240	220
B	350kw	330	16-18 hrs	280	330	270
C	400kw	390	8-10 hrs	300	340	390
		1020		900	930	880

Simultaneous Max load (Installed capacity basis)

$\therefore$ Diversity Factor $= \frac{1020}{930} > 1$

— The Installed capacity is selected based on the simultaneous maximum load on the system which is less so that the fixed cost is reduced and finally the cost/unit is minimized.

→ In a practical case it is more flexible to ~~minize~~ minimize the R. cost when compared to the fixed cost of the system.

→ In a large system which is dealing with more no. of industrial consumers it is very difficult to reduce the installed capacity in order to reduce the fixed cost. Hence the cost/unit ~~can be minimized~~ effectively by using the load factor in order to reduce the running cost.

Ex:- A 100kW alternator

	D_1	D_2
00 – 3 hrs	30 kW	50 kW
3 – 6 hrs	70 kW	60 kW
6 – 9 hrs	95 kW	95 kW
9 – 12 hrs	60 kW	70 kW

In D_2 the effective utilization of steam is good.

hence L.F ↑ since Avg load ≃ Max load.

***
P.L.F = 80% and above in Nuclear plant

P.L.F = 60%–70% ⟶ Thermal plants

P.L.F = 30 – 40% ⟶ Hydel plants

P.L.F = 10 – 20% ⟶ Gas plant

→ DIVERSITY FACTOR:

$$\text{Diversity Factor} = \frac{\text{Arithmatic Sum of max loads of all the Consumers}}{\text{Simultaneous max load on the system}}$$

> 1.0

→ If the diversity factor of the system is high then the cost/unit is minimize

** → In order to minimize the cost/unit, The Load factor & the Diversity factor should be high.

→ The maximum loads of the consumers exists for only few hours and if the installed capacity is choosen based on the arithmatic sum of maxloads of all the consumers then the installed capacity is high. Hence the fixed cost of the system ⇒ the Cost per unit is high.

→ In order to reduce the fixed cost there will be effective utilization of the installed capacity i.e. select the installed capacity for a simultaneous max load on the system which is always less than the arithmatic sum of Max load of all the consumers

→ PLANT CAPACITY FACTOR:

$$\text{PLANT CAPACITY FACTOR} = \frac{\text{Average Load}}{\text{Installed Capacity}}$$

< 1.0 (or) $< 100\%$

$\boxed{\text{For a given plant ; PCF < PLF}}$ Since $PLF = \frac{\text{Avg load}}{\text{Max Load}}$

the installed Capacity $>$ Max load

If $PCF = PLF \Rightarrow M.L = I.C \Rightarrow$ Reserve $= 0$

Reserve = Installed capacity − Max load.

(Q) A plant is having a max load of 100 MW having the P.C.F = 50% and P.L.F = 70%. The Reserve Capacity of plant in MW is

Sol

P.C.F = 50% , PLF = 70%

$$\frac{PCF}{PLF} = \frac{\text{Max load}}{\text{Installed Capacity}}$$

$$\frac{0.5}{0.7} = \frac{100}{\text{Inst. capacity}}$$

$I.C = 140$ $(100 \times 7/5)$

Reserve $= 140 - 100 = \underline{\underline{40\,MW}}$

→ $\text{Plant Capacity Factor} = \dfrac{\text{Actual no. of units that are generated}}{\text{Max possible no. of units that can be generated based on the installed capacity}}$

< 1.0 (or) $< 100\%$.

For Ex: 100 KW − Generator

00 − 3 hrs − 80 KW   15 − 18 hrs − 70 KW

3 − 6 hrs − 50 KW   18 − 21 hrs − 90 KW

6 − 9 hrs − 30 KW   21 − 24 hrs − 80 KW

9 − 12 hrs − [illegible]

12 − 15 hrs − 60 KW

$$\therefore \quad PCF = \frac{80\times3 + 50\times3 + 80\times3 + 40\times3 + 60\times3 + 70\times3 + 90\times3 + 20\times3}{100\times24}$$

≤ 1 or $< 100\%$

→ PLANT USE FACTOR:

$$P.U.F = \frac{\text{Actual No. of units that are generated}}{\text{Installed capacity} \times (\text{Actual no. of hrs does the plant is working})}$$

$\boxed{\text{For a given plant, } PUF > PCF}$

$$P.U.F = \frac{\text{Max load}}{\text{Installed capacity}}$$

→ In order to know the max utilization of plant out of the installed capacity so far. Then the above definition is consider.

$$PUF = \frac{\text{Max. load}}{\text{Installed Capacity}} = \frac{\frac{\text{Max. load}}{\text{avg. load}}}{\frac{\text{Installed capacity}}{\text{avg. load}}} = \frac{\frac{1}{PLF}}{\frac{1}{PCF}} = \frac{PCF}{PLF}$$

$$\therefore \boxed{PUF = \frac{PCF}{PLF}}$$

→ PLF, Diversity Factor → Minimize Cost / unit, PCF → Addition of capacity, PUF → size of each unit

→ The load on the system i.e. the Avg load and the max load are increases from year to year and it require a proper planning of the installed capacity. The PCF and PUF are the basis to decide the selection of the amount of additional capacity to be added and also the size of each unit of the additional capacity.

Ex: 1000 MW.

1000 × 1 = 1000 MW → less reliable & uneconomical at light loads.

✓ 500 × 2 = 1000 MW → Reliable & ~~Easy~~ to maintain Synchronisation + Economical

250 × 4 = 1000 MW → Difficult to maintain the synchronisation.

→ Graphical Representations

→ LOAD CURVE: It gives the variation of the load w.r.t time over a specified period in a graphical manner.

— It can be Daily load curve (or) Monthly (or) Annual load curve.

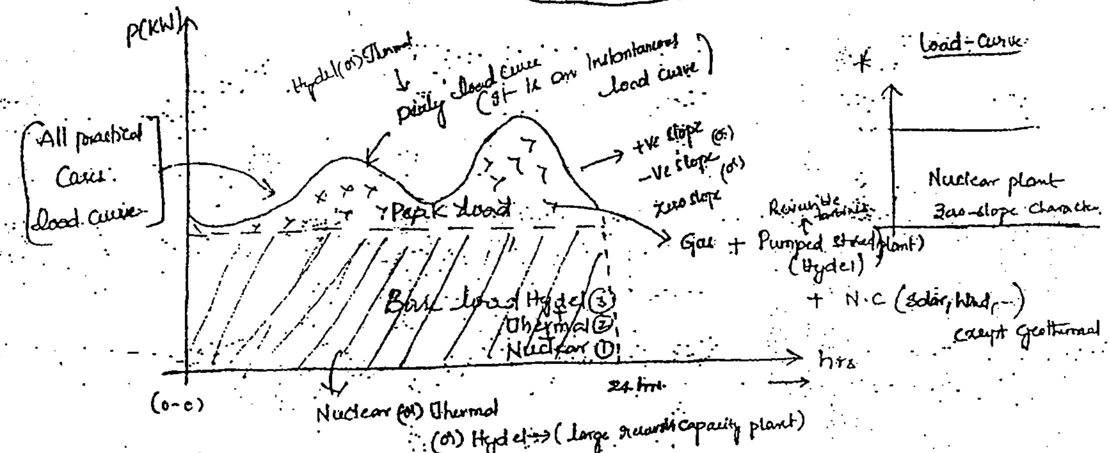


fig (i)

→

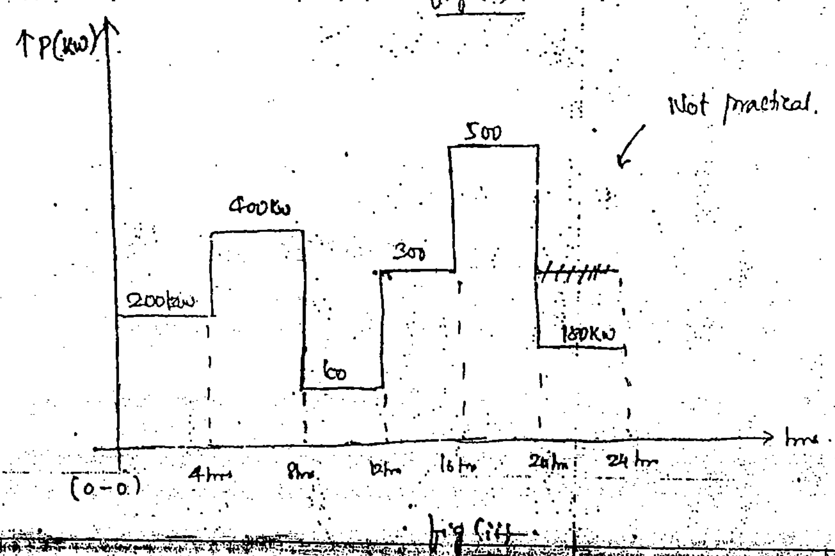


fig (ii)

From load Curve

(i) Area = $P \times t$ = No. of units generated (or) Consumed

(ii) Peak point = Max. load

(iii) Average load = $\frac{\text{Area}}{\text{no. of hrs}}$

(iv) PLF = $\frac{\text{average load}}{\text{Max. load}}$

(v) The load curve is the basis for load forecasting

∴ From fig(ii) Calculate the load curve values.

(i) No. of units generated = $4(200+400+100+300+500+150)$

$= 4(1650)$

Peak load = 500 KW.

Average load = $\frac{\text{Area}}{\text{No. of hrs}} = \frac{1650 \times \cancel{4}}{\cancel{24}_6}$ kms

PLF = $\frac{1650/6}{500} = \frac{1650}{6 \times 500}$

—x—

→ The No. of hours that the peak load plant will operate will be calculated by considering the cost analysis of the plants.

→ Cost Analysis:

1) Two-part

Base load ← Cost C_1 = Rs a_1/KW + Paise b_1/KWhr. → F.C / R.C

Peak load ← Cost C_2 = Rs a_2/KW + Paise b_2/KWhr.

⇒ $\boxed{a_1 > a_2}$, $\boxed{b_1 < b_2}$

$$C = C_1 + C_2$$

→ To get the total no. of time does the peak load plant will operate then ~~the total cost of the system should be minimum~~

$$P_1 = \text{Capacity of peak load}$$

$$P = \text{total capacity}$$

$$(P - P_1) = \text{Capacity of Base load}$$

'x_1' be the no. of units of peak load.

x be the total no. of units

$(x - x_1) \rightarrow$ be the no. of units of Base load

$$C = C_1 + C_2 = (P - P_1)a_1 + (x - x_1)b_1 + P_1 a_2 + x_1 b_2$$

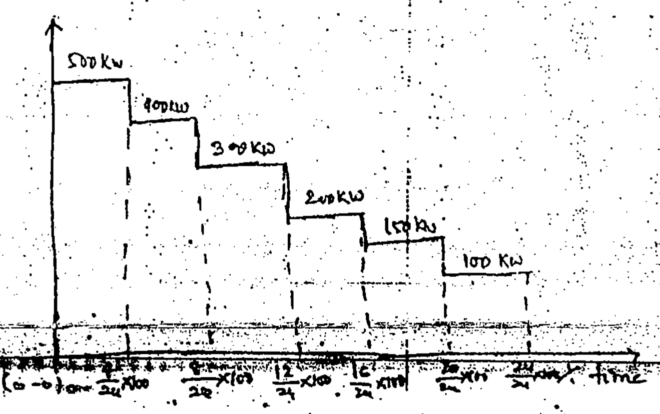
$$\frac{dC}{dP_1} = 0 = -a_1 + \left(-\frac{dx_1}{dP_1} \times b_1\right) + a_2 + \frac{dx_1}{dP_1} b_2$$

$$\Rightarrow \frac{dx_1}{dP_1}(b_2 - b_1) = -(a_2 - a_1)$$

No. of hrs $\Rightarrow$ $$\boxed{h = \frac{dx_1}{dP_1} = \left(\frac{a_1 - a_2}{b_2 - b_1}\right) \times 100}$$

→ LOAD DURATION CURVE (p.w) It can be obtained from a given load curve. It gives the variation of the load w.r.t percentage of time and the loads are rearranged in a descending order.

From fig (ii) Load curve



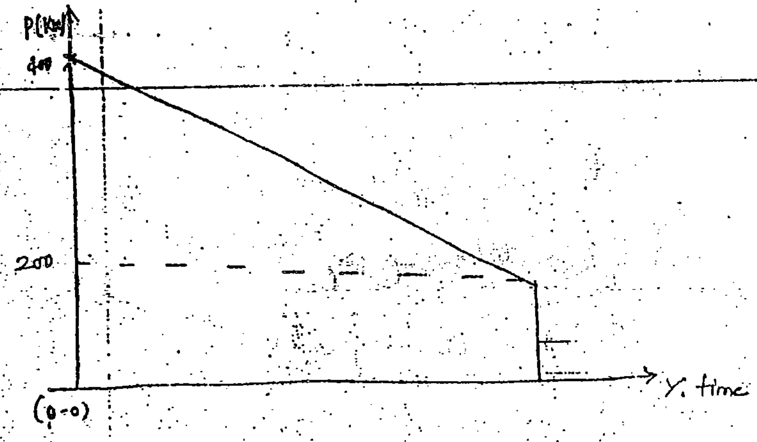
(Q) The Annual load duration curve of a system is as shown below.

(i) No. of units generated

(ii) Max load of the system

(iii) Avg load

(iv) PLF



(i) No. of units generated $= \frac{1}{2} \times b \times h + bl$.

$= \frac{1}{2} \times 8760 \times 200 + 8760 \times 200$

$= 8760 \times 300$ KWhrs.

(ii) Max load = 400 KW

(iii) Avg load $= \frac{\text{No. of Units}}{\text{No. of hours}} = \frac{8760 \times 300}{8760} = 300$ KW

(iv) PLF $= \frac{300}{400} = 0.75$

Another method

Avg load $= \frac{1}{2}(400+200) = 300$ KW.

No. of Units $= 8760 \times 300$ (Avg. load × No. of Hrs)

Max load = 400

(Q) The daily load duration curve of the system is as shown below

Sol/ Avg load $= \frac{1}{2}(300+0)$

$= 150$ KW

No of units $= 150 \times 24$ KW

Max load = 300 KW

PLF $= \frac{150}{300} = \frac{1}{2} = 0.5$

$= 50\%$

26/1/2010

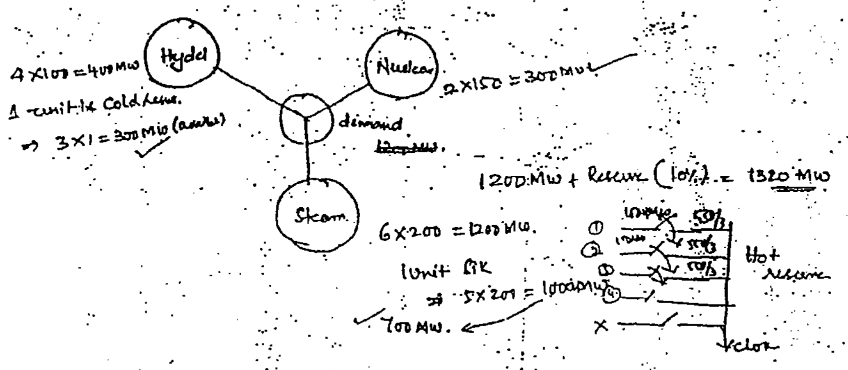
→ **ECONOMIC LOAD DISPATCH:**

(i) Pre-Load Dispatch (or) Unit Commitment

Select optimally the required no. of generating units from the available healthy units in order to meet the demand over a specified period of time with certain reserve capacity. The reserve capacity is necessary in order to meet the load over and above the demand to maintain the stability of the synchronous machines.

(ii) Online load dispatch: Allocate the existing load among the optimally selected units in such a way that the total fuel cost is minimised from time to time i.e. hour to hour basis.

Ex (i).



Ex (ii)

Load Cycle.

1) 00 – 3hrs — 750 MW.

⇒ 300 MW Nuclear + 300 MW Hydel + 150 MW Thermal

∴ Fuel cost is minimum

2) 3hrs – 6hrs — 900 MW.

⇒ 300 (N) + 300 (H) + 500 (Thermal)

⇒ Fuel cost is minimum

3) 6 – 9hrs ⇒ 1150 MW

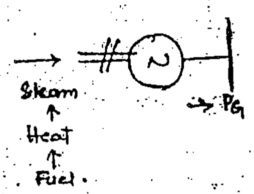
⇒ 300 (N) + 300 (H) + 550 (Thermal)

Thermal 200 200 H.R

⇒ 300 (N) + 300 (H) + 400 (Thermal)

⟹ The unit that is closed (operated) first is to open when the load decreases in the thermal p.station.

→ **Fuel cost Equation:**



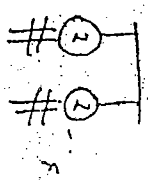
∴ Fuel cost equation

$$F = \frac{1}{2}\alpha P_G^2 + \beta P_G + \gamma \quad Rs/hr$$

(or)

$$C = \frac{1}{2}\alpha P_G^2 + \beta P_G + \gamma \quad Rs/hr.$$

If there are n-units connected to the bus, then

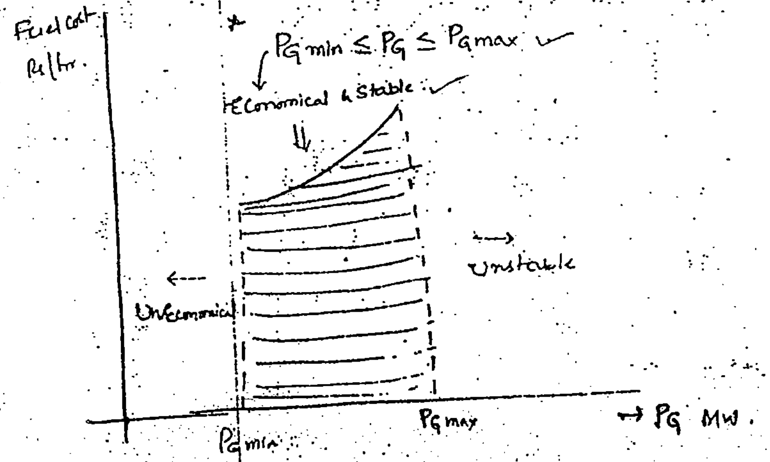


Fuel cost equation ⇒ $F_i = \frac{1}{2}\alpha_i P_{Gi}^2 + \beta_i P_{Gi} + \gamma_i \quad Rs/hr.$

$(i = 1, 2, 3 \dots n)$

→ Fuel cost equation is a Non-linear simultaneous equation.

→ α, β, γ are +ve real co-efficients



→ Minimize the Fuel cost

$$\therefore \frac{dF}{dP_G} = \text{Incremental Fuel cost equation}$$

$$= \alpha P_G + \beta \quad Rs/hr/MW = Rs/MWhr. \text{ (unit for Incremental fuel cost)}$$

For n-units

$$\frac{dF_i}{dP_{Gi}} = \alpha_i P_{Gi} + \beta_i \quad \text{Rs/MWhr.}$$

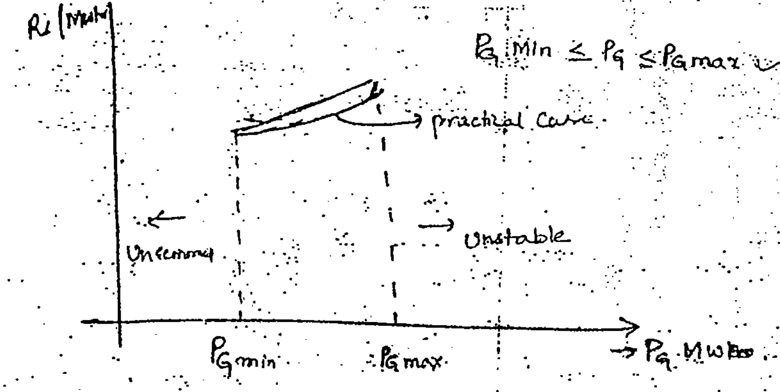
where $i = 1, 2, \ldots n$

α is the slope of Incremental fuel cost curve

β is the interception of the Incr. fuel cost curve

→ Graphical Representation

$P_{G\,min} \leq P_G \leq P_{G\,max}$ (IFC)



Ex: practical case

For a 200 MW plant

actual load — 100 MW

Fuel required is 500 Tonnes.

If actual load = 200 MW.

∴ Fuel required is less than 1000 Tonnes. because of internal efficiency of the system.

→ Two problems in Economic load dispatch

→ Problem 1: Minimize the total fuel cost of n-generating units which are optimally selected in such a way that the demand on system is equal to the total power generation and the tr. lines ~~are~~ loss are ignored. (loss-less problem)

$$\text{Min } F_T = F_1 + F_2 + \cdots + F_n = \sum_{i=1}^{n} F_i$$

Subjected to

$$P_d = P_{G1} + P_{G2} + \cdots + P_{Gn} = \sum_{i=1}^{n} P_{Gi}$$

Constrained Minimization

Ex:- Design $13.2/220kV$ power t/f of 200 MVA.

$\hookrightarrow$ Vijay ✗
CG ✓
SIEMENS ✓
L&T ✗
Radhika ✗
VVE ✗

design.

of $13.2/220kV$ PTR of 100 MVA with
No load loss not more than 0.5% of capacity

$\downarrow$ conditional manner for design. i.e. constrained manner.

$\rightarrow$ The above problem is having a constraint so that it cannot be solved by using ordinary minimization technique. The solution for the above problem can be obtained by using Simplex method of Optimization technique which says that construct an auxiliary function in terms the main function along with constraint

$\therefore$ Auxiliary function (F) = Main Function $F_T + \lambda$ (constraint)

$\lambda \rightarrow$ Lagrangian multiplier of the system.

$$\therefore F = \sum_{i=1}^{m} F_i + \lambda\left(P_d - \sum_{i=1}^{m} P_{Gi}\right)$$

Unconstrained Function

$\rightarrow$ If the auxiliary function is minimized then the main function will be minimized along with constraints

$$\therefore \frac{\partial F_i}{\partial P_{Gi}} = \frac{d}{dP_{Gi}} \sum_{i=1}^{m} F_i + \lambda\left(\frac{dP_d}{dP_{Gi}} - \frac{d}{dP_{Gi}} \sum_{i=1}^{m} P_{Gi}\right) = 0$$

$$\therefore \frac{d}{dP_{Gi}}\left(F_1 + F_2 + \cdots + F_i + F_n\right) + \lambda\left(\frac{dP_d}{dP_{Gi}} - \frac{d}{dP_{Gi}}\left(P_{G1} + P_{G2} + \cdots + P_{Gi} + P_{GN}\right)\right) = 0$$

$$= \frac{dF_i}{dP_{Gi}} + \lambda\left(0 - 1\right) = 0 \qquad \left[\because \frac{\partial F_i}{dP_{Gj}} = 0 \text{ when } i \neq j \text{ \& } \frac{dP_{Gi}}{dP_{Gj}} = 0 \text{ when } (i \neq j)\right.$$

$$\Rightarrow \boxed{\frac{dF_i}{dP_{Gi}} = \lambda \ \ Rs/MWhr}$$

$$\boxed{\frac{dF_1}{dP_{G_1}} = \frac{dF_2}{dP_{G_2}} = \frac{dF_3}{dP_{G_3}} = \cdots = \frac{dF_n}{dP_{G_n}} = \lambda} \ \text{Rs/MWhr} \longrightarrow (1)$$

~~The incremental fuel cost of m-generating units which are optimally~~ selected are same and is equal to the "Lagrangian multiplier" of the system

ASSIGNMENT: (Material)(Page 69–71)

(1) Given $F = 0.12\,P_g^2 + 20P_g + 40$ Rs/MWhr.

$P_G = 200$ MW

$\therefore \dfrac{dF}{dP_g} = 0.24P_g + 20$ Rs/hr.

$\Rightarrow$ 75% of capacity $= 150$ $\left(\frac{75}{100} \times 200\right)$

$\therefore F = 0.12\,(150)^2 + 20\,(150) + 40$ Rs/MWhr.

Fuel cost/day $=$ Fuel cost in Rs/hr $\times 24$

$\therefore \dfrac{dF}{dP_g} = 0.24\,(150) + 20$ Rs/MWhr.

When Full loaded

$F = 0.12\,(200)^2 + 20(150) + 40$

$\dfrac{dF}{dP_g} =$

(2) $F_1 = 0.2P_1^2 + 30P_1 + 60$

$F_2 = 0.15P_2^2 + 20P_2 + 80$

$\lambda = 120$

$\therefore \dfrac{dF_1}{dP_1} = \dfrac{dF_2}{dP_2} = \lambda = 120$

[illegible] $= 120$

$P_1 = 120 - 30 / 0.4$; $P_2 = \dfrac{120 - 20}{0.3}$

Power received by the load $P_d = P_1 + P_2$ (Assumption : Loss less)

(10) ~~Given~~ $\frac{dF_1}{dP_1} = 0.12P_1 + 16 = \frac{dF_2}{dP_2} = 0.2P_2 + 24 = \frac{dF_3}{dP_3} = 0.15P_3 + 18 = \lambda$

* The Lagragian multiplier 'λ' is also called as "The cost received for each plant"

(Q3). $P_1 + P_2 = 150 \longrightarrow (1)$

$\frac{dF_1}{dP_1} = \frac{dF_2}{dP_2} \Rightarrow 0.1P_1 + 20 = 0.12P_2 + 16$

$\Rightarrow P_1 = \frac{0.12P_2 + 16 - 20}{0.1}$

$P_1 = 1.2P_2 - 40 \longrightarrow (2)$.

$\therefore$ From (1) $1.2P_2 - 40 + P_2$ ~~$1.2P_2 + P_0 + P_2$~~ $= 150$

$P_2 = \frac{190}{2.2}$

$= \underline{86.36\ MW}$

$P = 1.2P_2 - 40 = \underline{63.64\ MW}$

$\lambda = 0.1P_1 + 20 = 0.1(63.64) + 20$

(or)

$= 0.12P_2 + 16 = 0.12(86.36) + 16$

(Q4) The fuel cost of the 3-units.

H.W.

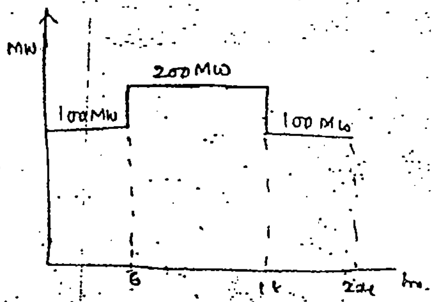
$F_1 = 0.1P_{G1}^2 + 20P_{G1} + 40$ Rs/hr $F_2 = 0.15P_{G}^2 + 16P_{G1} + 30$ Rs/hr

$F_3 = 0.2P_{G3}^2 + 12P_{G3} + 24$ Rs/hr The total load on the system is 600 MW. Neglect the tr. line losses and find the most economical division of the load among the three units.

Sol ~~$P_1 + P_2 + P_3 = 600\ MW$~~

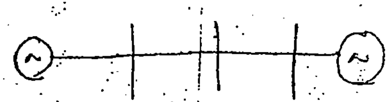
(04) $F_1 = 0.15P_1^2 + 20P_1 + 30$

$F_2 = 0.2P_2^2 + 16P_2 + 20$ } Rs/hr.



$F_T = \underbrace{(F_1 + F_2) \times 12}_{100 MW} + \underbrace{(F_1 + F_2) \times 12}_{200 MW}$.

(12) $F_1 = a + bP_1 + cP_1^2$, $F_2 = a + bP_2 + 2cP_2^2$



$P_1 + P_2 = 300$ MW.

$$\frac{dF_1}{dP_1} = \frac{dF_2}{dP_2} = 2P_1 + b = 4cP_2 + b$$

$P_1 = 2P_2$

$\therefore 2P_2 + P_2 = 300$

$P_1 = 200$ MW, $P_2 = 100$ MW.

(09) $I_{c1} = 0.3P_1 + 20$,

$I_{c2} = 0.4P_2 + 30$, $I_3 = 30$ Rs/MWhr.

$50 \le P_i \le 300$

$I_{c1} = I_{c2} \ne I_{c3}$

→ The $\overset{\text{Incr. Fu. c}}{IC_3}$ of unit '3' is 30 Rs/MWhr, which remains same for any generation of plant '3' hence 300 MW will be assigned for plant '3' and balance 400 MW will be allocated b/w plant 1 and plant 2.

$I_{c3} = 30$ — 50 ✗, 300 ✓

$\therefore P_{G_1} + P_2 = 400$.

$I_{c1} = I_{c2} = 0.3P_1 + 20 = 0.4P_2 + 30$.

(07) $P_{G1} = -120 + 60I_{c1} - 2.5I_{c1}^2$

$P_{G2} = -140 + 40I_{c2} - 2I_{c2}^2$

$P_{G3} = -90 + 50I_{c3} - 1.5I_{c3}^2$

$I_c \to$ Rs/MWhr.

P_G = MW.

$I_{c1} = I_{c2} = I_{c3} = \lambda$

$P_{G1} + P_{G2} + P_{G3} = 500$

$-120 + 60\lambda - 2.5\lambda^2 - 140 + 40\lambda - 2\lambda^2 - 90 + 50\lambda - 1.5\lambda^2 = 500$

$-6\lambda^2 + 150\lambda - 350 = 500$

$6\lambda^2 + 150\lambda - 850 = 0$.

$\lambda = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

$$\lambda = \frac{-150 \pm \sqrt{(150)^2 - 4(-6)(850)}}{2(-6)}$$

$\therefore \lambda = 8.68$ Rs/MWhr ✓ (less)

$\lambda = 16.31$ Rs/MWhr ✗ (More)

$\therefore PG_1 = -120 + 60(8.68) - 2.5(8.68)^2 =$

$PG_2 = -140 + 40(8.68) - 2(8.68)^2 =$

$PG_3 = -90 + 50(8.68) - 1.5(8.68)^2 =$

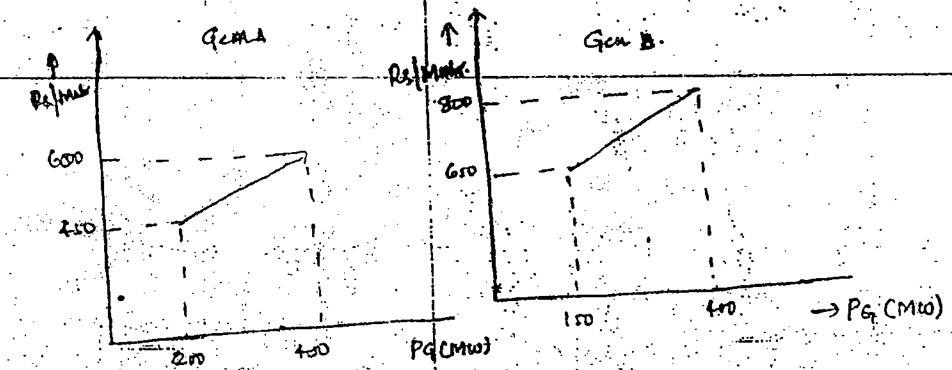
(22)

$$\left.\begin{aligned} C_1(PG_1) &= 0.006\,PG_1^2 + 8PG_1 + 350 \\ C_2(PG_2) &= 0.009\,PG_2^2 + 7PG_2 + 400 \end{aligned}\right\} \text{Thousand Rs/hr.}$$

$100\text{ MW} \le PG_1 \le 650$; $50\text{ MW} \le PG_2 \le 500$.

~~Total~~ $P = 600$

Gate-07
(Q5) The I.F. Cost of two generators are as follows.



The most economical division of the load of 700 MW b/w the two ___ units. Neglect the tr. line losses.

Sol

Gen A

Mini Gen — 200 — Rs. 450/MWhr.

Max Gen — 450 — Rs. 600/MWhr

Gen B

Min Gen — 150 MW — Rs. 650/MWhr.

Max. Gen — 400 MW — Rs. 800/MWhr.

The incremental fuel cost of a maximum generation for plant 'A' is less than the increment fuel cost of minimum generation from plant 'B' hence $PG_A = 450$ MW, $PG_B = 250$ MW

(06) $\frac{dF_1}{dP_1} = 0.1P_1 + 20$, $\frac{dF_2}{dP_2} = 0.12P_2 + 15$

Load = 300 MW.

Capacity of each = 200 MW.

(i) Most economical division

$P_1 + P_2 = 300 \rightarrow (1)$

$\frac{dF_1}{dP_1} = \frac{dF_2}{dP_2}$

$0.1P_1 + 20 = 0.12P_2 + 15$

$\Rightarrow P_1 = \frac{0.12P_2 + 15 - 20}{0.1} = 1.2P_2 - 50 \rightarrow (2)$

$P_1 = 140.9$ MW

$P_2 = 159.1$ MW

Total Fuel cost $F = F_1 + F_2 = 0.1\frac{P_1^2}{2} + 20P_1 + \gamma_1 + 0.12\frac{P_2^2}{2} + 15P_2 + \gamma_2$

~~$F = 0.05(140.9)^2 + 20(140.9) + 0.06(159.1)^2 + 15(159.1) + \gamma_1 + \gamma_2$ Rs/hr.~~

$F =$

(ii) Equal load Sharing

$P_1 = P_2 = 150$ MW.

$\therefore$ Total Fuel cost $F = F_1 + F_2 = 0.05(150)^2 + 20(150) + 0.06(150)^2 + 15(150) + \gamma_1 + \gamma_2$ Rs/h

When the load is shared equally the total fuel cost of the system is high so that it is to be called un economical division of the load.

(ii) − (i). = Saving of Fuel cost = Rs/hr.

Saving / Annum = Saving in Rs/hr × 8760

→ Problem 2 (Loss problem)

Minimise the total fuel cost of 'n' generating units which are optimally selected in such a way that the demand on the system and also the transmission line losses are equal to the total power generation

$$\left.\begin{array}{l} \text{Min } F_T = \sum_{i=1}^{n} F_i \\ \text{Subjected to} \\ P_d + P_L = \sum_{i=1}^{n} P_{Gi} \end{array}\right\} \text{Constrained Minimization}$$

P_L = Transmission line loss

→ If the trans. line loss is included for a given demand, then the generation capacity will increase so that fuel cost of the system will increase hence the tr. line loss should be expressed mathematically having as a function of generation schedules.

$\therefore\ P_L = \text{Trans. line loss} = \sum_{i=1}^{n} \sum_{j=1}^{n} P_{Gi} B_{ij} P_{Gj} \longrightarrow$ A Non-linear Simultaneous equation

P_{Gi} = Generation of i^{th} unit

P_{Gj} = Generation of j^{th} unit

B_{ij} = Loss co-efficient of i^{th} & j^{th} units.

n = no. of generating units.

* Unit of loss coefficient B_{ij} is MW^{-1} or $\frac{1}{MW}$.

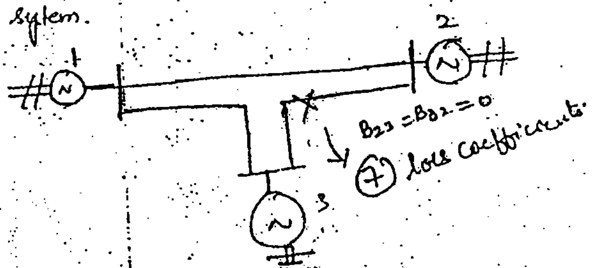
→ To express a trans. line loss.

Ex: Two Bus system.

$\therefore P_L = B_{11} G_1^2 + P_{G1} B_{12} P_{G2} + P_{G2} B_{21} P_{G1} + B_{22} P_G^2$

⟹ (4) loss coefficients.

— For 3-Bus system.



$P_L = B_{11} P_{G1}^2 + P_{G1} B_{12} P_{G2} + P_{G1} B_{13} P_{G3} + P_{G2} B_{21} P_{G1} + B_{22} P_G^2$
$+ P_{G2} B_{23} P_{G3} + P_{G3} B_{31} P_{G1} + P_{G3} B_{32} P_{G3} + B_{33} P_G^2$

⟹ (9) Loss Coefficients

→ For 4-Bus system

16 loss coefficients.

For n-Bus system n^2 — loss coefficients

→ For a given demand if all the loss coefficients are proposed then the total amount of loss will be high so that the generation schedules are high and the total fuel cost of the system is high. However, it is necessary to reduce the transline loss for a given demand for which some of the loss coefficients must be zero. i.e by using minimum no. of translines it should ensure that the power system n/w will be an interconnecting network.

→ For a n-bus system the most of the loss coefficients will become zero and there are few loss coefficients which are non-zero's

→ Loss Coefficients
- Self → B_{ii} (or) B_{jj} ($i=j$ (or) $j=i$) → Stronger Magnitude (+ve)
  $B_{ii} \neq B_{jj}$ (No two G.S has same production)
- Mutual → B_{ij} (or) B_{ji} ($i \neq j$) → Weak Magnitude (−ve)
  $B_{ij} = B_{ji}$

(Q) Which of the following relations holds good for the loss coefficients

(i) $B_{11} = B_{12} = 0.0088$, $B_{21} = B_{22} = 0.006$

(ii) $B_{11} = 0.008$; $B_{12} = B_{21} = -0.006$ $B_{22} = 0.004$

(iii) $B_{11} = B_{22} = 0.008$ $B_{12} = B_{21} = +0.004$ ~~$B_{22} = 0.004$~~

(iv) ✓ $B_{11} = 0.006$ $B_{12} = B_{21} = -0.002$ $B_{22} = 0.008$ (Magnitude of B_{12}, B_{21} must be less than B_{11}, B_{22})

→ Even though the demand on the system is constant but the connected transmission line loss will changes as the generation schedules are changes.

→ Even though the tran. line loss changes as the generation changes but the loss coefficient remains same.

Solution:

Auxillary Function (F) = Main Function F_T + λ (Constraint)

$$= \sum_{i=1}^{n} F_i + \lambda\left(P_d + P_L - \sum_{i=1}^{n} P_{Gi}\right)$$

— Minimize the Auxi Function along with constraints in order to minimize the of main function

$$\frac{dF}{dP_{Gi}} = \frac{d}{dP_{Gi}} F_i + \lambda \frac{dP_d}{dP_{Gi}} + \frac{dP_L}{dP_{Gi}} - \frac{d}{dP_{Gi}} \sum_{i=1}^{n} P_{Gi}) = 0$$

$$\therefore \underbrace{\frac{dF_i}{dP_{Gi}}}_{\text{incremental fuel cost}} + \lambda \Big(0 + \underbrace{\frac{dP_L}{dP_{Gi}}}_{\text{Incremental trans. line loss.}} - 1\Big) = 0$$

$$\frac{dF_i}{dP_{Gi}} = \lambda\left(1 - \frac{dP_L}{dP_{Gi}}\right)$$

$$\therefore \frac{dF_i}{dP_{Gi}} \times \left(\frac{1}{1 - \frac{dP_L}{dP_{Gi}}}\right) = \lambda$$

$$\frac{dF_i}{dP_{Gi}} \times L_i = \lambda$$

where L_i = Penalty factor of i^{th} unit

$$\boxed{L_i = \frac{1}{1 - \frac{dP_L}{dP_{Gi}}}} \rightarrow \text{Unit less}$$

$$\therefore \boxed{\frac{dF_1}{dP_{G1}} L_1 = \frac{dF_2}{dP_{G2}} L_2 = \cdots = \frac{dF_n}{dP_{Gn}} L_n = \lambda} \longrightarrow (2)$$

→ The product of incremental fuel cost & the penalty factor for all the units are same and it is equal to the Lagrangian multiplier of the system.

→ The inclusion of trans. line loss will result as the cost received for each plant (λ) should be more than the received per each plant of a loss less problem. This can understand by multiplying the incremental fuel cost with a penalty factor and the penalty factors are normally slightly more than '1'.

$$\rightarrow \frac{dF_1}{dP_{G1}} = \frac{dF_2}{dP_{G2}} = \frac{dF_3}{dP_{G3}} = \cdots \frac{dF_n}{dP_{Gn}} = \lambda \longrightarrow (1)$$

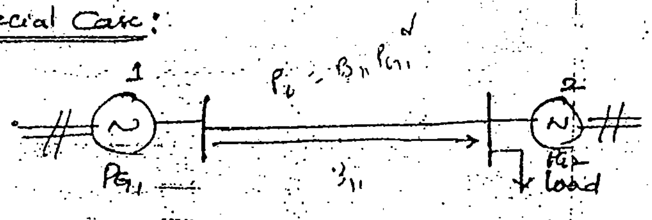
$$\frac{dF_1}{dP_{G1}} L_1 = \frac{dF_2}{dP_{G2}} L_2 = \cdots \frac{dF_n}{dP_{Gn}} L_n = \lambda \quad (2)$$

- ~~Eq~~ (2) is the most economical operation of the system ~~since~~ it is a practical case.

— The method for ~~solution~~ above solution is called <u>Penalty Factor Method</u>

→ <u>Special Case:</u>

(i)



In the above single-line diagram, the total load is placed on Station 2. Which of the following relations are holds good for loss coefficient

(I)

(i) $B_{11} \neq B_{12} \neq 0$, $B_{21} = B_{22} = 0$

(ii) $B_{11} \neq 0$, $B_{12} = B_{21} = B_{22} = 0$

(iii) $B_{11} = B_{12} = B_{21} = 0$, $B_{22} \neq 0$

(iv) $B_{11} = B_{22} \neq 0$, $B_{12} = B_{21} = 0$

(II)

(i) $L_1 = 1.0$, $L_2 \neq 1.0$

(ii) $L_1 \neq 0$, $L_2 = 1.0$

(iii) $L_1 \neq L_2 \neq 1.0$

(iv) $L_1 = L_2 = 1.0$

Expl (I): In the above diagram loss contributed by station '2' is 'Zero'. So that the loss co-efficients which are associated with station '2' are ZERO

ans: (ii)

$\therefore P_L = B_{11} P_{G_1}^2$

(II)

$$L_2 = \frac{1}{1 - \frac{dP_L}{dP_{G_2}}} = \frac{1}{1-0} = 1, \quad L_1 = \frac{1}{1 - \frac{dP_L}{dP_{G_1}}} \neq 1.0$$

$$\therefore \boxed{\frac{dF_1}{dP_{G_1}} L_1 = \frac{dF_2}{dP_{G_2}} = \lambda}$$

loss unit   lossless unit

(II) If load is on station 1 in (i)

Ans: $B_{11} = B_{12} = B_{21} = 0$, $P_L = B_{22} P_{G_2}^2$

$L_1 = 1.0$, $L_2 \neq 1.0$ $\quad \boxed{\frac{dF_1}{dP_{G_1}} = \frac{dF_2}{dP_{G_2}} L_2 = \lambda}$

→ Penality Factor method does applicable for the loss problem, which is defined with Lagragian Multiplier

$$\frac{dF_1}{dP_{G1}} L_1 = \frac{dF_2}{dP_{G2}} L_2 = \cdots \frac{dF_n}{dP_{Gn}} L_n = \lambda$$

$$P_d = \sum P_G - P_L$$

→ By knowing the Lagragian multiplier then the corresponding generation schedules are to be calculated. By calculating the generation schedules the connected to line loss will be calculated and finally the power received by the load is also calculated. However the loss problem is also defined with the demand and in such case the penality factor method is not suitable.

→ The above problem can be solved by using iterative method but the time taking is high.

→ To reduce the time taking an approximate method is considered which is known as "losses are included but not co-ordinated."

Ex: Two Bus system

$$P_{G1} + P_{G2} - P_L = P_d$$

$$P_{G1} + P_{G2} - [B_{11} P_{G1}^2 + 2B_{12} P_{G1} P_{G2} + B_{22} P_{G2}^2] = P_d \longrightarrow (1)$$

Eq (1) is non-linear equation with two unknowns (i.e) P_{G1} & P_{G2}

∴ Replace one with another by considering the entire problem as loss less problem

$$\frac{dF_1}{dP_{G1}} = \frac{dF_2}{dP_{G2}}$$

$$\alpha_1 P_{G1} + \beta_1 = \alpha_2 P_{G2} + \beta_2$$

$$P_{G1} = \frac{\alpha_2 P_{G2} + \beta_2 - \beta_1}{\alpha_1} \longrightarrow (2)$$

Substitute eq ② in eq ①

Now equation ① is non-linear equation with unknown P_{G_2}.

$$\therefore \quad P_{G_2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

roots

$$(P_{G_2}' \text{ and } P_{G_2}'')$$

$$\downarrow \qquad \downarrow$$

$$(P_{G_1}' \text{ and } P_{G_1}'')$$

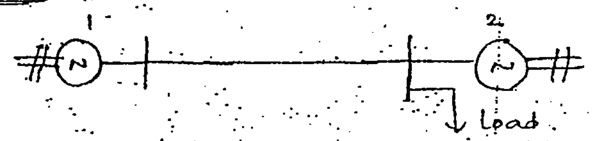
$$\therefore \quad (P_{G_1}', P_{G_2}'), \quad (P_{G_1}'', P_{G_2}'')$$

$$\boxed{P_L = \sum P_G' - P_d}$$

→ The generation schedules which can provide less amount of loss will be considered as the actual generation schedules for a given demand.

→ Special Case

(1)



$$P_{G_1} + P_{G_2} - P_L = P_d$$

$$P_{G_1} + P_{G_2} - B_{11} P_{G_1}^2 = P_d \longrightarrow ①$$

Repeat the above procedure to calculate P_{G_1} and P_{G_2}

→ Problems (Assignment)

(13) Given $\dfrac{dF}{dP} = 0.002P + 18$

$$\frac{dP_L}{dP_G} = 0.2, \qquad \lambda = 25$$

$$\frac{dF}{dP_G} \times L = \lambda$$

$$(0.002P + 18) \times \frac{1}{1 - 0.2} = 25$$

$0.002p + \cancel{12} = 25 \times 0.8$

$P = 1000\,MW$

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(15) $L_2 = 1.25$

$\cancel{= 400\ Rs/MWhr}$

$$\frac{dF_1}{dP_{G1}} L_1 = \frac{dF_2}{dP_{G2}} L_2 = \lambda$$

$$= 400 \times 1.25 = \lambda$$

$$\Rightarrow 500\ Rs/MWhr.$$

(19) $B_1 = 0.001$, $B_{22} = 0.002$, $B_{12} = B_{21} = -0.0008$

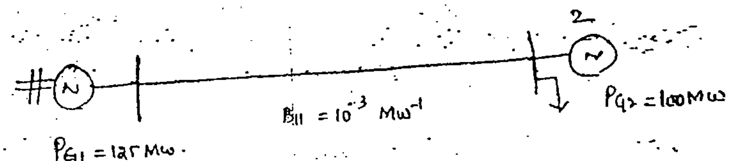
$P_1 = 150\,MW$ $\quad P_2 = 100\,MW$

$$P_L = B_{11} P_{G1}^2 + 2B_{12} P_{G1} P_{G2} + B_{22} P_{G2}^2$$

$$= 0.001 \times (150)^2 + 2 \times (-0.008) 150 \times 100 \times + 0.002 \times (100)^2$$

$$=$$

(Q)



O/c penalty factors of the both the units are

sol
$$L_1 = \frac{1}{1 - \frac{dP_L}{dP_{G1}}} = \frac{1}{1 - 2B_{11}P_{G1}}$$

$\cancel{L_2 = 0}$

$P_L = B_{11} P_{G1}^2$

$\frac{dP_L}{dP_{G1}} = 2 B_{11} P_{G1}$

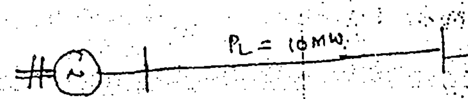
$=$

$$= \frac{1}{1 - 2 \times 10^{-3} \times 125}$$

$$= \underline{\underline{1.33}}$$

$L_2 = 1.0$ (No loss)

(Q)



$\frac{dF}{dP_G} = (0.1 P_G + 20)\ Rs/MWhr$

~~A load of line loss~~ ... the Lagrangian multiplier

~~The penalty factor of the unit and also~~

Sol

Pen. fac $L = \dfrac{1}{1 - \dfrac{dP_L}{dP_G}}$ $\quad P_G = P_L + P_d$

$(10 + 90)$ MW.

Since $P_L = 10$ MW Constant loss since only one unit, we cannot minimise the loss.

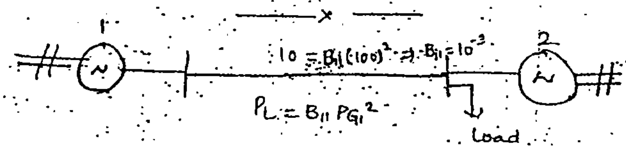
→ As the demand is contributed by only one generator so that the loss in the n/w is always constant and the differential loss can be ignored.

$$\therefore L = \frac{1}{1 - \frac{10}{100}} = \frac{100}{90} = \frac{10}{9}$$

$$\frac{dF}{dP_G} L = \lambda$$

$$\Rightarrow (0.1 \times 100 + 20) \times \frac{10}{9} = \lambda.$$

(16)



$\lambda = 25$ [MW $\quad L_2 = 1.0$

$$\therefore \frac{dF_2}{dP_2} = 25$$

$$0.06P_{G2} + 19 = 25 \Rightarrow P_{G2} = \frac{25 - 19}{0.06} \text{ MW}$$

$$P_{G2} = 100 \text{ MW}.$$

$$\frac{dF_1}{dP_1} L_1 = \lambda = 25$$

$$(0.02P_{G1} + 17) \frac{1}{1 - \frac{dP_L}{dP_1}} = 25$$

$P_L = B_{11} P_{G1}^2$

$10 = B_{11}(100)^2$

$B_{11} = 10^{-3}$

$$(0.02P_{G1} + 17) \frac{1}{1 - 2B_{11}P_{G1}} = 25$$

$$(0.02P_{G1} + 17) = 25(1 - 2B_{11}P_{G1})$$

$$0.02P_{G1} + 17 - 25 = -25 \times 2 \times 10^{-3} \times P_{G1}$$

$$\Rightarrow 0.02P_{G1} + 25 \times 2 \times 10^{-3} P_{G1} = -17 + 25$$

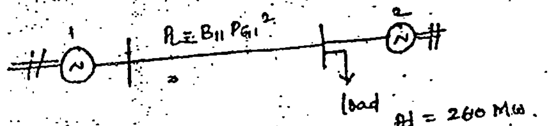
$PG_1 = 114.39\ MW$

$PG_2 = 100\ MW$

$\therefore\ Pd = PG_1 + PG_2 - P_L$

$= 114.39 + 100 - \underbrace{10^{-3}(114.38)^2}_{\text{New loss}}$

$Pd = 214.39 -$

(14) 

$PG_1 + PG_2 - B_{11} PG_1^2 = 260$

$P_L = B_{11} PG_1^2$

$10 = B_{11}(100)^2$

$B_{11} = 10^{-3}$

$\therefore\ PG_1 + PG_2 - 0.001\, PG_1^2 = 260 \rightarrow ①$

Replace PG_2 in terms of PG_1

$$\frac{dc_1}{dPG_1} = \frac{dc_2}{dPG_2}$$

$0.02P_1 + 16 = 0.04P_2 + 20$

$$PG_2 = \frac{0.02PG_1 + 16 - 20}{0.04} \rightarrow ②$$

Subst ② in ①

$PG_1 + 0.5PG_1 - 100 - 0.001\,PG_1^2 = 260$

$-0.001PG_1^2 + 1.5PG_1 - 360 = 0$

$$PG_1 = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$PG_1 = 1200\ MW \longrightarrow PG_2 = 500\ MW$ ✗

$PG_1 = 300\ MW \longrightarrow PG_2 = 50\ MW$ ✓ (Since load $Pd = 260\ MW$)

(20)

$$P_L = B_{11} P_{G1}^2 + 2B_{12} P_{G1} P_{G2} + B_{22} P_{G2}^2$$

$$\frac{dP_L}{dP_{G1}} = 2B_{11} P_{G1} + 2B_{12} P_{G2}$$

$$\frac{dP_L}{dP_{G2}} = 2B_{12} P_{G1} + 2B_{22} P_{G2}.$$

$$\frac{dF_1}{dP_{G1}} L_1 = \lambda = 2.6.$$

$$(0.01 P_{G1} + 20) \times \frac{1}{1 - \frac{dP_L}{dP_1}} = (0.0 P_{G1} + 2) \times \frac{1}{1 - 2B_{11}P_{G1} - 2B_{12}P_{G2}} = 2.6$$

$$\Rightarrow (0.0P_{G1}+2) = 2.6(1 - 2\times 0.0015 P_{G1} + 2\times 0.0005 P_{G2})$$

$$= \underbrace{0.01 P_{G1} + 2.6 \times 2 \times 0.0015 P_{G1}}_{P_{G1}} - \underbrace{2.6 \times 2 \times 0.0005 P_{G2}}_{P_{G2}} = 2.6 - 2 = 0.6. \rightarrow (1)$$

$$P_{G1} \quad P_{G2} = 0.6$$

Illy.

$$\frac{dF_2}{dP_{G2}} L_2 = \lambda$$

$$(0.01 P_{G2} + 1.5) \times \frac{1}{(1 - 2B_{12} P_{G1} - 2B_{22} P_{G2})} = 2.6$$

$$0.01 P_{G2} + 1.5 = 2.6(1 + 2\times 0.0005 P_{G1} - 2\times 0.0025 P_{G2})$$

$$-2.6\times 2\times 0.0005 P_{G1} + 0.01 P_{G2} + 2.6\times 0.0025 P_{G2} = 2.6 - 1.5 = 1.1 \rightarrow (2)$$

From eq's (1) & (2) $P_{G1} =$

$P_{G2} =$