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-: HAND WRITTEN NOTES:-

OF

ELECTRICAL ENGINEERING

-: SUBJECT:-

IInd

POWER SYSTEM - IV

1

• Components of HEPS :-

1. Reservoir: Reservoir stores water during rainy season and utilizes the stored water during summer season

2. Dam: Provides the necessary head of water for generation.

3. Trashrack: Trashrack prevents the flow of tree leaves or any other material to reach the turbine of Generation station. Trashrack is made of steel bars.

4. Spillway: During rainy season when the water reaching dam is very high the excess water may over the dam. this result the damage to the dam. Spillway is provided at the upper layer of the dam where the excess water flows through it.

5. Gates: the water stored in the reservoir is supplied to the generating station by opening the gates. Gates can be arranged in four different configuration

1. Radial
2. Axial
3. Horizontal
4. Vertical.

6. Inta[redacted]:

When the spillway fails to operate the excess water can be send to the turbine through the intake. Intake is provided with gates operating on principle of gravity.

7. Forebay:

It is the additional reservoir provided to ensure that the water stored in the main reservoir does not flow over the dam.

8. Surge Tank:

Surge tank is located near the turbine of HEGS when the load demand decreases, generat^n decreases, quantity of water to be supplied to the generating stat^n must decrease. Before signal reaches operator the quantity of water discharged is high. In order to supply less water to turbine, the excess water is stored in surge tank. When the load demand increases or decreases the volume of water supplied to the generating station increases or decreases. The water channel has to withstand the sudden variations in the load. This is known as 'water hammer'.

Penstock:

The water channel through which the water is flowing from dam to generating stat^n is known as Penstock.

for low discharges penstock is made of 'STEEL'. for high discharges penstock is made of "reinforced concrete".

Question:

A hydroelectric power station is supplied water from a reservoir having storage capacity $50 km^2$ across a dam. where the head of water is maintained at 50m. the efficiency of turbine-g/r set 60% calculate the rate of fall of water when hydro-electric power station is generating power at 30,000 kW.

Solution

$A = 50 km^2$

$h \rightarrow 50 m.$

$\eta_{t+g/r} = 60\%$

$P_t = 30,000 kW.$

$$\boxed{\text{Rate of fall of water m/sec} = \frac{Q(m^3/sec)}{A(m^2)}}$$

- Electrical power generated

$$P_t = 9.81 \times Q \times 50 \times 0.6$$

$$Q = \frac{30,000}{9.81 \times 50 \times 0.6} = 101.93 \, m^3/sec$$

$\Rightarrow$ Rate of fall: $\frac{101.93}{50 \times (10^3)^2} = 2.038 \times 10^{-6}$ m/sec

2) The quantity of water stored across the reservoir is $3\times10^7 m^3$. The head of the water $h = 150m$. If over all $\eta_{g/r} = 70\%$ calculate the energy generated.

Soln

$V = 3\times10^7 m^3$

$h = 150m$

$\eta = 70\%$.

$Q = m^3/sec$ $P_t \rightarrow KW$

$Q = m^3$ $P_t \rightarrow KW\,sec$.

$P_t = 9.81 \times Q \times h \times \eta$

$P_e = 9.81 \times 3\times10^7 \times 150 \times 0.70$ KW sec.

• electrical power output in KWsec = 3.089×10^{10} KW sec

electrical power O/p in KWh = $\frac{3.089\times10^{10}}{3600}$

$$\boxed{P_e = 8.58\times10^6 \text{ KWh}}$$

CLASSIFICATION OF TURBINE

1) Based on discharge of water:

1. High discharge
2. Medium discharge
3. Low discharge.

• 2. Based on pressure of water:

a) Impulse : Pelton,

b) Reaction: Francis, Keplan:

• 3. Based on direction of water flow:

a). Axial

b) Radial

c) Diagonal: → Deriaz → used in pumpstored plant

d) Tangential

Deriaz turbine pumps water in diagonal direction and used in used in pumped storage plant.

• 4. Based on output power:

a) Low : 0 - 150000 Hp

b) Medium: 150000 - 350,000 Hp

c) High: > 350,000 Hp.

• 5. Based on specific speed:

($N \rightarrow \frac{1m^2}{sec}$, P

the speed at which turbine rotates to develop 1 MHP, when water is discharged at 1m with the head of water maintain at 1m.

$$\boxed{\text{Specific speed } N_s = \frac{N \cdot P^{1/2}}{h^{5/4}}}$$

$P \rightarrow$ power output in HP

$h \rightarrow$ head of water

$N \rightarrow$ actual speed in rpm.

<u>Question:</u>

A ~~At~~ HEPS has average water discharge in a year as given below.

MONTH	DISCHARGE (m^3/sec)
Jan	200
Feb	400
March	600
April	2400
May	1800
June	1800
July	1600
Aug	1200
Sept	2000
Oct	1200
Nov	800
Dec	400

Calculate the average water flow and power generated when head of water is 50m and η of g/r stat^n being 90%. Draw the Hydrograph, flow duration curve and mass curve for given data. Estimate the total storage capacity of the reservoir

Solution.

1) $Q = \frac{\text{water discharged}}{\text{no. of month in year}} = \frac{1380}{12} = 1150 \, m^3/sec.$

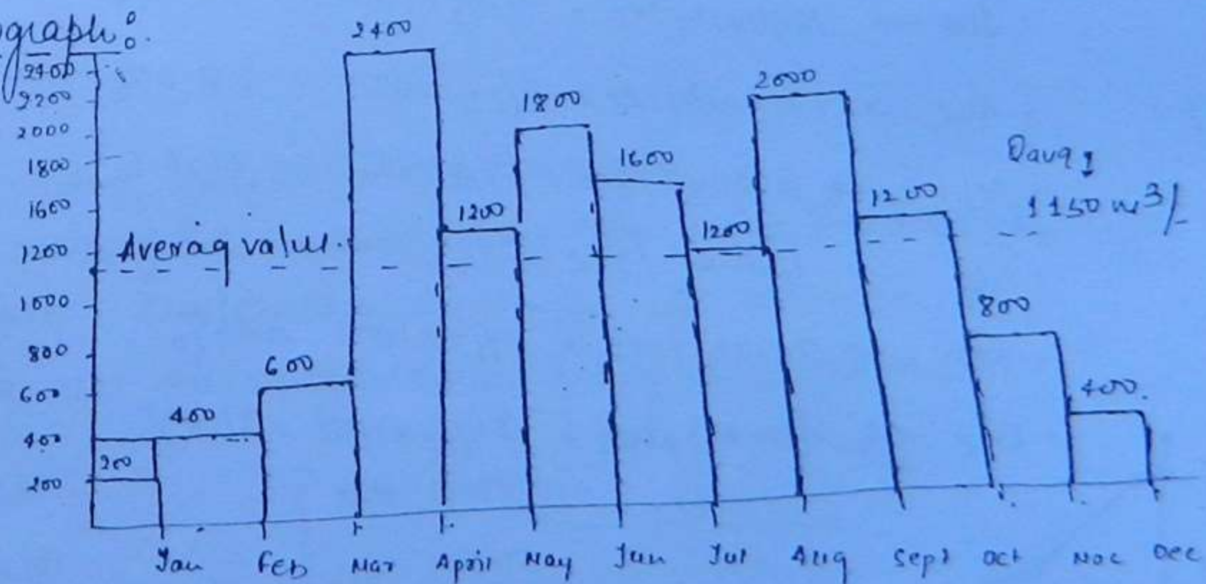
2) Po electrical power generated

$P_t = 9.81 \times 1150 \times 0.9 \times 50$

$P_t = 507.6 \times 10^3 \, KW$

$P_t = 507.6 \, MW.$

3). Hydrograph:

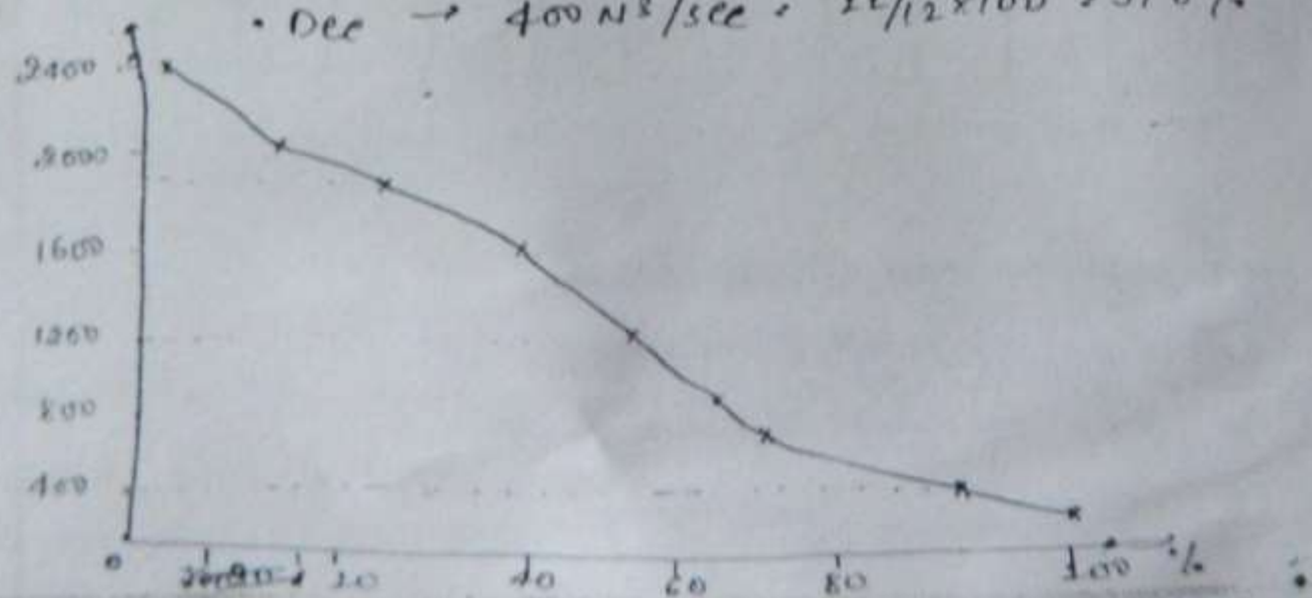


- From the hydrograph we can determine
  1) the duration of maxm discharge.
  2) the duration of minm discharge
  3) Average discharge.

5). Flow duration curve: It gives the relation b/w the discharge in m^3/sec represented along Y-axis and percentage of time represented ~~a~~ along X-axis.

(10)

- Jan → $200 m^3/sec$ = $12/12 \times 100$ = 100%
- Feb → $400 m^3/sec$ = $11/12 \times 100$ = ~~75%~~ 91.6%
- March → $600 m^3/sec$ = $9/12 \times 100$ = 75%
- April → $2400 m^3/sec$ = $\frac{1}{12} \times 100$ = 8.33%
- May → $1200 m^3/sec$ = $7/12 \times 100$ = 58.3%
- June → $1800 m^3/sec$ = $3/12 \times 100$ = 25%
- Jul → $1600 m^3/sec$ = $4/12 \times 100$ = 33.3%
- Aug → $1200 m^3/sec$ = $7/12 \times 100$ = 58.3%.
- Sept → $2000 m^2/sec$ = $2/12 \times 100$ = 16.67
- Oct → $1200 m^2/sec$ = $7/12 \times 100$ = 58.3%
- Nov → $800 m^3/sec$ = $9/12 \times 100$ = ~~78%~~ 66%
- Dec → $400 m^3/sec$ = $11/12 \times 100$ = 91.6%.



4) Total storage capacity:

• we store when water available > 1250 m³/sec.

• Water is stored in the reservoir when quantity of water available is gr8 than quantity water sent to generating statn.

Total storage capacity

$= \cancel{(2400-1150)+(1200-1150)}$

$= 1250 + 850 + 650 + 450 + 50 + 850 + 50$

$= 5350 \, m^3/sec.$

$= \frac{5350 \times 24 \times 60 \times 60 \times 30}{\cancel{1000}}$

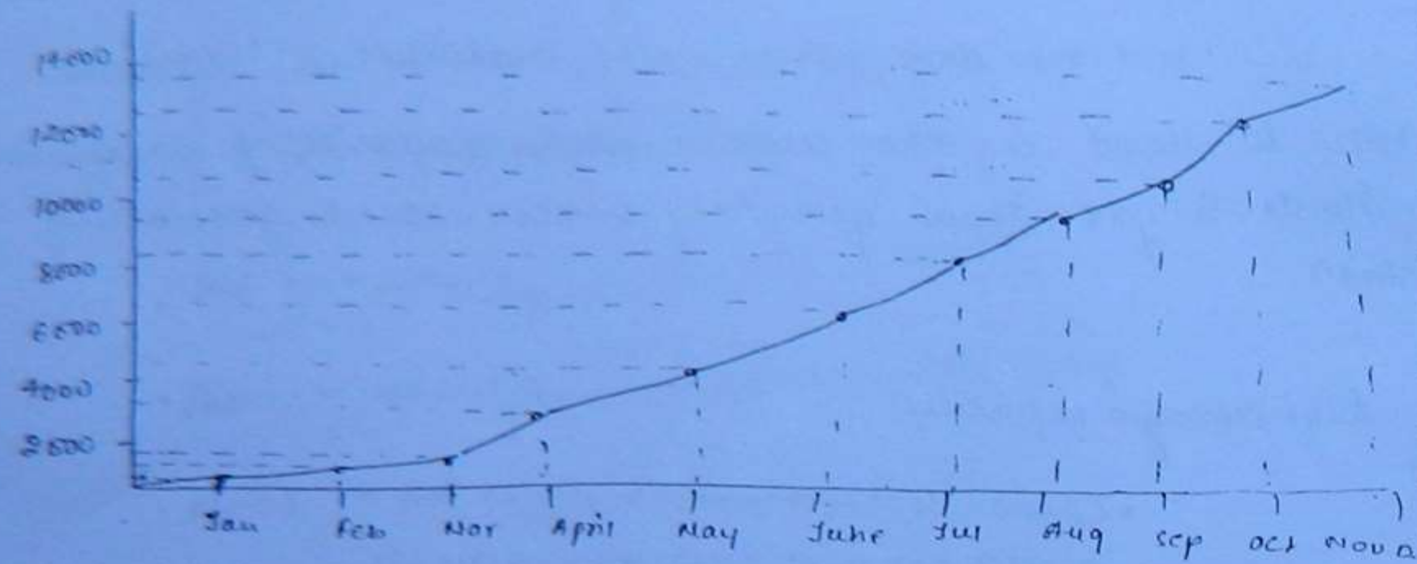
$= 8.7 \times 10^5 \, m^3/month$

5) MASS CURVE:.

• Find cumulative discharge.

• Mass curve gives the relation b/w cumulative discharge and time.. Cumulative discharge is obtained by adding all discharges upto end of that month

Jan - 200	sept 11400
feb = 600	oct · 12600
March → 1200	Nov 13400
April → 3600	Dec 13800
May → 4800	
June → 6600	
July → 8200	
Aug → 9400	



NUCLEAR GENERATING STATION

Nuclear fission:

When neutron collides with uranium isotope enormous amount of energy is released.

$$ {}_{92}U^{235} + n^1 \longrightarrow {}_{56}Ba^{139} + {}_{36}Kr^{94} + 3\,{}_0n^1 + \text{Energy} $$

$$ {}_{92}U^{235} + {}_0n^1 \longrightarrow {}_{42}Mb^{106} + {}_{50}Sn^{128} + 2\,{}_0n^1 + 11 $$

Critical Mass:

The minimum amount of mass required for nuclear chain reaction to continue is known as critical mass. For an uranium isotope, the critical mass require 10kg. The energy generated by 1kg of uranium is ~~850~~ 3500kg of coal.

- The process of chain reaction can be increased by following.

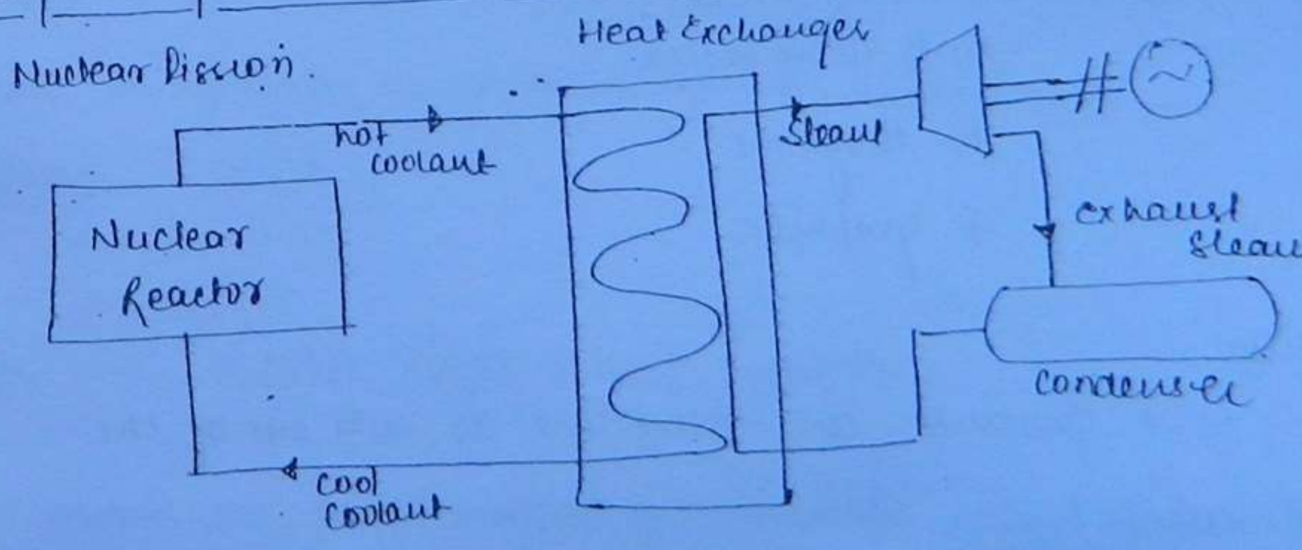
1. Conversion

- $_{92}U^{238} + {}_0n^1 \rightarrow {}_{92}U^{239} + \gamma$
- $_{92}U^{239} \longrightarrow {}_{93}Np^{239} + {}_{-1}e^0$
- $_{93}Np^{239} \longrightarrow {}_{94}Pu^{239} + {}_{-1}e^0$

2. Breeding

- $_{90}Th^{232} + {}_0n^1 \rightarrow {}_{90}Th^{233} + \gamma$
- $_{90}Th^{233} \longrightarrow {}_{91}Pa^{233} + {}_{-1}e^0$
- $_{91}Pa^{233} \longrightarrow {}_{92}U^{233} + {}_{-1}e^0$.

- Layout of Nuclear Power station:



- On nuclear reactor heat transfer takes place during d heat b/w heat generated during nuclear reaction. Water from the condenser is converted into steam by absorbing heat of coolant.

COMPONENTS OF NUCLEAR POWER STATION

1. **Reactor Core:**

• In the reactor core nuclear fission take place and the energy is released

• Reactor core consist of fuel rods in the form of thin plates made of stainless steel for low capacity reactor and zirconium for high capacity reactors.

2. **Moderator:**

• Moderator slows down the neutrons before they collide with uranium isotope

• Types of moderators are.

a) ~~B~~ Heavy water

b) Beryllium

c) Graphite

3. **Reflector:**

• It prevents the neutrons to come out of the reactor core

• Reflector surrounds the reactor core.

4) **Control Rod :**

• Control rod ensures the safety of nuclear reactor

• During earth-quakes control rod trips the nuclear-reactor and ensure safe operation.

• Material → high grade ~~gho~~ graphite

5. Coolant :

• Coolant is used as heat transfer

• the cool water from condenser is converted into steam by absorbing the heat from the hot coolant

6. Multiplication factor (K) :

$$\boxed{K = \frac{\text{no. nuetron released}}{\text{Nuetron absorbed.}}}$$

• 'K' determines the performance of nuclear reactor

• when no of neutrons released during fission is greater than no. of nuetron absorbed. $(K > 1)$

• Alway $1 < K < \infty$

LOAD FREQUENCY CONTROL

• To control the power output of alternators several generating station are connected into a grid

• Grid connected s/m ensures frequency to be constant.

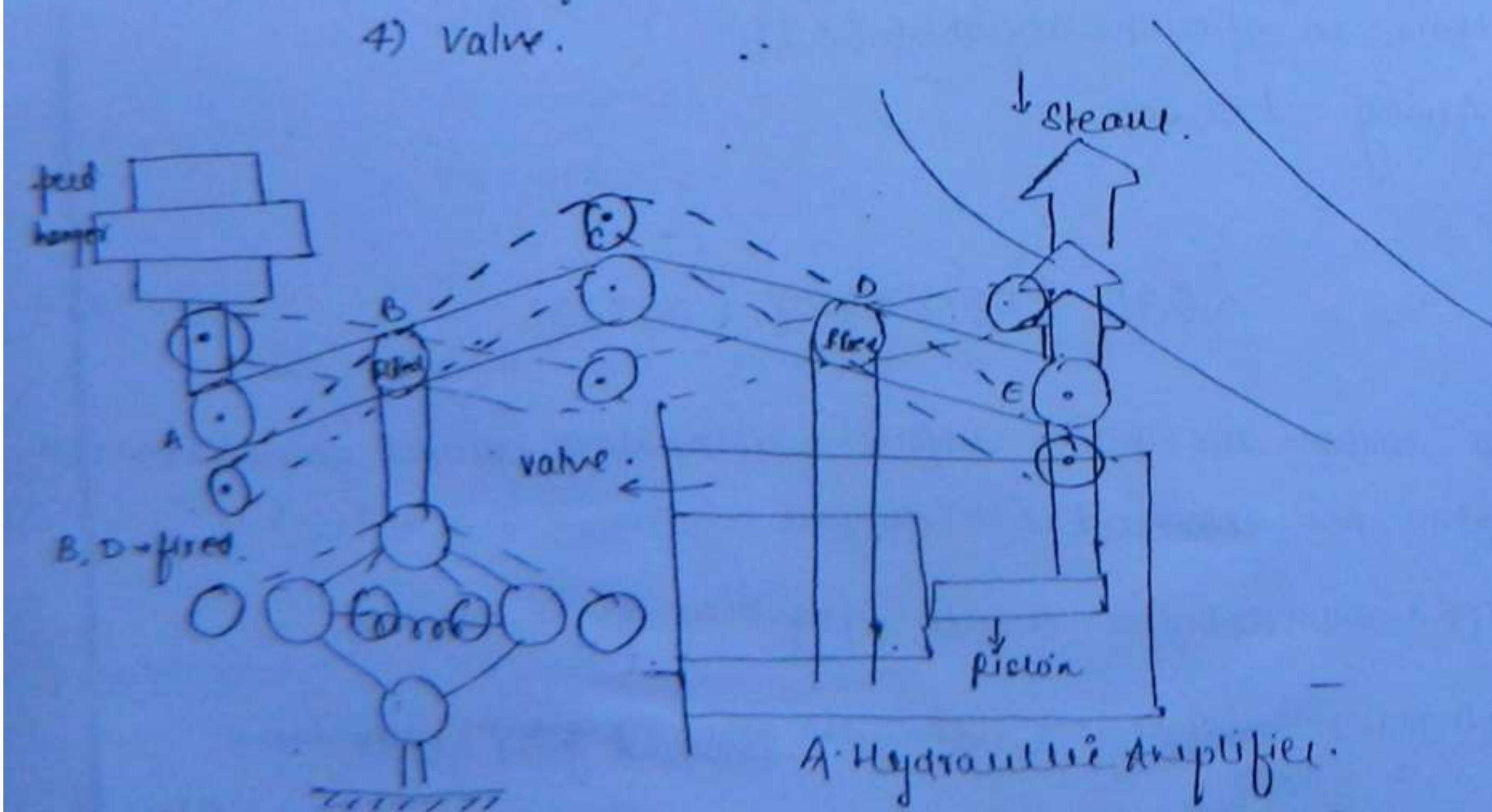
• Alternators connected in the form of group maintains constant frequency.

- When load demand increases, power generation must be increase, alternator must generate more electrical power, turbine has to supply more mechanical energy to the alternator, the steam supply to turbine must increase. and SPEED GORNER. must identify the increase in the load demand.

Design of speed governer:.

- It components are:

1) speed changer
2) Hydraullic Amplifier
3) Linkage Mechanism
4) Valve.



• Condition 1: Increase in load Demand

Generation must increase
Speed of turbine must increase.
Speed changer is pulled in downward directn
Point A moves in downward direction depends on speed governor signal.
Point 'C' moves in upward direction
Point 'E' moves in downward direction
The inlet to the steam is increased.
Mechanical energy at the I/P alternator increase
Electrical energy generated by alternator increa

• Condition 2: Decrease in load demand

Generation must decrease
Speed of turbine must decrease
Speed changer is pulled in upward directn depending on signal of speed governor
Point 'A' moves upward depending on speed governor signal
Point 'C' moves in downward direction
Point 'E' moves in upward direction
The inlet to steam is decreased
Mechanical energy at the I/P alternator

decreases

Electrical energy generated by alternator decreases

- The load frequency control depends on:

1. The movement of fly ball governor and there after the speed changer

- Hydraulic amplifier determines actual steam input to the turbine

DESIGN EQUATIONS:

- Point 'A' and 'C' moves in opposite direction
- Let $\Delta(P_C)$ be the command signal given by the speed governor to the speed changer

A ↓ downward directⁿ

speedchanger ↓ "

← governor → (expansion)

$$\therefore \quad y_A \propto \Delta P_C$$

$$\boxed{y_A = K_C \Delta P_C}$$

- The extent to which point 'C' moves in upward direction is equal to extent to point 'A' move in downward directⁿ.

$$y_c \propto (-y_A).$$

$$y_c \propto (-K_c \cdot \Delta P_c)$$

$$\boxed{y_c = -K_1 K_c \Delta P_c} \quad \text{------} \quad (1)$$

- Assume that volume of oil sent to hydraulic amplifier is increased. Therefore point E moves in downward directⁿ resulting in movement of point C in of upward directⁿ

$$y_c \propto (-y_E) \qquad C \uparrow \text{ when } E \downarrow.$$

$$\propto (\Delta f) \quad \text{---} \!\!> \text{as steam inlet} \uparrow.$$

generatⁿ ↑.

$$\boxed{y_c = K_2 \Delta f} \quad \text{---} \quad (2) \qquad \text{frequency} \uparrow.$$

- The movement of point 'A' is related w.r.t to frequence

$$\boxed{y_c = -K_1 K_2 \Delta P_c + K_2 \Delta f} \quad \text{----} \quad (5)$$

Δy_D =

- point 'D' is located at the middle of the the second section. The movement of point D is affected by the position 'C' and 'E'

$$\Delta y_C = -K_1 K_C \Delta y_A + K_2 \Delta f \quad \cdots \quad (3)$$

$$\Delta y_D = K_3 \Delta y_C + K_4 \Delta y_E \quad \cdots \quad (4)$$

$\Delta y_E =$

the volume of oil in hydraulic amplifier determine the movement point 'E'. For 'Δy_E' to be positive, oil is taken from the hydraulic cylinder.

depending on the position of point 'D', Δy_E is determined.

$$\Delta y_E \propto -\int (\Delta y_D)\,dt$$

since oil is stored in cylinder the integral is applied.

$$\boxed{\Delta y_E = -K_5 \int (\Delta y_D)\,dt} \quad \cdots \quad (5)$$

applying laplace transform to the equations (3), (4), (5)

$$\Delta Y_C(s) = -K_1 K_C \Delta Y_A(s) + K_2 \Delta f(s) \quad \cdots \quad (6)$$

Δy_D

$$\Delta Y_D(s) = K_3 \Delta Y_C(s) + K_4 \Delta Y_E(s) \quad - \quad (7)$$

$$\Delta Y_E(s) = -\frac{K_5}{s} \Delta Y_D(s) \quad \cdots \quad 8$$

substituting eqn (7) in (8)

from the equation (7) and (8)

$$\Delta Y_D(s) = K_3 \Delta Y_C(s) + K_4 \left\{ -\frac{K_5}{s} \Delta Y_D(s) \right\}$$

<u>8 → 7</u>

$$\Delta Y_D(s) + \frac{K_4 K_5}{s} \Delta Y_D(s) = K_3 \Delta Y_C(s)$$

$$= \Delta Y_D(s) \left\{ 1 + \frac{K_4 K_5}{s} \right\} = K_3 \Delta Y_C(s)$$

$$\Rightarrow \Delta Y_C(s) = \Delta Y_D(s) \left\{ \frac{1}{K_3} + \frac{K_4 K_5}{s K_3} \right\} \quad \text{---- (9).}$$

<u>9 → 6</u>

$$\Delta Y_D(s) \left\{ \frac{1}{K_3} + \frac{K_4 K_5}{s K_3} \right\} = -K_1 K_C \Delta P_C(s) + K_2 \Delta F(s) \quad \text{--- (10).}$$

equatⁿ 10 represents the change in position in terms of frequency.

from eqⁿ 8 we have:

$$\cancel{\Delta y_E(s) = -\frac{K_5}{s}} \quad \Delta y_D(s) = -\frac{s}{K_5} \Delta y_E(s) \quad \text{--- (11)}$$

<u>11 → 10</u>

$$= \frac{-s}{K_5} \Delta Y_E(s) \left\{ \frac{1}{K_3} + \frac{K_4 K_5}{s K_3} \right\} = -K_1 K_c \Delta P_C(s) + K_2 \Delta F(s)$$

$$= -\Delta Y_E(s) \left\{ \frac{s}{K_3 K_5} + \frac{K_4}{K_3} \right\} = -K_1 K_C \Delta P_C(s) + K_2 \Delta F(s)$$

$$= \Delta Y_E(s) \left\{ \frac{s + K_4 K_5}{K_3 K_5} \right\} = K_1 K_C \Delta P_C(s) - K_2 \Delta F(s)$$

$$\Rightarrow \Delta Y_E(s) = \left(\frac{K_3 K_5}{s + K_4 K_5} \right) \left(K_1 K_2 \Delta P_c(s) \right) - \left(\frac{K_3 K_5}{s + K_4 K_5} \right) K_2 \Delta F(s)$$

dividing K_4K_5

$$\Rightarrow \Delta Y_E(s) = \left[\frac{\frac{K_3K_5}{K_4K_5}}{1+\frac{s}{K_4K_5}}\right](K_1K_c\,\Delta P_c(s)) - \left[\frac{\frac{K_3K_5}{K_4K_5}}{1+\frac{s}{K_4K_5}}\right](\Delta f(s))$$

$$\Delta Y_E(s) = \left[\frac{\frac{K_1K_cK_3}{K_4}}{1+\frac{s}{K_4K_5}}\right](\Delta P_c(s)) - \left[\frac{\frac{K_2K_3}{K_4}}{1+\frac{s}{K_4K_5}}\right]\Delta f(s)$$

$$\Rightarrow \Delta Y_E(s) = \left[\frac{\frac{K_1K_cK_3}{K_4}\Delta P_c(s) - \frac{K_2K_3 \cdot \Delta f(s)}{K_4}}{1+\frac{s}{K_4K_5}}\right]$$

$$\Rightarrow \frac{\left(\frac{K_1K_cK_3}{K_4}\right)\left\{\Delta P_c(s) - \left(\frac{K_2K_3}{K_4}\right)\left(\frac{K_4}{K_1K_cK_3}\right)\Delta f(s)\right\}}{1+s\frac{1}{K_4K_5}}$$

$$\boxed{G(s) \Rightarrow \frac{\left(\frac{K_1K_cK_3}{K_4}\right)}{\left(1+s\frac{1}{K_4K_5}\right)}\left\{\Delta P_c(s) - \frac{1}{K_1K_c/K_2}\Delta f(s)\right\}}$$

- gain constant speed governor s/m

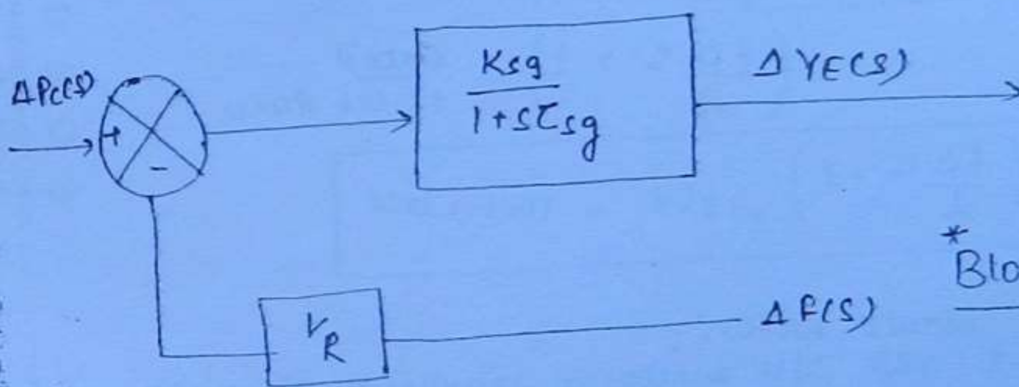
$$\boxed{K_{sg} = \frac{K_1K_cK_3}{K_4}}$$

$$\boxed{\tau_{sg} = \frac{1}{K_4K_5}}$$

- Regulation of speed governor is $\boxed{R = \frac{K_1 K_c}{K_2}}$

**

$$\boxed{\Delta Y_E(s) = \left\{\Delta P_c(s) - \frac{1}{R}\Delta F(s)\right\} \frac{K_{sg}}{1 + s\tau_{sg}}}$$



*Block Diagram

$$\boxed{\frac{\Delta Y_E(s)}{\Delta P_c(s) - \frac{1}{R}\Delta F(s)} = \frac{K_{sg}}{1 + sT_{sg}}}$$

- **DESIGN OF TURBINE:**

1. INPUT:- change in position 'E', $\Delta Y_E(s)$
2. OUTPUT:- Change in power developed by turbine ΔP_t.

$$\boxed{\frac{\Delta P_t}{\Delta Y_E(s)} = \frac{K_t}{1 + sT_t}}$$

• Block diagram:

$$\Delta Y_E(s) \longrightarrow \boxed{\dfrac{K_t}{1+sT_t}} \longrightarrow \Delta P_t(s)$$

$\Delta Y_E(s)$ = input to the turbine awell as output of speed governor.

Dated
11 Oct 2010

DESIGN OF ALTERNATOR.

• the design of alternator deals with:-

1) Kinetic Energy stored by rotor of alternator

At the operating frequency. $f_0 = 50Hz$. the K.E stored by alternator

$$W_{KE0} \propto f_0^2 \quad \text{- - - -} \quad (1)$$

let Δf be the change in frequency

$$\therefore \quad f_{new} = (f_0 + \Delta f)$$

$$W_{KE(new)} \propto f_{new}^2$$

$$\Rightarrow \quad W_{KE(new)} \propto (f + \Delta f)^2 \quad \text{- - - -} \quad (2).$$

the K.E stored by the alternator due to change in frequency is $W_{KE(new)}$.

from the equat^n (1) and (2)

$$\left(\frac{2}{1}\right) \rightarrow \quad \frac{W_{KE(new)}}{W_{KE_0}} = \frac{(f_0+\Delta f)^2}{f_0^2}$$

$$= \frac{f_0^2 + \Delta f^2 + 2 f f_0}{f_0^2}$$

$$= \frac{f_0^2}{f_0^2} + \underbrace{\frac{\Delta f^2}{f_0^2}}_{\text{neglected as } (2/50)^2 = \text{very small}} + \frac{2 f_0 \Delta f}{f_0^2}.$$

$$\left(1 + 2\frac{\Delta f}{f_0}\right)$$

$$\boxed{W_{KE(new)} = W_{KE_0}\left(1 + 2\frac{\Delta f}{f_0}\right)} \quad ---- (3)$$

According to dynamics rotating M/C the K.E stored by alternator

$$W_{KE_0} = H \times P_{rated} \quad ...... (4)$$

$$= \underbrace{H}_{\text{inertia constant}} \times P_r$$

$\underline{\underline{4 \rightarrow 3}}$.

$$W_{KE(new)} = (H \times P_r)\left[1 + 2\frac{\Delta f}{f_0}\right]$$

$$\boxed{W_{KE(new)} = HP_r + \frac{2HP_r}{f_0}\Delta f} \quad ---- (5)$$

By differentiating the above equat^n the electrical power developed by alternator is obtained:

$$\frac{d(W_{KE(new)})}{dt} = \frac{2H \cdot P_r}{f_0} \cdot \frac{d(\Delta f)}{dt} \quad ...... (6)$$

The change in the load demand w.r.t change in the frequency is represented as:

The change in load demand due to all factors → ΔP_D

The change in frequency due all factor → Δf.

Since the load demand changes not only due to frequency, the total change in load demand.

$$= \left(\frac{\partial P_D}{\partial f}\right) \Delta f.$$

$$= (B) \Delta f \quad \cdots \quad (7) \quad \text{unit W/Hz}$$

According to the power balance equation

$$\Delta P_G - \Delta P_D = \frac{2HP_r}{f_0} \frac{d}{dt}(\Delta f) + B\Delta f.$$

By considering rated capacity of alternator 'P_r' as the reference/Base value the power balance equatn can be expressed in terms P.U

$$\Rightarrow \frac{\Delta P_G}{P_r} - \frac{\Delta P_D}{P_r} = \frac{\frac{2HP_r}{f_0}}{P_r} \frac{d(\Delta f)}{dt} + B_{p.u} \Delta f$$

$$\Rightarrow \boxed{\Delta P_{G\,p.u} - \Delta P_{D\,p.u} = \frac{2H}{f_0} \frac{d(\Delta f)}{dt} + B_{p.u} \Delta f.} \quad --- \quad (8)$$

* In numerical B is given as $B_{p.u}$ MW/Hz.

Applying Laplace transform:

$$\Delta P_{G_{p.u}}(s) - \Delta P_{D_{p.u}}(s) = \frac{2H}{f_0}\left[s\Delta f(s)\right] + B_{p.u}\Delta f(s)$$

$$\Rightarrow \Delta P_{G_{p.u}}(s) - \Delta P_{D_{p.u}}(s) = \Delta f(s)\left[\frac{s.2H}{f_0} + B_{p.u}\right]$$

$$\Rightarrow \boxed{\Delta f(s) = \frac{1}{\left[\frac{s.2H}{f_0} + B_{p.u}\right]}\left\{\Delta P_{G_{p.u}}(s) - \Delta P_{D_{p.u}}(s)\right\}} \quad \text{---- (10)}$$

Divide by $B_{p.u}$

$$\boxed{\Delta f(s) = \frac{1/B_{p.u}}{\left[\frac{s.2H}{f_0 B_{p.u}} + 1\right]}\left[\Delta P_{G_{p.u}}(s) - \Delta P_{D_{p.u}}(s)\right]} \quad \text{---- (11)}$$

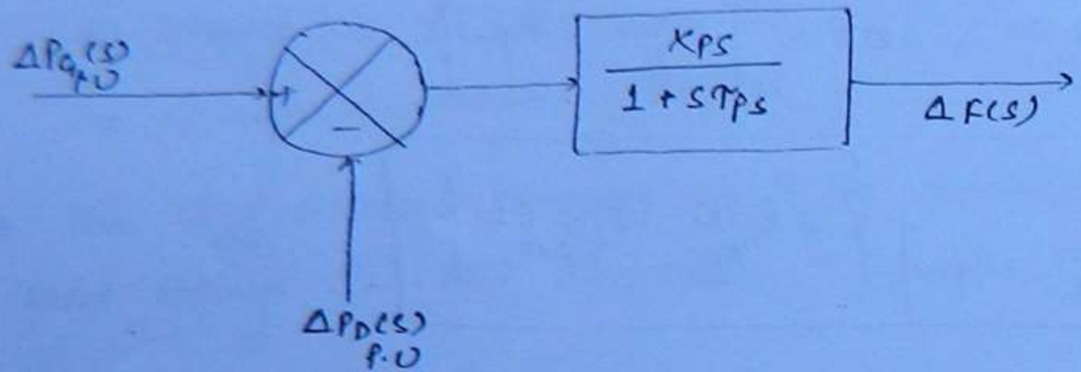
- gain constant of alternator $\rightarrow \frac{1}{B_{p.u}}$
- time constant of alternator/power sys $\rightarrow \frac{2H}{f_0 B_{p.u}}$

$$** \boxed{\Delta f(s) = \frac{K_{ps}}{(1+sT_{ps})}\left\{\Delta P_{G_{pu}}(s) - \Delta P_{D_{pu}}(s)\right\}}$$

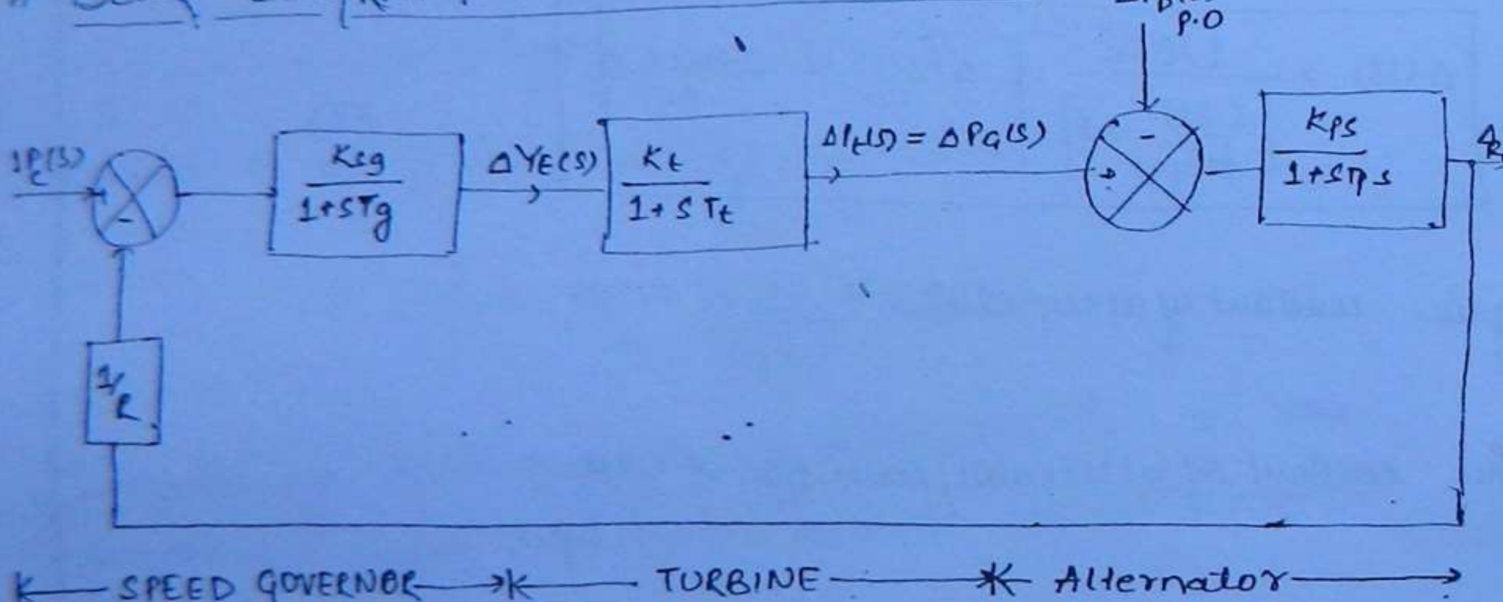
Transfer function of alternator is:

$$** \boxed{\frac{\Delta f(s)}{\Delta P_{G_{pu}}(s) - \Delta P_{D_{p.u}}(s)} = \frac{K_{ps}}{1+sT_{ps}}}$$

× Block diagram:



BLOCK DIAGRAM OF ISOLATED POWER SYMTEM:



Question:

Determine the load frequency control loop parameters of a control area with following data.

1) Total rated capacity 2000 MW
2) Normal operating load. 1000 MW
3) Inertia constanst $H = 5$

Regulation $R = 2.4\ Hz/MW$
change in load demand w.r.t frequency is $16.67\ MW/Hz$

Soln

$$B = \frac{\partial P_D}{\partial f} = 16.67\ MW/Hz$$

$$B_{pu} = \frac{B}{P_r} = \frac{16.67}{2000} = 8.335 \times 10^{-3}\ pu\ MW/Hz.$$

- $$K_{ps} = \frac{1}{B_{pu}} = 120\ Hz/MW$$

- $$\tau_{ps} = \frac{2H}{f_0 B_{pu}} = \frac{2 \times 5}{8.335 \times 10^{-3}} = 24\ sec.$$

- Default values of time constant when not given in numericals:

*

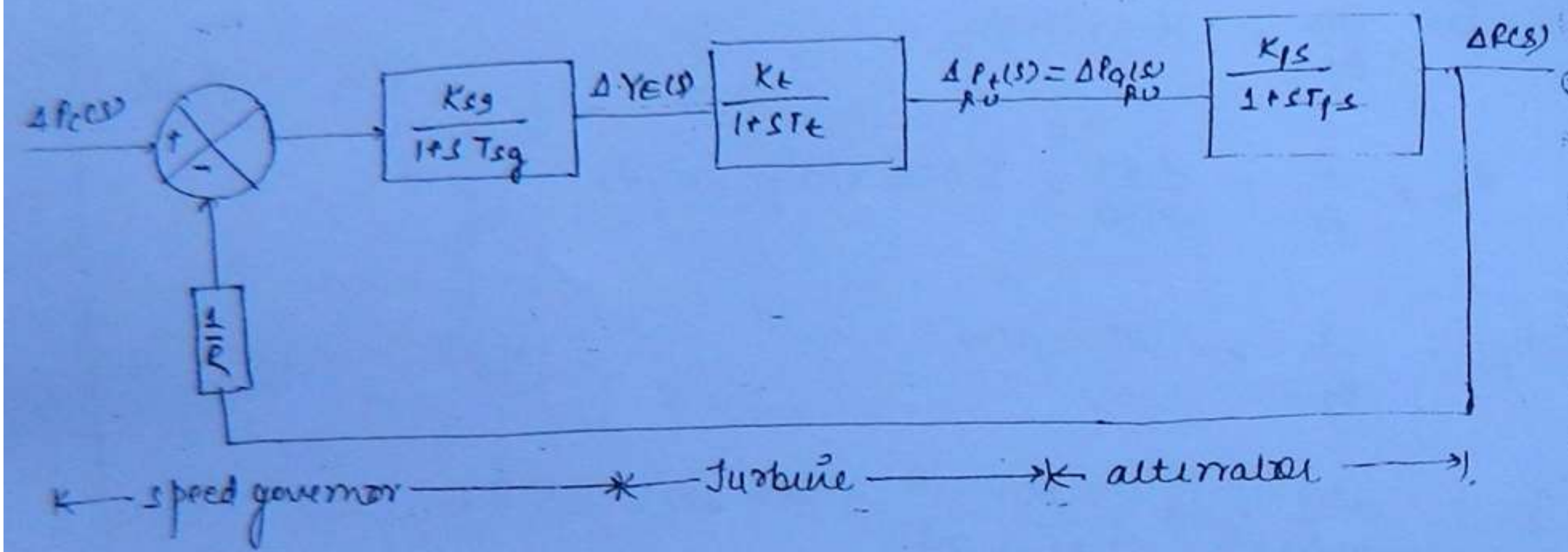
$$\boxed{\begin{aligned} T_{sg} &= 0.4\ sec \\ T_t &= 0.5\ sec \\ T_{ps} &= 20\ sec. \end{aligned}}$$

STEADY STATE ANALYSIS..

Steady-state analysis deals with determining 'Δf' due to ΔP_c and ΔP_D

- **Condition 1**: change in frequency Δf due to change in speed changer setting.

$\therefore \Delta P_D(s) = 0$



$$\left.\frac{\Delta F(s)}{\Delta P_c(s)}\right|_{\Delta P_D(s)=0} = \frac{\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{ps}}{1+sT_{ps}}\right)}{1+\frac{1}{R}\left[\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{ps}}{1+sT_{ps}}\right)\right]}$$

$$\Delta F(s) = \frac{\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{ps}}{1+sT_{ps}}\right)}{1+\frac{1}{R}\left[\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{ps}}{1+sT_{ps}}\right)\right]} \cdot \Delta P_c(s)$$

After taking L.C.M:

$$\left.\Delta F(s)\right|_{\Delta P_D(s)=0} = \frac{K_{sg} \cdot K_t \cdot K_{ps}}{(1+sT_{sg})(1+sT_t)(1+sT_{ps}) + \frac{1}{R} K_{sg} K_t K_{ps}} \cdot \frac{\Delta P_c(s)}{s}$$

error $e_{ss} = \lim_{s\to 0} sE(s)$

the steady state change in the frequency Δf.

$$\Delta f = \lim_{s\to 0} s \cdot \Delta f(s)$$

$$= \lim_{s\to 0} \cancel{s} \left\{ \frac{K_{sg} \cdot K_t \cdot K_{ps}}{(1+sT_{sg})(1+sT_t)(1+sT_{ps}) + \frac{K_{sg} K_t K_{ps}}{R}} \right\} \frac{\Delta P_c}{\cancel{s}}$$

$$= \frac{K_{sg} \cdot K_t \cdot K_{ps}}{(1+0 \cdot T_{sg})(1+0 \cdot T_t)(1+0\, T_{ps}) + \frac{K_{sg} K_t K_{ps}}{R}} \cdot \Delta P_c$$

$$= \frac{K_{sg} \cdot K_t \cdot K_{ps}}{1 + \frac{K_{sg} K_t K_{ps}}{R}} \cdot \Delta P_c$$

consider $K_{sg} K_t = 1$.

as in general
$K_{sg} = 0.7$
$K_t = 1.55$

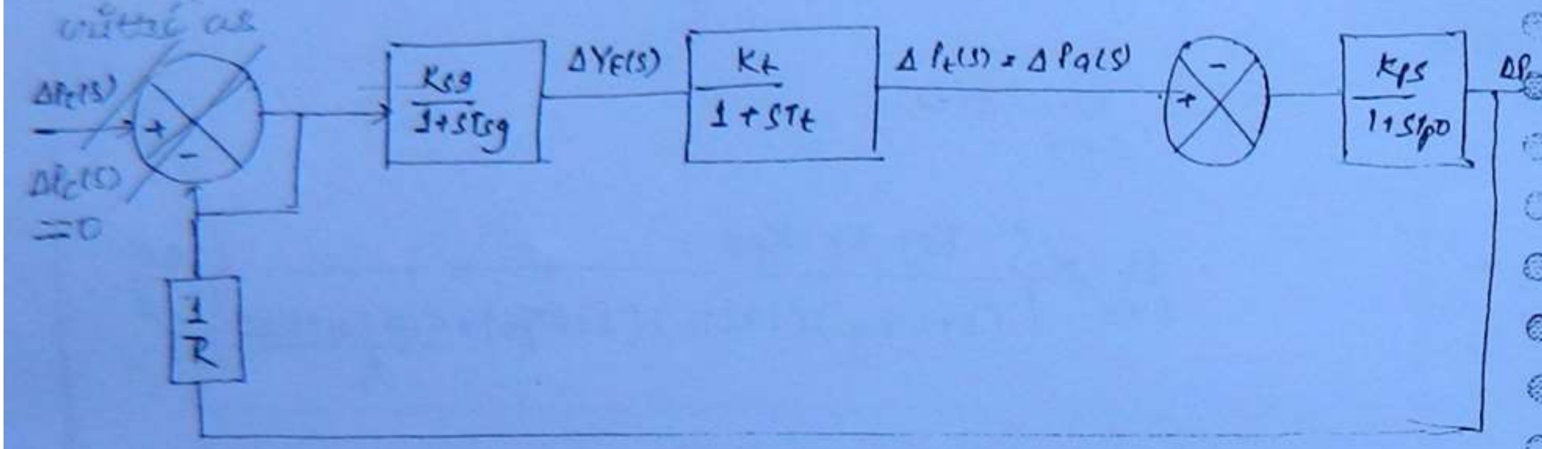
$$\Delta f\Big|_{\Delta P_D = 0} = \frac{K_{ps}}{1 + \frac{K_{ps}}{R}} \cdot \Delta P_c$$

$\div$ by K_{ps}.

$$\Delta f\Big|_{\Delta P_D = 0} = \frac{1}{\frac{1}{K_{ps}} + \frac{1}{R}} \cdot \Delta P_c$$

$$\boxed{\Delta f\Big|_{\Delta P_D = 0} = \frac{1}{B_{p.u} + \frac{1}{R}} \cdot \Delta P_c} \quad \text{------} \quad (1)$$

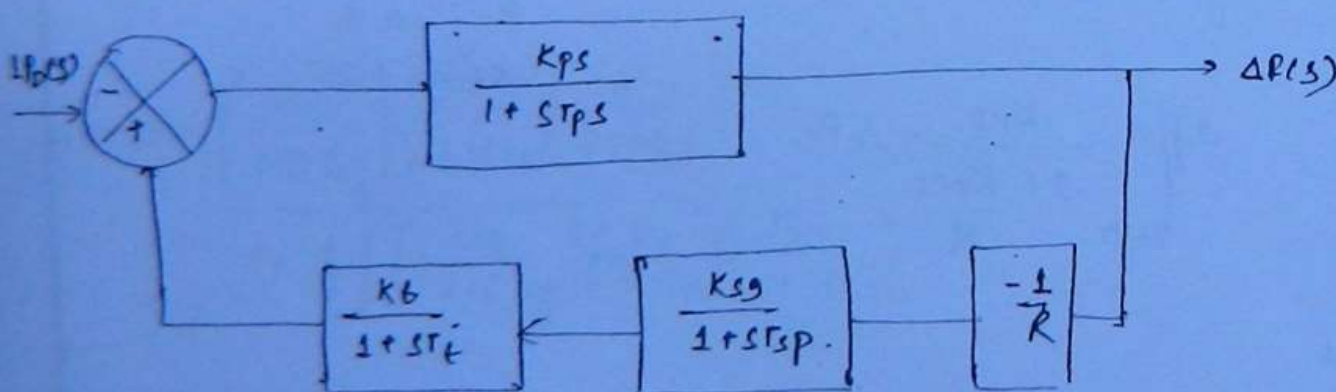
• condition 2: change in frequency Δf due to ΔP_D.



$\Delta P_c(S) = 0$

• ~~speed changer sett~~

• $\Delta P_c(S) = 0$ represents free governor operation
(speed changer setting is constant)



$$\left.\frac{\Delta f(s)}{\Delta P_D(s)}\right|_{\Delta P_c(s)=0} = \frac{-\left(\frac{K_{ps}}{1+sT_{ps}}\right)}{1+\left\{\left(\frac{K_{ps}}{1+sT_{ps}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(-\frac{1}{R}\right)\right\}}$$

Take L.C.M and Simplify:

$$\Delta F(s)\Big|_{\Delta P_c(s)=0} = \frac{-\left(\frac{K_{ps}}{1+sT_{ps}}\right)}{1+\left\{\left(\frac{K_{ps}}{1+sT_{ps}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{+1}{R}\right)\right.} \cdot \Delta P_D(s)$$

$$\Delta f(s)\Big|_{\Delta P_c(s)=0} = \frac{-K_{ps}}{(1+sT_{ps})(1+sT_t)(1+sT_{sg})+\frac{K_{ps}K_{sg}K_t}{R}} \cdot \frac{\Delta P_D}{s}$$

Steady state change in frequency

$$= \lim_{s\to 0} \cancel{s} \left[\frac{-K_{ps}(1+sT_t)(1+sT_{sg})}{(1+sT_{ps})(1+sT_t)(1+sT_{sg})+\frac{K_{ps}K_{sg}K_t}{R}}\right] \frac{\Delta P_D}{\cancel{s}}$$

$$\Delta f(s) = \frac{-K_{ps}}{1+\frac{K_{ps}K_{sg}K_t}{R}} \cdot \Delta P_D$$

Taking $K_{sg}K_t = 1$.

$$\Delta f(s)\Big|_{\Delta P_c(s)=0} = \frac{-K_{ps}}{1+\frac{K_{ps}}{R}} \cdot \Delta P_D$$

$\div K_{ps}$

$$\boxed{\Delta f(s)\Big|_{\Delta P_c(s)=0} = \frac{-1}{B_{p.u}+\frac{1}{R}} \cdot \Delta P_D} \quad \text{---- (2)} \qquad \because \frac{1}{K_{ps}} = B_{p.u}$$

$$\text{Total } \Delta f_{s.s} = \Delta f_{ss}\Big|_{\Delta P_D(s)=0} + \Delta f_{s.s}\Big|_{\Delta P_C(s)=0}$$

$$= \frac{\Delta P_C}{B_{p.u} + \frac{1}{R}} - \frac{\Delta P_D}{B_{p.u} + \frac{1}{R}}.$$

$$\boxed{\Delta f_{s.s.} = (\Delta P_C - \Delta P_D)\left(\frac{1}{B_{pu} + \frac{1}{R}}\right)}$$ .... steady state frequency change.

Question:

Consider the Block diagram of load frequency control.
The following approximation is made regarding the analysis

$$(1+sT_{sg})(1+sT_t) = 1 + (T_{sg} + T_t)s = 1 + sT_{eq}$$

Determine $\Delta f(t)$ when $\Delta P_D = 0.01$

Solution:

The given data corresponds to free governor operation when $\Delta P_C(s) = 0$

$$\frac{\Delta F(s)}{\Delta P_C(s)} = \frac{-\left(\frac{K_{ps}}{1+sT_{ps}}\right)}{1 + \left(\frac{K_{ps}}{1+sT_{ps}}\right)\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{K_t}{1+sT_t}\right)\frac{1}{R}}$$

$\Rightarrow$ Taking default value.

$$1 + (T_{sg} + T_t)s = 1 + (0.4 + 0.5)s = 1 + 0.9s.$$

$$\Delta F(s) = \frac{-\left[\frac{K_{ps}}{1+sT_{ps}}\right]}{1 + \left(\frac{K_{ps}}{1+sT_{ps}}\right)\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{K_t}{1+sT_t}\right)\frac{1}{R}}$$

$$\Delta F(s) \quad \frac{-\left(\frac{100}{1+20s}\right)}{1+\left(\frac{100}{1+20s}\right)\left(\frac{1}{1+0.9s}\right)\left(\frac{1}{3}\right)} \cdot \frac{0.01}{s}.$$

Since

$$K_{ps} = \frac{1}{B_{p.u}} = \frac{1}{0.01 \text{ (default value)}} = 100$$

$R = 3$ (default)

$K_{sg}K_t = 1$ (default)

$T_{ps} = 20$ (default)

$$\Delta F(s) = \frac{-100(1+0.9s)}{(1+20s)(1+0.9s) + \frac{100}{3}} \cdot \frac{0.01}{s}$$

$$\Rightarrow \frac{-100 - 90s}{1 + 20.9s + 18s^2 + \frac{100}{3}} \cdot \frac{0.01}{s}$$

$$\Delta F(s) = \frac{-(1+0.9s)}{s\left(18s^2+20.9s+\cancel{3}+\frac{103}{3}\right)}$$

$$\Delta f = \lim_{s\to 0} sF(s)$$

$$= \frac{-\cancel{s}(1+0.9s)}{\cancel{s}\left(18s^2+20.9s+\frac{103}{3}\right)}$$

$$= \frac{-1}{103/3}$$

$$\Delta f = \frac{-3}{103} = 0.0289\ Hz$$

$$\boxed{\Delta f = 0.0289\ Hz}$$

DYNAMIC RESPONSE

Dynamic response of a s/m is obtained for the step changes in the load demand.

- Dynamic response deals with following assumption:

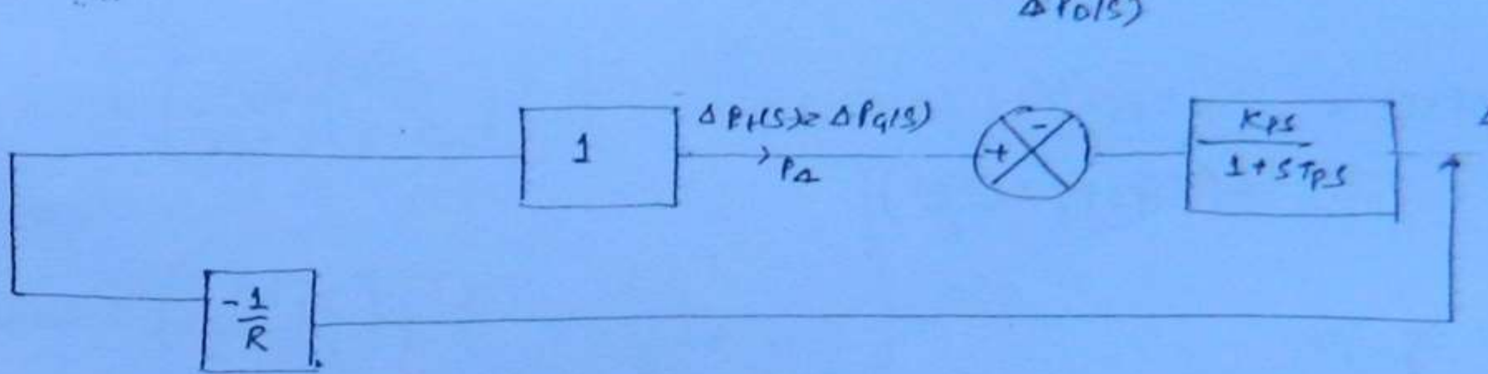
1) free governor operatn ($\Delta P_c(s)=0$)

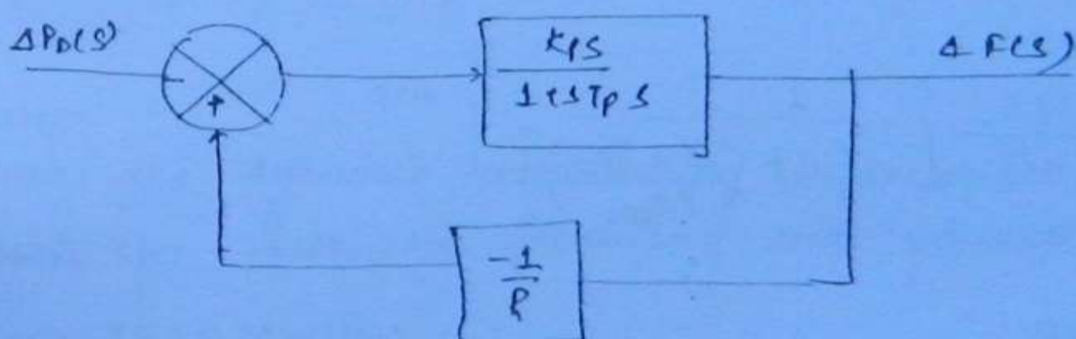
2) $K_{sg}K_t = 1$

3) $T_{sg} \cong 0$, $T_t \cong 0$

so,

$$\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{K_t}{1+sT_t}\right) = \frac{1}{(1+s\cdot 0)(1+s\cdot 0)} = 1.$$





$$\Delta F(S) = \frac{-\left(\frac{K_{ps}}{1+sT_{ps}}\right)\cdot \Delta P_D(S)}{1 - \left\{\left(\frac{K_{ps}}{1+sT_{ps}}\right)\left(\frac{-1}{R}\right)\right\}}$$

$$\Delta F(S) = \frac{-\left[\frac{K_{ps}}{1+sT_{ps}}\right]}{\left[1 + \left\{\left(\frac{K_{ps}}{1+sT_p}\right)\left(\frac{1}{R}\right)\right\}\right]} \cdot \frac{\Delta P_D}{S}.$$

$$= \frac{-K_{ps}}{\left[sT_{ps} + \left(1 + \frac{K_{ps}}{R}\right)\right]} \cdot \frac{\Delta P_D}{s}$$

$$\Delta F(s) = \frac{-K_{ps}}{s\left(sT_{ps} + \left(1 + \frac{K_{ps}}{R}\right)\right]} \Delta P_D.$$

Divide by T_{ps}

$$\Delta F(s) = \frac{-K_{ps}/T_{ps}}{s\left(s + \left\{\frac{1}{T_{ps}} + \frac{K_{ps}}{T_{ps} \cdot R}\right\}\right)} \cdot \Delta P_D.$$

$$\Delta F_s = \frac{-K_{ps}/T_{ps}.}{1} \left\{\frac{1}{s\left[s + \left(\frac{R + K_{ps}}{RT_{ps}}\right)\right]}\right\} \Delta P_D.$$

Applying partial fraction:

$$\frac{1}{s\left[s + \left(\frac{R + K_{ps}}{RT_{ps}}\right)\right]} = \frac{A}{s} + \frac{B}{s + \left[\frac{R + K_{ps}}{RT_{ps}}\right]}$$

$$1 = A \cdot \left(\frac{R + K_{ps}}{RT_{ps}}\right) \qquad \because A + B = 0$$

$$\Rightarrow A = \frac{RT_{ps}}{R + K_{ps}}$$

$$B = -A = \frac{-RT_{ps}}{R + K_{ps}}$$

$$\Delta f(s) = \left(-\frac{K_{ps}}{T_{ps}}\right)\left[\frac{R T_{ps}/R+K_{ps}}{s} - \frac{R T_{ps}/R+K_{ps}}{s+\left(\frac{R+K_{ps}}{R T_{ps}}\right)}\right]\Delta P_D.$$

$$= \left(\frac{-K_{ps}}{T_{ps}}\right)\left(\frac{R T_{ps}}{R+K_{ps}}\right)\left\{\frac{1}{s} - \frac{1}{s+\left(\frac{R+K_{ps}}{R T_{ps}}\right)}\right\}\Delta P_D.$$

$$\Delta f(s) = \left(\frac{-R K_{ps}}{R+K_{ps}}\right)\left\{\frac{1}{s} - \frac{1}{s+\left(\frac{R+K_{ps}}{R T_{ps}}\right)}\right\}\Delta P_D.$$

Taking inverse laplace:

$$\Delta f(t) = \left(-\frac{R K_{ps}}{R+K_{ps}}\right)\left\{1 - e^{-\left(\frac{R+K_{ps}}{R T_{ps}}\right)t}\right\}\Delta P_D.$$

Question:

Obtain the dynamic response of uncontrolled isolated power s/m with the following loop parameters. Regulation R = 2.

- $K_{ps} = 75$ p.u MW/Hz.
- $T_{ps} = 20$ sec
- $\Delta P_D = 0.02$ pu.

$$-\left(\frac{2\times 75}{2+75}\right)\left\{1 - e^{-\left(\frac{2+75}{2\times 20}\right)t}\right\} 0.02$$

$$-1.94\left\{1 - e^{-1.925t}\right\} 0.02$$

$$\Delta f(t) - 0.038\left(1 - e^{-3.87t}\right)$$

Dynamic response is represented in 4th Quadrant dynamic response is always exponential increasing in the fourth quadrant.

- Dynamic response alway gives $\boxed{\Delta f \neq 0}$

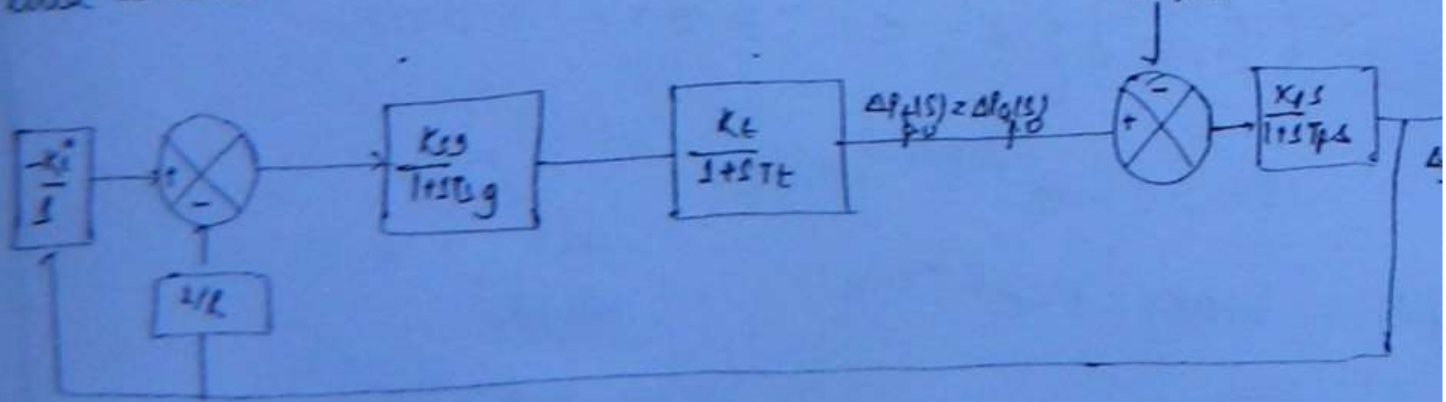
- The change in frequency Δf can be made equal to 0 by means of proportional and integral controller.

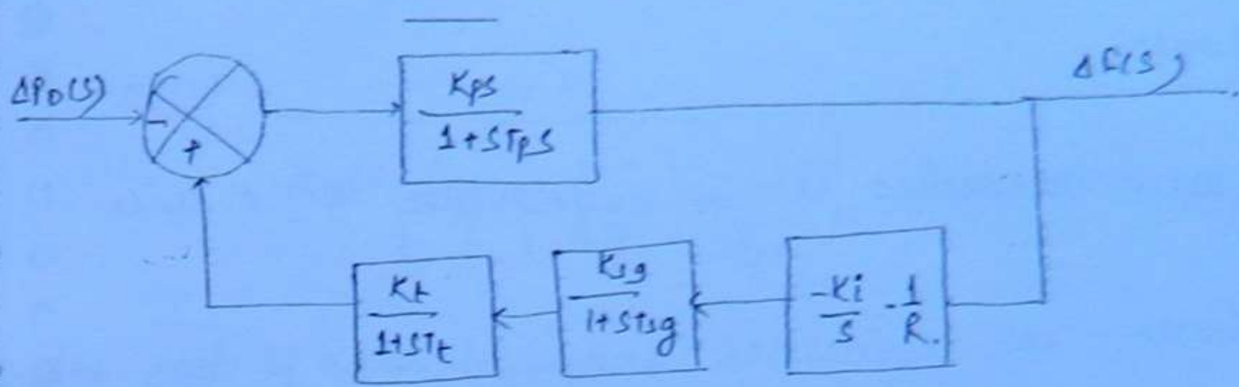
INTEGRAL CONTROLLER:-

- Integral controller is represented in the feedback path
- Let K_i be the gain constant of integral controller

negative sign indicates that for positive frequency error the speed changer should move in downward direction

- $\Delta f = 0$, can be made by replacing speed governor with integral controller ie FREE GOVERNOR OPERATION.
- change in frequency is determined for the changes in the load demand.





$$\frac{\Delta F(s)}{\Delta P_D(s)} = \frac{-\left(\frac{K_{ps}}{1+sT_{ps}}\right)}{1-\left(\frac{K_{ps}}{1+sT_{ps}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{-K_i}{s}\cdot\frac{1}{R}\right)}$$

$$\Delta F(s) = \frac{-\left(\frac{K_{ps}}{1+sT_{ps}}\right)}{1+\left(\frac{K_{ps}}{1+sT_{ps}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(+\frac{K_i}{s}+\frac{1}{R}\right)} \cdot \frac{\Delta P_D(s)}{s}$$

$$\Delta F_{s.s} = \lim_{s\to} s \cdot \Delta F(s)$$

$$\Delta F(s) = \frac{\cancel{s} \cdot -\left(\frac{K_{ps}}{1+sT_{ps}}\right)}{1+\left(\frac{K_{ps}}{1+sT_{ps}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(+\frac{K_i}{s}+\frac{1}{R}\right)} \cdot \frac{\Delta P_D(s)}{\cancel{s}}$$

$$= \frac{-(K_{ps})(1+sT_{sg})(1+sT_t)}{(1+sT_{ps})(1+sT_{sg})+K_{ps}K_{sg}K_t\left(\frac{K_i}{s}+\frac{1}{R}\right)} \cdot \Delta P_D$$

$$\boxed{\Delta f(t)_{s.s} = \frac{1}{\infty} = 0}$$

Dynamic Response:

- Dynamic response determines change in frequency w.r.t time.
- Assumption:

1) $K_{sg} K_t = 1$
2) $T_{sg} = T_t \equiv 0$
3)

So,

$$\Delta F(s) = \frac{-(K_{ps})(1+sT_{sg})(1+sT_t)}{(1+sT_{ps})(1+sT_{sg})(1+T_t)+K_{ps}K_{sg}K_t\left(\frac{K_i}{s}+\frac{1}{R}\right)} \cdot \frac{\Delta P_D}{s}$$

$$= \frac{-K_{ps}(1+s\cdot 0)(1+s\cdot 0)}{(1+sT_{ps})(1+s\cdot 0)(1+s\cdot 0)+1\cdot K_{ps}\left(\frac{K_i}{s}+\frac{1}{R}\right)} \cdot \frac{\Delta P_D}{s}$$

$$= \frac{-K_{ps}}{\left[(1+sT_{ps})+K_{ps}\left(\frac{K_i}{s}+\frac{1}{R}\right)\right]} \frac{\Delta P_s}{s.}$$

$$\Delta F(s) = \frac{-K_{ps}}{\left(s+s^2T_{ps}+K_{ps}K_i+s\frac{K_{ps}}{R}\right)}$$

$$\Delta F(s) = \frac{-K_{ps}}{\left[s^2 T_{ps}+s\left(1+\frac{K_{ps}}{R}\right)+K_{ps}K_i\right]} \Delta P_D.$$

$$\Delta f(s) = \frac{-K_{ps}/T_{ps}}{\left[s^2+s\left(\frac{1}{T_{ps}}+\frac{K_{ps}}{RT_{ps}}\right)+\frac{K_{ps}K_i}{T_{ps}}\right]}\Delta P_D \quad \text{------} \quad (A)$$

- The roots of quadratic equatn determines the nature of the integral controller.

CRITICAL GAIN: ($Ki_{critical}$)

Roots of above equation (A).

$$\frac{-\left(\frac{1}{T_{ps}}+\frac{K_{ps}}{RT_{ps}}\right) \pm \sqrt{\left(\frac{1}{T_{ps}}+\frac{K_{ps}}{RT_{ps}}\right)^2 - 4\cdot 1\cdot\left(\frac{K_{ps}}{T_{ps}}\cdot Ki_c\right)}}{2\cdot 1}$$

equating to 0.

$$\left(\frac{1}{T_{ps}}+\frac{K_{ps}}{RT_{ps}}\right)^2 - 4\cdot\left(\frac{K_{ps}Ki_c}{T_{ps}}\right) = 0$$

$$Ki_c = \frac{T_{ps}}{4K_{ps}}\left(\frac{1}{T_{ps}}+\frac{K_{ps}}{RT_{ps}}\right)^2$$

$$= \frac{T_{ps}}{4\cdot K_{ps}}\left[\frac{1}{T_{ps}^2}+\left(\frac{K_{ps}}{RT_{ps}}\right)^2+\frac{2K_{ps}}{RT_{ps}^2}\right]$$

$$= \frac{\cancel{T_{ps}}}{4\cancel{K_{ps}}}\cdot\frac{K_{ps}^{\cancel{2}}}{T_{ps}^{\cancel{2}}}\left[\frac{1}{K_{ps}^2}+\frac{1}{R^2}+\frac{2}{RK_{ps}}\right]$$

$$4Ki_c = \frac{K_{ps}}{T_{ps}}\left(\frac{1}{K_{ps}}+\frac{1}{R}\right)^2$$

$$\boxed{K_{ic} = \frac{K_{ps}}{4T_{ps}}\left[\frac{1}{K_{ps}} + \frac{1}{R}\right]^2}$$ ---- Critical Gain.

In terms of inertia constant:

$$K_{ic} = \frac{1/B_{p.u}}{2 \times \frac{2H}{Bf_0}}\left[B_{p.u} + \frac{1}{R}\right]$$

$\because \; T_{ps} = \frac{2H}{Bf_0}$.

$$\boxed{K_{ic} = \frac{1}{8H/Bf_0}\left[B_{p.u} + \frac{1}{R}\right]}$$

Imp $$\boxed{K_{ic} = \frac{f_0}{8H}\left(B_{p.u} + \frac{1}{R}\right)^2}$$

Question:

For an isolated integral controlled power s/m. find the value of critical gain the system parameters are given as follows

total capacity = 1000 MW

Load demand = 600 MW

inertia constant H = 5 sec

Regulation R = 4%

The nominal operating frequency is 50Hz

the s/m load increases by 1% if s/m frequency increases by 1%

Solution :

$$B = \frac{\partial D}{\partial f}$$

$$P_D = 600 MW$$

$$f = 50 Hz$$

$\frac{\partial D}{\partial f}$ load demand $\uparrow$ = $\frac{1\% \text{ of } 600}{1\% \text{ of } 50}$ = 12 MW/Hz

$$B_{p.u} = \frac{12}{1000} = 0.012 \, p.u/MW Hz$$

$$Ki_c = \frac{\cancel{50}^{10}}{8 \times \cancel{5}} \left(\frac{0.012}{} + \frac{1}{2} \right)^2$$

$$Ki_c = \frac{10}{8} (0.012 + 0.5)^2$$

$$\cancel{Ki_c = 0.085}$$

$$Ki_c = 0.32768$$

PERFORMANCE OF TRANSMISSION LINE

- The performance of overhead T.L can be obtained by

1) Efficiency
2) Regulation

- **Efficiency:-**

$$\frac{\text{Power O/P}}{\text{Power I/P}} \times 100$$

$$= \frac{\text{Power O/P}}{\text{Power O/P + Power losses}} \times 100$$

$$= \frac{\text{Power I/P} - \text{Power losses}}{\text{Power I/P}}$$

the power losses are the active power losses

$1\phi = I^2R$

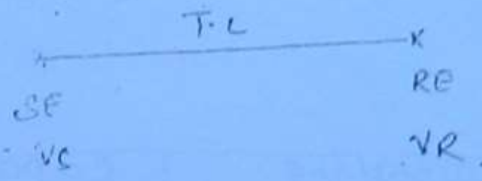
$3\phi = 3I^2R$

I = phase current

R = Resistance/phase.

- **Regulation** – for rotating M/C speed regulation is obtained

for static M/C or stationary M/C voltage regulation is measured.



$$\boxed{\%\epsilon = \frac{V_S - V_R}{V_R} \times 100}$$

• condition :-

When the receiving end is open circuited current I=0, voltage drop across TL = 0 &

$$V_S = V_R$$

$$\therefore \quad \boxed{\%\epsilon = \frac{V_{RO} - V_R}{V_R} \times 100}$$

the change in receiving end voltage from no-load to full load expressed w.r.t receiving end voltage at full load is V_R.

for a better T.L %η must be high & %ε must be ON.

CLASSIFICATION OF TL

TL are classified based on —

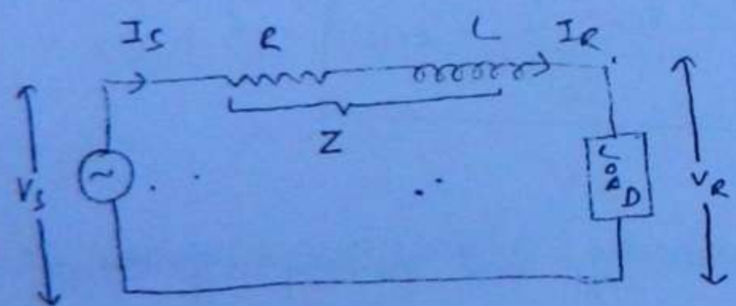
1) length.

ii) operating voltage
iii) effect of capacitance

	Length	operating voltage	capacitance
Short T.L	(0-80) km	(0-20) KV	Neglected
Medium T.L	(80-200) km	(20-100) KV	Lumped or concentrated
long T.L	(>200 km)	> 100 KV	uniformly distributed

• SHORT TRANSMISSION LINE :-

• Equivalent ckt



• Mathematical Relations:

• $I_s = I_R = I$ (say)

• Resistive voltage drop $= IR$

• Reactive voltage drop $= j X_L (I)$

• Total voltage drop $= I(R + jX_L)$

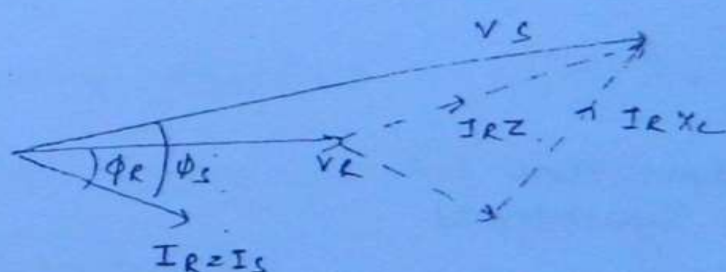
- Sending end voltage $V_S = V_R + I_R + j\,IX_L$

$$= V_R + I\underbrace{(R + jX_L)}$$

$$V_S = V_R + IZ.$$

5) Vector diagram -

- consider Recieving end voltage 'V_R' as the reference vector.
- Assume that the load is R-L load ∴ I_R lags V_R by an angle ϕ_R where ϕ_R lies b/w 0 to 90°.



Imp

- $\boxed{\phi_s > \phi_R}$
- $\boxed{\cos\phi_s < \cos\phi_R}$.

4) 2-port network parameter:

$$V_s = AV_R + BI_R \quad \text{- - - - (i)}$$

$$I_s = CV_R + DI_R \quad \text{- - - (ii)}$$

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \quad -$$

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

B → Impedance
C → Admittance.

$A = D = 1$ $\quad B = Z$

$C = 0$

alter →

$V_S = V_R + Z I_R$

$= 1 \cdot V_R + Z \cdot I_R$

$\therefore A = 1, \quad B = Z$

$I_S = I_R$

$= 0 \cdot V_R + 1 \cdot I_R$

$\therefore C = 0, \quad D = 1$

$A = D$ $\therefore$ Short line line Symmetrical.

Short line is Reciprocal because $\boxed{AD - BC = 1}$

$1 \times 1 - 0 \times Z = 1$

$1 = 1$

Questn

A - 1-ϕ T.L is transmitting 1.1 MW power to factory at 11 KV & 0.8 PF lagging. It has total resistance of 2 Ω & reactance of 3-0 Ω

Determine:
1) voltage at the sending end
2) Sending end P.f

3) %age regulation

4) %age efficiency.

unless specified by default take all data as recieving end data.

$P_R = 1.1$ MW

$V_R = 11$ KV

$\cos\phi_R = 0.8$ lag

R/phase $= 2\Omega$

X/phase $= 3\Omega$

$P_R = I_R V_R \cos\phi_R$

$I_R = \dfrac{1.1\times10^6}{0.8\times11\times10^3}$

$I_R = 125A$

$I_R = |I_R|\angle\phi_R$

$I_R = 125\angle-36.8^\circ$

Z/phase $= 2+j3$

$= 3.6\angle56.3$

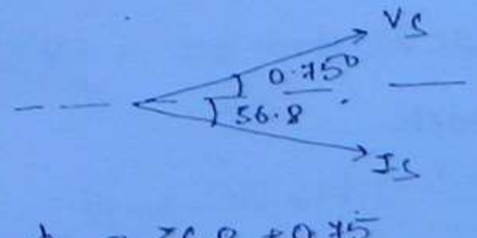
$V_S = V_R + I_R Z$

$= 11\times10^3 + 125\angle-36.8^\circ \times (2+j3)$

$= 11000\angle0^\circ + (125\angle-36.8^\circ)(3.6\angle56.5)$

$= 11.42\angle0.75^\circ$ KV

(ii) $\cos\phi_S = \cos\angle V_S.I_S$



$\phi_S = 36.8 + 0.75$

$= 37.55$

$\cos\phi_S = \cos(37.55)$

$\cos\phi_S = 0.79$ lag

) $\eta = \dfrac{\text{Power o/p}}{\text{Power o/p + losses}} \times 100$

$= \dfrac{1.1 \times 10^6}{1.1 \times 10^6 + I^2R} = \dfrac{1.1 \times 10^6}{1.1 \times 10^6 + (125)^2 \times 2}$

$\eta = 97.24\%$

7) $\% \epsilon = \dfrac{V_S - V_R}{V_R} \times 100$

$= \dfrac{11420 - 11000}{11000} \times 100$

$= 3.86\%$

If asked A, B, C, D

$A = 1$

$B = Z = 3.6$

$C = 0$

$D = 1$.

Quest?

An overhead 3-ϕ T.L deliver 5MW at 22kV at 0.8 lagging. The resistance & reactance of each conductor are 4Ω & 6Ω. Determine

1) Sending end voltage
2) % Regulation
3) %age η

Solution

$P_R = 5MW$

$V_R = 22kV$

$\cos\phi_R = 0.8 lag$

→ in 1-φ

$P_R = V_R I_R \cos\phi_R$

→ in 3-φ

$P_R = 3 V_{Rph} I_{Rph} \cos\phi_R$

$= \sqrt{3} V_{RL} I_{RL} \cos\phi_R$

until & unless specified all the value given is line value only

$P_R = \sqrt{3} V_{RL} I_{RL} \cos\phi_R$

$I_{RL} = \frac{5 \times 10^6}{22 \times 10^3 \times 0.8} = 164 A.$

$\boxed{V_{ph} \rightarrow V_L/\sqrt{3}}$

$I_R = 164 \angle -\cos^{-1} 0.8$

$= 164 \angle -36.8° A$

$V_L \rightarrow V_{ph} \rightarrow V_L/\sqrt{3}$

$Z = 4 + 6j$

$= 7.21 \angle 56.31$

$\hat{V_s} = \frac{22000 \angle 0°}{\sqrt{3}} + (164 \angle -36.8 (7.2 \angle 56.31°))$

$V_s = 13.817 \angle 1.63° kV$

$V_{sL} = \sqrt{3} V_s$

$= 23.94 kV$

$\% E = \frac{V_s - V_R}{V_R} \times 100$

$$= \frac{25940 - 22000}{22000} \times 100 = 8.82\%$$

$$\%\eta = \frac{O/P}{O/P + \text{losses}}$$

$$\text{losses} = 3 \cdot I^2 R$$
$$= 3 \times (164)^2 \times 4$$
$$= 322.75\ kW$$

$$\%\eta = \frac{5 \times 10^6}{5 \times 10^6 + 322.75 \times 10^3}$$

$$\%\eta = 93.9\%$$

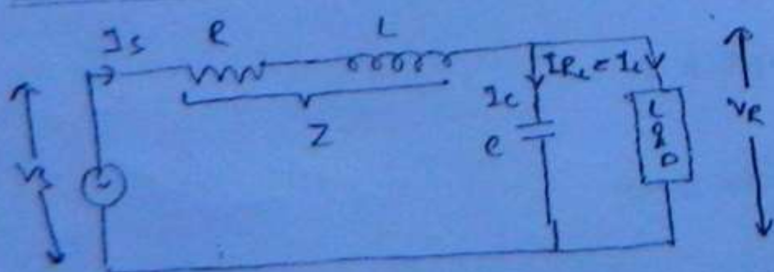
MEDIUM TRANSMISSION LINE

A medium T.L can be represented in 4 - method.

1) Load Condenser method
2) Source condenser method
3) Nominal - T method
4) Nominal - π method

LOAD CONDENSER METHOD

Equivalent Ckt:-



2) Mathematical Relation

- $I_s = I_R + I_C$
- Resitive voltage drop = $I_s R$
- Reactive voltage drop = $I_s(jX_L)$
- Total voltage drop = $I_s R + I_s(jX_L)$

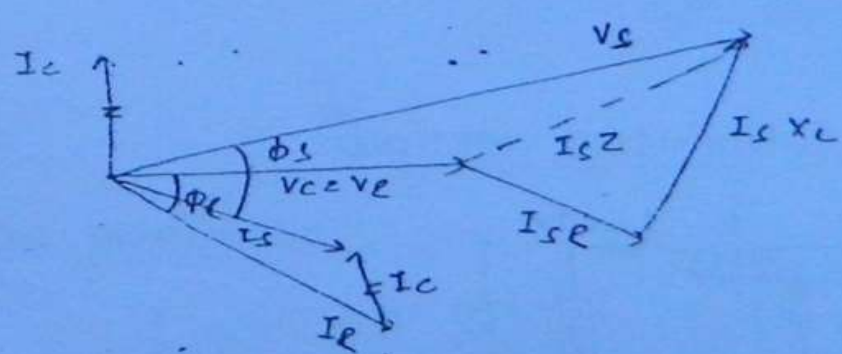
$$= I_s(R + jX_L)$$
$$= I_s . Z$$

- $V_s = V_R + I_s R + I_s(jX_L)$

$$V_s = V_R + I_s Z$$

- voltage across capacitor (V_C) = V_R

3) Vector diagram:



- for RL load I_R lags V_R by an angle ϕ_R

2) 2-port Network Parameters:-

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$$= \begin{bmatrix} 1+YZ & Z \\ Y & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$A = 1+YZ$

$B = Z$

$C = Y$

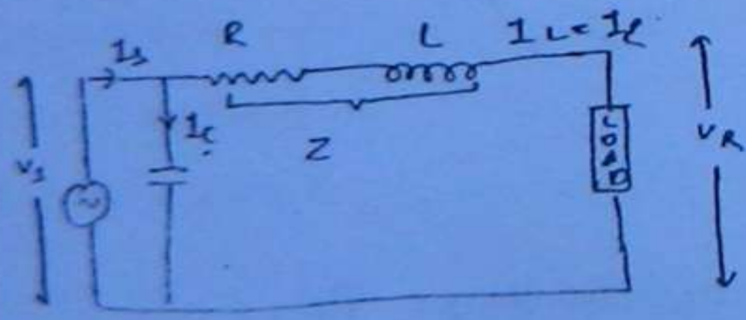
$D = 1$

- $A \neq D$ $\therefore$ Not symmetrical
- $AD - BC = (1+YZ).1 - Z.Y = 1$

$\therefore$ It is reciprocal

Load condenser method is not symmetrical
$\because$ capacitor is not symmetrical in the equivalent ckt.

2) SOURCE CONDENSER METHOD



$$I_S = I_R + I_C$$

1) Mathematical Relation :-

- Mathematical $I_S = I_R + I_C$
- Resistive voltage drop $= I_R . R$

• Reactive voltage drop $= I_R(jX_L)$

• Total voltage drop $= I_R R + I_R(jX_L)$

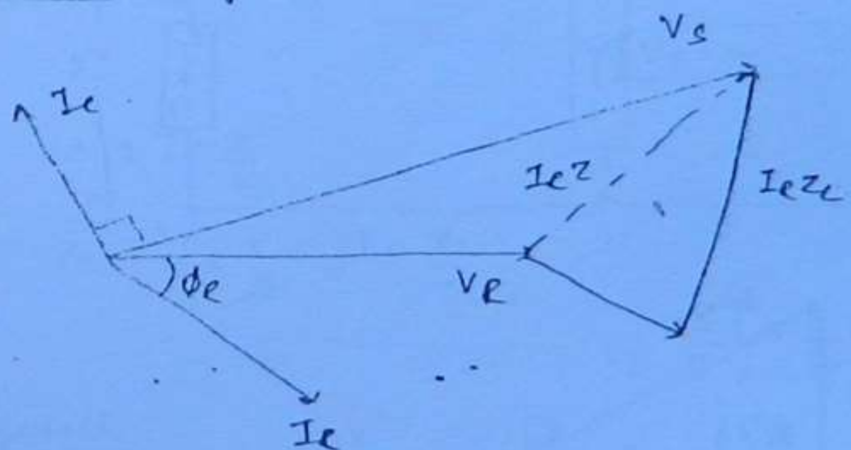
$$= I_R(R+jX_L)$$

$$= I_R Z$$

• Sending end voltage $V_S = V_R + I_R R + I_R(jX_L)$

$$V_S = V_R + I_R Z$$

Vector diagram



2-port N/W parameters:

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

→ see from the sending end, the branch that come first fill those values in 1st matrix.

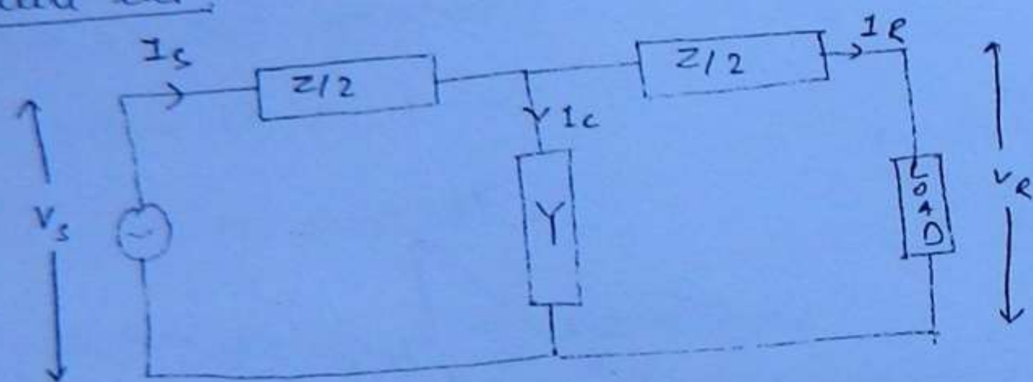
$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} 1 & Z \\ Y & 1+YZ \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$A = 1$ $B = Z$ $C = Y$ $D = 1 + YZ$

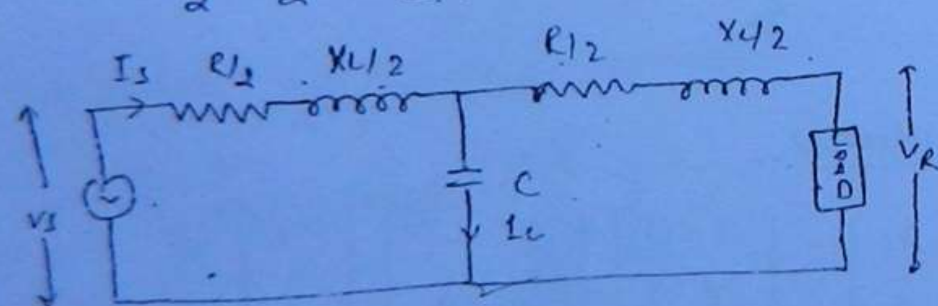
- $A \neq D$ So not symmetrical
- $AD - BC = 1$ $\therefore$ Reciprocal.

5) NOMINAL T-METHOD / MIDDLE CONDENSOR METHOD:

:) Equivalent ckt:



$$\frac{Z}{2} = \frac{R}{2} + j\frac{X_L}{2}$$



- $I_s = I_R + I_C$
- Resistive voltage drop $= I_s \cdot \frac{R}{2} + I_R \cdot \frac{R}{2}$

$\frac{R}{2}(I_s + I_R)$

- Total reactive drop $= I_s \left(j\frac{X_L}{2}\right) + I_R\left(j\frac{X_L}{2}\right)$

$$= j\frac{X_L}{2}(I_s + I_R)$$

- total voltage drop $= \left(\frac{R}{2} + j\frac{X_L}{2}\right) I_s + I_R\left(\frac{R}{2} + j\frac{X_L}{2}\right)$

$$= I_s \cdot \frac{Z}{2} + I_R \cdot \frac{Z}{2}.$$

- $V_C = V_R + I_R \cdot Z/2$

$$= V_R + I_R\left(R/2 + j\frac{X_L}{2}\right)$$

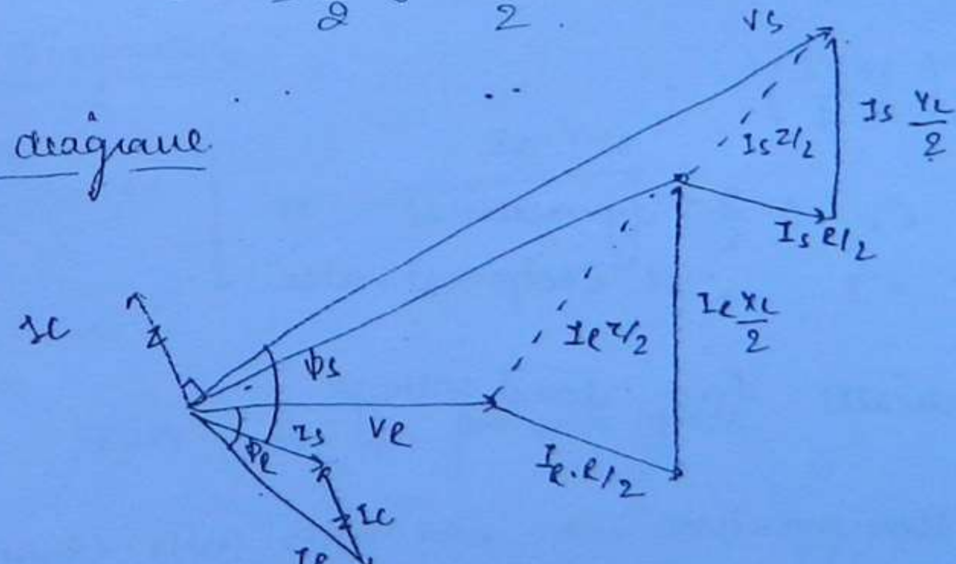
$$V_C = V_R + I_R \cdot \frac{R}{2} + j\, I_R \frac{X_L}{2}$$

$\boxed{V_R = V_C}$

- $V_s = V_C + I_s \frac{Z}{2}$

$$= V_C + I_s \cdot \frac{R}{2} + j I_s \cdot \frac{X_L}{2}.$$

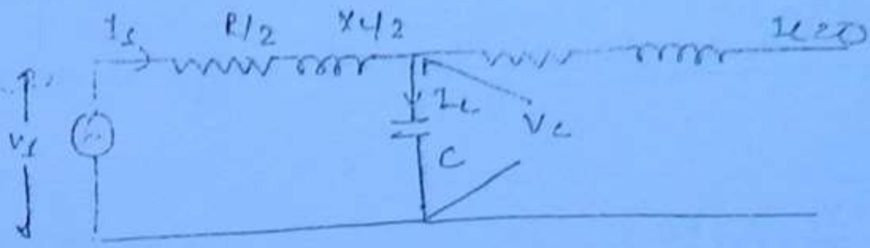
vector diagram



∴ 2-port N/W parameter :

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & Z/2 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} \begin{bmatrix} 1 & Z/2 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

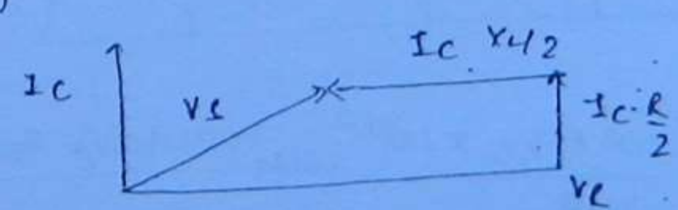
$$\boxed{I_S = I_C.}$$



- Total resistive drop $= I_C \cdot R/2$
- Total reactive drop $= I_C \, j \dfrac{X_L}{2}$
- $V_C = V_R$
- Sending end voltage $V_S = V_C + I_C \dfrac{R}{2} + I_C j \dfrac{X_L}{2}$

$$\text{or } V_S = V_R + I_C \frac{R}{2} + I_C \frac{jX_L}{2}.$$

<u>vector diagram:</u>



$V_R > V_S$ is the Ferranti effect.

- Ferranti effect occur when the receiving end of T.L is operating under no-load condition or very light load condition

or $V_{R0} > V_S$

V_{RD} = Voltage across Capacitor

$$= I_C \cdot (-jX_C)$$

&

$$I_C = \frac{V_S}{R/2 + j\frac{X_L}{2} - jX_C}$$

$$= \frac{V_S}{\frac{R}{2} + j\frac{\omega L}{2} - j\frac{1}{\omega C}}$$

Imp

$$\boxed{V_{RD} = \left(\frac{V_S}{R/2 + j\frac{\omega L}{2} - j\frac{1}{\omega C}}\right)\left(-j\frac{1}{\omega C}\right)}$$

Example

The %age rise in the voltage at the recieving end of a TL of length 200 km operating at 50 Hz is

$$\text{Increase in voltage} = \frac{\omega^2 l^2 V_r \times 10^{-10}}{18} \text{ volts}$$

$$\text{\%age} \uparrow \text{ in voltage} = \frac{\frac{\omega^2 l^2 V_R \times 10^{-10}}{18}}{V_R} \times 100$$

$$= \frac{\omega^2 l_2^2 \times 10^{-10} \times 100}{}$$

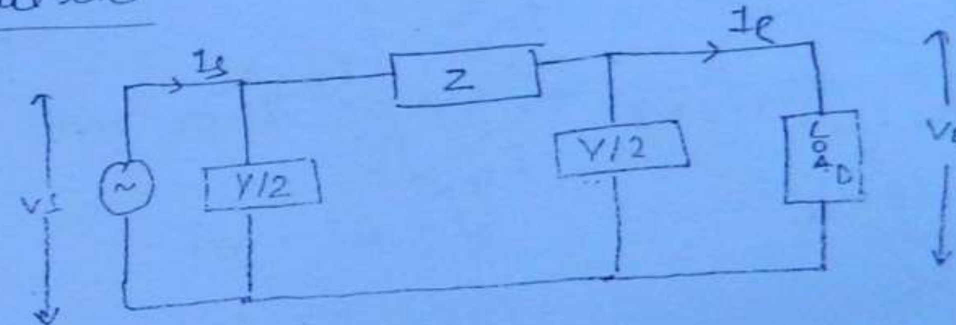
$$= \frac{(2\pi \times 50)^2 \times (200)^2 \times 10^{-8}}{18}$$

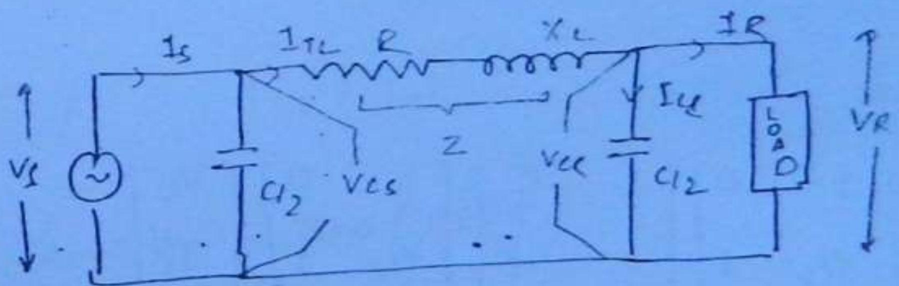
$$= 2.18\%$$

* Ferranti effect is more severe in long T.L when compared with medium T.L
* Ferranti effect is negligible in short T.L

4) NOMINAL-π METHOD / SPLIT CONDENSER METHOD

i) Equivalent ckt —



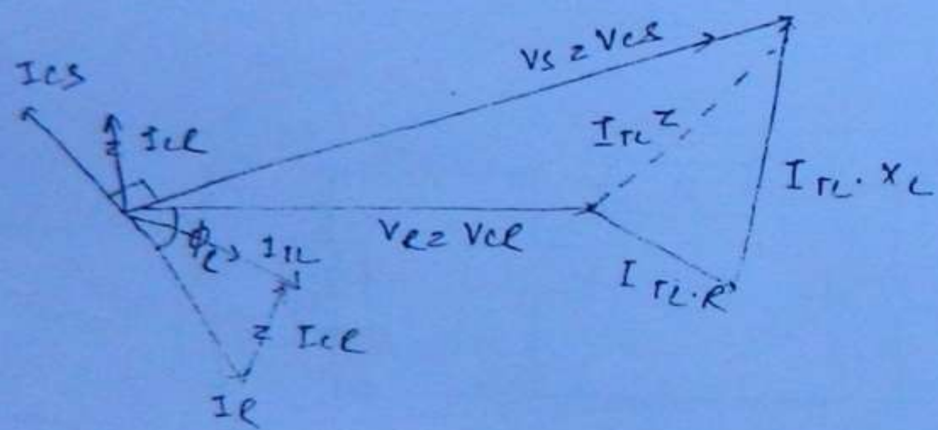


Mathematical Relations:

- $I_{TL} = I_R + I_{CR}$; $I_S = I_{CS} + I_{TL}$
- $V_{CR} = V_R$
- $V_{CS} = V_S$
- Total resistive drop = $I_{TL} \cdot R$
- Total reactive drop = $I_{TL} \cdot j X_L$
- Total voltage drop = $I_{TL}(R + jX_L)$

- Sending end voltage (V_s) = $V_R + I_{TL}R + I_{TL}jX_L$

Vector diagram:-



2 port N/W parameters —

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y/2 & 1 \end{bmatrix} \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y/2 & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1+\frac{ZY}{2} & Z \\ \frac{Y}{2}+\left(\frac{ZY}{2}+1\right)\frac{Y}{2} & \frac{1+YZ}{2} \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$A = 1+\frac{ZY}{2}$ $\qquad A = D$

$B = Z$

$C = \frac{Y}{2} + \frac{ZY^2}{4} + \frac{Y}{2}$

$$= Y + \frac{ZY^2}{4}$$

$$\therefore C = Y\left(1 + \frac{ZY}{4}\right)$$

- $A = D$ ∴ It is symmetrical.

$AD = BC = 1$ also so reciprocal also

<u>condition</u>-

Assume that receiving end of T.L is open circuited

$$I_{TL} = I_{ce} + I_R$$

$$= I_{ce} + 0$$

$$I_{TL} = I_{cL}$$

$$V_{R0} = V_{ce} = I_{ce}\left(\underbrace{-j\frac{X_C}{2}}_{\times}\right)$$ this is wrong

$$V_{R0} = I_{CR}(-jX_{C1/2})$$

where $X_{C1} = 2/\omega C$

$= 2/\omega C$

$$I_{ce} = V_S / R + jX_L - jX_{C1/2}$$

$$V_{RO} = \left(\frac{V_s}{R + jX_L - jX_{C1/2}}\right)(-jX_{C1/2})$$

$$\boxed{V_{RO} = \left(\frac{V_s}{R + j\omega L - j\frac{2}{\omega C}}\right)\left(-j\frac{2}{\omega C}\right)}$$

NOTE:

- Load condenser method is used to improve the P.F of the load.
- Source condenser method is used to improve the p.f of the source
- Nominal π - method is used to improved the p.f of both source & load
- Nominal T-method is used to improve the P.F in T.L.

Quesn

A 220KV T.L represented as π-method has the following parameter

$A = 0.9\angle 5^\circ \qquad B = 80\angle 65^\circ \Omega$

The sending end voltage is maintained at 220KV. The ↑ in voltage at the receiving end & the line losses on no-load condn are?

$V_s = 220\text{ KV}$

$V_S = AV_R + BI_R$

No-load so $I_R = 0$

$V_S = A V_{R0}$

$\therefore V_{R0} = \frac{V_S}{A} = \frac{220}{0.9} = 244.4 \text{ KV}$

$\uparrow$ in voltage = $(244.4 - 220)$ KVolts
$= 24.4 \text{KV}$

Line losses = 0 ($\because$ the system is under no load)

Quest^n

A 3-ϕ T.L, 120km long, 50Hz delivers a connected load of 30MVA, 110KV & 0.8 p.f lagging. the resistance is 10Ω/phase & reactance is 40Ω/phase. & capacitive, susceptance is 6×10^{-4} S. Find the voltage regulation by nominal π method.

from the capacitive susceptance

$I_{CR} = V_R/(-j X_{C1/2}) = V_R(j B_{C1/2})$

$= \left(\frac{110000}{\sqrt{3}}\right)(j\, 3 \times 10^{-4})$

$= (0 + j\, 11\sqrt{3})$ A

$11\sqrt{3} \angle 90°$ A

$I_{TL} = I_C + I_{CL}$

$= (157.46 \angle -36.8) + (11\sqrt{3} \angle 90^\circ)$

$I_{TL} = 146.8 \angle -30.9$ A.

voltage drop across TL $= I_{TL}(R + jX_L)$

$= (146.8 \angle -30.9)(10 + j40)$

$= 6052.49 \angle 45.12^\circ$ V.

Sending end voltage $V_S = V_R +$ voltage drop

$= \frac{11000}{\sqrt{3}} + (6052.49 \angle 45.12)$

$= 67990.74 \angle 3.6^\circ$ V

$V_{SL} = \sqrt{3} \times V_S |$phase

$= \sqrt{3} \times 67990.74$

$= 117.6$ KV

$\% \epsilon = \frac{V_S - V_R}{V_R} \times 100$

$= \frac{117.6 - 110}{110} \times 100$

$= 6.9\%$

Example

A - 3-ϕ feeder having a resistance of 5-Ω & reatance of 10Ω supplies a load of 2MW, at 0.85 p.f lagging. The receiving end voltage is maintained at 11KV by means of static condenser taking 2.1 MVAR from the line. Calculate sending end voltage, sending end P.F regulation & efficiency of feeder.

- The given data corresponds to load condenser method.

$$W = \sqrt{3} \cdot V_{RL} I_{RL} \cos\phi_R$$

$$2 \times 10^6 = \sqrt{3} \times 11 \times 10^3 \times I_{RL} \times 0.85$$

$$I_{RL} = 123.5 A$$

$$I_R = 123.5 \angle -31.78^\circ A$$

$I_C = ?$

Capacitive current

$$VAR = \sqrt{3} V_{RL} I_C \sin\phi$$

$$2.1 \times 10^6 = \sqrt{3} \times 11 \times 10^3 \times I_C \sin 90^\circ$$

$$I_C = 110.22 A$$

$$I_C = 110.22 \angle +90^\circ A$$

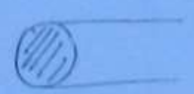
$$I_S = I_R + I_C$$

$$= 123.5 \angle -31.78 + (110.22 \angle 90^\circ)$$

Types of Conductors :-

1. Solid conductor
2. Stranded conductor
3. Composite conductor (≤ 220KV)
4. Bundled conductor (> 275KV)

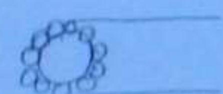
SOLID CONDUCTOR

- 

copper

- A solid conductor consists of single strand
- High electrical conductivity
- Due to solid mech. strength is ↑
- Transportation is difficult
- Stringing of solid conductor is very difficult

STRANDED CONDUCTOR

- 

copper.

- Stranded conductor consists of 2 or more strands arranged such that the required mech strength is obtained & are connected in parallel to ↑ the current carrying capacity.
- High electrical conductivity
- The required mech strength can be obtained by selecting no of strands
- Transportation is easier
- Stringing of stranded conductor is easy

• for a solid conductor in ac s/m skin effect is more	for a stranded conductor in ac s/m skin effect is less

SAG AND TENSION

1. parabolic method < 300km
2. catenary method > 300 km.
3. Effect of external factors on calculat^n of Sag & Ten
4. Calculation of sag and tension when Transmission towers are located at different height from ground level
5. Calculation of basic terms involved with Sag.

CALCULATION OF SAG AND TENSION BY PARABOLIC METHOD.

- Parabolic method is used to determine sag and tension for spans upto 300m and sag without exceeding 5% of the span length.
- CATENARY: A line conductor of uniform cross-section and material perfectly flexible but stretch inelastic b/w the two supports, hanging freely

cond[illegible] influence of its own weight takes the form of curve known as ~~k~~ catenary.

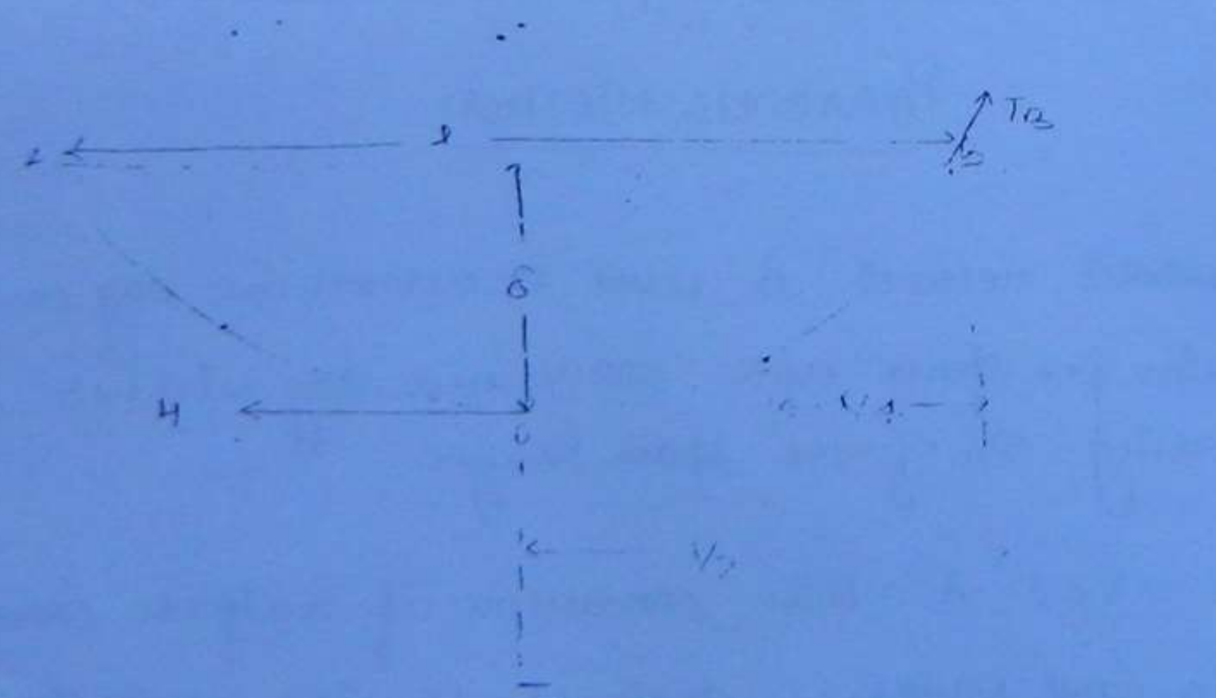
SPAN:

The horizontal distance b/w the adjacent supports is known as span.

SAG:

~~Sor~~ The vertical distance between the conductor at the midpoint and the ~~ter~~ line joining two adjacent level supports is known as sag.

. Sag is measured along the resultant load on the conductor.



. Consider a T.L 'AOB' freely suspended.

between the supports A and B. The lowest point is consider O.

- Let 'l' be span length

  $\omega \rightarrow$ weight/unit length of the conductor

  $\delta \rightarrow$ T.L line sag.

  $H \rightarrow$ Horizontal tension in T.L at the point of max^m sag.

  $T_B \rightarrow$ Tension at the support B due to T.L.

- Consider the equilibrium of the portion 'OB' of the conductor. The forces acting are:-

1) Horizontal tension 'H' at point O.
2) The weight of portion OB acting vertically downw through the center of gravity at a distance 'l/4' from the point 'B'.
3) Tension T_B at the support B.

- obtaining the moment at the point B

- $$H \cdot \delta = \omega \times OB \times l/4$$

$$H \cdot \delta = w \cdot \frac{l}{2} \cdot \frac{1}{4}$$

$$\Rightarrow \boxed{H = \frac{wl^2}{8\delta}} \quad \text{---- horizontal tension.}$$

and

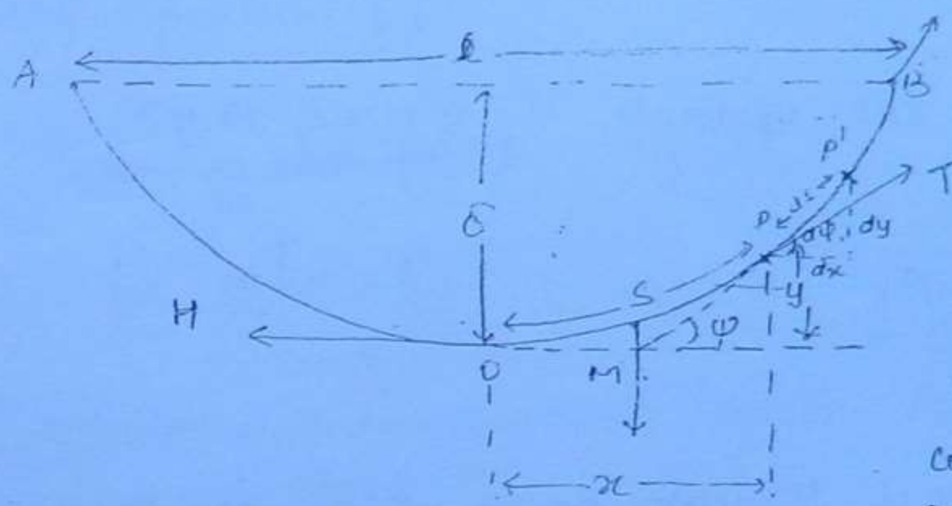
$$\boxed{\delta = \frac{wl^2}{8H}} \quad \text{---- sag.}$$

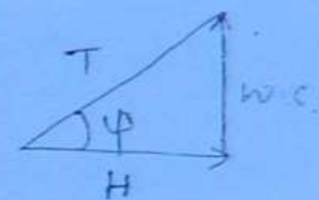
- The sag in a freely suspended conductor is directly proportional to weight/unit length of the conductor, square of span length and inversely proportional to horizontal tension (H).

CATENARY METHOD

- Catenary method is applicable when the length of span is greater than 300m and sag is more than 5% of the span length
- In catenary method a part of section OB is considered.
- Consider a point 'P' on the curve such that

$$OP = x \text{ m.}$$





$\cos\varphi = H/T$.

$\sin\varphi = w.s/T$

- the three forces acting on point 'P' on the curve are:

  1) Horizontal tension 'H' at lowest point
  2) weight of section OP. acting through its center of gravity i.e $\boxed{w.OP = w.s}$
  3) tension 'T' acting at point 'P' along the tangent to the curve at point 'P'

- finding the intersection point of the three forces and the intersection point is 'M'

so

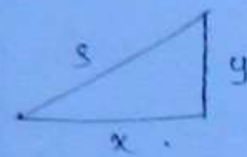
$$\boxed{\begin{aligned} H &= T\cos\varphi \\ ws &= T\sin\varphi \end{aligned}}$$

$$\boxed{\tan\varphi = \frac{ws}{H}}$$

- Let (x,y) be the coordinates of point P.

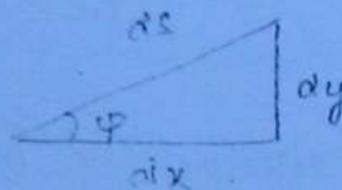
- Considering the triangle involving (x,y).

$$\boxed{s^2 = x^2 + y^2}$$



- Extend the point P upto point P' on the T.L such that $PP' = ds$.

$$\boxed{ds^2 = dx^2 + dy^2}$$



Divide by dx^2

$$\left(\frac{ds}{dx}\right)^2 = 1 + \left(\frac{dy}{dx}\right)^2$$

$\because \frac{dy}{dx} =$ slope of T.L $= \frac{\omega \cdot s}{H} = \tan\varphi$

$$\Rightarrow \left(\frac{ds}{dx}\right)^2 = 1 + \left(\frac{\omega \cdot s}{H}\right)^2$$

$$\frac{ds}{dx} = \sqrt{1 + \left(\frac{\omega \cdot s}{H}\right)^2}$$

$$\frac{dx}{ds} = \frac{1}{\sqrt{1 + (\omega \cdot s/H)^2}}$$

$$\Rightarrow \boxed{dx = \frac{ds}{\sqrt{1 + (\omega \cdot s/H)^2}}} \quad \text{---- (1)}$$

• Integrating equation (1)

$$\cancel{x = \frac{H}{\omega} \sinh^{-1}\left(\frac{\omega s}{H}\right)}$$

$$\boxed{x = \frac{H}{\omega} \sinh^{-1}\left(\frac{\omega s}{H}\right) + C_1} \quad \text{--- (2)}$$

$C_1 \rightarrow$ constant of integration which is evaluated from the condition at point O

At point O

$$x = 0 \; ; \; s = 0$$

so eqⁿ (2)

$$0 = 0 + C_1$$

$$\boxed{C_1 = 0}$$

so equation (2) will be

$$\boxed{x = \frac{H}{\omega} \sinh^{-1}\left(\frac{\omega s}{H}\right)} \quad \text{--- (3)}$$

rearranging we get

$$\boxed{\frac{H}{\omega}\left(\sinh \frac{x\omega}{H}\right) = s} \quad \text{--- (4)}$$

•

$$\frac{dy}{dx} = \tan\phi = \frac{\omega s}{H}$$

$$dy = \frac{\omega s}{H} \cdot dx \cdot$$

so

$$dy = \sinh\left(\frac{wx}{H}\right) dx \qquad \because \frac{ws}{H} = \sinh\left(\frac{wx}{H}\right)$$

on integrating above equation we have.

$$\boxed{y = \frac{H}{w}\cosh\left(\frac{wx}{H}\right) + C_2} \quad \text{----} (5)$$

now at $x=0$, $y=0$.

so $C_2 = -H/w$.

so

$$\boxed{y = \frac{H}{w}\cosh\left(\frac{wx}{H}\right) - \frac{H}{w}} \quad \text{----} (6)$$

→ vertical distance / catenary eqn.

- Equation '6' is known of <u>EQUATION OF CATENARY</u>
- Representing the parameter in terms of the tension 'T'.

using eqn $\quad T\cos\varphi = H$

$\quad T\sin\varphi = w \cdot s$.

on squaring and adding we get.

$$(T\cos\varphi)^2 + (T\sin\varphi)^2 = H^2 + w^2s^2$$

$$\boxed{T = \sqrt{T^2 + (ws)^2}} \text{ - Tangential tension } (7)$$

- The above equation represents the tension acting tangentially a point 'p' in terms of Horizontal tension and weight of the conductor for the section OP.

- Dividing the above equatⁿ with H or respective (ws/H).

$$T = \sqrt{H^2 + H^2\left[\sinh\left(\frac{wx}{H}\right)^2\right]}$$

$$T = H\sqrt{1 + \sinh^2\frac{wx}{H}}$$

$$\boxed{T = H\cosh\frac{wx}{H}} \quad \text{---} (8)$$

Evaluation of Sag(δ) Length of Conductor(L) and Tension(T). At Support B

- At support B:-

$$x = l/2$$

$$s = L/2$$

$$y = \delta.$$

, the above relation are satisfied at the support B i.e transmission tower located at the point B :

now equation 6:

$$y = \frac{H}{\omega}\cosh\left(\frac{\omega x}{H}\right) - \frac{H}{\omega}.$$

$$\delta = \frac{H}{\omega}\cosh\frac{\omega l}{2H} - \frac{H}{\omega} \qquad x = l/2$$

*

$$\boxed{\delta = \frac{H}{\omega}\left[\cosh\frac{\omega l}{2H} - 1\right].} \quad \text{----} (9)$$

now equation 8:

$$T = H\cosh\left(\frac{\omega x}{H}\right)$$

*

$$\boxed{T = H\cosh\left(\frac{\omega l}{2H}\right)} \quad \text{----} (10)$$

equation 4:

$$\frac{H}{\omega}\sinh\left(\frac{\omega x}{H}\right) = S.$$

$$\frac{H}{\omega}\sinh\left(\frac{\omega l}{2H}\right) = L/2$$

*

$$\boxed{L = \frac{2H}{\omega}\sinh\left(\frac{\omega l}{2H}\right).} \quad \text{----} (11)$$

$\frac{H}{\omega}\sinh\left(\frac{\omega x}{H}\right)$

δ

Approximate Results: By expansion series

- from eqn (9). on expanding cosh we get

$$\delta = \left(\frac{H}{w}\right)\left[\cosh\left(\frac{wl}{2H}\right) - 1\right]$$

$$\delta = \left(\frac{H}{w}\right)\left[\cancel{1} - \left(\frac{wl}{2H}\right)^2 \frac{1}{2!} + \left(\frac{wl}{2H}\right) \cdot \frac{1}{4!} - \cdots \cancel{1}\right]$$

$$\delta = \frac{H}{w} \cdot \frac{w^2 l^2}{2H} \cdot \frac{1}{2}.$$ neglecting higher terms

$$\boxed{\delta = \frac{wl^2}{8H.}} \quad \text{- - - - (13)}$$

- from equation (10)

$$T = H \cosh \frac{wl}{2H.}$$

$$T = H\left[1 + \left(\frac{wl}{2H}\right)^2 \frac{1}{2!} + \cdots\right]$$

$$T = H + \frac{\cancel{H} w^2 l^2}{4H^{\cancel{2}}} \cdot \frac{1}{2}$$

$$\boxed{T = H + \frac{w^2 l^2}{8H.}} \quad \text{- - - - (14)}$$

$$T = H + w \cdot \left(\frac{wl^2}{8H}\right)$$

$$\boxed{T = H + w \cdot \delta.} \quad \text{- - - (15)}$$

• equation (31)

$$L = 2\left(\frac{H}{w}\right) \sinh \frac{wl}{2H}.$$

$$L = 2\left(\frac{H}{w}\right) \left[\left(\frac{wl}{2H}\right) + \left(\frac{wl}{2H}\right)^2 \frac{1}{3!} + \cdots \right]$$

$$\cancel{L = 2\left(\frac{H}{w}\right) \cdot l.}$$

$$L = \frac{2H}{w} \cdot \frac{wl}{2H} + \frac{2H}{w} \cdot \frac{w^2 l^3}{8H^2} \cdot \frac{1}{6}.$$

$$\boxed{L = l + \frac{1}{24} \frac{w^2 l^3}{H^2}.} \quad \text{---} \quad (16)$$

$$L = l + \frac{1}{24} \frac{w^2 l^3}{\frac{w^2 l^4}{64 \delta^2}} \qquad \because H, \ \delta = \frac{w l^2}{8H}.$$

$$L = l + \frac{64 \delta^2}{24 \cdot l}$$

$$\boxed{L = l + \frac{8}{3} \frac{\delta^2}{l}.} \quad \text{----} \quad (17)$$

uestion:

he span b/w the two conductor/towers is 200m.
the ultimate tensile strength of conductor is 5758 kg/f
the weight of the conductor is 604 kgf/km
the safety factor is 2. the sag is

Ans =

$$\delta = \frac{5758 \times 250 \times 10^{-3}}{}$$

Horizontal tension = $\frac{\text{tensile strength}}{2}$ $5758/2$

$$\delta = \frac{604 \times (200 \times 10^{3})^2 \times 2}{5758 \times 8}$$

$$\delta = 1.048\,m$$

LOADING ON CONDUCTORS

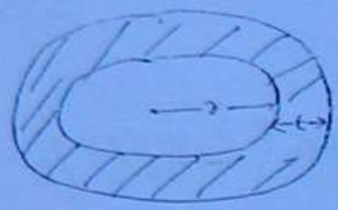
- There are three forces acting on conductor.

  1) weight of conductor
  2) Ice loading
  3) wind loading.

- The weight of conductor acts vertically downwards and depends on conductor type.

- The weight of conductor/unit length is obtained from mechanical characteristic of conductor.

Ice loading



$r \to$ radius of conductor

$t \to$ thickness of ice coating

- Due to deposition of ice on the surface of conductor the weight/unit length of conductor increases.

- Area of cross section of conductor. $\pi r^2 = \frac{\pi}{4} D^2$ ... (1)

Area of cross-section of conductor $\bar{c}$ ice coating

$$A_{con+ice} = \frac{\pi}{4}(D+2t)^2 \quad \text{--- (2)}$$

Area of cross section of ice coating

$$= \frac{\pi}{4}\left[D^2 - (D+2t)^2\right]$$

$$= \frac{\pi}{4}\left[\cancel{D^2} + \cancel{D^2} + 4t^2 + 4Dt\right]$$

$$= \frac{\pi}{\cancel{4}}\left[\cancel{4}t^2 + \cancel{4}Dt\right]$$

$$\boxed{A_{ice} = \pi t(t+D)\, m^2} \quad (3)$$

- Volume of ice per unit length of conductor

$$\boxed{V = \pi t(t+D)\, m^3} \quad \text{--- (4)}$$

- Let (ρ_i) be the weight density of ice. The weight of the ice coating per unit length:

$$\boxed{\omega = \underbrace{\pi t(t+D)}_{\text{Volume}} \cdot \underbrace{\rho_i}_{\text{weight density}}}$$

→ where $\rho_i = 913.5\ kgf/m$
$= 896\ N/m^3$.

- Due to ice coating the weight of the conductor increase and the vertical weight increases.

5) Wind loading:-

- Assume that conductor is covered with ice coating
- Let 'r' be the radius of conductor and
  't' be the thickness of ice coating
- Wind exterts horizontal pressure depending on velocity of wind acting ⊥.
  Area projected per unit length of ice cover conductor.

=

- The wind pressure acts on area - $\frac{\pi}{4}(D+2t)^2$

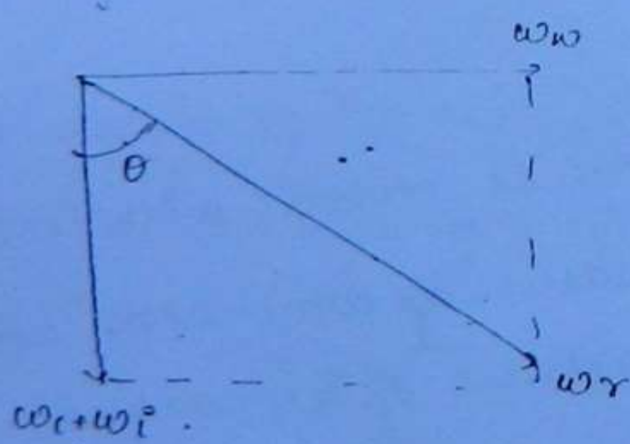
- $(D+2t)$ is surface exposed to wind pressure.
- Force exerted due to wind perpendicular to direcn of span per unit length of conductor.

$$F = (D+2t)_m \times P \ (N/m)$$

$$\boxed{F = (D+2t) \times P}$$ meter Newton.

where P is the wind pressure acting in a direction $\perp$ the direction of the span.

Resultant loading:-



- 'θ' represent the angle by which conductor is shifted from its original position due to wind pressure.

$$w_r = \left[(w_w)^2 + (w_c+w_i)^2\right]^{1/2}$$

Question:-

A T.L has span of 275m between level supports the conductor has diameter of 19.55 mm, weighs 0.844 kgf/ with ultimate breaking strength 7950 kgf. Each conduc has radial covering of ice 9.53 mm thick and is subjected to horizontal wind pressure 40 kgf/m² of ice covered projected area. If the factor of safety is two. The deflected sag and vertical component of sag are.

Soln

$l = 275 mm$

$D = 19.53 mm.$

$w = 0.844 \frac{kgf}{m}.$

· weight of ice per meter length of the conductor

$w_i = \pi t(D+t)\rho_i$

$= \pi t(D+t) \times 913.5$

1.54×10^{-1}

$= 3.14 \times 9.53 \times 10^{-6}(19.53 \times 10^{-6} + 9.53 \times 10^{-6}) \times 9$

$= 0.755 kgf$

$w_w = (D+2t) \times P$

$\Rightarrow (3.859 \times 10^{-5}) \times 40$

$= 1.54 \times 10^{-3} kgf/km$

$= 1.54 kgf/m.$

- weight of conductor, $0.844\ kgf$

resultant weight

$$w_r = \left[(1.54)^2 + (0.795 + 0.844)^2\right]^{1/2}$$

$$w_r = 2.25\ kgf.$$

- working tension $H. = \frac{\text{ultimate strength}}{\text{safety facto}} = \frac{7950}{2}$

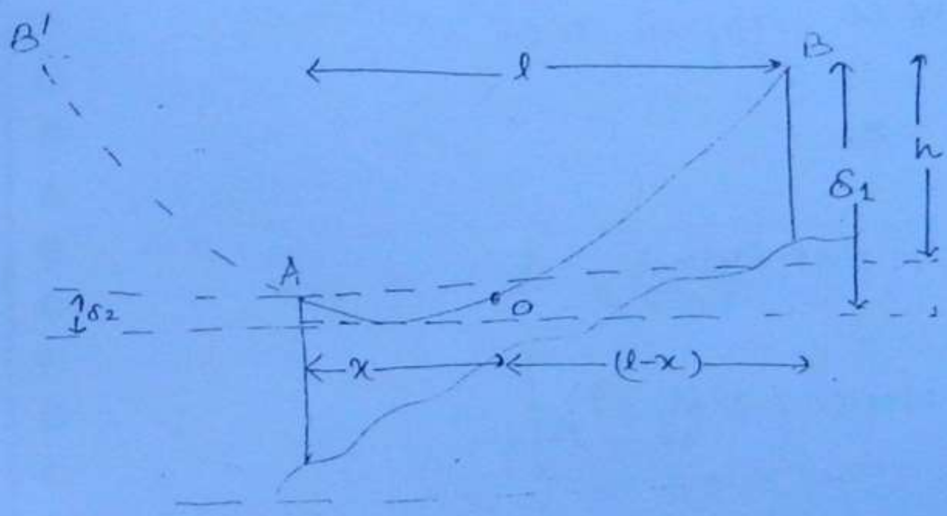
$$= 3975$$

$$\delta = \frac{wl^2}{8H}$$

→ deflected sag due to w_r. $\Rightarrow \frac{2.25 \times 275^2}{8 \times 3975} = 5.35\ m$

→ vertical sag δ. $\Rightarrow \frac{\overset{(w_c + w_i)}{1.639} \times 275^2}{8 \times 3975} = 5.89\ m.$

CALCULATION OF SAG WHEN TRANSMISSION TOWER ARE LOCATED AT DIFFERENT HIEGTH FROM GROUND LEVEL.



- the transmission towers are not at the same level in hilly area

- Let

  l → horizontal span length b/w A and B

  h → difference in level b/w two supports A B

  x → horizontal distance of support A from lowest point O

  (l-x) → horizontal distance of B from lowest point O.

- B'OB. represents the entire catenary conductor AOB is portion of catenary B'OB. the portion

OA and OB may be treated as catenaries of sag δ_2 and δ_1.

- The vertical reaction at lower support.. ωx.
- vertical reaction at higher support $\omega(l-x)$.
- Tension at support A

$$\boxed{\begin{aligned} T_A &= H\cosh\left(\frac{\omega x}{H}\right) \\ T_B &= H\cosh\left(\frac{\omega(l-x)}{H}\right) \end{aligned}} \quad \begin{aligned} &--- (1) \\ &--- (2) \end{aligned}$$

- sag b/w lowest point 'O' and the support 'A'

$$\boxed{\delta_2 = \frac{H}{\omega}\left[\cosh\left(\frac{\omega x}{H}\right) - 1\right]} --- (3)$$

- sag between lowest point and the support 'B'

$$\boxed{\delta_1 = \frac{H}{\omega}\left[\cosh\frac{\omega(l-x)}{H} - 1\right]} --- (4)$$

- In terms of tension T

$$\delta = \frac{\omega x^2}{2T} \quad ; \; x = l/2 \text{ and } \delta = \frac{\omega l^2}{8T}$$

$$\boxed{\begin{aligned} \delta_2 &= \frac{\omega(x)^2}{2T} \quad \text{--- (5)} \\ \delta_1 &= \frac{\omega(l-x)^2}{2T} \quad \text{--- (6)} \end{aligned}}$$

now

$$\boxed{h = \delta_1 - \delta_2}$$

$$= \frac{\omega}{2T}\left[(l-x)^2 - x^2\right]$$

$$h = \frac{\omega}{2T}\left[l^2 + \cancel{x^2} - 2lx - \cancel{x^2}\right]$$

$$h = \frac{\omega l}{2T}(l-2x)$$

$$\Rightarrow \quad (l-2x) = \frac{2hT}{\omega l}$$

$$2x = l - \frac{2hT}{\omega l}$$

Ans

$$\boxed{x = \frac{l}{2} - \frac{hT}{\omega l}} \quad \text{--- (7)}$$

so $(l-x) = l - \left[\frac{l}{2} - \frac{hT}{\omega l}\right]$

Ans

$$\boxed{(l-x) = \frac{l}{2} + \frac{hT}{\omega l}} \quad \text{--- (8)}$$

- If $\left[\frac{l}{2} < \frac{hT}{wl}\right]$ then x is negative i.e toward tower. A and B are located on the same side of the lowest point O.

Question:-

A TL conductor at a river crossing is supported by two towers at hieght 30m and 90m. above water level the horizontal distance b/w the tower is 270m. If the tension in conductor is 1800 kgf. and weight of conductor is 1kgf/m determine the clearance b/w conductor and the water at a point located at the center b/w the towers towers.

Solution:

- Horizontal distance b/w the towers (span) $l = 270m$
- vertical distance b/w two supports.

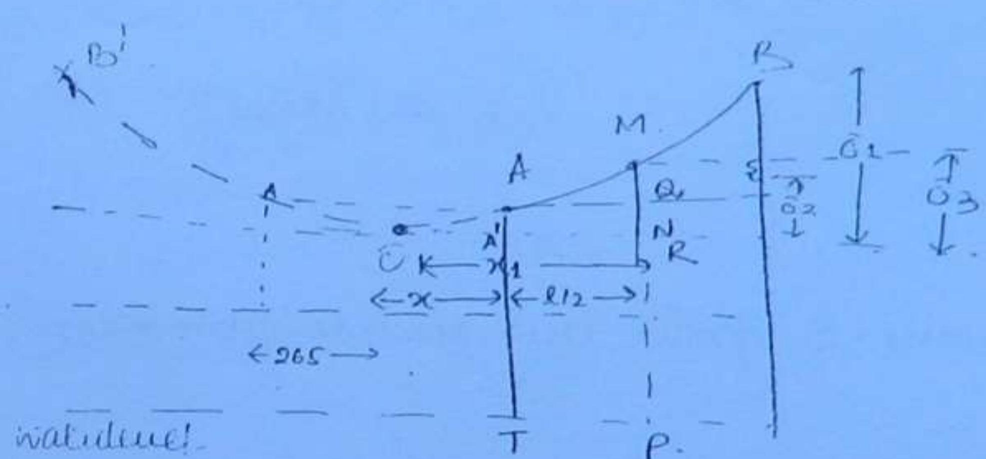
$$h = (90-30) = 60m$$

$$x = \frac{l}{2} - \frac{hT}{wl} = \frac{270}{2} - \frac{60 \times 1800}{1 \times 270}$$

$$= \frac{270}{2} - 400$$

$$= -265m.$$

negative value of x indicates that both towers are located on one side of lowest point O.



• let 'M' be the point located at the center between the two towers the horizontal distance of M from the lowest point 'O' is equal to

$$x_1 = OA' + A'N$$

$$= x + A'N.$$

$$= 265 + l/_2.$$

(+ve sign as representing in other side)

$$= 265 + \frac{270}{2}$$

$$\boxed{x_1 = 400m}$$

• the height of point 'A' from the lowest point 'O'

$$\delta_2 = \frac{\omega x^2}{2T} = \frac{1 \times 265^2}{2 \times 1800} = 19.50m.$$

- Height of point M from the lowest point O.

$$\delta_3 = \frac{w x_1^2}{2T} = \frac{1 \times 400^2}{2 \times 1800}$$

$$= 44.44m.$$

- Height of point B from the lowest point O

$$\delta_1 = \frac{w}{2T}(265+270)^2 = 79.50m.$$

- The distance b/w the midpoint M b/w the supports A and B to the water level.

$MP = MQ + QP$

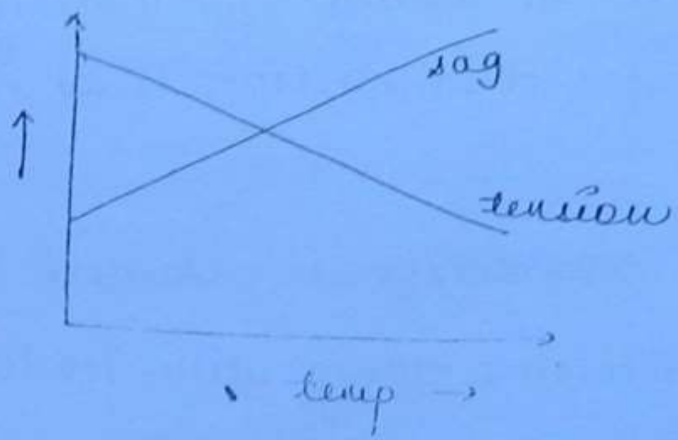
$MP = (\delta_3 - \delta_2) + AT$

$MP = (44.44 - 19.5) + 30$

$MP = 54.94m$

STRINGING CHART

#. stringing charts gives the relation b/w tension and temp and sag and temp.



SAG TAMPLATE: • Sag tamplate is used to allocate the position and high height of the supports.

• Sag tamplate is made of transparent i.e celluloid. or other material perspex.

• Sag tamplate consist of 4 different characteristic

1) HOT template curve / HOT curve : hot curve is obtained between sag at maxm temp

• HOT curve determines the ground clearence.

2) Ground Clearance Curve:

Ground clearance curve is below the hot curve. and it is drawn parallel to hot curve

3) Support foot curve:

This curve is drawn for locating the position of supports for transmission lines

4) Cold curve / uplift curve:

Cold curve is obtained by plotting the sag at minimum temp with ice loading and wind loading with respect to span length.

POWER CABLES

- A cable consists of 3 component
  1) conductor
  2) Insulator / Dielectric
  3) Sheath.

* CONDUCTOR:

- A conductor provides a path of conduction for current.

* DIELECTRIC:

- withstand service voltage and isolate conductor form other material.

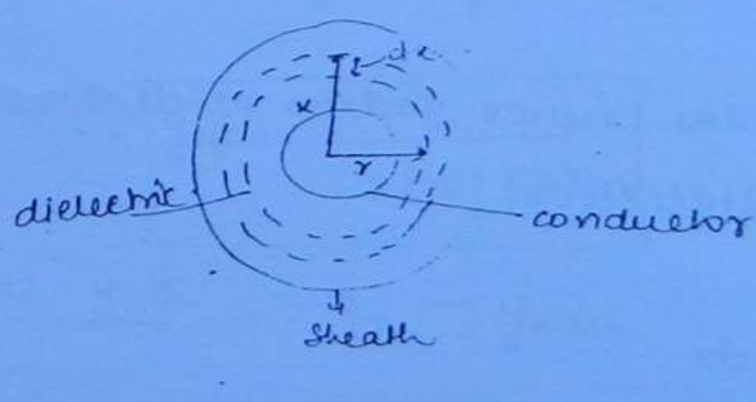
3) SHEATH :

Sheath donot allow the moisture content into the cables and prevent cables from chemical forces.

DIELECTRIC STRESS

- When the electrostatic field is uniform, the stress of dielectric $= \dfrac{\text{Applied voltage}(V)}{\text{thickness of dielectric}}$

- In underground cables the electro-static field is not uniform. Therefore the dielectric stress at any point in a single-core cable can changes w.r.t distance x.



- $r \rightarrow$ radius conductor / inner radius of dielectric

  $R \rightarrow$ internal radius of sheath / outer radius of insulation

  $\epsilon_0 \rightarrow$ permittivity of free space

Q → charge/unit of length of conductor

V → voltage b/n the phase and neutral

- Electric flux density at the distance x from centre of conductor

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

- dielectric stress

$$g_x = \frac{D_x}{\epsilon} = \frac{D_x}{\epsilon_0 \epsilon_r}$$

$$\boxed{g_x = \frac{Q}{2\pi \epsilon_0 \epsilon_r x}} \quad (1)$$

- total dielectric stress, is obtained by varying x from (r to R)..

- Potential difference b/w the inner radius of dielectric and outer radius of dielectric

$$V = \int_{x=r}^{x=R} g_x \, dx$$

$$V = \int_{r}^{R} \frac{Q}{2\pi \epsilon_0 \epsilon_r x} dx$$

$$V = \frac{Q}{2\pi\epsilon_0\epsilon_r} \ln(x)\Big|_r^R$$

$$\boxed{V = \frac{Q}{2\pi\epsilon_0\epsilon_r} \ln(R/r)} \quad \text{----} (2)$$

from eqn (1)

$$\boxed{\frac{Q}{2\pi\epsilon_0\epsilon_r} = x \cdot g_x} \quad \text{----} (3)$$

substituting in (2)

$$V = x \cdot g_x \ln(R/r).$$

$$\boxed{g_x = \frac{V}{x \ln(R/r)}} \quad \text{----} (4)$$

at $\underline{x = r}$. $g_x \rightarrow g_{max}$.

$$\therefore \boxed{g_{max} = \frac{V}{r \ln(R/r)}} \quad \text{----} (5)$$

at $\underline{x = R}$ $g_x \rightarrow g_{min}$

$$\boxed{g_{min} = \frac{V}{R \ln(R/r)}} \quad \text{----} (6)$$

g now ~~g_{max}~~ $\boxed{\frac{g_{max}}{g_{min}} = R/r}$ ---- (7)

Economical size of cable.

- For g_{max} to be minimum $r\ln(R/r)$ has to max.

- The condition for minimum g_{max} is

$$\frac{d}{dr}\left[r\ln(R/r)\right]=0$$

$$= \frac{d}{dr}\left[r\{\ln R - \ln r\}\right]=0$$

$$= \frac{d}{dr}\left[r\ln R - r\ln r\right]=0$$

$$\Rightarrow \left[\ln(R)\frac{d}{dr}(r)+r\frac{d}{dr}(\ln R)\right]-\frac{d}{dr}(r\ln r)=0.$$

$$= \left[\ln(R)+0-1-[\ln r]\right]=0$$

$$\Rightarrow \ln R - 1 - \ln r = 0$$

$$\boxed{R/r = e = 2.718}$$

Que?

A single core cable for a working voltage of 6.5 kV (b/w core and sheath) has conductor of 10mm over all diameter, which is insulated to a thickness of

7.5mm. the max^n electric stress on insulation is

Sol^n

$$r = \frac{10mm}{2} = 5mm$$

$$R = \underset{(r+t)}{5mm + 7.5} = 12.5mm.$$

$$g_{max} = \frac{V}{r \ln(R/r)} = \frac{6.5 \times 10^3}{5 \ln\left(\frac{12.5}{5}\right)} = 1.419 \ KV/mm.$$

Ques$^{(7)}$

A single core cable is operating on a 3-ϕ phase 275KV s/m.. the maximum dielectric stress should not exceed 15KV/mm. the overall diameter of single core cable and the most economical diameter of single core cable are.

Sol^n.

Rms value of phase voltage $= \frac{275}{\sqrt{3}} = 158.77 \ KV$

$$g_{max} = \cancel{V} \ 15KV/mm.$$

$$15KV = \frac{V}{r \ln(R/r)} = \frac{224.5}{r \ln R/r}.$$

Max^m value the phase voltage $= 158.77 \times \sqrt{2}$
$= 224.5 KV$

$$\Rightarrow r \ln(R/r) = 0.01496$$

For most economical diameter.

$$R/r = e$$

$$\ln(R/r) = 1$$

$$r = \frac{224.5}{15} = 14.96\,mm.$$

economical diameter of conductor $= 2 \times r = 29.92$

economical diameter of ~~so~~ cables $= 2 \times R$
$= 81.38\,mm$.

GRADING OF CABLES

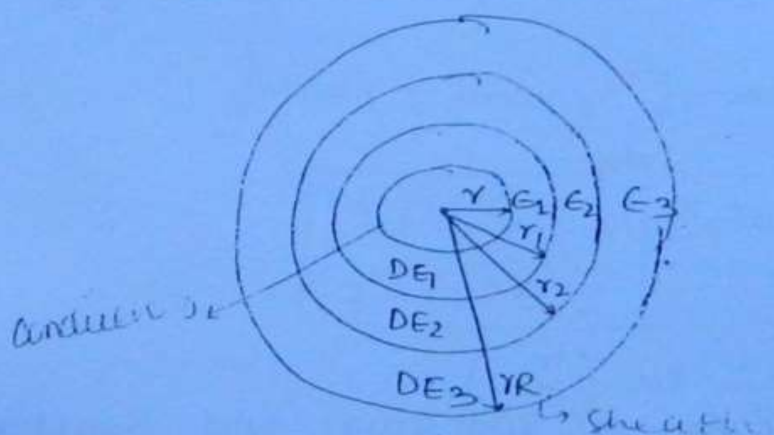
- The electrostatic stress in single core cable has maxm value at g_{max} and g_r decreases as we move towards sheath where electrostatic stress is minimum.

- For safe working of a cable having homogeneous dielectric, the strength of dielectric must be greater than g_{max}.

- If the dielectric of higher strength is used for cable. It is useful only near the conductance surface where the stress is maxm.

- As we move away from the conductor, electrostat stress decreases and dielectric unnecessarily strong. Therefore the cables must be graded such that the dielectric strength varies based on 'x'

1) Dielectric grading / Capacitance grading



- potential difference across inner layer.

$$V_1 = \int_{x=r}^{x=r_1} g_x \cdot dx$$

$$= \int_{r=r}^{x=r_1} \frac{Q}{2\pi \epsilon_0 \epsilon_1 x_1} dx$$

$$= \frac{Q}{2\pi \epsilon_0 \epsilon_1} \left[\ln(x_1) \right]_{r}^{r_2}$$

$$V_1 = \frac{Q}{2\pi\epsilon_0\epsilon_1} \ln\left(\frac{r_1}{r}\right).$$

$\because \quad g_{max} = \frac{Q}{2\pi\epsilon_0\epsilon_r r}$

$$\boxed{V_1 = g_{max_1} \cdot r \ln\left(\frac{r_1}{r}\right).}$$

$g_{max_1} = \frac{Q}{2\pi\epsilon_0\epsilon_1 r}$

$g_{max_2} = \frac{Q}{2\pi\epsilon_0\epsilon_2 r_1}$

$g_{max_3} = \frac{Q}{2\pi\epsilon_0\epsilon_3 r_2}$

- Potential difference across middle layer

$$V_2 = \int_{r_1}^{r_2} g_x \cdot dx.$$

$$= \int_{r_1}^{r_2} \frac{Q}{2\pi\epsilon_0\epsilon_2 x} \cdot dx$$

$$= \frac{Q}{2\pi\epsilon_0\epsilon_2} \ln\left(\frac{r_2}{r_1}\right).$$

$$= \left[\frac{Q}{2\pi\epsilon_0\epsilon_2 r_1}\right] r_1 \ln\left(\frac{r_2}{r_1}\right).$$

$$\boxed{V_2 = g_{max_2} \cdot r_1 \ln\left(\frac{r_2}{r_1}\right).}$$

- potential difference across outer layer.

$$V_3 = \int_{r_2}^{R} g_x \cdot dx.$$

$$\Rightarrow \int_{r_2}^{R} \frac{Q}{2\pi \epsilon_0 \epsilon_3} \ln\left(\frac{R}{r_2}\right).$$

$$= \frac{Q}{2\pi \epsilon_0 \epsilon_3 r_2} r_2 \ln\left[\frac{R}{r_2}\right].$$

$$\boxed{V_3 = g_{max_2} \cdot r_2 \ln(R/r_2).}$$

when $\quad \epsilon_1 r = \epsilon_2 r_2 = \epsilon_3 r_2$.

$$g_{max_1} = g_{max_2} = g_{max_3}.$$

$$\boxed{\begin{array}{l} r < r_1 < r_2. \\ \epsilon_1 > \epsilon_2 > \epsilon_3 \end{array}}$$

- voltage b/w core and sheath.

$$V = V_1 + V_2 + V_3.$$

$$\boxed{V = g_{max}\left[r \ln\left(\frac{r_1}{r}\right) + r_1 \cdot \ln\left(\frac{r_2}{r_1}\right) + r_2 \ln\left(\frac{R}{r_2}\right)\right]}$$

- capacitance of the cable.

$$C = Q/V$$

$$C = \frac{Q}{V_1 + V_2 + V_3}$$

$$= \frac{Q}{\frac{Q}{2\pi\epsilon_0\epsilon_1}\ln\left(\frac{r_1}{r}\right) + \frac{Q}{2\pi\epsilon_0\epsilon_2}\ln\left(\frac{r_2}{r_1}\right) + \frac{Q}{2\pi\epsilon_0\epsilon_3}\ln\left(R/r_2\right)}$$

$$= \frac{Q}{\frac{Q}{2\pi\epsilon_0}\left[\frac{1}{\epsilon_1}\ln\left(\frac{r_1}{r}\right) + \frac{1}{\epsilon_2}\ln\left(\frac{r_2}{r_1}\right) + \frac{1}{\epsilon_3}\ln\left(\frac{R}{r_2}\right)\right]}$$

*

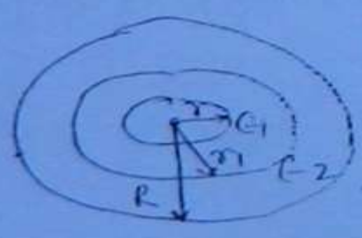
$$\boxed{C = \frac{2\pi\epsilon_0}{\left[\frac{1}{\epsilon_1}\ln\left(\frac{r_1}{r}\right) + \frac{1}{\epsilon_2}\ln\left(\frac{r_2}{r_1}\right) + \frac{1}{\epsilon_3}\ln\left(\frac{R}{r_2}\right)\right]}}$$

Date
26 m Oct 15

Questn

Single core cable has a conductor of 10mm diameter and 2 layers of different dielectric, each of 10mm thickness. The relative permittivities are 3 and 2.5, determine the potential gradient at the surface of the conductor when the potential difference b/w conductor and sheath is 60KV.

Solutn



Radius of conductor = $10/2$ = 5mm = 5×10^{-3}m

$\epsilon_1 = 3$

$\epsilon_2 = 2.5$

$R = 5+r = 15$mm

$r_1 = r_1+t = 15+10 = 25$mm

~~xoa~~. max^m potential gradient at surface of conductor

$$g_{1max} = \frac{Q}{2\pi\epsilon_0\epsilon_1 \cdot r} = \text{- - - - (1)}$$

$$g_{2max} = \frac{Q}{2\pi\epsilon_0\epsilon_2 \cdot r_1} \text{ - - - - (2)}$$

on dividing.

$$\frac{g_{2max}}{g_{1max}} = \frac{\epsilon_1 r}{\epsilon_2 r_1}$$

$$\frac{r_1 \cdot g_{2max}}{r\, g_{1max}} = \frac{\epsilon_1}{\epsilon_2} \text{ - - - - - - - (3).}$$

· potential difference between conductor and sheath

$V = V_1 + V_2$

$$60 = g_{1max} \cdot r \ln\frac{r_1}{r} + g_{2max} r_1 \ln\frac{R}{r_1}$$

$$\Rightarrow 60 = g_{1max} r \left[\ln\frac{r_1}{r} + \frac{g_{2max}}{g_1 max}\frac{r_1}{r}\ln\frac{R}{r_1}\right]$$

$$= g_{1max} \cdot r \left[\ln\frac{r_1}{r} + \frac{\epsilon_1}{\epsilon_2}\ln\left(\frac{R}{r_1}\right)\right]$$

$$60 = g_{1max} \cdot 5 \left[\ln\frac{15}{5} + \frac{3}{2.5}\ln\frac{35}{15}\right]$$

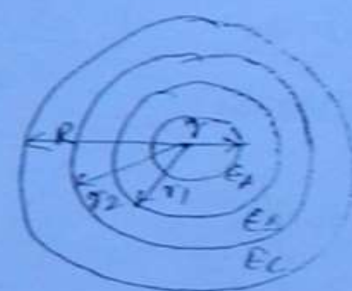
$g_{1max} = 7.01\, KV/mm$

Quest^n:-

A single core cable is to be designed for 66KV to ground. The radius of conductor is 10mm. and insulating materials A, B and C have relative permittivities of 5, 4 and 3. and corresponding max^m stresses 5.8, 2.6 and 2 KV/mm. determine the minimum diameter of sheath.

Sol^n

$$5.8 = g_{A max} \qquad \epsilon_A = 5$$
$$2.6 = g_{B max} \qquad \epsilon_B = 4$$
$$2 = g_{C max} \qquad \epsilon_C = 3$$



max^m ~~die~~ dielectric stress of dielectric A

$$g_{A max} = \frac{Q}{2\pi\epsilon_0\epsilon_A r}$$

$$5.8 = \frac{Q}{2\pi\epsilon_0 \times 5 \times 10 mm}.$$

$$\Rightarrow \frac{Q}{2\pi\epsilon_0} = 290$$

max^m dielectric stress of dielectric B.

$$= \frac{Q}{2\pi\epsilon_0\epsilon_B r_1}$$

$$2.6 = \frac{290}{4 \times r_1}$$

$$r_1 = 18.26mm.$$

- max^{m} dielectric stress of dielectric C

$$g_c max = \frac{Q}{2\pi \epsilon_0 \epsilon_c r_2}$$

$$2 = \frac{190}{3 \times r_2}$$

$$r_2 = 31.67 \; mm.$$

- Potential difference across inner layer.

$$V_1 = g_A max \, r . \ln\left(\frac{r_1}{r}\right)$$

$$= 3.5 \times 10 \ln\left(\frac{18.3}{10}\right)$$

$$V_1 = 22.96 \; KV$$

$$V_2 = g_B max . r_1 \ln\left(\frac{r_2}{r_1}\right)$$

$$= 2.6 \times 18.3 . \ln\left(\frac{31.67}{18.3}\right)$$

$$V_2 = 26.1 \; KV$$

as $V = V_1 + V_2 + V_3$

$$V_3 = g_c max . r_2 . \ln\left(\frac{R}{r_2}\right)$$

$$= 2 \times 31.67 \ln\left(\frac{R}{31.7}\right)$$

$$V_3 = 63.34 \ln\left(\frac{R}{31.7}\right)$$

$$66kV = 22.96 + 26.1 + 63.34 \ln\left(\frac{R}{31.7}\right)$$

$$\frac{16.91}{63.34} = \ln\left(R/31.7\right)$$

$$\cancel{0.29}\ 0.267$$

$$1.306 = \frac{R}{31.7}$$

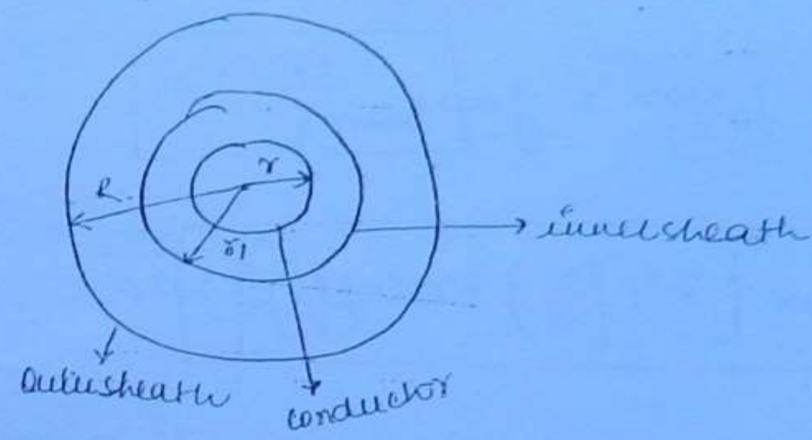
$$R = 41.40$$

$$\text{Diameter} = 2R = 82.8\,mm.$$

INTER-SHEATH GRADING

- In this method same insulating material is utilized through out the total thickness of the dielectric
- the dielectric is divided in two or more ~~sheaths~~ layers by provideing intersheaths.
- Intersheaths are thin metallic or cylindrical sheaths concentric with the conductor and placed b/w conductor and outside sheaths.
- Inter sheath are maintained at suitable potentials by connecting them to the

tappings from the supply x'mer.



- Let $r \rightarrow$ radius of conductor

  $r_1 \rightarrow$ radius of inter sheath

  $R \rightarrow$ radius of outer sheath.

  $V_1 \rightarrow$ voltage b/w conductor and intersheath.

  $V_2 \rightarrow$ voltage b/w intersheath and outer sheath.

  $V \rightarrow$ voltage b/w conductor and outer sheath.

- $$g_1 max = \frac{V_1}{r \ln(r_1/r)} \Rightarrow \boxed{V_1 = r\, g_{max} \ln\left(\frac{r_1}{r}\right)} \text{---(}$$

  $$g_2 max = \frac{V_2}{r_1 \ln\left(\frac{R}{r_1}\right)} \Rightarrow \boxed{V_2 = r_1 g_1 max \ln\left(\frac{R}{r_1}\right)} \text{-(}$$

Potential diffence b/w core and sheath

$$V = V_1 + V_2$$

$$= r g_{max} \ln\left(\frac{r_1}{r}\right) + r_1 g_2 max \left(\frac{R}{r_1}\right)$$

and $\quad g_1 max = g_2 max = g max.$

$$\therefore \boxed{V = g_{max}\left[r \cdot \ln\left(\frac{r_1}{r}\right) + r_1 \ln\left(\frac{R}{r_1}\right)\right]}$$

ECONOMICAL SIZE OF CABLE.

According to ~~di~~ dielectric grading

$$\boxed{\frac{r_1}{r} = e = \frac{\text{Sheath radius}}{\text{conductor radius}}} \quad \text{---} (1)$$

now

$$g_1 max = \frac{V_1}{r \ln\left(\frac{r_1}{r}\right)}$$

$$\boxed{g_1 max = \frac{V_1}{r}}$$

Since $\quad g_1 max = g max = \frac{V_1}{r}$

$$\therefore \quad r = \frac{V_1}{g max}$$

Substituting in eqn. (1)

$$\Rightarrow \quad r_1 = er = \frac{eV_1}{g_{max}}.$$

$$\boxed{r_1 = \frac{eV_1}{g_{max}}} \quad --- (2).$$

- since '$g_2$max' $= \dfrac{V_2}{r_1 \ln\left(\frac{R}{r_1}\right)}$

$$g_{max} = \frac{V_2}{r_1 \ln(R/r_1)}.$$

$$g_{max} = \frac{V_2}{r_1 \ln(R/r_1)}$$

$$\frac{V_1}{r} = \frac{V_2}{r_1 \ln(R/r_1)}$$

$$\Rightarrow \quad \ln(R/r_1) = \frac{V_2}{r_1} \times \frac{r}{r_1}.$$

$$\ln(R/r_1) = \frac{V_2}{V_1} \times \frac{1}{e} \qquad \because \frac{r_1}{r} = e.$$

since

$$V = V_1 + V_2$$

$$V_2 = V - V_1$$

thus

$$\ln(R/r_1) = \frac{(V - V_1)}{V_1} \times \frac{1}{e}.$$

$$\ln(R/r_1) = \frac{V}{eV_1} - \frac{1}{e}.$$

$$\Rightarrow \frac{R}{r_1} = e^{\left[\frac{V}{e r_1} - \frac{1}{e}\right]}$$

$$R = r_1 e^{\left[V/e r_1 - \frac{1}{e}\right]}$$

substitute eq^n (2) in above eq^n

$$R = \frac{e V_1}{g_{max}} e^{\left[\frac{V}{e V_1} - \frac{1}{e}\right]}$$

$$R = \frac{V_1}{g_{max}} \cdot e^1 \cdot e^{V/e V_1} \cdot e^{-1/e}$$

$$R = \frac{V_1}{g_{max}} \cdot e^{1 - \frac{1}{e}} \cdot e^{V/e V_1}$$

where $\boxed{A = \frac{e^{1-1/e}}{g_{max}}}$

$$\boxed{R = A \cdot V_1 \cdot e^{V/V_1}} \quad \text{- - - - (3)}$$

Equation (3) represents the relation b/w the radius of intersheath in terms of the potential difference across the intersheath.

For minimum radius of outersheath differentiate eq^n (3) w.r.t V_1 and equate to zero.

$$\frac{dl}{dV_1} = 0.$$

$$\therefore \frac{d}{dV_1}\left[A \cdot V_1 \cdot e^{e^{V/V_1}}\right] = 0$$

$$= A \cdot V_1 \frac{d}{dV_1}\left[e^{e^{V/V_1}}\right] = 0 + A \cdot e^{\frac{V}{eV_1}} \cdot \frac{d}{dV_1}(V_1) = 0$$

$$\Rightarrow A \cdot V_1 \cdot e^{V/V_1} \cdot e^{e^{V/V_1}} + A \cdot e^{V/eV_1} \cdot 1 = 0$$

$$\Rightarrow A \cdot e^{V/eV_1} \left\{ \frac{-VV_1}{eV_1^2} + 1 \right\} = 0$$

The above expression is equal to zero for the following condition.

$$1 - \frac{V\cancel{V_1}}{eV_1^{\cancel{2}}} = 0$$

$$1 = \frac{V}{eV_1}$$

$$\boxed{e = V/V_1} \text{ and } \boxed{V_1 = V/e}.$$

$$\boxed{\text{voltage across sheath} = \frac{\text{total voltage}}{e}}$$

- For economical size of cable the voltage across inner layer is $1/e$ times the voltage b/w conductor and sheath.

- Maxm dielectric stress across first layer.

$$g_{1max} = g_{max} = \frac{V}{r \ln(r_1/r)}$$

$$\Rightarrow g_{max} = V_1/r$$

$$g_{max} = \frac{V}{e \cdot r}$$

$$\boxed{r = \frac{V}{e \cdot g_{max}}} \quad \ldots (4)$$

this should be radius of conductor so that size of cable decrease

- now $\quad r_1/r = e$

$$r_1 = r \cdot e$$

$$= V/\cancel{e}\, g_{max} \cdot \cancel{e}$$

$$\boxed{r_1 = V/g_{max}} \quad \ldots (5)$$

- the most economical size of cable.

$$R = A \cdot r_1 e^{-V/v_1 e}$$

$$R = \frac{V_1}{g_{max}} \cdot e^{(1 - 1/e)} \cdot e^{V/eV_1}$$

$$= \frac{V}{\cancel{e} \cdot g_{max}} e^{1-1/e} \cdot \cancel{e}^{\frac{\cancel{V}}{\cancel{e} \cdot \cancel{V}/\cancel{e}}}$$

$$\boxed{R = \frac{V}{g_{max}} e^{1-1/e}}$$

$$\boxed{R = 1.881 \frac{V_1}{g_{max}}} \quad \text{.......} (6)$$

Radius of outer sheat

Questn

A 60KV single core cable is graded by means of metallic intersheath. The safe electric stress of insulating material is 4KV/mm. calculate

1) diameter of intersheath and voltage at which it must be maintained in order to obtained minimum overall diameter and the corresponding conductor diameter

2) compare the conductor diameter obtained in question (1) with that of and ungraded cable working under same condition

Soln 1) With intersheath

Voltage across inner layer = $V_1 = V/e = \frac{60}{2.718} =$

$= 22.1KV$

:- economical radius of conductor

$$r = \frac{V}{e\,g_{max}} = \frac{60}{2.718 \times 4}$$

$$r = 5.5\,mm$$

:- economical diameter of conductor $= 2 \times 5.5$
$= 11\,mm.$

radius of inter sheath $r_1 = \frac{V}{g_{max}} = \frac{60}{4} = 15\,mm.$

:- economical diameter of intersheath $= 2 \times r_1 = D_1 = 30\,mm$

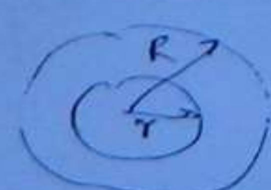
economical radius of outersheath or cable.

$$R = 1.881\frac{V}{g_{max}} = 28.2\,mm$$

So diameter $= 2 \times 28.2 = 56.43\,mm.$

now voltage across second layer $= (V - V_1)$
$\Rightarrow 60 - 22.1$
$V_2 = 37.5\,kV$

2) without intersheath



now $R/r = e$

$\Rightarrow R = e \cdot r = 2.718 \times r.$

now operating voltage = 60K., when sheath is not used the voltage totally operated at dielectric. Now voltage b/w conductor and sheath.

$$V = g_{max} \cdot r \ln(R/r)$$

$$V = g_{max} \cdot r \cdot 1$$

$\frac{60}{4} = 15mm = r$. and $d = 30mm$. (condu

so $R = 2.718 \times 15mm$
$= 40.77mm.$

; economical radius of cable $R = 40.77mm$

$D = 81.54mm.$

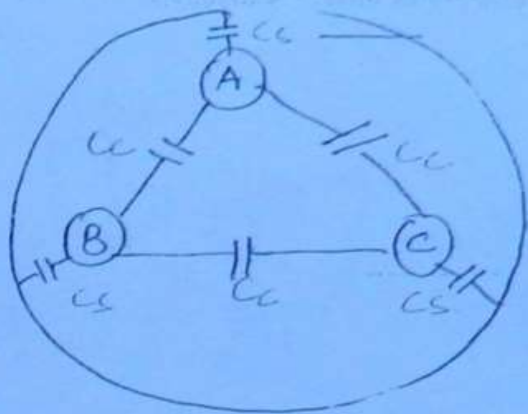
CHARGING CURRENT IN CABLE

- the capacitance of a cable determines
  1) charging current
  2) Charging KVA
  3) dielectric loss.

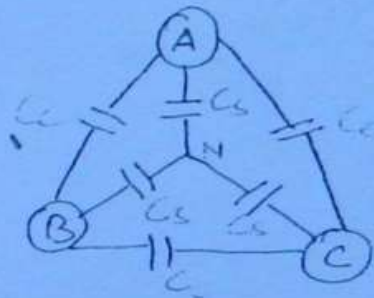
- charging current limits the use of cables on extra-high voltage HV lines.
- In a/c st system the charging current depends on length of line and location of capacitance. The current carrying capacity of a transmission line increases when the locatn of capacitance moves away from the sending end.
- In d/c system the current carrying capacity of d/c cable is independent of the length.
  - ∵ capacitor behaves like open circuit

CALCULATION OF CAPACITANCE IN 3-CORE CABLE

- conductors in cable are saperated from each other by dielectric. Similarly there is dielectric b/w conductor and sheath when potential difference is applied b/w conductors in a cable. the effect of combination of 6-capacitances must be considered.
- Capacitance b/w the conductors is denoted by 'C_c' and capacitance b/w conductor and sheath is denoted by C_s

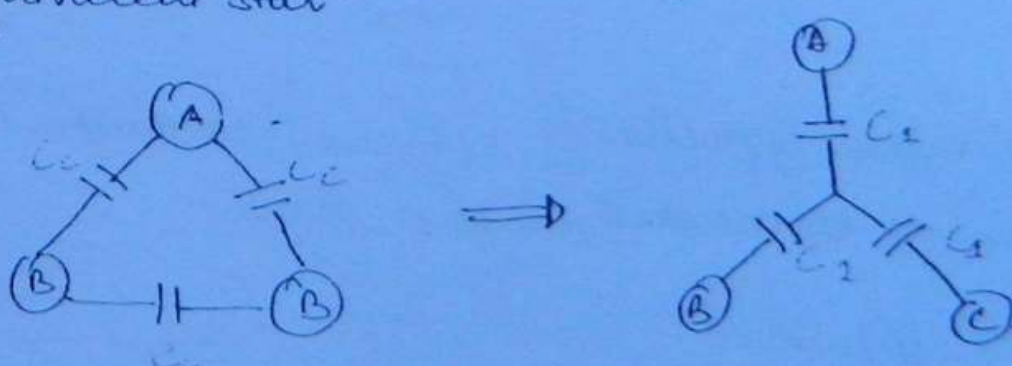


- Sheath operates at zero potential. therefore the entire sheath is represented by a ground/neutral point.



- Conductor capacitance is in delta and capacitance between conductor & sheath is in star.

- Converting capacitances connected in delta into equivalent star.



$-\Delta \rightarrow \quad C_{AB} = C_c + \frac{C_c}{2} = 1.5\,C_c.$

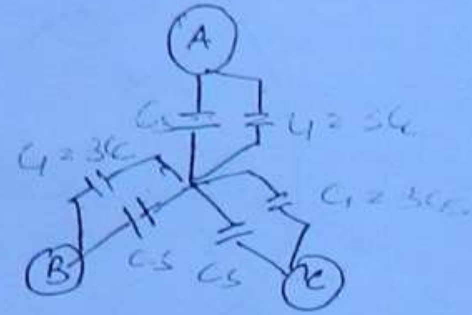
$Y \rightarrow \quad C_{AB} = \frac{C_1}{2}.$

now

$$C_{AB} = \frac{C_1}{2}$$

$$1.5\,C_c = C_1/2$$

$$\boxed{C_1 = 3C_c}$$



So

$$C_0 = C_{N-A} = C_1 + C_s = 3C_c + C_s$$

$$C_0 = C_{N-B} = C_1 + C_s = 3C_c + C_s$$

$$C_0 = C_{N-C} = C_1 + C_s = 3C_c + C_s$$

** $\boxed{C_0 = 3C_c + C_s}$

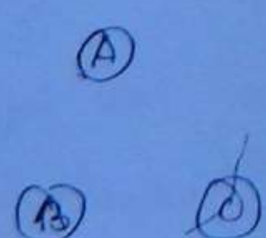
- charging current $= \dfrac{V_{ph}}{X_C}$

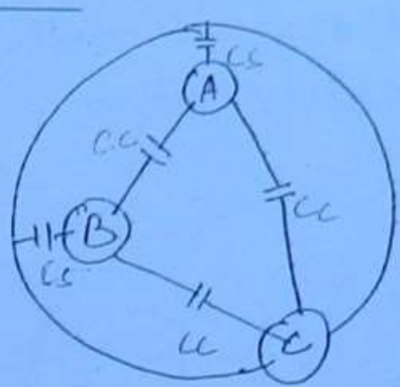
$$= \frac{V_{ph}}{\frac{1}{\omega C_0}} = \omega C_0 V_{ph}$$

$\boxed{\text{charging current} = \omega C_0 V_{ph}}$

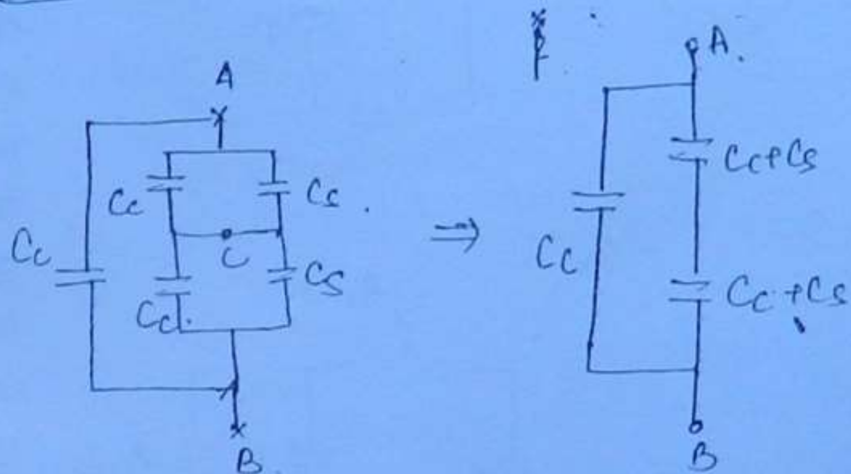
Questn

Determine the equivalent capacitance b/w two conductor A & B when conductor C is connected to the sheath





Solution:



$$C_{AB} = C_c + \frac{(C_c + C_s)}{2}$$

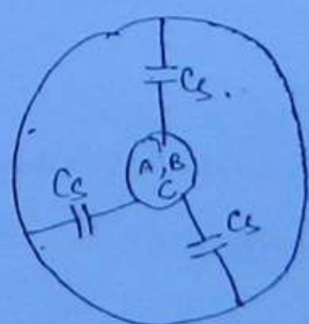
$$= \frac{1}{2}[3C_c + C_s]$$

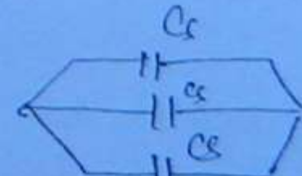
$$C_{AB} = \frac{1}{2} C_0$$

Quesⁿ

Determine the capacitance b/w conductor and sheath when all the 3 conductors are connected together are bunched together.

Solⁿ

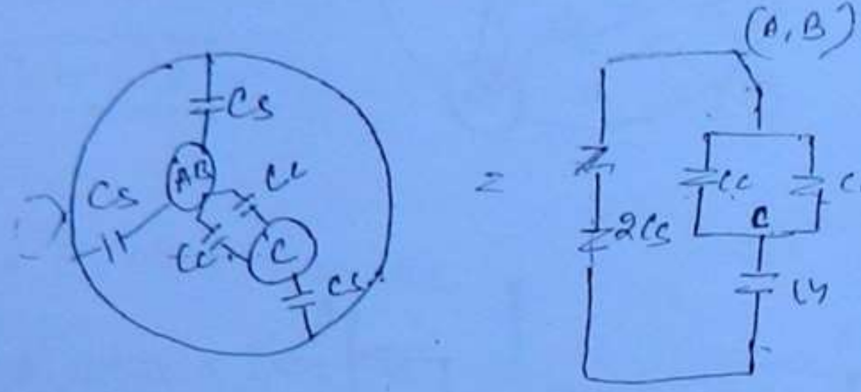




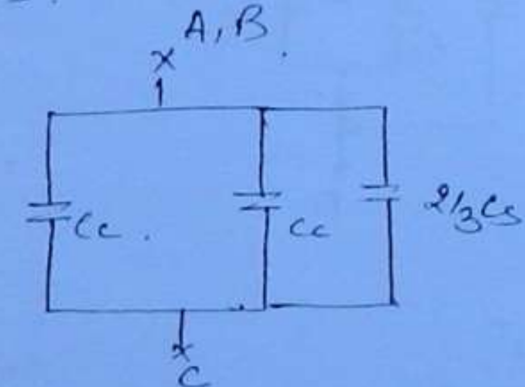
$$\Rightarrow 3C_s$$

Ques
Two conductors A and B are joined together determine the capacitance between the conductor A and C or conductor B and C.

Solutn



$$\frac{2C_s \times C_s}{3C_s} = \frac{2}{3}C_s$$



now $= 2C_c + \frac{2}{3}C_s$

$C_{A-C} / C_{B-C} = 2C_c + \frac{2}{3}C_s$

$2\left[C_c + \frac{1}{3}C_s\right]$

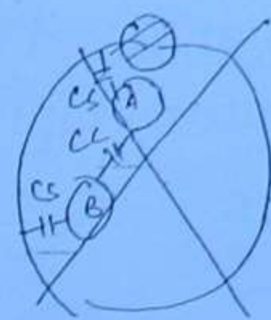
$6\left[C_c + C_s\right]$

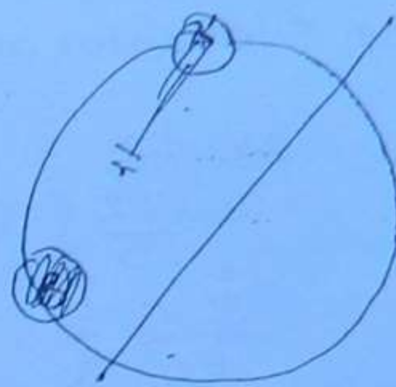
$\frac{2}{3}\left[3C_c + C_s\right]$

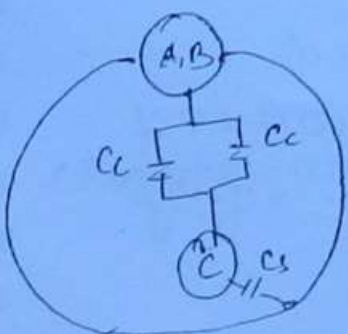
$C_{A-C} / C_{B-C} = \frac{2}{3}C_0$

Ques
Two conductors A and B are connected to sheath determine the capacitance b/w the conductors A and B and third conductor C.

Solution:







$\cancel{2C_s+}$

$\cancel{2C_c+C_s}$

$\cancel{2(C_c+}$

$$C_{A-C} = 2C_c + C_s$$
$$= (C_c + 2C_c + C_c) - C$$
$$= (3C_c + C_s) - C_s$$
$$C_{A-C} = C_o - C_c$$

Ques:
the unit of 1 km, 3-φ cable give measured capacitance 0.7μF between 1 conductor and other 2 conductors bunched together with earthed sheath and 1.2μF measure b/w 3-bunched conductors and sheath. Calculate
1) capacitance b/w any pair of conductors, sheath being isolated
2) charging current when cable is connected to 11kV at 50Hz supply.

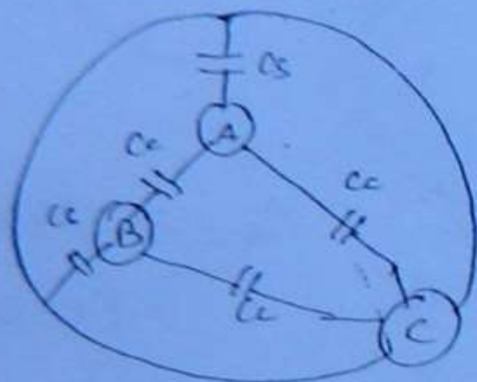
Soln
Capacitance b/w 1 conductor and other 2-conductors bunched together.

$$2C_c + 2C_s = 0.7\,\mu F$$

capacitance b/w 3-conductor and sheath.

$$3C_s = 1.2$$
$$C_s = \frac{1.2}{3} = 0.4\,\mu F$$

1)



$\therefore C_c + 0.4 = 0.7$

$C_c = 0.15\,F$

2) $C_{AB} = C_0/2.$

$= \frac{1}{2}(3C_c + C_s)$

$= \frac{1}{2}[3 \times 0.15 + 0.4]$

$C_{AB} = 0.425\,\mu F.$

3) charging current $= \frac{\times 11 \times 10^3 \cdot 2 \times \pi \times 50 \times}{\sqrt{3}}$

$= 1.69\,A/\text{phase}.$

Ex:

The capacitance measure b/w any two core of 3-φ cable is 0.3 μF/km. Determine the charging reactive power taken by 5km length of this cable when connected to an 11kV, 50Hz supply

when conductor 'c' is conn
the capacitance b/w condu

$C_{A-B} = C_o/2$

$\Rightarrow 0.3\mu f \times 5km = C_e$

$C_o = 3\mu f$.

charging current $= \frac{11 \times 10^{3}}{\sqrt{3}}$

$I_C = 5.98A$

reactive power $= \cancel{I_C^2 X_C}$
$= \cancel{V} \sqrt{3} V_L I_C$
$= \sqrt{3} \times 11 \times 10^3 \times 5.98$
$= 114KVAR$

Ques^n

A single core cable 5-km long has insulation resistance of 0.4 MΩ the diameter of core is 20mm. diameter over insulation is 50mm. Calculate the resistivity of insulating material. ρ

Insulation resistance of cable $R_i = \frac{\rho}{2\pi l} \ln(R/r)$

$l \to$ length of cable
$r \to$ radius of conductor or internal radius of dielectric

$$50mm$$

$$R = 25mm.$$

$$R_i = 0.4 M\Omega$$

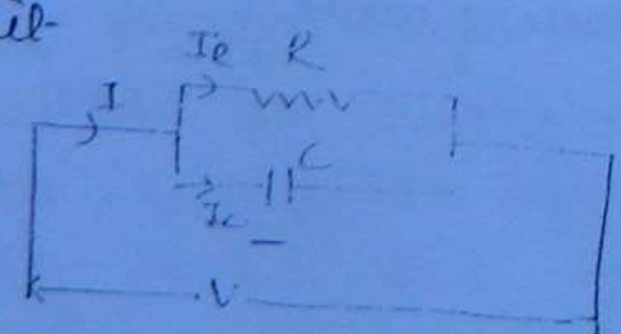
$$0.4 \times 10^6 = \frac{\rho}{2 \times 3.14 \times 5000} \ln\left(\frac{25}{10}\right)$$

$$R_i = 13.42 \times 10^3 \ M\Omega\text{-m}.$$

- The insulation resistance is inversely proportional to length of cable.

DIELECTRIC POWER LOSSES

- In a perfect cable resistance of dielectric is negligible
- All practical cables has dielectric resistance.
- The resistance are 'R' is connected in parallel to capacitance of cable.
- Equivalent circuit



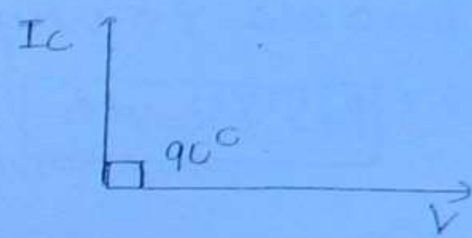
Vector diagram :-

1) Perfect cable

open circuit.

$R = 0, \ I_R = 0, \ I = I_C$

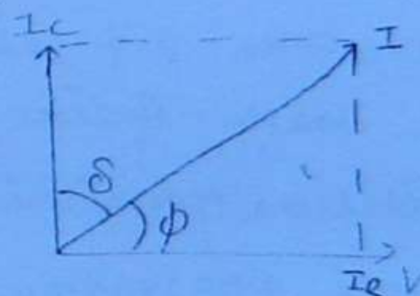
$\therefore I_C$ leads V by 90°



2) Practical cable

- $I = I_R + I_C$.
- I_R in phase with V
- I_C lead V by 90°

$\delta \rightarrow$ dielectric power loss angle.



- For a single phase line the dielectric power loss

*

$$\boxed{\begin{aligned} P_d &= V \cdot I_R. \quad \text{--- (1)} \\ P_d &= V I \cos\phi \quad \text{--- (2)} \end{aligned}}$$

- On applying $\tan\delta = \dfrac{I_R}{I_C}$

$$I_R = I_C \tan\delta \quad \text{--- (3)}$$

$$I_C = V C_0 \omega \quad \text{--- (4)}$$

so

$$\boxed{I_R = \omega C_0 V \tan\delta.} \quad \text{--- (5)}$$

⑤ → ③

$Pd = V\cdot(\omega C_0 V)\tan\delta$

$$\boxed{Pd = \omega C_0 V^2 \tan\delta} \quad \ldots (6)$$ dielectric loss

as $\tan\delta \approx \delta$ (δ very small)

$$\boxed{Pd = \omega C_0 V^2 \delta} \quad \ldots (7).$$

• For 3-φ line

$$\boxed{Pd = 3\omega C_0 V^2 \cdot \delta} \quad (8)$$

Questⁿ

A 11 kV, 50Hz 1-φ cable has diameter 20mm and Internal sheath Radius 15mm. If the dielectric has relative permittivity of 2.4 and dielectric loss angle 0.031 radian. Determine for 2.5 km length of cable.

1) Capacitance
2) charging current
3) Generated reactive volt ampere
4) Dielectric loss
5) equivalent insulatioⁿ resistance

Sol

$$C = \frac{\epsilon_r}{18 \ln(R/r)} = \frac{2.4}{18 \ln(\frac{15}{1})}$$

$= 0.322\,\mu F$

Charging current $= V \cdot \omega \cdot C_0$

$$= \frac{11 \times 10^3}{\sqrt{3}} \times 2 \times 3.14 \times 0.323 \times 2.5$$

$= 2.84$ Amp / phase

Reactive power $= V_L I_L = 11 \times 10^3 \times 2.84$

$= 11 \times 10^3$ KVAR

Dielectric loss $= \omega C_0 V^2 \tan\delta$.

$= 2 \times \pi \times 50 \times 0.8225 \times 10^{-6} \times \tan 0.03$

$\Rightarrow 968.75\,W$.

5) $V I_R = P_d$.

$= V^2/R = P_d$.

$R = V^2/P_d$

$$\Rightarrow \frac{(11000)^2}{968.75}$$

$R_i = 0.125\,M\Omega$

DISTRIBUTION SYSTEMS

- A distribution s/m consists of 3-components.

1. feeder [T.L]
2. Distributor
3. Service Mains.

FEEDER:

feeder is a conductor of large current carrying capacity, carrying the current to the feeding points.

- A current carrying element, carrying uniform current through out the length of the conductor is known as feeder.
- Transmission lines are also known as feeder lines

DISTRIBUTOR:

- Distributor is conductor from which current is tapped to supply to the consumer.
- A current carrying element carrying current for distance less than feeder is known as distributor

- SERVICE Mains :

 . The small cable located between distributor and consumer

- the size of feed, distributor or service main depends on current carrying capacity.

$$\left.\begin{matrix} HV \\ EHV \\ UHV \end{matrix}\right] \rightarrow$$ criteria to select the feeder is current carrying capacity.

- the selection of size of conductor for EHV line is based on current carrying capacity.

- the design of distributor size is based on voltage drop or percentage voltage drop

$$V = RI$$

$$V = \frac{\rho l}{A} \cdot I$$

current density equal → feeder

current density unequal → dist.

$$VA = \rho l \cdot I$$

$$I \propto A$$

$$I = J A$$

$$\boxed{\text{current density} = I/A}$$

A feeder has constant current density and distrib has variable current density

Ques

For same power, same material and equal length the operating voltage of EHV line is increased by n times. then the area of cross-section is

a) a

a) na

c) a/n

d) an^2.

Solution

$$V_2 = nV_1$$

at V_1 : $P_1 = V_1 I_1 \cos\phi$

at V_2 : $P_2 = V_2 I_2 \cos\phi$

$P_1 = P_2$

$V_1 I_1 \cos\phi = V_2 I_2 \cos\phi$

$\cancel{V_1} I_1 = n \cancel{V_1} I_2$

$\boxed{I_2 = I_1/n}$

$I \propto A$

$I_1 \propto a_1$

$I_2 \propto a_2$

$$\frac{a_2}{a_1} = \frac{I_2}{I_1}$$

$$a_2 = \frac{a_1 I_2}{I_1} = a/n.$$

2) weight of conductor:

$$\rho = \frac{wt}{vol}$$

$wt \propto vol.$ (current density is same)

$wt \propto vol$

$\propto (A \times l)$

$wt \propto (Al)$

$$\%\eta = \frac{P}{P + I(J\rho l)} \times 100$$

and $P = VI\cos\phi$

$$\Rightarrow I = \frac{P}{V\cos\phi}$$

so $$\%\eta = \frac{\cancel{P}}{\cancel{P} + \frac{\cancel{P}}{V}\cos\phi \cdot J\rho l} \times 100$$

$$\%\eta = \frac{1}{1 + \frac{J\rho l}{V\cos\phi}} \times 10$$

$$\%\eta = \left\{1 + \frac{J\rho l}{V\cos\phi}\right\}^{-1} \times 10$$

$$\%\eta = \left\{1 - \frac{J\rho l}{V\cos\phi}\right\} \times 100$$

<u>now</u> $P_2 = 1/n \, P$; $I_2^2 R_2 = \frac{1}{n}(I_1^2 R)$

$$I_2^2 \cdot \frac{1}{a_2} = \frac{1}{n}\left(I_1^2 \frac{1}{a_1}\right)$$

$$I_2(J_2) = \frac{1}{n}(I_1)(J_1)$$

$$\boxed{I_2 = I_1/n}$$

$V_1 = I_1 R_1$

$V_1 = I_1 \cdot \frac{1}{a_1}$

$V_1 = J_1$

$V_2 = I_2 R_2$

$V_2 = I_2 \frac{1}{a_2}$

$V_2 = j_2$

$0_1 = J_2$

$\boxed{V_2 = V_1}$

now for <u>ρl</u>

$$\rho = R \cdot \frac{a}{l}$$

$$\rho_1 \propto R_1$$
$$\propto 1/I_1$$

$$S_2 \propto R_2$$

$$\propto \frac{1}{I_2}$$

$$\boxed{\frac{S_2}{S_1} = \frac{I_1}{I_2} = n}$$

so

$$\% \eta = \left\{1 - \left(\frac{jl}{V\cos\phi}\right) \cdot S_1\right\} \times 100$$

$$\boxed{S_2 = nS_1}$$

$$\% \eta = \left\{1 - \left(\frac{jl}{V\cos\phi}\right)(nS_1)\right\} \times 100$$

- the percentage efficiency increases as per above relation

Questn

In a distributor line the operating voltage is increased by n-times. Determine the new resistance.

- R_2

Solution :-

At V_1 voltage drop $= \frac{I_1 R_1}{V_1}$

at V_2 voltage drop $= \frac{I_2 R_2}{V_2}$

given $\boxed{V_2 = nV_1}$

Based on the power equation

- voltage drop must be equal.

$$\therefore \frac{I_1 R_1}{V_1} = \frac{I_2 R_2}{V_2}$$

$$\frac{I_1 R_1}{V_1} = \frac{(1/n\, I_1)(R_2)}{n V_1}.$$

$$\frac{\cancel{I_1} R_1}{\cancel{V_1}} = \frac{\cancel{I_1} R_2}{n^2 \cancel{V_1}}$$

$$\boxed{R_2 = n^2 R_1}$$

$$P_1 = V_1 I_1 \cos\phi$$

$$P_2 = V_2 I_2 \cos\phi$$

$$V_1 I_1 \cos\phi = V_2 I_2 \cos\phi$$

$$V_1 \cancel{I_1} = n \cancel{V_1} I_2$$

$$\boxed{I_2 = \frac{1}{n} I_1}$$

a) for above condition the cross-sectional area

$$R \propto \frac{1}{a}$$

$$R_1 \propto \frac{1}{a_1} \text{ and } R_2 \propto \frac{1}{a_2}$$

$$\frac{R_1}{R_2} = \frac{a_2}{a_1}.$$

$$a_1 = a_2 \frac{R_2}{R_1} = a_2 \times \frac{n^2 \cancel{R_1}}{\cancel{R_1}}$$

$$\boxed{a_2 = \frac{a_1}{n^2}}$$ ---- distributor

$$\boxed{a_2 = a_1/n}$$ ---- feeder

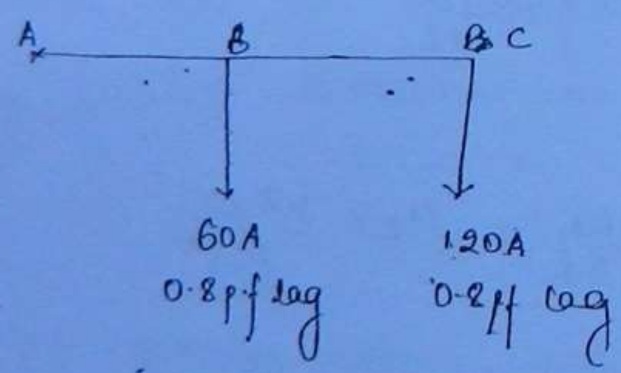
- for the same power, same material, length, when the operating voltage increased by 'n' times

— area of the cross sectⁿ of feeder $\boxed{a_2 = \frac{a_1}{n}}$ and of distributor is $\boxed{a_3 = \frac{a_1}{n^2}}$

Dated
27 Oct 2010

A two conductor feeder extending over a distance carries current of 120 Amp at point C a 60 Amp at point B. The impedences of the section AB and BC are

$Z_{AB} = (0.04 + j0.08)\Omega$ and $Z_{BC} = (0.08 + j0.12)\Omega$. Currents at point B and point C operates at power factor of 0.8 lagging the voltage at point C is 400 V Calculate currents at point B and C



Solⁿ current tapped at B

$$I_B = 60\angle -\cos^{-1}0.8$$

$$= 60\angle -36.8\ A$$

Current at point C

$$I_C = 120\angle -\cos^{-1}0.8$$

$$120\angle 36.8\ A$$

• current flowing in the section AB.

$$I_{AB} = I_B + I_C$$

$$= 60\angle{-36.8} + 120^{\circ}\angle{-36.8}$$

$$= 179\angle{-36.8^{\circ}}\,A.$$

• current flowing in section BC.

$$I_C = 120^{\circ}\angle{-36.8^{\circ}}\,A.$$

Voltage drop in the section AB

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

$$= 179\angle{-36.8} \cdot (0.04 + j0.08)$$

$$V_{AB} = 16\angle{26.6^{\circ}}\,V$$

Voltage drop in the section BC.

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

$$= 120\angle{-36.8^{\circ}}(0.08 + j0.12)$$

$$V_{BC} = 17.5\angle{19.54^{\circ}}\,V$$

Voltage at point B = $V_C + V_{BC}$

$$= 400 + 17.5\angle{19.54}$$

$$= \cancel{417.5\angle{19.54}}\ 416\angle{0.79^{\circ}}\,V$$

$$V_A = V_{AB} + V_B$$

$$416.4\angle{0.79} + 16\angle{26.6^{\circ}}$$

$$V_A = 450.8\angle 1.72^\circ \text{ V}$$

Questn

A single phase A/c distributor 500m long having impedence (0.02+j0.04) is fed with 250V at the extreme end. Currents are tapped at 3-points on the distributor

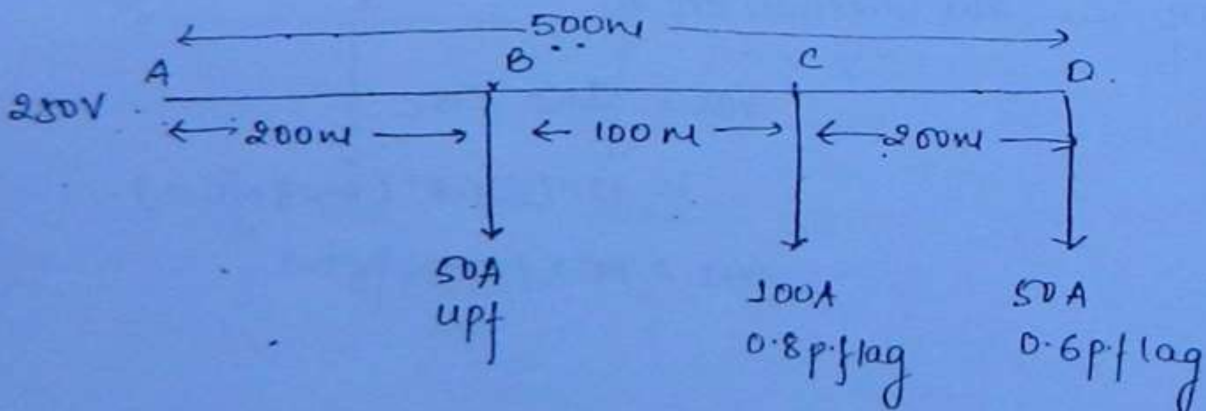
→ 50Amp ~~at~~ UPF and 200m from extreme end. &

→ 100 Amp 0.8 pf lag 300m from extreme end.

→ 50 Amp 0.6 pf lag 500m from extreme end.

Determine the voltage drop in each section and potential at the point where current 50Amp at 0.6 p.f lag is tapped.

Soln



• Current tapped at point B.

$$I_B = 50\angle 0^\circ \text{ Amp}$$

Current tapped at point C

$$I_C = 100\angle -\cos^{-1} 0.8 = 100\angle -36.8^\circ \text{ Amp}$$

$I_D = 50\angle -\cos^{-1} 0.6$

$= 50\angle -53.2°$ Amp.

<u>Section AB</u>

Impedence of section AB

$Z_{AB} = \frac{200}{500}(0.02 + j0.04)$

$= (0.008 + j0.016)\,\Omega$

$I_{AB} = I_B + I_C + I_D$

$= 100\angle -36.8° + 50\angle -53.2° + 50\angle 0.$

$= 188.6\angle -31.9$ Amp

$\cancel{V_{AB} =}$

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

$= 188.6\angle -31.9 \times (0.008 + j0.016)$

$V_{AB} = 3.37\angle 0.31$ Volt.

<u>Section BC</u>

$Z_{BC} = \frac{100}{500}(0.02 + j0.04)$

$Z_{BC} \Rightarrow (0.004 + j0.008)\,\Omega$

$I_{BC} = I_C + I_D$

$= 50\angle -\cos 0.6 + 100\angle -36.8.$

$I_{BC} = 148.5\angle -42.0\,A$

$V_{BC} = \bar{I}_{BC} \cdot Z_{BC}$

$= 1.32\angle 20.8°\,V$

Section CD

$$Z_{CD} = \frac{200}{500}(0.02 + j0.04)$$
$$= (0.008 + j0.016)$$

$$I_{CD} = I_D$$
$$= 50\angle -53.2^\circ A$$

$$V_{CD} = I_{CD} \cdot Z_{CD}$$
$$\Rightarrow 50\angle -53.2^\circ \times (0.008 + j0.016)$$
$$V_{CD} = 0.89\angle 10.2\ V$$

now

$$V_D = V - (V_{AB} + V_{BC} + V_{CD})$$
$$= 250 - [5.57\angle 0.31 + 1.32\angle 20.8 + 0.89\angle 10.2]$$
$$V_D = 245.08\angle -0.5^\circ V$$

Limitation of Radial System :-

- when a section of system is subjected to fault power is not supplied to the remaining sections. there by interruption of power supply takes place for the consumers to over come this disadvantage and increase reliability of supply RING MAIN SYM is adopted

Question:

A two wire d/c distributor ABCDEA is in the form of a ring main fed point A at 220V and is loaded as follows.

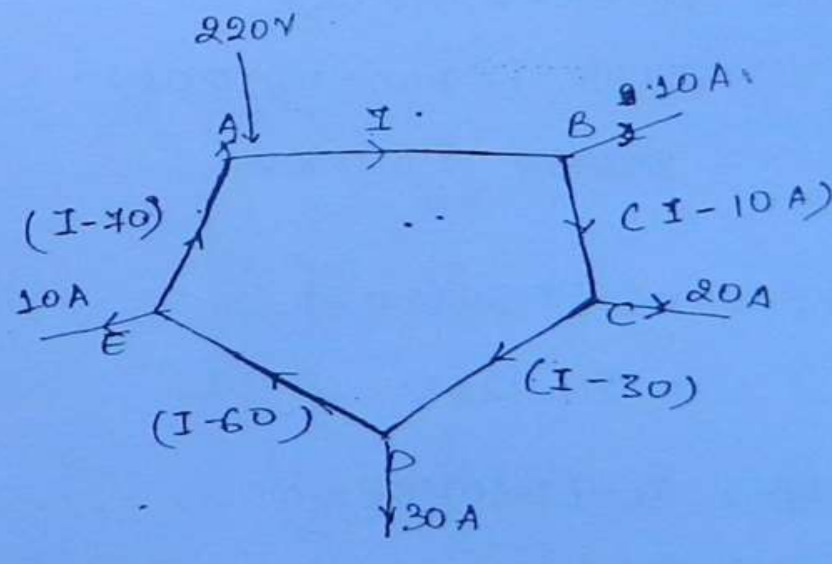
10Amp at point B, 20Amp at point C, 30Amp at point D. and 10 Amp at point E. the resistances of various sections are.

$$R_{AB} = 0.1\Omega ;\ R_{BC} = 0.5\Omega ;\ R_{CD} = 0.01\Omega$$

$R_{DE} = 0.025\Omega$. $R_{EA} = 0.075\Omega$. Determine

1) current flowing b/w point A and B.
2) the point of minimum potential
3) current in each section of distributor

Soln



Applying KVL to ring main system

$$= I(0.1) + (I-10)\times 0.5 + (I-30)0.01 + (I-60)0.025$$
$$+ (I-70)0.075\Omega.$$

$$= I(0.1 + 0.5 + 0.01 + 0.025 + 0.075) + 5 - 3 - 15 - 5$$

$I = 29.04$ Amp.

$I_{AB} = I = 29.04$ Amp

- potential at point B

$$V_B = V_A - I(0.01)$$

$$= 220 - (29.04)(0.01)$$

$$V_B = 217.09\ V$$

now

$$\boxed{\cancel{V_C = V_B - (I-10)(0.05)} \\ \cancel{= 208.48} \\ \cancel{22}}$$

$$V_C = V_B - (I-10)(0.05)$$

$$217.09 - (29.04-10)(0.05)$$

$$= \cancel{206.67}\ 216.158\ V$$

$$V_D = V_C - (I-30)(0.01)$$

$$= 216.128\ V$$

$$V_E = V_C - (I-60)(0.025)$$

$$V_E = 216.902\ V$$

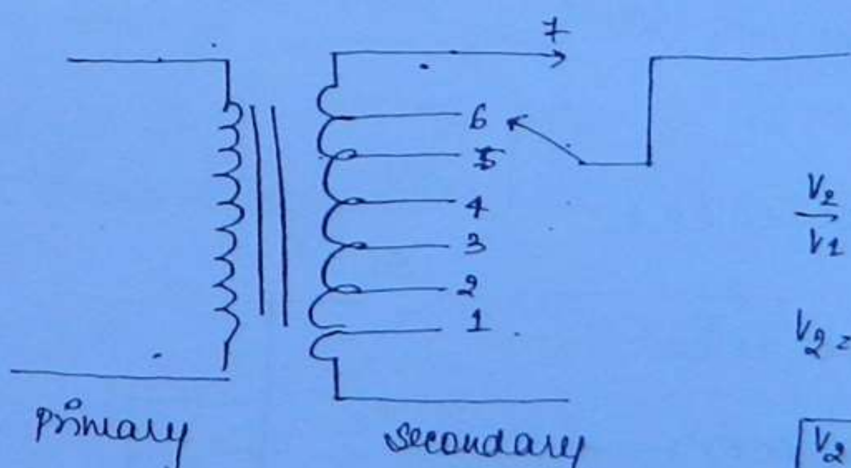
Voltag Control Methods

- for the ~~sam~~ safe operation of power s/m network the operating voltage of power s/m components must be with in the operating limits.

- Voltage control in power system equipment can be obtained by three methods.

1) Off-load tap changing xmer.
2) On load tap changing xmer
3) Autoxmer tap changing.

1) OFF-LOAD TAP CHANGING XMER



$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

$$V_2 = (N_2)\left(\frac{V_1}{N_1}\right)$$

$$\boxed{V_2 \propto N_2}$$

- S → 1 position | S → 7 positⁿ
  V → min | V → max

the voltage is minimum when the switch is

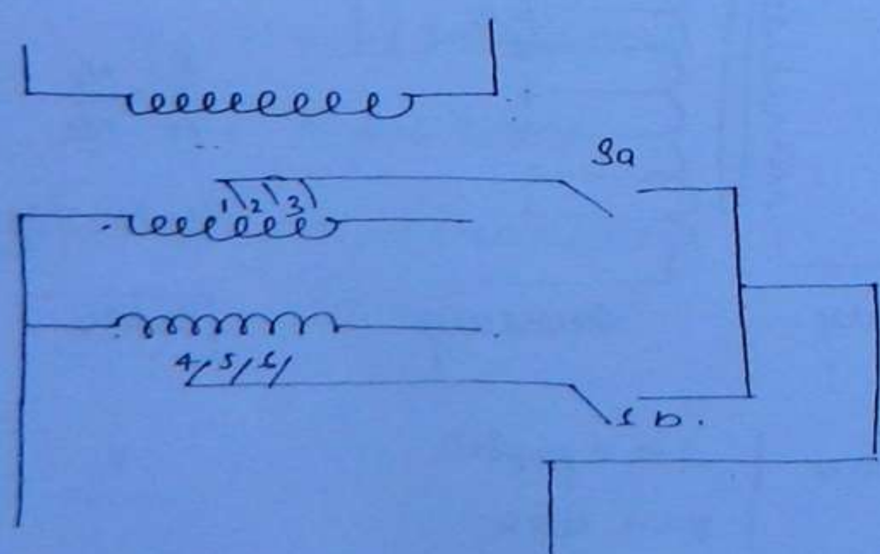
is located at position 1.

- Voltage is max^m. when the switch is located at the position 7.
- By varying the position of the switch the required voltage can be obtained
- Voltage control is acheived by changing turns in secondary.

Limitation:-

- The thickness of the switch must be less so that the switch donot come into contact with two positions at the same time which otherwise results in short-circuit of windings
-

2) ON-LOAD TAP CHANGING X^{mer}:-



- Using this method required voltage is obtained without disconnecting load from s/y

Steps:

1) 2 secondary winding

2) Sa → closed. Sb → closed.

→ 2 → 5

3) V↑ 2→3 5→6.

4) Sa → open , Sb → closed.
↓
carries twice previous current

2→3

Sa → closed. Sb → open

5) Sa → closed. Sb → open.
↓
carries twice previous current

6) Sa → closed Sb → closed.

- To decrease In this method voltage controll is achived by means of the load current flowing through secondary winding of the S/M.
- The changes in the voltage depends on the changes in the load demand and load current

SUBSTATION

- Substation are located from the generating statn to the consumer premisis

Types of Substation:

1) Step-up substation:- The step-up substation are located at generating statn.

- Step up substatn, steps up the generated voltage.
- Power is transmitted at stepped up voltage through

T.L.

6.6KV 132KV 33KV/11KV → primary

G/S VT 400V → secondary

C

2) <u>Primary substation:-</u>

- Primary substation are located at load centers along primary T.L.
- the primary Transmission voltage is stepped down. to a no. of secondary voltages.

3) <u>Secondary substations:-</u>

- A secondary substations the voltage level is further stepped down to sub transmission voltage and primary distribution voltage.

4) <u>Distribution substations:</u>

- Distribution sub-station supply power to the consumer ~~to~~ through distributor and service lines.

5) <u>Industrial Substations;</u>

- Industrial substations regulate voltage levels of componen in an industry

6). <u>Mining Substation:</u>

- Mining sub-station are the stand by sub-statn which operates when one of the existing substatn is subjected to abnormal conditions.

7) <u>Mobile substatn:</u>

- Mobile ~~st~~ substatn are utilized ail the. constructn of or an industry is completed.

- In the latest applications the mobile substations are used as the mining substatn.

- The mobile sub-statn is initial sub-statn i.e useful for completion of industry or generating statn.

HVDC - TRANSMISSION

- North
- Eastern
- Central North
- South
- North Eastern

→ Grids in INDIA

* A/c transmission takes place only when operating at same frequency
* when a/c frequency same, known as synchronous Tx
* In India HVDC transmissions are mainly used

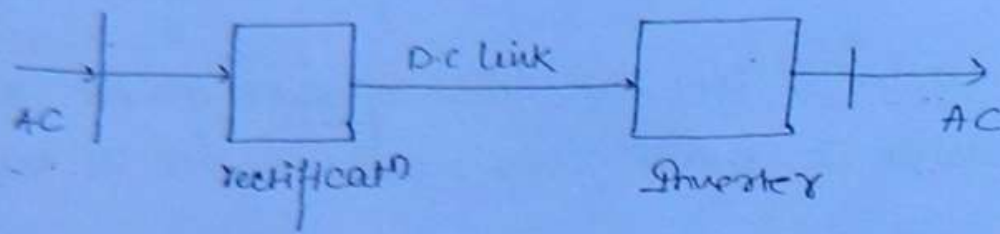
- All the generating statn, load centers and power s/m components in a grid operate at same frequency therefore with in a grid a/c transmission takes place because the entire grid operates at same frequency
- Two different grids may not operate at the same

same frequency.

- A/c power transmission b/w the grids operating at different frequencies is not possible.
- Since D/C transmission is independent of frequency power transfer b/w grids operating at different frequencies must be d/c in nature.
- HVDC transmission is b/w the two grids operating at different frequencies. HVDC
- HVDC transmission line is located b/w one grid and another grid
- A/c transmission is known as synchronous transmission because A.C transmission takes place when frequency is same.
- HVDC transmission is known as asynchronous transmission, coz d/c transmission takes place for different frequencies.

- HVDC Application :-

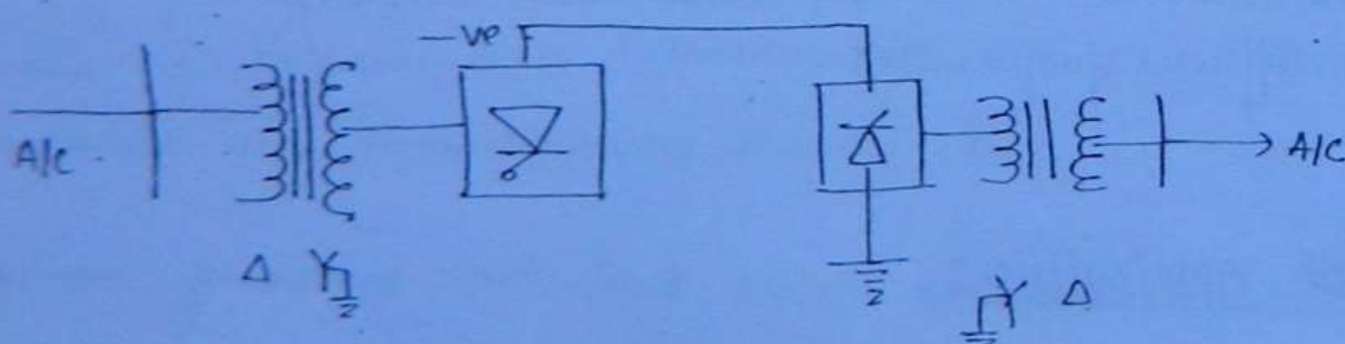
- HVDC transmission deals with transmission of power over long distances.
- There fore HVDC transmission is distance contraints



- A rectifier is located b/w generating stat^n and transmission line to convert generation which is in a/c to d/c transmission. Inverter is located b/w transmission line and load center to convert d/c transmission to the ac distribution.

TYPES OF DC LINKS :-

1) Monopolar DC link :-

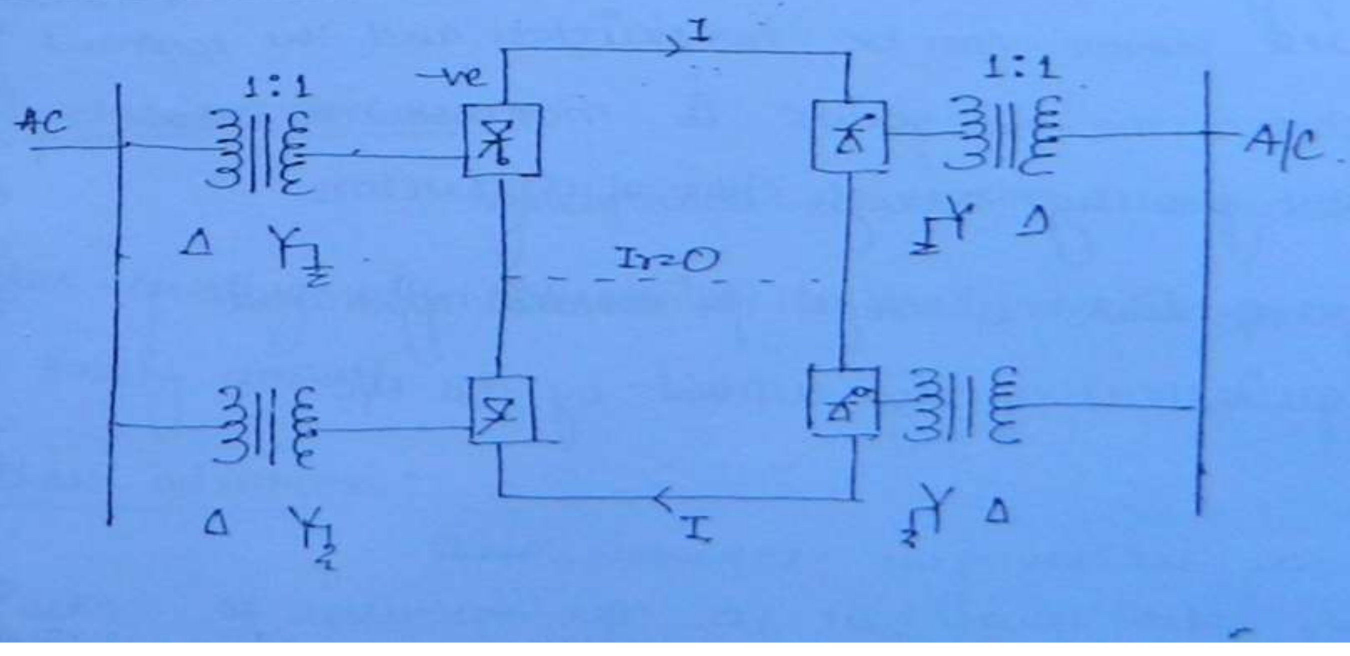


- A monopolar dc link consists of one conductor ~~with~~ w.r.t ground.
- Conductor operates at -ve polarity in order to

decrease corona loss.

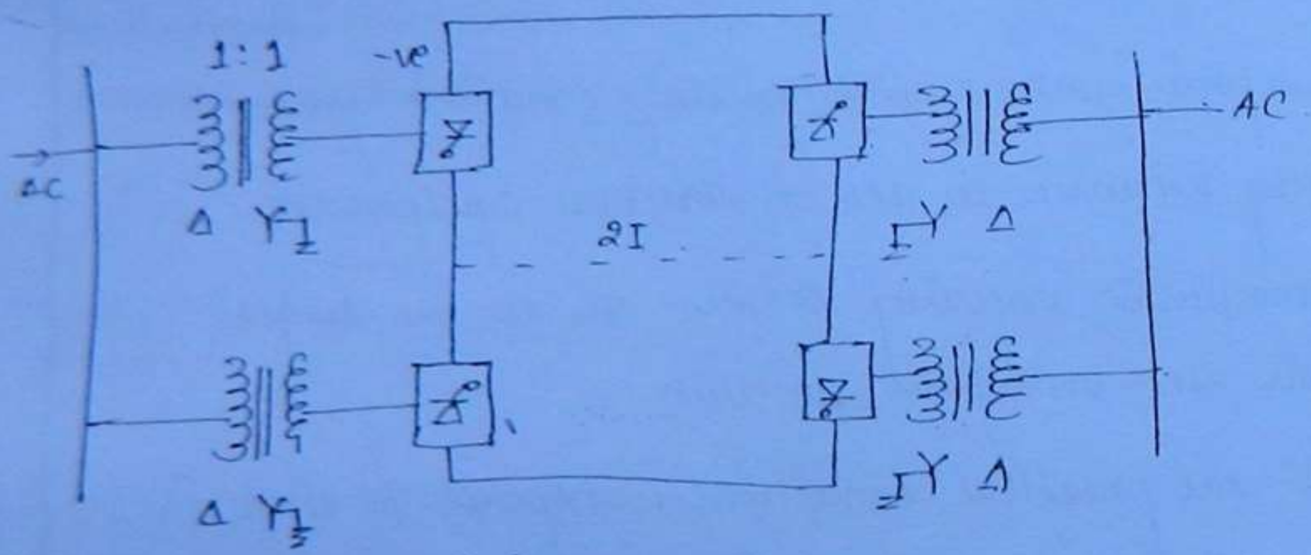
- Skin effect donot exist for a dc link.
- Since stringing of solid conductor is difficult, *stranded conductors are used.
- No of strands depends on operating voltage.
- The power transformer on either side of dc link operates at 1:1. Transformation ratio.
- The power transformer under normal operating condition prevents power frequency harmonic to act on terminal equipments
- The power transmission capacity is less. due to the single conductor in the monopolar dc link.
- Therefore in the practical conditions monopolar d/c link is not used.

2) Bipolar d/c link :-



- In bipolar dc link the current carrying capacity is increased by the two conductors in the d/c link
- All practical HVDC D/C links operates with bipolar d/c link

5) Homopolar d/c link:-



- By changing the position of thyristor of second conductors the required power can be transmitted and the current flowing between the two points is increased to 2 time the current flowing through either of conductors
- Homopolar d/c link is useful for certain application like requirement of high current by d/c n/c.

Advantages of HVDC Transmission:-

- Power transmitted per conductor is increased.
- The power transfered in a circuit increases.

Disadvantage:-

- To convert a/c to d/c we require rectifier unit and to convert d/c to a/c we require inverter unit

POWER FACTOR IMPROVEMENT

1) Static capacitor:

- Static capacitor are connected in parallel with the equipment operating at lagging power factor
- Static capacitor improve powerfactor in industries and factories.

2) Synchronous Condensor:-

Synchronous condensor is a synchronous motor, operating with over excitatn on load condition taking the leading current

3) Phase advancers:

Phase advancer improves the power factor of induction m/r. The low power factor in

Induction motor is due to the stator winding which draws exciting current which lags behind the supply voltage by 90°

Quesn

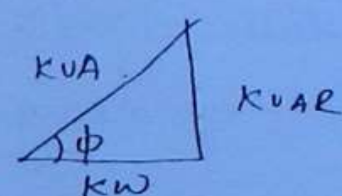
A synchronous g/r is supplying load of 300KW at p.f 0.6 lag. If the power factor is increased to unity, the no of kilowatts the synchronous g/r can supply for the same KVA loading is

a) 300KW
b) 200 KW
c) 500 KW
d) 700 KW

Soln

KW = 300 $\quad$ $\cos\phi = 0.6$

when pf → 0.6 lag



$$\cos\phi = \frac{KW}{KVA}$$

$$\frac{KW}{\cos\phi}$$

$$= \frac{300}{0.6} = 500KVA.$$

when pf — 1

$$KW = KVA \times \cos\phi$$
$$= 500KW$$

When the pf is increased from 0.6 to 1 the synchronous g/r has to supply 200 KW in excess.

Questn :

the following reading are obtained in a month of 30 days. at a consumer location

KVAR meter — 83830

Kwh meter — 291940

Demand meter — 1400 KW.

the average monthly load factor and power factor at the consumer premisis is.

Solutn

$$\text{Average load factor} = \frac{\text{Energy generated in a month}}{(30 \times 24) \times \text{Max}^m \text{ demand (KW)}}$$

$$\Rightarrow \frac{291940}{30 \times 24 \times 1400} \times 100$$

$$\Rightarrow 0.289 \times 100$$

$$28.9\%.$$

$$\cos\phi = \cos\left[\tan^{-1}\left(\frac{83830}{291940}\right)\right]$$

$$\cos\phi = 0.961.$$

Questn

A 3-ϕ, 50Hz, 30KM. T.L supplies a load of 5MW at a power factor 0.707 lag to the receiving end. when the voltage is Mantaind constant at 1Kv. the line resistance and inductance are 0.02 Ω and 0.84 mH/phase/KM a capacitor is connected across the load to rise the p.f 0.8 lag. calculate

1) capacitance / phase

2) Voltage regulation

3)

Soln length of the line $l = 30km$.

$$\text{load} = 5MW \text{ at } 0.707 \text{ lag}.$$

$$V_R = 11KV$$

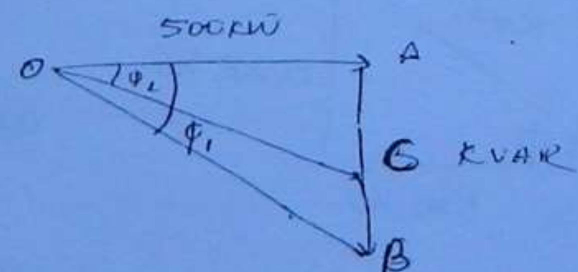
$$\text{resistance of } 30km \text{ length} = 0.02 \times 30$$

$$\Rightarrow 0.6 \Omega / \text{phase}.$$

$$\text{Reactance of } 3km = 2 \times 3.14 \times 50 \times 30 \times 0.84 \times 10^{-3}$$

$$= 7.9 \Omega / \text{phase}$$

Impedence of line $Z = (0.6 + j7.9) \Omega / \text{phase}$.



$\cos\phi_2 = 0.8$

B

capacitive reactive power

$BC = AB - AC$

AB:

$$\tan\phi_1 = \frac{AB}{OA}$$

$$AB = OA \tan\phi_1$$

$AB = OA \cdot \tan\phi_1$

$= 5000(\tan\{\cos^{-1}(0.707)\})$

$5000(\tan(45^\circ))$

$= 5000 KVAR = AB.$

AC : $\tan\phi_2 = \frac{AC}{OA}$

$AC = OA \tan\phi_2$

$= 5000 \tan\{\cos^{-1}(0.8)\}$

$= 3749.5 KVAR$

so $BC = AB - AC$

$= 1250 KVAR$

capacitive reactive power $V_R \cdot I_C = 1250$

$\sqrt{3} V_r I_C = 1250$

$\cancel{\sqrt{3}} V_r \cdot \frac{V_r}{\cancel{\sqrt{3}} X_C} = 1250$

$V_r^2 / X_C = 1250$

$\frac{1250 \times 10^3}{V_r^2 \times \omega} = 1250$

$\frac{1250 \times 1000}{(1100)^2 \times 2 \times \pi \times 50} = 3.289 \times 10^{-3} F.$

$\sqrt{3} V_r \cdot \frac{V_r}{X_C} = 1250$

$\sqrt{3} \frac{V_r^2}{X_C} = 1250$

$C = \frac{1250}{\omega V_r^2} = \frac{1250}{\sqrt{3} \times 2 \times \pi \times 50 \times (11 \times 000)^2}$

$C = 0.18 \times 10^{-6} F$

$V_s = V_r + IR\cos\phi_r + IX\sin\phi_r$

$\Rightarrow$ ~~I~~ $500 \times 10^{-6} = \sqrt{3} \times 11 \times 10^{-3} \times I_L \times 0.8.$

$I_L = 32.80 A.$

$V_s = 1\times10^3 + 32.80 \times 0.6 \times \cancel{100}\,0..$

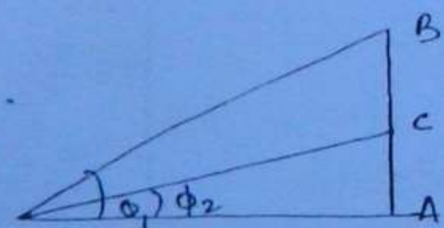
$$V_s = \frac{11000}{\sqrt{3}} + (37119.0)(0.6)\times0.8 + (37119.0)(7.9)\times0.6.$$

$$= 200.1 KV$$

$$\frac{V_s - V_r}{V_R}\times100 = \frac{200.1 - 1000}{1000}\times100.$$

Quesⁿ An industry draws 100KW at 0.7 pf lagging from a 3ϕ, 11KV supply. It is desired to increase the pf to .95 lag using series capacitor. The rating of req. capacitor

a) 90 KVAR
b) 69 "
c) 50 "
d) 79 "



Sol

$BC = AB - AC$

$AB =$

$$\tan\phi = \frac{AB}{OA}$$

$$AB = OA\tan\phi_1$$

$$BC = AB - AC = OA(\tan\phi_1 - \tan\phi_2)$$
$$= 100\times10^3 [\tan$$
$$= 69 KVAR$$

$w_1 \propto a_1 l$. $\quad \because$ length is same.

$w_2 \propto a_2 l$.

$$\therefore \frac{w_2}{w_1} = \frac{a_2}{a_1} = \frac{1}{n} \cdot w_1$$

$$\boxed{w_2 = \frac{1}{n} w_1.}$$

Gate

The operating voltage of a s/m is increased by 50%. The cost of the s/m increases by.

earlier = V_1

new = $1.5 = V_2$

$V_2 = 1.5\, V_1$

$$w_2 = \frac{1}{1.5} w_1$$

$$\boxed{cost_2 = \frac{1}{n} cost_1}$$

$$\frac{cost_2}{cost_1} = \frac{1}{n} = \frac{1}{1.5} = {}^{10}/_{15} = {}^{2}/_{3}$$

$\Rightarrow 66.67\%$

→ $cost_2$ is decreased by 66.67% of cost 1

3) BHEL-01

A current carrying elect $\bar{c}$ equal current density has its current carrying capacity decreased by n times the new power loss in feeder is

Sol.

$$I_2 = \frac{1}{n} I_1$$

$$P_1 = I_1^2 R_1$$

at $I_2 \Rightarrow P_2 = I_2^2 R_2$

$$\Rightarrow \frac{1}{n^2} I_1^2 \cdot n R_1$$

$$\boxed{P_2 = \frac{1}{n} P_1}.$$

$I_1 \propto \frac{1}{R_1}$

$I_2 \propto \frac{1}{R_2}$

$\Rightarrow \frac{I_1}{I_2} = \frac{R_2}{R_1}$.

$R_2 = n R_1$.

$\Rightarrow$ the power losses in T.L are decreased by n times $\left[P_2 = \frac{1}{n} P_1\right]$ the efficiency of the s/m increases by

Sol^n

percentage $\eta = \frac{P}{P + P_{loss}} = \frac{P}{P + I^2R} \times 100$.

$$\Rightarrow \frac{P}{P + I^2 \frac{\rho l}{a}} \times 100$$

$R = \rho l / a$.

and current density $J = I/a \Rightarrow a = I/J$

$$= \frac{P}{P + I^2 \frac{\rho l}{I/J}} \times 100$$

(Raman)

[redacted]

LOAD FLOW STUDIES

- → Network Modelling
- → Mathematical Modelling
- → Solution stage.

- Study means obtaining parametric values of s/s parameter.
- S/s parameter describe the condition of s/m.
- System parameters are of two type. → independent / → dependent.
- Studies are carried under two stage of s/m → steady state / → dynamic/Transient

- In steady state of system. system parameters are described as time invariant funcⁿ. and dynamic state of system they are represented as time variant function.

- In any study. we have to pass through three stage.
  - → Network Modelling
  - → Mathematical Modelling
  - → Solution stage.

- Network Modelling : Here various component of power system is represented by its electrical equivalent circuit component model. There by as overall n/w is obtained. [redacted]

[redacted]

• Mathematical Modelling: Here with the knowledge of n/w analysis the network model is converted into mathematical model. A mathematical model comprises of set of ~~auxiliary~~ ~~algebraic~~ algebric or set of differential eqn depending upon type of study we carry.

• Solution stage: In this stage by using appropriate numerical techniques the mathematical equatn are solved and system parameters are obtained. With the knowledge of system parameter we are able to analyse the s/m. this complete study.

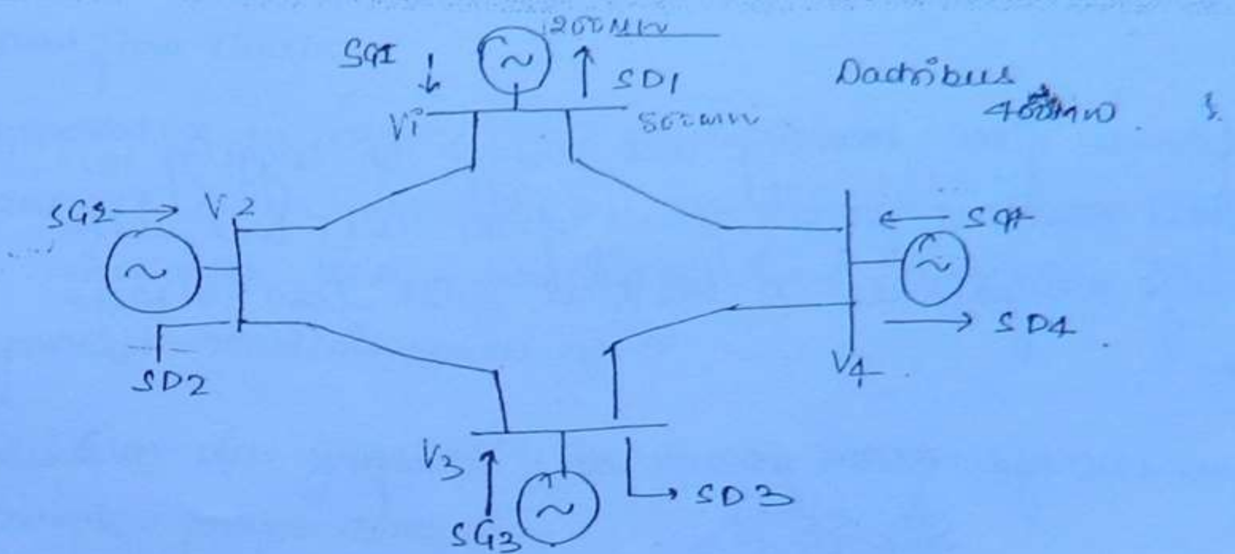
• When a load flow study is performed it is connected in two stages.

- Stage 1
  - Injected active Power (P)
  - Injected reactive power (Q)
  - Magnitude of Bus voltage (V)
  - Load torque Angle (δ)
- Stage 2
  - Line flow
  - losses

STAGE 1

$$\boxed{S_{Gi} = P_{Gi} + jQ_{Gi} = \text{Complex power generated at } i^{th} \text{ bus}}$$

$S_{Di} = P_{Di} + jQ_{Di}$ = Complex power demand at i^{th} bus



- $S_i = S_{Gi} - S_{Di}$ = Complex power injected to i^{th} bus.

$S_i = P_{Gi} + jQ_{Gi} - P_{Di} - jQ_{Di} = \underbrace{P_i}_{\text{active}} + j\underbrace{Q_i}_{\text{Reactive}}$.

$$\boxed{\begin{array}{l} \bullet \text{ If } S_{Gi} > S_{Di} \rightarrow S_i > 0 \rightarrow \text{Bus acts like exporting bus} \\ \bullet \text{ If } S_{Gi} < S_{Di} \rightarrow S_i < 0 \rightarrow \text{Bus acts like importing bus} \end{array}}$$

- Magnitude of bus voltage is measured by voltmeter.

- Load torque angle $\boxed{\delta_i = \angle V_i - \angle V_{ref}}$

Ex. $\delta_1 = \angle V_1 - \angle V_{ref} \rightarrow 0$ always zero

$\delta_2 = \angle V_2 - \angle V_1$

$\delta_3 = \angle V_3 - \angle V_1$

$\delta_4 = \angle V_4 - \angle V_1$

- Based on value of injected power a bus may act like an exporting bus [$S_i > 0$] or importing bus [$S_i < 0$]. The power will flow from exporting bus to importer.

buses

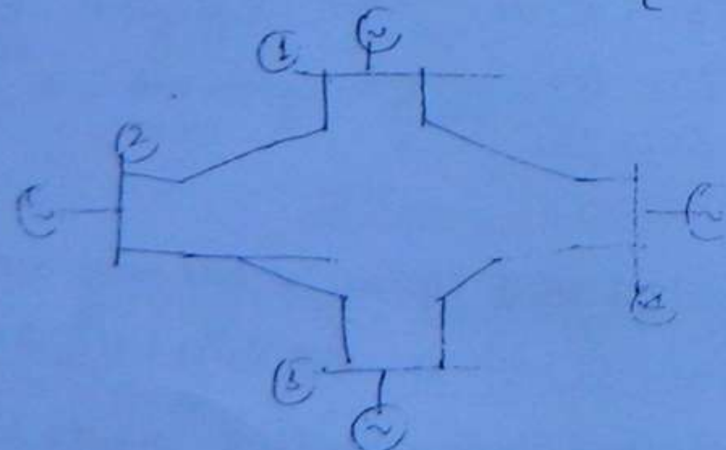
- Active power flow leading bus voltage to lagging bus voltage. And reactive power flows from the bus with high voltage magnitude to the bus with low voltage magnitude.
- With same voltage, active power still transfers due to ϕ leading. ~~STAGE 2~~

Application:

- It data is used for planning of power system.
- can be a estimated to voltage profile.
- Economic scheduling.
- Steady state data.

- Load flow analysis is mainly used for planning power s/m.

1. NETWORK MODELING

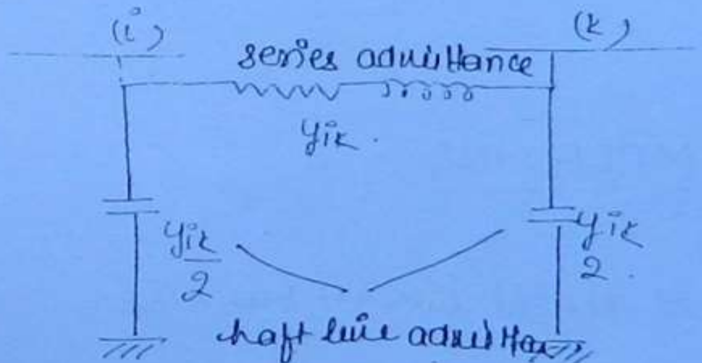


• In load flow studies

1). Generator are represented as complex power source., this means it is represented by complex no. where real no. indicates active power g/r^n and imaginary pt no. represent reactive power g/r^n

2) Similar to generator load are represented as complex power demand..

3) Transmission line are represented as π n/w. with series admittance & half line charging admittance.



• Data given

R_{ik}

X_{ik}

$\frac{y_{ik}'}{2}$

$$y_{ik} = \frac{R_{ik}}{R_{ik}^2 + jX_{ik}^2} - j\frac{X_{ik}}{R_{ik}^2 + X_{ik}^2}$$

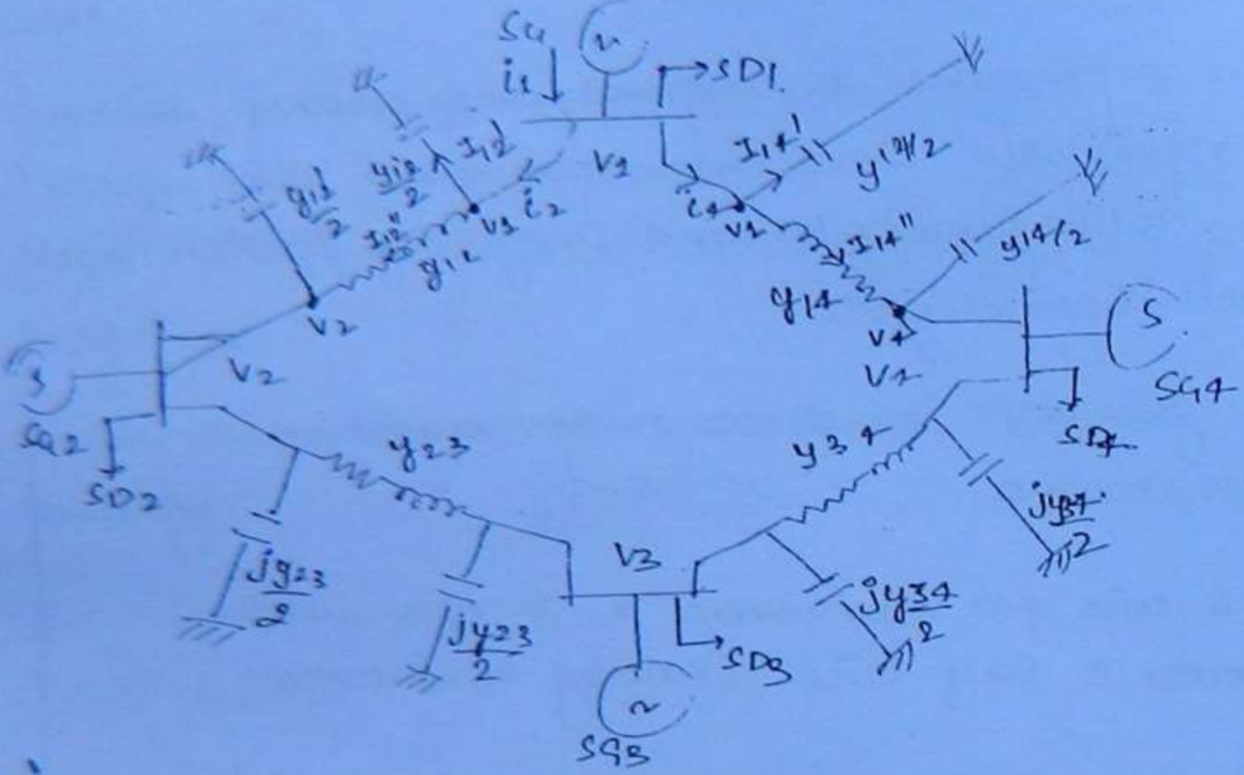
* T network is better than π n/w as, no. of junction of T n/w is less than π and T gives more good performance. still in load flow we use π n/w coz of mathematical simplification..

$$Z = R \pm jX$$

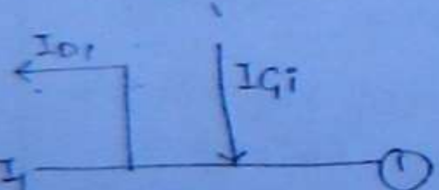
(+ → inductive, − → capacitive.)

$$Y = G \pm jB$$

(+ → C, − → L)



2) MATHEMATICAL MODELLING



Injected current into 1st bus = I_1

$$I_1 = I_{12} + I_{14}$$

$$= (I_{12}' + I_{12}'') + (I_{14}' + I_{14}'')$$

$$I = (V_i - V_k) y.$$

$$I_1 = \frac{V_1 y_{12}'}{2} + (V_1 - V_2) y_{12} + \frac{V_1 y_{14}'}{2} + (V_1 - V_4) y_{14}.$$

$$= V_1\left(\frac{y_{12}'}{2} + y_{12} + \frac{y_{14}'}{2} + y_{14}\right) + (-y_{12})V_2 + (0)V_3 + (-y_{14})V_4.$$

$$I_1 = Y_{11}V_1 + Y_{12}V_2 + Y_{13}V_3 + Y_{14}V_4.$$

and Y_{11} is total admittance connected to 1st bus.

$$\boxed{Y_{11} = \frac{y_{12}'}{2} + \frac{y_{14}'}{2} + y_{12} + y_{14}}$$ we see the directly connected to admittances.

- Y_{12} = Negative value of series admittance connected b/w bus ① & ②

$$Y_{12} = -y_{12}$$

- Similarly $\cancel{Y_{14}}$ $Y_{13} = -y_{13} = 0$

$$Y_{14} = -y_{14}.$$

Now

$$I_2 = Y_{21}V_1 + Y_{22}V_2 + Y_{23}V_3 + Y_{24}V_4.$$

$$Y_{21} = -y_{12}$$

$$Y_{22} = \frac{y_{12}'}{2} + \frac{y_{23}'}{2} + \frac{y_{24}'}{2} + y_{12} + y_{23} + y_{24}$$

$$Y_{23} = -y_{23}; \quad Y_{24} = -y_{24}.$$

* Off diagonal terms gives information about the no of T.L.

similarly eq^n of I_3 and I_4.

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix}$$

$$\Rightarrow \quad [I_{bus}]_{n\times 1} = [Y_{bus}]_{n\times n} [V_{Bus}]_{n\times 1} \quad \text{------} \quad (1)$$

:- equation for injected current into ith bus of n-bus power s/m

$$I_i = Y_{i1}V_1 + Y_{i2}V_2 \ldots\ldots Y_{in}V_n$$

$$\boxed{I_i = \sum_{k=1}^{n} Y_{ik}V_k} \quad \text{for } 1, 2, \ldots\ldots n. \quad \text{---} \quad (2)$$

YBUS

Ybus can be developed by direct inspection method.

Load flow analysis can done using Z-bus.

Y-bus is prefered. cox it is sparsity Matrix

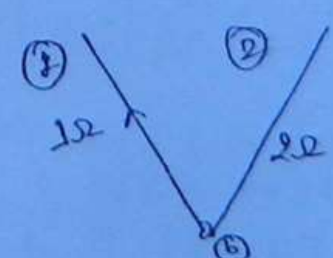
Sparsity Matrix:- When elements of matrix are often zero is known as sparsity matrix. a null matrix has 100% sparsity.

As Ybus is sparsity matrix the more no. of elements are zero thus the memory required for storage decreases greatly

Y_{bus}
- → sparsity Matrix.
- → symmetric Matrix [$Y_{bus} = Y_{bus}^{T}$]
- → square matrix [Inverse

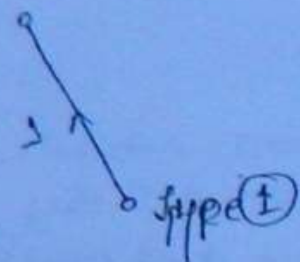
- In power system every bus is connected to 2-3 bus, in view of this Y bus is dominated by zero, and hence said to sparsity matrix.
- As Ybus is sparsity Matrix its inverse Zbus is FULL Matrix
- A matrix with less no of zero provide more information of the network therefore Z-bus is used in short circuit studies.
- Y-bus can be obtained by two methods.
  1) Direct inspection Method.
  2) Singular Transformation Method.
- When the mutual coupling is present b/w the two line direct inspectn method cannot be used to go for singular transformation method using A matrix.

<u>Question:</u> Form Z and Ybus?

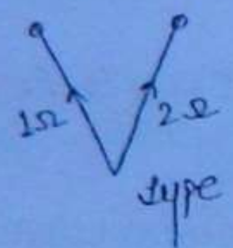


Solutⁿ: Z_{bus}

Step 1:



	(1)
(1)	1Ω



	(1)	(2)
(1)	1Ω	0
(2)	0	2Ω

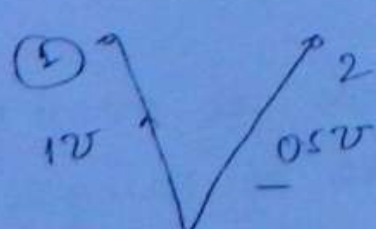
Method 1: Ybus through Z_{bus}^{-1}

$$Y_{bus} = \begin{bmatrix} 1 & 0 \\ 0 & 2 \end{bmatrix}^{-1}$$

$$= \frac{1}{2}\begin{bmatrix} 2 & 0 \\ 0 & 1 \end{bmatrix}$$

$$Y_{bus} = \begin{bmatrix} 1 & 0 \\ 0 & 0.5 \end{bmatrix}$$

Method 2: Direct inspection Method.



$Y_{11} = 1\mho$

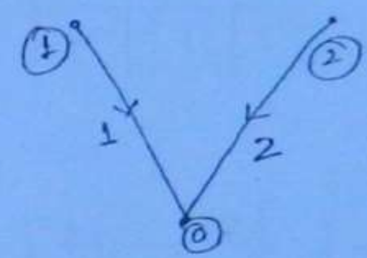
$Y_{12} = 0$

$Y_{21} = 0$

$Y_{22} = 0.5\mho$

$$Y_{bus} = \begin{bmatrix} 1 & 0 \\ 0 & 0.5 \end{bmatrix}$$

Method 5:- Single Transformation Method.



	①	②
1	+1	0
2	0	+1

$$A^T = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

primitive Interface MATRIX

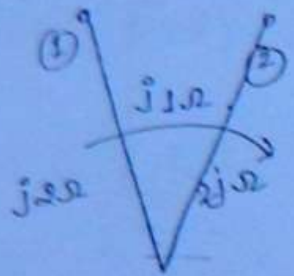
$$z = \begin{array}{c|c|c} & 1 & 0 \\ \hline 1 & 1\Omega & 0 \\ \hline 2 & 0 & 2 \end{array}$$

$$y = z^{-1} = \begin{bmatrix} 1 & 0 \\ 0 & 0.5 \end{bmatrix}$$

$$Y_{Bus} = [A^T][y][A]$$

$$= \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 0.5 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 \\ 0 & 0.5 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 0.5 \end{bmatrix}$$



primitive impedance matrix

$Z =$

	1	2
1	j2	j1
2	j1	j2

primitive admittance matrix

$$y = Z^{-1} = \frac{1}{-3}\begin{bmatrix} j2 & -j1 \\ -j1 & j2 \end{bmatrix}$$

-4+1

$$y = \begin{bmatrix} -0.66j & -j1/-3 \\ -1/3 j & -j0.667 \end{bmatrix}$$

$$y = \begin{bmatrix} -j0.667 & +j0.33 \\ +j0.33 & -j0.667 \end{bmatrix}$$

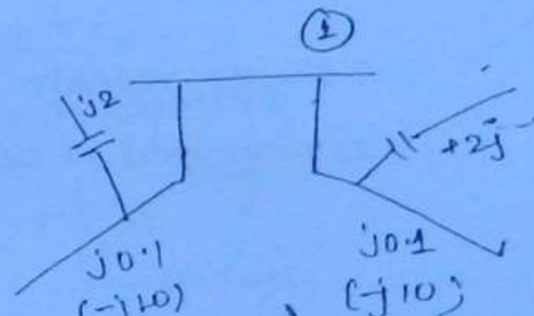
$[A] =$  $= \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ ... incidence matrix.

$$[A]' = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$Y = [A^T][y][A] = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} -j0.667 & +j0.33 \\ +j0.33 & +j0.667 \end{bmatrix}$$

$$Y_{bus} = \begin{bmatrix} -0.667j & +j0.33 \\ +j0.33 & -j0.667 \end{bmatrix}$$

Quest^n. In a pure imaginary Ybus matrix which element of Ybus are +ve imaginary and -ve imaginary



$$Y_{11} = +j2 + j2 - j10, -j10$$
$$= -j16$$

$$Y_{12} = -(-j10) = +j10$$

$$Y_{14} = -(-j10) = +j10$$

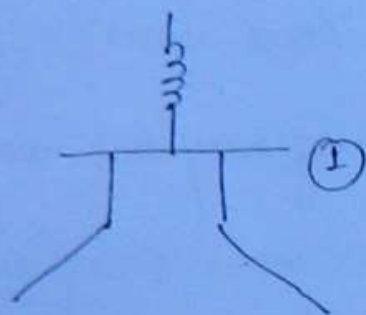
Ans + off diagonal → O +ve
Diagonal = -ve.

** The condition for convergence of load flow problem is all the diagonal element of Ybus must dominate the off diagonal element.

In oft above example mag Y_{11} is 16

and mag of Y_{12} is 10. As mag Y_{11} > mag Y_{12} problem converges.

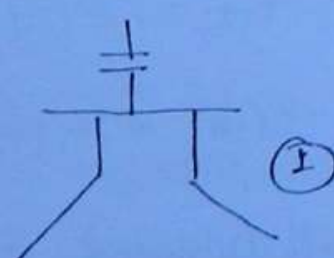
②



A shunt reactor of $-j10$ is connected to bus ①

$$Y_{11} = -j16 - j10$$
$$= -j26$$
$$Y_{12} = +j10$$
$$Y_{14} = +j10$$

$$Y_{11} = -j16 + j10$$
$$= -j6$$
$$Y_{12} = +j10$$
$$Y_{14} = +j10$$



A load flow problem may converge or diverge can be initially estimated by absorbing Y bus. The condition for convergence all of the diagonal element of Ybus must dominate off-diagonal elements otherwise diverges.

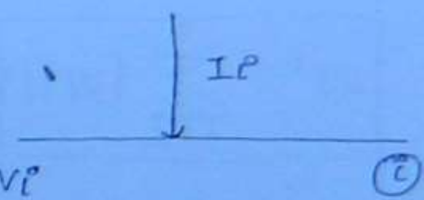
shunt reactor in power s/m improves the convergence condition where as shunt capacitors in power s/m improves divergence of load flow problem.

Dated
29th Oct 2010

• $Z = R \pm jX$. ($+ \rightarrow$ inductor, $- \rightarrow$ capacitor)

• $S = P \pm jQ$ ($+ \rightarrow$ lag, $- \rightarrow$ leading)

$$I_i = \sum_{k=1}^{n} Y_{ik} V_k \quad \text{--- (1)}$$



V → is taken as reference vector.

Pf is lagging $V = |V| \angle 0^\circ$

$I = |I| \angle -\theta$

$S = VI^* = |V||I| \angle \theta$

$= |V||I| \cos\theta + j|V||I| \sin\theta$

$= P + jQ$

$S_i = P_i + jQ_i$

$= V_i I_i^*$

$S_i = V_i \left[\sum_{k=1}^{n} Y_{ik} V_k \right]^*$

• So we calculate $S_i^* = V_i^* I_i^* = P_i - jQ_i$

$$\boxed{\begin{aligned} P_i &= \text{Real}\{S_i^*\} \\ Q_i &= -\text{Imag}\{S_i^*\} \end{aligned}}$$

Let

$V_i = |V_i| \angle \delta_i$

$V_i^* = |V_i| \angle -\delta_i$

$Y_{ik} = G_{ik} - jB_{ik}$

$$= \sqrt{G_{ik}^2 + B_{ik}^2} \;\angle \tan^{-1}\left(\frac{-B_{ik}}{G_{ik}}\right)$$

$$= |Y_{ik}| \angle -\gamma_{ik}.$$

$$\boxed{V_K = |V_K| \angle \delta_K.}$$

<u>and</u>

$$S_i^* = P_i + jQ_i$$

$$= |V_i| \angle -\delta_i \sum_{K=1}^{n} |Y_{ik}| \angle -\gamma_{ik} \cdot |V_K| \angle \delta_K$$

$$\boxed{S_i^* = \sum_{K=1}^{n} |V_i||V_K||Y_{ik}| \angle -(\delta_i - \delta_K + \gamma_{ik}).}$$

and

$$\boxed{P_i = Re\{S_i^*\} = \sum_{K=1}^{n} |V_i||V_K||Y_{ik}| \cos(\delta_i - \delta_K + \gamma_{ik})} \cdots (A)$$

12

$$Q_i = -\text{Imaginary}\{S_i^*\}$$

$$\boxed{Q_i = \sum_{K=1}^{n} |V_i||V_K||Y_{ik}| \sin(\delta_i - \delta_K - \gamma_{ik})} \cdots (B)$$

Eqn (A) and (B) are known as static load flow equatn.

- The load flow equations are non linear simultaneous algebric equatn.

- BUS VOLTAGE EQUATION :-

$$S_i^* = V_i^* I_i = P_i - jQ_i$$

$$I_i = \frac{P_i - jQ_i}{V_i^*}$$

$$\sum_{k=1}^{n} Y_{ik} V_k = \frac{P_i - jQ_i}{V_i^*}$$

$$Y_{ii} V_i + \sum_{k=1}^{n} Y_{ik} V_k = \frac{P_i - jQ_i}{V_i^*}$$

$$\boxed{V_i = \frac{1}{Y_{ii}} \left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik} V_k \right]}$$

for $i = 1, 2, \ldots n$.

3. SOLUTION OF STAGE :-

1) GAUSS & SEIDEL METHOD

Let take

$$y_1 = f_1(x_1, x_2) = x_1^2 - \log x_1 x_2 + x_2^2 = 2$$

$$y_2 = f_2(x_1, x_2) = -2x_1^2 + \log x_1 x_2 + x_2^2 = 5$$

$$x_1 = \sqrt{2 + \log x_1 x_2 - x_2^2} \quad \cdots \text{(i)}$$

$$x_2 = \sqrt{5 + 2x_1^2 - \log x_1 x_2}$$

$$= f_4(x_1, x_2)$$

→ Start with Guess of Guess:

$$x_1^0 = x_2^0 = 4$$

• First Iteration

$$x_1^{(1)} = f_3(x_1^0, x_2^0)$$

$$= \sqrt{2 + \log x_1^0 x_2^0 - (x_2^0)^2}.$$

$$x_2^{(1)} = f_4(x_1^{(1)}, x_2^0).$$

$$= \sqrt{5 + 2(x_1)^2 - \log x_1^{(1)} x_2^{(1)}}$$

→ Check for convergence:-

$$\cdot\ |x_1^{(1)} - x_1^{(0)}| \leq \text{Error}.$$

$$\cdot\ |x_2^{(1)} - x_2^{(0)}| \leq \text{Error}$$

NOTE:-

• Gauss method is not appropriate coz takes a very long process.

• Classification of Buses:-

→ Load flow study has to be performed under online CPU execution time is very important in this aspect. In order to reduce the total no. of iteratn

Out of four bus quantities of each bus, two bus quantities are specified.

- Depending upon which two bus quantities out of four bus quantities are specified, buses are classified into different type.

Classification of Buses

85%

PQ / Load Bus.

- specially P_i, Q_i [specified]

[mainly bus are connected to load, a very few are connected to G/r].

- unspecified: $|V_i|, \delta_i$

Slack bus.

[Max^m G/r capacity bus]

unspec: P_i, Q_i

spec: V_i, δ_i

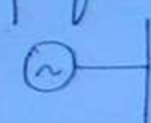
- Are called as reference bus swing bus

15%

- **PV / Generator / voltage controlled bus**

[At these buses generator are connected].

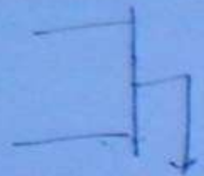
- specified: $P_i, |V_i|$
- unspecified: Q_i, δ_i



- Every PV bus can be generator or voltage controlled buses but it cannot be that every generator or voltage controlled buses is PV bus.

- Slack bus is called as the reference bus.

(1)

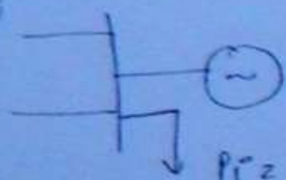


$P_i = -P_{Di}$

$Q_i = -Q_{Di}$

- Cannot be taken as PQ bus

(2)

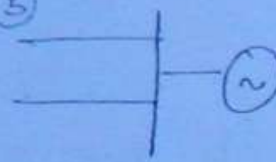


$P_i = P_{Gi} - P_{Di}$

$Q_i = Q_{Gi} - Q_{Di}$

- can be taken as PQ bus

(3)

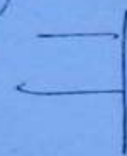


$P_i = P_{Gi}$

$Q_i = Q_{Gi}$

- can be taken as PQ. bus.

(4)

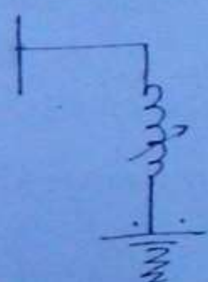


$P_i = 0$

$Q_i = 0$

- cannot be PQ bus.

- PURE VOLTAGE CONTROLED BUS:-



$P_i = 0$ (active power is ~~known~~ '0')

$V_i \rightarrow$ constant

$Q = V^2/X$

$\therefore \delta \rightarrow$ is unknown.

- Similar is the case with capacitor connected

In order to conduct load flow study under online condition CPU execution type should be less.

By reducing the total no of unknowns we can reduced the iteration, convergence need to be satisfied

PQ Buses :-

- If the values of P and Q are known the bus can be selected as PQ bus. By default all load buses are PQ buses

- Buses connected with generators can be selected as PQ bus since the values of P.Q are known voltage controlled buses can be selected as PQ bus.

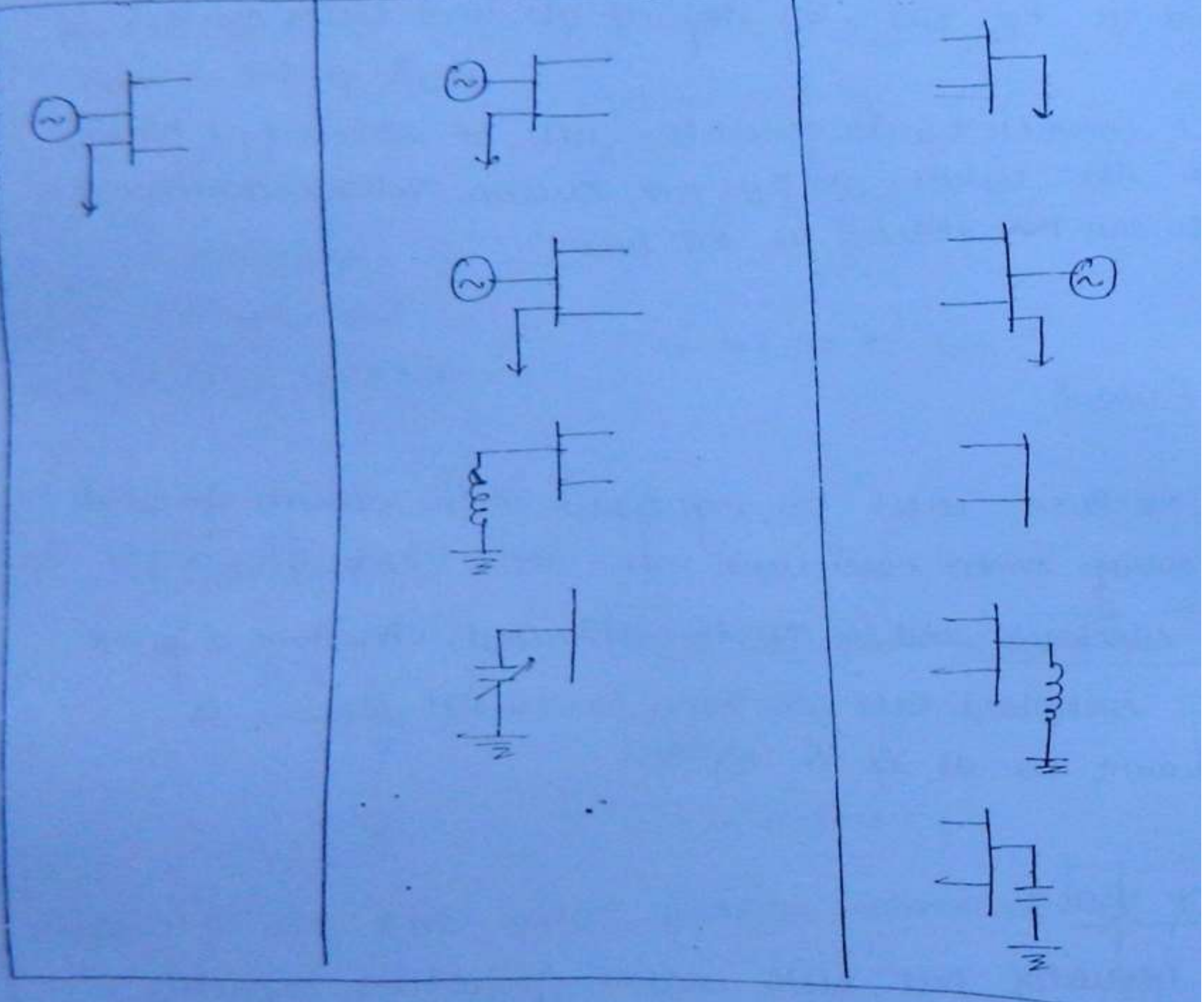
PV Buses :

- A PV Buse must be equipped with either generator or voltage control equipment. At these buses $\boxed{P_i = 0}$ $\boxed{V \text{ is constant}}$ and $\boxed{Q \text{ can be estimated}}$. Therefore a pure voltage controlled bus the only parameter which is unknown to us is 'δ'

SLACK Bus :

- A Generator bus with max^m Generating capacity is chosen as ~~slag~~ slack bus. As the generator is connected to the bus voltage can be specified and this bus voltage is taken as reference vector. Load angle for this bus is zero. Without slack bus load flow problem never converges

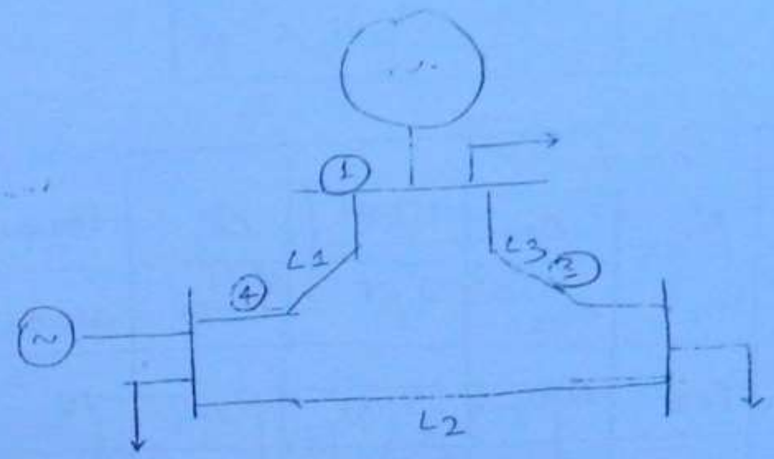
• Slack Bus	• PV Bus	• PQ bus.



ALGORITHM

Case 1: PV buses are absent

Stage 1: To find bus quantities -



• Line data.

Line no	From bus (i) to Bus (k)	R_{ik}	X_{ik}	$\frac{y'_{ik}}{2}$
L_1	1-2	R_{12}	X_{12}	$y'_{12}/2$
L_2	2-3	R_{23}	X_{23}	$y'_{23}/2$
L_3	3-1	R_{31}	X_{31}	$y'_{31}/2$

series impedance $Z_{ik} = R_{ik} + jX_{ik}$

Series admittance $= y_{ik} = \frac{R_{ik}}{R_{ik}^2 + X_{ik}^2} - j\frac{X_{ik}}{R_{ik}^2 + Y_{ik}^2}$

• Form Ybus by using Direct inspection Method.

$$Y_{Bus} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix}_{3\times3}$$

$Y_{11} = \frac{y'_{12}}{2} + y'_{13}/2 + y_{12} + y_{31}$

$Y_{12} = -y_{12}$

• Bus Data:

Bus no. (i)	Generator		Load		V_i	δ_i	Remark
	P_{Gi}	Q_{Gi}	P_{Di}	Q_{Di}			
1	?	?	P_{D1}	Q_{D1}	V_1	$\delta = 0$	slack.
2	P_{G2}	Q_{G2}	P_{D2}	Q_{D2}	$V_2 = ?$	$\delta_2 = ?$	PQ
3.	P_{G3}	Q_{G3}	P_{D3}	Q_{D3}	$V_3 = ?$	$\delta_3 = ?$	PQ.

$P_{G1} = P_1 + P_{D1}$
$Q_{G1} = Q_1 + Q_{D1}$.

Bus summary:

given: $V_1, \delta_1, P_2, Q_2, P_3, Q_3$.

not Given: $P, Q, V_2, \delta_2, V_3, \delta_3$

$$P_i = \sum_{k=1}^{n} V_i V_k Y_{ik} \cos(\delta_i - \delta_k + \gamma_{ik})$$

$$V_{Bi} = \frac{1}{y_{11}} \left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ k=1}}^{n} Y_{ik} V_k \right]$$

$$Q_i = \sum_{k=1}^{n} V_i V_k Y_{ik} \sin(\delta_i - \delta_k + \gamma_{ik})$$

• FLAT START:-

$$V_2^0 = V_3^0 = 1 \text{ p.u.}$$

$$\delta_2^0 = \delta_3^0 = 0 \text{ radians}$$

$$V_2^{(1)} = \frac{1}{Y_{22}} \left[\frac{P_2 - jQ_2}{|V_2|^0 \angle -\delta_2^0} - Y_{21}V_1 - Y_{23}V_3 \right]$$

$$\boxed{V_2^{(1)} = |V_2|^{(1)} \angle \delta_2^{(1)}.}$$

$$V_3' = \frac{1}{Y_{33}} \left[\frac{P_3 - jQ_3}{V_3^{0} \angle -\delta_3^{0}} - Y_{31} V_1 - Y_{32} V_2^{(1)} \right]$$

$$\boxed{V_3' = |V_3|^{(1)} \angle \delta_3^{(1)}}$$

- Check for convergence

$$\cancel{\left| V_i^{(1)} - V_i^{(0)} \right| \leq \epsilon}$$

$$\left| V_i^{r} - V_i^{(r-1)} \right| \leq \epsilon$$

$$\left| \delta_i^{r} - \delta_i^{(r-1)} \right| \leq \epsilon$$ ∴ where r is current iteration r

If convergence is occured, then calculated losses slack bus power and ~~it~~ then go to stage-2
If not repeat the process.

USE OF ACCELERATION

Example

The 20th iterated value

$$V_2^{20} = \frac{1}{Y_{22}} \left[\frac{P_2 - jQ_2}{|V_2|^{19} \angle -\delta_2^{19}} - Y_{21} V_1 - Y_{23} V_3^{19} \right]$$

$= |V_2|^{20} \angle \delta_2^{(20)}$.

before using V_2 in the next cal.

accelerate V_2 first and then used it

$$\boxed{V_2^{20} \text{ accelerated} = V_2^{19} + \alpha\left(V_2^{20} - V_2^{19}\right)}$$

acceleratⁿ factor

$\boxed{\alpha = 1.6}$

saturation of 20-30%

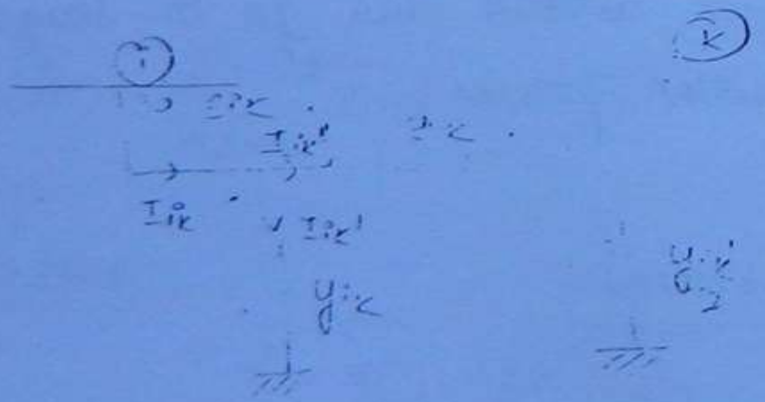
$$\boxed{\delta_2^{20} = \delta_2^{19} + \alpha\left(\delta_2^{20} - \delta_2^{19}\right)}$$

STAGE-2: to find line flow / losses.

$\left.\begin{matrix} P_i \\ Q_i \end{matrix}\right] S_i$

V_i

δ_i



$\left.\begin{matrix} P_k \\ Q_k \end{matrix}\right] S_k$

V_k

δ_k

$S_{ik} = P_{ik} + jQ_{ik}$ = Complex power transfered from bus (i) to bus (k)

$$I_{ik} = I_{ik}' + I_{ik}'' = V_i \frac{y_{ik}'}{2} + (V_i - V_k)\, y_{ik}$$

$$S_{ik} = V_i I_{ik}^* = V_i\left(V_i^* \frac{y_{ik}^*}{2} + (V_i^* - V_k^*)\, y_{ik}^* \right)$$

Similarly

$$S_{ki} = V_k I_{ki}^* = V_k\left[V_k^* \frac{y_k^*}{2} + (V_k^* - V_i^*)\, y_{ik}^* \right]$$

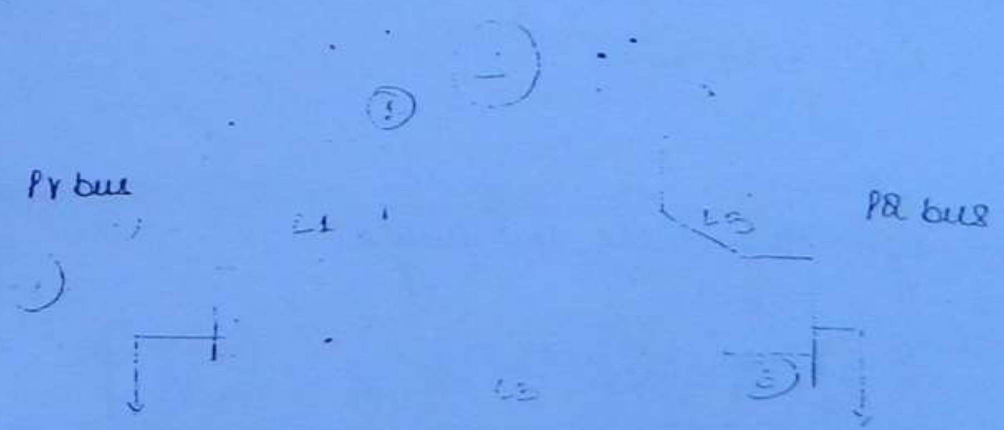
$S_{ki} = 1.1 + j0.9$ → sending (k to i) (importing)

$S_{ik} = -0.3 - j0.2$ → receiving (from i to k) (exporting)

Dated
9 Nov 2010

Case 2: PV buses are present.

Stage 1: to find bus quantities



- using line data from Y bus

- Bus data :

  Given: V_1, $\delta_1 = 0$

  P_2, V_2, Q_{2min}, Q_{2max}, P_3, Q_3

Find :

$V_1, \delta_1, \theta_2, \delta_2$

V_3, δ_3

Flat start:

$V_3^{(0)} = 1 \angle 0$

$\delta_2^{(0)} = \delta_3^{(0)} = 0$ radian

= Step 1: calculate $Q_2^{(0)}$

$$Q_2^{(0)} = -|V_2||V_1||Y_{21}| \sin(\delta_2^0 - \delta_1 + \gamma_{21})$$
$$+ |V_2||V_3|^0 |Y_{23}| \sin(\delta_2^0 - \delta_3^0 + \gamma_{23}).$$

= Step 2: check for reactive power limits

$$Q_{2min} \le Q_2^{(0)} \le Q_{2max}$$

= Step 3: update voltage magnitude and angle.

$$V_2^{(1)} = \frac{1}{Y_{22}} \left[\frac{P_2 - jQ_2^0}{|V_2| \angle -\delta_2^0} - Y_{21} V_1 - Y_{23} V_3^0 \right]$$

$$= |V_2|^{(1)} \angle \delta_2^{(1)}$$

omit $|V_2|^{(1)}$, retain $\delta_2^{(1)}$

$$V_2^{(1)} = |V_2| \angle \delta_2^{(1)}$$

$$V_3^{(1)} = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{|V_3|^0 \angle -\delta_3^0} - Y_{31}V_1 - Y_{32}V_2^{(1)} \right]$$

$$= |V_3|^{(1)} \angle \delta_3^{(1)}$$

Step 4: check for convergence.

$$|\delta_1^{r} - \delta_1^{(r-1)}| \le \epsilon$$

$$|V_3^{r} - V_3^{(r-1)}| \le \epsilon$$

- If convergence occurs than calculate slag bus power, P_1, Q_1 and find value of Q_2 then goto stage 2 calculation
- If convergence do not occur repeat step 2 to 4 using current iteration values until convergence occurs.

Reactive-Power Limit Voilation At PV Buses

- Let we have completed r^{th} no. of iteration, convergence couldnot be obtained even at the end of r^{th} iteration Before going to $(r+1)^{th}$ iteration for updating voltage and load angle, $Q_2^{(r)}$ is calculated using r^{th} iteration values of (V) and (δ) - Now $Q_2^{(r)}$ has voilated the limits. It can voilate limit in two ways.

$$Q_2^{(r)} \begin{cases} \rightarrow\ < Q_2 \min \\ \rightarrow\ > Q_2 \max. \end{cases}$$

- Under these circumstances the voltage at the second bus may be more than or less than specified value.
- Treating second bus as PV bus is **WRONG**; it should be treated as PQ bus only.
- The same active power V_2 can be selected as specified value. The reactive power Q_2 may be said $Q_{2(min)}$ or $Q_{2(max)}$ depending upon the case may be.

NEWTON-RAPHSON METHOD

(a) Single value function:

$$y = f(x) = x^2 - \log x + 1$$

$$f(x) = 0$$

Let $x = x^0$ is the root

$$y^{(0)} = f(x^0) \neq 0$$

$$x^{(1)} = x^0 + \Delta x^0$$

$$y^{(1)} = f(x)^{(1)} = f(x^0 + \Delta x^0) = 0$$

expand the eq^n by taylor series approximates

$$y^{(1)} = y^{(0)} + \Delta y^{(0)} = f(x^0) + \left(\frac{\partial y}{\partial x}\right)^0 \Delta x^0 + \left(\frac{\partial^2 y}{\partial x^2}\right)^0 \Delta^2 x^{(0)}$$

$$+ - - - - - -$$

$$f(x^0) + \left(\frac{\partial y}{\partial x}\right)^0 \Delta x^0 = 0$$

$$\Rightarrow \boxed{\Delta x^{(0)} = -\frac{f(x)^0}{\left(\frac{\partial y}{\partial x}\right)^0}}$$

175
x
375

$$\longrightarrow \quad x^{(1)} = x^{(0)} + \Delta x^0$$

check for convergence.

$$\left| x^{(1)} - x^{(0)} \right| \leq \in$$

$$x^{(2)} = x^{(1)} + \Delta x^{(1)}$$

$$\boxed{\Delta x^{(1)} = -\frac{f x^{(1)}}{\left(\frac{\partial f}{\partial x}\right)^1}}$$

—

b) Multi value fuction :-

$$y_1 = f_1(x_1, x_2) = x_1^2 - \log x_1 x_2 + x_2^2$$

$$y_2 = f_2(x_1, x_2) = -2x_1^2 + \log x_1 x_2^2 - x_2^2$$

$$f_1(x_1, x_2) = 0$$

$$f_2(x_1, x_2) = 0.$$

$x_1^{(0)}, x_2^0 \longrightarrow$ Intial guess

$$y_1^{(0)} = f_1(x_1^0, x_2^0) \neq 0$$

$$y_2^{(0)} = f_2(x_1^0, x_2^0) \neq 0.$$

New roots

$$x_1^{(1)} = x_1^{(0)} + \Delta x_1^{(0)}$$

$$x_2^{(1)} = x_2^{(0)} + \Delta x_2^{(0)}$$

$$y_1^{(1)} = y_1^{(0)} + \Delta y_1^{(0)} = f_1(x_1^{(1)}, x_2^{(1)}] = f_1(x_1^0 + \Delta x_1^0, x_2^0 + \Delta x_2) = 0$$

$$f_1(x_1^0, x_2^0) + \left(\frac{\partial f_1}{\partial x_1}\right)^0 \cdot \Delta x_1^0 + \left(\frac{\partial f_1}{\partial x_2}\right)^0 \Delta x_2^{(0)} = 0 \quad \text{---- (1)}$$

$$f_2(x_1^0, x_2^0) + \left(\frac{\partial f_2}{\partial x_1}\right)^0 \Delta x_1^0 + \left(\frac{\partial f_2}{\partial x_2}\right) \Delta x_2^0 = 0 \quad \text{---- (2)}$$

Put eqn s (1) and (2) in Matrix form.

$$\begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} \end{bmatrix}^0 \begin{bmatrix} \Delta x_1 \\ \Delta x_2 \end{bmatrix}^0 = - \begin{bmatrix} f_1(x_1, x_2) \\ f_2(x_1, x_2) \end{bmatrix}$$

Jacobian Matrix — Increment Matrix — Constant Matrix.

$$\boxed{[J]^0 [\Delta X]^0 = -[f]^0}$$ --- condensed form

so, $$\boxed{[\Delta x]^0 = -[J^0]^{-1}[f]^0}$$

After getting the increments update the values of (x_1 and x_2) using the increment value then check for convergence. If convergence is occurred take the solutⁿ of simultaneous algebric equatⁿ otherwise repeat the process.

new roots :-
$$x_1^{(2)} = x_1^{(1)} + \Delta x_1^{(1)}$$
$$x_2^{(2)} = x_2^{(1)} + \Delta x_2^{(1)}$$

$$\boxed{[\Delta x]^{(2)} = -[J^n]^{-1}[f^{(1)}]}$$

NR METHOD :

$$P_i = f_1(\delta_i\ |V_i|) \quad i = 1, 2 \ldots n$$

$$Q_i = f_2(\delta_i\ |V_i|) \quad i = 1, 2 \ldots n$$

$$\Delta P_i = \cancel{\left(\frac{\partial P_i}{\partial \delta_1}\right)\Delta\delta_1} + \left(\frac{\partial P_i}{\partial \delta_2}\right)\Delta\delta_2 + \cdots + \left(\frac{\partial P_i}{\partial(\delta_n)}\right)\Delta\delta_n$$

$$+ \cancel{\left(\frac{\partial P_i}{\partial |V_1|}\right)\Delta|V_1|} + \left(\frac{\partial P_i}{\partial |V_2|}\right)\Delta|V_2| + \cdots + \left(\frac{\partial P_i}{\partial |V_n|}\right)\Delta|V_n|$$

$$\Delta Q_i = \cancel{\left(\frac{\partial Q_i}{\partial \delta_1}\right)\Delta\delta_1} + \left(\frac{\partial Q_i}{\partial \delta_2}\right)\Delta\delta_2 + \cdots + \left(\frac{\partial Q_i}{\partial \delta_n}\right)\Delta\delta_n$$

$$+ \cancel{\left(\frac{\partial Q_i}{\partial |V_1|}\right)\Delta|V_1|} + \left(\frac{\partial Q_i}{\partial |V_2|}\right)\Delta|V_2| + \cdots + \left(\frac{\partial Q}{\partial |V_n|}\right)\Delta|V_n|$$

For slack buses δ_1 and V_1 are constant so the values like $\Delta\delta_1$ and ΔV_1 do not exist.

$$\underbrace{\begin{bmatrix} \Delta P_2 \\ \Delta P_3 \\ \hline \Delta Q_2 \\ \Delta Q_3 \end{bmatrix}}_{\text{Power mismatch matrix } [(2n-2)\times 1]} = \underbrace{\left[\begin{array}{cc|cc} \frac{\partial P_2}{\partial \delta_2} & \frac{\partial P_2}{\partial \delta_3} & \frac{\partial P_2}{\partial |V_2|} & \frac{\partial P_2}{\partial |V_3|} \\ \vdots & & \vdots & \\ \hline \frac{\partial Q_2}{\partial \delta_2} & \frac{\partial Q_2}{\partial \delta_3} & \frac{\partial Q_2}{\partial |V_2|} & \frac{\partial Q_2}{\partial |V_3|} \\ \frac{\partial Q_3}{\partial \delta_2} & \frac{\partial Q_3}{\partial \delta_3} & \frac{\partial Q_2}{\partial |V_2|} & \frac{\partial Q_3}{\partial |V_3|} \end{array}\right]}_{\text{Jacobian Matrix } [(2n-2)\times(2n-2)]} \cdot \underbrace{\begin{bmatrix} \Delta\delta_2 \\ \Delta\delta_3 \\ \hline \Delta|V_2| \\ \Delta|V_3| \end{bmatrix}}_{\text{Increment of Matrix } [(2n-2)\times 1]}$$

$$\boxed{\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \left[\begin{array}{c|c} H & N \\ \hline J & L \end{array}\right] \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix}}$$

condensed matrix

H, N, J, L $\longrightarrow$ submatrices of [J]

$$H = \frac{\partial P}{\partial \delta} \; ; \; N = \frac{\partial P}{\partial |V|} \; ; \; J = \frac{\partial Q}{\partial \delta} \; ; \; L = \frac{\partial Q}{\partial |V|}.$$

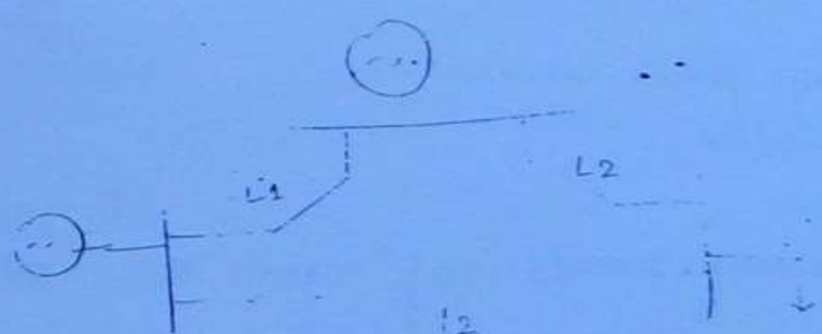
ex -

$$H_{22} = \frac{\partial P_2}{\partial \delta_2} \; ; \; H_{23} = \frac{\partial P_2}{\partial \delta_3} \; ; \; L_{32} = \frac{\partial Q_2}{\partial |V_2|}.$$

NR METHOD :-

case 1 : PV buses are ~~present~~ absent.

stage 1 : To find the bus quantity.



→ using line data form Ybus.

Bus data :-

Given : $V_1, \delta_1, P_2, Q_2, P_3, Q_3$

To find : $P_1, Q_1, V_2, \delta_2, V_3, \delta_3$

* Flat start :-

$$V_2^{(0)} = V_3^{(0)} = 1\ p.u$$

$$\delta_2^{(0)} = \delta_3^{(0)} = 0\ \text{radian}$$

* Step 1:

• calculate P and Q values for PQ buses.

$$P_2^{(0)} = |V_2|^0 |V_1| |Y_{21}| \cos(\delta_2^0 - \delta_1 + \gamma_{21})$$
$$+ |V_2|^0 |V_2|^0 |Y_{22}| \cos \gamma_{22}$$
$$+ |V_2|^0 |V_3|^0 |Y_{23}| \cos(\delta_2^0 - \delta_3^0 + \gamma_{23})$$

similarly calculate P_3^0, Q_2^0, and Q_3^0

* Step 2:

• calculate power mismatches

$\Delta P_2^0 = P_2^0 - P_2$ || fill up power mismatch matrix.

$$\Delta P_3^0 = P_3^0 - P_3$$

$$\Delta Q_2^0 = Q_2^0 - Q_2$$

$$\Delta Q_3^0 = Q_3^0 - Q_3$$

Step 3: Fill up $[J]^0$ elements

$$\left(\frac{\partial P_2}{\partial \delta_2}\right)^0 = H_{22}^0 = -|V_2|^0 |V_1| |Y_{21}| \sin(\delta_2^0 - \delta_1 + \gamma_{21})$$
$$- |V_2|^0 |V_3|^0 |Y_{23}| \sin(\delta_2^0 - \delta_3^0 + \gamma_{23})$$

$\left(\frac{\partial P_2}{\partial |V_3|}\right)^0 = Y_{23}^0 = |V_2|^0 |Y_{23}| \cos(\delta_2^0 - \delta_3^0 + \gamma_{23})$

Similarly all other elements can be found.

- After filling up the Jacobian elements and power mismatch elements the increments for delta and magnit. |V| can be ~~eo~~ obtained as

$$\begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix}^0 = \left[J^0\right]^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$$

Step 5:

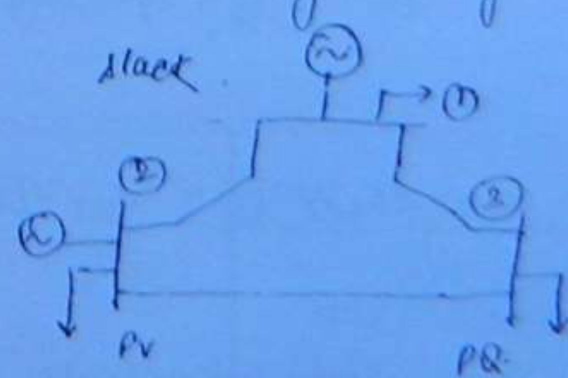
- Using the increments obta update and magnitude of V values.

Step 6:

The ~~ck~~ check for convergence, if convergence occur then calculate slack bus power P_1, Q_1 and go to stage 2 calculatn, if not repeat the process

Case 2: PV buses are present

Stage 1: To find bus quantities



$$\begin{bmatrix} \Delta P_2 \\ \Delta P_3 \\ \hline \Delta Q_3 \end{bmatrix} = \left[\begin{array}{cc|c} \frac{\partial P_2}{\partial \delta_2} & \frac{\partial P_2}{\partial \delta_3} & \frac{\partial P_2}{\partial |V_3|} \\ \frac{\partial P_3}{\partial P_2} & \frac{\partial P_3}{\partial \delta_3} & \frac{\partial P_3}{\partial |V_3|} \\ \frac{\partial Q_3}{\partial \delta_2} & \frac{\partial Q_2}{\partial \delta_3} & \frac{\partial Q_3}{\partial |V_3|} \end{array}\right] \begin{bmatrix} \Delta \delta_2 \\ \Delta \delta_3 \\ \Delta |V_3| \end{bmatrix}$$

Non-existing elements:

$J_{22}, J_{23}, L_{23}, L_{22}, N_{22}, N_{32}, L_{32}$

-- using line form Ybus

Bus data:

Given: $V_1, \delta_1, P_2, V_2, Q_{2min}, Q_{2max}, P_3, Q_3$

to find: $P_1, Q_1, Q_2, \delta_2, V_3, \delta_3$

Flat start:

$V_3^0 = 1.0$

$\delta_2^0 = \delta_3^0 = 0$ rad.

Step 1: check Q_2^0 for limits

Step 2: ~~that~~ calculate P and Q values for PQ buses and P values of PV buses

Step 3 calculate power mismatches ΔP_2°, ΔP_3° and ΔQ_3° and fill up the matrix.

Step 4 Evaluate Jacobian element and fill the matrix.

Step 5 Calculate increment for δ and $|V|$ as from.

$$\begin{bmatrix}\Delta\delta \\ \Delta|V|\end{bmatrix} \begin{matrix} = \cancel{[J^\circ]^{-1}} \\ = \cancel{[J^\circ]^{-1}}\end{matrix} \; [J^\circ]^{-1}\begin{bmatrix}\Delta P \\ \Delta Q\end{bmatrix}^0$$

Step 6: using the increments update δ and $|V|$ value

Step 7: Check for convergence, if occurs calculate slack bus power P_1, Q_1 and final value of Q_2 if not repeat the process.

Latif
10|Nov|20

= COMPARISION B/W NR AND GSM :-

Parameter of comparision	GS METHOD	NR METHOD
1 time for each iteration	LESS	MORE —
2. Complexity of iteratn.	Easy	very Difficult.

3. Type of convergence	Linear	Quadratic
4. Convergence rate	slow	fast.
5. Total no. of iteration	Increase with size of P.S	Independent of size of P.S
6. Gaurantee of Convergence ~~Acceleration~~	Not Gauranteed.	Gauranteed.
7. Acceleration	External	Internal.
8. Selection of slag bus on convergence	more dependent	less dependent
9. Suitability	for small size P.S	for large size P.S.
10. So Accuracy	less	Highest

DECOUPLED LOAD FLOW METHOD

NR Method

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & N \\ J & L \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix}$$

$$H = \frac{\partial P}{\partial \delta} \begin{matrix} 100 \\ 50 \\ 10 \end{matrix} \qquad N = \frac{\partial P}{\partial |V|} \begin{matrix} 0.1 \\ 0.1 \\ 0.001 \end{matrix}$$

$$J = \frac{\partial Q}{\partial \delta} \begin{matrix} 0.1 \\ -0.1 \\ 0.001 \end{matrix} \qquad L = \frac{\partial Q}{\partial |V|} \begin{matrix} 100 \\ 50 \\ 200 \end{matrix}$$

Decoupled LF Method

$$\boxed{\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \left[\begin{array}{c|c} H & 0 \\ \hline 0 & L \end{array}\right] \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix}}$$

$$\Delta P = H \cdot \Delta \delta$$

$$\Delta Q = L \cdot \Delta |V|$$

<u>Further assumption made</u> :- (<u>fast decoupled load flow method</u>)

1) Neglect resistance of Generator, T/F, Transmission lines etc.

$$Y_{Bus} = j\,[B] \rightarrow \text{Integer Matrix}$$

2) $\delta_i - \delta_k \simeq 0$ rad. [as the value of difference in radian is very small value.]

$$\boxed{\begin{aligned} H_{ii} &= L_{ii} \\ H_{ik} &= -L_{ik} \end{aligned}}$$

Advantages of Decoupled Load flow Method over NR Method:-

1) Instead of finding 100% of Jacobian element in NR method, in DCLF method we find 50% of J. element

2) Sparsity of Jacobian matrix is improved.

3) No. of calculations are reduced.

Advantages of FDCLF over DCLF Method:-

1) In contrast to 50% of Jacobian element in FDLF method we calculate only 25% of the J. elements.

2) By neglecting the resistance Ybus is stored as integer matrix.

3) Less memory space is required for storing J matrix.

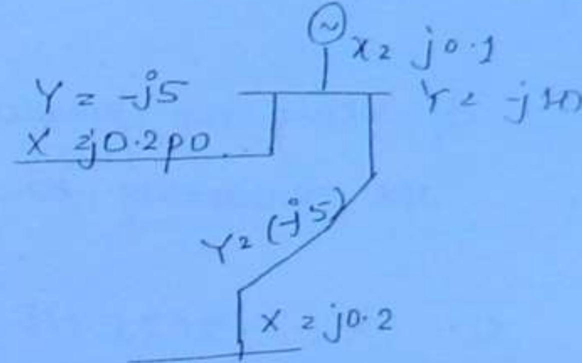
NOTES:

- For small size p/s or offline p/s GS method is used.
- For large size power s/m and for online applicatn ~~NR~~ FDLF is used.

• for evaluating sensitivity co-efficients NR methods is used.

WORK BOOK

1) Total admittance connected to bus 2



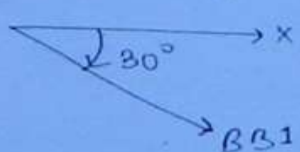
$Y_{22} = -j10 - j5 - j5$

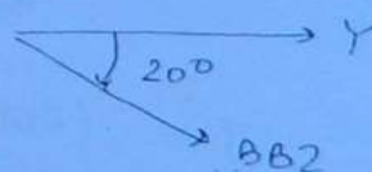
$Y_{22} = -j20$

2) d.

3). Active power transfer from BB1 to BB2 i.e zero if busbar voltage are in phase

Reactive power transfer from BB1 to BB2 is zero if busbar voltage magnitude V are same

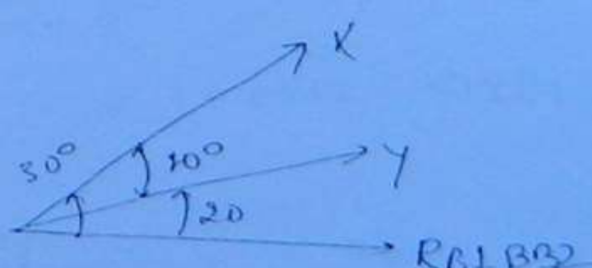




BB1 voltage lag voltage by 30°

BB2 voltage lag Y by 20°.

after either connection



A) Ans

4) $n = 300$; 20 buses → G/r buses

25 buses → reactive power

15 buses → Shunt capacities

240 buses → PQ buses

Size of Jacobian .

Solution: By taking one Generator bus as the slack bus the remaining no buses connected with $Q/r = 19$.

Let $x = 19 + 25 + 15 = 59$ PV buses.

Jacobian $(2 \times 300 - 2$

$600 - 2 - 59)$

$\Rightarrow 539 \times 539$ X

(i) Let 19 generator bus and 25 bus of reactive power support are taken as PV buses

$x = 19 + 25 = 44$

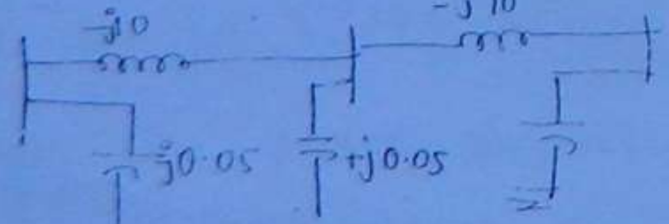
$J = (600 - 2 - 44)$

$\Rightarrow 554 \times 554$ d)

12) $2 \times 12 - 2 - 3 = 19 \times 19$

5) c

6)



$-j10 + j10 + j0.05$

$= 19.95j$

7) $Z = \begin{bmatrix} 0.9 & 0.2 \\ 0.2 & 0.6 \end{bmatrix}$

$0.54 - 0.04$

$$Y = \frac{1}{0.50} \begin{bmatrix} 0.6 & -0.2 \\ -0.2 & 0.9 \end{bmatrix}$$

$\Rightarrow Y_{22} = 1.8.$

8) $Z_{bus,(new)} = Z_{bus\,(old)} - \frac{1}{Z_{22}+Z_{b}} [2'$

$$\begin{bmatrix} & j0.3408 & j0.2586 \end{bmatrix} - \frac{1}{j0.3408 + j0.2} \begin{bmatrix} j0.2860 \\ j0.3408 \\ j0.2586 \\ j0.2414 \end{bmatrix} \begin{bmatrix} j0.2660 & j5408 \\ & j0.2581 \\ & j0.24 \end{bmatrix}$$

$$Z_{22}(new) = j0.3408 - \frac{1}{j0.5408} \times j0.3408 \times j0.3408$$

$= 0.1266$

$$Z_{33}(new) = j0.2586 - \frac{1}{j0.5408} \times j0.348 \times j0.2586$$

$= j0.0956$

9) b

13) C

14) Total no of zero element = 9000

Total no of non-zero elements = 1000

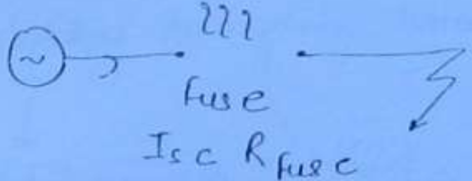
total no of non zero elements in the upper / lower triangle

$$= \frac{1000 - 100}{2} = 450.$$

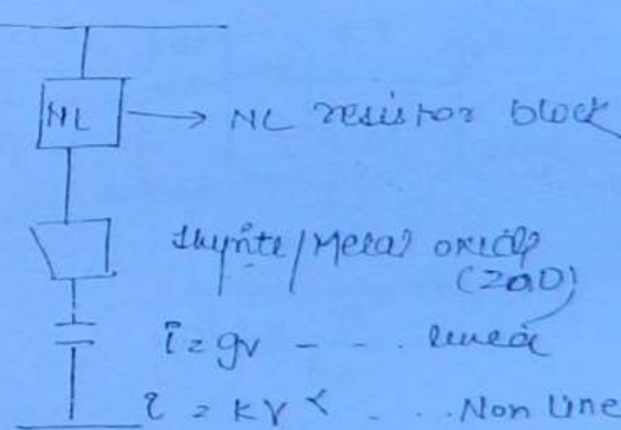
No of transmission line = 450.

SWITCH GEAR PROTECTION.

Circuit Breaker | Relays | Lighting Arresters (over voltage) | Fuse (over current)



Fuse



* Lighting arresters

* Every circuit breaker acts as the series switch

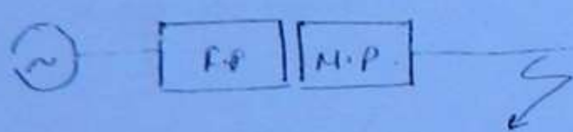
CIRCUIT BREAKERS

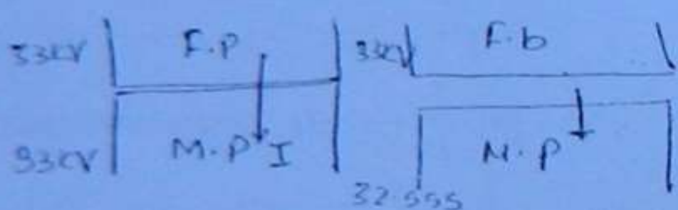
- The only difference arc and current is, if the flow of charges take place in conducting Material like Al, Cu, we call it as current.
- If same flow of charges take place in medium

we call it an 'arc'

- During the time of arching I^2 losses are very high and high heat is produced. This in-term produces light.

7. ARC INITIATION :-





$$\frac{\Delta V}{\Delta d} \text{ K.V./cm}$$

- Dielectric stress increases tremendously as distance is in micron

- In circuit breakers arc is initiated because of field emission process, at the instant when two poles are separating a high dielectric stress will occur because of negligible less distance b/w two contacts. This dielectric stress is much near higher than the dielectric strength of any dielectric medium. therefore ionisation begins / arc strikes. This process is known as field emission process

- In circuit breakers arc is maintained because of thermionic emission process.

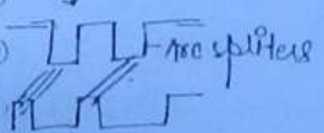
ARC INTERRUPTION:-

(methods)

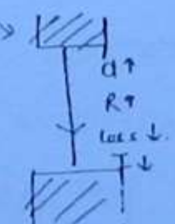
High resistance
(D/C Bus)

- Arc splitting
- Arc lengthening
- Forced blast

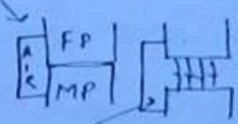
Low resistance.
Natural current zero
(A/c Bus)



* metal evaporates near arc



* size of C.B need to be big



* High pressures compressor are needed.

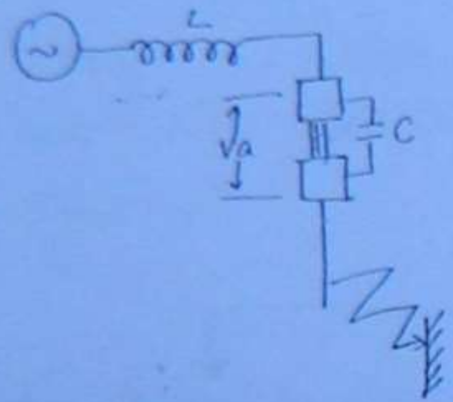
* low pressure is used.
* Here arc itself goes to zero

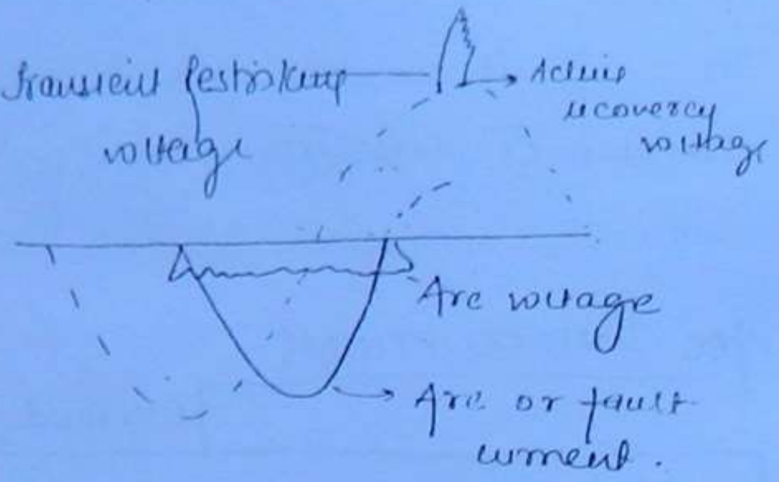
- In a/c CB arc interruptⁿ takes places ones after the arc passes natural current zero.

Date:
12 Nov 2019

ARC RESTRICKING

Consider a power s/m with negligible resistance



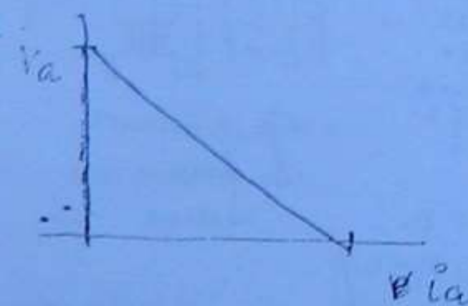


L → inductance of s/m upto fault resistance.

$V_a = i_a R_a$

(1) Arc has unity power factor*

2) characteristic of arc



Arc has negative resistance characteristic

- During the time of arching the voltage across the breaker poles is the arc voltage which is generally a small value due to short circuit condition.

- At the instant when the arc passes its natural current zero arc is interrupted. At this point of time some heat is present in gap.

- the system response is oscillatory coz a capacitance is appearing a across the breaker poles due to open circuit condition.

- the arc may restrike or not will depend on behavior of restriking voltage. the behaviour of restriking voltage depends upon L and C. the values of L and C are such that restriking voltage is raising rapidly this means in this short time the heat in gap cannot be removed and contact can not be cooled. therefore all the conditions in the gap helping restriking voltage to make arc restrike again; In other way the values of L and C are such the restriking voltage is raising slowly this means ample of time is available to remove the heat and to cool the contacts therefore no condition are helping the restriking voltage to make arc restrike again. Hence final arc interruption takes place.

Transient Restriking voltage (V_r):-

The transient voltage that appears across breaker pole at instant of arc interruption is known as transient restriking voltage

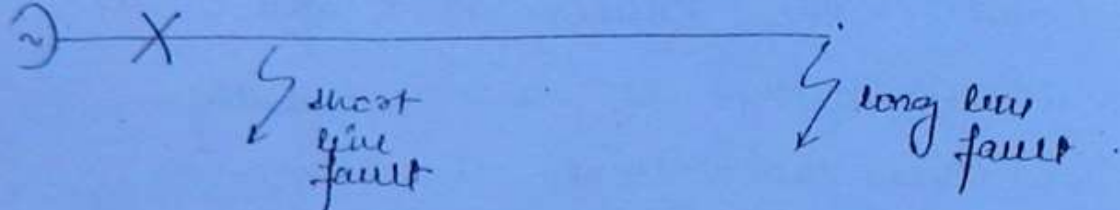
$$\boxed{V_r = V_{max}\left[1 - \cos\frac{t}{\sqrt{LC}}\right]}$$

$V_{max} \rightarrow$ supply peak voltage.

$t \rightarrow$ time instance

$L, C \rightarrow$ line inductance and capacitance.

<u>xample</u>



Short line fault: L and $C \downarrow \frac{t}{\sqrt{LC}} \uparrow \cos\frac{t}{\sqrt{LC}} \downarrow 1 - \frac{\cos t}{\sqrt{LC}} \uparrow V_r \uparrow$

Long line fault: L and $C \uparrow \frac{t}{\sqrt{LC}} \downarrow \cos\frac{t}{\sqrt{CL}} \uparrow 1 - \frac{\cos t}{\sqrt{LC}} \downarrow V_r \downarrow$

In view of restriking voltage a short line fault is more sever compare to long line fault

<u>Rate of Rise of Restriking voltage</u> :- [RRRV]

For restriking free operation of CB RRRV should be less

$$RRRV = \frac{dV_r}{dt}$$

$$\boxed{RRRV = \frac{V_m}{\sqrt{LC}} \sin\left(t/\sqrt{LC}\right)} \quad KV/\mu sec$$

$$\boxed{\text{Maximum RRRV} = \frac{V_m}{\sqrt{2c}}\ \text{kv}/\mu\text{sec}}$$

- Natural frequency of oscillation $f = \frac{1}{2\pi\sqrt{LC}}$

- Average RRRV = (Max value of restriking voltage) / time taken to reach the value

$$\boxed{\text{Average RRRV} = \frac{2V_{max}}{\pi\sqrt{LC}}\ \text{kv}/\mu\text{sec}}$$

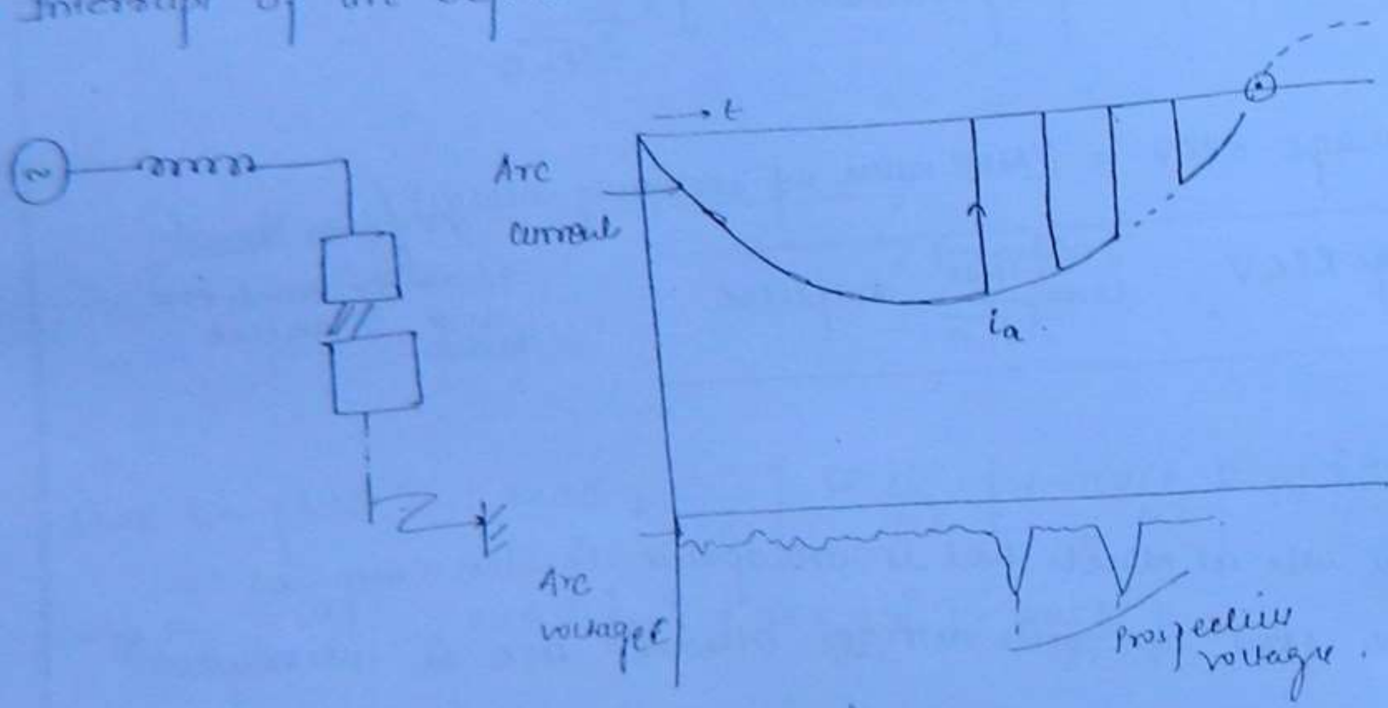
objective:
If the rate at which heat is dissipated is less compared to RRRV then arc will restrikes otherwise arc is interrupted

Active Recovery Voltage :
The instantaneous voltage that appear across breaker force after final arc interruption is known as active recovery voltage

Recovery voltage :
The rms voltage that appear across breaker for after final arc interruption is known as recovery voltage.

CURRENT CHOPPING PHENOMENON

- "Interrupt" of arc before natural current zero."



i_a = Instantaneous current i.e interrupted

energy stored by inductance $V^2 = \frac{1}{2} L i_a^2$

- Energy balance equation

$$\frac{1}{2} C V^2 = \frac{1}{2} L i_a^2$$

$$\boxed{V = i_a \sqrt{\frac{L}{C}}}$$ - prospective voltage.

- As the strength of deionising force is so high and severity of fault current is so so less arc will be interrupted well be bef before it passes to natural current zero.

the energy stored in the inductance will start converting into electro-static energy by the capacitor. when the capacitor is charging the voltage across breaker poles as well as dielectric stress starts increasing. At particular value of dielectric stress. arc will restrike again. As the de-ionising force is still ongoing the arc will interrupt again. this process repeats until arc passes natural zero.

Disadvantage:-

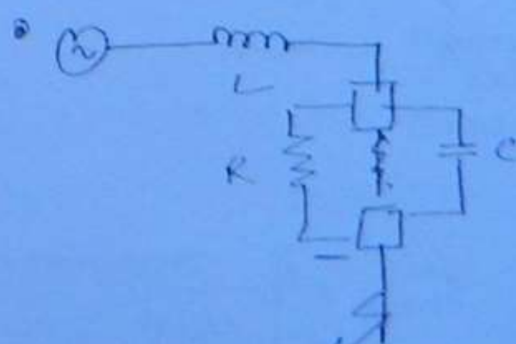
Transient off voltage known as switching overvoltage s/w will appear.

* the installation requirement for EHV lines is designed based on switching over voltages.

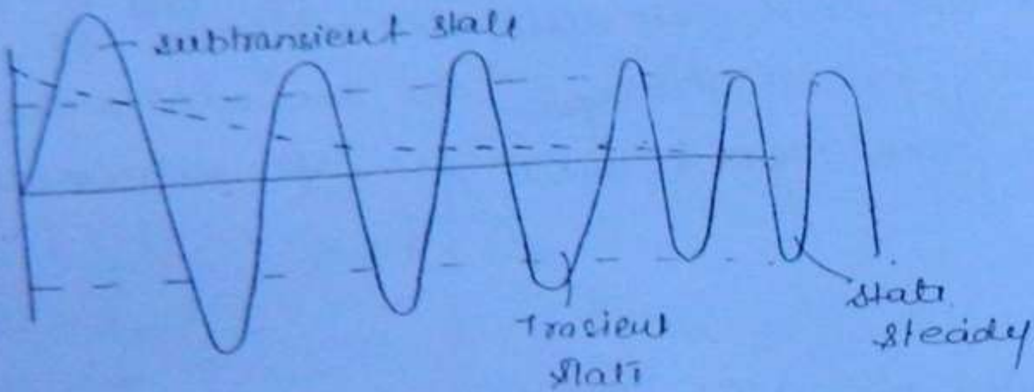
RESISTANCE SWITCHING OF CIRCUIT Breaker

* Resistance switching is employed in ckt breaker to avoid C C phenomena.

* $\boxed{R = 0.5\sqrt{\frac{L}{C}}}$



CIRCUIT BREAKER RATING



- Subtransient current → Breaking current

A CB can make the circuit during subtransient state or brake the circuit during transient or steady state.

CB Rating

- Breaking capacity
  - KV
    - Symmetrical
    - Asymmetrical
  - MVA
- Making capacity
  - KA
  - MVA
- Short time rating (Rated breaking capacity for specified duration)

$I_{break} = \frac{y}{\sqrt{2}}$

$I_{break} = \sqrt{x^2 + \left(\frac{y}{\sqrt{2}}\right)^2}$

$$\boxed{\text{Making Capacity} = 2.55 \times \text{Breaking Capacity}}$$

Numerical:

A 33KV 3300MVA, 1500A, 3sec, 50Hz 1-ϕ Oil CB has

1) Rate normal current = 1500 A
2) Rate breaking capacity 3300MVA
3) Rated breaking capacity in KA = 3300/33 = 100KA
4) Rated making capacity in KA = 2.55 x 100 KA = 255KA
5) Short time rating = 3300MVA for 3sec or 6600MVA for 1.5 sec

Classification based on dielectric:-

- Oil Circuit Breaker
  - Oil less
    - Air blast CB [ABCBs]
    - Sulphur Hexafloride [SF$_6$CBs]
    - Vacuum [VCBs]
  - Oil type
    - Minimum Oil (MOCB)
    - Bulk Oil CB [BOCB]

- current chopping phenomenon is more severe in case of abca ABCBs

- Resistance switching is mainly employed in ABCBs.
- Resistance switching reduces the severity RRRV.
- Air pressure in AB CB's is maintained around $30 kg/cm^2$
- ABCB's are more suitable for high speed and repeated operatn.
- ABCB's are more suitable for EHV and UHV applicatn [400kV range].
- Both arc energy and arcing time are least in case of ABCB's
- SF_6 gas is 3 to 5 time better than air due to its electronegativity properties. Electronegativity means affinity of electrons
-

$$SF_6 + \bar{e} \rightarrow SF_5^- + F$$

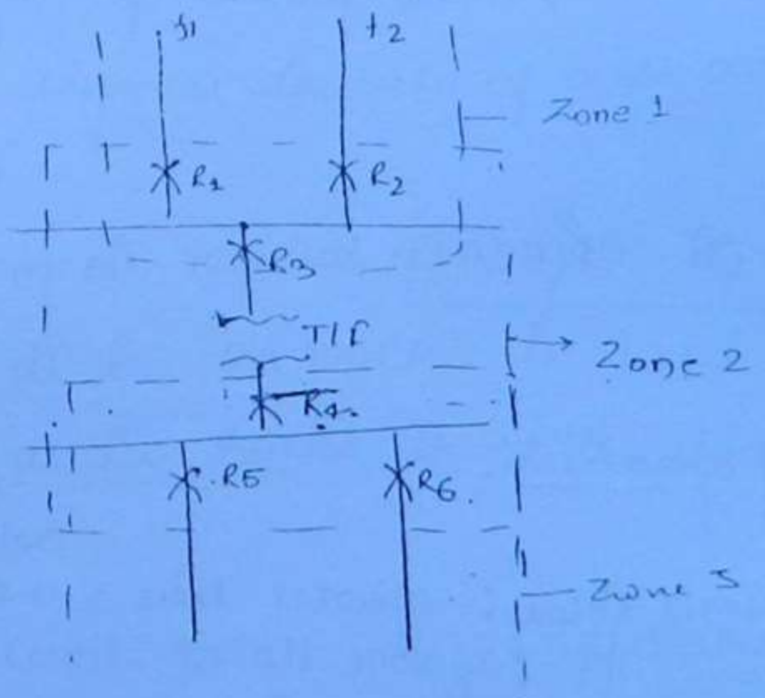
- Because of its low molecular weight SF_6 gas has excellent thermal conducting properties
- SF_6 CB's are very popular and they are available from 11 KV to 220 KV.
- SF_6 gas is maintained at $14 Kg/cm^2$ below this pressure it is in powder form form. Hence heaters may be used.
- For interrupting low inductive or low capacitive current without resistance switching the CB employed is SF_6 CB's
- Transformer oil in OCB's has two application

FUNCTIONAL CHARACTERISTICS:-

1) Sensitivity:

Relay is able to produce sufficient operating torque to close the trip ckt even for small change in operating quantity

2. Selectivity (zone of protection)



- the simultaneous operation of Relay 1, 2, 3, fault occur at BB:

(3) Speed:-

↳ clear the fault in time < 5 cycles time

$5 \times 0.02 sec = 0.1 sec.$

[redacted]

④ Simplicity:-

→ Design of the relay must be simple

⑤ Cost:-

20% of the cost of the equipment can be spend on protectⁿ.

⑥ Reliability:-

:- when fault occurs Relay should operate

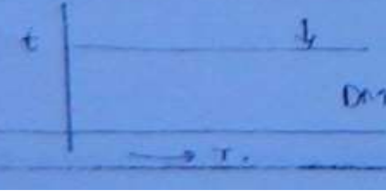
TYPE OF RELAY

1) Based on type of operation:-

a) Instantaneous Relay:- operates time ≤ 0.1 sec

used for generator protection
made up of Balanced beam and induction cup.

b) Definite Minimum time: time is constant



1) It acts as dielectric medium [dielectric strength of T/r 50KV,
,, ,, ,, air 30Kg
mark

2) At 658° K xmer oil decomposes and produces various gases, out of these gases & 70% of gas is Hydrogen which act like coolant.

- In oil CB the strength of ~~die~~ deionising force shall adjust in accordance to severity of fault current. Therefore current chopping phenomenon is least in this case.
- The chance for arc interruption in subsequent natural current zero improves in case of OCB's but reduces in other types
- The volume of oil required for MOCB's is only 10% of BOCB's as oil in BO MOCB's is used for arc interru only where as in BOCB's it ~~is~~ is used for insulating live parts also.
- OCB's are used for all voltage applications from 11 KV to ~~130~~ 132KV.
- The vaccum pressure in VCB's is maintained around 10^{-8} to 10^{-6} Torr

$$1 \text{ Torr} = 1 \text{mmHg}$$

- The principal of arc interruptn in VCB's is condensificatn of arc products like copper vapours etc.

maintanance is least in case of VCB's

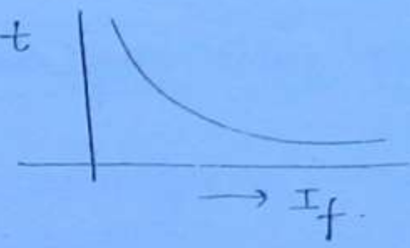
VCB's are suitable for remote and rural electrification

for interrupting high current and low voltage (11KV range) VCB's are used

AUTO-RECLOSING FEATURES

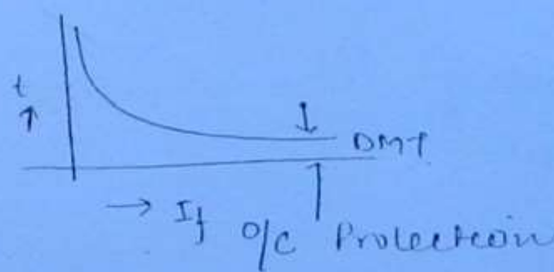
used for over current protectn of Induction Motor.

c) Inverse Relays :-

#. 

#. generally not used.

d) IDMT relay : [combination of Inverse and DMT relay]



Commercially used.
Over current relay.

2) Based on the construction / operating principal :-

a) Electromagnetic attraction type :-

Balanced beam [differential protection]
Attracted armature
Moving plunger

b) Electromagnetic Induction Type.

Shaded pole
Wattmeter [o/c protection]
Induction Cup : fastest relay [distance relay].

c) Gas protected Type :-

Buchholz relay [used for protecting oil immersed xmer from internal / incipient faults]

d) Thermal Relays :-

Overload protection.

e) Static / Microprocessor base relays.

Not widely used as need much precaution.

OVER CURRENT PROTECTION

Definition :-

) PICK-UP VALUE :- It is the minimum value of operating quantity at which relay is 'WEDGE' of operation of

② RESET VALUE:- It is a maximum value of operating quantity at which relay is at the wedge of non-operation.

$$\boxed{\text{wedge condition} \Rightarrow \text{operation force} = \text{Restraining force}}$$

- Reset and Pick values are different because of hysteresis error
- For well-designed relays ratio of Reset to pick up value is unity. Howere for induction type relay it is 0.9

③ TIME MULTIPLIER SETTING:-

$$\text{TMS required} = \frac{\text{Time of operation required}}{t_{TMS=1}} \left[\frac{t_{required}}{t_{TMS=1}}\right]$$

Example:

1) A relay operates in 5 sec when TSM = 1, to operate relay in 2 sec TMS should be adjusted to.

$$\text{Tms required} = \frac{2}{5} = 0.4 \text{ sec}$$

2) A relays operates in 4 sec when TSM = 1. to operate relay in 1.98 sec, TMS should be adjusted to

$$\text{Tms} = \frac{1.98}{4} = 0.495 \approx 0.5 \text{ sec}$$

= time taken by relay = 0.5 × 4 = 2 sec

Relay takes more time to react: delay of 0.02 sec

so take value as = 0.4 sec.

NOTE:--
TMS should always be rounded to nearest lower values always

$$\boxed{\frac{TMS_2}{TMS_1} = \frac{t_2}{t_1}}$$

) A relay operate in 3 sec when TMS = 0.7 when A TMS is adjusted to 0.2, the relay operate in —— sec

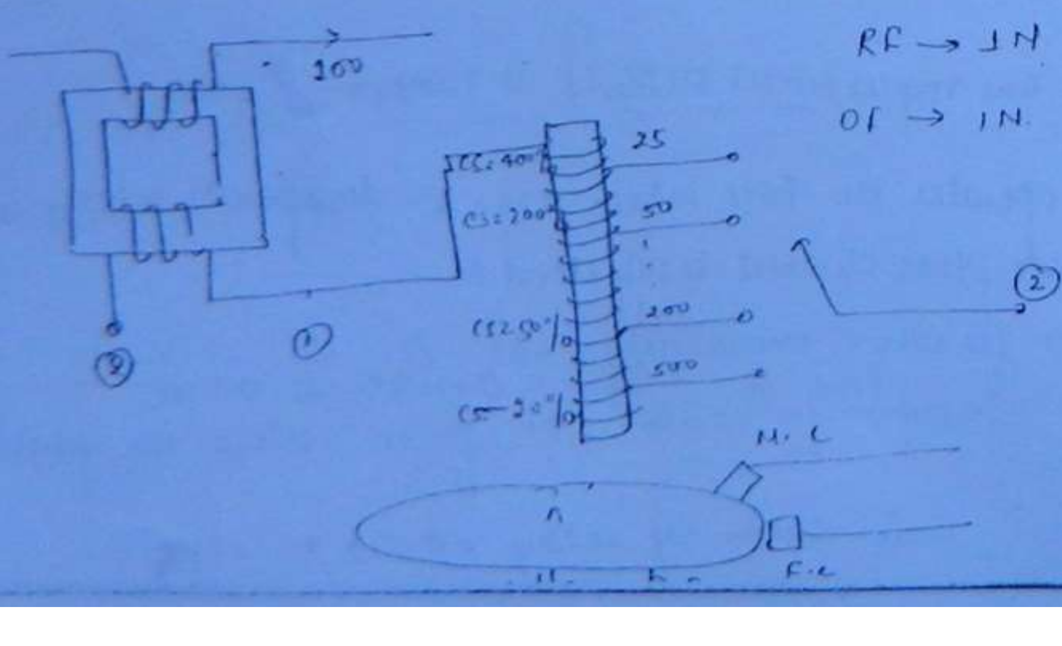
Solutn.

$$\frac{0.2}{0.7} = \frac{t_2}{3}$$

$$0.6/0.7 = t_2$$

$$t_2 = 0.857 \text{ sec}$$

3) PLUG SETTING MULTIPLIER:(PSM).



• Relay normal current

= CT sec rated current = 5A

• Relay operating current = 20A

= 4×5

Relay operating current = current setting × CT secondary rated current
Relayed operating current = Current setting × CT secondary rated current × CT ratio

↳ related to CT primaries.

$PSM = \dfrac{\text{Fault current}}{\text{Current setting} \times \text{CT secondary rated current} \times \text{CT ratio}}$

Example:

1) Current setting = 40%, fault current 2000A, CT = $\frac{100}{5}$, the PSM

$$PSM = \frac{2000}{\frac{40}{100} \times \cancel{8}\ \frac{100}{5} \times 5 \times} = 50$$

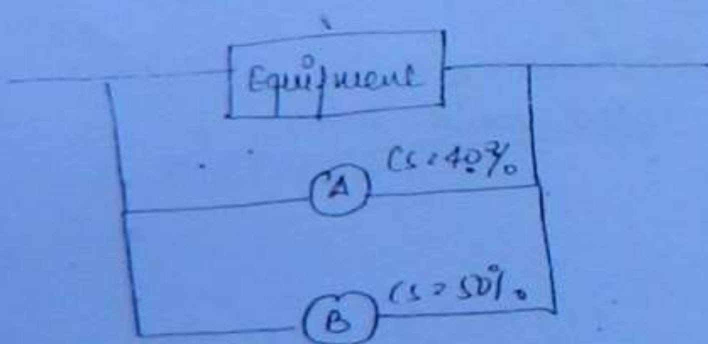
• PSM increases with fault current

- Higher the fault current lower is time of operation.

$$\boxed{\begin{array}{l} \cdot\ PSM\uparrow\ I_f\uparrow \\ \cdot\ I_f\uparrow\ PSM\uparrow\ t\downarrow \\ \cdot\ PSM\uparrow\ t\downarrow \end{array}}$$

- Higher the PSM higher the speed of disc.

- If $PSM < 1 \rightarrow$ will not operate
  $PSM = 1 \rightarrow$ wedge of operation
  $PSM > 1 \rightarrow$ Relay operates.



as # $PSM_A > PSM_B$

relay A acts like Primary relay.

As $\boxed{PSM \propto \dfrac{1}{CS}}$

NOTE :-

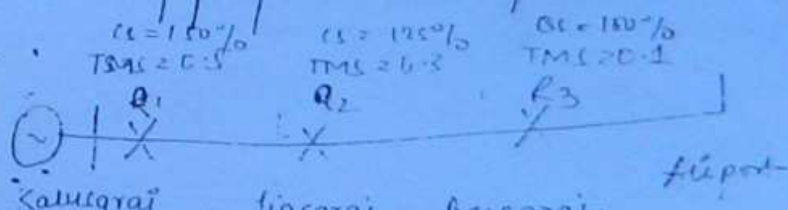
- The TMS for primary relay is less than back up relay

- Current setting for Primary and Back up relay is generally same.

- Except the protecting equipment there should not be anything common b/w primary and back-up relays.

OVER CURRENT RADIAL FEEDER PROTECTION

- The feature required in O/C radial feeder protection is if fault occurs at the far end from the supply we should clear the fault there itself, this leaves minimum no. of customers are given interruption and majority of customers are continued to be given need supply. This improves reliability of radial feeder.



- Methods used:

a) Time graded Method:

According to this method for the relay farthest from the source minimum TMS is set. As we are approaching towards the source the TMS is gradually increased.

- Disadvantage:

The disadvantage of this method is if the fault occur near the source the magnitude of fault current is very high. This high magnitude fault current is cleared in more time

b) current graded method:-

According to this method for the relay farthest from the source minimum current setting is set, as we are approaching towards the source the over current setting is gradually increased.

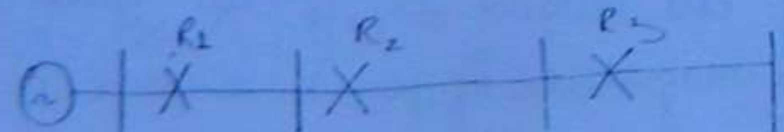
- The **disadvantage** is as we have only four over current setting viz 125, 150, 175 and 200%. we can make the rat radial feeder section. However by adopting time current graded method we can make the radial feeder into more no. of section of improve the reliability further.

c) Time-current graded method:-

According to this method for the relay farthest from the source minimum PMS and CS are set as we are approaching towards the source these setting are gradually increased.

Example:-

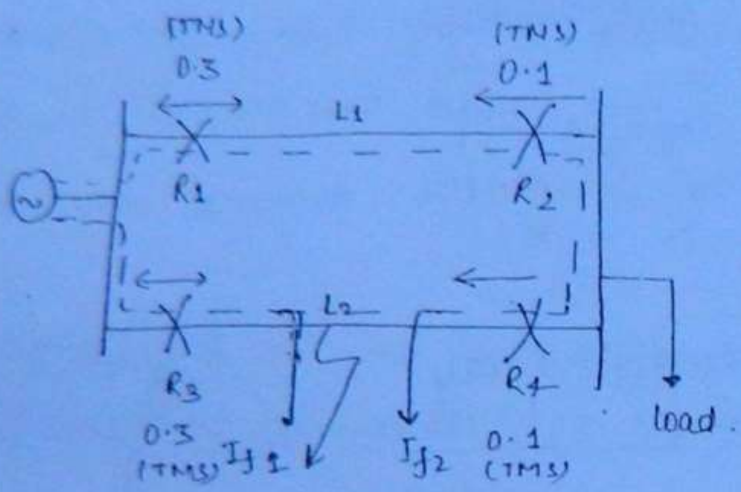
The CS and TMS for relay zone



CS = 200% CS = 125%

TMS = 0.5 TMS = 0.3

PROTECTION OF PARALLEL LINES



I_{f1} : R_3

directional relay

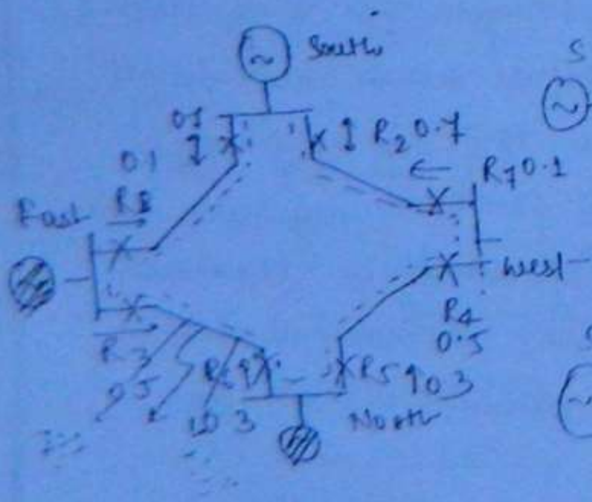
I_{f2} : R_1, R_2, $R_4 \rightarrow 0.1$

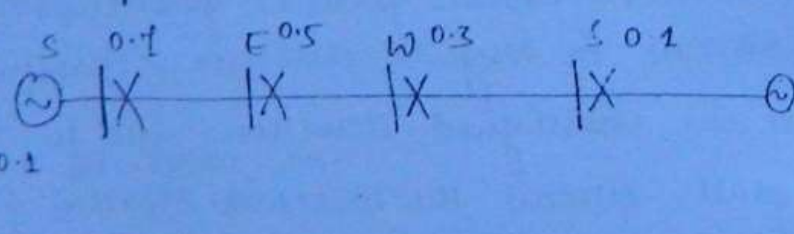
0.3

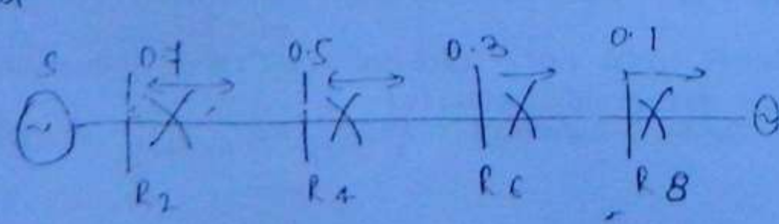
(R_4 operate first.

O/C PROTECTION OF RING MAIN FEEDER.

= While providing over current protection for ring main feeder it is treated as two radial feeders.





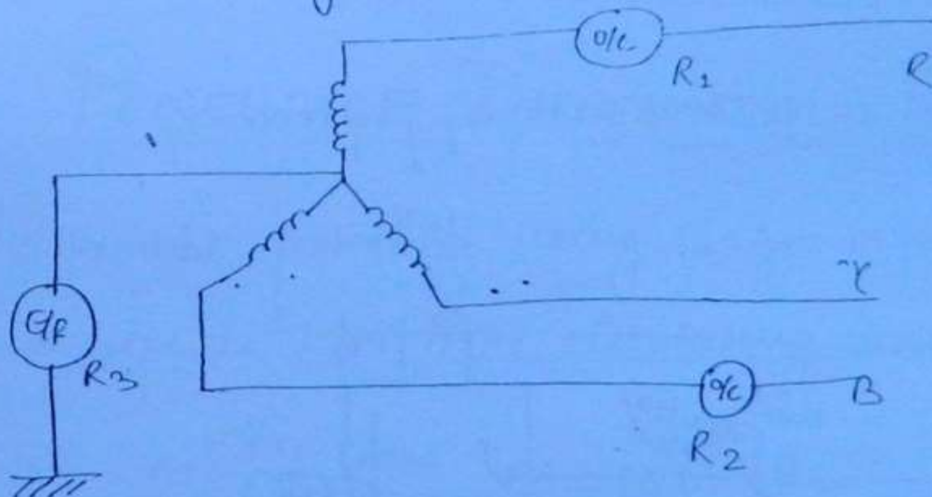


I_{f1}: R_1 R_8 $R_3 \xrightarrow{\text{direc}} R_3$ [operate]
$\downarrow$ 0.7 $\quad \downarrow$ 0.5

I_{f2}: R_2 R_7 R_4 R_5 $R_6 \rightarrow R_6$ (operates
$\downarrow$ 0.7

OVERCURRENT PROTECTION OF G/r

For complete over current protectn of generator two we need. two overcurrent relay and one earth fault relay.



$R_1, R_2 \rightarrow$ phase f/t relay

$R_3 \rightarrow$ Earth fault Relay

- The R_3 is known as earth fault relay since it can detect only earth ~~fott~~ fault, in ~~edit~~ addition to earth fault this relay also ~~+~~ detects unbalanced condition therefore setting for this relay well of minimum like 20% - 40% etc

3ϕ faults $\longrightarrow$ R_1 and R_2 operates

LLG $\quad$ R-Y $\rightarrow$ R_1, R_3
$\quad$ Y-B $\longrightarrow$ R_2, R_3
$\quad$ R-B $\longrightarrow$ R_1, R_2, R_3

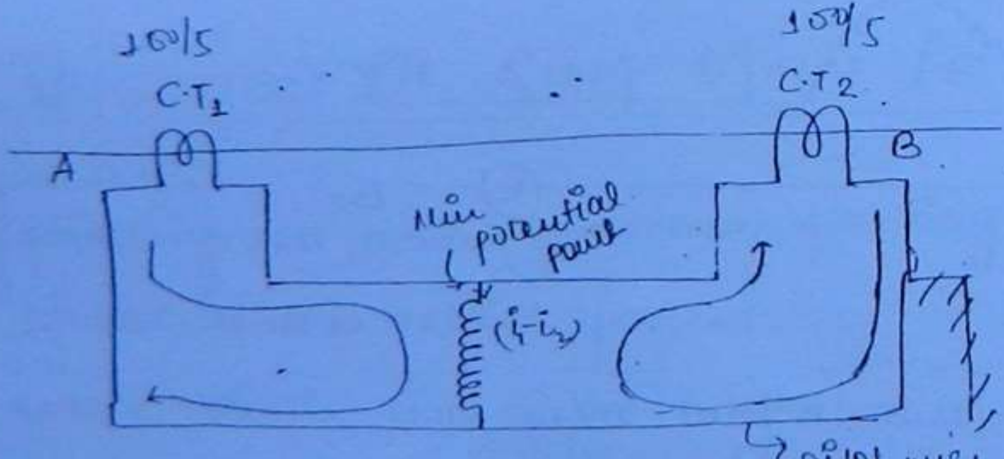
LL
- R-Y → R_1
- Y-B → R_2
- R-B → R_1, R_2

[redacted]
- R → $R_1 R_3$
- Y → R_3
- B → R_2, R_3

unbalanced condition → R_3

DIFFERENTIAL PROTECTION

→ Main application is to have zone of protection



→ A differential relay operates well when the difference of two same electrical quantities [$i_1 - i_2$ or $V_1 - V_2$ but not $P_1 - P_2$] exceed the set of assigned value.

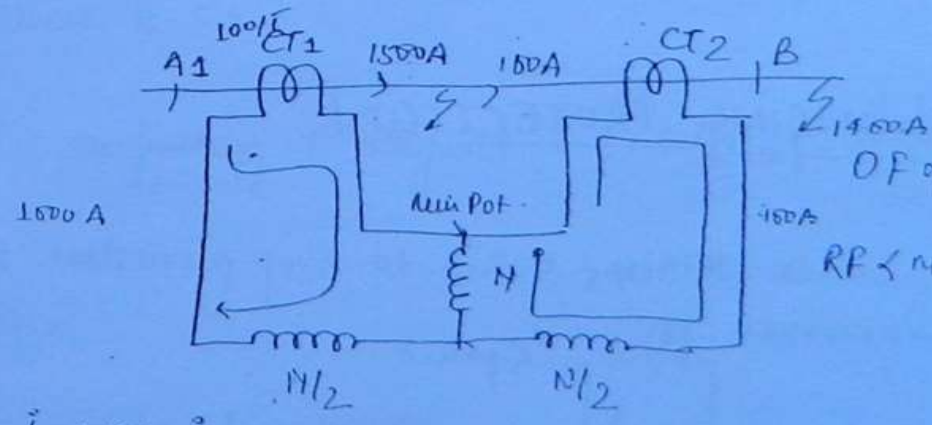
→ this relay operates only for internal fault and provide zone of protection. it cannot operate for external or through fault condition.

→ A differential protection comparing voltage is known as Translay Protect?.

→ A differential relay may "mal operate" either due to unequal saturation level of two CTs or due to CT error. to avoid this mal operation ordinary differential relay is modified to percentage differential relay

PERCENTAGE DIFFERENTIAL RELAY

→ A differential protection using %age differential relay is known as Merz Price circulating current Method.



$OF \propto MMF \propto (i_1 - i_2) N$

$RF \propto MMF \propto i_1 \frac{N}{2} + i_2 \frac{N}{2}$

$\propto \left[\frac{i_1 + i_2}{2}\right] N$

$i_1 = 50;\ i_2 = 45$

$OF \propto (i_1 - i_2) N$

$RF \propto \left(\frac{i_1 + i_2}{2}\right) N$

$\propto 47.5 N$

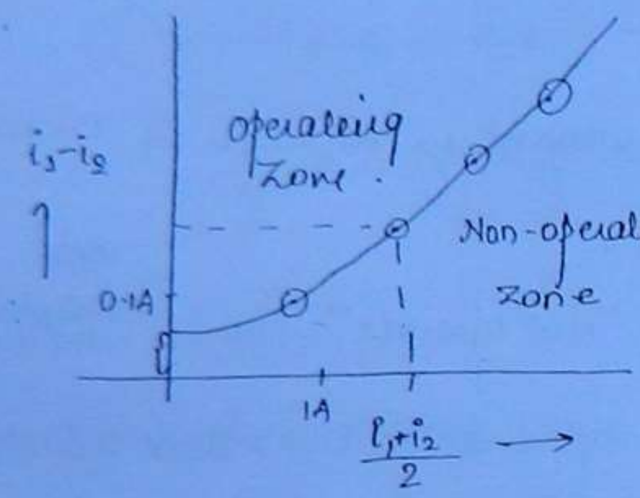
$i_1 = 50,\ i_2 = 5$

$OF \propto (50 - 5) N$

$\propto (45)$

$RF \propto (50 + 5)/2 = 27.5 N$

Characteristic:-

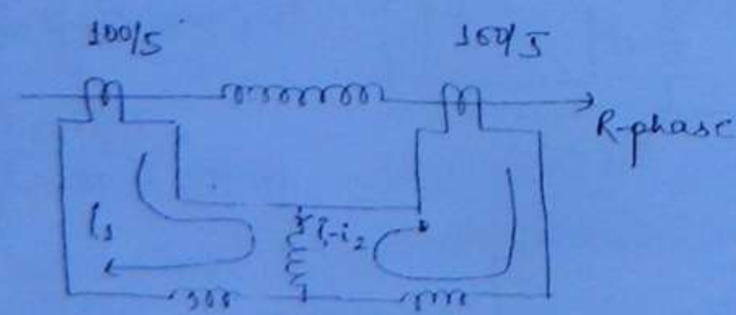


- The characteristic of differential relay starts above origin due to inertial problems.

$$\boxed{\% \text{ slope} = \frac{i_1 - i_2}{\left(\frac{i_1+i_2}{2}\right)} \times 100.}$$

10% slope, means operating force is 10% of restraining force the relay is on wedge of operation.

STATOR WINDING PROTECTION



Ques 1 : $CT, CT_2 \rightarrow 100/5$

$\%$ slope $= 10\%$

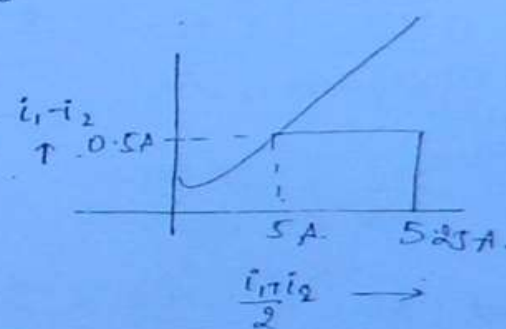
$I_f = 10A$.

1) for the fault of 10A, with % slop 10, will relay opera CB or not.

1) $I_1 = 110A \Rightarrow i_1 = 110 \times \frac{5}{100} = 5.5A$

$I_2 = 100A. \quad i_2 = 100 \times \frac{5}{100} = 5A$.

$O.C = i_1 - i_2 = 0.5A$.



from % slope $\frac{i_1 - i_2}{i_1 + i_2/2} = 0.1$

$\frac{i_1 + i_2}{2} = \frac{0.5}{0.1} = 5$

For an operating current of 0.5A, the restraining current at which current at which the relay is at the wedge operation is 5A.

Now ~~on further~~ R = Original R.C $= \frac{i_1 + i_2}{2} = \frac{5.5+5}{2} = 5.25A$

as restraining force at 5.25A > at 5A, the relay will not operate

Ques 2

$CT_1, CT_2 = 100/5$

$\%$ slope $= 5\%$

$I_f = 10A$.

Soln

$I_1 = 110A$

$i_1 = \frac{110 \times 5}{100} = 5.5A$

$I_2 \quad i_2 = \frac{100 \times 5}{100} = 5A$

$O.C = i_1 - i_2 = 0.5A$

$$\frac{i_1 - i_2}{(i_1 + i_2)/2} = 0.05$$

$$\Rightarrow \frac{0.5}{0.05} = \frac{i_1 + i_2}{2}$$

$$= \frac{.1}{.01} = 10 \text{ Ans.}$$

original $RC = \frac{i_1 + i_2}{2} = 5.25$

$5.25A < 10A$ so relay will operate

NOTE :-

the relay sensitivity is increasing with decreasing % slope

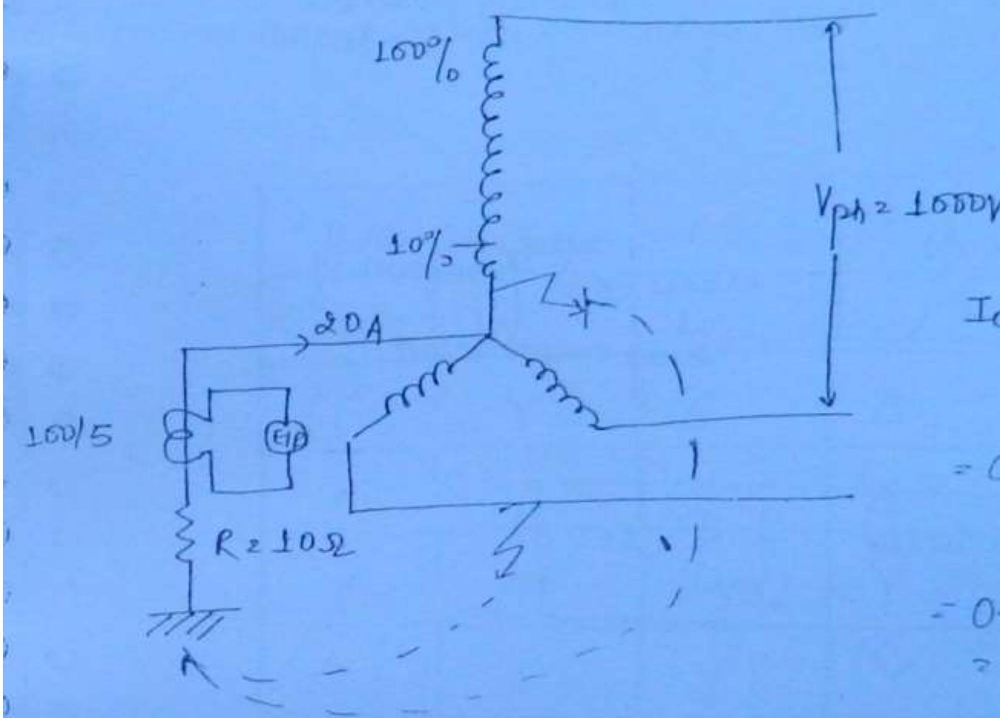
PERCENTAGE WINDING PROTECTED / UNPROTECTED

→ Out of 100% generator total 100% are star connected

→ 100
- → 85% LG
- → 5 LLG

] - 90%
- → 8 LL
- → 2.3?

→ At zero % winding 0% voltage induce and with 100% winding, 100% voltage is induced.



I_0 = Min picking current of relay

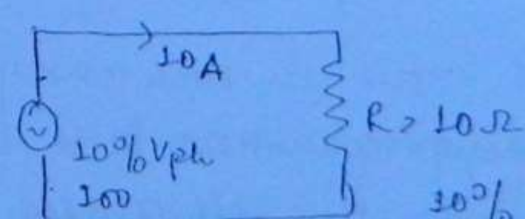
= C setting × CTs sec rated current × CT ratio

= 0.2 × 5 × 20

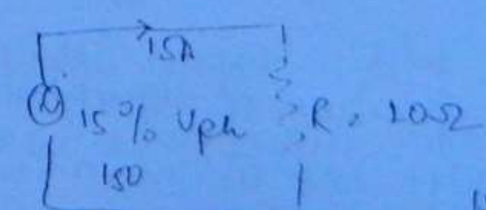
= 20A

→ to minimise most frequently occuring fault (earth), the neutral of g/r is grounded with resistance 'R'

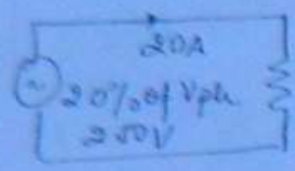
→ Generally for detecting unbalance current the current setting of earth fault relay is set to minimum say 20%



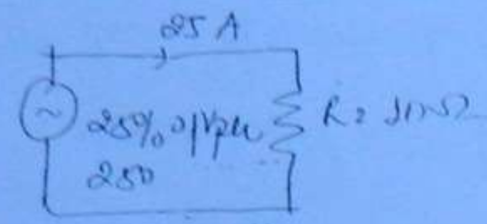
30% winding unprotected



15% winding unprotected



20% wdg unprotected



25% wdg protected

$$\boxed{I_0 = \frac{x V_{ph}}{R}}$$

where x is fraction of wdg unprotected.

$$\boxed{\%\text{ wdg of unprotected} = \frac{I_0 R}{V_{ph}} \times 100}$$

DIFFERENTIAL PROTECTION OF TRANSFORMER

→ Before providing differential protectn to power transfer, there are two ~~to~~ issues to resolve.

1) How to design CT ratio in such a way that under normal operating condition the current flowing through operating coil is zero

2) How to avoid mal operation of differential relay due to 30° phase shift b/w line currents of ~~Sta~~ star-delta and delta star power transformer.

1. To avoid the mal operation of differential relay due to 30° ratio between line currents of star-delta, delta-star power xmer, the secondaries of the CT's must be connected as per following table.

Power Transformer		CT's secondary	
LV	HV	LV	HV
Y	Y	Δ	Δ
Δ	Y	Y	Δ
Y	Δ	Δ	Y
Δ	Δ	Y	Y

Numerical:

A 8MVA, 33/11kV, star Y-Δ power xmer is protected by Merz-price circulating current method. Design the CT's ratio for a nominal CT-secondary current of 5Amp

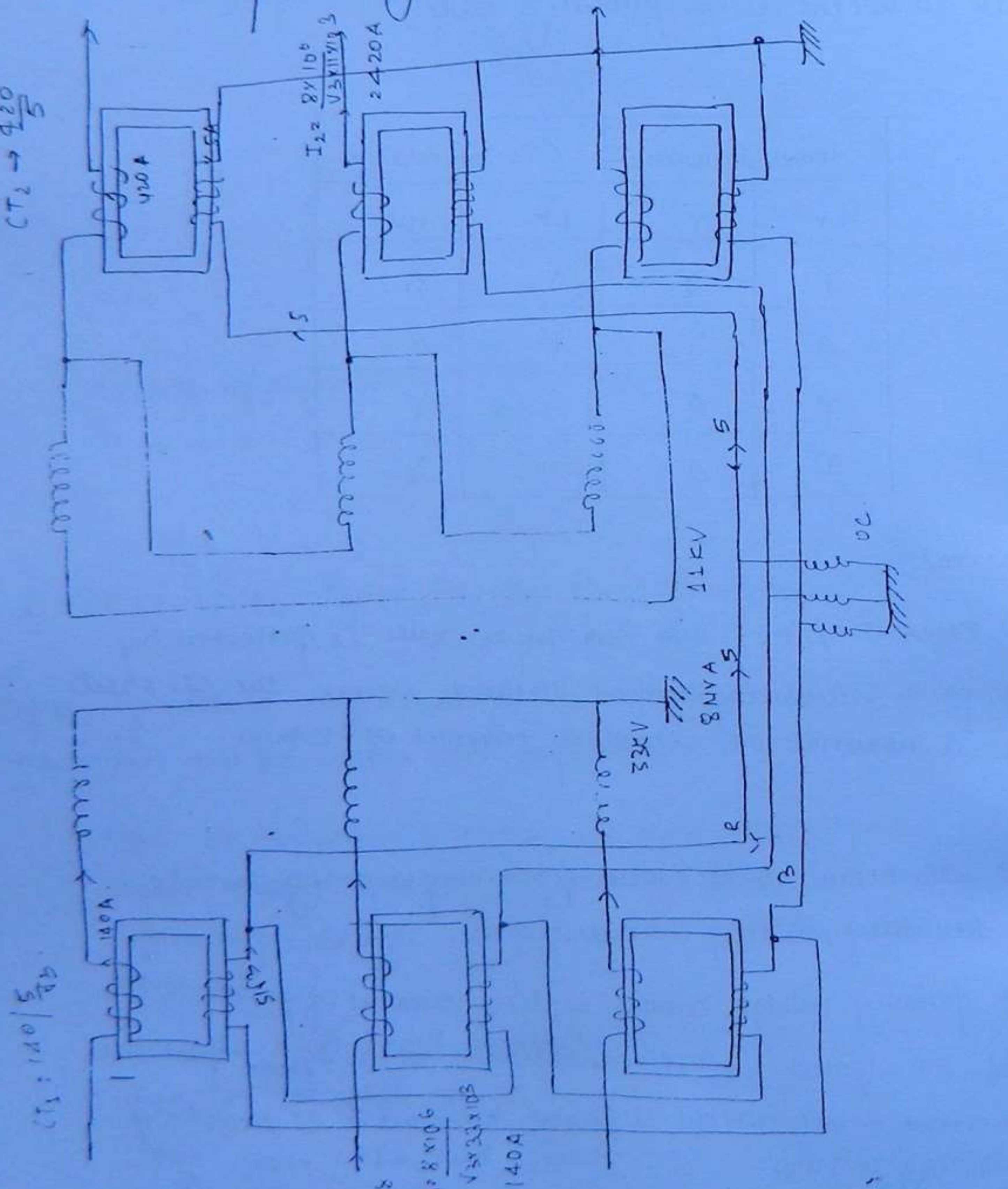
Sol:

1) CT ratio means it is a ratio of primary winding current to secondary winding current

2) CT primary windg current = line current of power xmer

3) If CT secondaries are connected in Y then pilot wire current = line current = phase current = CT secondary winding current.

4) If CT secondaries are connected in delta then pilot wire current is equal line current = √3 phase current = √3 secondary winding current



Distance Protection

→ Can not be used for xmer protectn.

→ Can be used for generator and transmission line protectn

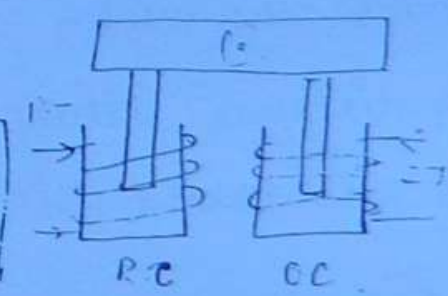
→ Main application is protectn of T.L

→ used as primary protection for long lines .

→ In this type of relay operating force is produced due CT secondary and restraining force is produced due to PT secondary.

→ Know as Double actuating quantity relay.

→ If induction type relay are used



$$\boxed{\begin{array}{l}\text{operating force} \propto I^2 \Rightarrow OF = K_1 I^2 \\ \text{Restraining force} \propto RF = K_2 V^2\end{array}}$$

→ Relay will operate when

$$RF < OF$$

$$K_2 V^2 < K_1 V^2$$

$$\frac{V^2}{I^2} < \frac{K_1}{K_2}$$

$$\boxed{\frac{V}{I} < \sqrt{\frac{K_1}{K_2}}}$$

→ The relay is operating when ratio of voltage to current seen by the relay is less than sense some - set or designed value., K_1, K_2 are designed constant.

This relay is known as Ratio relay. aswell as impedence relay. [∵ V/I = Impedence]

→ As impedence and distance are proportional quantities is relay is also known as distance relay.

→ REACH :- It is the distance at which a distance relay is at the wedge of operation.

→ A distance relay operate for all the faults occuring below the reach.

→ A distance relay has a problem of under reach or over reach due to dc offset current.

Dated
14 Nov 2010

DEFINITE DISTANCE, DEFINITE TIME DISTANCE PROTECTION

(3-zone of Protection)

1st ov disc — $Z < 8\Omega$

→ Instantaneously

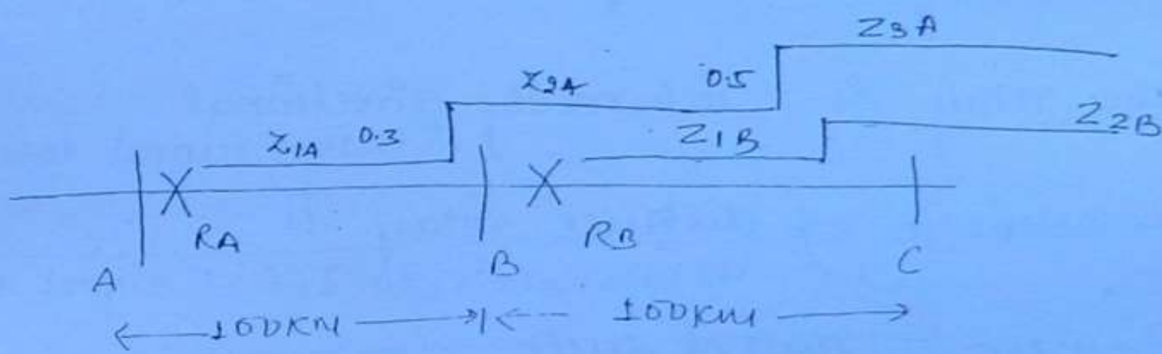
2nd disc — $Z < 15\Omega$ $t > 0.3sec$

• exclusively Z ~~buses~~ values at which exclusive 2nd disc alone operate at 8-15Ω.

• 3rd disc — $Z < 20\Omega$ $t = 0.05sec$

exclusive Z values at which 3rd disc alone operates 15-20Ω.

Example:



Relay - A has 3 zones

Z_{1A} : 80% distance of section

Z_{2A} : 20% remain distance of section AB + 50% distance of adjecent section BC

Z_{3A} : Remaining 50% distance of adjacent section BC

Comments:

1) Distance relay are 3 types

1) Impedence Relay
2) Reactance Relay
3) Admittance / Mho relay

2) An impedence relay is voltage restrained over current relay.

3) The ~~distance~~ reactance relay is directional restrained over current relay.

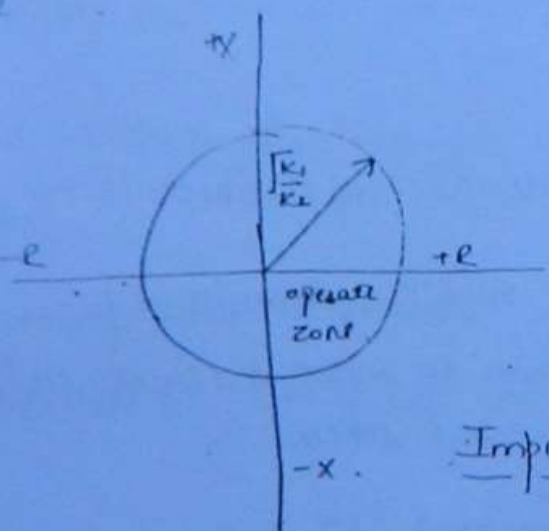
4) The MHO relay is voltage restrained directional relay

5) A MHO relay is inherently directional

→ The characteristic of distance relay is

$c^2 = a^2 + b^2$ — eqn of circle

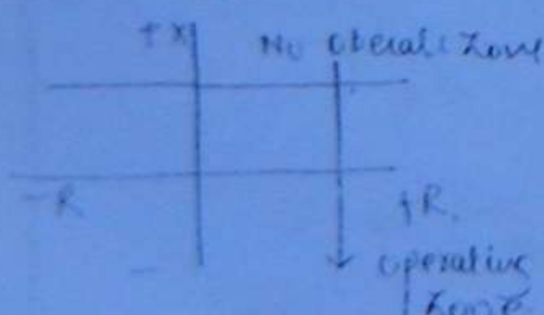
$Z^2 = R^2 + X^2$



A circle having origine as center

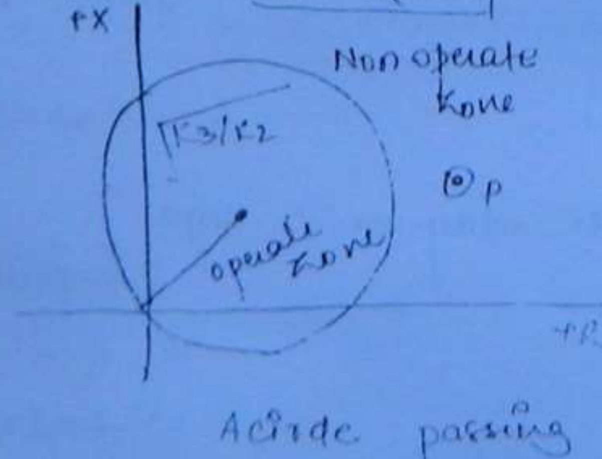
Impedence Relay

→ X-relay

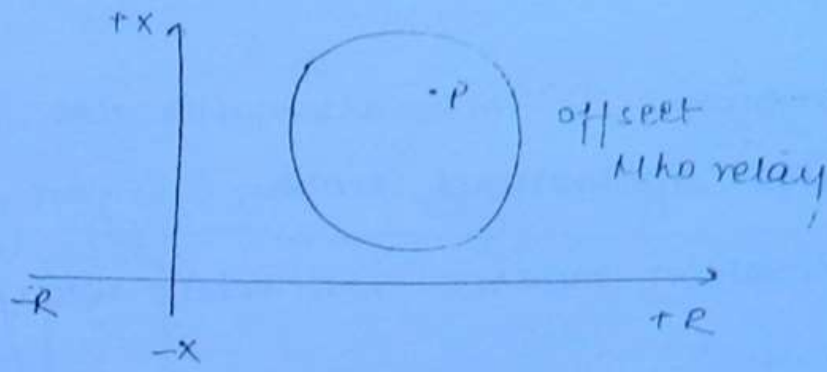


A straight line parallel to real axis

MHO Relay



A circle passing through origin



Universal torque equatⁿ:

$$\boxed{\text{Net torque } T = K_1I^2 + K_2V^2 + K_3VI\cos(\theta-\tau) + K_4}$$

- Overcurrent → $T = K_1I^2 - K_4$
- Overvoltage → $T = K_2V^2 - K_4$

7). For earth fault reactance relay are normally used.

8). For phase faults.

Short line → X-relay
Medium line → Z-relay
Long line → Mho relay

9). Where the power swings are high Mho relay is used.

10) For over load protectⁿ of G/r thermal relays are used

11) For severe unbalance condition of alternator negative.

sequence relay is used ~~as~~

2) when prime mover/turbine is lost alternator acts like ~~induction~~ generator. synchronous motor.

for this problem direction reverse wattmetric relay is relay is used.

3). when the excitation is lost alternator acts as ~~synchronous~~ motor induction G/r. for this problem offset mho relay is used.

4) for ~~in-tur~~ inter-turn fault differential ~~fault~~ protection can not be used. for this problem split-phase relay is used.

5). for stator winding protectn differential protectn is used.

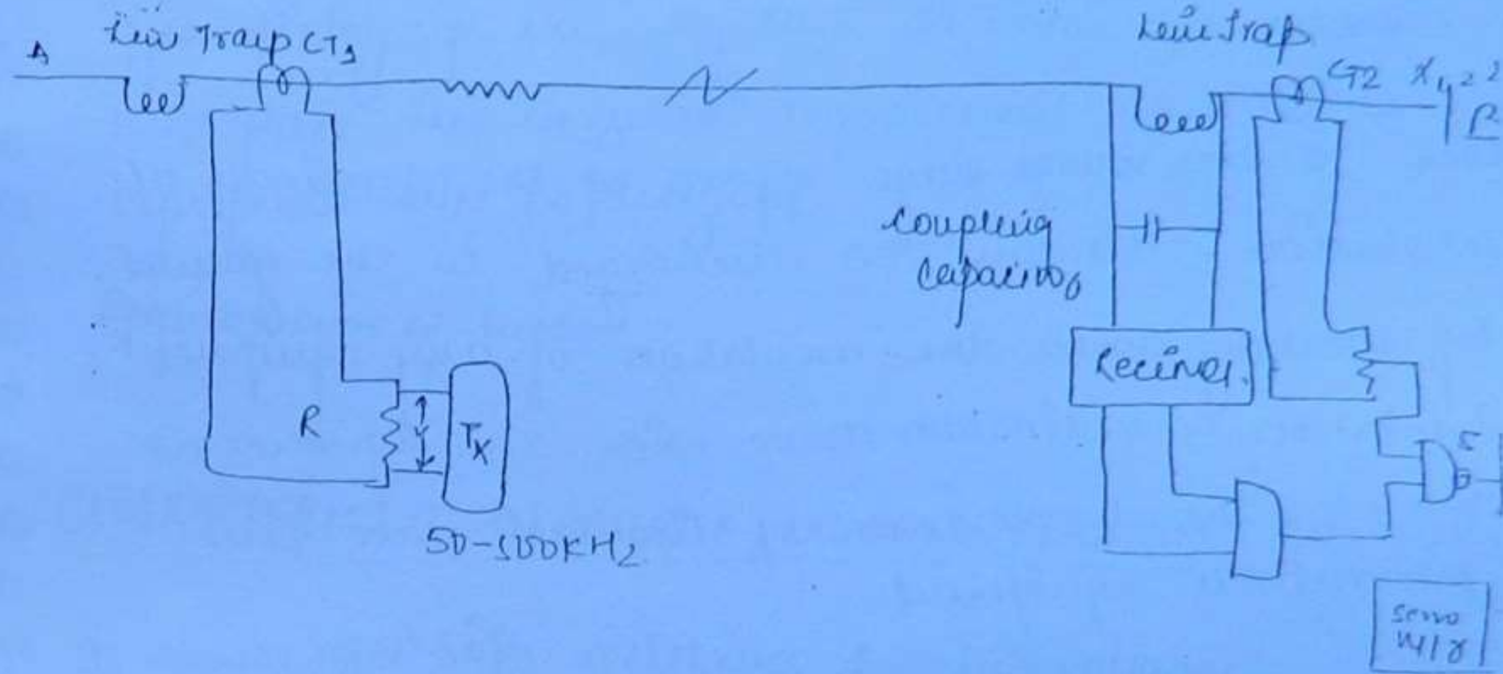
16). A differential protection comparing voltages is known as translay relay.

17). to avoid the 'mal operation' of relays due to initial inrush currents of 2nd harmonic restrain relay is used.

18) Pilot wire relaying is not economical for the protection of long line. for such line differential protectn is provided using carrier communicatn scheme.

~~17~~

#



→ The frequency of ~~carry~~ carrier signal will be in range 50 x 500 KHz and some time it may go to GHz depending upon distance of T.L

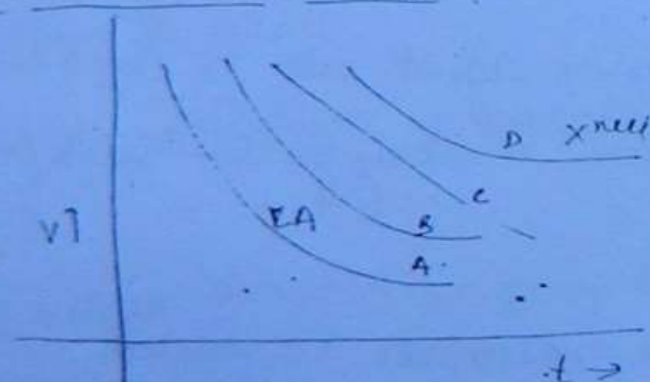
→ A line or wave trap is a resonate LC circuit, shall & resonate for carrier frequency and bi-passes 50Hz signal. in other words they offer high resistance for carrier signal and low resistance for 50 Hz

→ A coupling capacitor blocks the 50Hz signal and transits the carrier signal

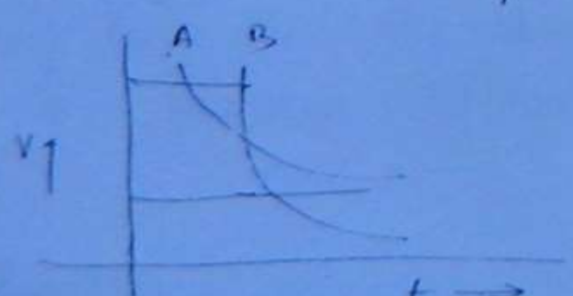
Insulation ~~Condition~~ Co-ordination.

- When a over voltage surge appears on the terminals of substation this can be discharged to the ground by breaking down the insulation of any equipment. Insulation co-ordination deals with the sequence at which the break down of insulatn take place for various equipment.

- Break down characteristic:



- For proper insulation coordinatn of lighting arrestor must be found below than any other equipment breakdown characteristic and the breakdown characteristic of most important equipment should be place above all other equipment.



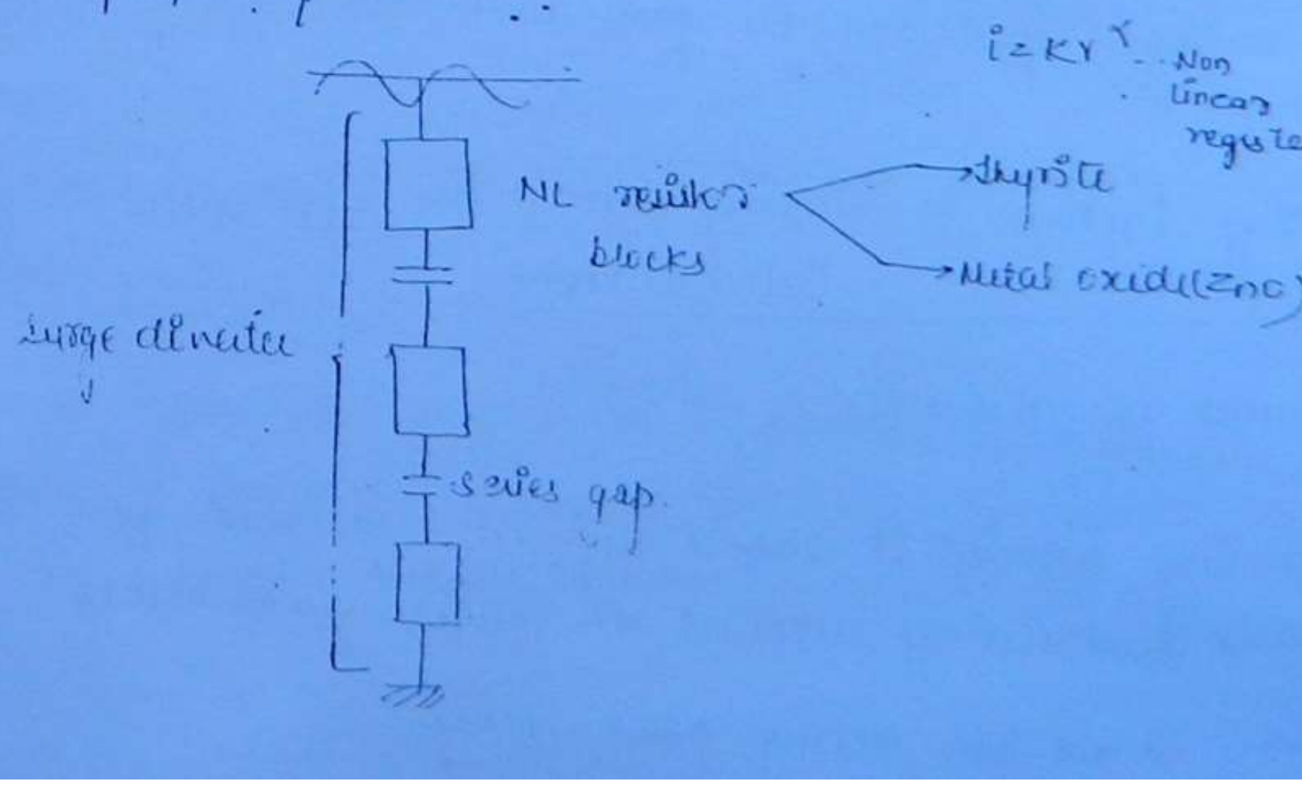
- For proper insulation co-ordinat^n, the breakdow charac. should not cut and over lap each other.

- After fixing up the sequence at which breakdown take place. the insulat^n requirement for various equipment will be designed.

~~Requirements of such~~

CHARACTERISTIC OF SURGE DIVERTOR / LIGHTING ARRESTOR

1) It should offer high resistance for low voltages
2) It should offer low resistance for high voltage.
3) Arcing should not be not be continued due to power frequency follow currents.



Types of Lighting arrestors:-

Lighting Arrestor

Station type	Line type	Distribution type
V: 3-512KV	V: 20 to 73KV	V: 8 to 15KV
I > 100KA	I: 65-100KA	I < 65KA

- These voltages are ~~ph~~ phase voltages of switching voltage

- In decending order of cost of fused material the various fused material are Platinum., gold, silver, copper, Aluminium Tin, lead.

- For current upto 10A Tin fuse, above 10A Copper fuses are used.

- $\boxed{\text{Fusing Factor} = \dfrac{\text{Fusing Current}}{\text{Rated current}}}$, this value should be around 2.

- fusing current is rated current at which fuse melt and ~~curr~~ cut-off current actual current at which fuse melts.

- Fuse should low melting point temp.

• A fuse protect equipment from prospective current.

ECONOMIC SCHEDULING

• the problem of economic scheduling firsts begin with unit commitment. A unit commitment problem suggest the schedule of the unit must be kept on or off. unit commitment problem is more complex because of variety of constraints present in the problem. following the schedule, the economic scheduling problem allocate the load among the unit in service in such a way the total cost of generation is minimum.

• Optimum power flow problem is similar to economic scheduling problem. the only difference is OPF is very complex ~~during~~ due concentration of large variety of constraints.

Dated
15 Nov 2010

Economic scheduling Problem :-

→ is an optimization pr problem.

→ objective function

$$\min\left[C_T(P)\right] = \min\left[\sum_{i=1}^{n} C_i(P_i)\right]$$

→ subject to the satisfaction of equation equality/ inequality constraint.

Constraint

Equality

1) Load flow solution must be obtained

2) $\sum P_i - P_D = 0$

--- without losses

$\sum P_i - P_D - P_{loss} = 0$

--- with losses

Inequality

1) Generator power limits

$P_{i\,min} \leq P_i \leq P_{i(max)}$

2) Transformer tap setting

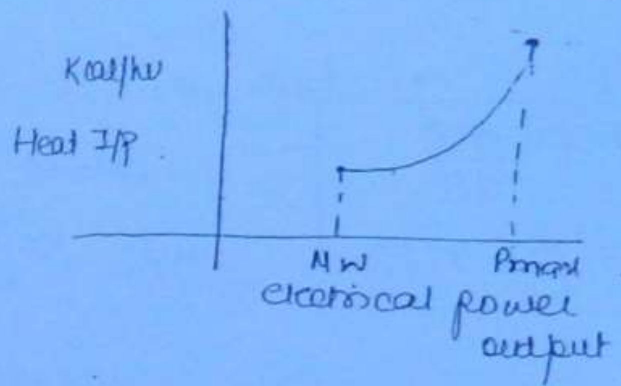
$t_{min} \leq t \leq t_{max}$

(3) voltage limits.

(4) T.L thermal capabilities

CHARACTERISTIC OF THERMAL UNIT

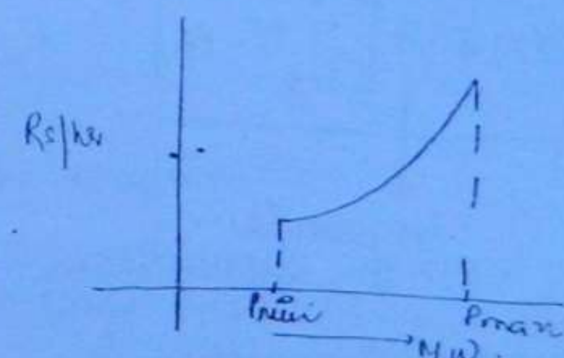
1) HEAT CURVE:



• slope of this graph is known as "Heat rate"

$$\boxed{\text{slope} = \text{Heat rate} = \frac{dF_i}{dP_i}}$$

2) COST CURVE:-



— using the parabolic eqn, the equatn of cost curve is

$$\boxed{C_i = \alpha_i + P_i\beta_i + \gamma_i' - P_i^2}$$

α_i' β_i' & γ_i' — cost coefficient of i^{th} M/C

for $i = 1, 2, \ldots \ldots n$.

• The slope of this curve is known as "Incremental cost of production (IC).

$$\boxed{\begin{aligned} \text{slope} = IC_i &= \frac{dC_i}{dP_i} \\ &= \beta_i + \gamma_i P_i \end{aligned}}$$ unit Rs/MWh

Economic scheduling Problem by neglecting losses :-

(Method of Lagrangian)

• We define Lagrangian funcⁿ as

$$\boxed{L = \sum_{i=1}^{n} C_i(P_i) - \underbrace{\lambda}_{\text{Lagrangian multiplier}} \left[\sum_{i=1}^{n} P_i - P_D\right]}$$

• For objective function minimization

$$\frac{dI}{dP_i} = 0 \quad i = 1, 2, \ldots n.$$

$$\frac{dL}{dP_i} = \frac{dC_i}{dP_i} - \lambda [1] = 0$$

condition of cost minization is

$\frac{dC}{dP}$ $\boxed{\frac{dC_1}{dP_1} = \frac{dC_2}{dP_2} - - - - - = \frac{dC_n}{dP_n} = \lambda}$ coordinate eqⁿ

- The unit of $\lambda \rightarrow$ Rs/MWh, and it is also known as cost of recieved power.

Algorithm:-

1. Start with $\lambda = \lambda^0$

2. $P_D = P_1 + P_2 + - - - P_n$

3. Solve for using
$$\frac{dC_i}{dP_i} = \lambda^0 = \beta_i + \gamma_i P_i \quad \text{for } i = 1, 2, - - - n$$

3. Check $\left| \sum_{i=1}^{n} P_i - P_D \right| \leq \epsilon$ $\quad \epsilon$ = error

Give solution

If $\sum P_i - P_D \rightarrow$ large negative (demand more, it less) - - - increase λ

On $\sum P_i - P_D \rightarrow$ large position (gen more demand less) - - decrease λ.

4. Repeat problem

- In the iteration process if any unit violates the limit then set the generation of that unit as $P_i = P_{min}$ or

$P_i = P_{i(max)}$ at the remaining load $P_D - P_i$ is optimally allocated in the remaining $(n-1)$ units (generating).

Numerical:

Increment cost of production in rupees Rs/MWh for a plant consisting of two unit

$$I_{C_1} = \frac{dC_1}{dP_1} = 0.2P_1 + 40 \quad \cdots \text{(1)}$$

$$I_{C_2} = \frac{dC_2}{dP_2} = 0.25P_2 + 30 \quad \cdots \text{(2)}$$

1
56
0.2
172

Assume both the unit in operation vary, a total load varies from 40 to 250MW

$P_D = 40 \rightarrow 250$ MW
$P_{i\,min} = 20$ MW
$P_{i(max)} = 125$ MW for $i = 1, 2$

Solution:

How will the load is shared b/w 2 unit when the load varies from 40MW to 250MW.

1) $P_D = 40$ MW

let $P_1 = P_2 = 20$ MW

$I_{C_1} = 0.2 \times 40 + 40$
$= 44$ Rs/MWh

$I_{C_2} = 0.25 \times 20 + 30$
$= 35$ Rs/MWh

P_1	P_2	P_D'	Plant λ
—	40MW2	40W	—
—	60MW	60MW	—
20MW	56MW	76MW	44.
33.33	66.66	100	46.6
61.33	88.88	150	52.2
88.89	111.11	200	57.7
106.95	125MW	245	61.25

→ Begining of economic stability (row 76MW)

→ Economic ... (row 245)

• for minimum load we start Plant (2)

• when a minimum load of 20MW

$$IC_1 = 44 \text{ Rs/MWh} \quad \text{for what load of}$$

$$P_2 \quad IC_2 = 44 \text{ Rs/MWh}$$

$$44 = 0.25 \times P_2 + 30$$

$$P_2 = 56 \text{ MW}$$

120	125	245	—
125	125	250	—

3) $P_D = 150\text{MW}$

i.e $P_1 + P_2 = 150 \text{ MW}$.

$\longrightarrow IC_1 = IC_2$

so $0.2P_1 - 0.25P_2 = -10$.

$P_1 = 83.33 \text{ MW}$

$P_2 = 66.66 \text{ MW}$.

* when any plant reaches 125 MW the economic count stops.

with 125 MW

$$IC_1 = 0.2 \times 125 + 40 = \text{Rs } 65/\text{MWh}$$

$$IC_2 = 0.25 \times 125 + 30 = \text{Rs } 61.25/\text{MWh}$$

Question:-

the incremental generating cost is of two generating unit are given by

$$IC_1 = 0.1x + 20$$

$$IC_2 = 0.1y + 18 \text{ Rs/MWh}.$$

for a total load demand of 300 MW the value

value of x and y?

$$x+y = 300$$

$$\cancel{0.1x + 20 +}$$

$$0.1x - 0.15y = -2$$

$x = 172$ MW $\quad y = 128$ MW.

the incremental cost of production of ~~two~~ 3 units are.

$$IC_1 = 0.00284P_1 + 7.2$$

$$IC_2 = 0.00388P_2 + 7.85$$

$$IC_3 = 0.00964P_3 + 7.97$$

find optimum scheduling for total load of 850 MW.

$$P_1 + P_2 + P_3 = 850 \quad - (1)$$

$$IC_1 = IC_2$$

$$IC_3 = IC_1$$

$$0.00284P_1 + 7.2 = 0.00388P_2 + 7.85$$

$$\frac{0.00284P_1 + 7.2 - 7.85}{0.00388} = P_2$$

$$\frac{0.00284P_1 + 7.2 - 7.97}{0.00964} = P_3$$

$$P_1 + (0.731P_1 - 167.52) + (0.294P_1 - 79.875) = 850$$

$\Rightarrow$

$P_1 = 541.92 \text{ MW}$.

$P_2 = 228.62 \text{ MW}$

$P_3 = 7944 \text{ MW}$

Economic ~~sorra~~ Solution (considering the losses)

- objective function

$$\min\left(\sum_{i=1}^{n} C_i \cdot P_i\right).$$

- subject to

$$\sum_{i=1}^{n} P_i - P_D - P_{loss} = 0$$

Lagrangian fn. is defined as

$$L = \sum_{i=1}^{n} C_i(P_i) - \lambda\left[\sum_{i=1}^{n} P_i - P_D - P_{Loss}\right]$$

objective function is minimised when

$$\frac{dL}{dP_i} = 0 \Rightarrow \frac{dL_i}{dP_i} - \lambda\left[1 - \frac{dP_{loss}}{dP_i}\right]$$

Let $\frac{dP_{loss}}{dP_i}$ = Incremental T.L losses

Penality factor $L_i = \dfrac{1}{1 - \dfrac{\partial P_{loss}}{\partial P_i}}$ for $i = 1, 2 \ldots n$.

then

$$\boxed{L_1 \frac{dC_1}{dP_1} = L_2 \frac{dC_2}{dP_2} = \cdots = L_n \frac{dC_n}{dP_n} = \lambda}$$

-- co-ordinate equat^n

Penality factor of i^{th} M/C is

$$L_i = \frac{1}{1 - \frac{\partial P_{loss}}{\partial P_i}}.$$

the loss equation for a two plant system is

$$P_{loss} = \sum_{m=1}^{n} \sum_{n=1}^{n} B_{mn} P_m P_n \cancel{B_{mn}}$$

when $P_m, P_n \rightarrow$ generation of two units

$B_{mn}, B_{nm} \rightarrow$ loss co-efficients

→ Let $m=1$

$n=1$ $\quad P_{loss} = B_{11} P_1 P_1 \cancel{B_{11}}$

$$= B_{11} P_1^2$$

$n=2$ $\quad P_{loss} = B_{12} P_1 P_2$

$m=2$

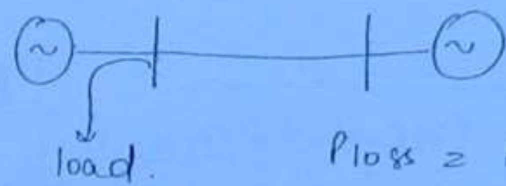
$n=1$ $\quad P_{loss} = B_{22} P_2 P_2$

$$= B_{22} P_2^2$$

Total loss $\boxed{P_{loss} = B_{11} P_1^2 + 2 B_{12} P_1 P_2 + B_{22} P_2^2}$

$$\boxed{B_{12} = B_{21}}$$

Case 1: Load connect near plant 1:



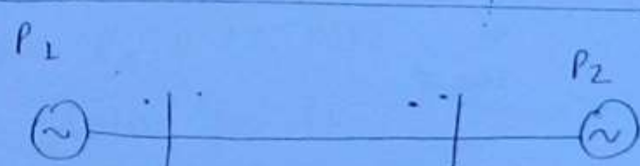
$$P_{loss} = B_{22} P_2^2$$

$$B_1 = B_{12} = B_{21} = 0$$

Penality factor L_1: $L_1 = \dfrac{1}{1 - \dfrac{\partial P_{loss}}{\partial P_1}} = \dfrac{1}{1-0} = 1$

$$L_2 = \dfrac{1}{1 - \dfrac{\partial P_{loss}}{\partial P_2}} = \dfrac{1}{1 - 2B_{22}P_2} > 1$$

Case 2: Load connected near plant 2



$$P_{loss} = B_{11} P_1^2$$

$$B_{22} = B_{21} = B_{21} = 0$$

$$L_1 = \frac{1}{1 - 2B_{11}P_1} > 1$$

$$L_2 = \frac{1}{1-0} = 1$$

Case 3: Load connected near both loads plants

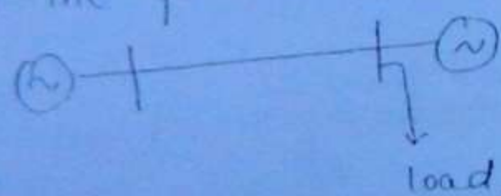
$$P_{loss} = B_{11} P_1^2 + 2B_{12}P_1P_2 + B_{22} P_2^2$$

$$L_1 = \frac{1}{1-\frac{\partial P_{loss}}{\partial P_1}} = \frac{1}{1-(2B_{11}P_1 + 2B_{12}P_2)} > 1$$

$$L_2 = \frac{1}{1-\frac{\partial P_{loss}}{\partial P_2}} = \frac{1}{1-(2B_{22}P_2 + 2B_{12}P_2)} > 1$$

Numerical

A two bus sys is shown in figure, if 100MW power is transfer plant 1 to load a 100 transmission loss 10MW is occured. Find the required g/r^n for each plant and the power reached by the load is 25Rs/MWh.
when sys λ



P

$IC_1 = 0.02P_1 + 16\,Rs/MWh$

$IC_2 = 0.04P_2 + 20\,Rs/MWh$

soln

$$P_{loss} = B_{11} P_1^2$$

$$10MW = B_{11} \times 100^2\,MW$$

$$B_{11} = \frac{10}{100 \times 100}$$

$$= 0.001\,MW^{-1}$$

$$P_{loss} = 0.001 P_1^2$$

$$L_1 = \frac{1}{1-\frac{\partial P_{loss}}{\partial P_1}} = \frac{1}{1-0.002P_1} \quad \text{--- (1)}$$

$$L_2 = \frac{1}{1-0} = 1 \quad \text{--- (2)}$$

coordinate eqn.

$$L\frac{dC_1}{\partial P_1} = \lambda \quad \text{--- (3).}$$

$$= \frac{1}{1-0.002P_1} \times (0.02P_1 + 16) = 25$$

$$L_2\frac{\partial C_2}{\partial P_2} = \lambda.$$

$$= 0.04P_2 + 20 = 25 \text{ Rs/MWh}$$

$$0.04P_2 = 5 \text{ Rs/MWh}$$

solving P_2

$$P_2 = 125 \text{ MW}$$

Solve for P_1

$$P_1 = 128.5 \text{ MW}$$

$$P_{loss} = 0.001 P_1^2$$

$$= 0.001 \times 128.5^2$$

~~solving $P_1 = P_2$~~

$$P_D = P_1 - P_2 - P_{loss}$$

$$= 237.04 \text{ MW}$$

Given the incremental product^n cost 2 two unit

$$IC_1 = P_1 + 85 \text{ Rs/MWh}$$
$$IC_2 = 1.2P_2 + 72 \text{ Rs/MWh}$$

given the B matrix.

$$B = \begin{bmatrix} 0.015 & -0.001 \\ -0.001 & 0.02 \end{bmatrix}$$

for $\lambda = 150$ Rs/MWh

find P_1, P_2, P_{loss}, P_D

Soln

$$P_{loss} = 0.015 P_1^2$$
$$= -2 \times 0.001 P_1 P_2 + 0.02 \cancel{B_{22}} P_2 .$$

Ans

$P_1 = 12.4$ MW

P_2 11.3 MW

$P_{loss} = 4.64$ MW

$P_D = 19.88$

$$\frac{\partial P_{loss}}{\partial P_1} = 0.03 P_1 - 0.002 P_2$$

$$\frac{\partial P_{loss}}{\partial P_2} = -0.002 P_1 + 0.04 P_2$$

1.5

$$L_1 = \frac{1}{1 - \frac{\partial P_{loss}}{\partial P_1}} = \frac{1}{1 - 0.03 P_1 - 0.02 P_2}$$ 0.03

$$L_1 \frac{\partial C_1}{\partial P_1} = L_2 \frac{dC_2}{\partial P_2} =$$

$$\frac{1}{1 - 0.03P_1 + 0.002P_2} \times (P_1 + 85) = 150.$$

&

$$\frac{1}{1 + 0.02P_1 - 0.04P_2} \times (1.2P_2 + 72) = 150.$$

Power System Stability

→ power of any m/c $\propto D^2 L n_s$ where $D \rightarrow$ diameter

$L \rightarrow$ length of shaft.

$n_s \rightarrow$ speed.

- power s/m stability refers to the ability of ~~power s/m~~ machines working in power s/m to maintain synchronism after the disturbance.
- whenever there is imbalance in the mechanical input and electrical power output the rotor of alternator may ~~acce~~ accelerate or deaccelerate. If all the machines are accelerating or deaccelerating at the same rate then they form a co-herent group. Coherent group of machines will not give a problem of synchronism. Practically ~~going~~ Owing to the difference in inertias, size and rating the machines can not form a co-herent group.

- If the synchronism is lost there will be wild fluctuations in voltage and currents. That may lead to tripping of machine and collapse of the machine.

- Power system stability problem is also known as angular stability problem, is occurring mainly due to generator dynamics

- Voltage stability problem is due to load dynamics whereas angular ~~stang~~ stability problem is due to generator dynamics

FORMS OF STABILITY

Small signal stability

→ the amplitude of disturbance is small and occur for long duration

→ Non-linearity are ignored

- Steady state stability
- Dynamic stability

Large signal Transient stability

→ the amplitude of disturbance is quite large and occur sudden

ex Loss of major load, 400 KV lines tripping sudden increase in mech I/P, short ckt

→ Steady state stability
- the action of control s/m (AVR, exciter etc.) are not included
- Pessimistic Result

→ Dynamic stability
- the control s/m components are considered
- optimistic Results.

→ Non-linearity are considered and they play vital role in the st

→ study is completed in 1sec

→ the action of AVR, exciter are not included since these are slow acting devices

Steady state stability	Dynamic stability	Transient stability
—	• study period is from several min to hours	• study period < 1sec

NOTE :

Dynamic study is evaluated by developing the matrices $\boxed{\dot{x} = Ax + Bu}$, where $[A]$ is s/m matrix, after developing the system matrix A we find the eigen values of A. For s/m to be stable the values must be found on left hand side of the scale. Various types of stabalizer and controllers are designed to maintain stability. As these stabalizers used the linearized ~~s/m~~ power s/m model their effectiveness for transient stability problem is less

STABILITY LIMIT:-

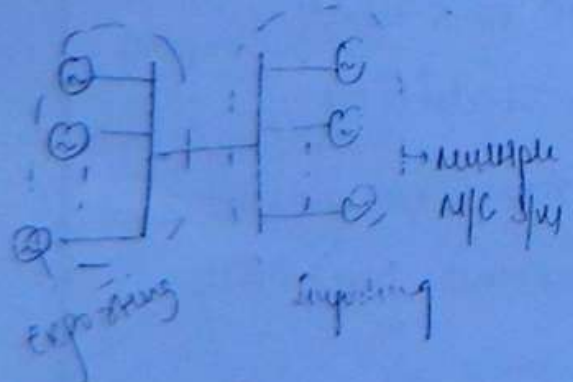
- Sensitivity • the amount of power that will be transfered to the point of disturbance to maintain the stability is known as stability limit.
- Compare Dynamic stability limit is highest and transient stability limit is lowest.
- Transient stability limit can be improved up to steady state stability limit but beyond this is not possible.

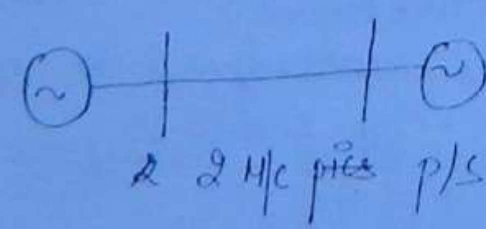
Q. system highest steady stability limit is garanteed for high transient stability?

- No, because system non-linearity play a vital roles.

[A s/m with high transient stability gaurantees the high steady state stability].

MODELLING ISSUES





If an alternator is connected to Induction M/r, s/m ~~must~~ may become unstable, but stability (synchronism) is never ~~lowe~~ lost, However if an alternator is connected to synchronous M/r, system may become unstable or it may loss the stability (synchronism)

A two M/c system are is further reduced to a single M/c a single machine connected to infinite bus system In such SMIP s/m., if the disturbance is present it effects only generated dynamics.

SWING EQUATION

- this equation describes Rotor dynamics of synchronous M/C
- whenever there is an imbalance b/t mech. input to electrical power output, the rotor of alternator either accelerate or deaccelerate.

Acceleration Torque

$$\boxed{T_a = T_m - T_e = I \cdot \frac{d^2\delta}{dt}} \rightarrow \text{acceleratn}$$

T_a – accelerating Torque

T_m – mechanical I/p

T_e – mech equivalent torque

I – Inertia constant in $kg\text{-}m^2$

multiplying on both sides with 'ω'

$$T_a \cdot \omega = T_m \cdot \omega - T_e \omega = I\omega \cdot \frac{d^2\delta}{dt^2}$$

i.e

$$\boxed{P_a = P_m - P_e = M\frac{d^2\delta}{dt^2}}$$

M = Inertia constant
M can be obtained from $M = I\omega$ eqn.
or by using another inertia constant 'H'

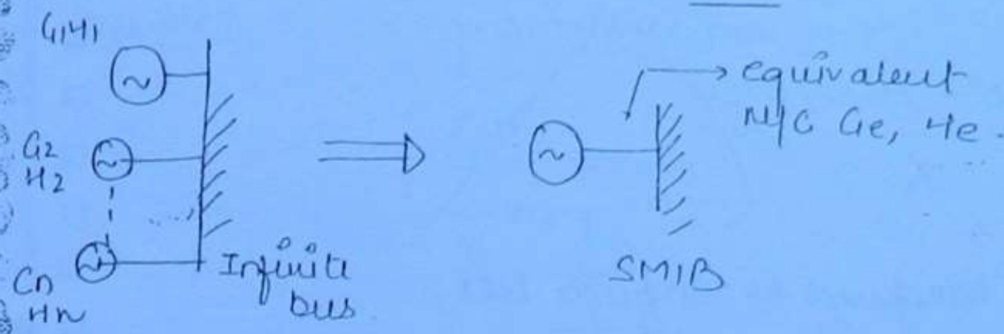
$$H = \frac{\text{stored KE (in MJ)}}{\text{Rating of M/C } G \text{ (MVA)}}$$

from above stored K.E = G.H.
from Law of Mechanics

* $\text{Stored K.E} = \frac{1}{2} I\omega^2 = \frac{1}{2} M\omega$

$\text{Stored KE} = \frac{1}{2} M\omega = GH.$

$$\boxed{\begin{aligned} M &= \frac{GH}{\pi f} \ \frac{\text{MW-sec}}{\text{elect rad}} \\ &\rightarrow \frac{GH}{180 f} \ \frac{\text{MW-sec}}{\text{elec-rad degree}} \end{aligned}}$$



Multiple M/S stored KE $= G_eH_e$

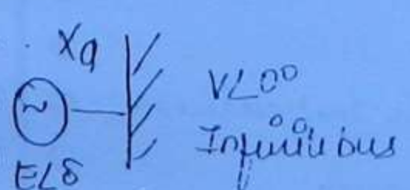
$$= G_1H_1 + G_2H_2 + \cdots G_nH_n$$

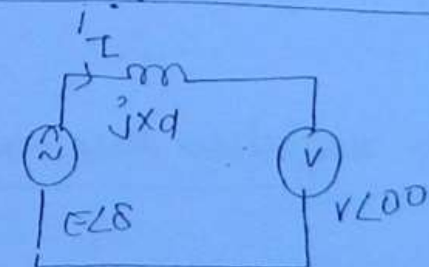
$$H_e = \left(\frac{G_1H_1}{G_e}\right) + \left(\frac{G_2H_2}{G_e}\right) + \cdots \left(\frac{G_nH_n}{G_e}\right)$$

If $G_e = G_{base}$

$$\boxed{H_e(\text{in p.u}) = \frac{G_1H_1}{G_{base}} + \frac{G_2H_2}{G_{base}} + \cdots \frac{G_nH_n}{G_{base}}}$$

POWER ANGEL CURVE AND TRANSFER REACTANCE





$$I = \frac{E\angle\delta - V\angle 0^\circ}{jX_d} = \frac{E\angle\delta - V\angle 0^\circ}{jX_d} \times \frac{j}{j}$$

$$= \frac{(E\angle\delta - V\angle 0^\circ) \times j}{j^2 X_d}$$

$$I = j\,\frac{V\angle 0^\circ - E\angle\delta}{X_d}.$$

$$= \frac{V\angle 90^\circ - E\angle \delta+90^\circ}{X}$$

complex power transferred to Infinite bus.

$$S = VI^* = VE \times \left[\frac{V\angle -90^\circ - E\angle -\delta-90^\circ}{Xd}\right]$$

$$S = \frac{V^2\angle -90^\circ - EV\angle(\delta-90^\circ}{Xd}$$

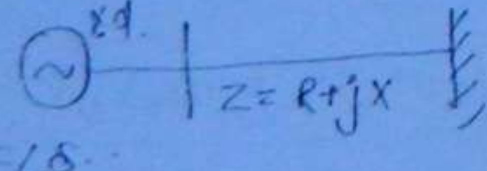
$$S = \frac{-jV^2 - EV(\cos(\delta+90^\circ) - j\sin(\delta+90^\circ))}{Xd}$$

$$\rightarrow \frac{-jV^2 - EV[-\sin\delta - j\cos\delta]}{Xd}$$

$$S = \frac{EV}{Xd}\sin\delta - j\left[\frac{V^2}{Xd} - \frac{EV}{Xd}\cos\delta\right]$$

$$S = P - jQ$$

Generator connected to Infinite bus through Impedence:-

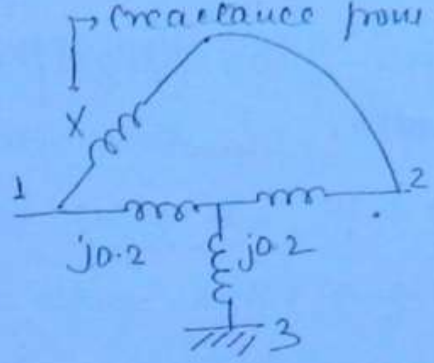


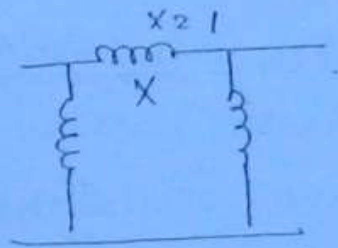
$$Pe = \frac{EV}{X}\sin\delta$$

$$X = Xd + X_{line}$$

X, it is the reactance that appear b/w sending end and receiving end terminal example :-

(reactance from Δ-Y)





$$\boxed{X = X_1 + X_2 + \frac{X_1 X_2}{X_3}}$$

at $\boxed{X = \sqrt{3}R \rightarrow \text{max}^{m} \text{ power transfer}}$

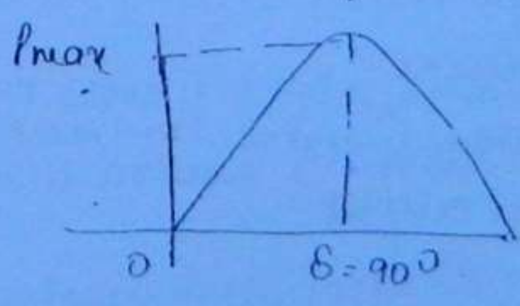
Power angle curve :-

P_e = electrical power transfered.

$= \frac{EV \sin\delta}{X}$.

$\frac{EV}{X} \rightarrow$ steady state power limit

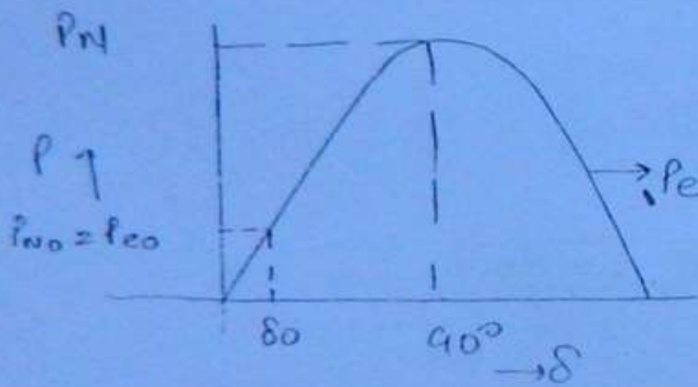
X : transfer reactance



- In ac T.L for transfer of electrical power reactance is compulsory, resistance is not required the condition for maximum power transfer in a short T.L is $X=\sqrt{3}R$.

STABILITY STATE

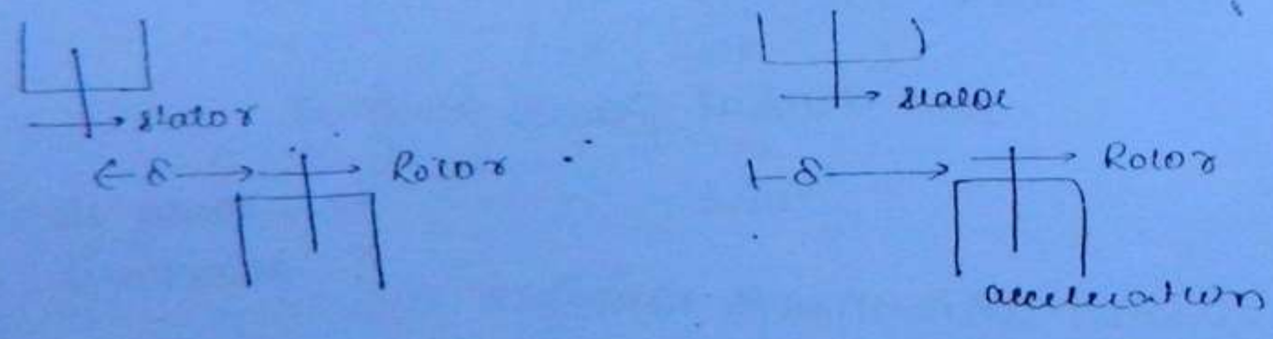
Steady state Stability: EVALUATION TECH



$\frac{dP}{d\delta} > 0$ at $\delta < 90^\circ$

$\frac{dP}{d\delta} = 0$ at $\delta = 90^\circ$

$\frac{dP}{d\delta} < 0$ at $\delta > 90^\circ$



- when δ increases P_e increases
- when δ cross 90°, any further increases in mech. I/P decrease the electrical output.
- $\frac{dP_e}{d\delta}$ = synchronising power coefficient (stiffness of electrical M/C)

  $= P_m \cos\delta$.

when δ is changing from 0-90°, the electrical power output increase and for delta above 90°, the electrical power output decreases. If a mechanical input is increased when rotor angle [$\delta = 90°$] (say) the extra mechanical input store as K.E in the rotor, the rotor start accelerate and delta increases. The increase in del 'δ' reduces electrical power output this gives further acceleration and increase in 'δ'. finally the system will reach the point when $P_e = 0$

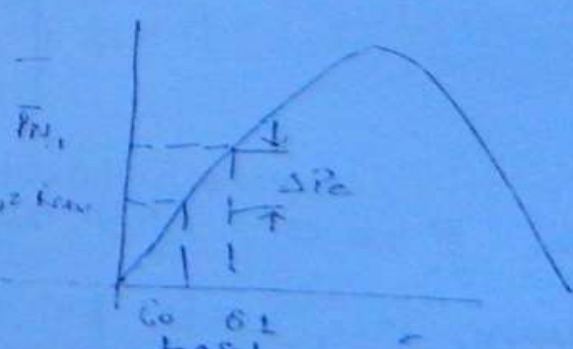
NOTE:

- System has steady state stability as long as $\frac{dP}{d\delta} > 0$
- system loss stability when $\frac{dP}{d\delta} < 0$
- $\frac{dP}{d\delta} > 0$ when $0 < \delta < 90$, beyond $\delta = 90°$, $\frac{dP}{d\delta}$ is -ve.
- system cannot have steady state stability beyond $\delta = 90°$, In power system in order to have good steady state stability margins, δ is maintained around 30° to 40°

Eq Evaluation technique-2:

$$\frac{\Delta P_e}{\Delta \delta_0} = \frac{dP_e}{d\delta}$$

- linearized diff. eqn



$$\Delta P_{e0} = \left(\frac{dP_e}{d\delta}\right) \cdot \Delta\delta_0 \quad \text{--- (1)}$$

accelerating energy

$$\boxed{P_a = P_{m0} - (P_{e0} + \Delta P_{e0})}$$

$$P_a = P_{m0} - (P_{e0} + \Delta P_{e0}) = M\frac{d\delta^2}{dt^2}$$

$$\cancel{P_{e0}} - \cancel{P_{e0}} - \Delta P_{e0} = M\frac{d^2\delta}{dt^2}$$

$$M\frac{d^2\delta}{dt^2} = -\Delta P_{e0} \quad \text{--- (2)}$$

substitute eqn (2) in (1)

$$M\frac{d^2\delta}{dt^2} + \left(\frac{dP_e}{d\delta}\right)^0 \cdot \Delta\delta_0 = 0$$

let operator $p = \frac{d}{dt}$; $p^2 = \frac{d^2}{dt^2}$

$$\left(Mp^2 + \frac{dP_e}{d\delta}\right)\Delta\delta = 0$$

roots of characteristic equation are

$$p = \mp\left[\frac{-\left(\frac{dP_e}{d\delta}\right)^0}{M}\right]^{0.5} = \pm j\omega_n.$$

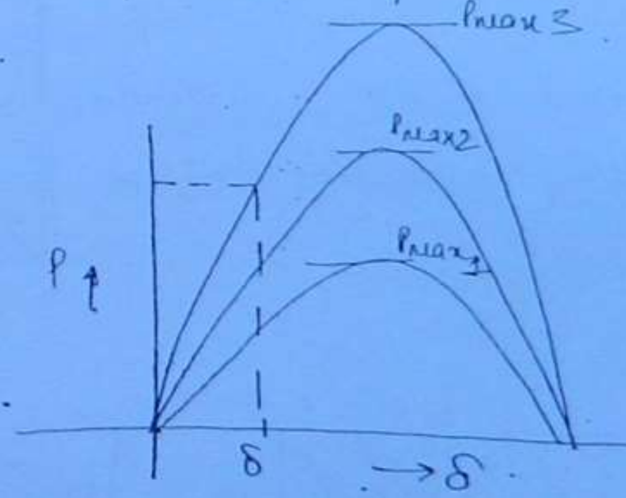
- When $\frac{dP}{d\delta} > 0$, s/m has 2 conjugate poles on imaginary axis for this condition system is stable with undamped frequency of acceleration. However the inertial force are considered. Each acceler will be damped after some time

- when $\frac{dP}{d\delta} < 0$, the sp has two real poles, one on right axis and other on left side. Indication of poles on R.H.S is indication for loss of stability.

Improvement of Steady state a stability:-

$P_e = P_{max} \sin\delta$.

- By improving ss power limit as for given P value of δ we can transfer more electrical power.



$$\boxed{P_{max} = EV/X}$$

1) Operate T.L at high voltage
2) Reduce the reactance X.

- use parallel line
- use bundled conductor
- series capacitances

for bundle

$L = 2\times10^{-7} \ln \frac{D_m}{D_s}$

$D_s \uparrow L \downarrow$.

series — capacitor → improve steady state power limit
series — Reactor → $I_{sc}\downarrow$

shunt reactor → to reduce ferranti effect
shunt → capacitor → to impro

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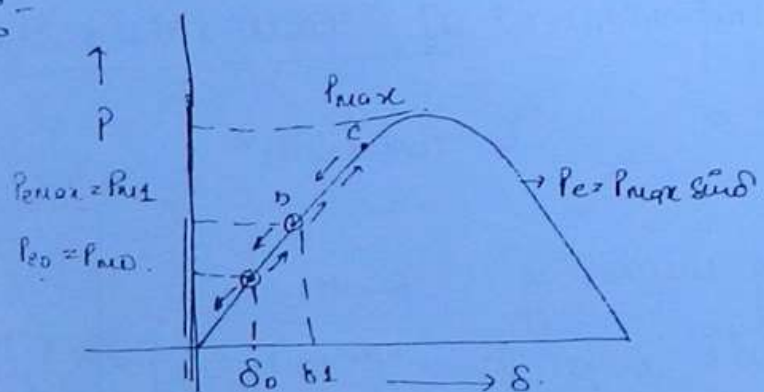
TRANSIENT STABILITY :-



operating point	δ value	rotor speed	Acceleration & Deceleration	P_a	Remark
a	$\delta = \delta_0$	$N_r = N_s$	None	$P_a = 0$	equilibrium [mechanical suddenly raised]
a-b	$\delta\uparrow$	$N_r > N_s$	Acceleration	$P_a > 0$	—
b	$\delta = \delta_1$	$N_r > N_s$	Acceleration stops	$P_a = 0$	—
b-c	$\delta\uparrow$	$N_r > N_s$	Deceleration	$P_a < 0$	δ increases due to inertia
c	$\delta = \delta_2$	$N_r = N_s$	Deceleration	$P_a < 0$	Inertia absent
c-b	$\delta\downarrow$	$N_r < N_s$	-do-	-do-	

b	$\delta = \delta_1$	$N_r < N_s$	Deacceler^n STOP	$P_a = 0$	—	
b-a	$\delta \downarrow$	$N_r < N_s$	Accelerat^n	$P_a > 0$	Due to inertia	Speed here increases.
a	$\delta = \delta_0$	$N_r = N_s$	— do —	$P_a > 0$	Inertia absent.	

cycle repeats further.

NOTE:

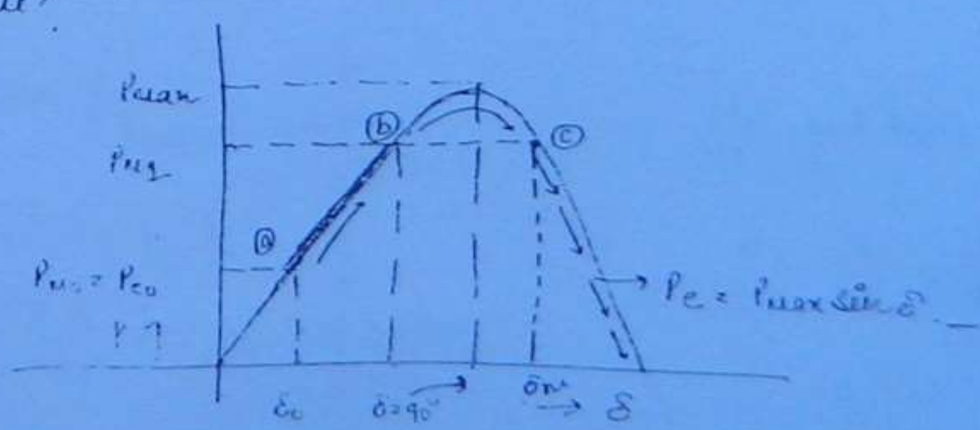
- During this transient period. $\frac{d\delta}{dt}$ for some time it is positive and for another type time it is negative.

When these oscillation are died. system restores ~~from~~ stability condition, in other words transient stability is achieved when

$$\boxed{\frac{d\delta}{dt} = 0}$$

LIMITING CASE:-

From the present value of mechanical I/p to any value?



- electrical power input at point (b) and (c) are same.

$$\boxed{P_{max} \sin\delta_2 = P_{max} \sin\delta_m}$$

$$\sin\delta_2 = \sin\delta_m$$

$$\boxed{\delta_m = \pi - \delta_2}$$ critical angle.

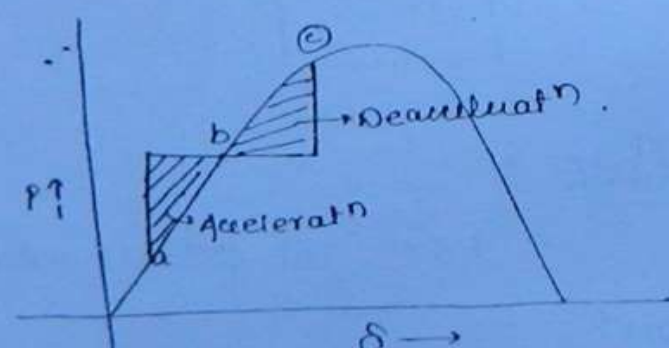
If the mechanical input raised corresponding to ($\delta = \delta_c$) the system is critically stable. During first swing rotor will travel upto $[\delta_m]$ and may likely come back. During the first swing if δ crosses δ_c then system loses stability.

EQUAL-AREA CRITERION

swing equatn

$$M \frac{d^2\delta}{dt^2} = P_a$$

$$\frac{d^2\delta}{dt^2} = \frac{P_a}{M}$$

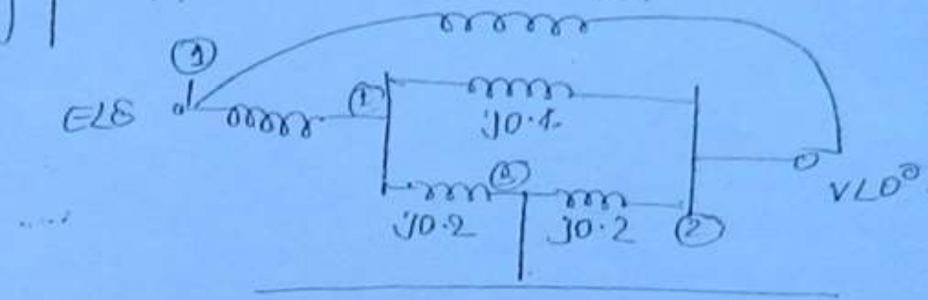


multiply both side by $\frac{d\delta}{dt}$

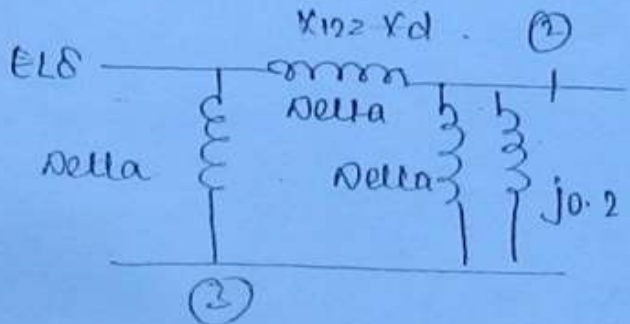
$$\frac{d\delta}{dt} \cdot \frac{d^2\delta}{dt^2} = \frac{P_a}{M} \cdot \frac{d\delta}{dt}$$

$$\frac{1}{2}\left[\frac{d}{dt}\left(\frac{d\delta}{dt}\right)^2\right] = \frac{P_a}{M} \cdot \frac{d\delta}{dt}$$

during fault:



Convert star, reactance b/w (1)(N), (2)N and (3)N



$$X_{12} = X_1 + X_2 + \frac{X_1 X_2}{X_3}$$

$$= j0.2 + j0.4 + \frac{j0.2 \times j0.4}{j0.2}$$

$$= j1$$

$$P_{maxd} = \frac{1.2 \times 1}{1} = 1.2\,p.u$$

$$P_{ed} = 1.2 \sin\delta.$$

68.53

after fault

$$X_a = X_d' + X_1 = 0.6\,p.u$$

$$P_{maxa} = \frac{1.2 \times 1}{0.6}$$

$$\boxed{P_{ea} = 2 \sin\delta}$$

$$\delta_m = \pi - \sin^{-1}\left(\frac{P_{m0}}{P_{maxa}}\right).$$

$$= \pi - \sin^{-1}\left(\frac{1.5}{2}\right)$$

$$= 131.4$$

$$\delta_0 = 30^\circ$$

POWER SYSTEM – II