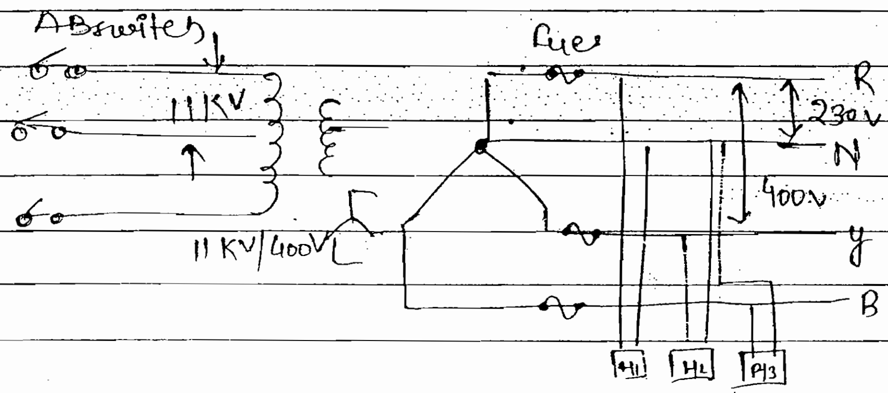
Power System. Bala Ji

Date 5/7/2014

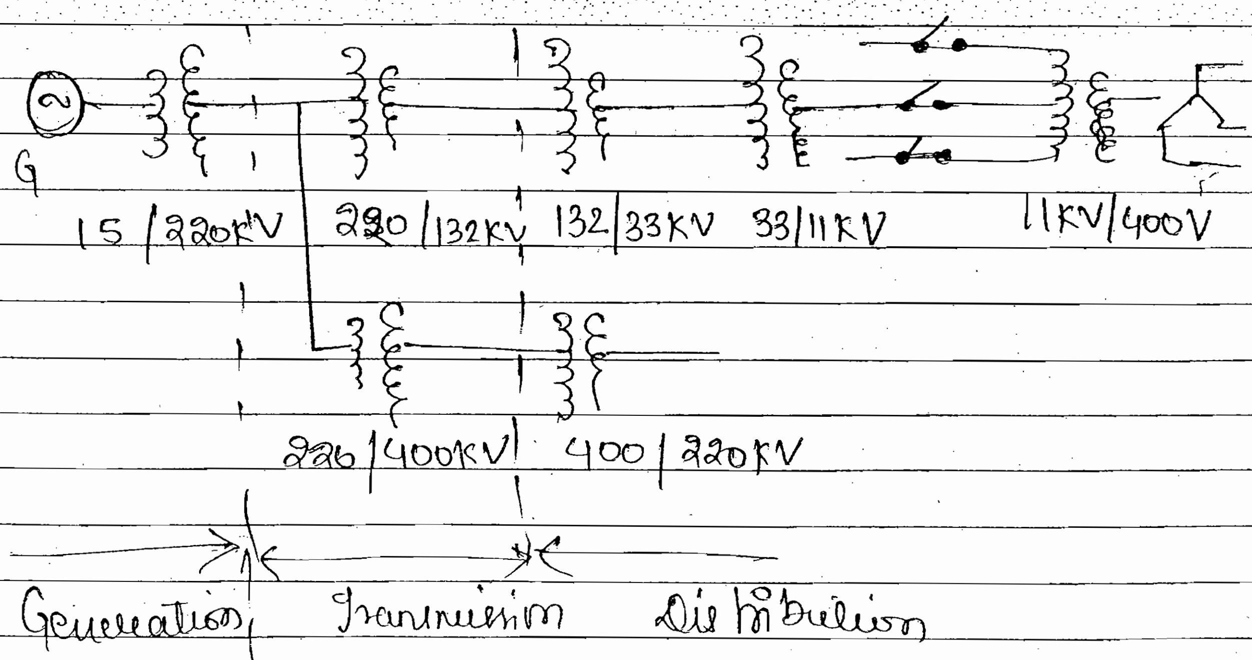
• (I) Transmission
↳ Basics
↳ voltage / Reactive Power control
↳ Power flow through Tr- line
↳ Tr- line parameters
↳ " " performance
↳ Travelling waves
↳ Corona

• II
↳ Power generation
↳ Economic factors
↳ Load freq. Control

• III.
↳ Switchgear and protection.



↳ When the power cut take place in any one phase, then AB switch are get open, after replacing fuse AB switch again closed.



Date.

↳ RMS line (OR) line - line voltage $[V_{LL}/V_L]$

400V, 11KV, 33, 132, 220, 400, 765KV

↳ RMS phase voltage (V_{ph}) $V_{ph} = 230V$

• Objective of Power System:-

(1) Cost of electrical energy per unit must be minimum

→ Economic load dispatch

→ Economic factors

→ Generation Method.

(2) Rated voltage and freq. has to be supplied to the consumers.

→ voltage control

→ load freq. Control

(3) Reliable power supply has to be available

→ Generation Method

→ Transmission

→ HVDC.

(4) Most efficient protection system has to be available for faster identification and isolation of faulty section from the healthy section.

→ fault analysis

→ Switch gear and protection

(5) Most efficient generator has to be used which are to be most stable, should not loose synchronism under faulty condition

→ Stability.

(6) flexible power transfer has to be available.

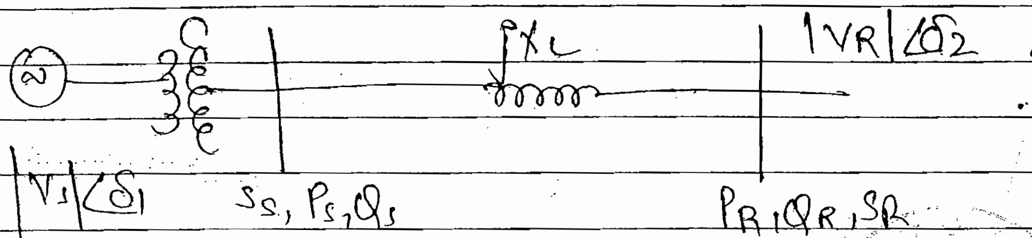
→ power cables.

Date________

- **Transmission :-** By using transmission line elec. power is Transferred from the remote generating generating station to the load centre where the electrical power is utilise.

- **Objective :-**

(1) X-mission line must be capable of transferring Maximum power with minimum x-mission line losses and more η.



$$P_S = P_R = \left|\frac{V_S \times V_R}{X_L}\right| \sin(\delta_1 - \delta_2)$$

Let $\delta = \delta_1 - \delta_2$.

$$P_R = \left|\frac{V_s V_R}{X_L}\right| \sin\delta \qquad \text{Assume } |V_R| = |V_s|$$

$$P_R = \left|\frac{V_s^2}{X_L}\right| \sin\delta = P_{max} \sin\delta \qquad P_{max} = \left|\frac{V_s^2}{X_L}\right|$$

$$P_{max} = \left|\frac{V_s^2}{X_L}\right|$$

- **Advantage of higher V_s :-**

(1) $P_{max} \propto V_s^2$. By $\uparrow V_s$ maximum power can be transferred.

$$\boxed{P_{max} \propto V_s^2}$$

(2) Transmission line losses are minimise

Date

$P = VI\cos\phi$ $\qquad$ $P_{loss} = I^2R$

$I = \dfrac{P}{V\cos\phi}$ $\qquad$ $P_L = \dfrac{P^2 \cdot R}{V^2\cos^2\phi}$ — (1)

$$\boxed{P_L \propto \frac{1}{V^2}}$$

Condition:- $P, R, \cos\phi$ = constant.

(3) Area of cross section and volume of conductor is minimised.

$R = \dfrac{\rho l}{A}$ $\qquad$ $A = \dfrac{\rho l}{R} = \dfrac{\rho l \cdot P^2}{V^2 \cos^2\phi P_L}$ [from (1)]

$$\boxed{A \propto \frac{1}{V^2}}$$

Volume = $K = Al$ $\qquad$ $\boxed{K \propto A \propto \frac{1}{V^2}}$

Condition: $\rho, l, R, P_L, \cos\phi$ = constant

(4) By reducing volume material requirement will be reduce. So the cost is minimised.

Because of above advantage we operating voltage of x-mission sys. is ranges from 11 - 33 - 132 - 220 - 400 - 765 KV.

• Limitat^n. (1) Beyond 765 KV more insulation required which increases the cost of x-mission

• Methods of Reducing X_L:

$$\boxed{P_{max} \propto \frac{1}{X_L}}$$

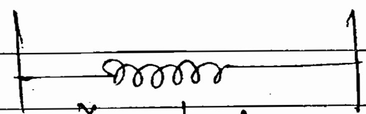
Date

↳ By reducing X_L P_{max} is increased.

(a) By using parallel (or) double circuit line

Single line

$|V_S| = 1$ $\quad |V_R| = 1$

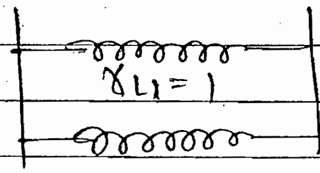


$X_L = 1\,pu.$

$P_{max_1} = \frac{1 \times 1}{1} = 1\,p.u.$

Double line

$|V_S| = 1$ $\quad |V_R| = 1$



$X_{L_1} = 1$

$X_{L_2} = 1$

$X_L = \frac{1 \times 1}{1+1} = 0.5$

$P_{max_2} = \frac{1 \times 1}{0.5} = 2$

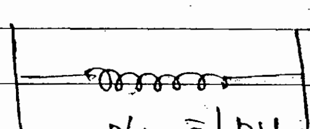
$$\boxed{P_{max} \propto \frac{1}{X_L}}$$

$P_{max_2} > P_{max_1}$

(b) By using series capacitor

Without Series Capacitor

$|V_S| = 1$



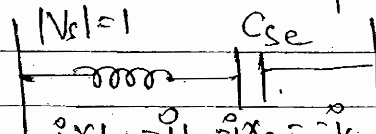
$|V_R| = 1$

$X_{L_1} = 1\,pu$

$P_{max_1} = \frac{1 \times 1}{1} = 1\,p.u.$

With Series Capacitor [Cse]

$|V_S| = 1$ $\quad C_{se}$ $\quad |V_R| = 1$



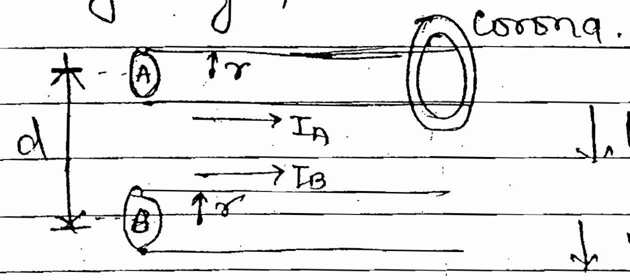
$jX_{L_1} = j1 \quad -jX_C = -j0.5$

$X_L = 1 - 0.5 = 0.5$

$P_{max_2} = \frac{1 \times 1}{0.5} = 2 > P_{max_1}$

Date________

(c) By using Bundle Conductors :-



$\downarrow L_A = L_B = 2\times10^{-7} \ln\left(\dfrac{d\downarrow}{\underbrace{0.7788\,r\uparrow}_{\downarrow\ \text{Bundle conductor}}}\right)$

$\downarrow X_l = 2\pi f L_A \downarrow$

$\uparrow P_{max} \propto \dfrac{1}{X_L\downarrow}$

↳ By $\downarrow X_L$ we can $\uparrow P_{max}$, we can $\downarrow X_L$ by $\downarrow L_A$
L_A can be $\downarrow$ by (1) $\downarrow d$ (2) $\uparrow r$.

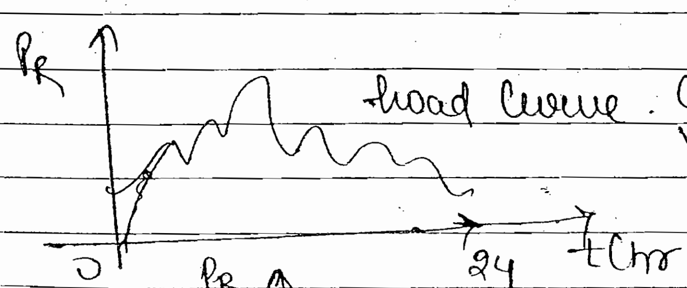
- $0.7788r \rightarrow$ Bundle Conductor.

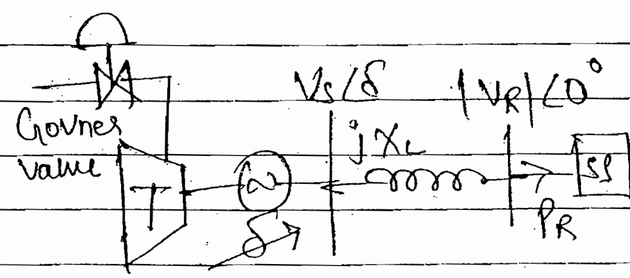
↳ By $\downarrow d$(diameter) $\rightarrow$ effect corona losses so we $\uparrow r$

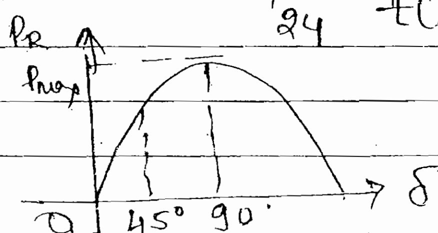
- By using Bundle conductor effective radius of conductor is $\uparrow$ so that L and X_L are $\downarrow$
 P_{max} increases.

★ $P_s = P_R = P_{max}\sin\delta$ $\qquad P_R = \left|\dfrac{V_s^2}{X_L}\right| \sin\delta$

SS $\rightarrow P_R$ substatⁿ
- → Colleges — 9 AM to 5 pm
- → Shop — 10 Am to 10 pm
- → hospital → 24 hours.







$P_R = \left|\dfrac{V_s V_R}{X_L}\right| \sin\delta$

can't use as changing parameter

Date________

- **Importance of δ :-**

(1) Load demand is continously variable parameter w.r.t time. for supplying this variable load, load or power angle δ is selected as variable.

Practical value of δ → 32° to 45° due to stability limitation.

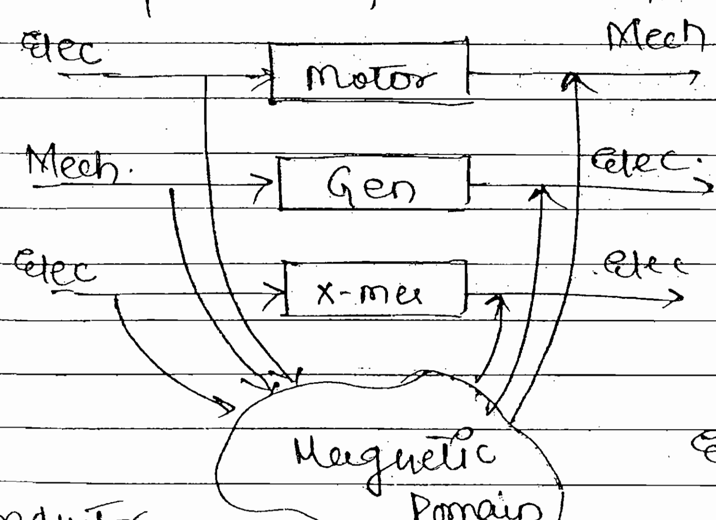
(2) Voltage Regulation is to be minimum or zero.

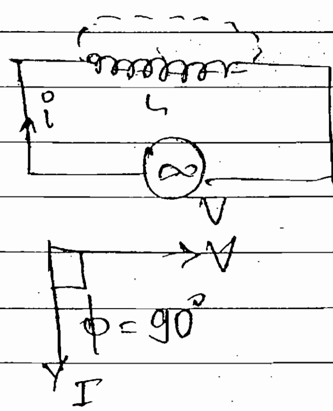
$$\% V_{REG} = \frac{|V_S| - |V_R|}{|V_R|} \times 100.$$

If $|V_S| = |V_R| \Rightarrow \boxed{V_{REG} = 0\%}$

- For controlling the voltage reactive power of the supply has to be control

- **Important of Reactive Power :-**





Inductor consume reactive power for producing $\frac{1}{2} L I^2$ Magnetic domain

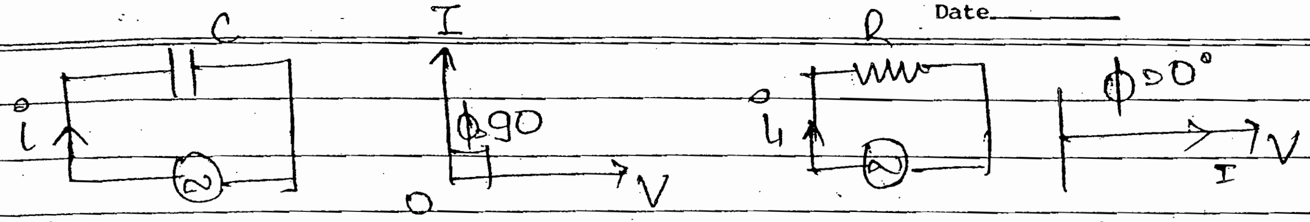
$$\text{Energy} = \frac{1}{2} L I^2$$
$$= \text{Power} \times \text{time}$$

$Q = VI \sin\phi$ $\quad P = VI \cos\phi$

$= VI \sin 90°$ $\quad P = VI \cos 90°$

$= VI$ $\quad = 0.$

Date



Energy = $\frac{1}{2} CV^2$ = Power × time

- $P = VI\cos\phi = VI\cos 90° = 0$
- $Q = VI\sin\phi = VI\sin 90°$, $Q = VI$ → $\frac{1}{2}CV^2$

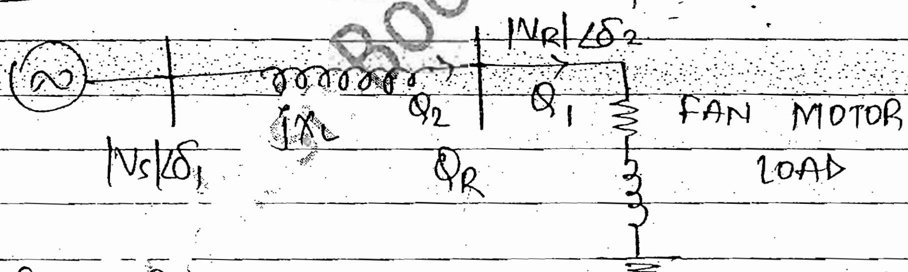
Capacitor consume Reactive power for storing energy

Heat = I^2Rt = Power × time

- $P = VI\cos\phi = VI\cos 0°$, $P = VI$ → I^2Rt
- $Q = VI\sin\phi = VI\sin 0°$, $Q = 0$

Resistor consume active power for giving heating effect.

- Relation Between Reactive Power and Voltage



Q_1 = Reactive power demand by load

Q_2 = — " — " supply by source

$Q_R = Q_1 - Q_2$

$$Q_R = \left|\frac{V_s V_R}{X_L}\right| \cos(\delta_1 - \delta_2) - \left|\frac{V_R^2}{X_L}\right|$$

Assume $(\delta_1 - \delta_2) \approx 0$

$$Q_R = \left|\frac{V_s V_R}{X_L}\right| - \left|\frac{V_R^2}{X_L}\right|$$

$V_R^2 - V_S V_R + X_L \cdot Q_R = 0$ $\quad [ax^2 + bx + c = 0]$

$$V_R = \frac{V_S}{2} \pm \frac{\sqrt{V_S^2 - 4X_L Q_R}}{2}$$

(1) $$\cancel{V_R} = \frac{V_S}{2} + \frac{\sqrt{V_S^2 - 4X_L Q_R}}{2}$$

(a) If $Q_R = 0 \Rightarrow Q_1 = Q_2$

$V_R = V_S \Rightarrow V_{REG} = 0\%$

(b) If $Q_R > 0 \Rightarrow Q_1 > Q_2$

$V_R < V_S$

$\Rightarrow V_{REG} = +ve$

- Occur during peak load timing

(c) If $Q_R < 0 \Rightarrow Q_1 < Q_2$

$V_R > V_S$

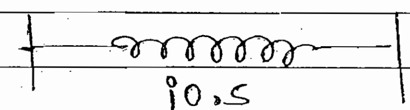
$\Rightarrow V_{REG} = -ve$

- Occur during off peak load timing. (Ferranti effect)

(2) $$V_R = \frac{V_S}{2} - \frac{\sqrt{V_S^2 - 4X_L Q_R}}{2}$$ Not a valid eqn.

Q A x-line has a reactance of 0.5 p.u. operating at $V_s = 3$ p.u. and receiving end Reactive power = 0.5 p.u. find voltage drop across the line.

Solution



$Q_R = 0.5$

$V_s = 3$ p.u $\qquad V_R = ?$

$$V_R = \frac{V_s}{2} + \frac{\sqrt{V_s^2 - 4X_L Q_R}}{2}$$

$$= \frac{3}{2} + \frac{\sqrt{3^2 - 4 \times 0.5 \times 0.5}}{2} = 2.914$$

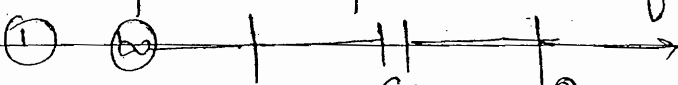
Date

$\Delta V = V_S - V_R = 3 - 2.9 = 0.1 \text{ p.u.}$

$\% V_{REG} = \frac{V_S - V_R}{V_R} \times 100 = \frac{3 - 2.9}{2.9} \times 100 = 3.4\%$ Ans

Q A Nuclear power gen. stat. is generating 500MW to a load center which of the following is more suitable for this power transfer

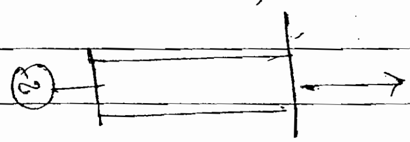
Solution (1)



Cse

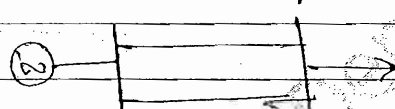
132 KV, 30% Cse

(2)



220KV, Double line

(3)



Load center.

132 KV Double line.

(4)

400KV, Double line.

Q A 133 KV X-line is delivering 10MW. If the line voltage is change to 1338 KV then the power deliver by line is

Solution $P = \frac{V_s^2}{X_L}$ $\quad P \propto V_s^2$

$\frac{P_1}{P_2} = \frac{V_{s_1}^2}{V_{s_2}^2}$ $\qquad P_2 = P_1 \frac{V_{s_2}^2}{V_{s_1}^2} = 160 \text{ MW}.$

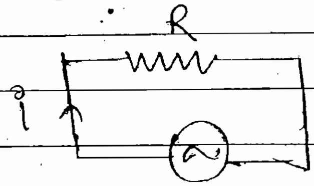
$P_2 = \left(\frac{132}{33}\right)^2 \times 10 = 160 \text{ MW}$

Date________

- **Power Factor:-** For controlling of the voltage reactive power has to be control which is control by using power factor compensation Methods like
(1) Shunt capacitor (2) Shunt Reactor
(3) Syn. phase Modifier (4) Tap changing x-mer etc.

✓ It is a degree at which a given load (RL, RC) matches with that of pure resistive load.

(1) **R-load:-**



$v = V_m \sin\omega t$

$i = \frac{V_m}{R}\sin\omega t$

$i = I_m \sin\omega t$

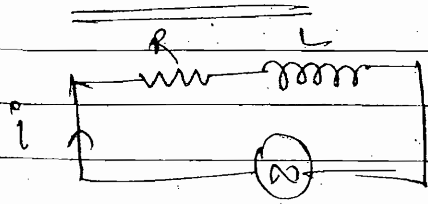
- Instantaneous power.

$$P = v.i$$
$$= V_m I_m \sin^2\omega t$$
$$= \frac{V_m I_m}{2}(1-\cos 2\omega t)$$
$$= \frac{V_m}{\sqrt{2}}.\frac{I_m}{\sqrt{2}}(1-\cos 2\omega t)$$
$$= V_{Rms}.I_{Rms}(1-\cos 2\omega t)$$
$$\boxed{P = VI(1-\cos 2\omega t)}$$

- Average Power

$$P_{avg} = \frac{1}{2\pi}\int_0^{2\pi} p.d(\omega t) \qquad \boxed{P_{avg} = VI = P_R}$$

(2) **RL load:-**



$v = V_m \sin\omega t$

$$i = I_m \sin(\omega t - \phi)$$
$$I_m = \frac{V_m}{Z} = \frac{V_m}{\sqrt{R^2+\omega^2L^2}}$$
$$\phi = \tan^{-1}\left(\frac{\omega L}{R}\right)$$

Date________

- Instantaneous Power:-

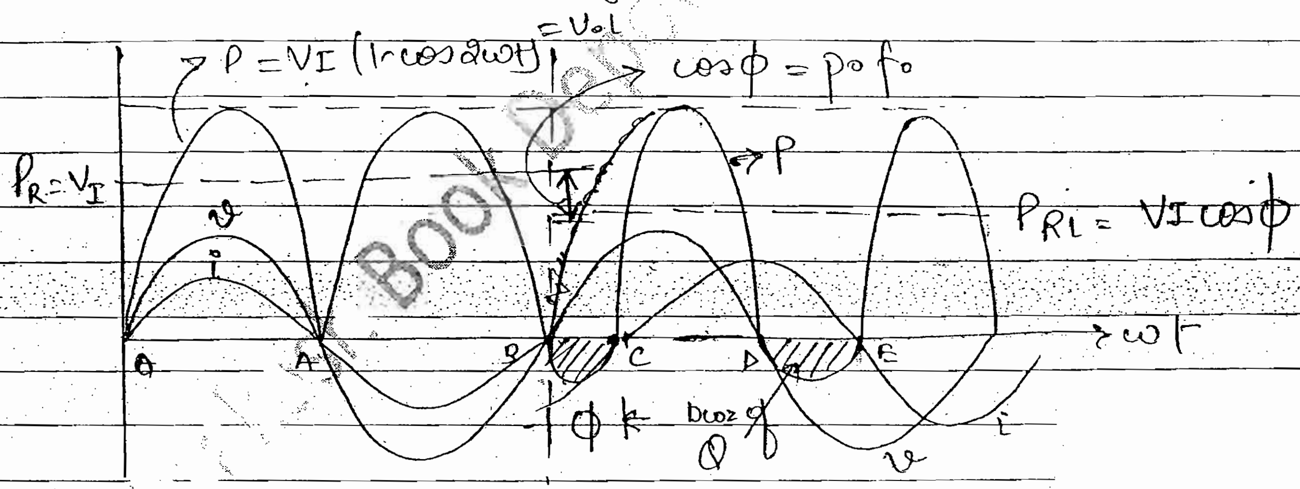
$$p = v \cdot i = V_m I_m \sin\omega t \sin(\omega t - \phi)$$
$$= \frac{V_m I_m}{2} \left[\cos\phi - \cos(2\omega t - \phi) \right]$$
$$= \frac{V_m I_m}{2} \left(\cos\phi (1 - \cos 2\omega t) \right) - \frac{V_m I_m}{2} \sin\phi \sin 2\omega t$$

$$\boxed{p = P(1 - \cos 2\omega t) - Q \sin 2\omega t}$$

where $P = VI\cos\phi$, $Q = VI\sin\phi$

- Avg. Power:-

$$P_{avg} = \frac{1}{2\pi} \int_0^{2\pi} p \cdot d(\omega t) \qquad \boxed{P_{avg} = VI\cos\phi = P_{RL}}$$



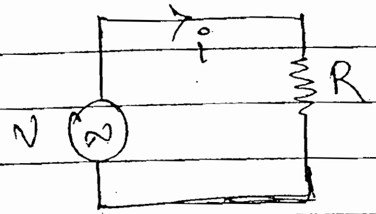
$$\boxed{\frac{P_{RL}}{P_R} = \frac{VI\cos\phi}{VI} = \cos\phi = p.f}$$

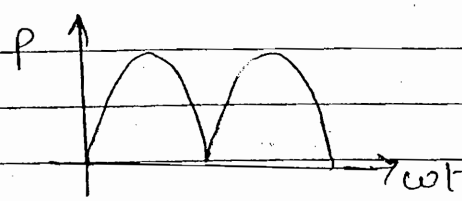
→ average power of RL load reduce due to pos–ve power. (This is due to reactive power)

→ In –ve portion power deliver by L to source

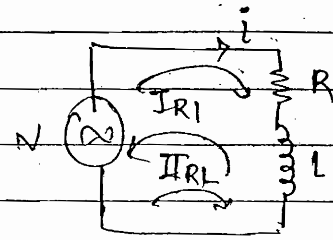
Date

- **R-Load :-**

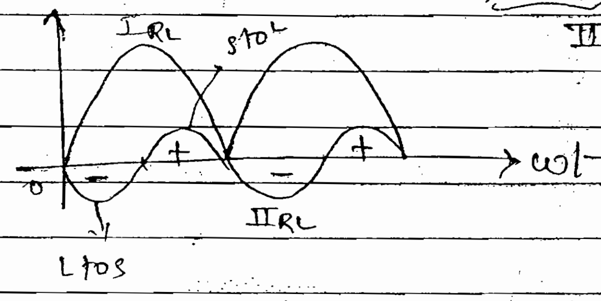




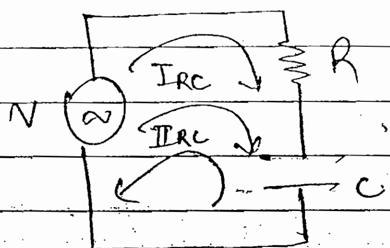
- **RL Load :-**



$$p = \underbrace{P(1-\cos 2\omega t)}_{I_{RL}} - \underbrace{Q\sin 2\omega t}_{II_{RL}}$$

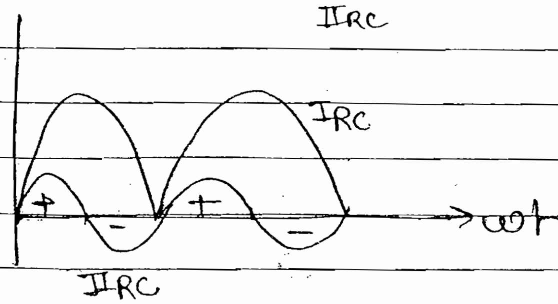


- **RC Load :-**

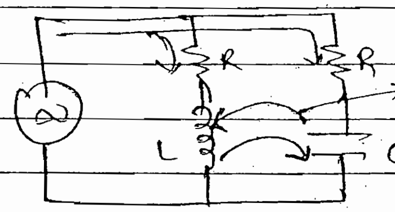


$p = vi$

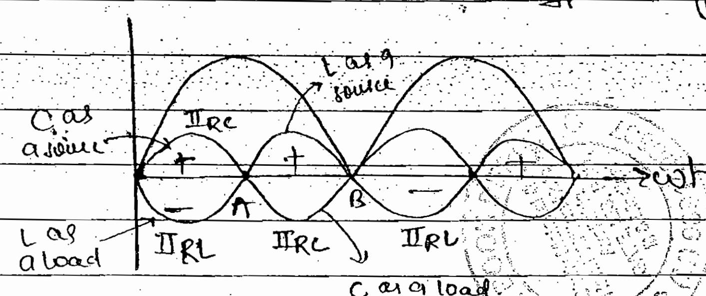
$= \underbrace{P(1-\cos 2\omega t)}_{I_{RC}} + \underbrace{Q\sin 2\omega t}_{II_{RC}}$



- **RL & RC combine ! -**



power exchange b/w L & C by some time delay



	(Deliver) Source	(Absorb) Sink
L	Leading VARs	Lagging VARs
C	Lagging VARs	Leading VARs

→ Inductor absorb lagging power and deliver leading power

→ Capacitor absorb leading power and deliver lagging power

Date________

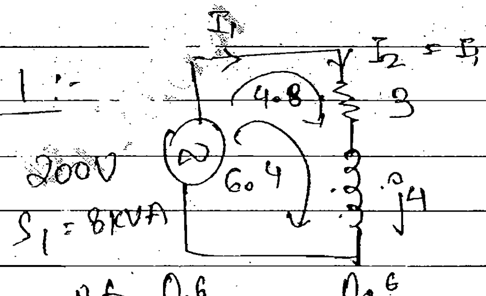
- If the voltage regulation is +ve indicates lagging VAR's demand is more than supply. By using a capacitor lagging VAR's can be compensated so that voltage regulation is zero and improvement of power factor can be achieve.

- If the voltage regulation is -ve indicates lagging VAR's demand is less than supply. For absorbing this excess lagging VAR's inductor or shunt reactor has to be used so that zero voltage regulation can be achieved.

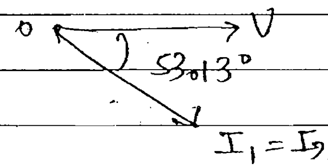
Q1 A single-ϕ Induction Motor having Impedance of $3+j4$ is connected to 200 V supply. Find currents and power and power factor of the load and source.

Q2 If the capacitance of $-j6.25$ is connected parallel to I/M. Find currents, p.f. and powers across each device

Solution 1 :-



$I_1 = I_2 = \frac{200}{3+j4} = 40\angle -53.13^\circ$



$\cos\phi_1 = \cos\phi_2$
$= 0.6$

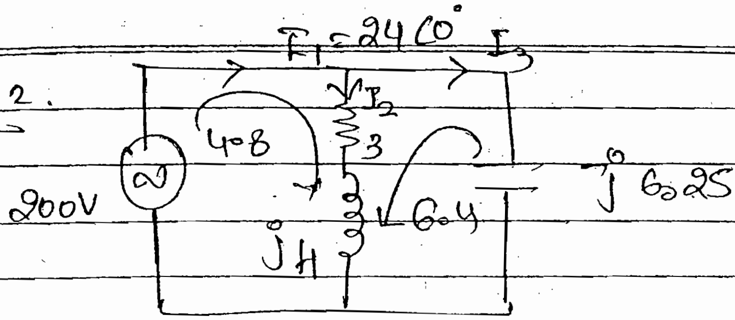
$S_1 = S_2 = V \cdot I_1^*$
$= 200 \times (40\angle -53.13^\circ)^*$
$= (4.8 + j6.4)$ KVA

$P_2 = 4.8 KW \qquad Q_2 = 6.4$ KVAR

$|S_1| = 8KVA$

Date________

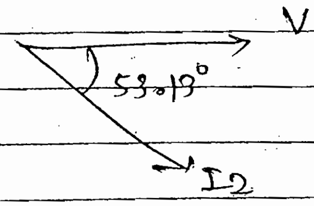
Solution 2.



$I_2 = \dfrac{200}{3+j4}$

$= 40\angle -53.13^\circ$

p.f = 1 0.6 0



$\cos\phi = \cos 53.13^\circ = 0.6$

$S_2 = V_2 I_2^* = 200 \times (40\angle -53.13^\circ)^*$

$= (4.8 + j6.4)$ KVA.

$I_3 = \dfrac{200}{-j6.25} \Rightarrow 32\angle 90^\circ$

$\cos\phi_3 = \cos 90^\circ = 0$

$S_3 = V \cdot I_3^* = 200 \times 32\angle 90^\circ$

$= -j6.4$ KVA

$= 0 - j6.4$ KVAR

$I_1 = I_2 + I_3$

$= 40\angle -53.13^\circ + 32\angle 90^\circ$

$= 24\angle 0^\circ$

$\cos\phi_1 = \cos 0^\circ = 1$

$S_1 = V \cdot I_1^*$

$= 200 \times 24\angle 0^\circ$

$= 4.8$ KW.

$= 4.8 + j0$ KVA

$|S_1| = 4.8$ KVA.

- Advantage of Higher P.F.:-

(1) Current through X-line reduce

(2) X-mission η improves.

(3) Power loss is reduce

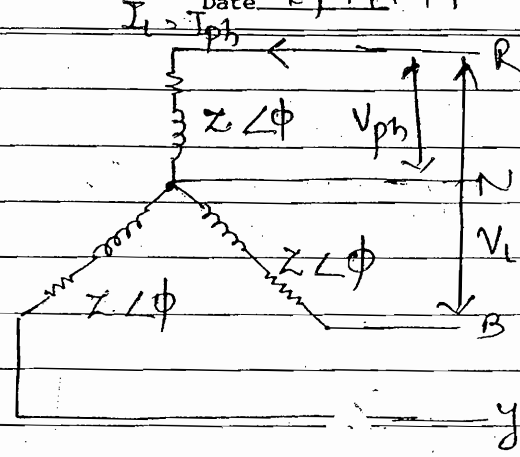
(4) Voltage regulatn can be minimised

(5) Rated of generator is minimised

Date 6/7/2014

- **Star**

$$V_{ph} = \frac{V_L}{\sqrt{3}} \quad , I_{ph} = I_L$$



$$P_{3\phi} = \sqrt{3} V_L I_1 \cos\phi$$

$$= \left|\frac{V_L^2}{Z}\right| \cos\phi$$

$$Q_{3\phi} = \left|\frac{V_L^2}{Z}\right| \sin\phi .$$

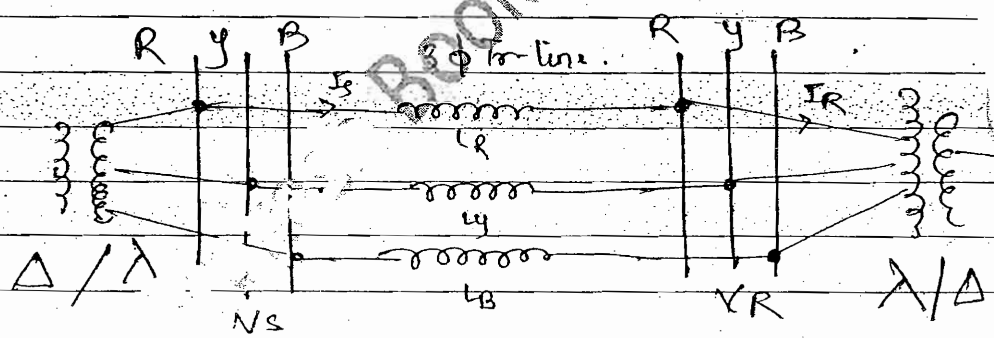
- **Delta** $\quad V_{ph} = V_L \qquad I_{ph} = I_L/\sqrt{3}$

$$P_{3\phi} = \sqrt{3} V_L I_L \cos\phi = 3\left|\frac{V_L^2}{Z}\right| \cos\phi$$

$$Q_{3\phi} = 3\left|\frac{V_L^2}{Z}\right| \sin\phi$$

$$\boxed{Q_{3\phi} = P_{3\phi} \cdot \tan\phi}$$

-



→ Y & Δ are neither series connected nor parallel connected.

$$\left.\begin{matrix} R, L, C, G \\ \text{or} \\ A, B, C, D \end{matrix}\right\} \rightarrow$$ 3ϕ Tr-line are represented in per phase only

ex:-1

$$V_S = A V_R + B I_R$$

? ph ~~ph~~ V_L ph ?

Date________

→ convert all terms in phase values.

$$V_{sph} = A\frac{V_R}{\sqrt{3}} + B.I_R$$

[By V_R related to $\sqrt{3}$. I_R remain same.

$$\boxed{V_{SL} = \sqrt{3}\,V_{sph}}$$

$$I_S = C V_R + D I_R$$

I_S ↓ ?, C ↓ ph, V_R ↓ ~~ph~~ L, D ↓ ph, I_R ↓ ?

$$I_{sph} = C\frac{V_R}{\sqrt{3}} + D.I_R$$

$$\boxed{I_{SL} = I_{sph}}$$

As V_R related to $\sqrt{3}$. $I_{SL} = I_{sph}$

ex:- 2

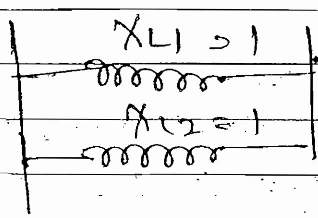
$$P_R = \left|\frac{V_s V_R}{X_L}\right| \sin\delta$$

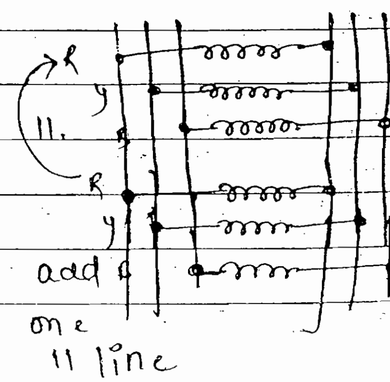
$$P_{Rph} = \left|\frac{V_{sph}.V_{Rph}}{X_{Lph}}\right| \sin\delta$$

$$P_{R,3\phi} = 3\left|\frac{V_{sph}.V_{Rph}}{X_{Lph}}\right| \sin\delta = \cancel{3}\left|\frac{\frac{V_{SL}}{\cancel{\sqrt{3}}}\cdot\frac{V_{RL}}{\cancel{\sqrt{3}}}}{X_{Lph}}\right| \sin\delta$$

$$P_{R,3\phi} = \left|\frac{V_{SL}.V_{RL}}{X_{Lph}}\right| \sin\delta.$$

- voltages are always line values whereas R, L, C, G A, B, C, D parameters are always in per phase values. in 3ϕ





$$X = \frac{1 \times 1}{1+1} = 0.5$$

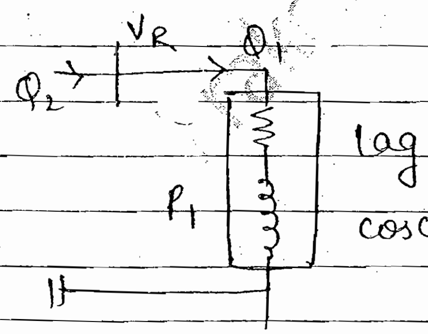
• Methods of Reactive Power Control :-

Receiving End Methods	Source End Method.
(1) Shunt Capacitor	(1) Gen. excitatⁿ Control.
(2) Shunt Reactor	
(3) Series Capacitor	
(4) Syn. phase Modifier (SPM)	
(5) On-load Tap changing (OLTC) X-mes	
(6) Booster X-mes	

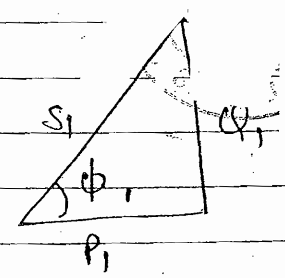
(1) Shunt Capacitor Compensation :-

Shunt Capacitor is used for :-
(1) Improve voltage regulation
(2) Improve power factor
(3) Improve sys. stability. By reducing load angle δ.

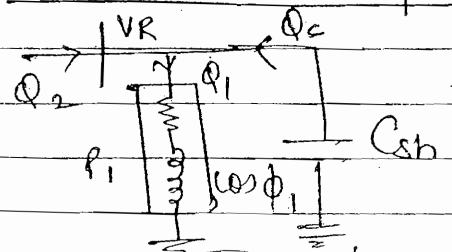
(a) without Shunt capacitor :-

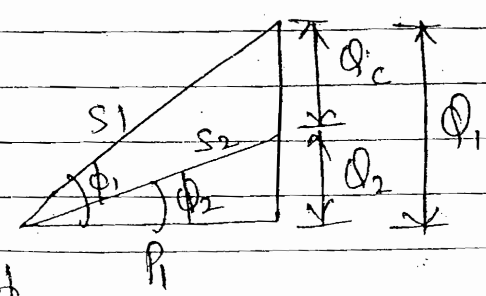


Assume
$Q_1 > Q_2$
$V_R < V_S$



(b) With Shunt Capacitor :-





$\cos\phi_2 > \cos\phi_1$

Date________

Q_c = VAR Rating of C_{sh}.

$Q_1 = Q_2 + Q_c$ $\qquad$ $Q_c = Q_1 - Q_2$

$$\boxed{Q_c = P_1(\tan\phi_1 - \tan\phi_2)}$$

Q_c = 3ϕ VAR Rating of C_{sh}.

P_1 = 3ϕ Input Active power to load.

$= \dfrac{P_0}{\eta}$

• Practical Arrangement of Cap. Bank In Substation :-

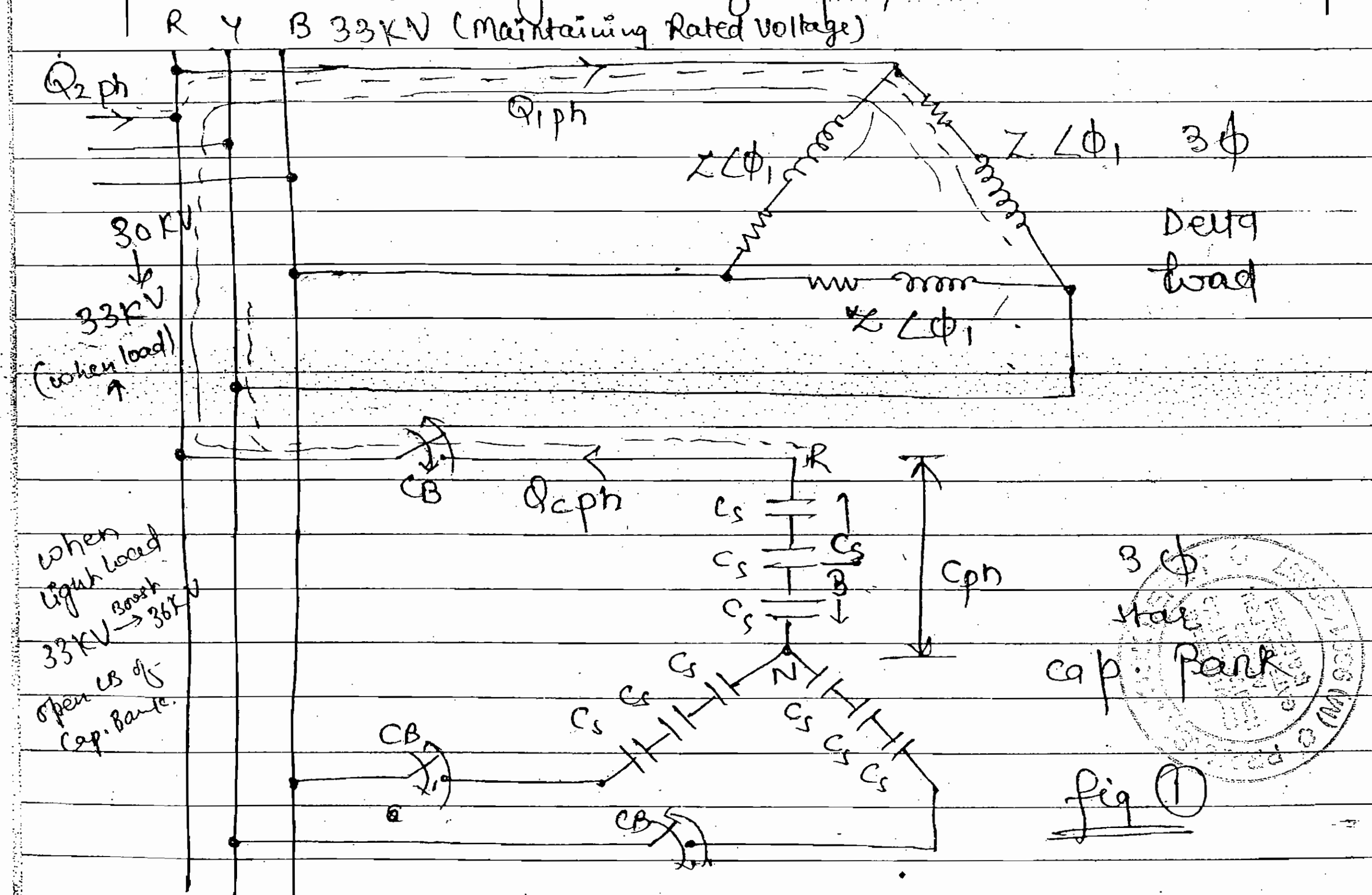


fig (1)

• Capacitor per phase [Cph] :-

$Q_{cph} = V_{ph} \cdot I_{ph} \cdot \sin\phi$

Date

For pure capacitor $\phi = 90°$, $I_{ph} = \frac{V_{ph}}{X_C} = 2\pi f C_{ph} V_{ph}$

$$Q_{cph} = V_{ph} (2\pi f C_{ph} V_{ph}) \sin 90°$$

$$\boxed{Q_{cph} = 2\pi f C_{ph} \cdot V_{ph}^2}$$

$$C_{ph} = \frac{Q_{cph}}{2\pi f V_{ph}^2} = \frac{Q_C}{3(2\pi f V_{ph}^2)}$$

$$\boxed{C_{ph} = \frac{\overset{\text{load power}}{P_1} (\tan\phi_1 - \tan\phi_2)}{3(2\pi f V^2_{ph})}}$$

(1) Star Cap. Bank = $V_{ph} = \frac{V_L}{\sqrt{3}}$

(2) Delta Cap. Bank = $V_{ph} = V_L$

- Capacitance of Each Cell :- [Cs] :-

$\boxed{C_s = n C_{ph}}$ n = No. of cells/phase

- In cap. Bank, multiple capacitor are used Bcoz if we use single capacitor insulatn ↑, cost ↑.

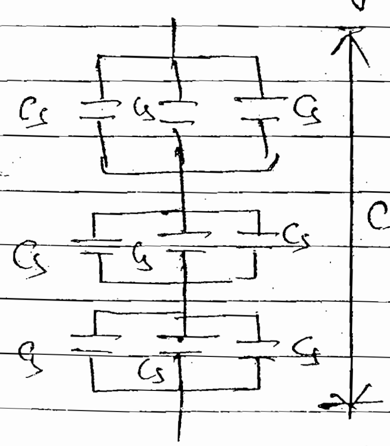


fig ① can also show as.

Date

Q A 3ϕ IM having p.f = 0.6 lag is connected to a O/p load of 9 MW and has η of 90%. Find the rating of shunt capacitor required for improving the power factor to 0.8 lagging

Solution $\eta = \frac{O/p}{I/p}$ $\quad I/p = \frac{O/p}{\eta} = \frac{9}{0.90} = 10$ MW

$Q_c = 10[\tan\phi_1 - \tan\phi_2]$

$= 10[\tan\cos^{-1}0.6 - \tan\cos^{-1}0.8]$

$= 5.8$ MVAR.

Q A 3ϕ I/M connected in Δ across 11 KV and the Motor has impedance of $3+j4\ \Omega$/phase a star connected cap. Bank is used for improving p.f to 0.9 lag If the capacitor Bank has 5 cells per phase Calculate capacitance of each cell.

Solution $C_s = 5C_{ph}$. $\quad Q = 2\pi f C_{ph} V_{ph}^2$

Δ load:- $P_1 = \frac{3V_L^2}{Z}\cos\phi = \frac{3 \cdot 11^2}{\sqrt{3^2+4^2}}\cos\left[\tan^{-1}\frac{4}{3}\right]$

$P_1 = 43.56$ MW

$C_s = nC_{ph} = \frac{n \cdot P_1(\tan\phi_1 - \tan\phi_2)}{3(2\pi f V_{ph}^2)}$

$= \frac{5 \times 43.56(\tan\cos^{-1}0.6 - \tan\cos^{-1}0.9)}{3(2\pi \times 50 \times (11/\sqrt{3})^2}$

$C_s = \frac{217.8\,(0.8490)}{38013.27} = 4.86 \times 10^{-3}$

dangerous than current.

Date________

- Capacitor Banks are used in the 33 and 132 KV substation.

(2) Shunt Reactor [L_{sh}]:-

Shunt Reactor is used:-

(1) For compensation of Ferranti Effect.
(2) Changes the factor from leading to lagging. That is p.f. is reduce.
(3) System Stability is reduce By increasing δ.

Ferranti Effect:- Neglecting R, & G parameter.

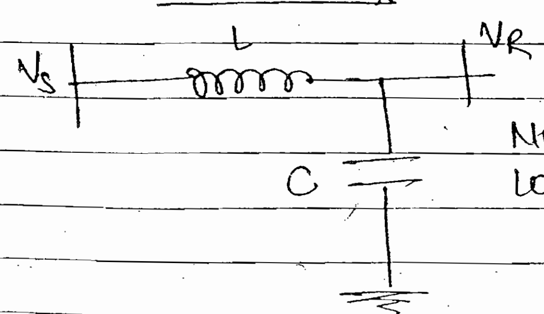
In case of NO LOAD or LIGHT LOAD due to RC component of the Tr-line VAR $V_R > V_S$ occures and this is dominant in medium and long Tr-line. For compensating this ferranti effect shunt reactor is used.

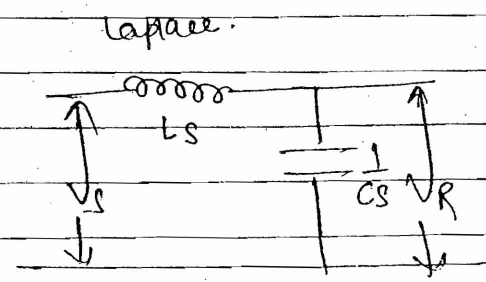
- Voltage is more dangerous than current.

Voltage $\uparrow \longrightarrow$ insulation Breakdown

Current $\uparrow \longrightarrow \underbrace{I^2R \text{ losses}}_{\text{delay.}} \longrightarrow$ insulat^n failure

- Shunt Reactor are used in 400 KV and 765 KV substation.





L, C = Tr-line parameter

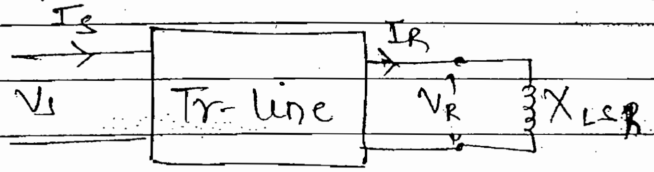
$$V_R = \frac{V_s \cdot \frac{1}{Cs}}{Ls + \frac{1}{Cs}} = \frac{V_s}{LCs^2 + 1}$$

$$V_R = V_s + V_s \cdot \omega^2 LC$$

$$V_R = V_s + \Delta V_R$$

$$\boxed{\Delta V_R = V_s \omega^2 LC} \qquad \boxed{V_R > V_s}$$

Compensation of Ferranti Effect :-



$$X_{Lsh} = \text{Reactance of } L_{sh} = \frac{V_R}{I_R}$$

At No load $\quad V_R > V_s$

with L_{sh} :- $\quad V_R = V_s$

$$V_R = AV_R + BI_R \qquad [V_s = AV_R + BI_R]$$

$$V_R[1-A] = B \cdot I_R$$

$$\boxed{X_{Lsh} = \frac{V_R}{I_R} = \frac{B}{(1-A)}}$$

$$V_s = AV_R + BI_R$$

At No load :- $\quad I_R = 0 \Rightarrow V_s = AV_R$

$$\boxed{V_R = V_s / A}$$ $V_R \rightarrow$ Receiving end voltage

$$I_s = CV_R + DI_R$$

At No load $\quad I_R = 0 \Rightarrow \boxed{I_s = CV_R}$

I_s = charging current of line $= I_c$

Date________

$$V_{Rph} = \frac{V_{sph}}{A_{ph}} \Rightarrow \frac{V_{RL}}{\cancel{\sqrt{3}}} = \frac{V_{SL}}{\cancel{\sqrt{3}}\, A_{ph}}$$

$$\boxed{V_{RL} = \frac{V_{SL}}{A}}$$

$A \to$ phase value.

$$I_{s_{ph}} = I_{C_{ph}} = C_{ph} \cdot V_{R_{ph}}$$

$$\boxed{I_C = C \cdot \frac{V_{RL}}{\sqrt{3}}}$$

Q A 3ϕ Tr-line has $V_s = 400\,KV$ $A = D = 0.8\angle 0^\circ$ $B = 100\angle 90^\circ\,\Omega$, $C = 0.5\times10^{-6}$ ℧ (1) Calculate V_R and I_C on no load (2) Shunt Reactor required for compensating ferranti effect.

Solution $V_R = \frac{V_s}{A} = \frac{400}{0.8\angle 0^\circ} = 500\,KV$

$$X_{Lsh} = \frac{B}{(1-A)} = \frac{100\angle 90^\circ}{(1 - 0.8\angle 0^\circ)} = \frac{100\angle 90^\circ}{0.2}$$

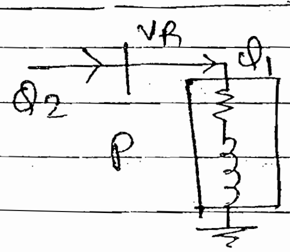
$$= 500\angle 90^\circ$$

$$I_C = C \times \frac{V_{RL}}{\sqrt{3}} = 0.5\times10^{-6} \times \frac{500\times10^3}{\sqrt{3}}$$

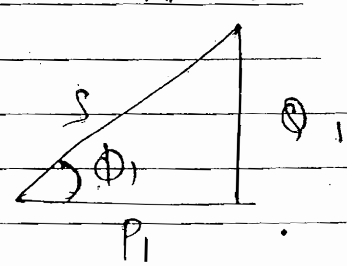
$$= 0.14\ A/\text{phase}.$$

(a) Without L_{sh}: Assume $Q_1 < Q_2$

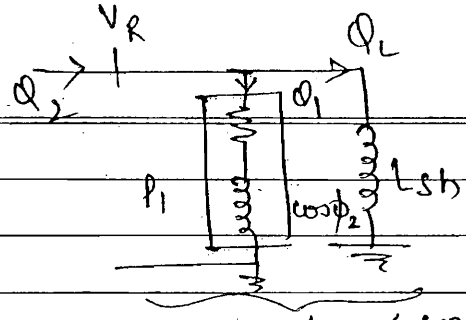
$V_R > V_s$

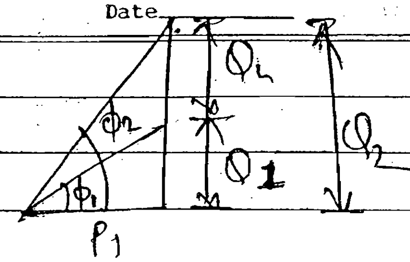


lag $\cos\phi_1$



(3) With L_{sh} :-





$\cos\phi_2 < \cos\phi_1$

Q_L = 3φ VAR Rating of L_{sh} :-

$$Q_2 = Q_1 + Q_L \qquad Q_L = Q_2 - Q_1$$

$$\boxed{Q_L = P_1(\tan\phi_2 - \tan\phi_1)}$$

Inductance per phase [L_{ph}]:-

$$Q_{Lph} = V_{ph} \cdot I_{ph} \sin\phi$$

For pure L_{sh}, $\phi = 90°$, $I_{ph} = \dfrac{V_{ph}}{2\pi f L_{ph}}$

$$\boxed{Q_{L\,ph} = \frac{V_{ph}^2}{2\pi f L_{ph}}} \qquad \boxed{L_{ph} = \frac{V_{ph}^2}{2\pi f Q_{Lph}}}$$

Exam point of view $Q_{Lph} = Q_L / 3$

- Relation Between Q, f, V :-

(1) Shunt Capacitor:-

$$Q_{cph} = 2\pi f V_{ph}^2 C_{ph}$$

$$\boxed{Q \propto f V^2}, \qquad \boxed{\frac{Q_2}{Q_1} = \left(\frac{V_2}{V_1}\right)^2 \left(\frac{f_2}{f_1}\right)}$$

(2) Shunt Reactor :-

$$Q_{Lph} = \frac{V_{ph}^2}{2\pi f L_{ph}}$$

Date

$$\boxed{Q \propto \frac{V^2}{f}} \qquad \boxed{\frac{Q_2}{Q_1} = \left(\frac{V_2}{V_1}\right)^2 \left(\frac{f_1}{f_2}\right)}$$

Q If the voltage ↑ by 10%, f ↓ by 5%. How much of Reactive power has to be compensated using
(1) Shunt Capacitor.
(2) Shunt Reactor

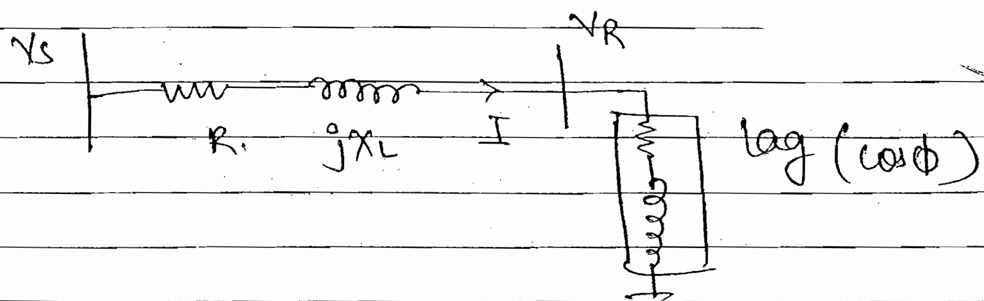
Solut (i) Shunt Capacitor (ii) Shunt Reactor.

$$\frac{Q_2}{Q_1} = \left(\frac{1.01 V_1}{V_1}\right)^2 \times \left(\frac{0.95 f_1}{f_1}\right) \qquad \frac{Q_2}{Q_1} = \left(\frac{1.01 V_1}{V_1}\right)^2 \times \frac{f_1}{0.95 f_1}$$

$Q_2 = 1.15 Q_1$, 15% Excess. $Q_2 = 1.27 Q_1 = 27\%$ Excess

(3) Series Capacitor Compensation:
By using series capacitor :- system. also
(1) System stability ↑
(2) power transferred to the Tr. line is ↑.
(3) Voltage Regulation is reduce.

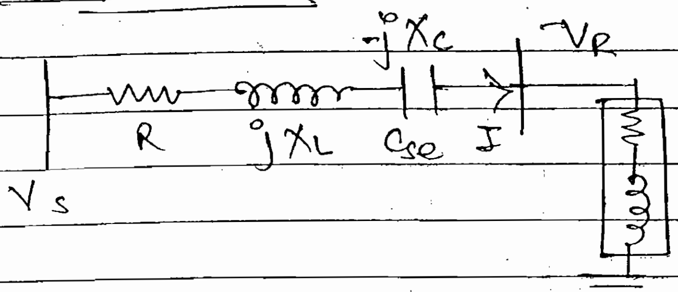
(a) Without C_{se} :-



$$\% V_{REG} = \frac{V_S - V_R}{V_R} \times 100 = \frac{I(R\cos\phi + X_L \sin\phi)}{V_R} \times 100$$

Date

(b) With C_{se} :-



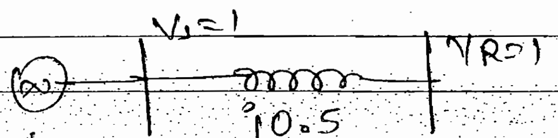
$\boxed{V_{REG2} < V_{REG1}}$

$$\% V_{REG} = \frac{I(R\cos\phi + (X_L - X_C)\sin\phi)}{V_R} \times 100$$

Q. A Tr-line a reactance $Z = 0.5$ p.u is connected b/w generator and load center operating $V_s = V_R = 1$ p.u. If the load 1 p.u is delivered by the line. Find the load angle of the generator

(1) Without compensatⁿ (2) With series cap. compensatⁿ of 0.25 p.u.

Solution (a) Without C_{se} :-



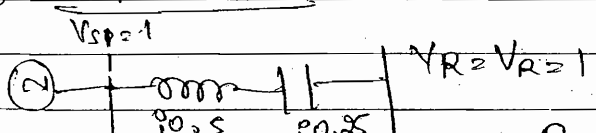
$P_s = P_R = 1$

$$P_s = P_R = \frac{V_s V_R}{X_L} \sin\delta_1$$

$$1 = \frac{1 \times 1}{0.5} \times \sin\delta_1 = 2\sin\delta_1$$

(b) With C_{se} :-

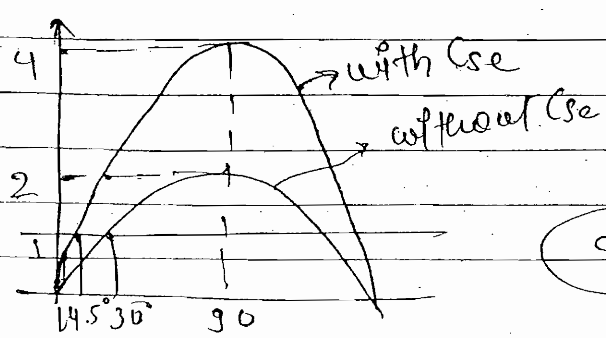
$\boxed{\delta_1 = 30^\circ}$



$$P_s = P_R = \frac{V_s V_R}{(X_L - X_C)} \sin\delta_2$$

$P_s = P_R = 1$

$$1 = \frac{1 \times 1}{(0.5 - 0.25)} \sin\delta_2 = 4\sin\delta_2$$



$\boxed{\delta_2 = 14.5^\circ}$

$\delta_2 < \delta_1$ $\delta_2 \rightarrow$ More Stable

Date________

(4) Synchronous Phase Modifier :- (SPM)

SPM is basically a syn Motor. It is used for

(1) Driving Mechanical load

(2) Controlling the reactive power voltage and p.f.

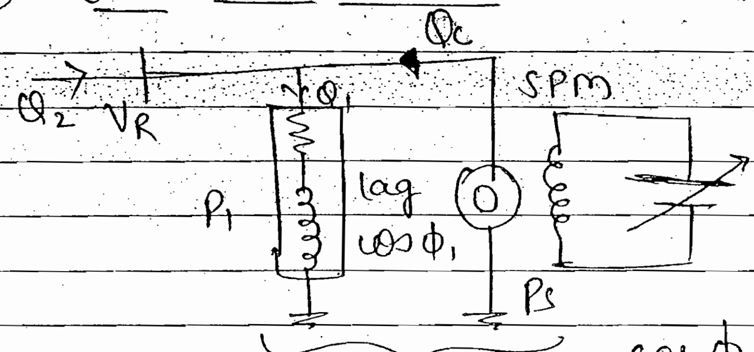
(3) If It is used for driving any mechanical load ~~with~~ than the load angle $\neq 0$ and maintaining b/w $30°$ to $45°$ due to stability limitatⁿ

(4) If it is used for pf or voltage control it is normally normally maintaining at NO LOAD so that $\delta = 0$.

(5) The over excited SPM is used for supply lagging VAR's and working similar to the shunt capacitor.

(6) Under excited SPM is used for absorbing lagging VAR's or delivarying leading VAR's. It is working similar to the shunt Reactor.

(a) Over Excited SPM:- Assume $V_R < V_S$



$\cos\phi_2 > \cos\phi_1$

- Rating of SPM:-

(1) If $P_s \neq 0$

$$Q_c = P_1 \tan\phi_1 - (P_1 + P_s)\tan\phi_2$$

Rating of SPM = $(P_s + jQ_c)$ .... VA $\quad V_A = V_R$

(2) If $P_s = 0$

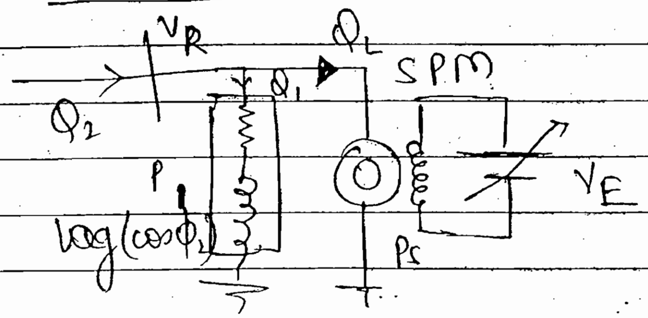
$V_A > V_R$

Date_________

$Q_c = P_1(\tan\phi_1 - \tan\phi_2)$

Rating of SPM $= Q_c$ ---- VA.

(b) Under Excited SPM:- Assum $V_B < V_R$



$\cos\phi_2 < \cos\phi_1$

- Rating of SPM:-

(1) If $P_s \neq 0$

$Q_L = (P_1+P_s)\tan\phi_2 - \tan\phi_1 P_1$

Rating of SPM $= P_s + jQ_L$ ---- VA

(2) If $P_s = 0$

$Q_L = P_1(\tan\phi_2 - \tan\phi_1)$

Rating of SPM $= Q_L$ ---- VA

Q. A 3ϕ IM as a rating of 10 MW 0.6 lagging is connected with SPM for improving pf to 0.8 lag. Find the rating of SPM If SPM

(1) Consume 1 MW of active power

(2) Running under No-load.

Solu: (1) $Q_c = P_1\tan\phi_1 - (P_1+P_s)\tan\phi_2$

$= 10\tan\cos^{-1}0.6 - (10+1)\tan\cos^{-1}0.8$

$= 5.083$

Rating of SPM $= (P_s + jQ_c)$ MVAR

$= (1 + j\,5.083)$ MVA

Date________

(2) No load. $Q_c = P_1(\tan\phi_1 - \tan\phi_2)$

$= 10[\tan\cos^{-1}0.6 - \tan\cos^{-1}0.8]$

$= 5.833$ MVA.

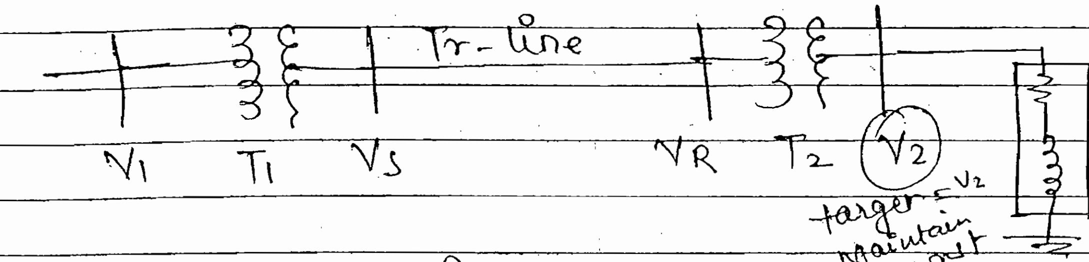
Rating of SPM $= Q_c = 5.833$ MVAR

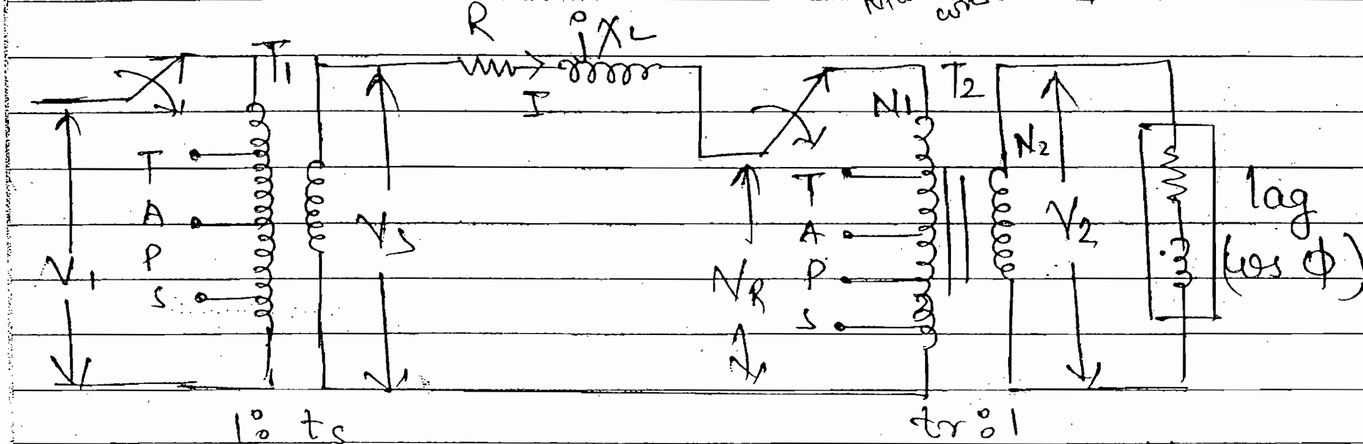
• Comparison Between SPM and Shunt Compensatn.

SPM	Shunt Compensatn
(1) A single unit of SPM can be used both inductor & capacitor by adjusting excitation	(1) Two separate units are required that is inductor & capacitor for adjustment of voltage
(2) Smooth voltage Regulatn is possible	(2) Step By step voltage Regulatn is possible
(3) Initial cost of SPM is higher	(3) Initial cost is low
(4) SPM required More maintenance	(4) It required less maintenance.
(5) Initial starting Methods are required for bringing the syn. Motor upto synchronus speed.	(5) Their is No starting mechanism required.
(6) It consume both active & Reactive power	(6) consume only Reactive power.
(7) Bcoz of above discdv. SPM is practically NOT preferred in the substatn	(7) It is most practically used in substatn for the voltage control.

Date________

(5) OLTC Transformer :-





$\text{const}\ \frac{N_2}{N_1} = \frac{V_2}{V_R}\ \text{const}$

$$\left.\begin{array}{l} \frac{V_1}{V_s} = \frac{1}{t_s} \Rightarrow V_s = V_1 t_s \\[2ex] \frac{V_2}{V_R} = \frac{1}{t_r} \Rightarrow V_R = V_2 t_r \end{array}\right\} \text{— (1)}$$

$$V_s - V_R = RI\cos\phi + X_L I \sin\phi$$

$$I\cos\phi = \frac{P_R}{V_R}, \qquad I\sin\phi = \frac{Q_R}{V_R}$$

$$V_s - V_R = \frac{P_R R}{V_R} + \frac{X_L \cdot Q_R}{V_R}$$

$$V_R V_s - V_R^2 = R P_R + X_L Q_R$$

$$\Rightarrow V_R^2 - V_s V_R + R P_R + X_L Q_R = 0 \quad \text{— (2)}$$

Substitute (1) in (2)

Date

$$\boxed{V_2^2 t_r^2 - V_1 V_2 t_r t_s + RP_R + X_L Q_R = 0}$$

$V_2 = f\,[t_r, t_s]$; V_2 is controlled by controlling Transformer taps t_r, t_s.

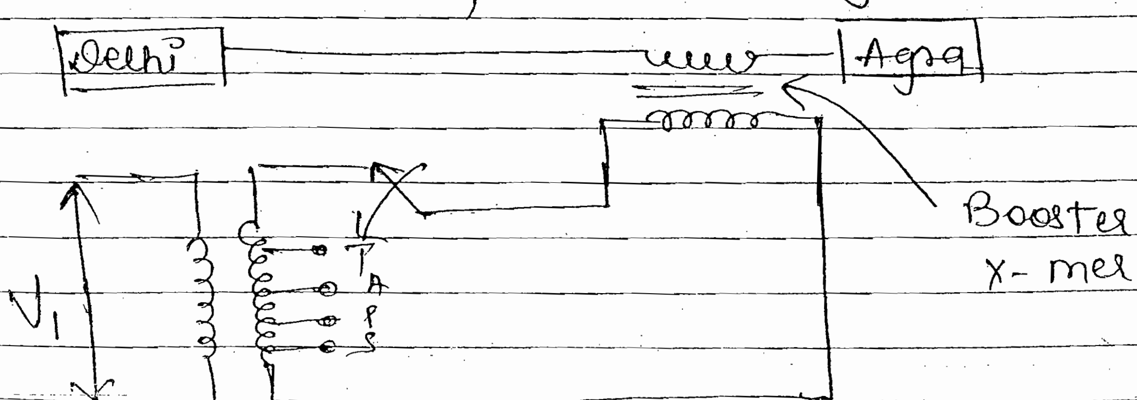
$\boxed{\text{Off Normal Setting} = t_r \cdot t_s = 1}$

- tap changing at H.V bcoz current value is small, small arcing, less heat produce.
- OLTC is most practically used for the voltage control in the substation.
- It is used in all voltage levels like 400/220, 220/132, 132/33 and 33/11 KV
- X-mer normally provided on the H.V side where current is small so that the intensity of arcing is minimized which enhances the life of the X-mer.

- **BOOSTER TRANSFORMER** :- (for line side) (previous decided are for load side)

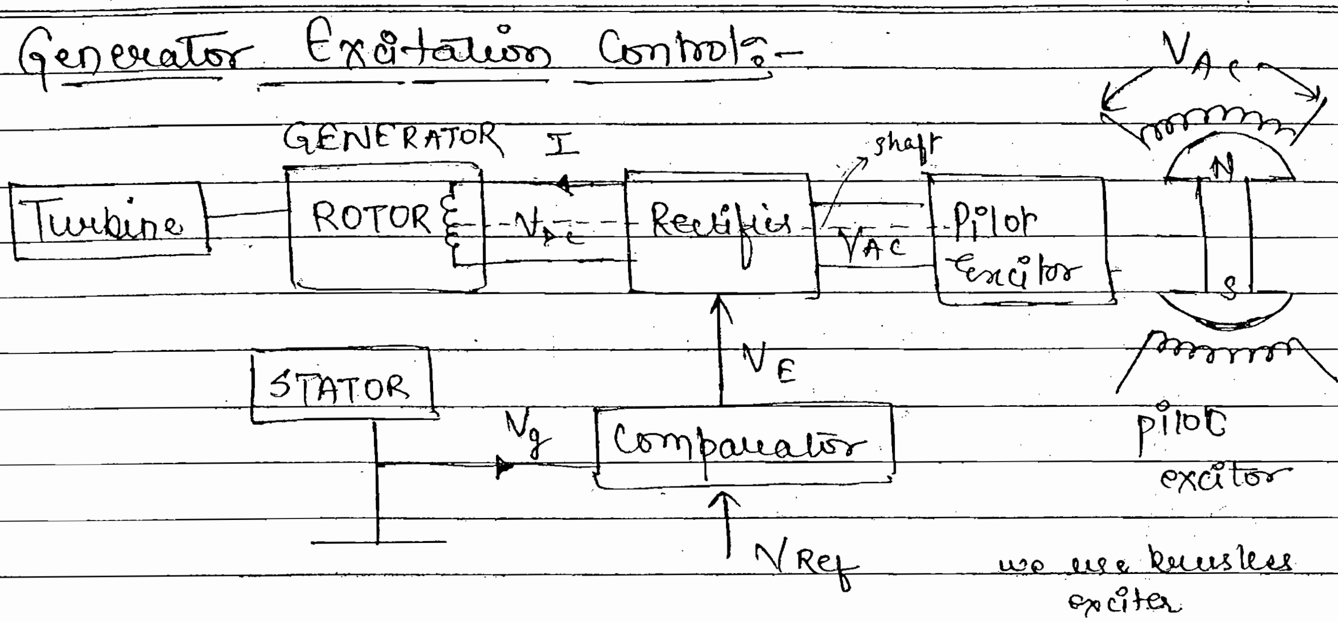
(1) It is used to maintain uniform voltage throughout the Tr-line

(2) It is practically used in remote substatn and in traction applicatn. for maintaining uniform voltage



Date 7/7/14

Generator Excitation Control:-



$V_E = V_g - V_{Ref}$

(1) If $V_g = V_{Ref}$ $\Rightarrow V_E = 0$ $\Rightarrow$ Constant Excitation.

(2) If $V_g > V_{ref}$ $\Rightarrow V_E > 0$ $\Rightarrow$ Reduce excitatn until $V_E = 0$

(3) If $V_g < V_{ref}$ $\Rightarrow V_E < 0$ $\Rightarrow$ Increase excitatn until $V_E = 0$

- Generator excitation control is most practically used for maintaining constant voltage at the terminals of the generator. This method is adopated after applying shunt capacitor and OLTC operation of the x-mer. Because the consumer nearer to be do not experience over voltage. The type of voltage control is called automatic voltage regulation.

- C_{sh1} to C_{sh4} are capacitor Bank used to maintain the voltage.

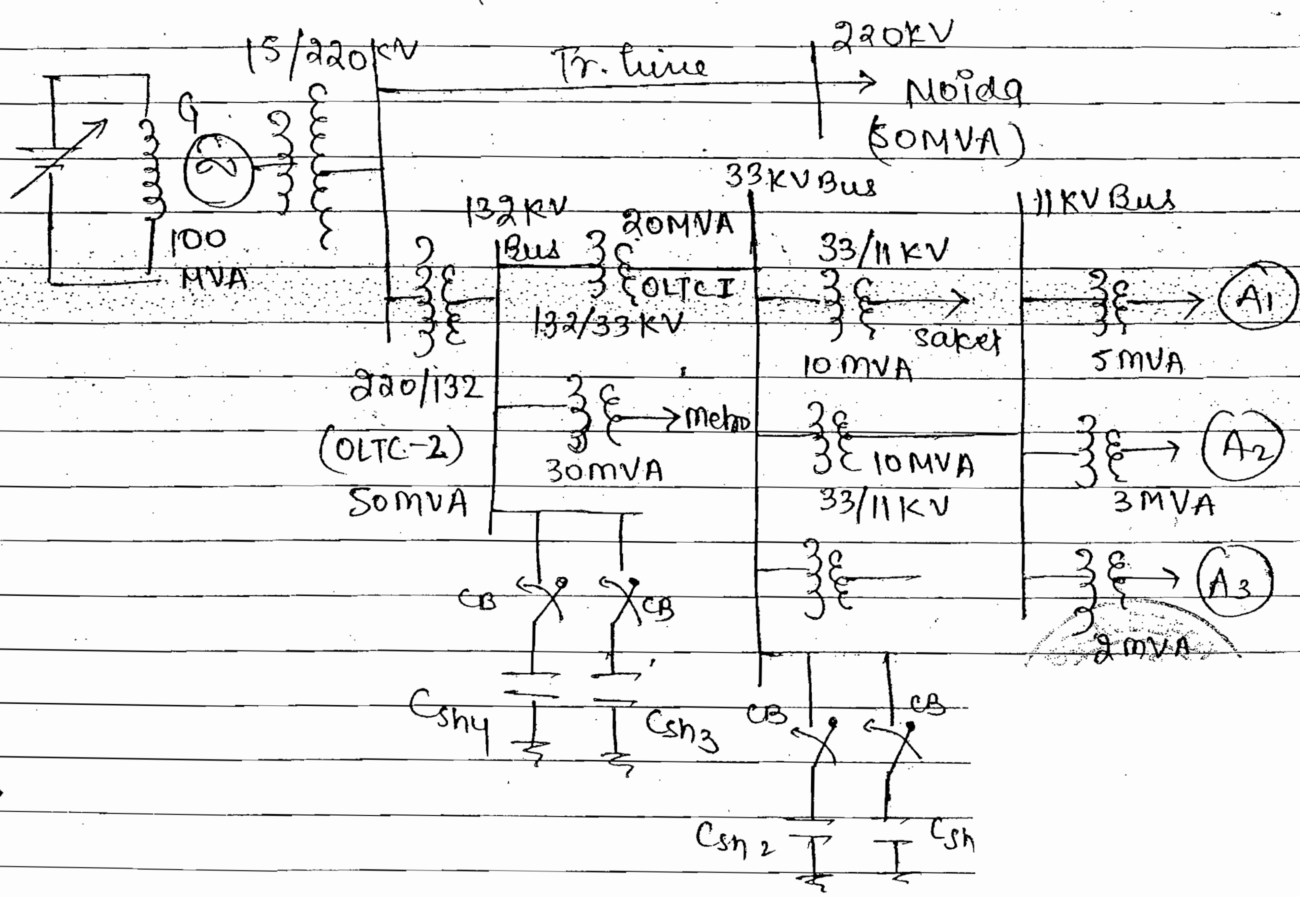
- When there is a voltage drop in 33 KV Bus, C_{sh2} or C_{sh1} or both are switch ON, when still there is not maintaining 33 KV (ex:- 30 KV) go for OLTC-1, when still OLTC-1 get fail to maintain voltage constant, C_{sh1} or C_{sh3} or both

Date________

are switch ON. Before switch ON these two capac. bank, first they check, wheather incoming voltage is 132KV or not. Then they switch ON the the capa. Bank when not maintaining 132kV, go for OLTC-2. When is it ~~not~~ also fail to maintain 220, check the incoming voltage is 220kV or not, then finally go for generator exciter case.

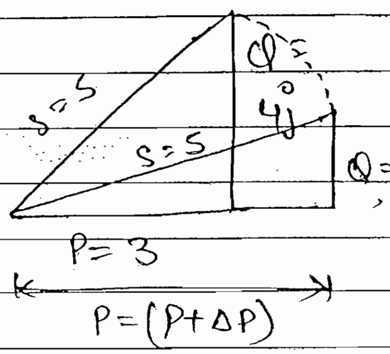
- When there is over voltage same sequence will follow, in this case, cap. Banks are removed.

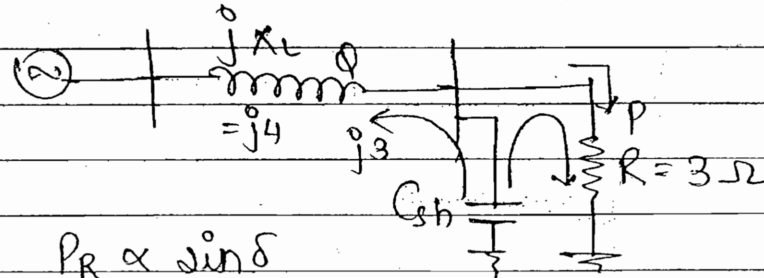
Sequence:- 1) Cap. Bank
2) OLTC
3) Gen. Excitatn.



- Power Flow through Tr-line :-

- When install C_{sh}, burden of reactive power on generator will reduce and convert into active power.
- Gen → only active power, Reactive power by other means.
- Aim → transfer maximum active power through x-line.
- Compensator deliver reactive power to x-line as well as load.





$$P_R \propto \sin\delta$$

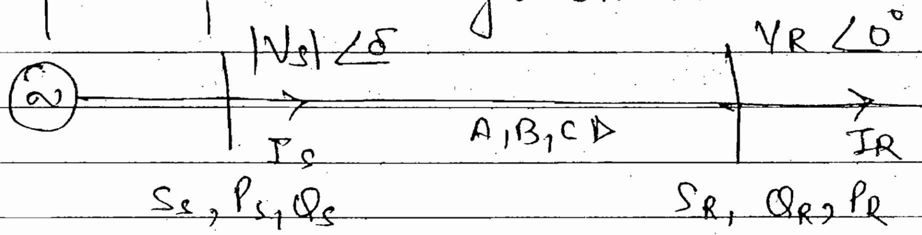
$$Q_R = \frac{V_s V_R \cos\delta}{X_L} - \frac{V_R^2}{X_L}$$

V_R & X_L = constant

$\cos\delta \simeq 1$

$$\boxed{Q_R \propto (V_S - V_R)}$$

- Relation Between ABCD parameter, voltage and power flow through the x-line.



Let $A = |A| \angle\alpha$ $\quad B = |B| \angle\beta$ $\quad C = |C| \angle\gamma$ $\quad D = |D| \angle\alpha$

$V_s = |V_s| \angle\delta$ $\quad V_R = |V_R| \angle 0^\circ$

$$AD - BC = 1$$

Receiving End Power :- $\quad V_s = AV_R + BI_R$

$$I_R = \frac{V_s}{B} - \frac{AV_R}{B} \quad \text{--- (1)}$$

Date

$$= \frac{|V_S| \angle\delta}{|B| \angle\beta} - \frac{|A|\angle\alpha . |V_R| \angle 0^\circ}{|B| \angle\beta}$$

$$I_R = \left|\frac{V_S}{B}\right| \angle\delta-\beta - \left|\frac{A V_R}{B}\right| \angle\alpha-\beta .$$

$$I_R^* = \left|\frac{V_S}{B}\right| \angle\beta-\delta - \left|\frac{A V_R}{B}\right| \angle\beta-\alpha \quad \text{--- } (2)$$

$$S_R = P_R + j Q_R = V_R . I_R^* \quad \text{--- } (3)$$

Substitute (2) in (3).

$$P_R + j Q_R = \left|\frac{V_S V_R}{B}\right| \angle\beta-\delta - \left|\frac{A V_R^2}{B}\right| \angle\beta-\alpha .$$

Separate Real and Imaginary terms.

$$\boxed{\begin{aligned} P_R &= \left|\frac{V_S V_R}{B}\right| \cos(\beta-\delta) - \left|\frac{A V_R^2}{B}\right| \cos(\beta-\alpha) \\ Q_R &= \left|\frac{V_S V_R}{B}\right| \sin(\beta-\delta) - \left|\frac{A V_R^2}{B}\right| \sin(\beta-\alpha) \end{aligned}}$$

Sending End powers:-

$$I_S = C V_R + D I_R \quad \text{--- } (4)$$

Substitute (1) in (4)

$$I_S = C V_R + D\left(\frac{V_S}{B} - \frac{A V_R}{B}\right)$$

$$= \frac{D V_S}{B} + \left(\frac{BC - AD}{B}\right) V_R$$

$$= \frac{D V_S}{B} - \frac{V_R}{B} = \frac{|D| \angle\alpha \, |V_S| \angle\delta}{|B| \angle\beta} - \frac{|V_R| \angle 0^\circ}{|B| \angle\beta}$$

$$I_S = \left|\frac{D V_S}{B}\right| \angle\alpha+\delta-\beta - \frac{V_R}{B} \angle-\beta$$

$$I_S^* = \left|\frac{D V_S}{B}\right| \angle\beta-\alpha-\delta - \left|\frac{V_R}{B}\right| \angle\beta \quad \text{--- } (5)$$

Date

$S_s = P_s + jQ_s = V_s I_s^*$

$= V_s \angle\delta \cdot I_s^*$ —— (6)

Substitute (5) in (6)

$$S_s = P_s + jQ_s = \left|\frac{DV_s^2}{B}\right| \angle\beta-\alpha - \left|\frac{V_s V_R}{B}\right| \angle\beta+\delta$$

Separate Real and Imaginary terms.

$$\boxed{P_s = \left|\frac{DV_s^2}{B}\right| \cos(\beta-\alpha) - \left|\frac{V_s V_R}{B}\right| \cos(\beta+\delta)}$$

$$\boxed{Q_s = \left|\frac{DV_s^2}{B}\right| \sin(\beta-\alpha) - \left|\frac{V_s V_R}{B}\right| \sin(\beta+\delta)}$$

- Condition for Receiving Maximum Active Power :-

$$P_R = \left|\frac{V_s V_R}{B}\right| \cos(\beta-\delta) - \left|\frac{A V_R^2}{B}\right| \cos(\beta-\alpha)$$

δ is variable.

For Receiving ~~end~~ Maximum P_R.

$$\frac{dP_R}{d\delta} = 0$$

$$\Rightarrow -\left|\frac{V_s V_R}{B}\right| \sin(\beta-\delta) = 0 \qquad \left|\frac{V_s V_R}{B}\right| \neq 0$$

At $\beta = \delta$

$$\boxed{P_{R\,max} = \left|\frac{V_s V_R}{B}\right| - \left|\frac{A V_R^2}{B}\right| \cos(\beta-\alpha)}$$

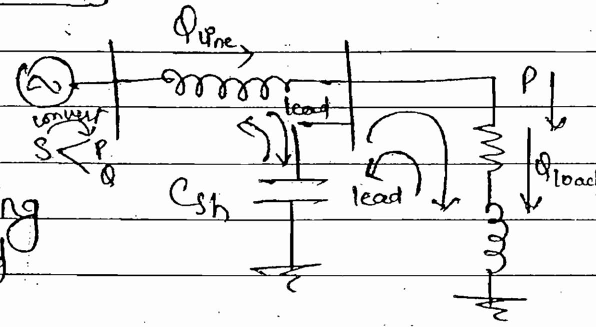
At $\delta = \beta$

$$Q_R = \left|\frac{V_s V_R}{B}\right| \sin(\beta-\beta) - \left|\frac{A V_R^2}{B}\right| \sin(\beta-\alpha)$$

Date

$$\boxed{Q_R = -\left|\frac{V_R^2 A}{B}\right| \sin(\beta-\alpha)}$$

NOTE:- $Q_R = -ve$ indicates leading nature of load and for this leading load leading VARs has to be supplied for Receiving P_{Rmax}.



• LOCUS OF POWER:-

$$P_R + \left|\frac{AV_R^2}{B}\right| \cos(\beta-\alpha) = \left|\frac{V_s V_R}{B}\right| \cos(\beta-\delta) \quad \text{— (1)}$$

$$Q_R + \left|\frac{AV_R^2}{B}\right| \sin(\beta-\alpha) = \left|\frac{V_s V_R}{B}\right| \sin(\beta-\delta) \quad \text{— (2)}$$

Squaring and adding eq^n (1) & (2)

$$\left[P_R + \left|\frac{AV_R^2}{B}\right| \cos(\beta-\alpha)\right]^2 + \left[Q_R + \left|\frac{AV_R^2}{B}\right| \sin(\beta-\alpha)\right]^2 = \left(\frac{V_s V_R}{B}\right)^2 \quad \text{— (3)}$$

eq^n (3) represents circle equat^n.

$$(x-a)^2 + (y-b)^2 = r^2$$

r = Radius of circle $\left|\frac{V_s V_R}{B}\right|$

Center of Circle

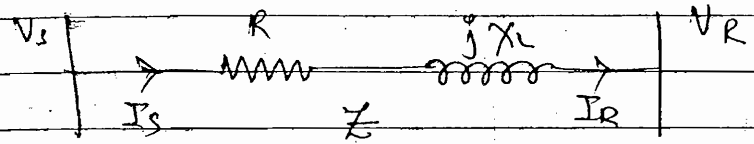
$$(a,b) = \left[-\left|\frac{V_R^2 A}{B}\right| \cos(\beta-\alpha),\ -\left|\frac{AV_R^2}{B}\right| \sin(\beta-\alpha)\right]$$

NOTE:- Locus of P_R, Q_R is a circle at constant $|V_s|$, $|V_R|$. Similarly locus of P_s, Q_s is a circle at constant $|V_s|$, $|V_R|$

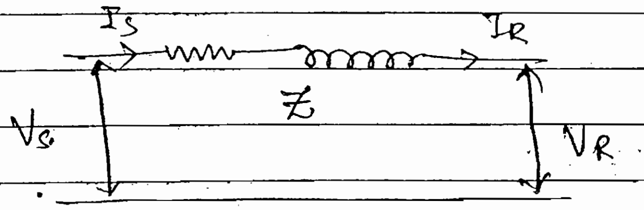
Date

• Generalised Equation of Powers :-

Assume short Tr. line : (C, G are neglected)



$Z = R + jX_L$



$V_s = V_R + I_R . Z$

$\rightarrow V_s = 1.V_R + Z.I_R$

$\rightarrow I_s = I_R = (0)V_R + 1.I_R$

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

Assume $R << X_L$

$Z = jX_L = X_L \angle 90° = B \angle \beta \qquad A\angle\alpha = 1\angle 0° = D, \; C = 0$ — eqn (1)

Receiving End powers:-

use when A, B, C, D parameters are given

$$P_R = \left|\frac{V_s V_R}{B}\right| \cos(\beta - \delta) - \left|\frac{V_R^2 A}{B}\right| \cos(\beta - \alpha) \quad -(2)$$

Substitute (1) in (2)

$$P_R = \left|\frac{V_s V_R}{X_L}\right| \cos(90 - \delta) - \left|\frac{1 \times V_R^2}{X_L}\right| \cos(90° - 0)$$

use when only X_L are given

$$\boxed{P_R = \left|\frac{V_s V_R}{X_L}\right| \sin\delta} \qquad \boxed{P_R \propto \sin\delta}$$

use when parameters are given

$$Q_R = \left|\frac{V_s V_R}{B}\right| \sin(\beta - \delta) - \left|\frac{A V_R^2}{B}\right| \sin(\beta - \alpha) \quad -(3)$$

Substitute (1) in (3)

Date________

when only X_L is given

$$\boxed{Q_R = \left|\frac{V_S V_R}{X_L}\right| \cos\delta - \left|\frac{V_R^2}{X_L}\right|}$$

If δ is small, $\cos\delta \approx 1$

$$\boxed{Q_R = \frac{V_R (V_S - V_R)}{X_L}} \qquad \boxed{Q_R \propto (V_S - V_R)}$$

- Sending End power:-

Substitute ① in P_S, Q_S

$$P_S = \left|\frac{V_S V_R}{X_L}\right| \sin\delta = P_R$$

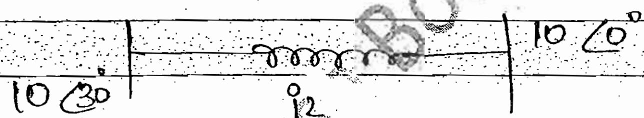
$$Q_S = \left|\frac{V_S^2}{X_L}\right| - \left|\frac{V_S V_R}{X_L}\right| \cos\delta$$

Average Reactive Power:-

$$Q_{avg} = \frac{Q_R + Q_S}{2}$$

$$\boxed{Q_{avg} = \frac{V_S^2 - V_R^2}{2X_L}}$$

Q From the following N/W calculate the active power and reactive power flow through the x-line.



Solution $V_S = 10\angle 30°$ $V_R = 10\angle 0°$

$$P_R = \left|\frac{V_S V_R}{X_L}\right| \sin\delta$$

$$= \frac{10 \times 10}{2} \sin(30-0) = 25\ W$$

$$Q_R = \left|\frac{V_S V_R}{X_L}\right| \cos\delta - \frac{V_R^2}{X_L} = \frac{10 \times 10}{2}\cos(30-0) - \frac{10^2}{2}$$

$$= 6.7 \text{ VARs}$$

$$Q_S = \frac{V_S^2}{X_L} - \frac{V_S V_R}{X_L}\cos\delta = 6.7 \text{ VARs}$$

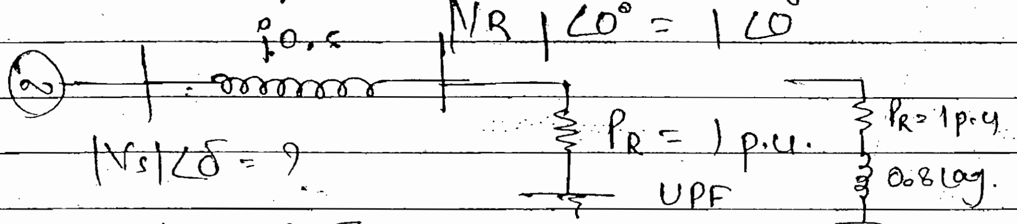
Date________

- The sequence of impedance of equipment is equal to the equipment original equipments impedance.

$$\boxed{Z_{p.u} = Z_{\Omega}\,\frac{(MVA)_b}{(KV_b)^2}} \qquad X_{p.u},\ R_{p.u}$$

Q. A Tr-line impedance of $j0.5$ p.u is connected to a load of 1 p.u UPF. If $V_R = 1\angle 0^\circ$. Calculate V_s and δ.

Solution



$Q_{load} = P\tan\phi$
$= 1\times\tan\cos^{-1}0.8$
$= 0.75$ p.u

$$P_R = \frac{V_s V_R}{X_L}\sin\delta$$

$$1 = \frac{V_s \times 1}{0.5}\sin\delta \qquad V_s\sin\delta = 0.5 \quad \text{(1)}$$

$$Q_R = \left|\frac{V_s V_R}{X_L}\right|\cos\delta - \left|\frac{V_R^2}{X_L}\right|$$

Load is resistive UPF $Q_R = 0$

$Q_R = 0.75$ p.u.

$$0 = \left|\frac{V_s \times 1}{0.5}\right|\cos\delta - \frac{1^2}{0.5} \qquad V_s\cos\delta = 1 \quad \text{(2)}$$

Solving (1) & (2)

$$\frac{\cancel{V_s}\sin\delta}{\cancel{V_s}\cos\delta} = \frac{0.5}{1} \qquad \tan\delta = 0.5$$
$$\delta = 26.56^\circ$$

$$V_s \sin 26.56' = 0.5$$
$$V_s = 1.11823 = 1.12 \text{ p.u Ans.}$$

- $V_s = 1.12$ $\quad V_R = 1$ $\quad$ Maintain the voltage for inductive.

when shunt capacitor is ...
Q, which is diff.

Date________

Q In the previous problem if $V_s = V_R = 1$ p.u is maintain by using compensators, find the rating of compensator required for
(i) 1 p.u of UPF load
(ii) 1 p.u 0.8 lagg load.
(iii) 1 p.u. 0.6 leading load.
(iv) 1 p.u. 0.995 leading load.

Solution:- (i) $P_R = 1$ p.u, UPF : , $|V_s| = |V_R| = 1$

$$P_R = \left|\frac{V_s V_R}{X_L}\right| \sin\delta$$

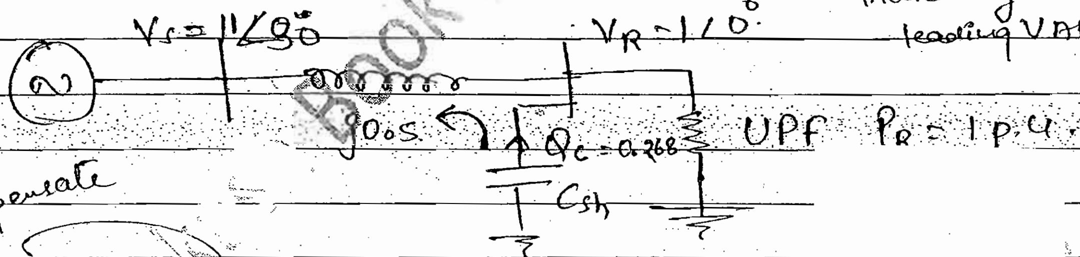
$$1 = \frac{1\times 1}{0.5}\sin\delta \qquad \sin\delta = 0.5 \qquad \boxed{\delta = 30^\circ}$$

$$Q_R = \left|\frac{V_s V_R}{X_L}\right|\cos\delta - \left|\frac{V_R^2}{X_L}\right|$$

$$= \frac{1\times 1}{0.5}\cos 30^\circ - \frac{1^2}{0.5} = \underbrace{-0.268 \text{ p.u.}}$$

demainding

indicating delivering leading VAR

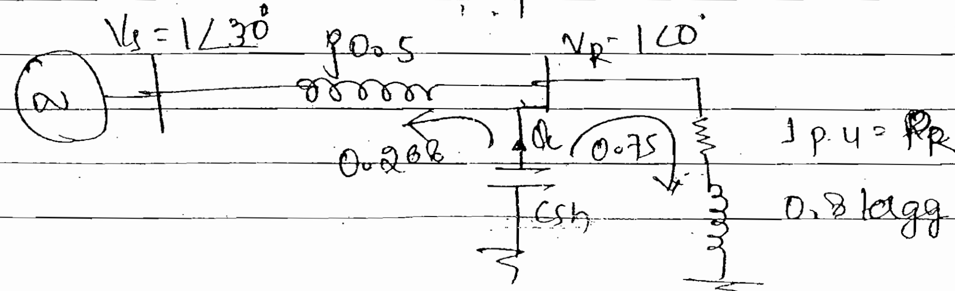


To compensate -0.268

$$Q_c = -Q_R = -(-0.268) = 0.268 \text{ p.u}$$
$$= Q_{line}$$

(ii) $P_R = 1$ p.u 0.8 lagging load.

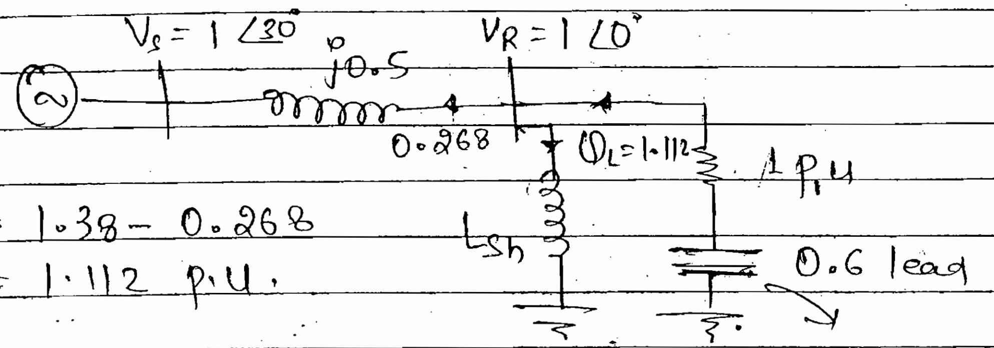
$$Q_{load} = P_R \times \tan\phi = 1\times \tan\cos^{-1}0.8$$
$$= 0.75 \text{ p.u}.$$



$Q_c = Q_{line} + Q_{load} = 0.268 + 0.75 = 1.018$ p.u.

(3) $P_R = 1$ p.u., 0.6 load.

$Q_{load} = 1 \times \tan(\cos^{-1} 0.6) = 1.38$ p.u.

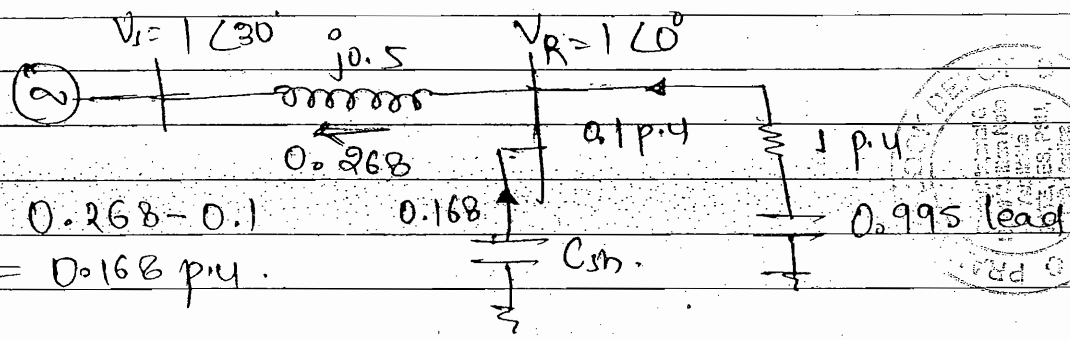


$Q_L = 1.38 - 0.268$
$= 1.112$ p.u.

deliver lagging VAR of 1.38

(4) $P_R = 1$ p.u., 0.995 load.

$Q_{load} = 1 \times \tan\cos^{-1} 0.955 = 0.1$ p.u.



$Q_c = 0.268 - 0.1$
$= 0.168$ p.u.

- Refer 1 p.u. → 0.995 → near to unity leading → Resistive more, capacitive less.

→ 0.6 leading → far to unity

→ less Resistive, capacitive more

we require more reactive power.

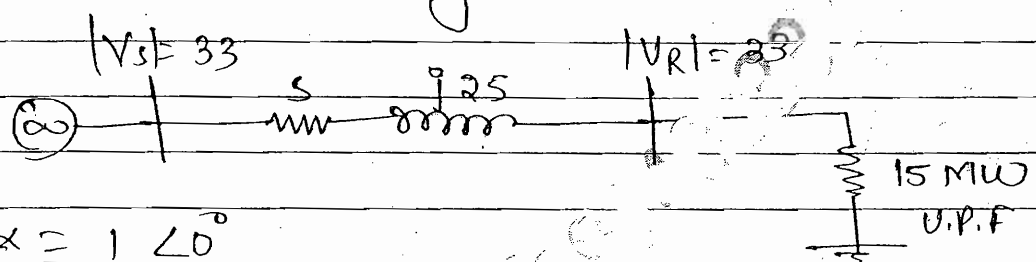
Date________

Q) A - Tr-line has an impedance of $5+j25\ \Omega$/phase is operating at $V_S = V_R = 33$ KV. Find rating of compensator required for a load of

1. 15 MW U.P.F.
2. 15 MW 0.8 lagging
3. 15 MW 0.8 leading
4. 15 MW. 0.95 leading.

$\delta = 21.7$
$Q_{line} = 6.13$

Solution :-



$$A\angle\alpha = 1\angle 0^\circ$$

$$B\angle\beta = Z = 5+j25 = 25.55\angle 78.7^\circ$$

$$P_R = \left|\frac{V_S V_R}{B}\right|\cos(\beta-\delta) - \left|\frac{A V_R^2}{B}\right|\cos(\beta-\alpha)$$

$$15 = \frac{33^2}{25.55}\cos(78.7^\circ-\delta) - \left|\frac{1\times 33^2}{25.55}\right|\cos(78.7-0)$$

8.3516

$$15+8.3516 = \frac{33^2}{25.55}\cos(78.7-\delta)$$ $1+8.3516 = \frac{33^2}{25.55}\cos(78.7-\delta)$

$$\frac{23.35\times 25.55}{33^2} = \cos(78.7-\delta)$$ $\cos(78.7-\delta)$

$78.7-\delta$

$78.7-\delta$

$$\cos^{-1} 0.5478 = 78.7-\delta$$

$$\delta = 78.7-56.77 = 21.9$$

$$Q_R = \left|\frac{V_S V_R}{B}\right|\sin(\beta-\delta) - \left|\frac{V_R^2 A}{B}\right|\sin(\beta-\alpha)$$

= -

$$Q_C = -Q_R = \quad = Q_{line}$$

Date________

Date________

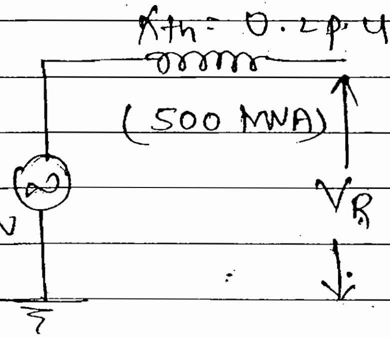
(1) The Thevein's equivalent Imped. of a Bus Bar with 3-ϕ 400 kV sys. is 0.2 p.u at a base of 500 MVA. Calculate the reactive power needed.

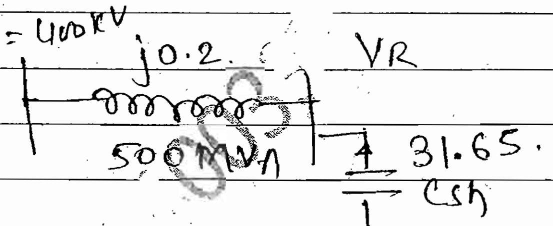
(1) To Boost the voltage by 5 kV at the Bus Bar

(2) Reduce the voltage by 4 kV at the Bus Bar

What equipment is needed in each case.

Solution :-





$$X_{pu} = X_{\Omega}\frac{(MVA)_b}{(kV)^2_b}$$

$$0.2 = X_{\Omega} \times \frac{500}{(400)^2}$$

$$X_{\Omega} = 64\,\Omega$$

(1) Boost By 5 kV

$$V_R = 400 + 5 = 405\,kV$$

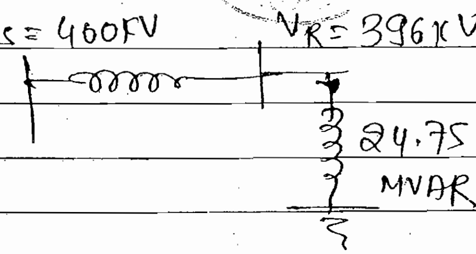
No. δ, ∞ & parameter line so.

$$Q_R = \frac{V_S V_R}{X_L} - \frac{V_R^2}{X_L} = \frac{400 \times 405}{64} - \frac{405^2}{64}$$

$$= -31.65\,MVAR$$

$$Q_C = -(-31.65) = +31.65$$

(2) Reducing by 4 kV $\quad V_R = 400 - 4 = 396\,kV$



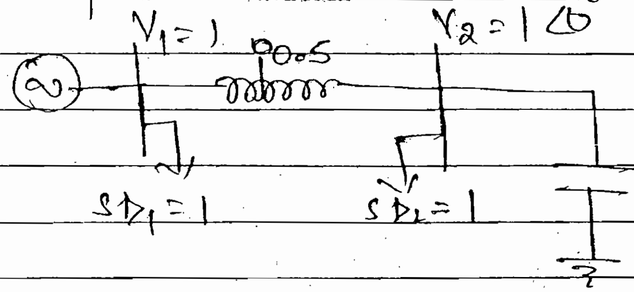
$$Q_R = \frac{400 \times 396}{64} - \frac{396^2}{64}$$

$$= +24.75\,MVAR$$

$$Q_R = -(24.75) = -24.75\,MVR.$$

Date ______

Q A complex power flow are represent on the N/w. Find the compensator rating required for maintaining $V_1 = V_2 = 1$ p.u.



Solution $\cancel{V_s = 1\angle\delta}$

$S_{D2} = 1 = P_R$

$= \dfrac{V_1 V_2}{X_L} \sin\delta$

$1 = \dfrac{1\times 1}{0.5} \sin\delta$ $\Rightarrow \sin\delta = 0.5$ $\therefore \boxed{\delta = 30^\circ}$

$Q_R = \left|\dfrac{V_1 V_2}{X_L}\right| \cos\delta - \dfrac{V_2^2}{X_L}$

$= \dfrac{1\times 1}{0.5} \cos 30 - \dfrac{1^2}{0.5} = -0.268$

$Q_C = -(-0.268) = 0.268$ compensate

Q Page No. → 52 Q:- 39, 40, 41, 42, 43, 44, 45, 51, 53, 54

(53) → Correct ans 200 ~~kΩ~~ → kW.

(39) → List I

(d) Reduce Ferranti effect

Pg No. → 43 Q: 41, 42, 43

★ Imp

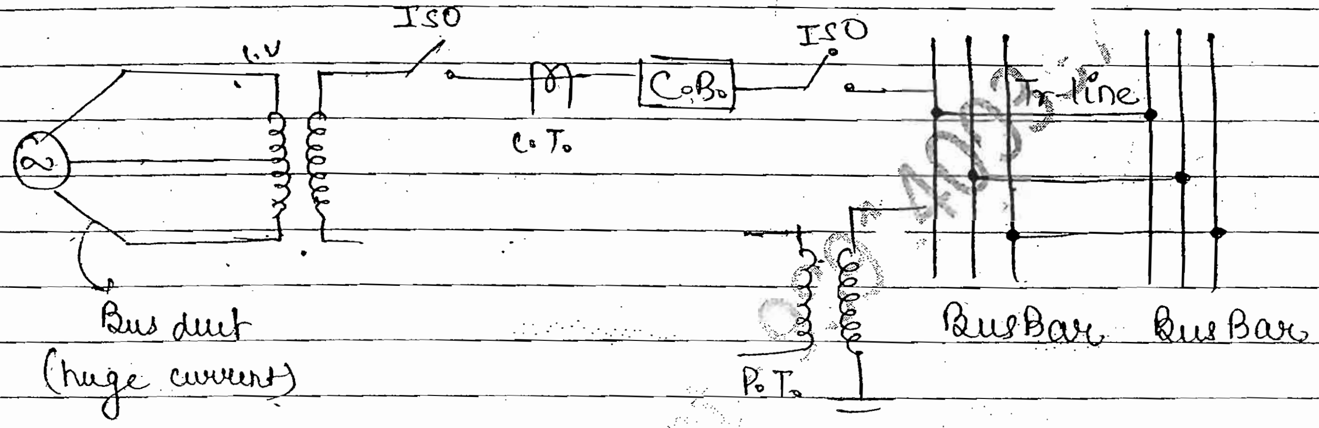
Transmission Line Parameters

Types of Conductor :-

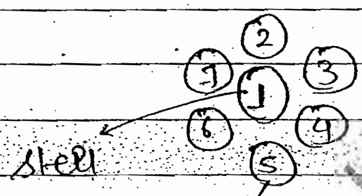
(1) SOLID → Copper → CB, CT, PT terminals

(2) HOLLOW → Copper → Isolators, Bus Duct

(3) STRANDED → ACSR → Tr-lines, Bus Bars.



ACSR :- Steel Cored Reinforced Aluminium



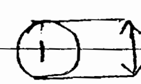
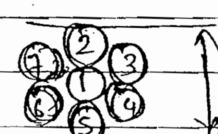
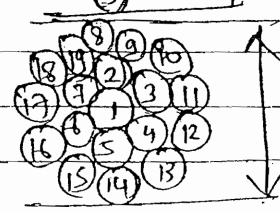
No. of strands $= N = (3x^2 - 3x + 1)$

Total Diameter of conductor $= D = (2x-1)d$

x = layer Number

d = diameter of each strand

7 - strand ACSR conductor

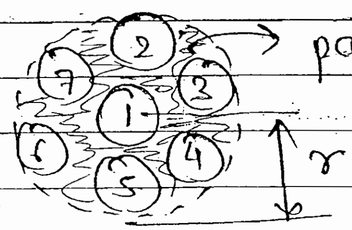
x	N	D	Arrangement
1	1	d	 $D = d$
2	7	$3d$	 $D = 3d$
3	19	$5d$	 $D = 5d$

Date

- **Tech. Name of ACSR:-**

Zebra, Panther, Moose, Fox, Dog

Expanded ACSR :- In expanded ACSR, insulating material is kept b/w the strands so that effective radius will be increase and hence inductance and inductive reactance reduce, power transfer capacity ↑

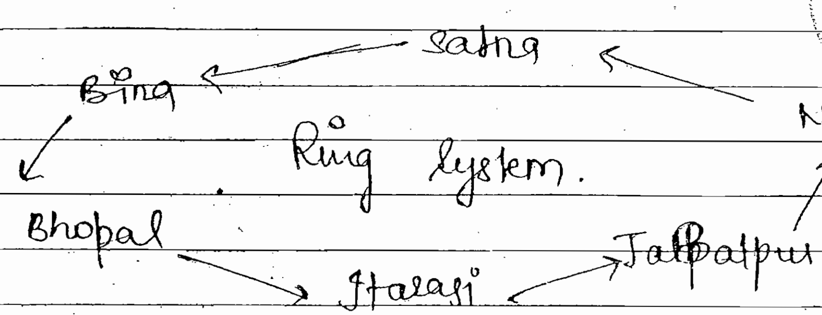


8/7/2014

Ring System :- Ad. ① uniform voltage maintain.
(close loop) ② Reliable.. (Alternate supply possible)

(Open loop) → **Radial feeder** :- Alternate ~~sys~~ supply not possible

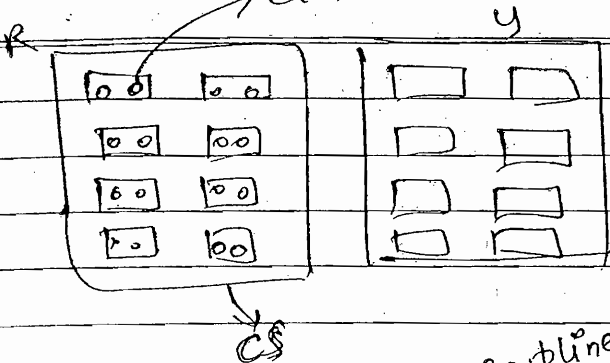
Ad:- Gen - less, demand more, freq. will fall then load will isolates, CB - open, so freq. ↑
↓
for isolate current carrier are used



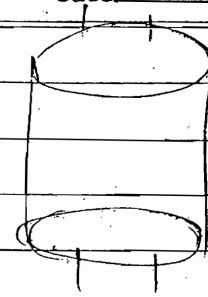
Isolater → open when maintenance required.

password:- powersystem123.

Date



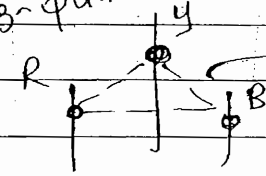
B.



Shunt Reactor.

765 or 400 KV.

Moose → 54



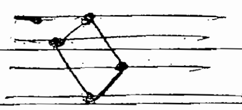
→ Δ configuration Inductance will be minimise.

∴ Power Tr-mission ↑

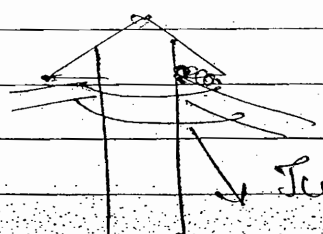
R ═══ ACSR each same phase carrying $\frac{R}{2}$ current.

Y ═══

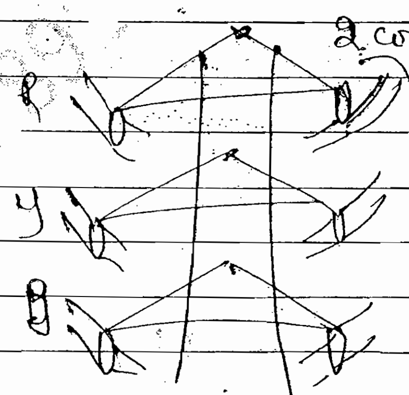
B ═══ 2-Bundle Tr-Line.



4 Bundle conductor



→ Jumper for power transfer



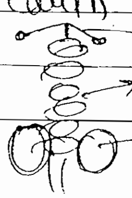
1 circuit   2 circuit.

2-Bundle - Double circuit

- Coloured Ball used in Tr-line which are crossing the river, when fault occurs, line will fall into river, for floating the line we use Ball, or for indication also.

- Corona → voltage greater than air dielectric strength

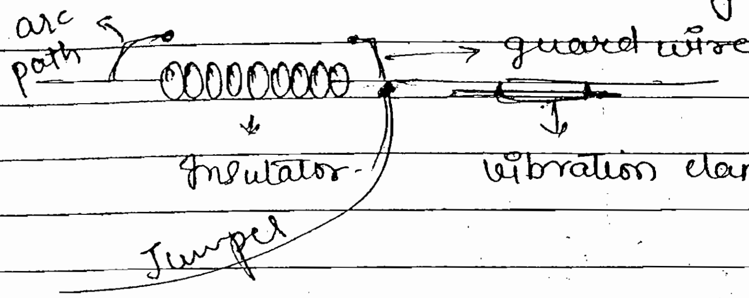
- Counter poise → discharging the lightening.
  Earth electrode → deeper length ↑, fastly discharge

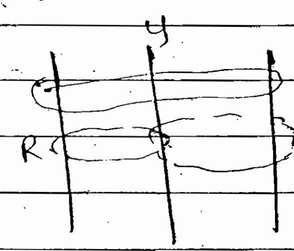


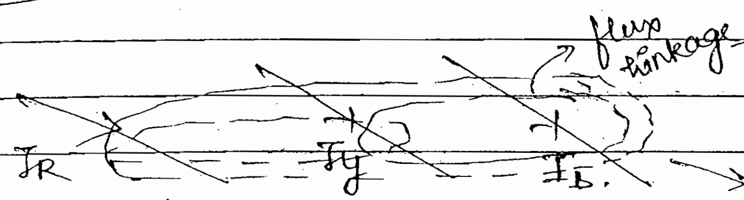
uniform voltage maintain

Date________

• Strain Insulator → used in river and road crossing reducing the sag.







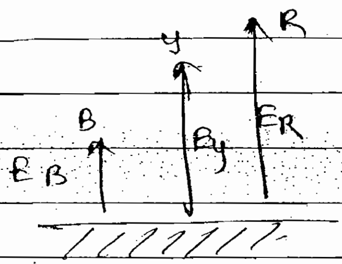
y is experience maximum flux linkage.

→ Electro Magnetic

$\uparrow L_y \overset{\text{flux linkage}}{=} \dfrac{\lambda_y \uparrow}{I}$ $\qquad \uparrow X_L = 2\pi f L_y \uparrow$ $\qquad \downarrow I_y = \dfrac{V}{X_L \uparrow}$

$|I_R| \neq |I_y| \neq |I_B| \Rightarrow I_R + I_y + I_B \neq 0$ unbalanced fault!

Radio Interference. bcoz of Magnetic interference.

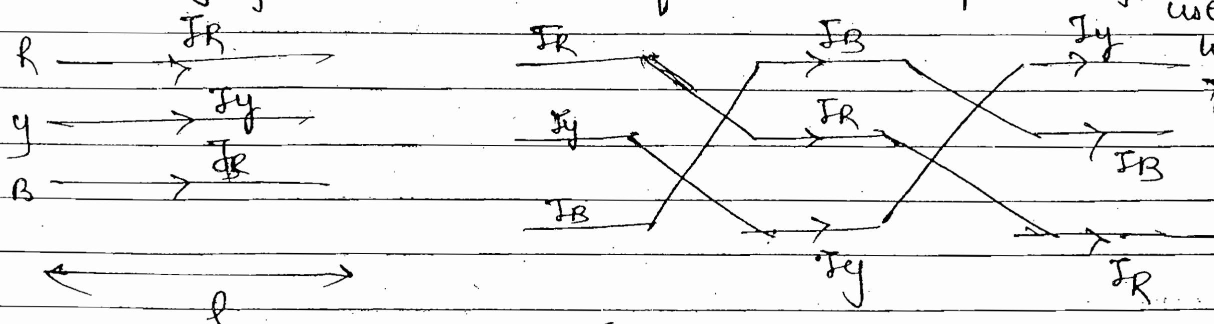


$\uparrow E \propto \dfrac{1}{d^2 \downarrow}$ $\qquad$ Electro static

$|V_R| \neq |V_B| \neq |V_y|$

Nullyfy the Radio Interference Transposition

use for long Tr-line



(Done for Balancing).

$V_R + V_y + V_B \neq 0$

$I_R + I_y + I_B \neq 0$

Earth

Date________

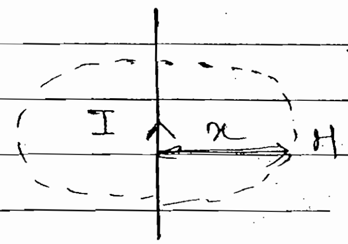
• Parameters of Tr-line :-

(1) Inductance (L)
(2) capacitance (C)
(3) Resistance (R)
(4) Conductance (G)

(1) Inductance (L):-

$P_R \propto \frac{1}{X_L}$

Steps :-



(1) $\oint H \cdot dx = I$

(2) $B = \mu_0 \mu_r \cdot H$

(3) $\phi = B \cdot A$

(4) $\lambda = n\phi$

(5) $L = \frac{\lambda}{I}$

• Inductance of Single Conductor :-

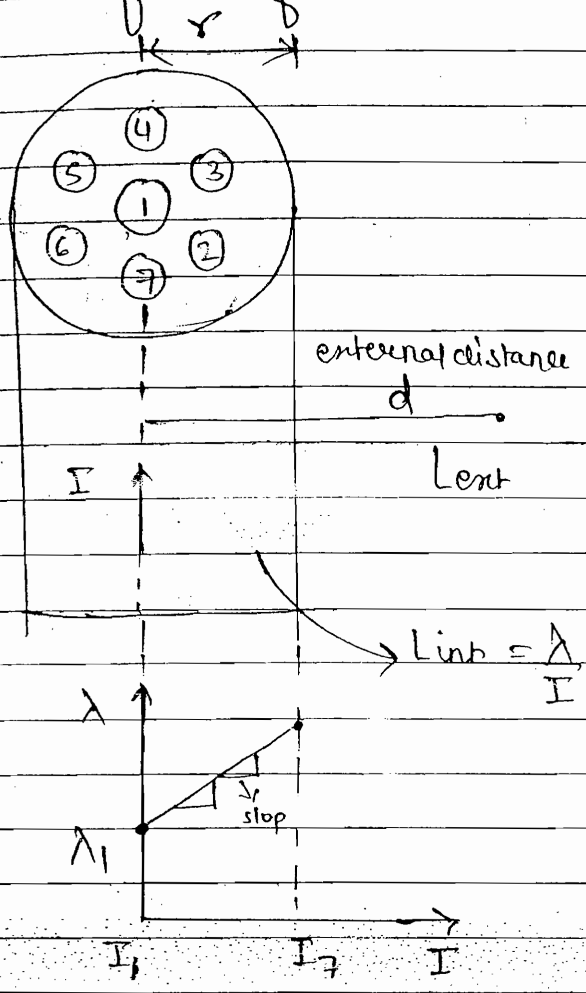
Assumption :- (1) ACSR are solid conductor is considered.
(2) Skin and proximity effect are neglected
(3) ACSR are solid conductor consisting of.
(a) Internal inductance
(b) External inductance

INTERNAL INDUCTANCE :- Internal inductance is due to flux linkage occurs within the conductors areas due to the current flowing in the strands of the conductor.

• This internal inductance proportional to the relative permeability of the conductor material and it is independent of radius or size of conductor use. It is mainly bcoz flux linkage or the flux density increases linearly is proportional

Date

to the current from the center of conductor to the surface of conductor.



- Internal Inductance : (L_{int})

$$L_{int} = \frac{\mu_r}{2} \times 10^{-7} \ H/m$$

$$\boxed{L_{int} \propto \mu_r}$$

If $\mu_r = 1$

$$\boxed{\begin{aligned} L_{int} &= \frac{1}{2} \times 10^{-7} \ H/m \\ &= 0.05 \ mH/Km \end{aligned}}$$

- Independent of value of radius.

- External Inductance : (L_{ext})

$$L_{ext} = \frac{\mu_0}{2\pi} \ln\left(\frac{d}{r}\right) \ H/m$$

$$\mu_0 = 4\pi \times 10^{-7}$$

$$\boxed{\begin{aligned} L_{ext} &= 2 \times 10^{-7} \ln\left(\frac{d}{r}\right) H/m \\ &= 0.2 \ln\left(\frac{d}{r}\right) mH/km \end{aligned}}$$

- Total Inductance (L) :-

$$L = L_{int} + L_{ext}$$

$$\boxed{L = 0.05 + 0.2 \ln\frac{d}{r} \ mH/km}$$

(OR)

$$L = \frac{1}{2} \times 10^{-7} + 2 \times 10^{-7} \ln\left(\frac{d}{r}\right)$$

$$= 2 \times 10^{-7} \left[\frac{1}{4} + \ln\left(\frac{d}{r}\right)\right]$$

$$= 2 \times 10^{-7} \left[\ln_e e^{1/4} + \ln\left(\frac{d}{r}\right)\right]$$

for hollow conductor ... and

$$\boxed{L = 2\times10^{-7} \ln \frac{d}{r}} \quad H/m.$$

Date________

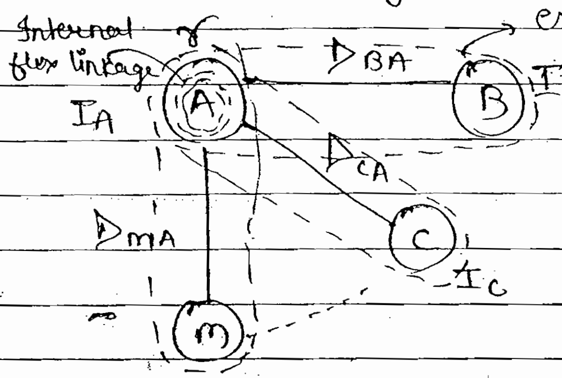
$$L = 2\times10^{-7} \ln\left[\frac{d e^{1/4}}{r}\right] = 2\times10^{-7} \ln\left(\frac{d}{r e^{-1/4}}\right)$$

$$\boxed{L = 2\times10^{-7} \ln\left(\frac{d}{0.7788 r}\right) H/m} \qquad e^{-1/4} = 0.7788.$$

$$r' = 0.7788 r$$

$$\boxed{L = 2\times10^{-7} \ln \frac{d}{r'}} \quad H/m.$$

- Flux Linkage to a Conductor in a Group of Conductor:-



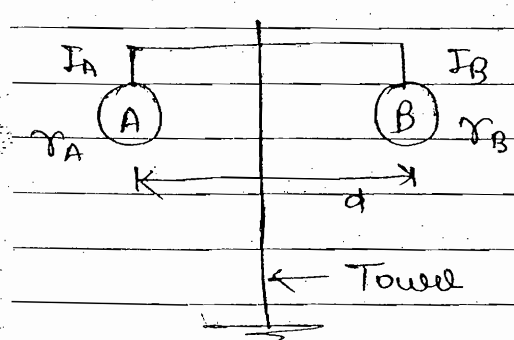
flux linkage to A:

$$\lambda_A = \frac{\mu_0}{2\pi}\left[I_A \ln \frac{1}{r'_A} + I_B \ln \frac{1}{D_{BA}} + I_C \ln \frac{1}{D_{CA}} + \dots + I_m \ln \frac{1}{D_{mA}}\right]$$

At Balance :-

$$I_A + I_B + \dots + I_m = 0$$

CASE I :- Inductance of a single ϕ or 2 wire line



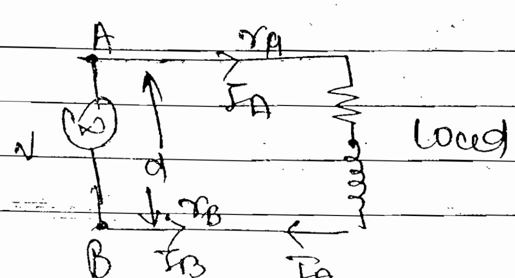
Inductance of A $[L_A]$:-

Flux linkage to A :-

$$\lambda_A = \frac{\mu_0}{2\pi}\left[I_A \ln \frac{1}{r'_A} + I_B \ln \frac{1}{d}\right]$$

At Balance:-

$$I_A + I_B = 0 \Rightarrow I_A = -I_B$$



$$\lambda_A = \frac{\mu_0 I_A}{2\pi} \ln\left(\frac{d}{r'_A}\right)$$

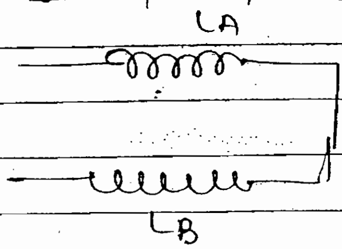
Date

$$\boxed{L_A = \frac{\lambda_A}{I_A} = \frac{\mu_0}{2\pi} \ln\left(\frac{d}{r'_A}\right)} \quad H/m.$$

- Inductance of B (L_B):-

$$\boxed{L_B = \frac{\lambda_B}{I_B} = \frac{\mu_0}{2\pi} \ln\left(\frac{d}{r'_B}\right)} \quad H/m.$$

- Total / loop / Circuit Inductance:-



$$L = L_A + L_B$$
$$= \frac{\mu_0}{\pi} \ln\left(\frac{d}{\sqrt{r'_A r'_B}}\right) H/m.$$

If $r'_A = r'_B = r$ $\quad \boxed{L = \frac{\mu_0}{\pi} \ln\left(\frac{d}{r'}\right) H/m}$

l = length of line ...... (meter)

$L = L \cdot l$ ...... (Henry)

$X_L = 2\pi f L$ ...... Ω

CASE II:- Radio Interference in telecommunication line due to power line

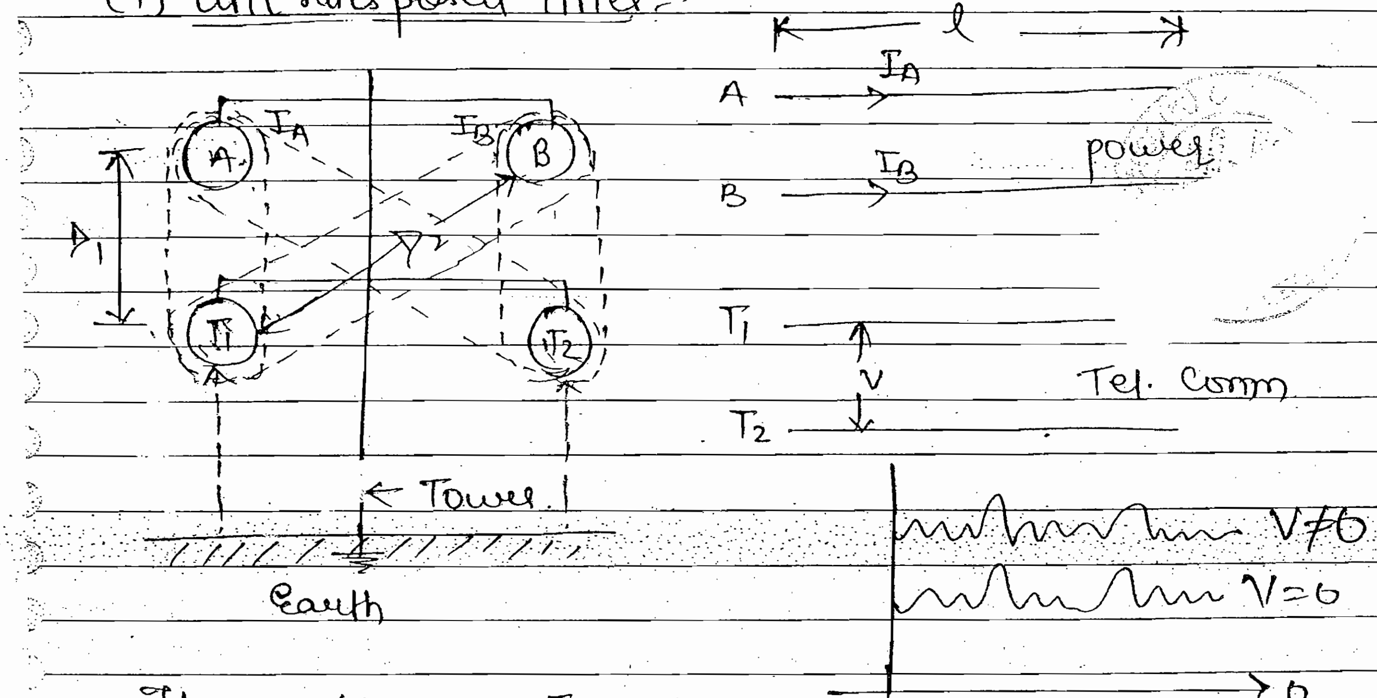
- If the power and telecommunicatⁿ line are running close to each other. The current flowing in the power line reduces the magnetic flux linkage with the communication line. This will induce an emf in the communication line conductors. Similarly due to earth charges produces electric field on the communication line conductor which will induces emf between the communicatⁿ line conductor which is called electro static Inductance

Date

Both this electrostatic and electromagnetic produce interference for the communication signals passing through the communication line. This is called RADIO INTERFERENCE in the communicatn line. To reduce this effect. of

(i) either power and both, power and communicatn line are transpose at regular intervals of length of the Tr-line.

(a) Untransposed lines:



Flux linkage to T_1 and T_2

$$\lambda T_1 = \frac{\mu_0}{2\pi}\left[I_A \ln \frac{1}{D_1} + I_B \ln \frac{1}{D_2} \right]$$

$$\lambda T_2 = \frac{\mu_0}{2\pi}\left[I_A \ln \frac{1}{D_2} + I_B \ln \frac{1}{D_1} \right]$$

Net $\lambda T = \lambda T_1 - \lambda T_2$

$$= \frac{\mu_0}{2\pi}\left[I_A \ln \frac{D_2}{D_1} + I_B \ln \frac{D_1}{D_2} \right]$$

At Balance $I_A + I_B = 0$, $I_B = -I_A$

$$\lambda_T = \frac{\mu_0 I_A}{2\pi} \ln\left(\frac{D_2}{D_1}\right)^2$$

$$= \frac{\mu_0 I_A}{\pi} \ln\left(\frac{D_2}{D_1}\right)$$

$$L = \frac{\lambda_A}{I_A} = \frac{\mu_0}{\pi} \ln\left(\frac{D_2}{D_1}\right)$$

Voltage induced b/w communication line due to I_A is

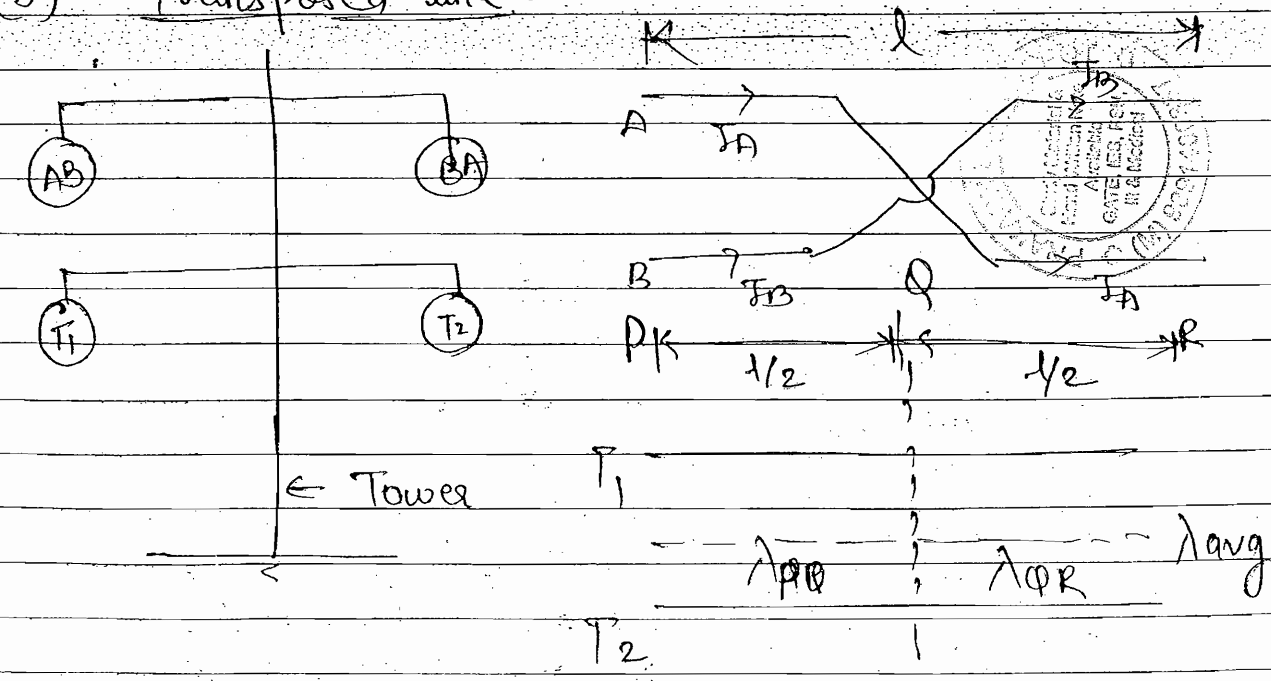
$$V = (2\pi f L) I_A$$

$$= 2\cancel{\pi} f I_A \cdot \frac{\mu_0}{\cancel{\pi}} \ln\left(\frac{D_2}{D_1}\right)$$

$$\boxed{V = 2\mu_0 f I_A \ln\left(\frac{D_2}{D_1}\right)} \quad V/m.$$

D_1 = shortest Distance $\quad D_2$ = longest distance

(b) Transposed line:



Date________

Flux linkage b/w PQ and QR.

$$\lambda_{PQ} = \frac{\mu_0}{2\pi}\left[I_A \ln\left(\frac{D_2}{D_1}\right) + I_B \ln\left(\frac{D_1}{D_2}\right)\right]$$

$$\lambda_{QR} = \frac{\mu_0}{2\pi}\left[I_B \ln\left(\frac{D_2}{D_1}\right) + I_A \ln\left(\frac{D_1}{D_2}\right)\right]$$

$$\lambda_{avg} = \frac{\lambda_{PQ} \times l/2 + \lambda_{QR} \times l/2}{l} = \frac{1}{2}\left[\lambda_{PQ} + \lambda_{QR}\right]$$

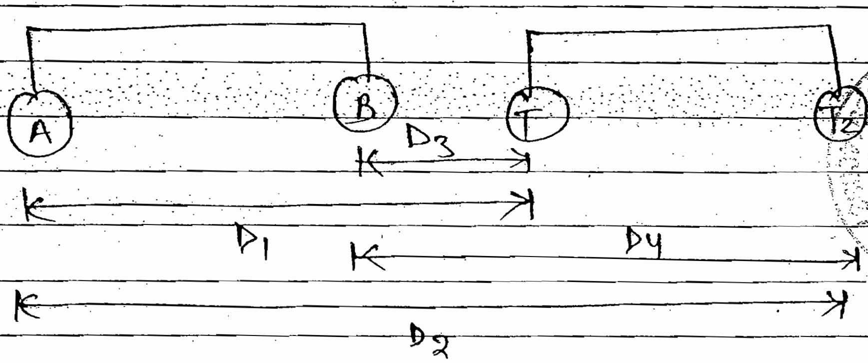
$$\lambda_{avg} = \frac{1}{2} \cdot \frac{\mu_0}{2\pi}\left[(I_A + I_B) \ln \frac{D_2}{D_1} + (I_A + I_B) \ln \frac{D_1}{D_2}\right]$$

At Balance $(I_A + I_B) = 0$

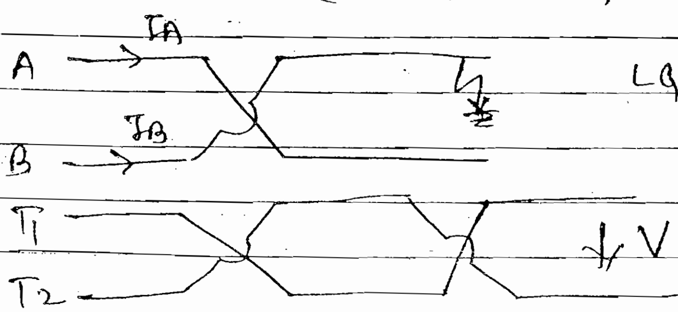
- $\lambda_{avg} = 0$
- $L = \frac{\lambda_{avg}}{I_A} = 0$

$\boxed{\bullet\ V = 2\pi f L \cdot I_A = 0}$

practical case:-



- Through distance we can't make $\lambda_{avg} = 0$. In this case $(I_A + I_B)$ help in making $\lambda_{avg} = 0$



LG, LL, LLG $(I_A + I_B) \neq 0$

$\therefore V \neq 0$

For making voltage = 0

Telecommunicat^{n} line

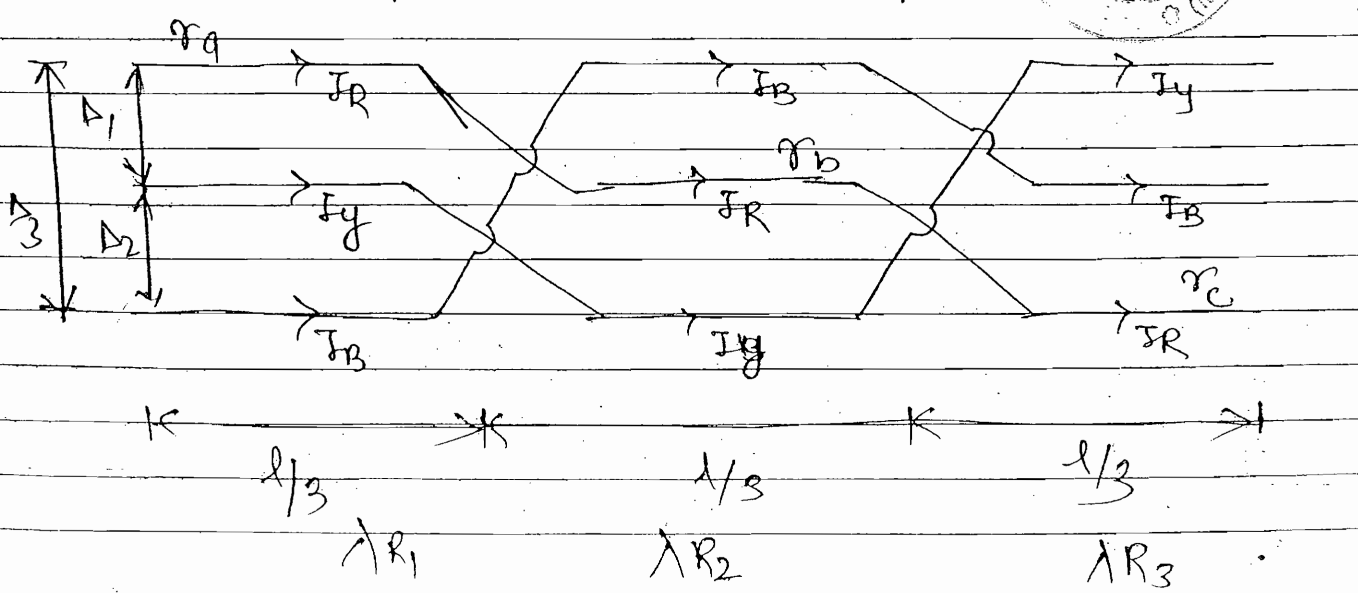
Date

are also transpose at regular interval, so that V can be reduce.

Case III :- Radio Interference in 3ϕ power Tr-line

In case of $3-\phi$ Tr-line due to electro-magnetic induction the middle conductor experiences maximum flux linkage so that X_L & L increase so that current reduce. This will produce unbalance in the system currents that is $I_R + I_Y + I_B \neq 0$ occurs.

- The bottom most conductor which is nearer to the earth experience maximum electric field stress compare to the other conductors causing unbalance in the voltage i.e. $V_R + V_Y + V_B \neq 0$ occurs. This is called electro static induction. Both electro static and electromagnetic produces unbalance to sys which is called radio interference in the 3ϕ line.
- To reduce this effect and maintain Balanced in voltages and currents Tr-line is transpose at regular intervals of length of the line.
- Consider transponce line for untranspose it is mentioned.



Date________

Flux linkage to R-phase:-

$$\lambda R_1 = \frac{\mu_0}{2\pi}\left[I_R \ln \frac{1}{r'_a} + I_y \ln \frac{1}{D_1} + I_B \ln \frac{1}{D_3}\right]$$

$$\lambda R_2 = \frac{\mu_0}{2\pi}\left[I_R \ln \frac{1}{r'_b} + I_y \ln \frac{1}{D_2} + I_B \ln \frac{1}{D_1}\right]$$

$$\lambda R_3 = \frac{\mu_0}{2\pi}\left[I_R \ln \frac{1}{r'_c} + I_y \ln \frac{1}{D_3} + I_B \ln \frac{1}{D_2}\right]$$

$$\lambda avg = \frac{\lambda R_1 + \lambda R_2 + \lambda R_3}{3}$$

$$\lambda avg = \frac{1}{3} \cdot \frac{\mu_0}{2\pi}\left[I_R \ln \frac{1}{r'_a r'_b r'_c} + (I_y + I_B)\ln \frac{1}{D_1 D_2 D_3}\right]$$

At Balance $I_y + I_B = -I_R$

$$\lambda avg = \frac{\mu_0}{2\pi} I_R \ln\left(\frac{D_1 D_2 D_3}{r'_a r'_b r'_c}\right)^{1/3}$$

$$\boxed{L_R = L_{ph} = \frac{\lambda avg}{I_R} = \frac{\mu_0}{2\pi} \ln\left(\frac{D_1 D_2 D_3}{r'_a r'_b r'_c}\right)^{1/3}}$$

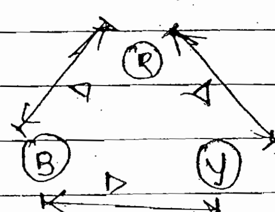
H/m/ phase.

(1) If $r'_a = r'_b = r'_c = r'$

$$L_{ph} = \frac{\mu_0}{2\pi} \ln\left(\frac{D_1 D_2 D_3}{r'}\right)^{1/3} \quad H/m/phase$$

(2) If $D_1 = D_2 = D_3 = D$

Δ configuratn

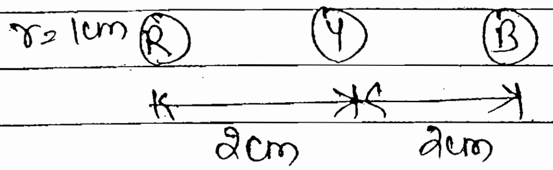


$$L_{ph} = \frac{\mu_0}{2\pi} \ln\left(\frac{D}{r'}\right) \quad H/m/phase$$

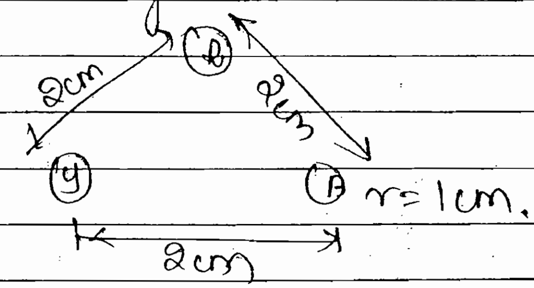
Date________

Q Find the inductance / phase for the following configuration.

(1) Horizontal



(2) Triangular



Solution

$$L_{ph} = \frac{\cancel{4}^{2}\cancel{\pi}\times10^{-7}}{\cancel{2\pi}}\ln\left(\frac{(2\times2\times4)^{1/3}}{0.7788\times1\times10^{-2}}\right)$$

$= 1.15\times10^{-6}$ H/m

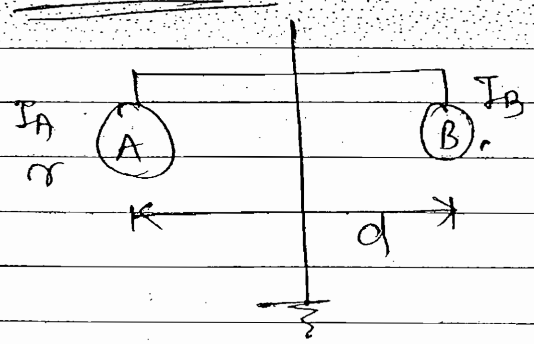
$= 1.15$ mH / km

$$L_{ph} = \frac{4\pi\times10^{-7}}{2\times\pi}\ln\left(\frac{2}{0.7788\times10^{-2}}\right)$$

$= 1.10$ mH / km

$\boxed{L_\Delta < L_H}$ $\boxed{P_\Delta > P_H}$

Case IV: Bundle Conductor:



$L_A = L_B = 2\times10^{-7}\ln\frac{d}{r'}$

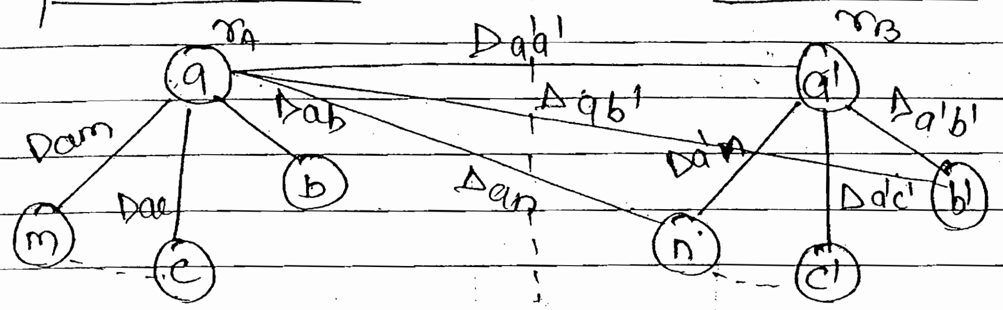
$L_A = L_B = 2\times10^{-7}\ln\frac{D_m}{D_s}$

D_m = Mutual geometric Mean Distance (GMD)

D_s = Self GMD (or)

= GMR [Geometric Mean Radius]

Phase A (I_A) | Phase B (I_B)



m = No. of Conductor Bundle of phase A
n = No. of Conductor Bundle of phase B.

$$L_A = 2\times10^{-7}\ln\left(\frac{D_{mAB}}{D_{sA}}\right)$$

$$L_B = 2\times10^{-7}\ln\left(\frac{D_{mBA}}{D_{sB}}\right)$$

$$D_{mAB} = D_{mBA} = \Big[(D_{aa'}\,D_{ab'}\ldots D_{an})(D_{ba'}\,D_{bb'}\ldots D_{bn}) \ldots (D_{ma'}\,D_{mb'} \ldots D_{mn})\Big]^{\frac{1}{m\times n}}$$

$$D_{sA} = \Big[(D_{aa}.D_{ab}\ldots D_{am})(D_{ba}\,D_{bb}\ldots D_{bm})\ldots(D_{ma}\,D_{mb}\ldots D_{mm})\Big]^{1/m^2}$$

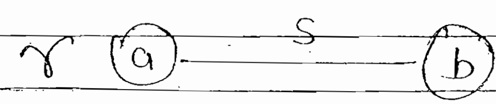
where $D_{aa} = D_{bb} = \ldots = D_{mm} = r'_A = 0.7788\,r_A$

$$D_{sB} = \Big[(D_{a'a'}\,D_{a'b'}\ldots D_{a'n})(D_{b'a'}\,D_{b'b'}\ldots D_{b'n})\ldots(D_{na'}\,D_{nb'}\ldots D_{nn})\Big]^{1/n^2}$$

where $D_{a'a'} = D_{b'b'} = \ldots = D_{nn} = r'_B = 0.7788\,r_B$

Q Find the self GMD for the following conductor configurⁿ.

(I) Bundle of 2 :-



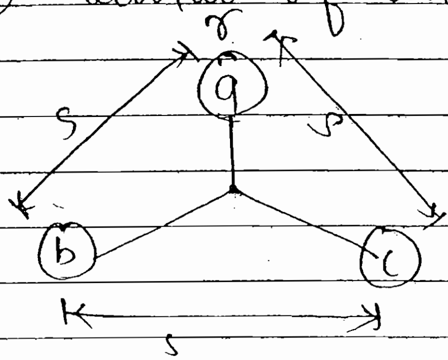
Date

$$D_s = \left[(D_{aa} D_{ab}) [D_{bb} D_{ba}) \right]^{1/2\times2}$$

$$= \left[(r' \cdot S)(r' \cdot S) \right]^{1/4}$$

$$D_s = (r' \cdot S)^{1/2}$$

(2) Bundle of Conductor 3.

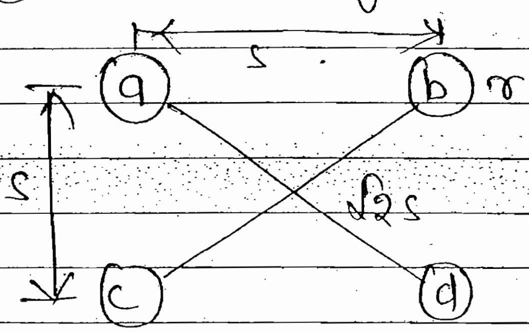


$$D_s = \left[(D_{aa} D_{ab} D_{ac})(D_{bb} D_{ba} D_{bc})(D_{ca} D_{cb} D_{cc}) \right]^{1/3\times3}$$

$$= \left[(r' \cdot s \cdot s)(s \cdot s \cdot r')(s \cdot r' \cdot s) \right]^{1/9}$$

$$= \left[r' s^2 \right]^{1/3}$$

(3) Bundle of Conductor 4.



$$D_s = \left[(D_{aa} D_{ad} D_{ab} D_{ac}) (D_{bb} D_{ba} D_{bc} D_{bd}) (D_{cc} D_{ca} D_{cb} D_{cd}) (D_{dd} D_{dc} D_{da} D_{db}) \right]^{1/4^2}$$

$$= \left(\sqrt{2}\, r' \cdot s^3 \right)^{1/4}$$

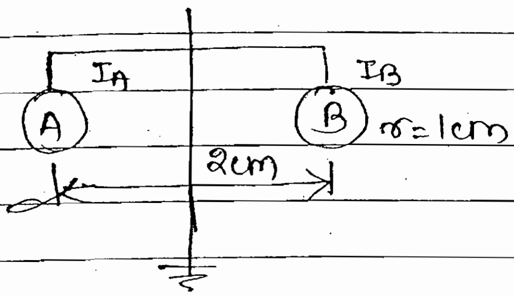
$$= 1.09 \left(r' \cdot s^3 \right)^{1/4}.$$

Chap:- 1 → 11012.

4mk Comparison of Bundle or Without Bundle 9|7|2014.

Q For the following configuration Calculate inductance per phase

(1) Without Bundle conductor.

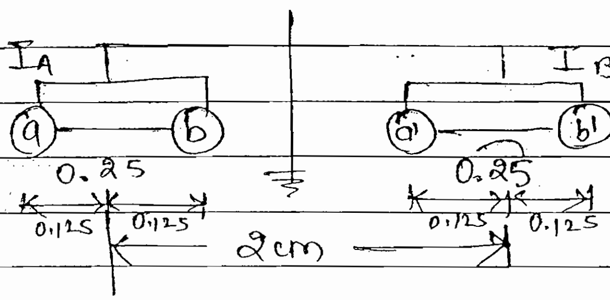


$$L_A = L_B = 2\times10^{-7}\ln\left(\frac{d}{r'}\right)$$

$$= 2\times10^{-7}\ln\frac{2}{0.7788\times10^{-2}}$$

$$= 1.109\ mH/km$$

(2) With Bundle Conductor:



$$L_A = L_B = 2\times10^{-7}\ln\frac{D_m}{D_s}$$

$$D_s = \left(D_{aa}D_{ab}D_{ba}D_{bb}\right)^{1/2^2}$$

$$= \sqrt[4]{\left((0.7788\times1\times10^{-2})^2\times(0.25)^2\right)}$$

$$= 0.044m$$

$$D_m = \left(D_{aa'}D_{ab'}D_{ba'}D_{bb'}\right)^{1/4}$$

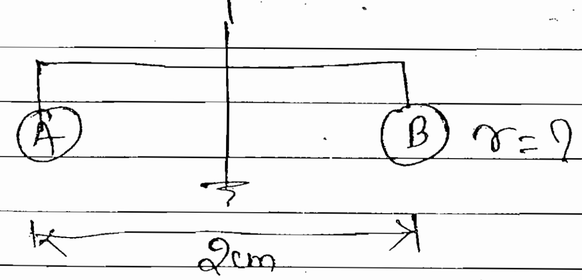
$$= \left[2\times2.25\times1.75\times2\right]^{1/4}$$

$$= 1.99 \approx 2m$$

$$L_A = L_B = 2\times10^{-7}\ln\left(\frac{2}{0.044}\right) = 0.768\ mH/km$$

- With Bundle conductor power x-fer is more.

Q To get $L_A = 0.768\ mH/km$ without Bundle how much r required?



$$L_A = 0.768\times10^{-6}\ H/m$$

$$= 2\times10^{-7}\ln\frac{2}{0.7788\times r}$$

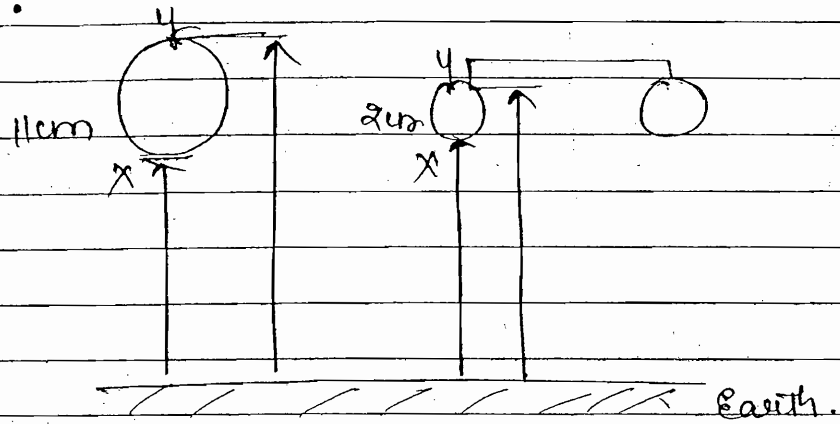
$$r = 5.6\ cm.$$

$$\Rightarrow A = \pi r^2 = \pi\times5.6^2$$

$$\approx 100\ cm^2$$

Date________

Bundle : $r = 1cm \Rightarrow 2\pi r^2 = 2\pi \times 1^2 = 6.28 cm^2$.

- More area will required without Bundle, cost will ↑.
- 

- Corona and radio Interference is less in Bundle conductor

- Advantages of Bundle conductor :-

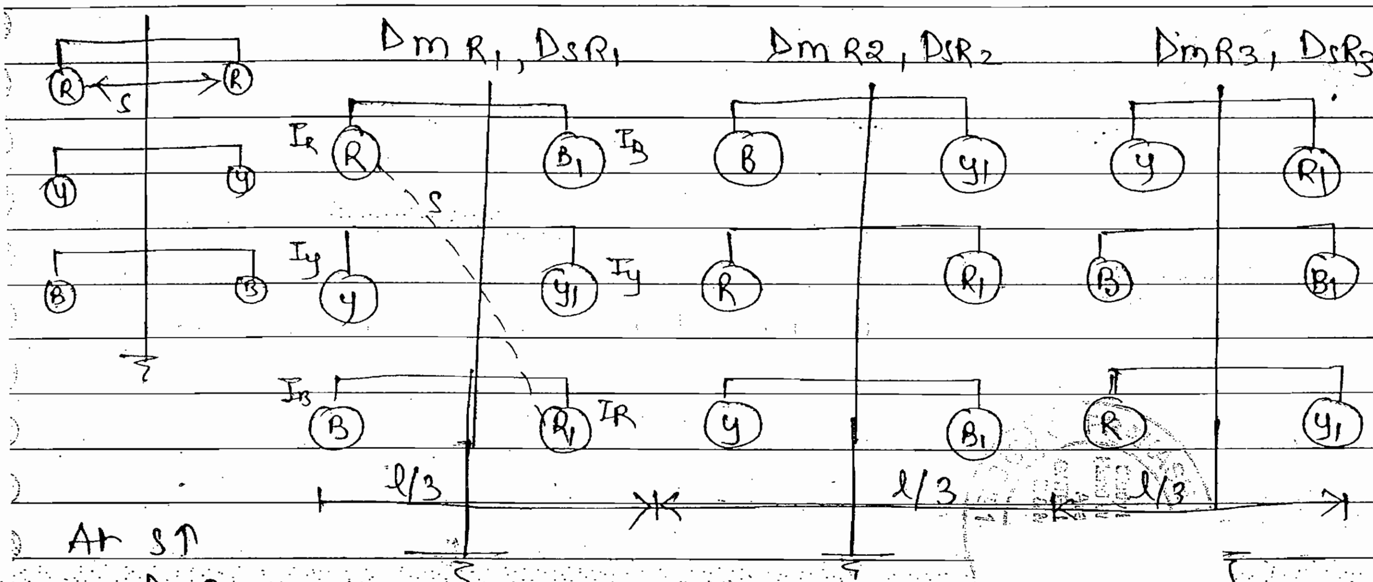
(1) Effective Radius of conductor Di will increase
(2) Inductance and inductive reactance are reduced.
(3) Power transferred capability is increased
(4) Volume of the conductor is reduce, so that No. of towers will minimise.
(5) Electrical field stress on the conductors are minimised.
(6) Surge impedance is reduce.
(7) Surge impedance loading is increased
(8) Corona power loss is reduce
(9) Interference b/w adjacent line is minimized.

Because of above advantage Bundle conductors are practically used for power transfer of higher rating in 220 KV and above voltage levels.

Date________

<u>case V</u> <u>Double Circuit line</u> :- In case of two conductor Bundle $D_s = (r' s)^{1/2}$ that is $D_s \propto s^{1/2}$ by $\uparrow s$, $D_s \uparrow$ so that L and X_L are reduce. Power transferred is $\uparrow$. This principle is used in case of double circuit line.

- It consisting of two circuit each has R, Y, B. phases kept one one side of tower.

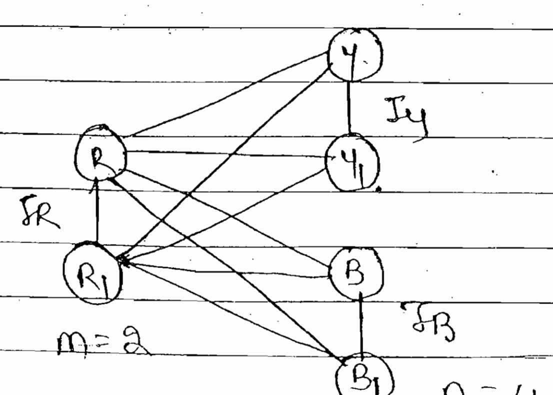


At $S \uparrow$

$D_s \uparrow$, $X_L \downarrow$

$$L_R = L_{ph} = 2\times10^{-7} \ln \left(\frac{D_m R_1 \, D_m R_2 \, D_m R_3}{D_s R_1 \, D_s R_2 \, D_s R_3} \right)^{1/3} \text{ H/m/phase}$$

<u>Calculation of D_{mR}</u>



$$D_m R_1 = \left[\left(D_{Ry} D_{Ry_1} D_{RB} D_{RB_1} \right) \left(D_{R_1 Y} D_{R_1 Y_1} D_{R_1 B} D_{R_1 B_1} \right) \right]^{\frac{1}{2\times4}}$$

Similarly calculate $D_m R_2$, $D_m R_3$

Calculation of D_{sR}

$$D_s R_1 = \left[D_{RR} \, D_{RR_1} \, D_{R_1 R} \, D_{R_1 R_1} \right]^{\frac{1}{2^2}}$$

Similarly calculate $D_s R_2$, $D_s R_3$

Page No. 45. Date

Conventional L:- Conductor radius = 12 mm.

(a) I_R (b) I_y (c) I_B | (a') I_R (b') I_y (c') I_B — D_{mR_1} D_{sR_1}

2m, 2m, 2m, 2m, 2m

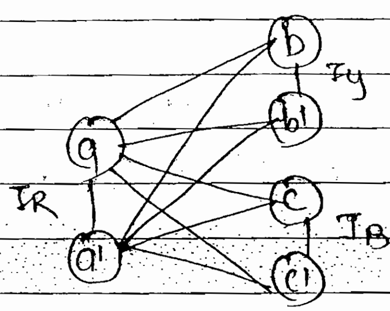
Assumption → Transposition

$aa' \to I_R \qquad bb' \to I_y \qquad cc' \to I_B$

(c) (a) (b) (c') (a') (b') — D_{mR_2} D_{sR_2}

(b) (c) (a) (b') (c') (a') — D_{mR_3} D_{sR_3}

Calculatⁿ the DmR



$m = 2 \qquad n = 4$

$$D_{mR_1} = \left(\left[D_{ab} D_{ab'} D_{ac} D_{ac'}\right]\left[D_{a'b} D_{a'b'} D_{a'c} D_{a'c'}\right]\right)^{1/2\times 4}$$

$$= \left[2 \times 8 \times 4 \times 10 \times 4 \times 2 \times 2 \times 4\right]^{1/8}$$

$$= 3.77\text{ m}$$

$$D_{mR_2} = \left[2 \times 8 \times 2 \times 4 \times 4 \times 2 \times 8 \times 2\right]^{1/8}$$

$$= 3.36\text{ m}$$

$$D_{mR_3} = \left[4 \times 2 \times 2 \times 4 \times 10 \times 4 \times 6 \times 2\right]^{1/8}$$

$$= 3.77\text{ m}$$

$$D_{sR_1} = \left(D_{aa} D_{aa'} D_{a'a} D_{a'a'}\right)^{1/2^2}$$

$$= \left[(0.7788 \times 12 \times 10^{-3})^2 \times 6^2\right]^{1/4} = 0.236$$

$$= D_{sR_2} = D_{sR_3}$$

$$L_R = l_{ph} = 2 \times 10^{-7} \ln\left[\frac{D_{mR_1} D_{mR_2} D_{mR_3}}{D_{sR_1} D_{sR_2} D_{sR_3}}\right]^{1/3}$$

Date______

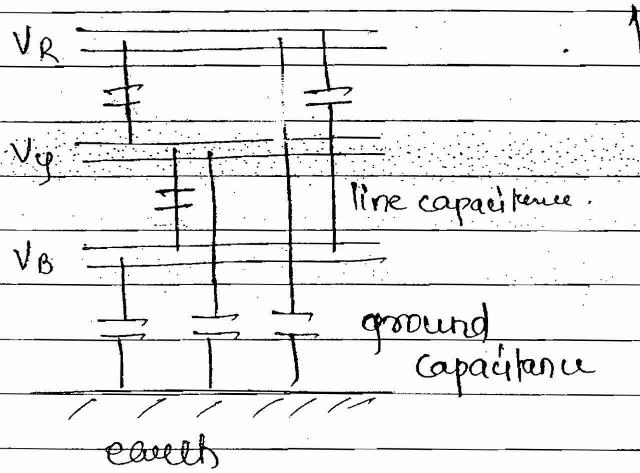
$$= 2\times10^{-7} \ln \left[\frac{3.77 \times 3.36 \times 3.77}{(0.236)^3}\right]^{1/3}$$

$$= 0.546 \text{ mH/km/phase}$$

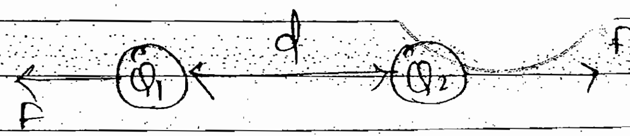
CAPACITANCE:

In case of NO-load or light load condition of a Tr-line charging current flows through the line due to capacitance exist b/w the conductors and conductors to the ground.

Due to capacitance effect under No load $V_R > V_S$ (ferranti effect occurs) for compensating this ferranti effect shunt reactor/capacitor has to be used for designing proper value of shunt reactor line capacitances has to be calculated According to the configuration of the Tr-line

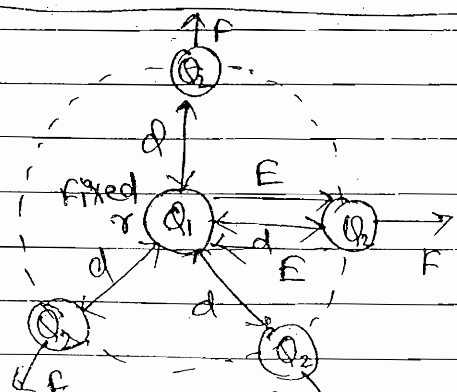


Columb's law



$$F = \frac{Q_1 Q_2}{4\pi\epsilon_0\epsilon_r d^2}$$

$$E = \frac{F}{Q_2} = \frac{Q_1}{4\pi\epsilon_0\epsilon_r d^2}$$



Voltage $= dV = \frac{\text{work done}}{\text{charge}} = \frac{\text{Force} \times \text{Distance}}{\text{charge}}$

$$= \frac{F}{Q} \cdot dx$$

$$dV = -E \cdot dx$$

bcoz E is working in opp. direct

Date

$$\boxed{V = -\int_d^r E \cdot dx} \qquad \boxed{C = \frac{Q}{V}}$$

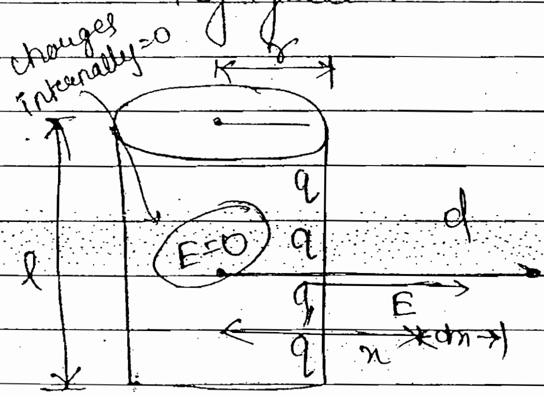
where r = smallest distance

d = longest distance, it may be ∞.

- Capacitance due to Single Conductor :-

Assumption: ① Tr-line is of ACSR conductor having line charge configuration.

② Charge is accumulating on the surface of the conductor bcoz the conductivity is higher so that the electrical field on the center of the conductor is negligible. ∴ charge is neglected at the center.



$\sigma = \infty$

$J = \sigma . E$

$E = \frac{J}{\sigma} = \frac{J}{\infty} = 0$

E = 0 inside so charges are at surface, E is not axially, it is radially.

q = line charge C/m.

$$E = \frac{q}{2\pi \epsilon_0 \epsilon_r x}.$$

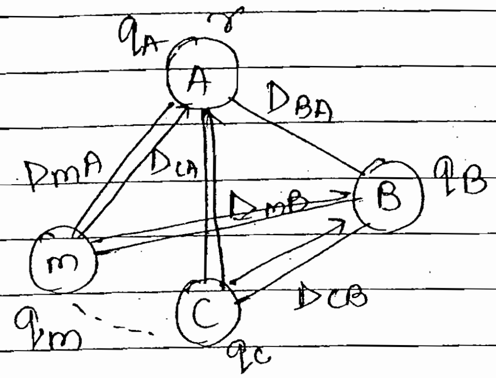
$$V = -\int_d^r E . dx$$

$$= -\int_d^r \frac{q}{2\pi \epsilon_0 \epsilon_r} . dx$$

$$\boxed{V = \frac{q}{2\pi \epsilon_0 \epsilon_r} \ln\left(\frac{d}{r}\right)}$$

$$\boxed{C = \frac{q}{V} = \frac{2\pi \epsilon_0 \epsilon_r}{\ln(d/r)}} \text{ F/m}$$

- ## Voltage Between 2 Conductor in a group of Conductors

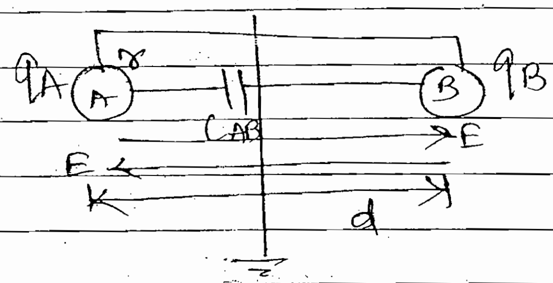


Voltage Between AB:-

$$V_{AB} = \frac{1}{2\pi\epsilon_0\epsilon_r}\left[q_A \ln\frac{D_{AB}}{r} + q_C \ln\frac{D_{CB}}{D_{CA}} + q_B \ln\frac{r}{D_{BA}} + \dots + q_m \ln\frac{D_{mB}}{D_{mA}}\right]$$

At Balance $q_A + q_B + \dots + q_m = 0$.

Capacitance Between Conductors of single phase 2-wire line



$$C_{AB} = \left|\frac{q_A}{V_{AB}}\right| = \left|\frac{q_B}{V_{\cancel{B}AB}}\right|$$

$$V_{AB} = V_A - V_B = \frac{q_A}{2\pi\epsilon_0\epsilon_r}\ln\left(\frac{d}{r}\right) - \frac{q_B}{2\pi\epsilon_0\epsilon_r}\ln\left(\frac{d}{r}\right)$$

$$V_{AB} = \frac{1}{2\pi\epsilon_0\epsilon_r}\left[q_A \ln\frac{d}{r} - q_B \ln\frac{d}{r}\right]$$

$$= \frac{1}{2\pi\epsilon_0\epsilon_r}\left[q_A \ln\frac{d}{r} + q_B \ln\frac{r}{d}\right]$$

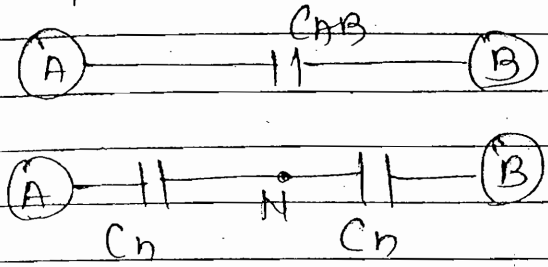
at Balance $q_B = -q_A$

$$V_{AB} = \frac{q_A}{2\pi\epsilon_0\epsilon_r}\ln\left(\frac{d}{r}\right)^2 \qquad V_{AB} = \frac{q_A}{\pi\epsilon_0\epsilon_r}\ln\left(\frac{d}{r}\right)$$

$$\boxed{C_{AB} = \frac{q_A}{V_{AB}} = \frac{\pi\epsilon_0\epsilon_r}{\ln(d/r)}} \quad F/m$$

Date________

- Capacitance to Neutral (C_n) or Capacitance /phase:-



$$C_{AB} = \frac{C_n \cdot C_n}{C_n + C_n} = \frac{C_n}{2}$$

$$\boxed{C_n = 2C_{AB}}$$

$$\boxed{C_n = \frac{2\pi\epsilon_0\epsilon_r}{\ln(d/r)}} \quad F/m/phase$$

- Effect of Earth on capacitance b/w Conductors

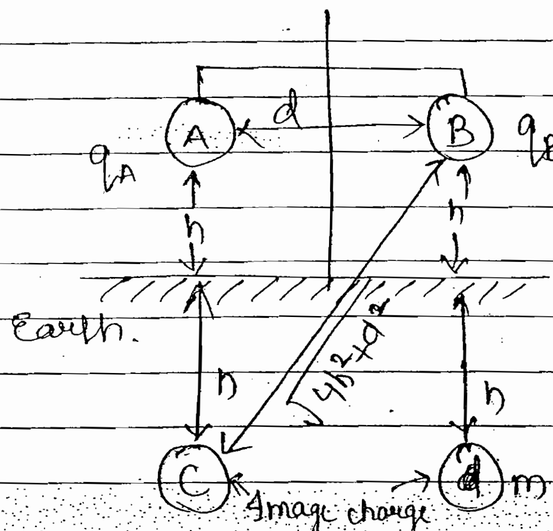
Earth consisting of ∞ No. of charge carrier of Both +ve and -ve. These charge carrier produces addition electrical field on the charges existing in the Tr-line conductor. Due to this capacitane b/w the conductor is increased which causes ↑ in charging current and Reactive power so that over voltage occurs in the system which causes insulation failure and some times initates corona. If the voltage of the system is higher than critical intereny distruptive voltage To avoid this abnormality and reduce the capacitance, earth effect the height of tower is ↑ as the operating voltage is ↑

KV	h (meters)
11	7
33	11
132	20
220	35
400	50
765	65

Date

- **Methods of Images**:- For calculation of earth effect b/w the conductors of Tr-line method of images is used. It is a mathematical technique adopted from electromagnetic fields. In this method image charges are assumed below the ground which are opposite in sign and have equal magnitude with the charges existing on the conductors of Tr-line.

- $\boxed{\text{No. of image Charges} = \text{No. of Conductors existing above the earth.}}$



Voltage b/w AB:-

$$V_{AB} = \frac{1}{2\pi\epsilon_0\epsilon_r}\left[q_A \ln\frac{D_{AB}}{r} + q_B \ln\frac{r}{D_{BA}} + q_c \ln\frac{D_{CB}}{D_{CA}} + \cdots + q_m \ln\frac{D_{mB}}{D_{mA}}\right]$$

$q_c = -q_A \qquad q_m = -q_B$

At Balance $q_A + q_B = 0$, $q_B = -q_A$, $q_c = -q_A$, $q_m = -q_B = q_A$

$D_{AB} = D_{BA} = d$, $D_{CA} = D_{mB} = 2h$

$D_{mA} = D_{CB} = \sqrt{4h^2 + d^2}$

$$V_{AB} = \frac{q_A}{2\pi\epsilon_0\epsilon_r} \ln\left[\frac{2h \cdot d}{r\sqrt{4h^2+d^2}}\right]^2$$

$$V_{AB} = \frac{q_A}{\pi\epsilon_0\epsilon_r} \ln\left(\frac{d}{r\sqrt{1+\frac{d^2}{4h^2}}}\right)$$

Date

$$\boxed{C_{AB} = \frac{q_A}{V_{AB}} = \frac{\pi \epsilon_0 \epsilon_r}{\ln\left(\frac{d}{r\sqrt{1+d^2/h^2}}\right)}}$$ With Earth effect.

NOTE :- If height of tower (h) is ↑. $h >> d$

$$\Rightarrow \frac{d^2}{4h^2} \approx 0$$

$$\boxed{C_{AB} = \frac{\pi \epsilon_0 \epsilon_r}{\ln\left(\frac{d}{r}\right)}}$$ without Earth effect.

- As $h \downarrow$, $\sqrt{1+\frac{d^2}{h^2}} \downarrow$, $\ln\left(\frac{d}{r\sqrt{1+d^2/h^2}}\right) \downarrow$, $C_{AB} \uparrow$.

- Generalised Equation :-

(1) 3ϕ Transposed line :-

$$C_n = \frac{2\pi \epsilon_0 \epsilon_r}{\ln\left[\frac{(D_1 D_2 D_3)^{1/3}}{r}\right]} \quad F/m/\text{phase}$$

(2) If $D_1 = D_2 = D_3 = D$

$$C_n = \frac{2\pi \epsilon_0 \epsilon_r}{\ln(D/r)}$$

(3) Bundled Conductors :-

$$C_n = \frac{2\pi \epsilon_0 \epsilon_r}{\ln\left(\frac{D_m}{D_s}\right)}$$

Date________

(4) Double ckt line :-

$$C_n = \frac{2\pi \epsilon_0 \epsilon_r}{\ln\left(\frac{D_{mR1}\ D_{mR2}\ D_{mR3}}{D_{SR1}\ D_{SR2}\ D_{SR3}}\right)^{1/3}}$$

(5) Capacitance Reactance.

$$X_c = \frac{1}{2\pi f C_n} \quad \Omega/m/\text{phase.}$$

(6) Capacitance susceptance.

$$B = \frac{1}{X_c} = 2\pi f C_n \quad \mho/m/\text{phase}$$

(7) Charging Current.

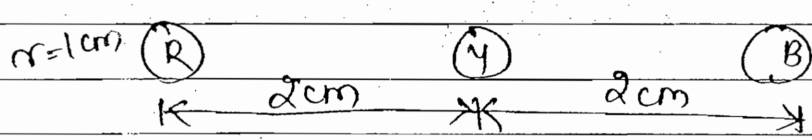
$$I_c = 2\pi f C_n V_{ph} \quad A/m/\text{phase}$$

(8) Reactive Power:-

$$Q_c = 2\pi f C_n V_{ph}^2 \quad \ldots \text{VARs}/m/\text{phase}$$

Q Find the capacitance / phase for the following configurat

(1) Horizontal

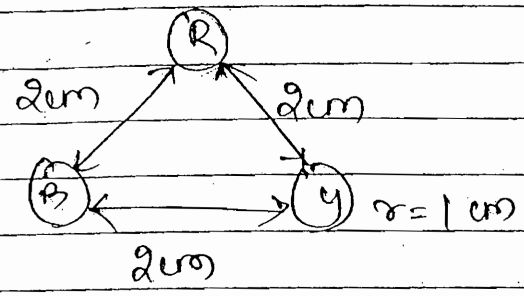


$$C_n = \frac{2\pi \epsilon_0 \epsilon_r}{\ln\left(\frac{(2\times 2\times 4)^{1/3}}{1}\right)}$$

$$= \frac{2\times 3.14\times 8.854\times 10^{-12}\times 1}{\ln\left(\frac{(2\times 2\times 4)^{1/3}}{1\times 10^{-2}}\right)} = 10\ pF/m/\text{phase}$$

$$= C_H$$

② Triangular :-



$$C_n = \frac{2\pi \epsilon_0 \epsilon_r}{\ln\left(\frac{D}{r}\right)}$$

$$= \frac{2\pi \times 8.854 \times 10^{-12} \times 1}{\ln\left(\frac{2}{1 \times 10^{-2}}\right)}$$

$$= 10.5 \text{ pF/m/phase}$$

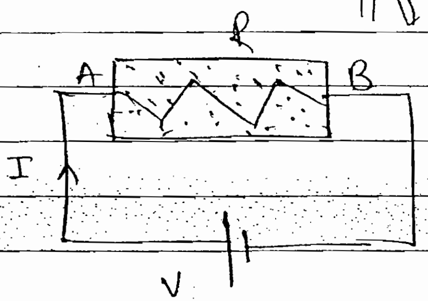
$$= C_\Delta$$

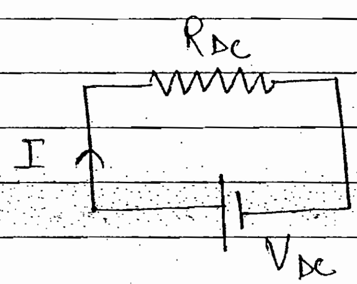
$$\boxed{C_\Delta > C_H}$$

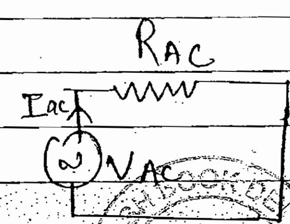
$$\boxed{L_\Delta < L_H}$$

Prefer Δ one even C_n has disadv.

RESISTANCE :-



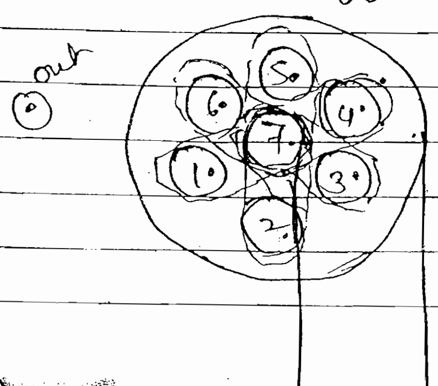


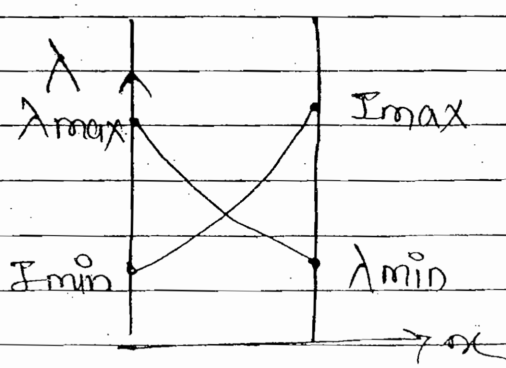


$R_{AC} > R_{DC}$ → ① Skin effect

$\approx 1.5\, R_{DC}$ → ② Proximity effect

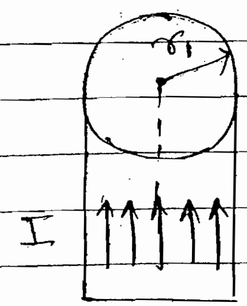
① Skin Effect :-

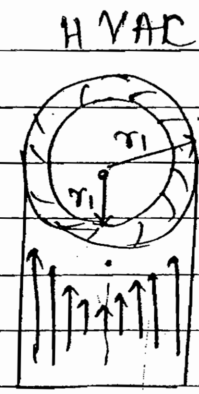




Date

HVDC | HVAC



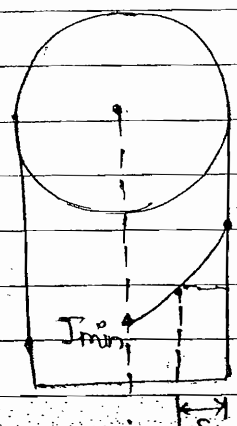


$$R_{AC} = \frac{\rho l}{\pi (r_1^2 - r_2^2)}$$

$$R_{AC} = \frac{\rho l}{\pi r_1^2}$$

$$\therefore \boxed{R_{ac} > R_{DC}}$$

<u>Skin Depth</u> :-



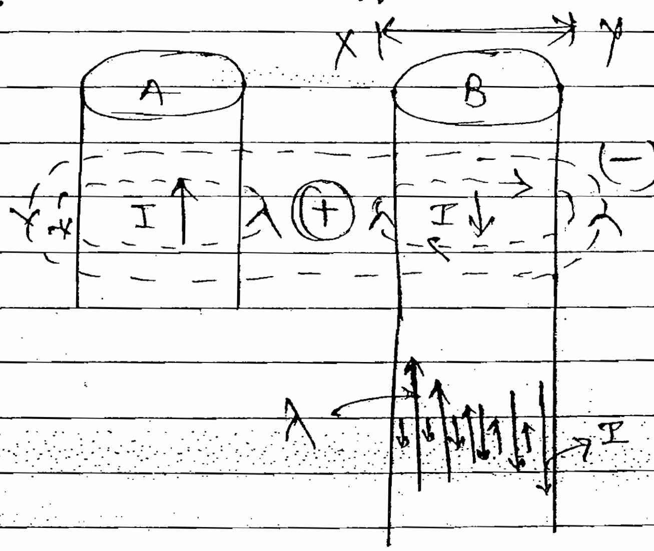
$I_{max} = 27.18A$

$$\frac{I_{max}}{e} = \frac{27.18}{2.718} = 10\,A$$

$$\delta = \frac{1}{\sqrt{\mu_0 \mu_r \sigma \pi f}}$$

$$\boxed{\text{Skin effect} \propto \frac{1}{\delta}}$$

<u>Proximity Effect</u> :-



B/w → flux in same dirⁿ → +
Surf → flux in opp dirⁿ → −

- Accumulation of current on the surface of conductor is called <u>skin effect</u>.
- Due to skin effect effective area of current flowing path is ↓ which causes $R_{ac} > R_{dc}$

Date

- Skin Depth :- The depth of the conductor at which the surface current is reduce to $\frac{1}{e}$ times the surface value. As the skin depth is ↑ skin effect is ↓. In case of communicatn lines frequency is very high so that skin depth is small skin effect is larger.
- Skin effect depends on
  1. frequency
  2. Conductivity
  3. μ_r
  4. Size of the conductor

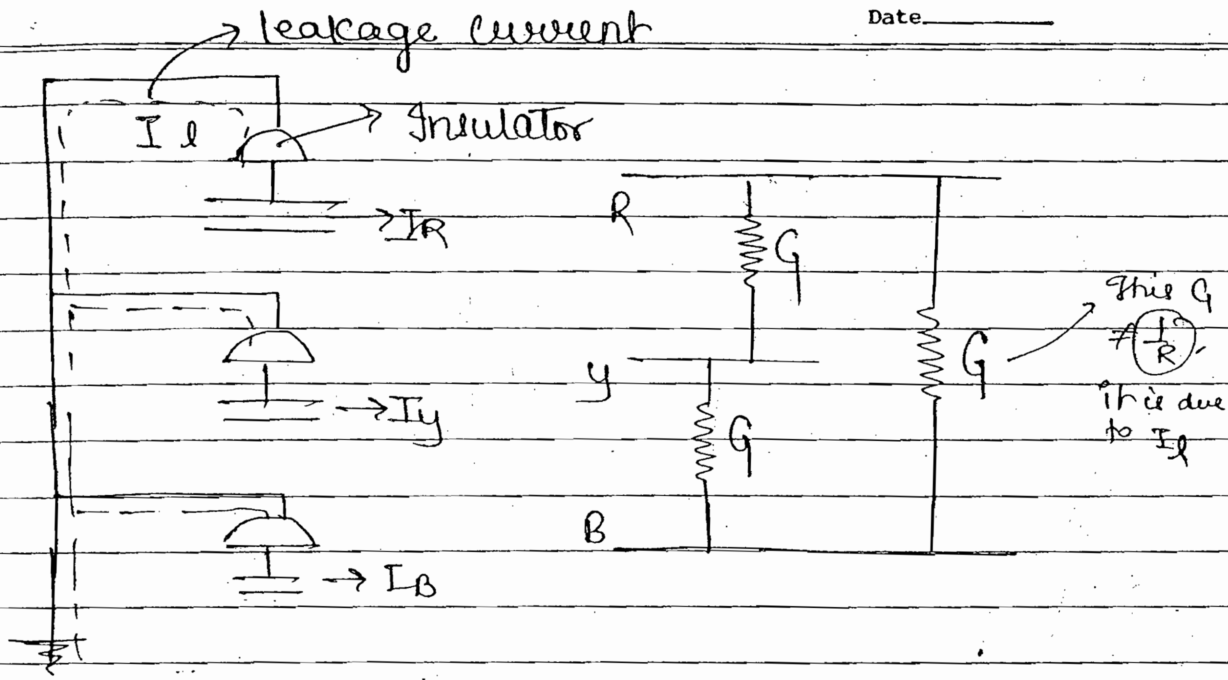
- Proximity Effect :- It is occur due to current flowing in the adjacent conductors produces Non-uniform flux linkage, so that Non-uniform current flows and the effective area of current flowing path is reduced which causes $R_{ac} > R_{dc}$.

- Proximity effect depends on:-
  1. frequency
  2. σ
  3. μ_r
  4. Distance b/w the conductors

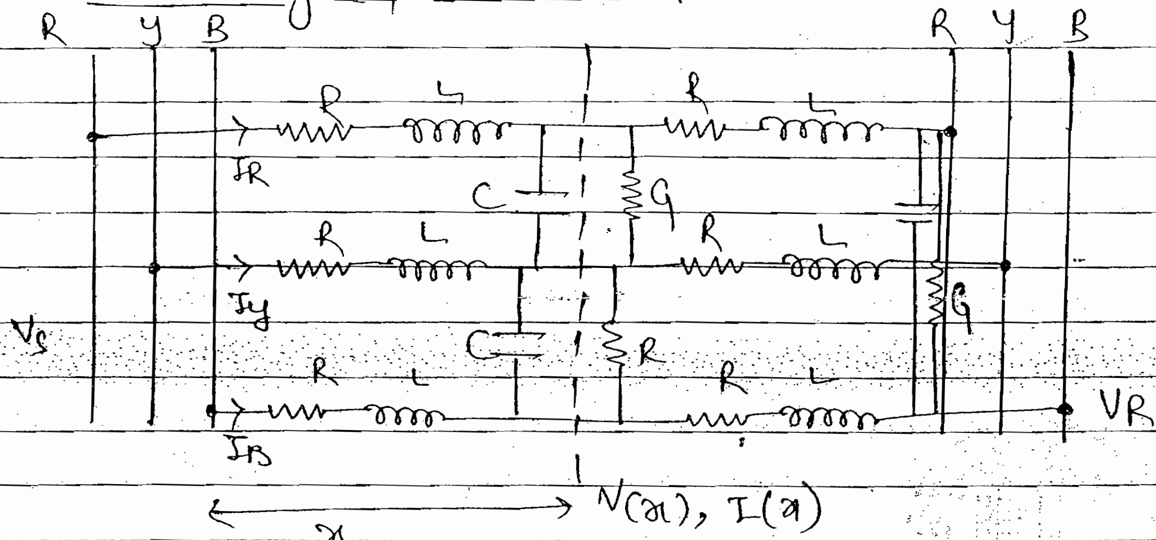
- Proximity effect is More if the distance is small b/w the conductor ex:- power cables. In overhead lines distance b/w the conductor is larger so that proximity effect is negligible

(4) Conductance :- The leakage current flowing b/w conductor and the insulation is represent with electrical equivalence of conductor parameter G. It value is neglected in case of short and medium lines and it is conside in case of long lines.

Date.________

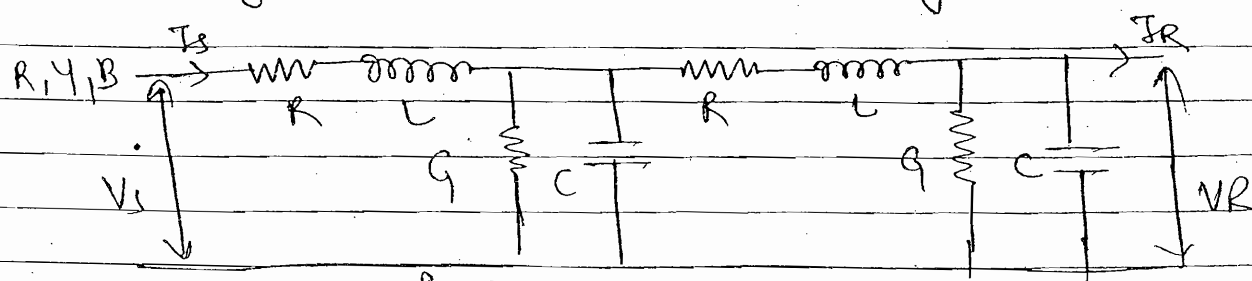


- ## Modelling Of Tr-line:-



Assumption:-

① System is balanced $(|I_R| = |I_y| = |I_B|)$



Distributed N/W.

Date

② Lumped N/W :-

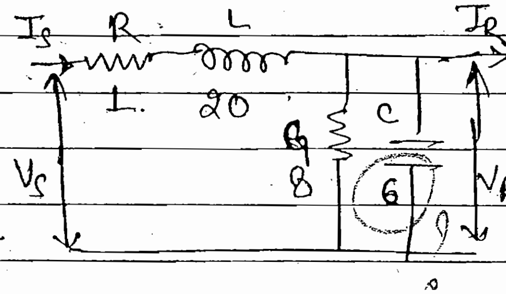
$l > 100$ km

$R = 0.001 \times 100 = 1\,\Omega$.

$L = 0.2 \times 100 = 20\,H$

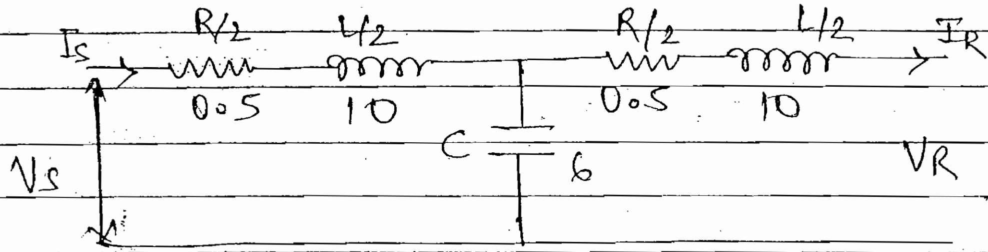
$C = 0.04 \times 100 = 4\,MF$

$G = 0.08 \times 100 = 8\,n\mho$

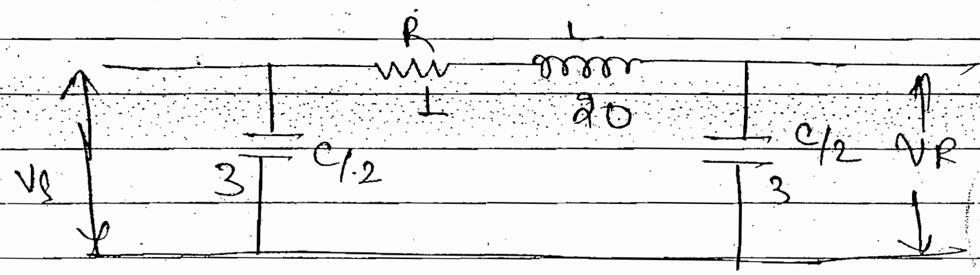


③ Medium line :- [G is neglected]

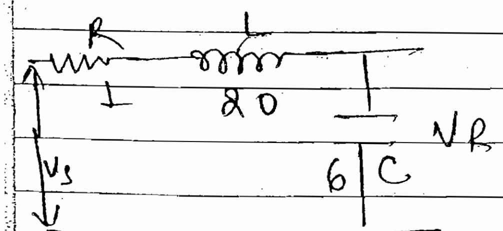
(a) Nominal T N/W. :-



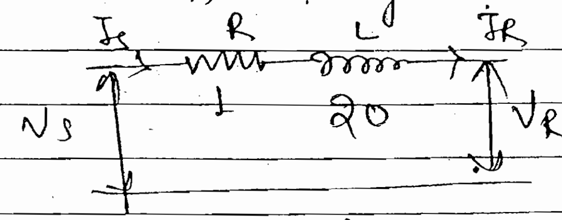
(b) Nominal π N/W :-



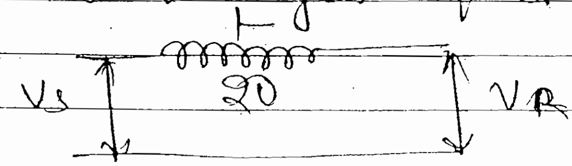
(c) End Condense :-



(d) Short line (G, C neglected)

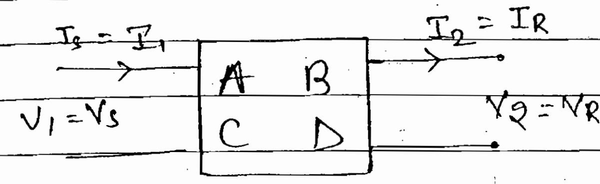


⑤ Fault analysis Eq. Ckt. ($R << X_L$)



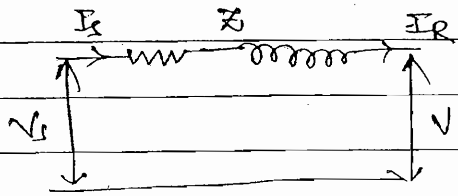
Date 10/7/2014.

ABCD or Tr. LINE PARAMETERS



- $\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}$
- $A = D \Rightarrow$ Symmetrical co, $AD - BC = 1 \Rightarrow$ Reciprocal

(1) Z Network :- (Short Tr line)



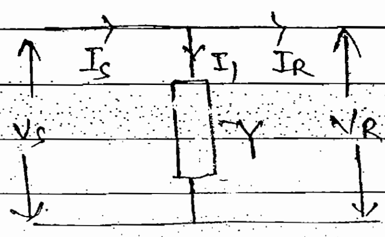
$V_S = V_R + I_R \cdot Z$

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

$I_s = I_R = (0) V_R + 1 \cdot I_R$

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

(2) Y Network :-

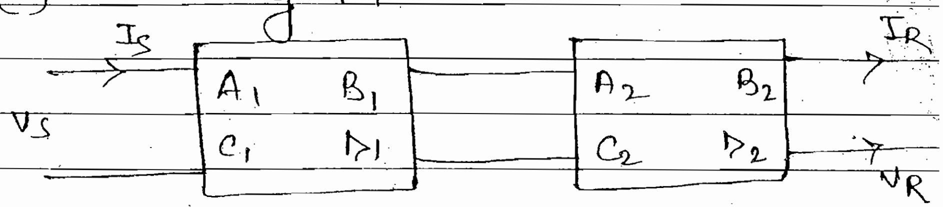


$V_s = V_R = 1 \cdot V_R + (0) I_R$

$I_s = I_1 + I_R = Y V_R + 1 \cdot I_R$

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

(3) Cascading N/w :-

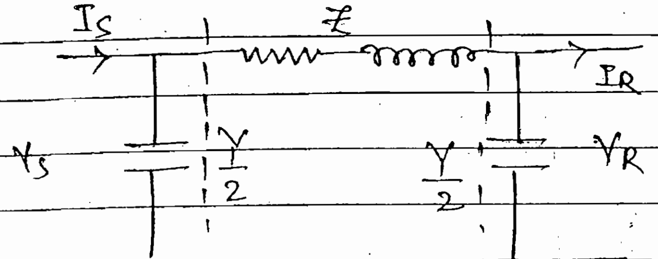


$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

- Reciprocal :- By reversing - value will remain same.
  ex:- V_s, V_R are reversed, values remain same.

Date__________

(4) Nominal π N/w:-



where

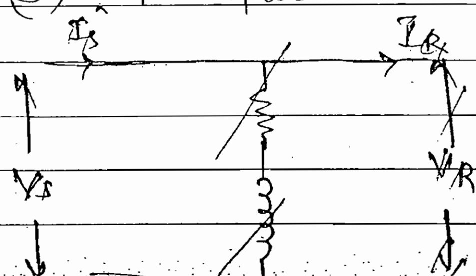
$Z = R + j\omega L$

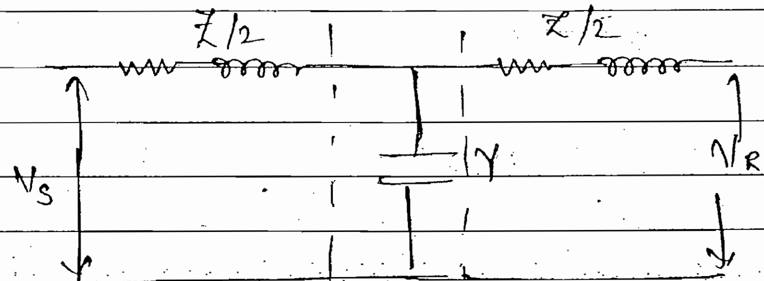
$Y = j\omega C$

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

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} \left(1 + \frac{YZ}{2}\right) & Z \\ Y\left(1 + \frac{YZ}{4}\right) & \left(1 + \frac{YZ}{2}\right) \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

(5) Nominal T N/w:-

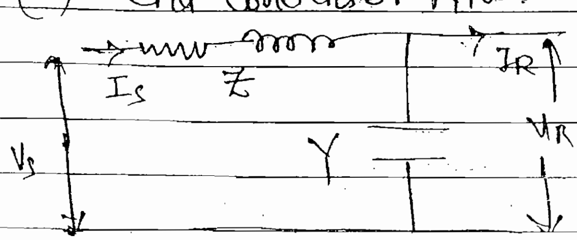




$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & Z/2 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} \begin{bmatrix} 1 & Z/2 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} \left(1 + \frac{YZ}{2}\right) & Z\left(1 + \frac{YZ}{4}\right) \\ Y & \left(1 + \frac{YZ}{2}\right) \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

(6) End Condenser N/w:-



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

Date

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} (1+YZ) & Z \\ Y & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$ $A \neq D$ unsymmetrical.

• Transmission Line Performance Parameters :-

(1) Transmission η :-

$$\% \eta = \frac{P_R}{P_S} \times 100 = \left| \frac{V_R I_R}{V_S I_S} \right| \frac{\cos \phi_R}{\cos \phi_S} \times 100$$

$$= \frac{P_R}{P_R + P_L} \times 100$$

P_L = Tr line loss $= P_S - P_R$

↳ Ideal: $\eta = 100\%$ ↳ practical $\eta > 90\%$

• Calculation of I_R if V_R, P_R are given :-

$1-\phi$

$$|I_R| = \frac{P_R}{V_R \cos \phi_R}$$

V_R = phase voltage

P_R = $1-\phi$ power

$3-\phi$

$$|I_R| = \frac{P_R}{\sqrt{3}\, V_R \cos \phi_R}$$

$V_R = V_L$ = line voltage

P_R = 3ϕ power

(2) Voltage Regulation :-

$$\% V_{REG} = \frac{|V_{RNL}| - |V_{RFL}|}{|V_{RFL}|} \times 100$$

V_{RNL} = No load Receiving End Voltage

$V_S = AV_R + BI_R$

At No load $I_R = 0 \Rightarrow V_S = A V_{RNL}$

$$|V_{RNL}| = \left| \frac{V_S}{A} \right|$$

V_{RFL} = Full load or Rated Receiving End Voltage

$= |V_R|$

Date

$$\boxed{\% V_{REG} = \frac{\left|\frac{V_S}{A}\right| - |V_R|}{|V_R|} \times 100}$$

for short line
$A = 1$

valid for short / Medium / long lines

↳ Ideal V_{REG} : 0% , ↳ Practical $V_{REG} = \pm 5\%$

- Classification of Transmission line :-

(1) Short Tr. line $\longrightarrow$ $l < 80$ km, $lf < 4000$

(2) Medium Tr. line $\longrightarrow$ $80 \leq l \leq 200$ km , $4000 \leq lf \leq 10{,}000$

(3) Long Tr. line $\longrightarrow$ $l > 200$ km , $lf > 10{,}000$

ex :- $l = 80$ km ; $f = 50$ Hz.

$lf = 80 \times 50 = 4000$

- Communication lines are operation in MHz rang so that they are considered as long line equivalent ckt

- All the parameters R, L, C, G are distributed throughout the length of line

Q A Tr line has a length of 10 km is excited by
(i) 50 Hz (ii) 500 Hz (iii) 5 KHz.
Find the type of Tr line.

Solution $l = 10$ km,

(i) $f = 50$ Hz
$lf = 10 \times 50$
$= 500$
Short

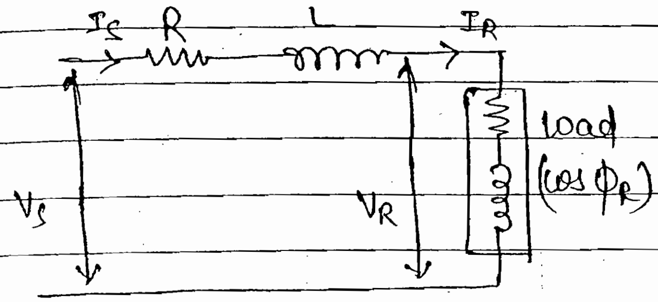
(ii) $f = 500$
$lf = 10 \times 500$
$= 5000$
Medium

(iii) $f = 5 \times 10^3$
$lf = 10 \times 10^3 \times 5$
$= 5 \times 10^4$
Long.

only A,C given / short line

Date________

(1) Short Tr.-line:-



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

$(Z) = (R + j\omega L)$

(1) $\% VEG = \dfrac{\left|\frac{V_S}{A}\right| - |V_R|}{|V_R|} \times 100$

For short line $A = 1$

$\% VEG = \dfrac{|V_S| - |V_R|}{|V_R|} \times 100$

(2) $\% \eta = \dfrac{P_R}{P_R + P_L} \times 100$

- $1-\phi$: $P_L = R \cdot I_R^2$
- $3-\phi$: $P_L = 3 R I_R^2$

Pg NO. → 45

Conventional 2 $\quad l = 40\,km \quad 220\,kV, 3\phi.$

$R = 0.15\,\Omega/km \quad f = 50\,Hz.$

$lf = 40 \times 50 \quad L = 1.5923\,mH/km.$

$= 2000$ short $\quad S_R = 381\,MVA \quad \cos\phi_R = 0.8.$

(1) Convert into lumped Nw. $\quad$ default = lagging

$R = 0.15 \times 40 = 60\,\Omega$

$L = (2\pi f L) \cdot l = 2\pi \times 50 \times 1.5923 \times 10^{-3} \times 40$

$= 20\,\Omega.$

$Z = 60 + j20 = 20.8\ \angle 73.3^\circ\,\Omega$

For short line $B = Z = 60 + j20$

$A = D = 1$

$I_R = \dfrac{P_R}{\sqrt{3}\, V_R \cos\phi_R} = \dfrac{S_R \cdot \cos\phi_R}{\sqrt{3}\, V_R \cos\phi_R}$

$= \dfrac{381 \times 10^6 \times 0.8}{\sqrt{3} \times 220 \times 0.8 \times 10^3}$

$|I_R| = 1000\,A$

Date

$\cos\phi_R = 0.8$ lag, $\phi_R = 36.86°$

$I_R = 1000 \angle -36.86° A = I_s$

Remember these

① (a) $V_s = A V_R + B I_R$

$= 1 \times \frac{220 \times 10^3}{\sqrt{3}} + 20.8 \angle 73.3° \times 1000 \angle -36.86$

$= 144.8 \angle 4.8°$ kV/phase.

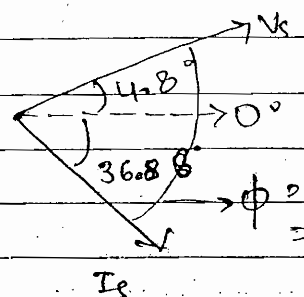
$V_{SL} = \sqrt{3} \times 144.8 \angle 4.8°$

$= 250 \angle 4.8°$ kV

(b) $P_s = \sqrt{3} |V_s I_s| \cos\phi$

$V_s = 250 \angle 4.8°$ kV.

$I_s = I_R = 1000 \angle -36.86°$ A



$\phi = 4.8 + 36.86$

$= 41.66°$

$P_s = \sqrt{3} \times 250 \times 10^3 \times 1000 \times \cos(36.86 + 4.8°)$

$\boxed{P_s = 323 \text{ MW}}$

② (a) % $V_{REG} = \frac{|V_s| - |V_R|}{|V_R|} \times 100$

$= \frac{250 - 220}{220} \times 100$

$= \frac{30 \times 100}{220}$

V_{REG} % $= 13.67$ %.

(b) $\eta \% = \frac{P_R}{P_s} \times 100 = \frac{381 \times 0.8}{323} \times 100$

$\% \eta = 94\%$

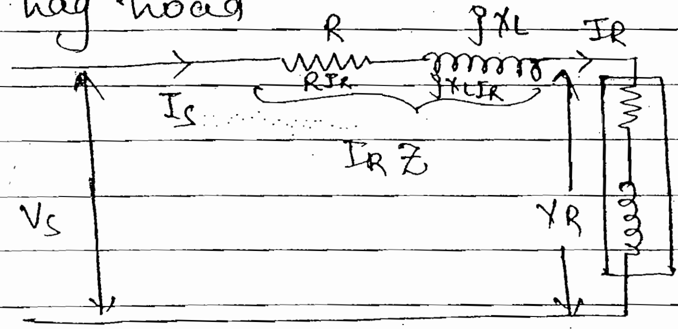
(OR) $P_L = 3 R I_R^2 = 3 \times 6 \times (1000)^2 = 18$ MW

$\% \eta = \frac{P_R}{P_R + P_L} \times 100 = \frac{381 \times 0.8}{381 \times 0.8 + 18} \times 100 \approx 94\%$

2.18

- Phasor Diagram:-

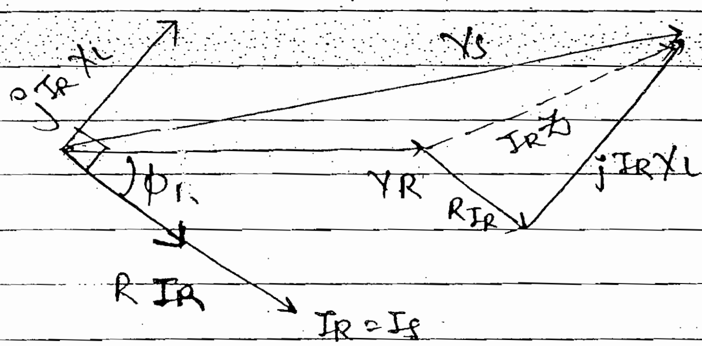
(1) Lag Load



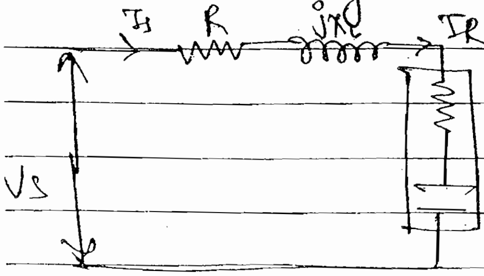
$V_S = V_R + I_R R + jI_R X_L$

lag ($\cos\phi_R$)

- Start from Receiving end, add all drop, final reach to sending end



(2) Leading Load:-



leading $\cos\phi_R$

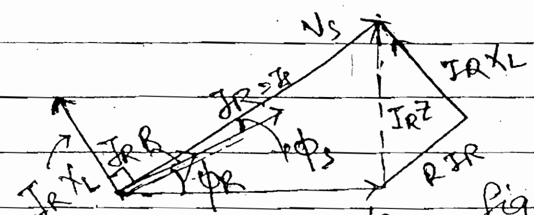
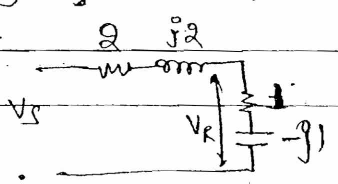


fig ①



$Z = (3 + j1)$
lagging

Date

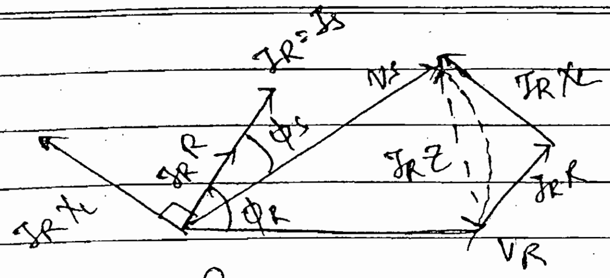
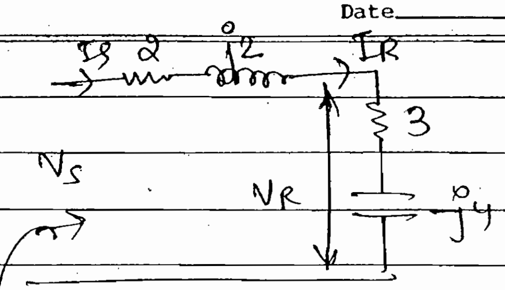


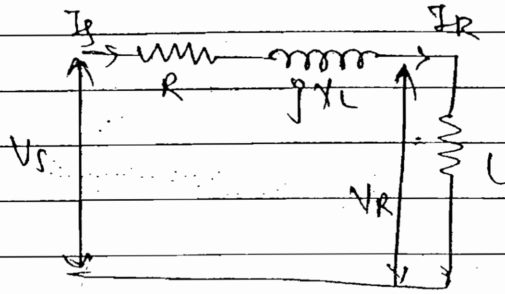
fig ②

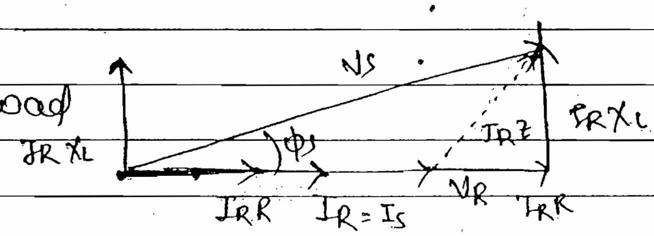


$(5 + (-j2)) = 5 - j2$

leading.

- (3) UPF Load.

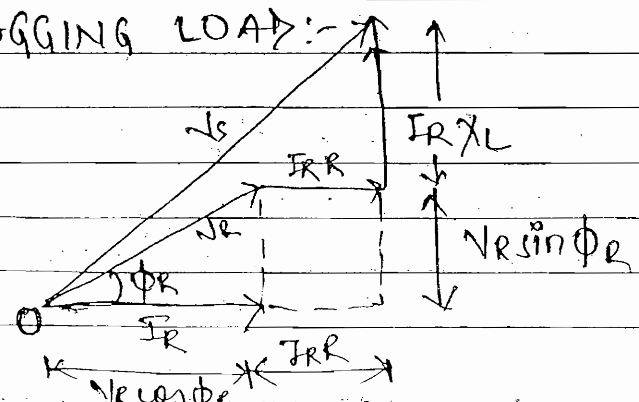




- In lagging load:- $\phi_S > \phi_R$. Bcoz More lagging load.
  $V_S > V_R$
  +ve VREG $\qquad V_{REG} \neq 0$
- UPF load:- $V_S > V_R \qquad V_{REG} \neq 0$
- Leading Load:- possibility of $V_{REG} \approx 0$
  $V_S \approx V_R$

- Effect of Load Power factor ON Voltage Regulation

(1) LAGGING LOAD:-



Date

$$V_s^2 = (V_R\cos\phi_R + I_R R)^2 + (V_R\sin\phi_R + I_R X_L)^2$$

$$= V_R^2 + I_R^2(R^2+X_L^2) + 2V_R I_R(R\cos\phi_R + X_L\sin\phi_R) \quad (1)$$

Assume $I_R^2(R^2+X_L^2) \ll V_R^2$

$$V_s = \left[V_R^2 + 2V_R I_R(R\cos\phi_R + X_L\sin\phi_R)\right]^{1/2}$$

$$= V_R\left[1 + \frac{2I_R}{V_R}(R\cos\phi_R + X_L\sin\phi_R)\right]^{1/2}$$

use $(1+x)^{1/2} \simeq 1 + \frac{x}{2}$

$$V_s = V_R\left[1 + \frac{2I_R}{2V_R}(R\cos\phi_R + X_L\sin\phi_R)\right]$$

$$V_s - V_R = I_R\left[R\cos\phi_R + X_L\sin\phi_R\right]$$

$$\%\,V_{REG} = \frac{V_s - V_R}{V_R} \times 100$$

$$\boxed{\%\,V_{REG} = \frac{I_R(R\cos\phi_R + X_L\sin\phi_R)}{V_R} \times 100}$$

Condition for Max. V_{REG}:-

$$\frac{d}{d\phi_R}\left[R\cos\phi_R + X_L\sin\phi_R\right] = 0$$

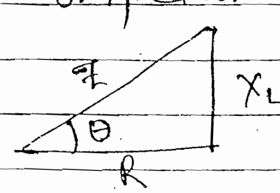
$$-R\sin\phi_R + X_L\cos\phi_R = 0$$

$$\boxed{\phi_R = \tan^{-1}\left(\frac{X_L}{R}\right)}$$ condition for Max V_{REG}

$R, X_L \rightarrow$ Tr line parameter, ϕ_R = load p.f. angle

If $Z = (R + jX_L)$ = Tr. line Impedance.

$$\theta = \tan^{-1}\left(\frac{X_L}{R}\right)$$

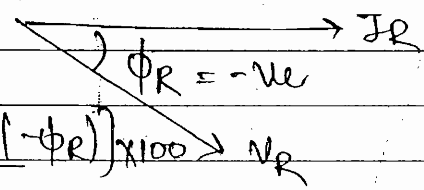


$$\boxed{\theta = \phi_R = \tan^{-1}\left(\frac{X_L}{R}\right)}$$

- p.f. of lag load for Max. V_{REG}.

$$\boxed{\cos\phi_R = \cos\theta = \frac{R}{Z}}$$

(2) Lead Load.



$$\% V_{REG} = \frac{I_R\left(R\cos(-\phi_R) + X_L\sin(-\phi_R)\right)}{V_R} \times 100$$

$$\boxed{\% V_{REG} = \frac{I_R\left(R\cos\phi_R - X_L\sin\phi_R\right)}{V_R} \times 100}$$

Condition for $V_{REG} = 0\%$

$$R\cos\phi_R - X_L\sin\phi_R = 0$$

$$\boxed{\phi_R = \tan^{-1}\frac{R}{X_L}}$$

If $\theta = \tan^{-1}\left(\frac{X_L}{R}\right)$ Then $\left(\phi_R = \frac{\pi}{2} - \theta\right)$

p.f. of lead load for $V_{REG} = 0\%$

$$\boxed{\cos\phi_R = \sin\theta = \frac{X_L}{Z}}$$

Date

$$(3)\quad \frac{V_{REG}(\text{lead})}{V_{REG}(\text{lag})} = \frac{R\cos\phi_R - X_L\sin\phi_R}{R\cos\phi_R + X_L\sin\phi_R}$$

lead

lag.

(4) Cal. of I_R, P_R if $V_{REG} = 0\%$ or $|V_S| = |V_R|$ given

from (1)

$$V_S^2 = V_R^2 + I_R^2(R^2+X_L^2) + 2V_R I_R[R\cos\phi_R + X_L\sin\phi_R]$$

If $|V_R| = |V_S|$

$$\boxed{|I_R| = \frac{2V_R(R\cos\phi_R + X_L\sin\phi)}{(R^2+X_L^2)}}$$

lag load

$$\boxed{|I_R| = \frac{2V_R(R\cos\phi_R - X_L\sin\phi)}{(R^2+X_L^2)}}$$

lead load

where $V_R, R, X_L \Rightarrow$ phase values

$$\boxed{P_R = \sqrt{3}\, V_R I_R \cos\phi_R}$$

where $V_R = V_L$ = line voltage

Q A Tr-line has an impedance of $3+j4\ \Omega$/phase p.f of load required for maintaining maximum and zero voltage regulation or respectively

(a) 0.8 lead, 0.6 lag.
(b) 0.6 lag, 0.8 lead
(c) 0.6 lead 0.8 lag
(d) 0.8 lag 0.8 lead

Max:- $\frac{3}{5} = 0.6$ lag.

Zero:- $\frac{4}{5} = 0.8$ lead

Date________

Q Tr line impedance = 60° the load p.f. angle required for zero maximum voltage regulatn is respectively.

Sol $p.f = zero.$ $\frac{\pi}{2} - \theta = \theta$

Q Tr-line is an impedance of $2+j8$ is connected with 0.8 lagging load produces 10% of voltage regulation find the voltage Regulatn for a leading load of 0.707.

Solut $Z = 2+j8$ 0.8 lagging 10% VR.

leading =

$$\frac{V_{REG}\ lead}{V_{REG}\ lag.} = \frac{2\times0.707 - 8\times0.707}{2\times0.8 + 8\times0.6}$$

$$= -5\%$$

Q A 3ϕ Tr-line having $Z = 3+j4$ connected with a 0.8 lagging load and operating $V_s = V_R = 11KV$ find the active power drawn by load

Sol

$$I_R = \frac{2V_R(R\cos\phi_R + X_L\sin\phi_R)}{X_L^2 + R^2}$$

$$= \frac{2\times 11/\sqrt{3}\times(3\cos 0.8 + 4\sin 0.6)}{(4^2+3^2)}$$

$$= 2.68$$

$$P_R = \sqrt{3}\ V_R\ I_R \cos\phi$$

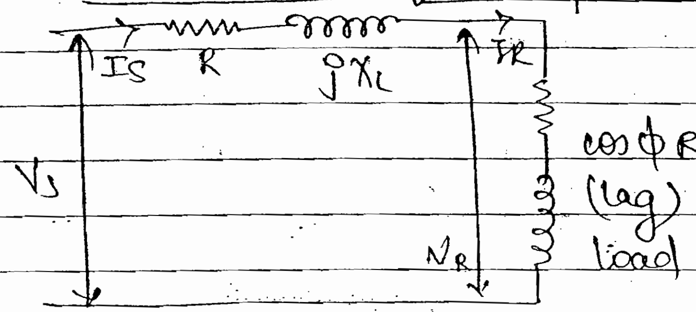
$$= \sqrt{3}\times 2.68\times 11\times \cos 0.8$$

Date________

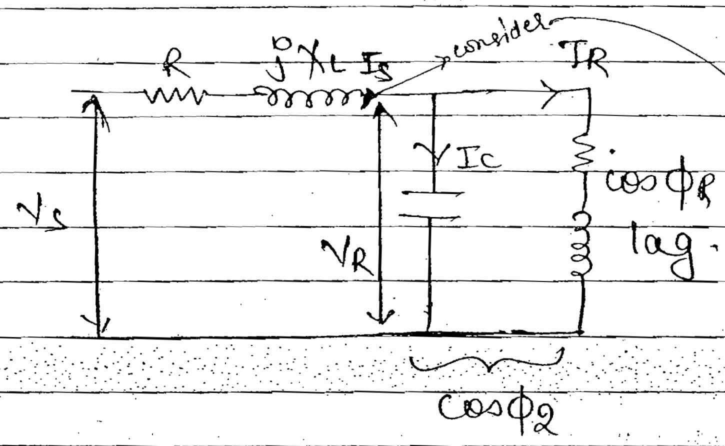
$$I_R = \frac{2 \times 11/\sqrt{3} \times 10^3 (3 \times 0.8 + 4 \times 0.6)}{(3^2+4^2)} = 2.4\,kA$$

$$P_R = \sqrt{3}\, V_R I_R \cos\phi_R$$
$$= \sqrt{3} \times 11 \times 10^3 \times 2.4 \times 10^3 \times 0.8 = 37.1\,MW.$$

- Calculation of Compensator (capacitor) for Reducing VR:-



$\Rightarrow V_S - V_R$ = Voltage drop
$$= I_R(R\cos\phi_R + X_L \sin\phi_R)$$



$$V_S - V_R =$$
$$= I_S (R\cos\phi_2 + X_L \sin\phi_2)$$
$$= \frac{P_R}{V_R \cos\phi_2}(R\cos\phi_2 + X_L \sin\phi_2)$$

$$V_S - V_R = \frac{RP_R}{V_R} + \frac{P_R X_L}{V_R} \tan\phi_2$$

$$\boxed{\tan\phi_2 = \frac{|V_S V_R| - |V_R^2| - |RP_R|}{|P_R X_L|}}$$

$$\phi_2 = \tan^{-1}\left(\frac{|V_S V_R| - |V_R^2| - |RP_R|}{|P_R X_L|}\right)$$

$$|I_S| = \frac{P_R}{V_R \cos\phi_2}$$

Date________

$I_s \angle \phi_2 = I_R \angle -\phi_R + j I_c$

$I_c = I_s \angle \phi_2 - I_R \angle -\phi_R$ [check wheather I_c angle coming 90° or not as it pure capaci]

$2\pi f C V_R = I_c$

$$\boxed{C = \frac{I_c}{2\pi f V_R}}$$

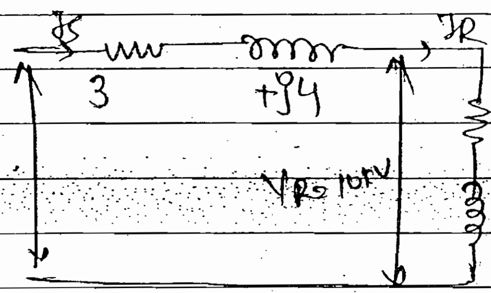
Q 1-ϕ Tr-line has an $Z = 3+j4\,\Omega$ operating at $V_R = 10kV$ connected with load of 10MW 0.8 lagging, Calculate (Assume V_R = const)

① Voltage Regulation

② How much capa. compensator required for reducing voltage regulatⁿ.

(a) 50% (b) 25%.

Solution



0.8 lag. 10MW

$$I_R = \frac{P_R}{V_R \cos\phi_R} = \frac{10 \times 10^6}{10 \times 10^3 \; 0.8} = 1250\,A$$

$$\% V_{REG} = \frac{I_R (R \cos\phi_R + X_L \sin\phi_R)}{V_R} \times 100$$

$$= \frac{1250 (3 \times 0.8 + 4 \times 0.6)}{10 \times 10^3} \times 100$$

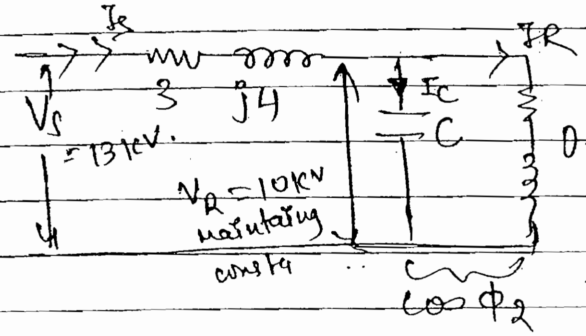
$$= 60\,\%$$

$\Rightarrow \dfrac{V_S - V_R}{V_R} = 60\% = 0.6$

$\Rightarrow V_S = (0.6 \times 10\times10^3) + (10\times10^3)$

$= 16\ kV.$

(2) With compensator:-



(9) VREG reduce of 50% of 60%

$\dfrac{V_S - V_R}{V_R} \cancel{\times 100} = \dfrac{0.6}{2} = 0.3$

$\dfrac{V_S - 10}{10} = 0.3$

$V_S = 13\ kV.$

(b) $\phi_2 = \tan^{-1}\left(\dfrac{|V_S||V_R| - |V_R^2| |R P_R)}{|P_R X_L|}\right)$

$= \tan^{-1}\left(\dfrac{|13\times10| - |(10)^2)\ \cancel{x} - |(3\times10)|}{10\times4}\right)$

$= 0°.$

$I_s = \dfrac{P_R}{V_R \cos\phi_2} = \dfrac{10\times10^6}{10\times10^3\times1} \Rightarrow 1000A$

$I_C = I_s\angle\phi_2 - I_R\angle-\phi_R$

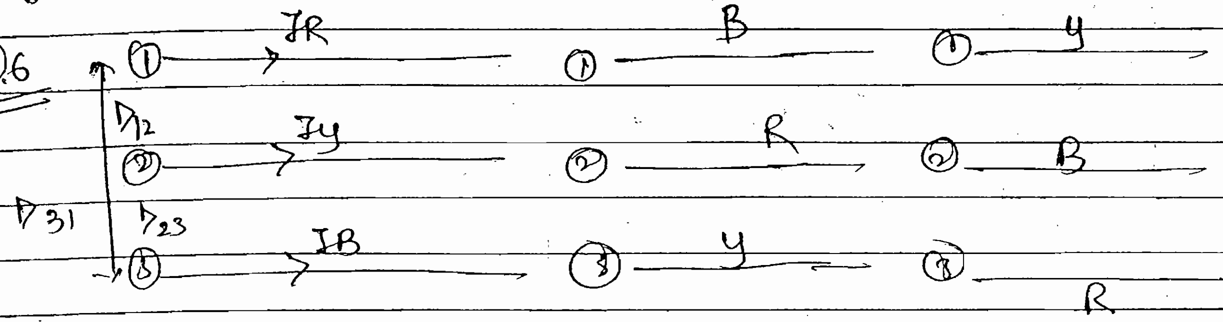
$= 1000\angle0° - 1250\angle-36.86$

$= 750\angle90°$ Amp.

$C = \dfrac{I_c}{2\pi f \times V_R} = \dfrac{750}{2\pi\times50\times10\times10^3}$

$= 238\ \mu F.$

Q.6



$$\lambda_1 = \frac{\mu_0}{2\pi}\left[I_R \ln\frac{1}{r'} + I_y \ln\frac{1}{D_{12}} + I_B \ln\frac{1}{D_{13}} \right]$$

$$\lambda_2 = \frac{\mu_0}{2\pi}\left[I_R \ln\frac{1}{r'} + I_y \ln\frac{1}{D_{23}} + I_B \ln\frac{1}{D_{12}} \right]$$

$$\lambda_3 = \frac{\mu_0}{2\pi}\left[I_R \ln\frac{1}{r'} + I_y \ln\frac{1}{D_{13}} + I_B \ln\frac{1}{D_{23}} \right]$$

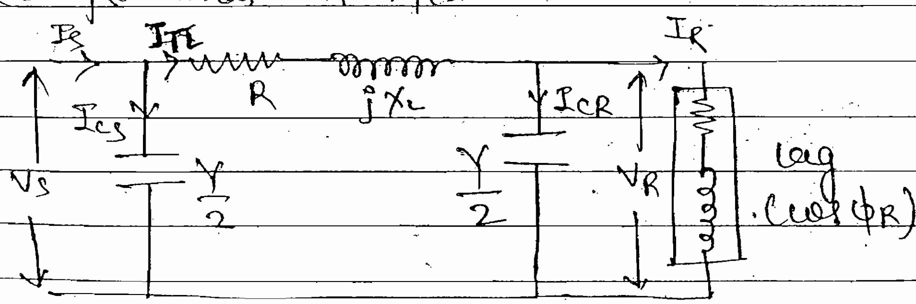
$$I_y = I_R \angle -120^\circ = -0.5 - j0.866\, I_R$$
$$I_B = I_R \angle -240^\circ = -0.5 + j0.866\, I_R$$

Take these avg. value. Real Terms will cancel out only R will eff.

11/7/2014

(2) Medium Tr-line:

(1) Nominal π N/w:



$Z = R + j\omega L$

$Y = j\omega C$

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 + \frac{YZ}{2} & Z \\ Y\left(1 + \frac{YZ}{4}\right) & \left(1 + \frac{YZ}{2}\right) \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

Date________

(1) $\% V_{REG} = \dfrac{\left|\frac{V_S}{A}\right| - |V_R|}{|V_R|} \times 100$

where $A = \left(1 + \frac{YZ}{2}\right)$

(3) $\% \eta = \dfrac{P_R}{P_R + P_L} \times 100$

where $P_L = R I_{TL}^2$ for $1-\phi$, $= 3 R I_{TL}^2$ for $3-\phi$

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

$= I_R + \frac{Y}{2} V_R$.

Steps:

(1) V_R as Ref

(2) I_R lags V_R by ϕ_R

(3) $I_{CR} = V_R Y/2$

I_{CR} leads V_R by $90°$

(4) $I_{TL} = I_R + I_{CR}$

(5) $I_{TL} Z = R I_{TL} + j I_{TL} X_L$

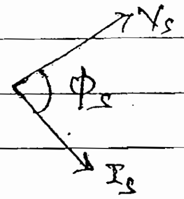
(6) $V_S = V_R + I_{TL} Z$

(7) $I_{CS} = V_S \frac{Y}{2}$

I_{CS} leads V_S by $90°$

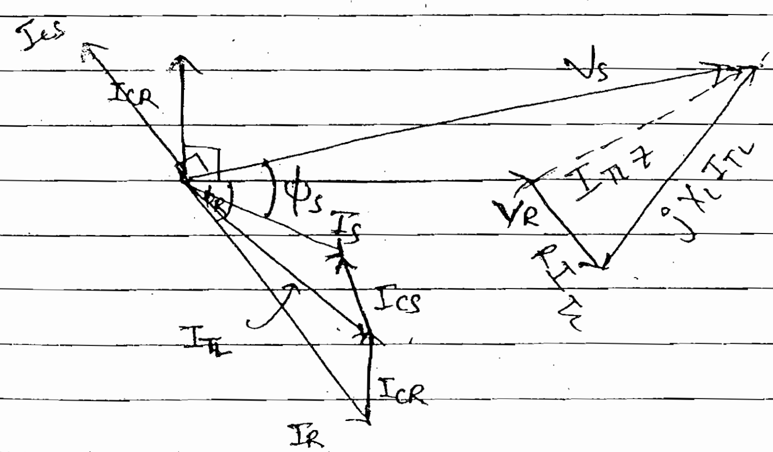
(8) $I_S = I_{CS} + I_{TL}$

(9)



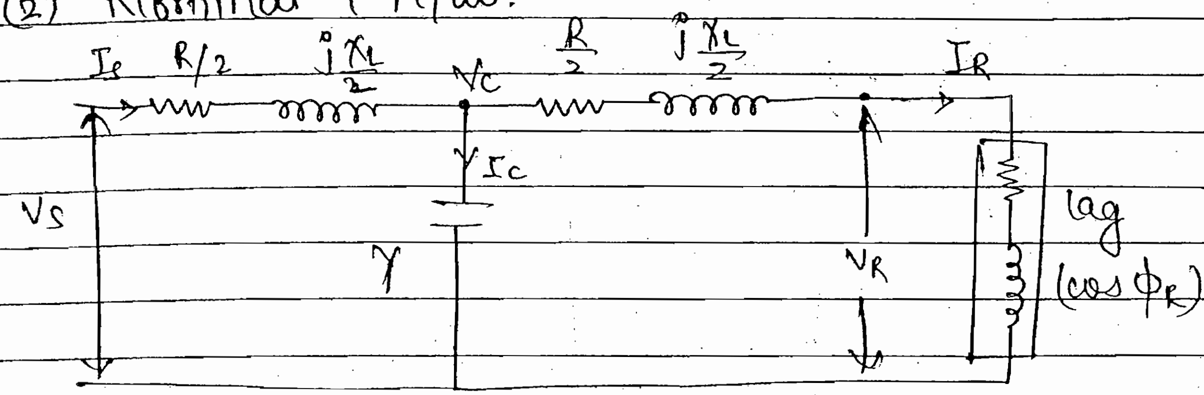
• If the load current I_R and voltage is V_R, lag by ϕ_R

PHASOR DIAGRAM



Date

(2) Nominal T N/w:-



$Z = R + jX_L \qquad Y = j\omega C$

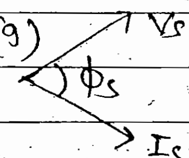
Steps (1) V_R as Ref. (2) I_R lags V_R by ϕ_R

(3) $I_R \frac{Z}{2} = I_R \cdot \frac{R}{2} + j I_R \frac{X_L}{2}$ (4) $V_c = V_R + I_R \frac{Z}{2}$

(5) $I_c = V_c Y$ (6) $I_s = I_c + I_R$

I_c leads V_c by 90° (7) $I_s \frac{Z}{2} = I_s \frac{R}{2} + j I_s \frac{X_L}{2}$

(8) $V_s = V_c + I_s \cdot Z/2$ (9)



$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} \left(1 + Y\frac{Z}{2}\right) & Z\left(1 + Y\frac{Z}{4}\right) \\ Y & \left(1 + YZ/2\right) \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

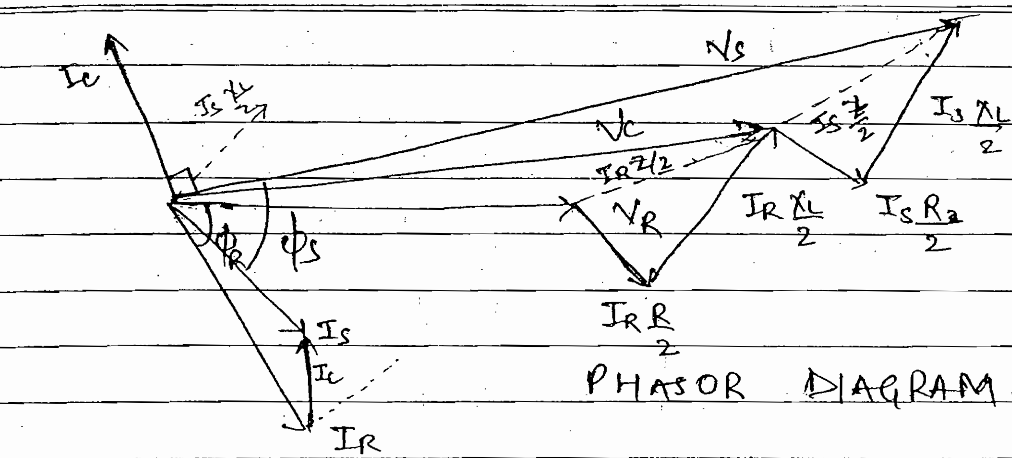
(1) $\% V_{REG} = \dfrac{\left|\frac{V_S}{A}\right| - |V_R|}{|V_R|} \times 100$ where $A = 1 + Y\frac{Z}{2}$

(2) $\% \eta = \dfrac{P_R}{P_R + P_L} \times 100$

where $P_L = \frac{R}{2}\left(I_R^2 + I_S^2\right)$ for $1-\phi$

$= \frac{3R}{2}\left[I_R^2 + I_S^2\right]$ for $3-\phi$

Date



PHASOR DIAGRAM.

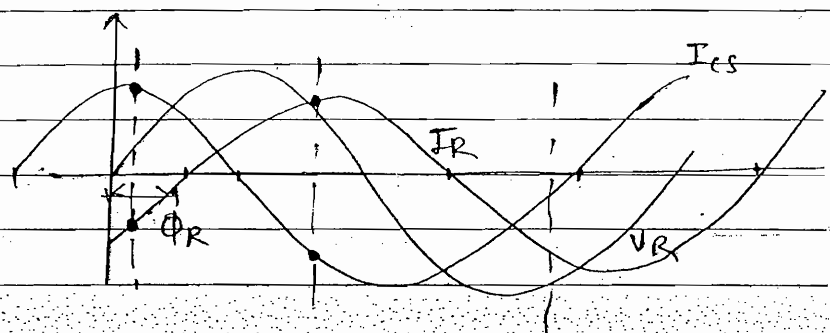
$$I_s = I_R + I_C = |I_R \angle -\phi_R + |I_c| \angle 90^\circ$$

$$= I_R \cos\phi_R - j I_R \sin\phi_R + j I_c$$

$$I_s = I_R \cos\phi_R + j(I_c - I_R \sin\phi_R) \downarrow$$

{ Imag part is ↓ ∴ so I_s is ↓

$$|I_s| < |I_R|$$



$I_{TL} = \overline{I_R} + \overline{I_{cs}}$

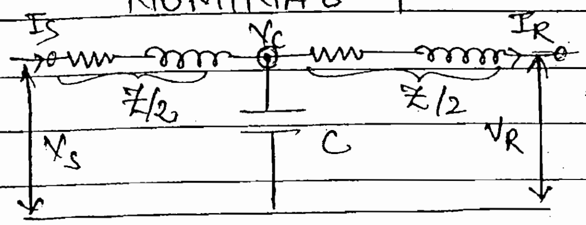
- Comparison B/w short & Medium Tr-line: -

PARAMETER	SHORT LINE	MEDIUM LINE
I_s	$\lvert I_s \rvert = \lvert I_R \rvert$	$\lvert I_s \rvert < \lvert I_R \rvert$ due to I_c
P_L	More	Less "
η	less	More "
% VREG	More	less "
P_c	More	less "

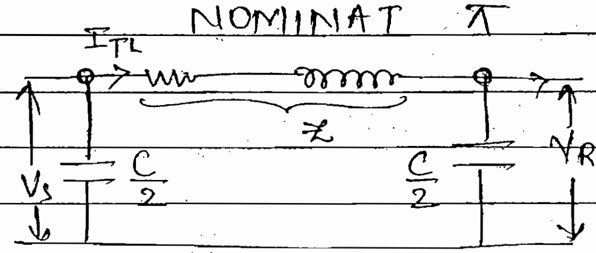
Date________

- Comparison b/w Nominal T and Nominal π N/w.

NOMINAL T



NOMINAT π

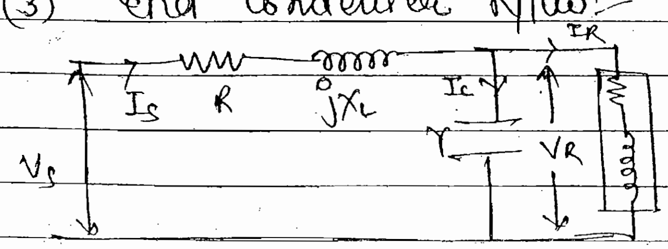


$I_S = \dfrac{V_S - V_C}{Z/2}$; $I_R = \dfrac{V_C - V_R}{Z/2}$ $\qquad$ $I_{TL} = \dfrac{V_S - V_R}{Z}$

Node = 3 $\quad$ $eq^n = 2$ $\qquad$ Node = 2 $\quad$ $eq^n = 1$

NOMINAL T	NOMINAT π
• No. of Nodes are 3, so that No. of eq^n are more	• No. of Nodes are only 2 so that No. of eq^n are less
• The external shunt capacitor can't be easily combine with the line capacitance	• It is easily combine with the line capacitance.
• The line capacitance is concentrated at the middle of the line.	• Line capacitance is distributed at both sending and receiving end
• It is used for analysis the effect of capacitance at the middle of the line	• It is used in the load flow analysis as an equivalent ckt due to no. of eq^n are less so that faster calculat^n is possible

(3) End Condenser N/w:-



Lag
$\cos\phi_R$

Date

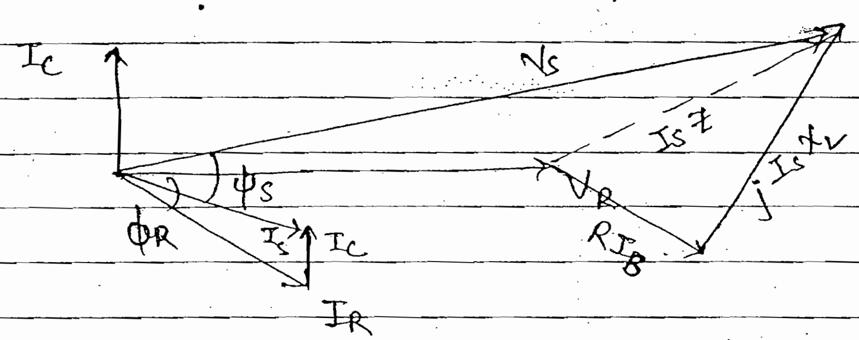
$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} (1+YZ) & Z \\ Y & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

(1) $\% V_{REG} = \dfrac{|V_S/A| - |V_R|}{|V_R|} \times 100$

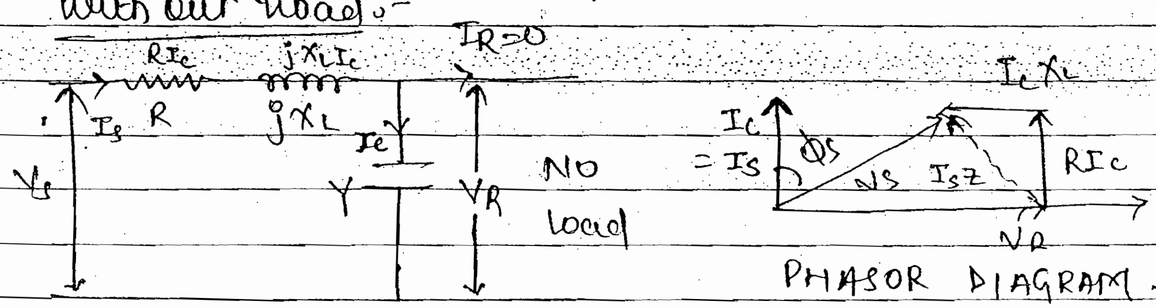
where $A = (1+YZ)$

(2) $\% \eta = \dfrac{P_R}{P_R + P_L} \times 100$ $\qquad P_L = RI_S^2$ for $1-\phi$; $\quad P_L = 3RI_S^2$ for $3-\phi$

PHASOR DIAGRAM:-



With out load:-



PHASOR DIAGRAM.

Ferranti effect. $\qquad |V_S| < |V_R|$

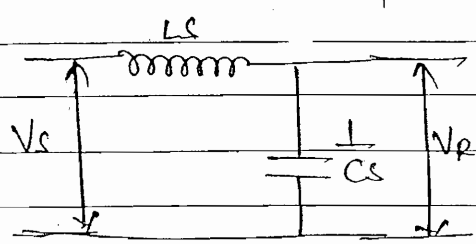
- Ferranti effect occurs in case of Medium and long Tr-line under No load or light load condition
- If the loading of line is more than surge impedance loading (SIL) than $V_R < V_S$ occurs

Date

- If the loading of line is equal to SIL Then $V_R = V_S$ occurs.
- If the loading of line is less than SIL Then $V_R > V_S$ i.e. ferranti effect occurs. For compensation of this ferranti effect shunt reactor is connected at the load end. The value of shunt reactor $X_{L_{sh}} = \frac{B}{(1-A)}$

- The overhead Tr-line can be loaded more than SIL
- In case of power cables, these should be operate less than SIL for safe operation of the power cable.

- Increment of V_R (ΔV_R)



$$V_R = V_S + V_S \cdot \omega^2 LC$$
$$= V_S + (\Delta V_R)$$

$$\boxed{\Delta V_R = V_S \cdot \omega^2 LC} \quad \text{—(1)}$$

- Velocity of signal (v):-

$$L_1 = \frac{\mu_0 \mu_r}{2\pi} \ln\left(\frac{d}{r'}\right) \text{ H/m}$$

Assume $r' \approx r$

$$L_1 = \frac{\mu_0 \mu_r}{2\pi} \ln\left(\frac{d}{r}\right) \text{ H/m}$$

$$C_1 = \frac{2\pi \epsilon_0 \epsilon_r}{\ln(d/r)} \text{ F/m}$$

$$L_1 C_1 = \mu_0 \mu_r \epsilon_0 \epsilon_r$$

$$\boxed{v = \frac{1}{\sqrt{L_1 C_1}} = \frac{3 \times 10^8}{\sqrt{\mu_r \epsilon_r}}} \text{ m/sec} \rightarrow (2)$$

l = length of line

X_L = Total inductive Reactance

$= 2\pi f L_1 l$

Date

$$L_1 = \frac{X_L}{2\pi f l} \quad (3)$$

B = Total capacitive susceptance

$$\boxed{C_1 = \frac{B}{2\pi f l}} \quad (4).$$

Substitute (3), (4) in (2)

$$\boxed{v = \frac{2\pi f l}{\sqrt{B \cdot X_L}}} \quad (5)$$

Substitute (2) in in eq^n (1).

$\Delta V_R = V_s \omega^2 LC \Rightarrow V_s (2\pi f)^2 L_1 l C_1 l$

$\Delta V_R = 4\pi^2 f^2 l^2 L_1 C_1 V_s$

$$\boxed{\Delta V_R = \frac{4\pi^2 f^2 l^2 V_s}{v^2}} \rightarrow (6)$$

Substitute (5) in (6)

$$\boxed{\Delta V_R = V_s \cdot B \cdot X_L} \qquad \boxed{V_R = V_s + \Delta V_R}$$

(1) Ideal : $v = 3 \times 10^8$ m/s $= 300$ m/μs

(2) Practical: overhead line $v = 200 - 250$ m/μs

(3) cable ($\epsilon_r \gg 1$) $v = 40 - 50$ m/μs

Q A 300 km long line is operating at NO load at a freq. of 60 Hz at $V_s = 2$ p.u. Calculate receiving end voltage.

Solve $\Delta V_R = \frac{4 \times 3.14^2 \times 60^2 \times (300 \times 10^3)^2 \times 2}{(3 \times 10^8)^2}$

$= 0.98$

$V_R = V_s + \Delta V_R = 2.98$ p.u.

 Date

Q.13 $f = 50Hz$ $X_L = 0.045$ $B = 1.2\,p.u$
$v = 3\times10^5$ $l = ?$

$$v = \frac{2\pi f l}{\sqrt{B \cdot X_L}}$$

$$l = \frac{v \times \sqrt{B \cdot X_L}}{2\pi f} = \frac{3\times10^5 \times \sqrt{1.2\times0.045}}{2\times3.14\times50}$$

$= 222.0\,km$ Ans

Q A ~~star~~ 220 kV Tr-line operating at $V_s = 220\,kV$ and $A = D = 0.9\angle0°$ $B = 150\angle90°\ \Omega$
$C = 0.4\times10^{-6}$ ℧. Calculate

① V_R and I_C at No load

② Shunt reactor required for maintaining $V_s = V_R$

Solution

$V_s = AV_R + BI_R$

$I_s = CV_R + DI_R$

① $V_R = \frac{V_s}{A} = \frac{220}{0.9\angle0°}$

$= 244.4$

② $I_s = I_C = CV_R = 0.4\times10^{-6}\times\frac{244.4}{\sqrt{3}}\times10^3$

$= 0.056$

③ $X_{sh} = \frac{B}{(1-A)} = \frac{150\angle90°}{(1-0.9\angle0°)}$

$=$

Conventional IES Imp

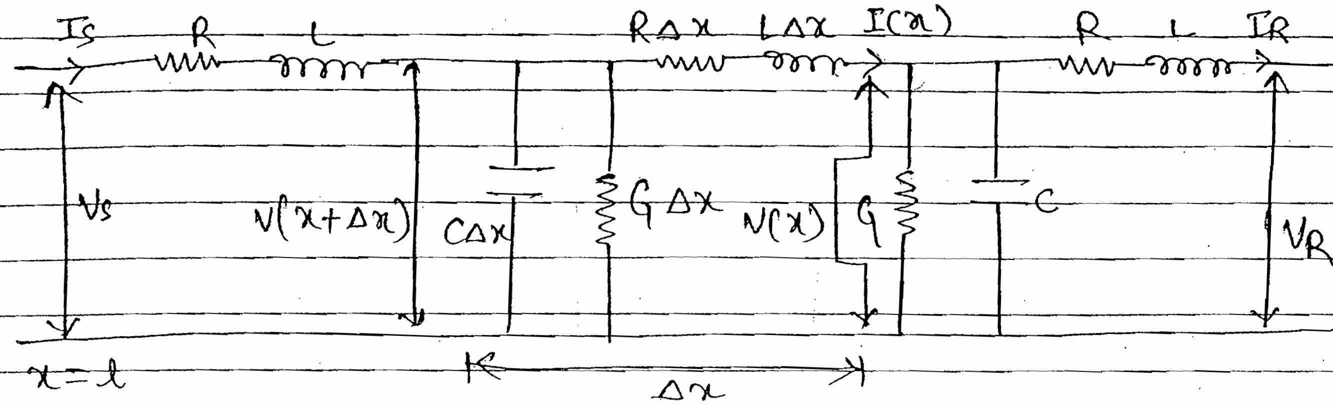
③ **Long Tr-line :-**

- ABCD parameter using long Tr-line Rigorous solution Method :- (Repeat and extend on both side)

Boundary Condition : At $x=0$ $V(x) = V_R$
$I(x) = I_R$

Date_________

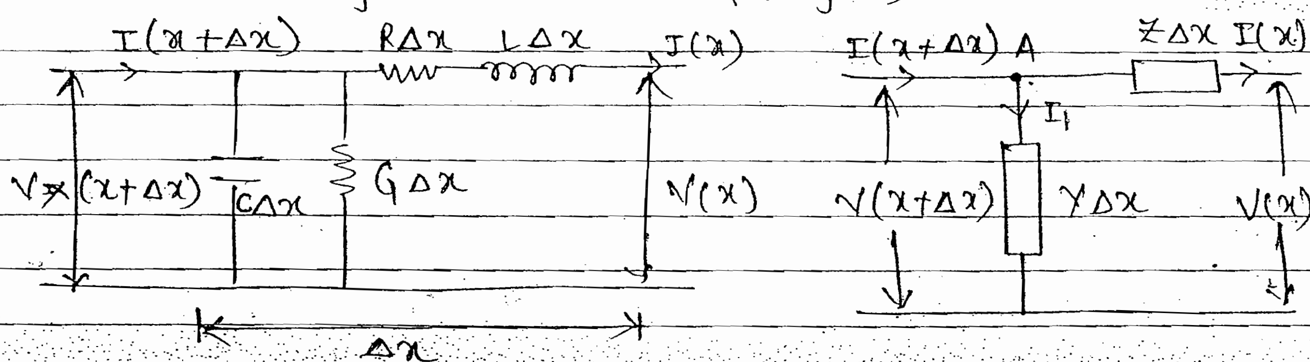
$x = l \;,\; V(x) = V_S \qquad I(x) = I_S$



propagation Constant $= \gamma = \alpha + j\beta = \sqrt{ZY}$

Characteristic Impedance $= Z_c = \sqrt{\dfrac{Z}{Y}}$

$Z = (R + j\omega L) \;,\; Y = (G + j\omega C)$



Apply KVL $\quad V(x+\Delta x) = V(x) + Z\Delta x \cdot I(x)$

$$\lim_{\Delta x \to 0} \frac{V(x+\Delta x)}{\Delta x} = \lim_{\Delta x \to 0} Z\, I(x)$$

$$\frac{dV}{dx} = Z\, I(x) \quad \text{—— (1)}$$

Apply KCL at Node-A

$I(x+\Delta x) = I_1 + I(x)$

$I(x+\Delta x) - I(x) = Y\Delta x \cdot V(x+\Delta x)$

$$\lim_{\Delta x \to 0} \frac{I(x+\Delta x) - I(x)}{\Delta x} = \lim_{\Delta x \to 0} Y\, V(x+\Delta x)$$

$$\frac{dI}{dx} = Y\, V(x) \quad \text{—— (2)}$$

Date

from (1) :- $\frac{d}{dx}\left[\frac{dV}{dx}\right] = \frac{d}{dx}\left[Z\, I(x)\right]$

$$\frac{d^2V}{dx^2} = Z . \frac{d\,I(x)}{dx} = Z\,Y\,V(x)$$

$$\frac{d^2V}{dx^2} = \gamma^2\, V(x) \quad \text{--- (3)} \qquad \left[\because \gamma = \sqrt{ZY}\right]$$

Solution of (3)

$$V(x) = A_1 e^{\gamma x} + A_2 e^{-\gamma x} \quad \text{--- (4)}$$

$$\frac{dV(x)}{dx} = Z\, I(x) = \gamma\left[A_1 e^{\gamma x} - A_2 e^{-\gamma x}\right]$$

$$I(x) = \frac{\gamma}{Z}\left[A_1 e^{\gamma x} - A_2 e^{-\gamma x}\right]$$

$$I(x) = \frac{1}{Z_C}\left[A_1 e^{\gamma x} - A_2 e^{-\gamma x}\right]$$

$$\left[\because \frac{\gamma}{Z} = \frac{\sqrt{ZY}}{Z} = \sqrt{\frac{Y}{Z}} = \frac{1}{Z_C}\right]$$

Apply at $x = 0$

$V(x) = V_R$, $I(x) = I_R$

in eqn (4) and (5)

$$V_R = A_1 + A_2 \quad \text{--- (6)}$$

$$I_R = \frac{1}{Z_C}(A_1 - A_2)$$

$$I_R Z_C = A_1 - A_2 \quad \text{--- (7)}$$

By solving (6) & (7)

$$A_1 = \frac{V_R + I_R Z_C}{2} \quad \text{--- (8)}$$

$$A_2 = \frac{V_R - I_R Z_C}{2} \quad \text{--- (9)}$$

Substitute (8) (9) in (4)

$$V(x) = \left[\frac{V_R + I_R Z_C}{2}\right] e^{\gamma x} + \left[\frac{V_R - I_R Z_C}{2}\right] e^{-\gamma x} \quad \text{--- (10)}$$

$$= V_R\left[\frac{e^{\gamma x} + e^{-\gamma x}}{2}\right] + I_R Z_C \left[\frac{e^{\gamma x} - e^{-\gamma x}}{2}\right]$$

$$= V_R \cosh \gamma x + I_R Z_C \sinh \gamma x \quad \text{--- (11)}$$

Apply at $x = l$, $V(x) = V_s$ in (11)

$$\boxed{V_S = V_R \underbrace{\cosh \gamma l}_{A} + I_R Z_C \underbrace{\sinh \gamma l}_{B}} \quad \text{--- (12)}$$

Substitute 8, (9) in (5)

$$I(x) = \frac{1}{Z_C}\left[\frac{V_R + I_R Z_C}{2}\right] e^{\gamma x} - \frac{1}{Z_C}\left(\frac{V_R - I_R Z_C}{2}\right) e^{-\gamma x} \quad \text{--- (13)}$$

Date

$$= \frac{V_R}{Z_C}\left[\frac{e^{\gamma x} - e^{-\gamma x}}{2}\right] + I_R\left[\frac{e^{\gamma x} + e^{-\gamma x}}{2}\right]$$

$$= \frac{V_R}{Z_C}\sinh \gamma x + I_R \cosh \gamma x \quad \text{—— (14)}$$

Apply at $x = l$, $I(x) = I_s$ in (14).

$$\boxed{I_s = \frac{V_R}{Z_C}\cdot \sinh \gamma l + I_R \cosh \gamma l} \quad \text{—— (15)}$$

from (12) and (15)

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} \cosh \gamma l & Z_C \sinh \gamma l \\ \frac{\sinh \gamma l}{Z_C} & \cosh \gamma l \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$A = D = \cosh \gamma l$, $AD - BC = 1$

(1) $\% V_{REG} = \frac{|V_s/A| - |V_R|}{|V_R|} \times 100$

where $A = \cosh(\gamma l)$

(2) $\% \eta = \frac{P_R}{P_s} \times 100 = \frac{|V_R I_R \cos\phi_R|}{|V_s I_s \cos\phi_s|} \times 100$

$P_l = P_s - P_R$

⊙ Equivalent π Network of long line :-

From long line :-

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} \cosh \gamma l & Z_C \sinh \gamma l \\ \frac{\sinh \gamma l}{Z_C} & \cosh \gamma l \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \quad \text{—— (1)}$$

From Nominal π Network :-

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} \left(1 + \frac{YZ}{2}\right) & Z \\ \left(Y\left(1 + \frac{YZ}{4}\right)\right) & \left(1 + \frac{YZ}{2}\right) \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \quad \text{—— (2)}$$

Date

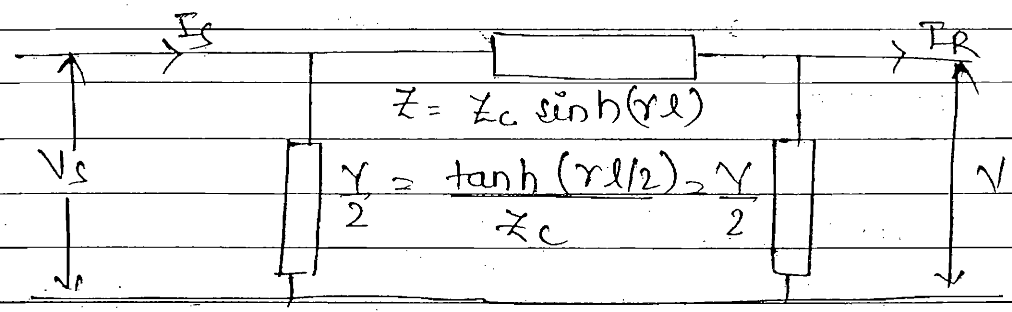
Comparing (1) & (2) $\boxed{Z = Z_c \sinh(\gamma l)}$

$$1 + \frac{Y}{2} \cdot Z = \cosh(\gamma l) \quad , \quad \frac{Y}{2} = \frac{\cosh(\gamma l) - 1}{Z}$$

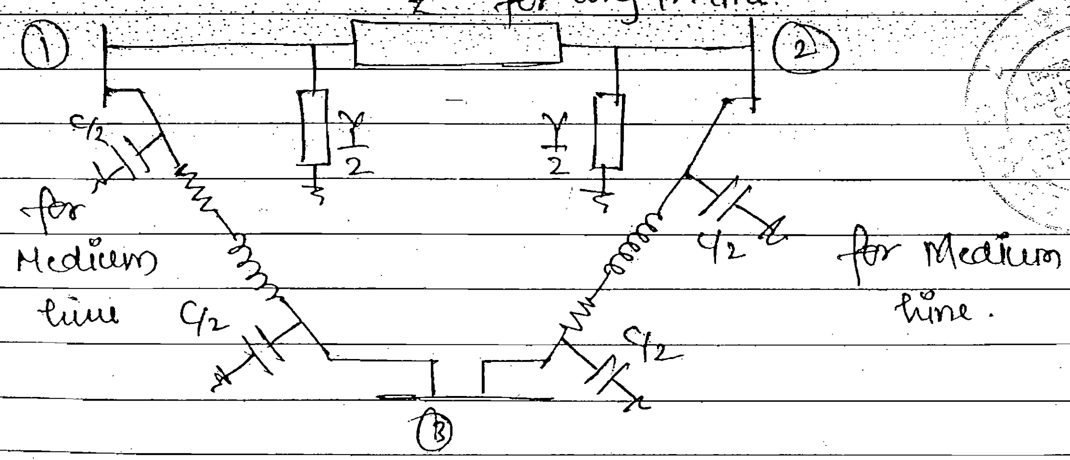
$$\left|\frac{Y}{2}\right| = \frac{1 - 2\sinh^2(\gamma l/2 - 1)}{Z_c \sinh(\gamma l)}$$

$$= \frac{2\sinh^2(\gamma l/2)}{Z_c\left(2\sinh\left(\frac{\gamma l}{2}\right) \cdot \cosh\left(\frac{\gamma l}{2}\right)\right)}$$

$$\boxed{\left|\frac{Y}{2}\right| = \frac{\tanh(\gamma l/2)}{Z_c}}$$



Z for long Tr-line.



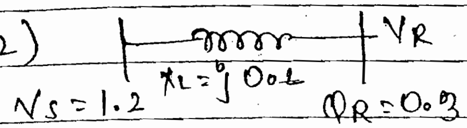
- for Representing the long Tr-line in the load flow analysis equivalent π N/w is used

Pg No. 53. Date

(41). $Q_c = P_1(\tan\phi_1 - \tan\phi_2)$ $\Rightarrow 2 = 4[\tan\phi_1 - \tan\cos^{-1}0.99]$

$\phi_1 = 36.86$, $\cos\phi_1 = 0.8$ lagg.

(42)



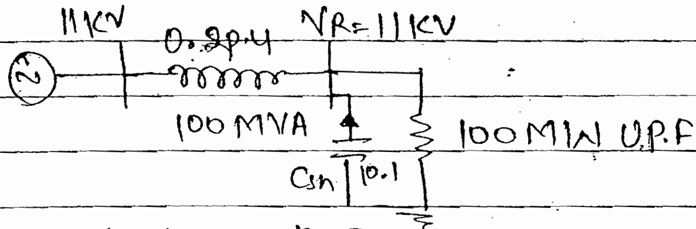
$V_R = \frac{V_s}{2} \pm \frac{\sqrt{V_s^2 - 4X_L Q_D}}{2} = 1.147$ p.u

$\Delta V = V_s - V_R = 0.053 = 0.05$ p.u.

(43) $\frac{Q_2}{Q_1} = \left(\frac{V_2}{V_1}\right)^2 \cdot \left(\frac{f_1}{f_2}\right)$ $\Rightarrow \frac{Q_2}{100} = \left(\frac{0.98V_1}{V_1}\right)^2 \times \frac{f_1}{0.96f_1}$

$\Rightarrow Q_2 = 100.04$

(44)



$X_L = 0.5$ p.u

$X_{p.u} = \frac{X_\Omega (MVA)_b}{(KV_b)^2}$

$P_R = \frac{V_s V_R}{X_L} \times \sin\delta$

$0.2 = \frac{X_\Omega \cdot (100)^2}{(11)^2}$

$100 = \frac{11 \times 11}{0.242} \times \sin\delta$

$X_L = 0.242\ \Omega$

$\sin\delta = 0.2$ $\boxed{\delta = 11.53^\circ}$

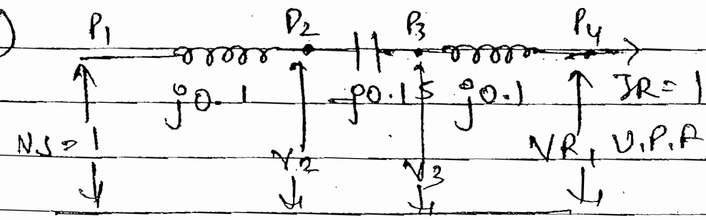
$Q = \left|\frac{V_s V_R}{X_L}\right| \cos\delta - \left|\frac{V_R^2}{X_L}\right| = \frac{11 \times 11}{0.242}\cos(11.53) - \frac{11^2}{0.242}$

$= -10.1$ MVAR.

$Q_c = -(-Q_R) = +10.1$ MVAR.

(45) $X_{L\,sh} = \frac{B}{(1-A)} = \frac{200\angle 90^\circ}{1-0.9} = 2000\angle 90^\circ$

(46)



$V_3 = V_R + j0.1 \times 1$

$= V_R + j0.1$

$V_2 = V_3 - j0.15 \times 1$

$= V_R + j0.1 - j0.15$

$= V_R - j0.05$

$V_s = V_2 + j0.1 \times 1$

$= V_R - j0.05 + j0.1$

$= V_R + j0.05$

V_3 is maximum

Date

(51) $Z = 8+j6$, $V = 400V$ $\cos\phi_2 = 0.9$ lagg.

$$Q_c = P_1(\tan\phi_1 - \tan\phi_2)$$

$$= \frac{3V_1^2}{Z}(\tan\phi_1 - \tan\phi_2)$$

$$= \frac{3 \times 400^2}{\sqrt{8^2+6^2}}\left[\tan.\tan^{-1}\left(\frac{6}{8}\right) - \tan\cos^{-1}0.9\right]$$

$$= 10.2 \text{ KVAR}$$

Bcz of UPF

(53) $$C_{ph} = \frac{P_1(\tan\phi_1 - \tan\phi_2)}{3(2\pi f V_{ph}^2)} = \frac{200 \times 10^3[\tan\cos^{-1}0.8 - \tan\cos^{-1}1]}{3 \times (2 \times \pi \times 50 \times (11 \times 10^3)^2)}$$

cap. Bank Δ

$$= 1.316 \ \mu F.$$

(54) (a) $$P_s = \left|\frac{V_s V_R}{X_L}\right| \sin\delta = \left|\frac{100^2}{5}\right| \sin 30 = 1000 W$$

$$Q_s = \left|\frac{V_s V_R}{X_L}\right|\cos\delta - \left|\frac{V_R^2}{X_L}\right| \Rightarrow 268 \text{ VARs.}$$

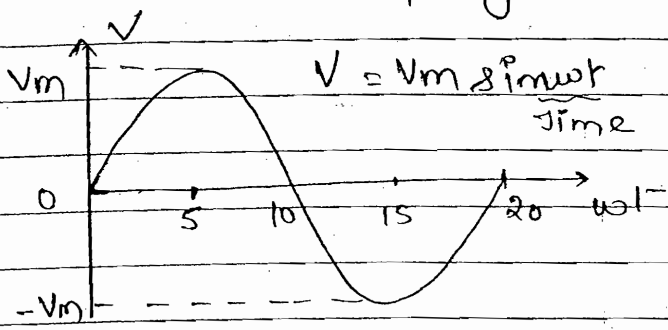
12/7/2014.

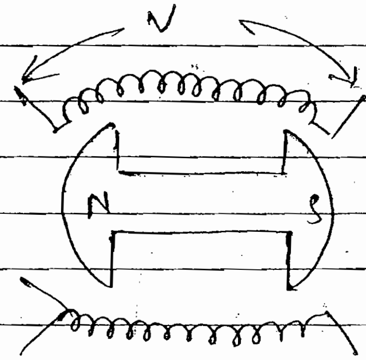
• Travelling Waves OR Transient In Tr-line:-

Power sys N/w experiences abnormalities like short ckt, open circuit and lightening surges so that power flow within the line is distrub produces transient in the sys. These transients causes over voltages, over currents so that demaging of electrical appliances and equipments like Transformer, Tr-line, generators, bus bar etc. These equipment must be propected from this transient abnormalities. For desgining and location of protecting equipement lightening arrestors, surge diverters, earth conductors, ground rods, counter poise, arcing horn

Date______

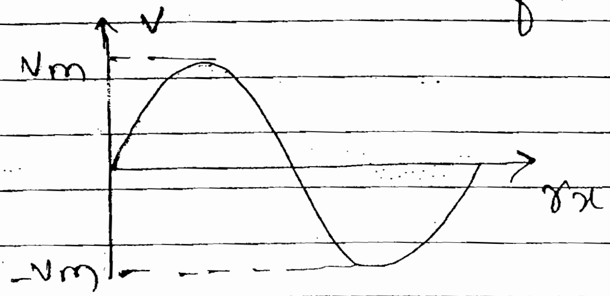
has to be properly located.





$\leftarrow T = 20ms \rightarrow$

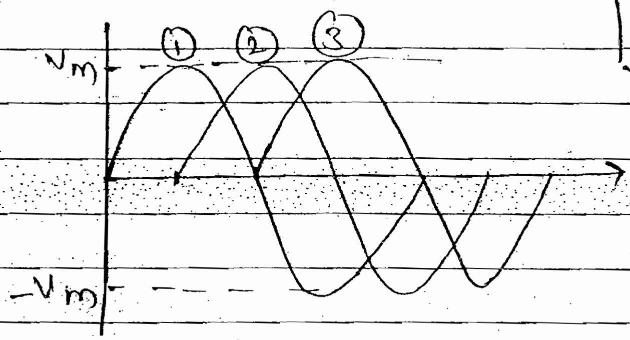
$f = 50Hz \quad T = \frac{1}{f} = 20ms = 1$ cycle.



$V = V_m(\gamma x)$

space / Distance.

$V = V_m(\omega t - \gamma x)$



$$\boxed{V = V_m \sin(\omega t - \gamma x)}$$

Travelling wave equation

	γx	V
1	0	$V_m \sin\omega t$
2	90°	$-V_m \cos\omega t$
3	180	$-V_m \sin\omega t$

$V_m = V_m \sin(\omega t \pm \gamma x)$

$$\left|\frac{dV_m}{dx}\right| = +\gamma \, V_m \cos(\omega t \pm \gamma x)$$

$$\left|\frac{d^2 V_m}{dx^2}\right| = \gamma^2 \, V_m \sin(\omega t \pm \gamma x)$$

$\therefore V_m \sin(\omega t \pm \gamma x) = V$

$$\boxed{\frac{d^2 V}{dx^2} = \gamma^2 . V}$$

eqn (3) in long Tr-line.

- $V = V_m \sin(\omega t \mp \gamma x)$ represents Travelling wave equation, $+\gamma$ indicates wave is travelling on $-$ve x axis, $-\gamma$ indicates wave is travelling on $+$ ve x axis

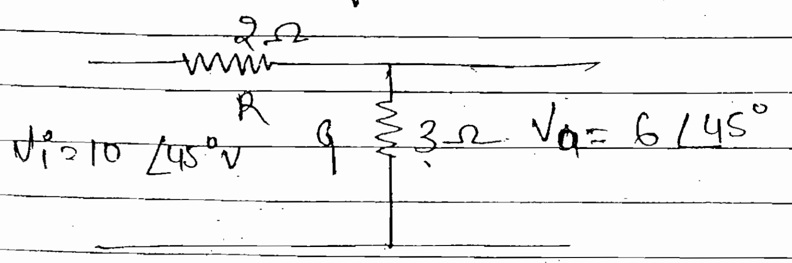
- During travelling or propagating voltage or current singnal through the Tr-line due to R and G parameters attenuation of signal occurs. This is measure in dB represented as α

- Due to LC components phase shift of the signals occurs it is measured in degrees or radians represented as β

- This attenuation and phase shift occurs if the voltage and current signals are travelling through the Tr-line This also called propagation. represented as γ which is a constant.

- The relation between voltage and currents are depending on the values of R, G, L, C which are depends on type of configuration used so that characteristic behaviour of current and voltages are depends on characteristic impedance of line which are represented by Z_c measured in ohms

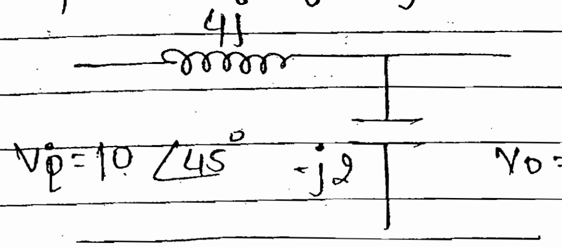
- Attenuation Network (α):-



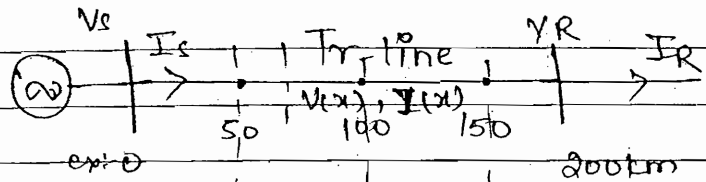
$\rightarrow$ magnitude $\rightarrow$ change
phase $\rightarrow$ same

Date________

- Phase shifting N/w :- (β)



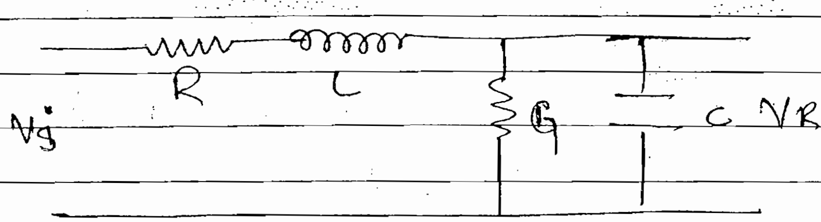
magnitude → same
phase → change.



$Z_c = \sqrt{\frac{L}{C}} = \sqrt{\frac{L}{C}} = \sqrt{\frac{L}{C}}$

at any point In Tr-line Z_c remain same. Independ To length of Tr-line.

- Combing both the N/w :-



Losses occur mainly due To R, G.

- $\gamma = \alpha + j\beta = \sqrt{ZY} = \sqrt{(R+j\omega L)(L+j\omega C)}$

$Z_c = \frac{V(x)}{I(x)} = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{(R+j\omega L)}{(G+j\omega C)}}$

- Loss less / loss free line :- $G = R = 0$ ⇒ Loss less line

- α, β, γ for loss less line :-

$\gamma = \alpha + j\beta = \sqrt{(0+j\omega L)(0+j\omega C)}$

$\gamma = \alpha + j\beta = j\omega\sqrt{LC}$ $\qquad \gamma = j\beta \quad \because \alpha = 0$

$\boxed{\alpha = 0}$ $\qquad \boxed{\beta = \omega\sqrt{LC}}$ $\qquad j\omega\sqrt{LC} = j\beta$

$\beta = \omega\sqrt{LC}$

v = velocity = 3×10^8

$$\boxed{\beta = 2\pi f\sqrt{L_1 C_1 l^2}}$$ $$\boxed{\beta = \frac{2\pi f l}{v}}$$ $$\boxed{\beta = \frac{360^\circ f l}{v}}$$

radians   Degrees

- A, D for lossless line:

$$A = D = 1 + \frac{YZ}{2}$$

For loss less line $Z = j\omega L$, $Y = j\omega C$

$$A = D = 1 + \frac{(j\omega L)(j\omega C)}{2}$$

$$= 1 - \frac{\omega^2 LC}{2}$$

$$\boxed{A = D = 1 - \frac{\beta^2}{2}}$$ $\beta \Rightarrow$ radian $\beta = \omega\sqrt{LC}$

Surge / Loss less / Loss free / Tuned line / Flat line / Infinite line / Reasonant Impedance (Z_s)
$[R = G = 0]$

$$\boxed{Z_c = Z_s = \sqrt{\frac{L}{C}} = \sqrt{\frac{L_1 l}{C_1 l}} = \sqrt{\frac{L_1}{C_1}}}$$

$L = L_1 l$
$C = C_1 l$

- ① Overhead line:- $Z_s = 300 - 500\,\Omega$
- ② Cable :- $Z_s = 40 - 50\,\Omega$
- Surge impedance is indepent to length of the Tr- line
- Distortion-less line:- Line indepent to frequency is called distortion less line.

It is practically used in communication line.

$$Z_c = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$ $$\boxed{Z_D = \sqrt{\frac{R}{G}}}$$

L, C, freq. depend neglect them.

$Z_D \rightarrow$ distortion less Impedance

Date________

Q 600 km long Tr. line operating at 50Hz Calculate phase shift of signal at 300km.

Solution. $f = 50\,Hz$. $\beta = \frac{2\pi f l}{v} = \frac{360 f l}{V}$

$$\beta = \frac{360^\circ \times 50 \times 300\times10^3}{3\times10^8} = 18^\circ$$

$$= \frac{18\times\pi}{180}\ rad = 0.314\ rad.$$

Q A lossless Tr line has $\beta = 200\angle 90^\circ$ $V_s = 400\,kV$ $l = 800\,km$ Find the voltage at 500 km at different length & at 800 km. Calculate shunt reactor required for compensating ferranti effect

Solution $V_s = 400\,kV$ $B = 200\angle 90^\circ$

$$C_q = \frac{B}{2\pi f l} = \frac{200\angle 90^\circ}{2\times3.14\times50\times500}$$

(1) $l = 500\,km$ $\beta = \frac{2\pi f l}{v} = \frac{2\times3.14\times50\times500\times10^3}{3\times10^8} = 0.523\ rad.$

(2) $l = 800\,km$ $\beta = \frac{2\times3.14\times50\times800\times10^3}{3\times10^8} = 0.837\ rad.$

$l = 500\,km$ $A = 1 - \frac{\beta^2}{2} = 1 - \frac{(0.523)^2}{2} = 0.863$

$$X_{Lsh} = \frac{B}{(1-A)} = \frac{200\angle 90^\circ}{1-0.863} = 1459.85\angle 90^\circ$$

$$V_R = \frac{V_s}{A} = \frac{400}{0.863} = \cancel{1459.85\angle 90^\circ}\ 463.49.$$

$l = 800\,km$ $A = 1 - \frac{\beta^2}{2} = (1 - \frac{(0.837)^2}{2} = 0.649$

$$V_R = \frac{V_S}{A} = \frac{400}{0.649} = 616.33$$

$$X_{Lsh} = \frac{B}{1-A} = \frac{200\angle 90^\circ}{1-0.649} = 569.\angle 90^\circ$$

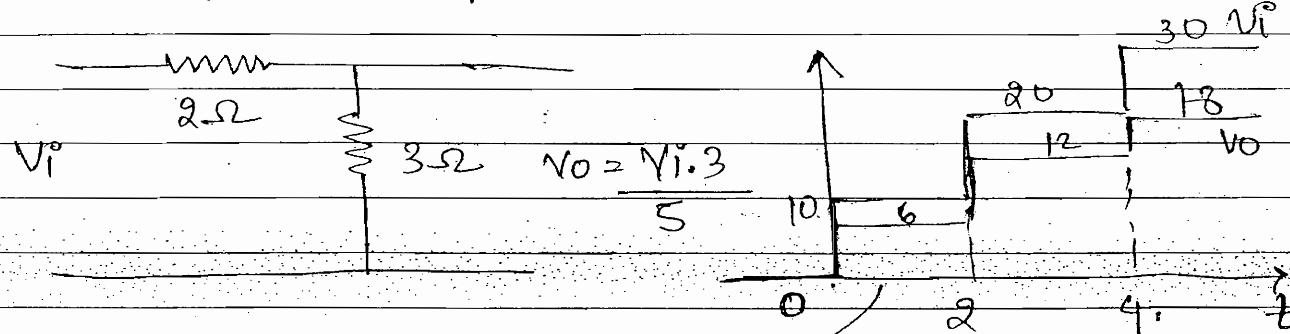
Date

Q A 400 km long Tr- line has a surge impedance of 4 p.u. If the length of line is reduce to 300 km then th surge impedance is 400 km.

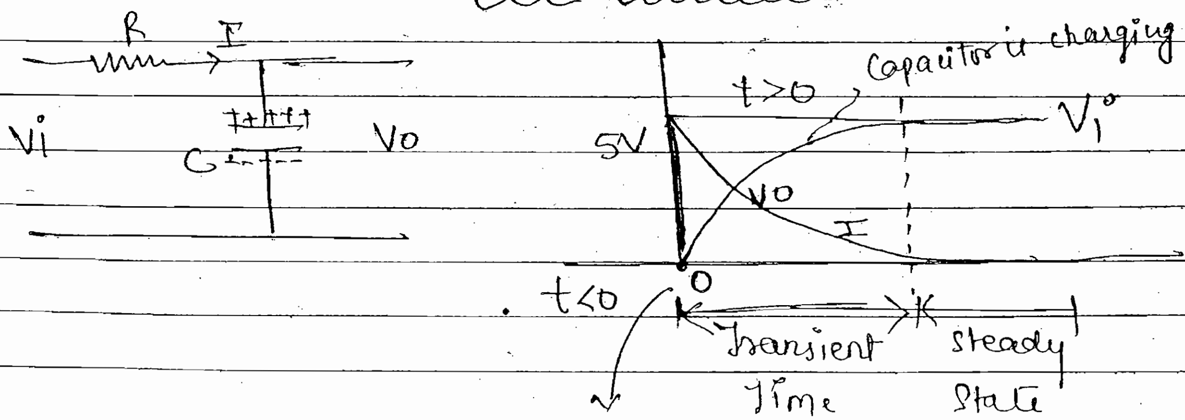
- $\beta = \frac{2\pi f l}{v} \Rightarrow \frac{2\pi f l}{\lambda f}$

$\beta = \frac{2\pi l}{\lambda}$ $\left\{ \begin{array}{l} v = \lambda f \\ \lambda = \text{wave length} \end{array} \right.$

- Transient → when I/p change (sudden) O/p will not change sudden, it will cause delay in O/p w.r.t. I/p called Transient.
  - R, G → do not response to Transient.
  - L, C → response to Transient.



No Transient "Zero ORDER"



T = 0

$f = \frac{1}{T} = \frac{1}{0} = \infty$

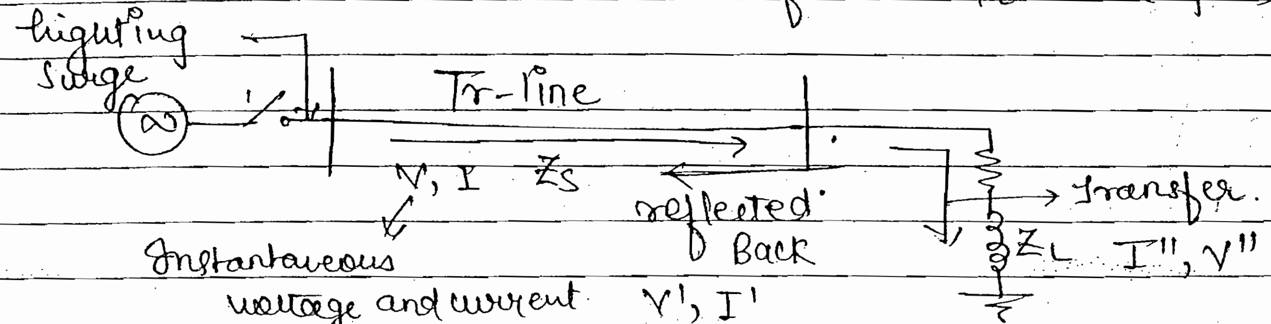
when $f = \infty$ C → short. ∴ Vo = 0

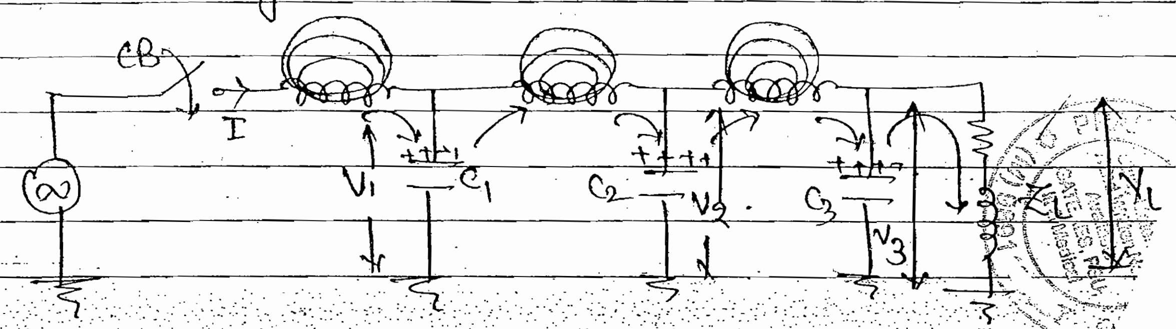
Date________

- Energy storing device responsible for transient. Energy dissipating device don't responsible for -"-

$X_C = \frac{1}{2\pi f C}$ DC $\Rightarrow f = 0 \Rightarrow X_C = \infty$ (Open)
AC $\Rightarrow f = \infty \Rightarrow X_C = 0$ (short)

$X_L = 2\pi f L$ DC $\Rightarrow f = 0 \Rightarrow X_L = 0$ (short)
AC $\Rightarrow f = \infty \Rightarrow X_L = \infty$ (open)





$t = 0$, CB-closed $t > 0$ $\frac{1}{2} L I^2 = \frac{1}{2} C V^2$

- when CB closed at $t=0$

$L = $ open $C = \infty$

$V_1 = V_2 = V_3 = 0$ $V_L = 0$

$$\boxed{Z_S = \frac{V}{I} = \sqrt{\frac{L}{C}}}$$

- when $t>0$ L short, C = open, inductor store energy and charged the capacitor, current will start falling, charged capacitor gives it energy to next inductor, this inductor gives it energy to next capacitor and so on...., and finally reach to load. This way waves are travelling.

$V = V' + V''$ $I = I' + I''$

Transmission coefficient of current

$$T_V = \frac{V''}{V} \quad , \quad T_I = \frac{I''}{I}$$

Transmission coefficient of voltage

$$R_V = \frac{V'}{V} \quad , \quad R_I = \frac{I'}{I}$$

Reflected coeffici. of voltage — Reflected coeff of current.

Z_L
1. $Z_L \neq Z_s$
2. $Z_L = Z_s$
3. $Z_L = 0$
4. $Z_L = \infty$
5. $Z_L = L_1 s$
6. $Z_L = \frac{1}{C_1 s}$
7. Z_L = parallel lines.

- Incident Wave:- The voltage and current signal travelling from source to the load through the Tr-line is called incident wave

$$\boxed{I = \frac{V}{Z_s}}$$

- Reflected Wave:- Voltage and current signals travelling from load to source are called reflected waves.

$$\boxed{I' = -\frac{V'}{Z_s}}$$

where Z_s = Surge Impedance of Tr-line $= \sqrt{\frac{L}{C}}$

- The voltage and current signals which are transmitting into the load are called transmitted or refracted wave

$$\boxed{I'' = \frac{V''}{Z_L}}$$

where Z_L = load impedance

from long line eqn (10) & (13).

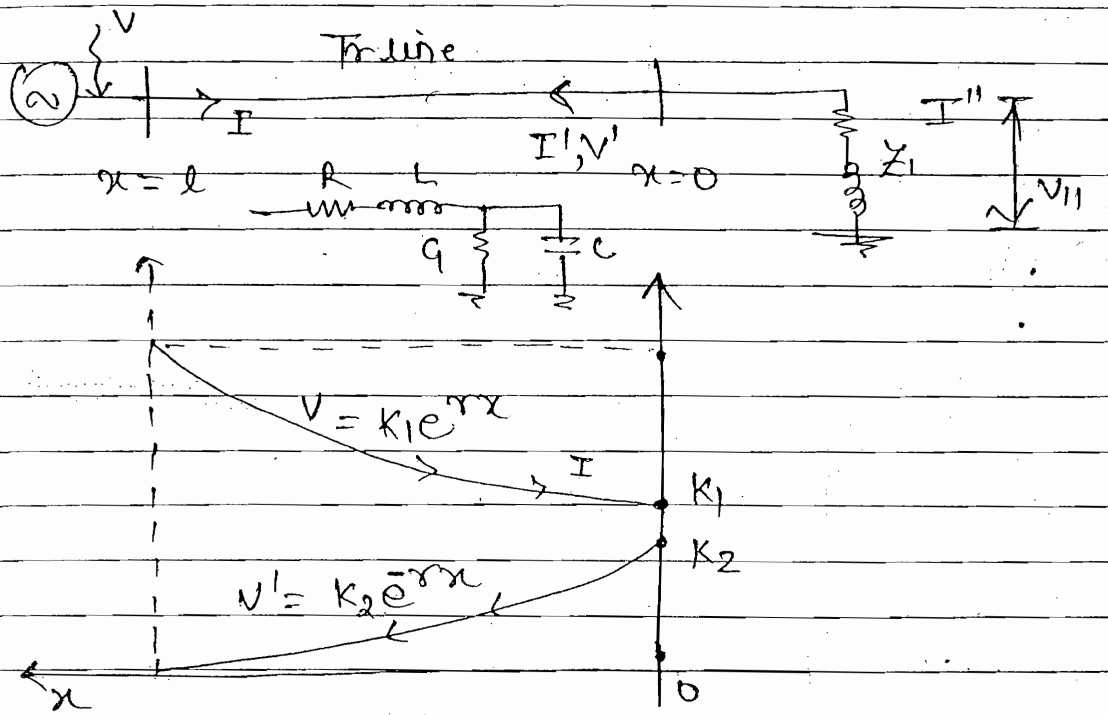
$$V(x) = \left(\frac{V_R + I_R Z_C}{2}\right) e^{\gamma x} + \left(\frac{V_R - I_R Z_C}{2}\right) e^{-\gamma x}$$

Date__________

$$= K_1 e^{\gamma x} + K_2 e^{-\gamma x}$$

$$I(x) = \frac{1}{Z_c}\left(\frac{V_R + I_R Z_c}{2}\right)e^{\gamma x} - \frac{1}{Z_c}\left(\frac{V_R + I_R Z_c}{2}\right)e^{-\gamma x}$$

$$= \frac{1}{Z_c} K_1 e^{\gamma x} - \frac{1}{Z_c} K_2 e^{-\gamma x}$$



(1) $I = \frac{V}{Z_c}$, $R, G \neq 0$

$= \frac{V}{Z_s}$, $R = G = 0$

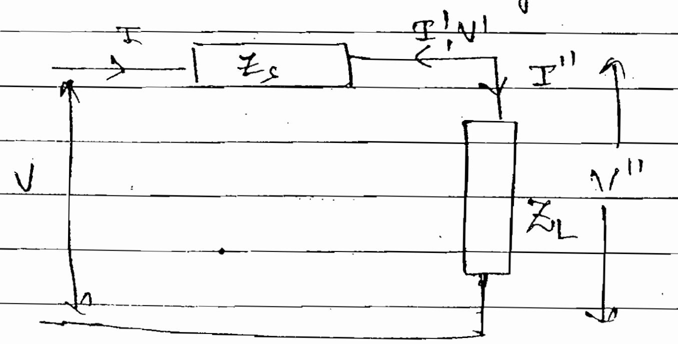
we get constant straight line

(2) $I' = \frac{-V'}{Z_c}$; $R \neq 0, G \neq 0$

$= \frac{-V'}{Z_s}$ if $G = R = 0$

straight line

(3) $I'' = \frac{V''}{Z_L}$

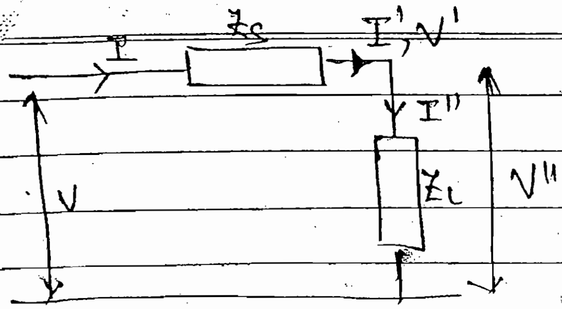


$V = V' + V''$

$I = I' + I''$

$Z_s \neq Z_L$ so reflecth.

In infinite lines → No Reflectn.



$V = -V' + V''$ (bcoz of opposite directn Sign conventn)

$I = -I' + I''$

$\boxed{Z_L \neq Z_S}$

$$\boxed{\begin{aligned} V'' &= V + V' \\ I'' &= I + I' \end{aligned}}$$

Coefficients:-

Reflection coefficient of voltage $= R_V = \dfrac{V'}{V}$

Reflection Coefficient of Current $= R_I = \dfrac{I'}{I}$

Transmitted/Refracted Coefficient of voltage $= T_V = \dfrac{V''}{V}$

Transmitted/Refracted Coefficient of current $= T_I = \dfrac{I''}{I}$

Relation Between Coefficient:-

(1) $V'' = V + V' \Rightarrow \dfrac{V''}{V} = 1 + \dfrac{V'}{V}$

$\boxed{T_V = 1 + R_V}$

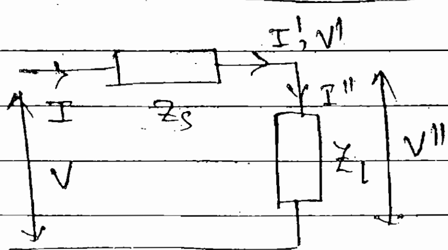
(2) $I'' = I + I' \Rightarrow \dfrac{I''}{I} = \dfrac{I + I'}{I}$

$\boxed{T_I = 1 + R_I}$

(3) $R_V = \dfrac{V''}{V} = -\dfrac{I' Z_S}{I Z_S}$ $\boxed{R_V = -R_I}$

(4) $T_I = \dfrac{I''}{I} = \dfrac{V''/Z_L}{V/Z_S}$ $\boxed{T_I = T_V \cdot \dfrac{Z_L}{Z_S}}$

Case (1): $Z_L \neq Z_S$



$V'' = V + V'$

$V' = V'' - V$ —— (1)

Date________

$$I'' = I + I' \quad , \quad \frac{V''}{Z_L} = \frac{V}{Z_S} - \frac{V'}{Z_S} \quad \text{--- (2)}$$

Substitute (1) in eqn (2)

$$\frac{V''}{Z_L} = \frac{V}{Z_S} - \frac{(V'' - V)}{Z_S}$$

$$\left[\frac{1}{Z_L} + \frac{1}{Z_S}\right] V'' = \frac{2V}{Z_S} \qquad \boxed{T_V = \frac{V''}{V} = \frac{2Z_L}{Z_L + Z_S}}$$

- By Using Relation:- $R_V = T_V - 1$

$$\boxed{R_V = \frac{Z_L - Z_S}{(Z_L + Z_S)} = \frac{V'}{V}} \qquad \boxed{R_I = \frac{I'}{I} = -R_V}$$

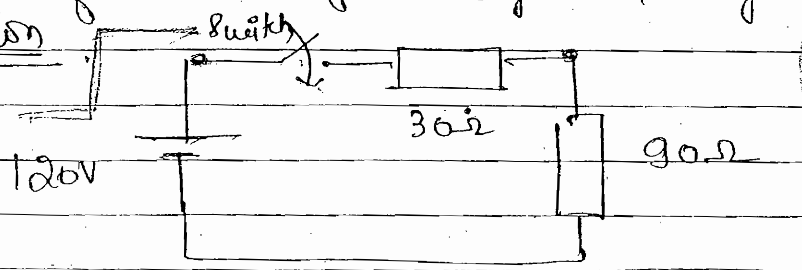
$$T_I = 1 + R_I = 1 - R_V \qquad \boxed{T_I = \frac{2Z_S}{(Z_L + Z_S)} = \frac{I''}{I}}$$

- Conclusion ($Z_L \neq Z_S$)

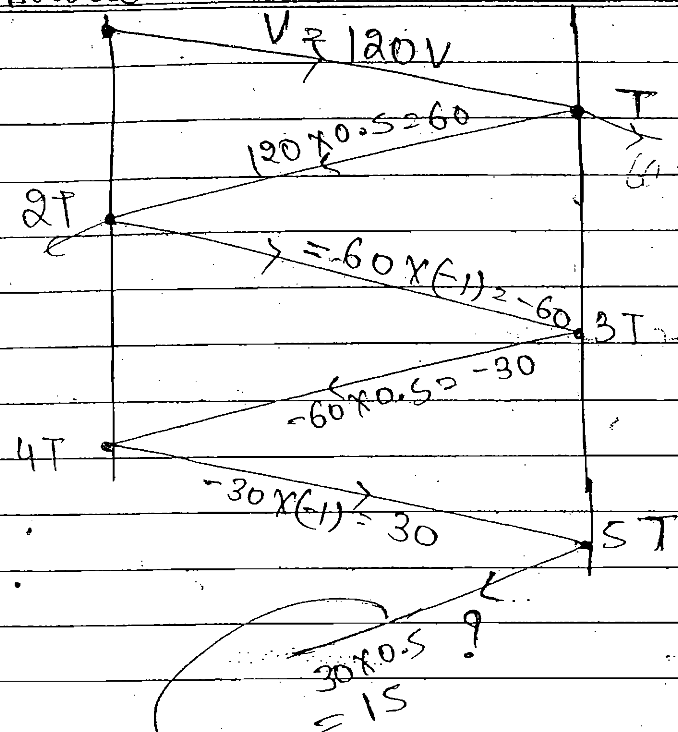
$$\boxed{\begin{array}{ll} T_V = \dfrac{V''}{V} = \dfrac{2Z_L}{(Z_L + Z_S)} & T_I = \dfrac{I''}{I} = \dfrac{2Z_S}{(Z_L + Z_S)} \\ R_V = \dfrac{V'}{V} = \dfrac{Z_L - Z_S}{Z_L + Z_S} & R_I = \dfrac{I'}{I} = -R_V \end{array}}$$

Q A dc voltage of 120V magnitude is applied to the N/w shown in fig. Calculate the voltage reflecting from the load end at the end of 5T where T = Time of travel of the signal through the line

Solution



$RV_s = -1$ source $\qquad$ $RV_R = 0.5$ load $\qquad$ Date________



$$RV_R = \frac{Z_L - Z_S}{Z_L + Z_S} = \frac{90-30}{90+30} = \frac{60}{120} = 0.5$$

$$RV_S = \frac{Z_L - Z_S}{Z_L + Z_S} = \frac{0-30}{0+30} = -1$$

$$\frac{V'}{V} = RV_R \qquad \boxed{V' = RV_R\, V} \text{ load side}$$

$$\boxed{V' = RV_S . V} \text{ source side}$$

$$\Sigma V = 120 + (60) + (-60) + (-30) + 30 + 15$$
$$= 135 \text{ V} \quad \text{Ans}$$

Q. A Tr. line has a surge impedance of $400\,\Omega$ is terminated with a cable having surge impedance of $50\,\Omega$. If a lighting surge of 100 kV magnitude is travelling from the Tr-line towards the cable. Calculate

1. All the coefficients
2. Incident voltage and current
3. Reflected voltage and current
4. Transmitted voltage and current.

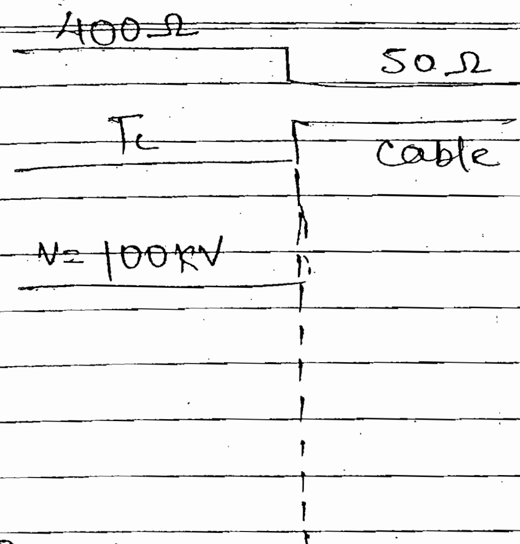
Solution (1) $Z_s = 400\,\Omega \qquad Z_L = 50\,\Omega$

$$RV = \frac{Z_L - Z_s}{Z_L + Z_s} = \frac{50 - 400}{50 + 400} = \frac{-350}{450}$$

$$= -0.77$$

$$R_I = -RV = 0.77$$

Date



$$T_V = \frac{2Z_L}{Z_L+Z_s} = \frac{2\times 50}{50+400}$$
$$= 0.222$$
$$T_I = \frac{2Z_s}{Z_L+Z_s} = \frac{2\times 400}{50+400}$$
$$= 1.777.$$
$$T_I = T_V \cdot \frac{Z_L}{Z_s} = 0.22 \times \frac{50}{400}$$
$$= 0.0275.$$

(2) $V = 100\,kV'$

$$I = \frac{100\times 10^3}{400} = 250A.$$

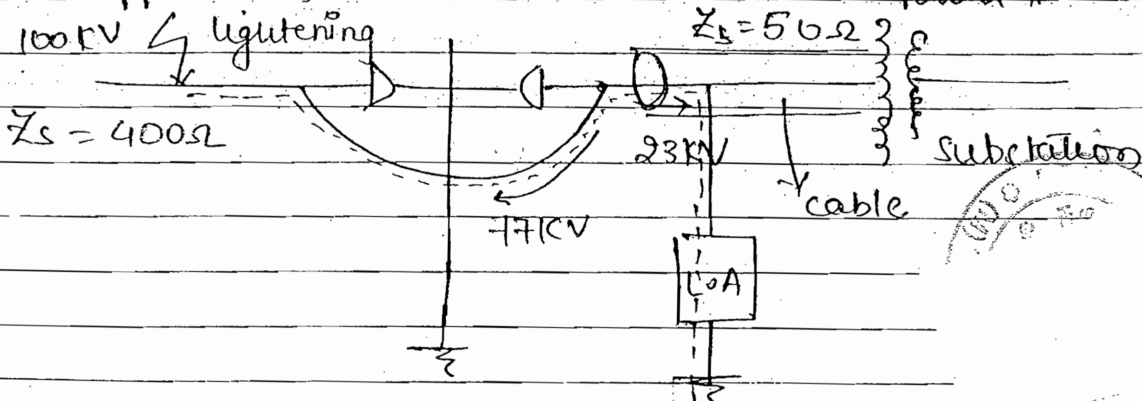
(3) $V' = R_V \cdot V$

$$= (-0.777)\times 100$$
$$= -77.7\ kV$$
$$I' = -\frac{V'}{Z_s} = \frac{-77.7\times 10^3}{400}$$
$$= 194.25$$

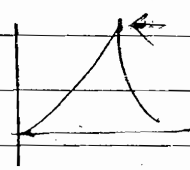
(4) $V'' = T_V \cdot V$

$$= 0.22\times 100\times 10^3$$
$$= 23\ kV$$
$$I'' = \frac{V''}{Z_L}$$
$$= \frac{23\times 10^3}{50}$$
$$= 460$$

- Application



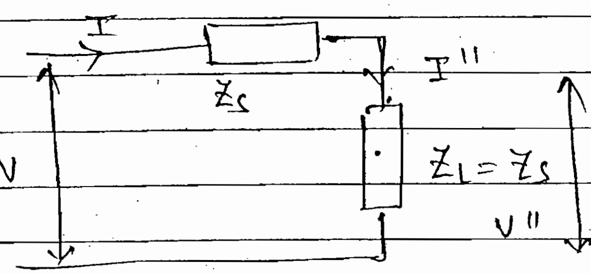
Advantages :- (1) $|V_{surge}|\downarrow$ (2) velocity $\downarrow$

(3)  steepness $\downarrow$

Date_______

↳ In hilly areas where lightening occurs mostly, cables are used for reducing the magnitude of surge voltage so that rating of L.A. can be reduce, ex: 23 KV through L.A and 77 KV is reflected.

case 2 : $Z_L = Z_s$



$$T_V = \frac{V''}{V} = \frac{2Z_L}{Z_L + Z_s}$$

$$T_V = \frac{V''}{V} = \frac{2Z_s}{Z_L + Z_s} = 1$$

$$R_V = T_V - 1 = 1 - 1 = 0$$

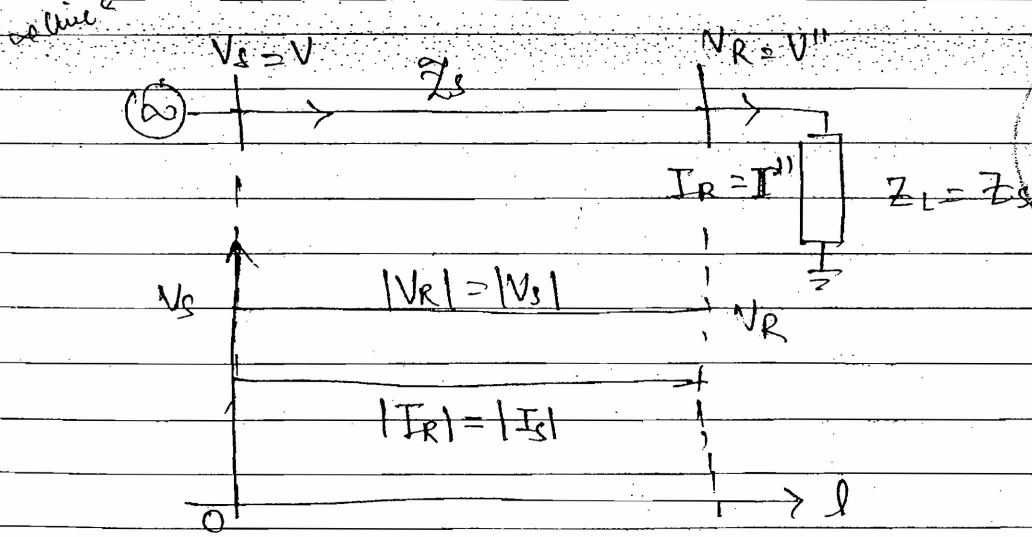
$$R_I = -R_V = 0$$

$$T_I = 1 + R_I = 1$$

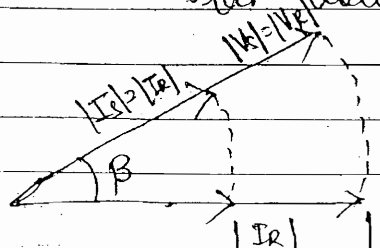
Conclusion ($Z_L = Z_s$):-

$T_V = 1$	$\Rightarrow V'' = V$	$T_I = 1$	$\Rightarrow I'' = I$
$R_V = 0$	$\Rightarrow V' = 0$	$R_I = 0$	$\Rightarrow I' = 0$

online



Flat voltage & current profile



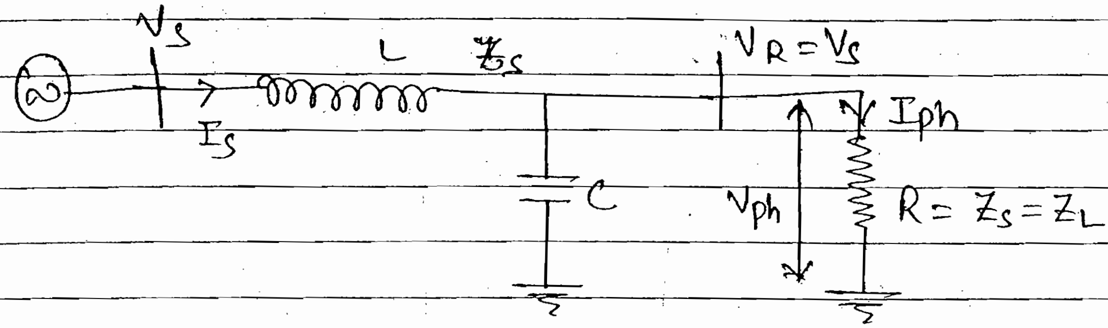
$$\boxed{\beta = \omega\sqrt{LC}}$$

I_s, V_s lead I_R, V_R by β But mag. remain same

Ideal ... convert into active power, [Q = 0]

Date________

- Surge Impedance Loading (SIL):-



3φ active power supplied to pure R load [cosφ = 1] $\Big\} = 3\, V_{ph} I_{ph}$.

$$I_{ph} = \frac{V_{ph}}{R} = \frac{V_{ph}}{Z_s} = \frac{V_L}{\sqrt{3}\cdot Z_s};$$

$$|SIL| = P_{3\phi} = 3\cdot\frac{V_L}{\sqrt{3}}\cdot\frac{V_L}{\sqrt{3}\,Z_s} = \frac{V_L^2}{Z_s} = \frac{V_s^2}{Z_s}$$

$$\boxed{SIL = \left|\frac{V_s^2}{Z_s}\right|}$$

where $Z_s = \sqrt{\frac{L}{C}}$, L, C ⇒ phase values.

$V_s = V_L =$ line voltage

$$\boxed{SIL = \frac{V_s^2}{Z_s} = V_s^2\sqrt{\frac{C}{L}}}$$

(1) $SIL \propto V_s^2$ (3) $SIL \propto \frac{1}{\sqrt{L}}$

(2) $SIL \propto \sqrt{C}$

- If $Z_L = Z_s$:- (1) Transmission coefficient $T_V = T_I = 1$
  (2) Reflection coefficient $R_V = R_I = 0$

Hence line is called Infinite line

Date

(3) $V_R = V_S =$, $I_R = I_S$ is maintain so that Tr-line produce flat voltage and current profile.

(4) V_S lead V_R By β, I_S lead I_R By β

(5) V_S and I_S and V_R and I_R are in phase ~~produces~~ unity works as unity p.f. load.

(6) Inductance of line required reactive power is supplied By capacitance of the line. There is No need of reactive power from the source

(7) Maximum three phase active power is transmitting through the transmission line which is called

$$SIL = \frac{V_S^2}{Z_S}$$

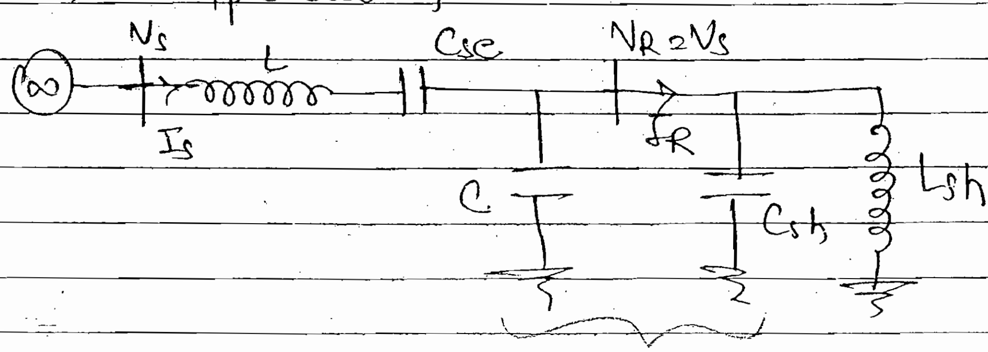
(8) Because of $V_S = V_R$ uniform voltage i.e. uniform insulation level for all the equipment like x-mer PT and CT can be maintain at both ends of line.

- Effect of Compensation on SIL :-

(1) Without Compensation :-

$$Z_{S1} = \sqrt{\frac{L}{C}} \qquad (SIL)_1 = V_S^2 \sqrt{\frac{C}{L}}$$

(2) With compensation.



$C_T = C + C_{sh}$
$= C[1 + (C_{sh}/C)]$

Date 13/7/2014

$K_{cse} = \frac{1}{\omega^2 L C_{se}}$ = % or Degree of C_{se}.

$K_{csh} = \frac{C_{sh}}{C}$ = % or Degree of C_{sh}

$K_{Lsh} = \frac{1}{\omega^2 L_{sh} C}$ = % or Degree of L_{sh}

$(SIL)_c$ = SIL with compensation

Z_{sc} = Surge impedance with Compensation.

$$\boxed{\begin{gathered} Z_{sc} = Z_{s1}\sqrt{\frac{(1-K_{se})}{(1+K_{csh})(1-K_{Lsh})}} \\ (SIL)_c = \frac{V_s^2}{Z_{sc}} = (SIL)_1\sqrt{\frac{(1+K_{csh})(1-K_{Lsh})}{(1-K_{se})}} \end{gathered}}$$

Q A 3 ϕ Tr. line surge impedance = 400 Ω applied at 400 kV Find

(1) Surge Imp. loading without Compensatn

(2) If the line is compensated with 30% of shunt capacitor. Calculate Z_s and SIL with compensatn

Q (3) If the generator is connected at source end delivering 200 MW through these lines Calculate load angle δ.

(1) without compensation (2) with Compensatn.

Solution (1)

Without compensation :- $V_s = 400$ kV $Z_{s1} = 400\,\Omega$

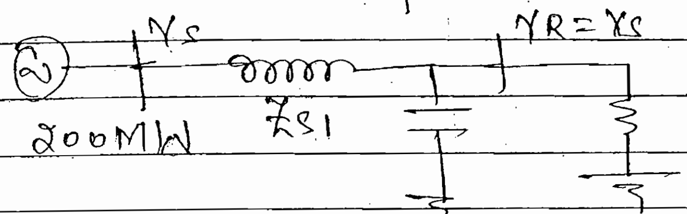
$$SIL = \frac{V_s^2}{Z_{s1}} = \frac{400^2}{400} = 400\text{ MW}$$

(2) With C_{sh} :- $K_{csh} = 30\% = 0.03$

$$Z_{sc} = \frac{Z_{s1}}{\sqrt{1+K_{csh}}} = \frac{400}{\sqrt{1+0.3}} = 350.8\,\Omega$$

$$(SIL)_c = (SIL)_1 \cdot \sqrt{1+K_{csh}}$$
$$= 400 \cdot \sqrt{1+0.3} = 456\ MW$$

(3) (a) Without Compensation



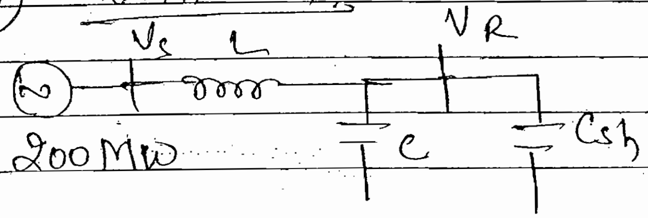
$$P_s = \left|\frac{V_s^2}{Z_{s1}}\right| \sin\delta_1$$

$$P_s = (SIL)_1 \sin\delta_1$$

$$200 = 400 \sin\delta_1$$

$$\boxed{\delta_1 = 30^\circ}$$

(b) With Csh :-

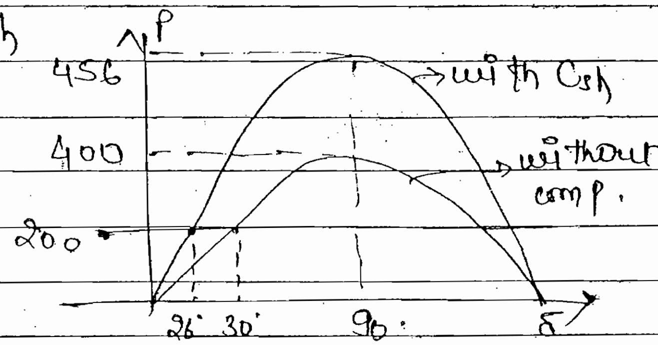


$$P_s = (SIL)_c \cdot \sin\delta_2$$

$$200 = 456 \cdot \sin\delta_2$$

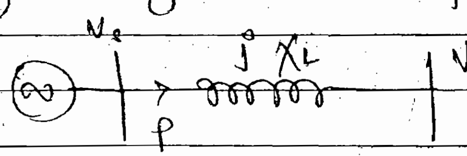
$$\boxed{\delta_2 = 26^\circ} < \delta_1$$

stability ↑.



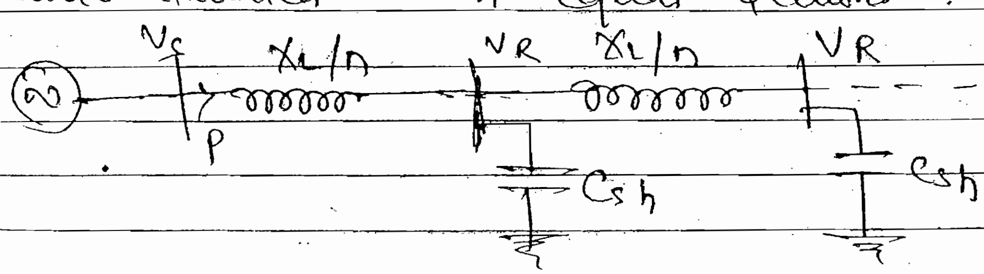
• Effect of Csh Compensation in n-Section of line

(1)



$$\boxed{P = \left|\frac{V_s V_R}{X_L}\right| \sin\delta}$$

(2) line divided in n-Equal Sections.



$$P = \left|\frac{V_s V_R}{\left(\frac{X_L}{n}\right)}\right| \sin\left(\frac{\delta}{n}\right) = \left|\frac{n V_s V_R}{X_L}\right| \sin\left(\frac{\delta}{n}\right)$$

Date

If $V_S = V_R \Rightarrow$ $\boxed{P = \left|\frac{n V_S^2}{X_L}\right| \sin\frac{\delta}{n}}$

Max (or) Ideal or steady state power:-

$P_{max} = \left|\frac{n \cdot V_S V_R}{X_L}\right|$

If $V_R = V_S$ $\boxed{P_{max} = \left|\frac{n V_S^2}{X_L}\right|}$

Pg No. 54.

Q.50 $X_L = 0.4$ $V_{midpt} = 0.96$

$P = \frac{2 V_S^2}{X_L} \sin\frac{\delta}{2}$ $= \frac{2 \times 0.96}{0.4_{0.2}}$ $P_{max} = 4.8$ p.u.

Q.47 $(SIL)_c = \frac{(SIL)_1}{\sqrt{1-K_{se}}} = \frac{2280}{\sqrt{1-0.3}} = 2725$ MW.

Q.48 $SIL = V_S^2 \cdot \sqrt{\frac{C}{L}} = 800^2 \times \sqrt{\frac{11.68 \times 10^{-9}}{1.1 \times 10^{-3}}} = 2085$ MW

Pg. No. 41. (33) $Z_s = 250\,\Omega$ $V_S = 400$ kV 400 kV 10 kA

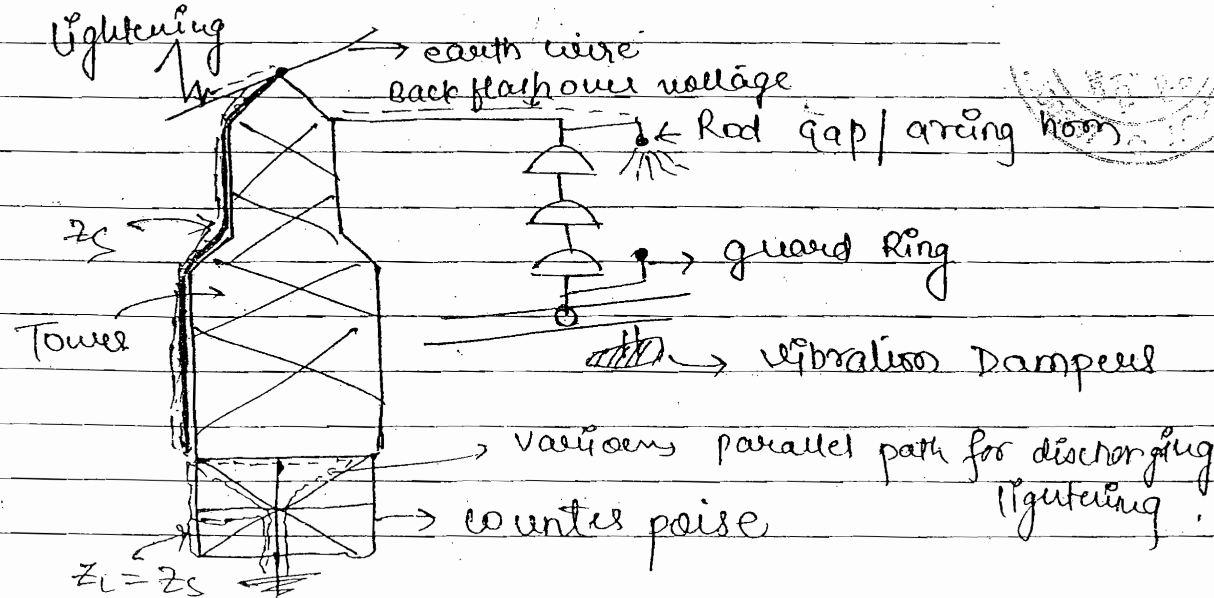
$V = 10 \times 250$

$= 2500$ kV Ans.

(36) (d) 1, 2 and 3

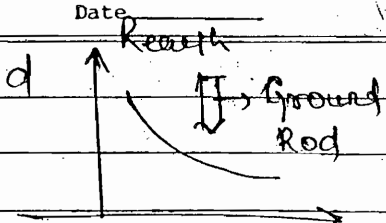
Pg No 55 $v = \frac{2\pi f l}{\sqrt{B \cdot X_L}} = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{0.201 \times 10^{-6} \times 196.2 \times 10^{-12}}}$

$= 159.24$ M/s.

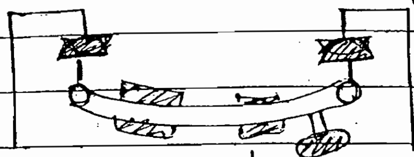


we ... $Z_L = Z_S$ for no reflection

- As the depth ↑ Z ↓ so use earth Rod



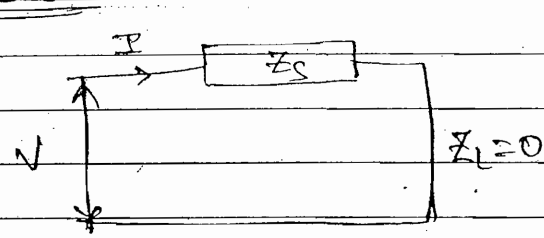
- guard Ring → for improving η, uniform voltage can maintain



When snow will accumulated over the conductor VD or stock Bridge which causes vibration because of non-uniform accumulatn of snow. So we use vibration damper for reducing the vibratn.

- For protecting insulating disc from flash over voltage arcing horn are used which discharge the arc in air and not pass to next one.

<u>Case 3 :-</u> $Z_L = 0$



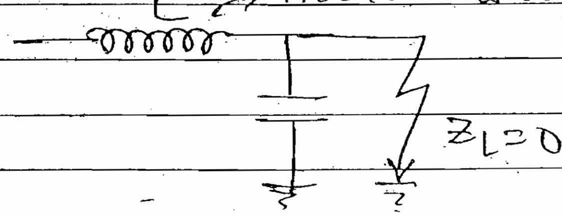
$$T_V = \frac{2Z_L}{Z_L + Z_S} = \frac{2(0)}{0 + Z_S} = 0$$

$$R_V = T_V - 1 = 0 - 1$$
$$= -1$$

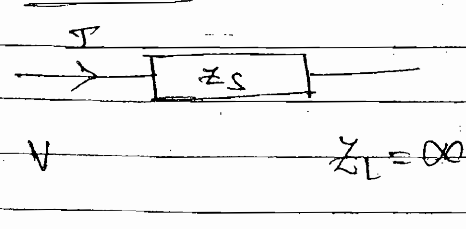
$$R_I = -R_V = +1$$

$$T_I = 1 + R_I = 1 + 1 = 2$$

$$\boxed{\begin{array}{l} T_V = 0 \Rightarrow V'' = 0 \\ T_I = 2 \Rightarrow I'' = 2 \\ R_V = -1 \Rightarrow V' = -V \\ R_I = 1 \Rightarrow I' = I \end{array}}$$



<u>Case 4 :-</u> $Z_L = \infty$



$$T_V = \frac{2\cancel{Z_L}}{\cancel{Z_L}\left[1 + \frac{Z_S}{Z_L}\right]} = \frac{2}{\left[1 + \frac{Z_S}{\infty}\right]}$$

$$= \frac{2}{1 + 0}$$

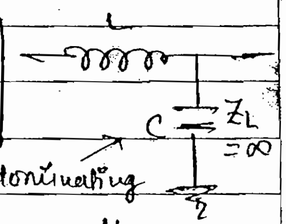
$$= 2$$

Date________

$R_V = T_V - 1 = 2 - 1 = 1$ $T_I = 1 + R_I = 1 - 1$

$R_I = -R_V = -1$ $= 0$

$$\boxed{\begin{matrix} T_V = 2 \Rightarrow V'' = 2V, & T_I = 0 \Rightarrow I'' = 0 \\ R_V = 1 \Rightarrow V' = V, & R_I = -1 \Rightarrow I' = -I \end{matrix}}$$



capacitor is dominating

- Counter poise is used at the bottom of the tower for discharging of lightning surge. It is containing parallel paths for effective discharging of lightening surges.

- In place of counter poise Ground Rods can also be used which has thinner in diameter and higher length and used because earth resistance reduces as the depth of the earth increases

- ~~Earthe~~ Arcing horn are used for protecting the insulating disc from the Back flash over voltage produce due to lightening surge.

- Guard Ring is used for maintaining uniform voltage in the disc so that string η is ↑

- Vibration dampers are used for protecting the reducing the vibrations only conductors which are produce due to non-uniform ice loading

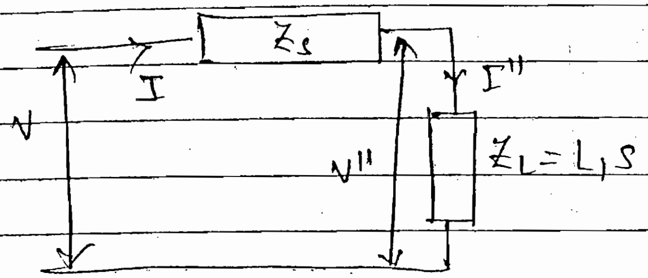
- When $Z_L = 0$ Tr-line behaves as highly lagging N/w demanding for the lagging VAR's.

- When $Z_L = \infty$ Tr-line behaves as highly leading N/w ~~demand~~ causes the receiving end voltage to ↑

Date

• If ~~Z_c~~ $Z_L = Z_s$ Tr-line has unity power factor.

Case 5 $Z_L = L_1 S$:-



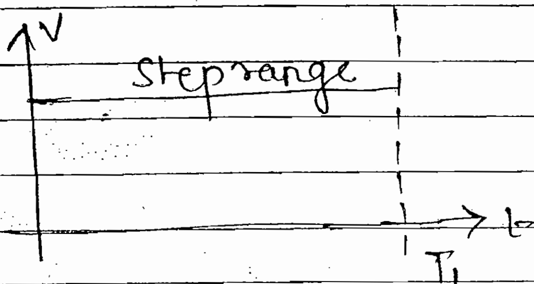
Assume step range

$V(s) = \frac{V}{s}$

$$V''(s) = \frac{2Z_L}{Z_L+Z_s} \cdot V(s)$$

$$= \frac{2L_1\cancel{s}}{(L_1 s + Z_s)} \cdot \frac{V}{\cancel{s}}$$

$$V''(s) = \frac{2V\cancel{L_1}}{\cancel{L_1}\left[s + \frac{Z_s}{L_1}\right]}$$



$$V''(t) = L^{-1}[V''(s)]$$

$$= L^{-1}\left[\frac{2V}{s + \frac{Z_s}{L_1}}\right]$$

surge touching inductor $\leftarrow t = T_1 = 0$

Time constant $= \boxed{T = \frac{L_1}{Z_s}}$

$$\boxed{V''(t) = 2Ve^{-tZ_s/L_1}}$$

Z_s = Surge Imp. of line $= \sqrt{\frac{L}{C}}$

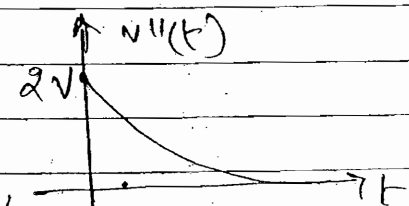
L_1 = Load Inductance

(1) At $t = T_1 = 0 \Rightarrow$ Instant at which step range surge touching $Z_L = L_1 S$

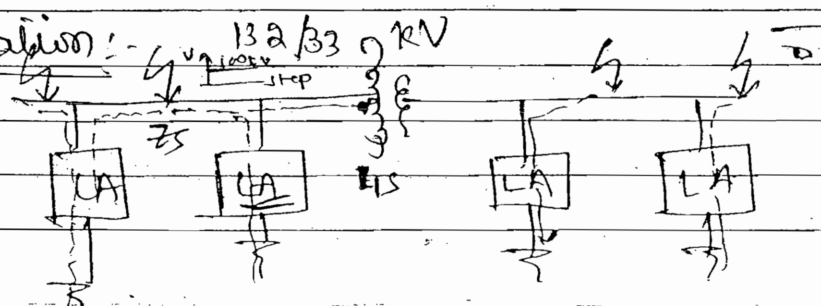
$$V''(t) = 2Ve^{-0} = 2V$$

(2) At $t = \infty$

$$V''(t) = 2V \cdot e^{-\infty} = 0$$



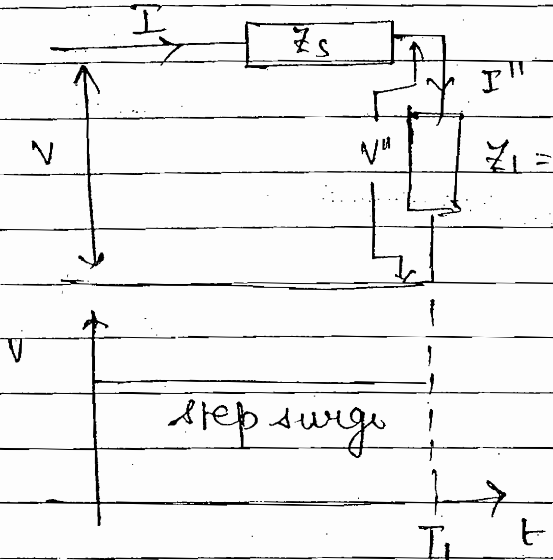
Application :-



Date________

- When L·A is not present and lightning of 100 kV surge is occurs, it will hit the x-mer wdg. x-mer has inductor behaves as load of L/S. (Voltage will rise up) x-mer has insulatn protectn upto 132 kV + 10%, and the surge is of 2 × 100 kV = 200 kV, than exp.l demage x-mer. So we kept LA on both side of x-mer.

Case 6 :- $Z_L = \frac{1}{C_1 S}$



$t = T_1 = 0$

Time constant $\boxed{T = C_1 Z_S}$

Z_S = surge imp. of line $= \sqrt{\frac{L}{C}}$

C_1 = load capacitance.

Assume step range

$$V(s) = V/s$$

$$V''(s) = \frac{2 Z_L}{(Z_1 + Z_S)} \cdot V(s)$$

$$= \frac{2 \cdot 1/C_1 S}{\left(\frac{1}{C_1 S} + Z_S\right)} \cdot \frac{V}{S}$$

$$V''(s) = \frac{2V}{s(1 + sC_1 Z_S)}$$

$$V''(t) = L^{-1}[V''(s)]$$

$$= L^{-1}\left[\frac{2V}{S[1 + SC_1 Z_S]}\right]$$

$$\boxed{V''(t) = 2V\left[1 - e^{-t/C_1 Z_S}\right]}$$

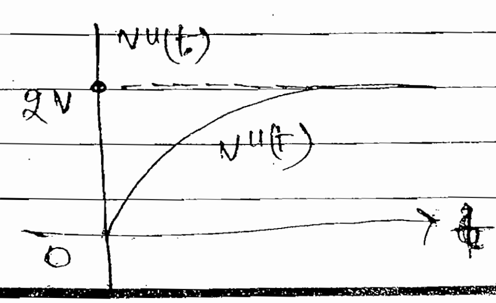
(1) At $t = T_1 = 0$ ⇒ instant at which step surge reaching

$Z_L = 1/C_1 S$

$$V''(t) = 2V[1 - e^{-0}] = 0$$

(2) At $t = \infty$

$$V''(t) = 2V[1 - e^{-\infty}] = 2V$$



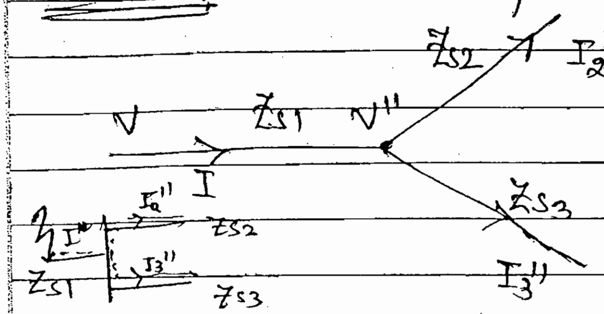
- No protecting device used.

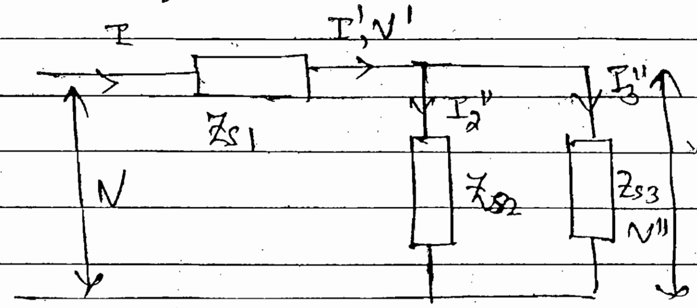
because $V = 0$ at $t = 0$

for Conventional Imp

Date________

Case 7:- Z_1 = parallel lines / T Junction:-





For parallel voltage is equal.

$$V'' = V + V'$$

$$V' = V'' - V \quad -(1)$$

$$I'' = I_2'' + I_3'' = I + I'$$

$$\frac{V''}{Z_{S2}} + \frac{V''}{Z_{S3}} = \frac{V}{Z_{S1}} - \frac{V'}{Z_{S1}} \quad -(2)$$

Substitute (1) in (2).

$$V''\left[\frac{1}{Z_{S2}} + \frac{1}{Z_{S3}}\right] = \frac{V}{Z_{S1}} - \frac{V''-V}{Z_{S1}}$$

$$V''\left[\frac{1}{Z_{S1}} + \frac{1}{Z_{S2}} + \frac{1}{Z_{S3}}\right] = \frac{2V}{Z_{S1}}$$

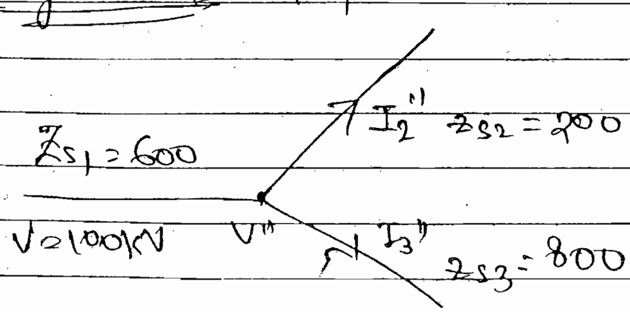
$$\boxed{T_V = \frac{V''}{V} = \frac{2/Z_{S1}}{\left(\frac{1}{Z_{S1}} + \frac{1}{Z_{S2}} + \frac{1}{Z_{S3}}\right)}}$$

$$R_V = \frac{V'}{V} = T_V - 1, \quad R_I = \frac{I'}{I} = -R_V$$

$$T_{I_2} = \frac{I_2''}{I} = \frac{V''/Z_{S2}}{V/Z_{S1}}, \quad T_{I3} = \frac{I_3''}{I} = \frac{V''/Z_{S3}}{V/Z_{S1}}$$

$$= T_V \frac{Z_{S1}}{Z_{S2}} \qquad\qquad = T_V \cdot \frac{Z_{S1}}{Z_{S3}}$$

Page No. 45 Q. 9



$$T_V = \frac{V''}{V} = \frac{2/Z_{S1}}{\left(\frac{1}{Z_{S1}} + \frac{1}{Z_{S2}} + \frac{1}{Z_{S3}}\right)}$$

$$V'' = 42.1 \text{ kV}$$

$$I_2'' = \frac{V''}{Z_{S2}} = \frac{42.1 \text{ kV}}{200}$$

$$= 0.210 \text{ kA}$$

Date________

$I_3'' = \frac{V''}{Z_{s3}} = \frac{421.1\,kV}{800} = 52.5\,A$

Page No 41 (34) $V = 20\,kV$ $L =$

$L_1 = 0.4 \times 10^{-3}$
$C_1 = 0.5 \times 10^{-6}$
cable

Tr-line 2

$L_2 = C_2 = Z_{s2} = Z_{s3} = \sqrt{\frac{L_2}{C_2}} = 316.2$

Tr-line 3.

$Z_{s1} = \sqrt{\frac{L_1}{C_1}}$

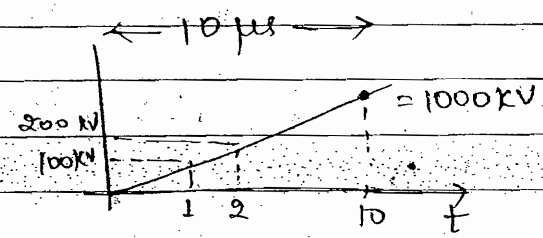
$= 28.28$

$V'' = \frac{2 \times 20}{28.28\left[\frac{1}{28.28} + \frac{1}{316.2} + \frac{1}{316.2}\right]} = 33.93\,kV$

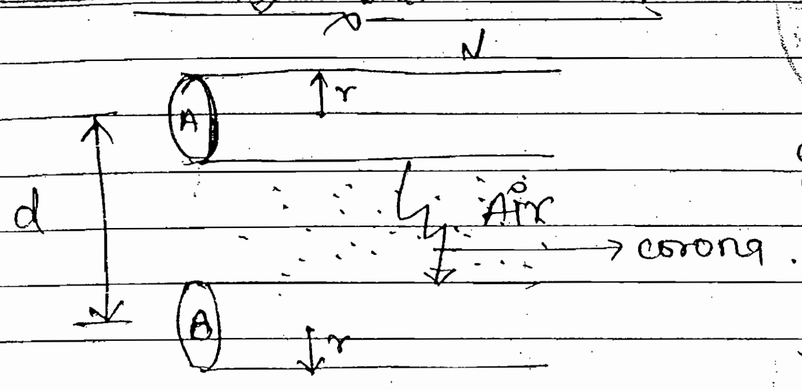
(32)

$Z_L = \infty$ $V' = V = 1000$

(c) $1000\,kV/\mu s$



CORONA:-



$g = 21\ kV/cm$ (RMS)

Peek Emperical
Name of Scientist.

- Corona is is self electrical discharge of atmospheric air.
- If the operating voltage is b/w the conductor is more than dielectric strength of atmospheric air. The air molecules get ionised and initates corona.
- The corona is form ozone gas is released.
- Critical Distruptive voltage :- V_c :- The voltage at which corona is just initiated is called V_c. The sound can be heard at this voltage

$$\boxed{V_c = m g r \delta \ln\left(\frac{d}{r}\right)} \quad kV/phase\ (RMS)$$

m = Surface factor
= 0.8 – 0.9 for ACSR / Rough Conductors
= 0.9 – 1 for Hollow / Smooth Conductor

g = Dielectric strength of air = 21 KV (cm (RMS)

r = Radius of conductor in cm.

d = Distance between Conductors in cm.

δ = Air density factor

$$= \frac{3.92\, b}{(273+T)}$$

b = barometric pressure of air in cm of Hg

T = Atm. Temp. °c.

Date.

- Critical Visual Voltage :- V_v :- The voltage at which corona is visible with violet or blue colour is called V_v.

$$\boxed{V_v = m g r \delta \left(1 + \frac{0.3}{\sqrt{r\delta}}\right) \ln \frac{d}{r}}$$ KV/phase (RMS)

- Power loss Due to Corona : If corona is form power loss will occur which is given by peek empirical formula.

$$\boxed{P_L = 241 \times 10^{-5} \left(\frac{f + 25}{\delta}\right) \sqrt{\frac{r}{d}} \, (V_{ph} - V_c)^2}$$ ... KW/km/phase

$$\boxed{P \propto (f+25)}$$

V_{ph} = Tr-line voltage / phase

V_c = Critical Disruptive Voltage

NOTE :- (i) If $V_{ph} > V_c$ CORONA OCCURS

$P_L \neq 0$

(ii) If $V_{ph} \leq V_c$ NO CORONA

$P_L = 0$.

Q 1-ϕ Tr-line with conductor $A = 0.5$ cm distance b/w conductor is 40 cm operating at voltage of 30 kV

Calculate (1) V_c Assume $m = \delta = 1$

(2) Power loss at 50 Hz

Solution: $A = \pi r^2$

$0.5 = \pi r^2$

$r = \sqrt{\frac{0.5}{\pi}}$

$r = 0.39$

$V_c = 1 \times 21 \times 0.5 \times 1 \times \ln \frac{40}{0.5}$

$= 46.011$ kV/phase

circular shape and uniform surface so compare to rectangular or irregular shape

Date

(2) $V_{ph} = 30KV < V_c \Rightarrow$ No corona loss

$\therefore P_L \neq 0$

• Factors affecting Corona and Methods of Reducing

(1) Higher value of V_c preferred so that corona doesnot occur and $P_L = 0$

(2) $V_c \propto m$, m is higher for hollow and smooth conductor so that corona is less compare to ACSR or rough conductor

(3) $V_c \propto r$, Bundle conductor radius ↑, V_c ↑. By using Bundle conductor effective radius of conductor is ↑ so that corona is minimised.

(4) At higher V_c, $P_L = 0$ and hence do not consider $P_L \propto \sqrt{r}$

(5) $V_c \propto \delta \propto b$. In hill areas b is smaller so that corona is more frequent compare to plain areas. | b → pressure, b↓ in hilly areas

(6) As the operating voltage ↑, distance b/w conductor are ↑ (d), for maintaining higher V_c because $V_c \propto \ln d$

(7) By ↑ height of tower corona is reduced. (capac ↑ if height is less, X_L ↑ over voltage cause, and greater than V_c, corona start.)

(8) By using transposition corona is reduce.

(9) $P_L \propto (f + 25)$, Corona power loss is more in HVAC compare to HVDC.

Dis advantages:

(1) Power loss occurs

(2) Produces interference to other lines

(3) ~~Line~~ charging current ↑

Date

Advantage :-

(1) Intensity OR Peak voltage of lightening surge is reduce if lightening surge initiate corona.

(lightening is $\geq V_c$, start corona, $\rightarrow$ change into corona) so peak value of lightening of surge is $\downarrow$).

Date 29/10/2014

Hydro Power Plant

- Surge Tank:- It is used in the medium and high head hydro power stations. It is mainly used for protectn of penstock from the water hammering effect.

→ It is used to supply water to the turbine in case of emergency load demande.

- Spillway:- It is used as a safety valve for the hydro station for protection of hydro plant from the excess water due to heavy rain. This water is diverted using spillway.

- Trash Track:- It is used for collecting waste materials from the water so that turbine blades are protected

- Hydrograph:- It is a graph b/w discharge of a water v/s (and) tank. By using this hydrograph the power generated by the plant can be predicated so that schedulling of the maintaince for the hydro & thermal & nuclear are programmed

- Pumped Storeage plant:- It is one of the type of hydro plant containing two times i.e. down stream and upstream tanks during peak load demand water flows from upstream to downstream. through the turbine for supplying peak load demand.

→ during off peak load time water will resert from downstream to upstream. during this time turbine is working is pump and gen. working as motor. Taking the power from other parallel generator.

Date________

Advantages of Pumped storage:-

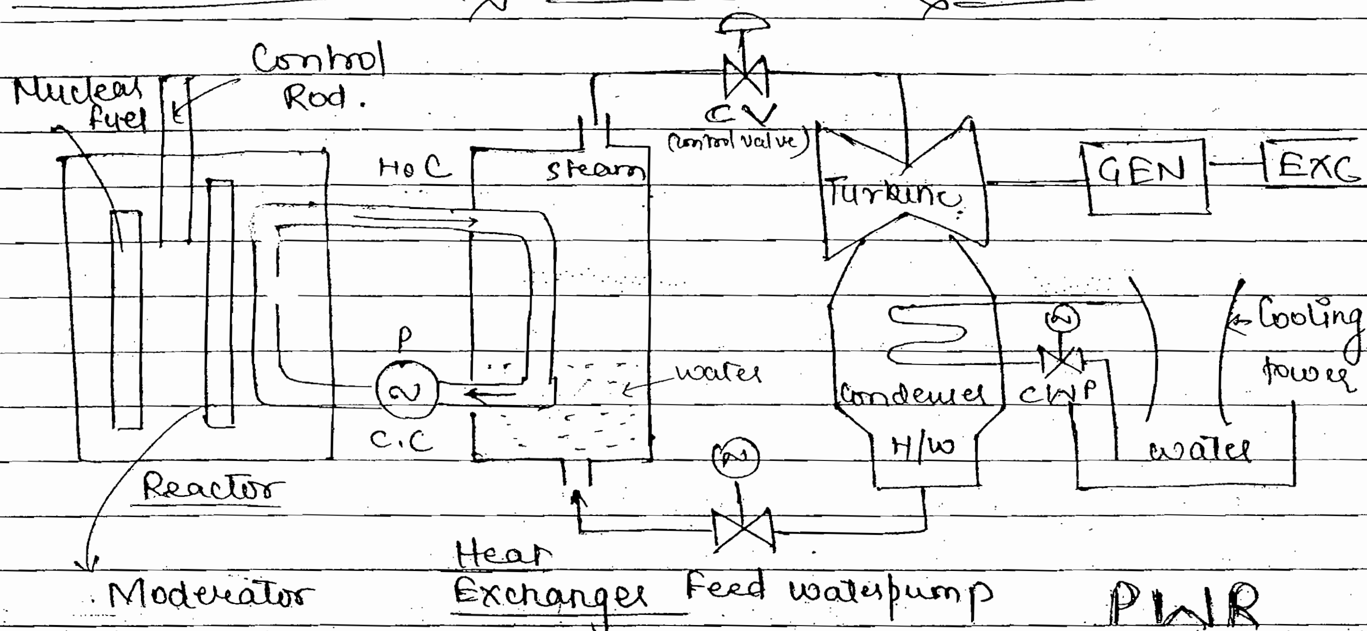
(1) Most economical as a peak load supply plant

(2) Used as load frequency control unit.

(3) If it is combine with thermal plants, plant load factor is increased.

(4) Pollution free

(5) Easily adoptable for remote control operation.



Nuclear Power Plant (Layout)

CC → Cold coolant   HC → Hot coolant   P = pump

	BWR	PWR.	CANDU	Liquid Na	FBR
Fuel.	Enriched	Enriched	Natural	Enriched	Enriched
Coolant	Water	Water	Heavy water	liquid Na	liquid Na
Moderator	Water	Water	Heavy water	Graphite	←
Control Rod	Cadmium	Cadmium	—	Boron	Water

enriche → fuel → 99% USA

Natural → fuel → 0.07% India

Date

BWR = Boiling water Reactor	Enriched:
PWR = Pressurised water Reactor	U^{238}_{92}
CANDU = Canadian Deuterium Uranium	Natural:
FBR = Faster Breeder Reactor	U^{235}_{92}

- Principle:- Nuclear Fission.

→ Mostly use CANDU, PWR.

→ Liquid Na, FBR → Laboratory purpose.

→ Pressure is less than thermal p.p. But flow Rate is high.

→ Moderator → ordinary water → to moderate control the speed of neutron.

BWR:- In BWR ⇒ we donot use the Heat exchanger. water is directly goes to Reactor where it will change into steam. This steam will send to turbine.

PWR

Working:- When fuel get hot, (after fission), It hottness is collected by the cold coolant, which is circulated through pump. cold coolant get converted into hot coolant, Heat exchanger having the water, The heat of ~~heat~~ hot coolant transfer to water. Water will convert into steam. This steam will sent to turbine. Remaining steam will condense and convert into water again. This water is again used in heat exchanger for converting into steam.

- If feed water pump get damage:- (for BWR) disadvantage, water level will goes down, It Moderator and control Rod also not working, than neutron produce heat extreme high, which Brust the Reactor.

ex:. Happened in Japan 4 out of 6 → Brust.

Date________

Reproduction and Multiplication Factor :- (K)

$$K = \frac{\text{No. of Neutrons released in present cycle}}{\text{No. of Neutrons released in previous cycle}}$$

K = 1 ⇒ Constant power O/p
K > 1 ⇒ Increased power O/p.
K < 1 ⇒ Decreased power O/p

practical value of K is just higher than 1

ex:- 09:00 - 100 MW - 100 Neutron -
10:00 - 100 MW - 100 Neutron - $K = \frac{100}{100} = 1$.

11:00 - 120 MW - 120 Neutron - $K = \frac{120}{100} = 1.2 > 1$

18:00 - 80 MW - 80 Neutron - $K = \frac{80}{120} = \frac{80}{120} < 1$

- In nuclear reactor heat is produced due to nuclear fission chain reaction.
- This heat is absorbed by coolant which is used to convert water into steam in Heat exchanger. This steam admitting into turbine for producing power generation.
- The amount of heat released is depending on velocity of neutron and No. of Neutrons released.
- Moderator is used for moderating the speed of the neutron. The molecular weight of the moderator is to be minimum
- Ordinary water is used as moderator in the enriched uranium plants.
- Control Rod : It is used for absorbing excess neutrons released during Nuclear fission chain reaction.

Load Frequency Control

Date________

Rated value of freq. = 50 Hz.

Range: Ideal: 50 ± 1% (49.5 – 50.5 Hz)

: Practical: 50 ± 3% (48.5 – 51.5 Hz)

Disadvantages of frequency variation:-

(1) For maintaining constant voltage at low freq. The ϕ to the x-mer core has to be increased. This will increase the causes saturation of the x-mer core.

(2) All the electrical Motor speeds are freq. dependent By changing the frequency. The performance of electrical motor are effected

(3) Due to core saturation of C.T. at low frequency, relays produces trip signals without any fault

(4) PA, FD and ID fans are runned by induction Motor. If the freq. changes the performance will be effected. so that thermal efficiency is effected.

(5) The turbine Blades are damaged at higher frequency & speed. [at low speed Blades will compress and at high speed Blades will come out due to centrifugal force)

- Method of Frequency Control:-

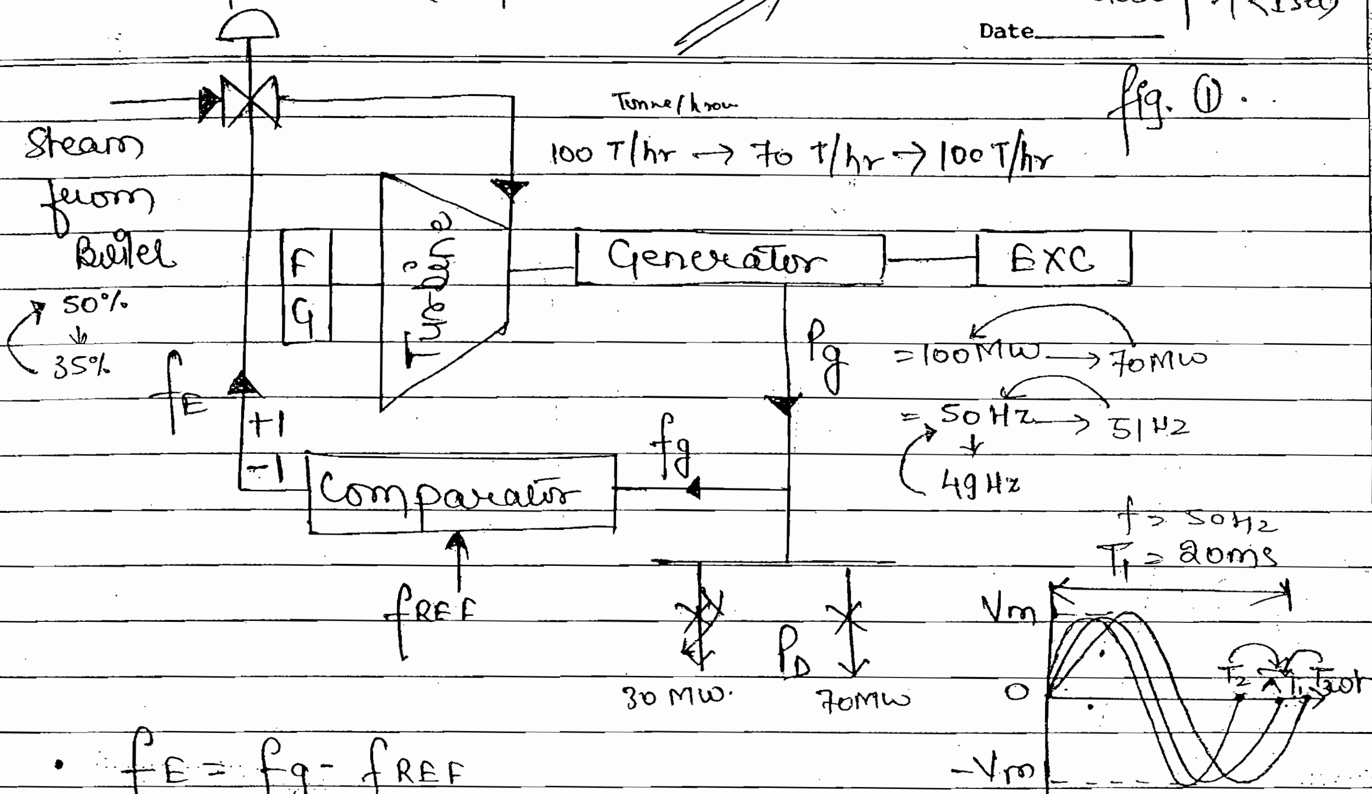
(1) Primary control:- Speed governing control valve
(2) Secondary control:-
   (A) Pumped storage plant
   (B) Load regulation.

Speed Governing Control Valve:

Diagram in Next page.

This process take some time delay. (< 1 sec)

Date_______



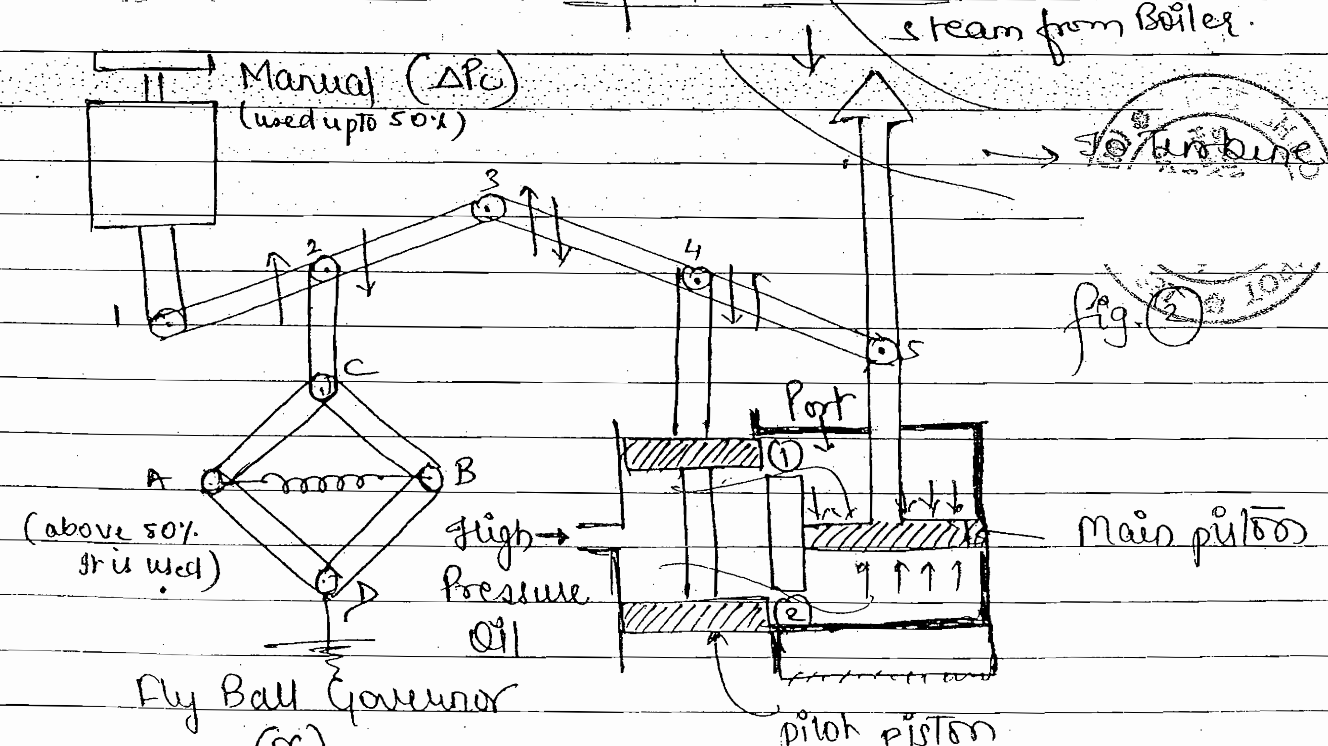
- $f_E = f_g - f_{REF}$

① If $f_g = f_{REF} \Rightarrow f_E = 0 \rightarrow$ Constant opening position of Govn. Val

② If $f_g > f_{REF} \Rightarrow f_E > 0 \Rightarrow$ close valve until $E = 0$

③ If $f_g < f_{REF} \Rightarrow f_E < 0 \Rightarrow$ open valve until $E = 0$

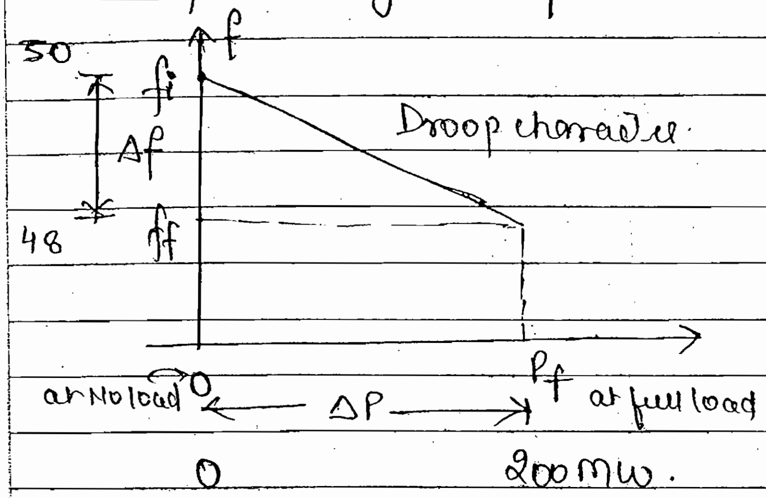
Internal Structure of Govn. Valve



practically freq. at No. load $\Rightarrow$ $> 50\,Hz$.

Date

Speed Regulation Parameter



$$\boxed{R = -\frac{\Delta f}{\Delta P}} \quad Hz/MW$$

Ex:- $R = -\left(\frac{50-48}{200-0}\right) = -\frac{1}{100}$ Hz/MW

$= -0.01$ Hz/MW.

$$\boxed{\frac{\Delta f_2}{\Delta P_2} = \frac{\Delta f_1}{\Delta P_1}}$$

Speed Regulation Constant:

$\Delta f \longrightarrow \%$

$f_i - f_f \Rightarrow \Delta f$

$\frac{f_i - f_f}{f_i} \Rightarrow \frac{\Delta f}{f_i}\ \%$

Ex:- 4% of speed Regulation or (0.04 p.u).

$\frac{\Delta f}{50} = 4\% \Rightarrow \Delta f = 2\,Hz$.

Q Ques. I ask like for 2MW How much freq. will affected...

Q A 200 MVA turbo gen. have speed Regu. of 8%. How much of turbine I/P has to be ↑ for steady state operation for freq. droop. of 0.05 Hz.

Solu ~~R = 8%. = 0.08~~

~~$\frac{f_2}{P_2} = \frac{f_1}{P_1}$ ⇒ 0.05~~

$|R| = +\frac{\Delta f}{\Delta P} = \frac{8\% \text{ of } 50}{200} = \frac{\frac{8}{100} \times 50}{200} = \frac{4}{200}$ Hz/MW

$\frac{\Delta f_2}{\Delta P_2} = \frac{\Delta f_1}{\Delta P_1}$

$\frac{0.05}{\Delta P_2} = \frac{4}{200}$ $\quad \Delta P_2 = \frac{200 \times 5}{100 \times 4} = 2.5$ MW.

Date________

fig. ① explaination :- Suppose the generated power $P_g = 100$ MW and demand is also 100 MW, for this 100 Tonne/hour coal is required for which 50% valve is opened (∴ freq = 50Hz) Time period of 1 cycle is $T_1 = 20$ms.

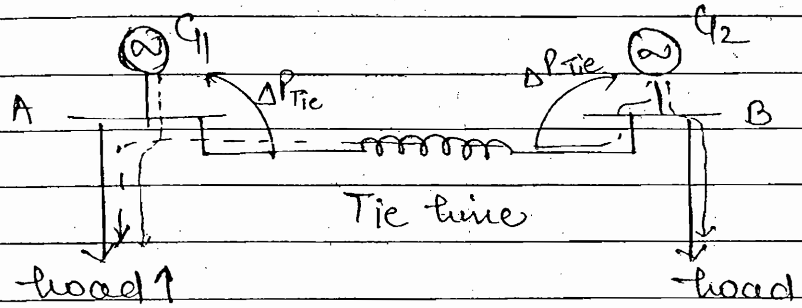
- Suppose CB of 30 MW get opened due to fault. $P_D = 70$ MW and $P_g = 100$ MW, rotor speed get high K.E. $\propto \omega^2$ because of which freq get ↑ 51 Hz. Comparator will generate of an error of +1, which send to govn. valve It will close the valve upto 35%, Now coal requirement will be 70 T/hr. [51 Hz set to again 50Hz]
- Suppose CB. of 30 MW get closed, Now $P_D = 100$ MW But $P_g = 70$ MW, Rotor speed get ↓ due to which freq. will ↓ and become 49 Hz, $T_3 = \frac{1}{f}$ = more than $T_1 = 20$ms. Comparator will generate error of −1. and send signal to govn. valve. It will open the valve, Now coal requirement ↑, 70 T/hr ⟶ 100 T/hr freq. will again set to 49 Hz ⟶ 50Hz. So maintain the freq.

fig ② Explaination :-

- for ↓ in demand, FG will expand pull c down, 2 ↓, 3 ↑, 4 ↓, high pressure oil will enter through ② gate and close the valve.
- for ↑ in demand, FG will compressed push c upward, 2 ↑, 3 ↓, 4 ↑, oil will enter through ① gate and open the valve.

Date________

- Area frequency Control :-



(1) Flat frequency control
(2) Flat Tie line / Tie Bias Control
(3) Parallel frequency control.

- Area freq. control is used to maintain constant frequency for an inter connected grid sys. containing more generators connected in parallel.

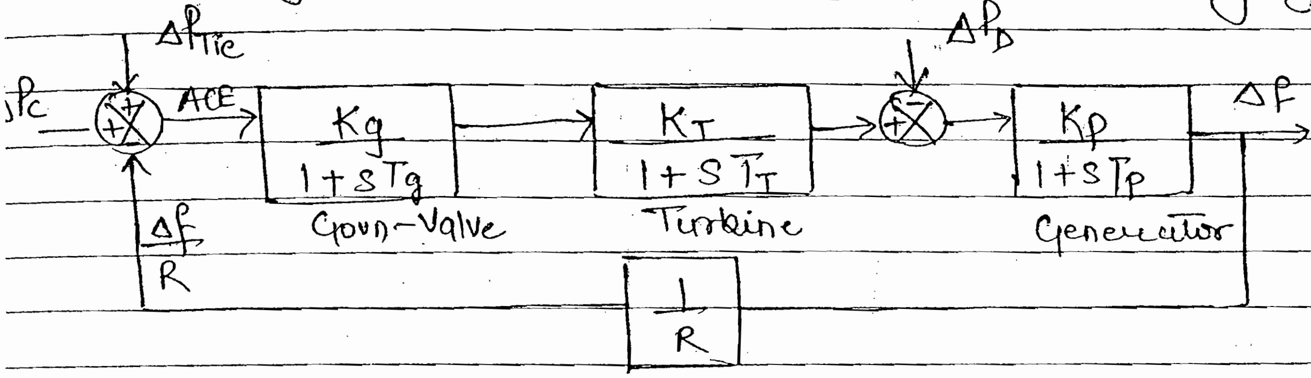
(1) Flat frequency Control :- Load changes of Bus Bar A is supplied By the generator G_2 for maintaining constant frequency. in In this method the Tie line may be over loaded

(2) Flat Tie line / Tie Bias Control :- Load changes of Bus Bar A or B supplied By G_1 and G_2 without over loading of the tie-line so that the control signal is proportional to changes in the Tie line power and frequency.

(3) Parallel freq. Control :- Load changes of Bus Bus A or B is supplied simultaneously By Both the generators without overloading for maintaing constant freq. This method is most practically used in Area freq. control.

Date________

Block Diagram Representation of Speed Governing Sys



ACE = Area Control Error

$= \Delta P_c + \Delta P_{Tie} - \Delta f/R$

For auto control ΔP_c = constant

Bias Coefficient $= b = -\frac{1}{R}$

$$\boxed{ACE = \Delta P_{Tie} + b \cdot \Delta f}$$

Time Constants : T_p, T_g, T_T

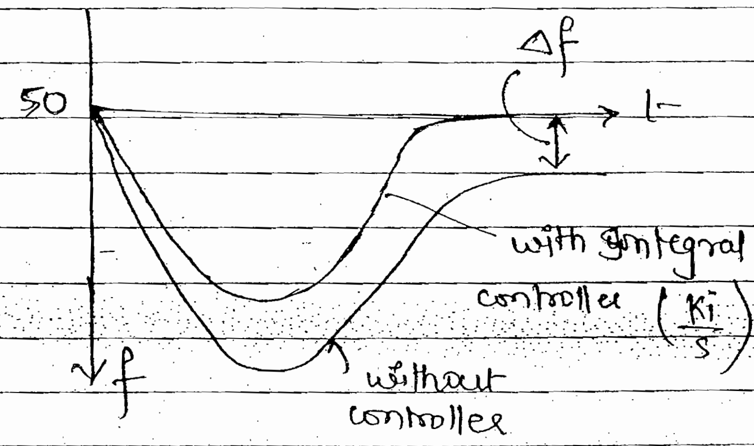
Gain Constants : K_p, K_g, K_T

$T_p = 0.1 - 0.2$ sec

$T_T = 0.1 - 0.3$ sec

$T_g = 0.1 - 0.2$ sec

Δf = steady state freq deviation / drop



- Integral controller eliminates steady state freq. drop

~~ss~~ Steady state freq. Drop (Δf):-

$$\Delta f = (f_N - f_i)$$

(1) Isolated Generator

(a) Sudden Load Demand :- (ΔP_D)

$$\boxed{f_N = f_i \left[\frac{H \cdot S. - (\Delta P_D) T_d}{H \cdot S}\right]^{1/2}}$$

Date

(b) Sudden Load loss (ΔP_D) (Trip of load)

$$\boxed{f_N = f_i \left[\frac{H.S + (\Delta P_d).T_d}{H.S}\right]^{1/2}}$$

H = Interia constant of Gen. MW Sec/MVA.
S = Rating of Generator in MVA.
ΔP_D = Load / Loss Demand in MW.
T_d = Time Delay in Govn. Sys. in Sec.
f_N = New frequency
f_i = Initial frequency.

(2) Area Control: -

$$\boxed{\Delta f = -\frac{\Delta P_D}{(\beta + 1/R)}}$$

$$\beta = \frac{\text{Rated value} \times \text{\% change in power}}{\text{Rated freq} \times \text{\% change in frequency}}$$

R = Speed Reg. parameter in Hz / MW
ΔP_D = -ve for Load loss
= +ve for load Demand.

Q An interconnected pow sys. N/W. As the pow of 1500 MW at 50Hz. The freq. is changing 2.5% for a load change of 1.5%. Calculate the steady state freq. drop If a 200 MW of Industrial load is trip. Assumed R = 0.005 Hz/MW

Solution. $\Delta f_0 = -\dfrac{-200}{\dfrac{\frac{1500 \times 1.5}{100}}{\frac{50 \times 2.5}{100}} + \dfrac{1}{0.005}} = \dfrac{200}{\dfrac{\frac{225}{10}}{\frac{2.5}{2}} + \dfrac{1000}{5}}$

Date________

$\Delta f = 0.917\ Hz.$

$f_N - f_i = 0.917$ $\qquad f_N - 50 = 0.917$

$\therefore f_N = 50.917\ Hz$

Q 200 MVA 50 Hz Turbo gen. is operating at No load if a load of 70 MW is applied at the terminals of generator. Calculate
(1) Steady state freq. drop
(2) New freqe. due To Time delay of gov. sys. of 0.5 sec. Assume Interia Const. of the generators is 4 MW sec / MVA

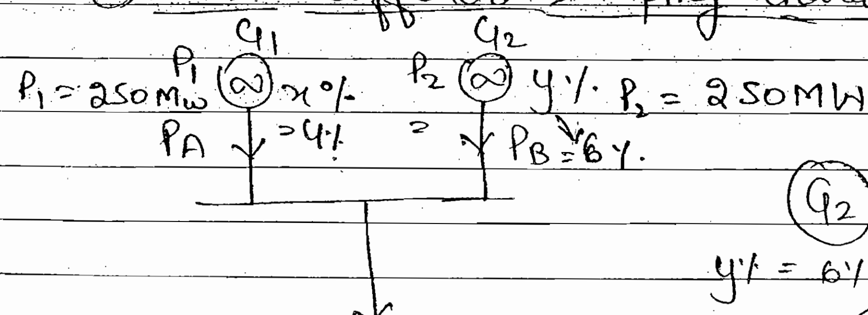
Solution:- $f_N = \left[\dfrac{4 \times 200 - 70 \times 0.5}{4 \times 200}\right]^{1/2} \times 50$

$= 48.89\ Hz$

$\Delta f = 50 - 48.89 = 1.11\ Hz$

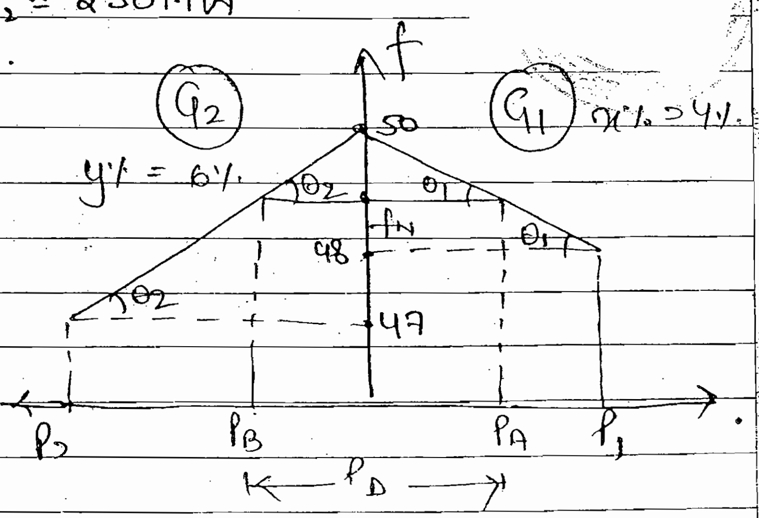
• Load Sharing of Parallel Generator

(1) With different Drooping Characteristic :-



$P_A + P_B = P_D = 400$

$P_D = 400.$



Date

G_1 $\qquad\qquad\qquad\qquad$ G_2

$\tan\theta_1 = \frac{50-f_N}{P_A} = \frac{50-48}{250} = \frac{1}{125}$ —— (1) $\qquad$ $\tan\theta_2 = \frac{50-f_N}{P_B} = \frac{50-47}{250} = \frac{3}{250}$ —— (2)

$P_A + P_B = 400$ given

$P_B = 400 - P_A$

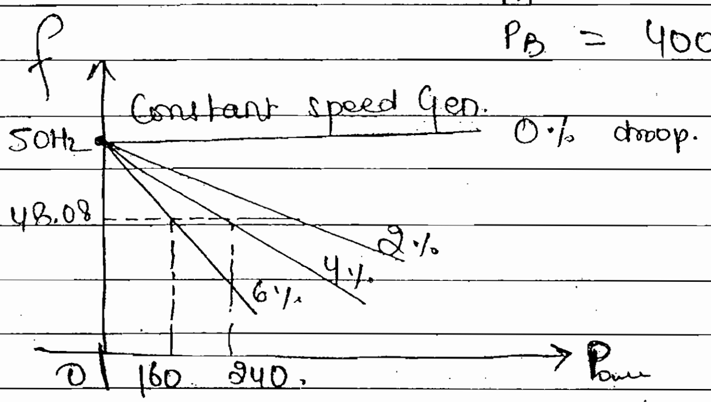
Put in eqn (2) $\qquad$ $\frac{50-f_N}{400-P_A} = \frac{3}{250}$ —— (3)

Solve (1) & (3) $\quad f_N = 48.08\ Hz.$

$P_A = 240\ MW$

$P_B = 400 - P_A = 400 - 240$

$= 160\ MW.$



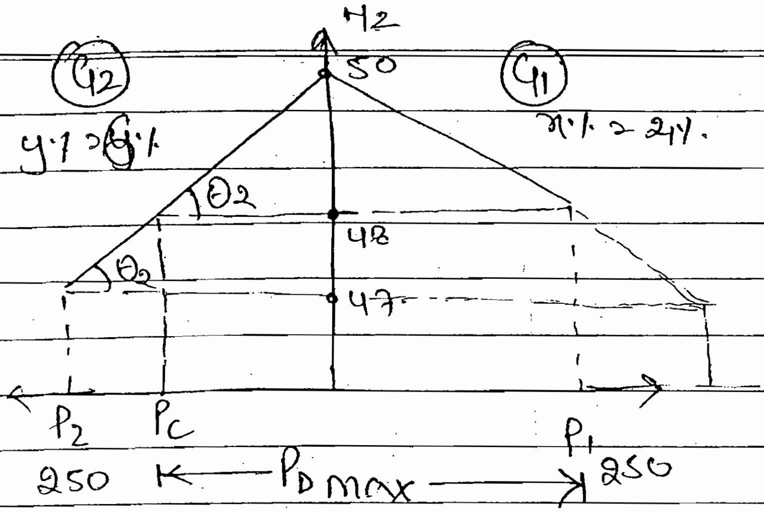
- In parallel operation generators, The generator with lowest % of droop character. will share Maximum load
- If a 0% or Constant Speed Gen. is connected in parallel to the other generators with 2, 4, 6%. droop characters than 0% generator can supply entire load changes with loading other generator. This is an ideal generator.

Case (ii) Maximum Load supply By gen. without over loading

G_1 $\quad x\% = 4\%$ $\quad P_1 = 250\ MW$ $\quad \rightarrow P_A$

$P_{Dmax} = P_A + P_B = ?$

G_2 $\quad y\% = 6\%$ $\quad P_2 = 250\ MW$ $\quad \rightarrow P_B$



Date________

$\tan\theta_2 = \frac{50-48}{P_C} = \frac{50-47}{250}$

$P_C = 166.66\,MW$

$P_{Dmax} = P_1 + P_C$

$= 250 + 166.6$

$\boxed{P_{Dmax} = 416.66\,MW}$

$\boxed{f_N = 48\,Hz}$

∴ If operate at 47 Hz freq. P_1 deliver more than 250 so we can't take this condition.

- Because of different drooping characteristic. Generators are not able of loaded to the maximum full load capacity.
- The lowest dropping characters is loaded to full load capacity

② **Both Generator has same droop characteristic**

G1: $P_1 = 250$, $x\% = 4\%$, P_A

G2: $P_2 = 250$, $y\% = 4\%$, P_B

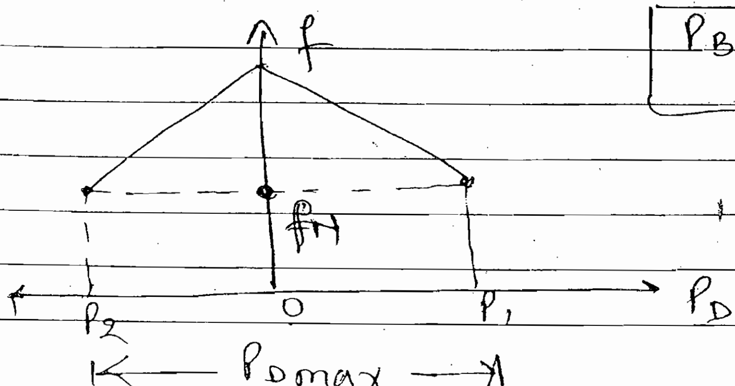
$P_D = P_A + P_B$

$\boxed{P_A = \frac{P_1}{P_1+P_2} \times P_D}$

$= \frac{250}{250+250} \times 400$

$P_A = 200\,MW$

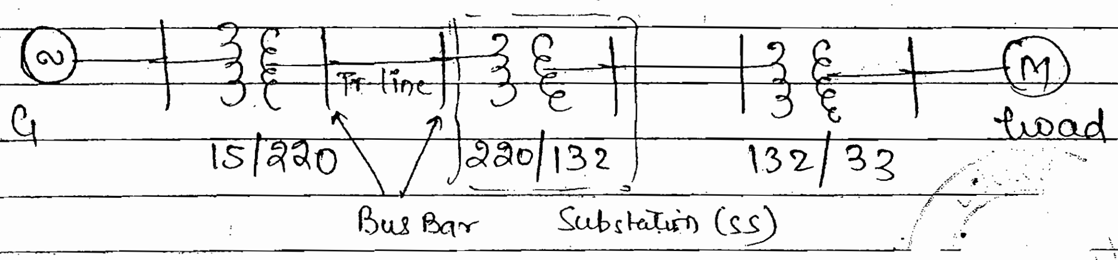
$\boxed{P_B = \frac{P_2}{P_1+P_2} \times P_D} = 200\,MW$



- If both generator have equal droop character can supply the load demand as per their capacity proportionately.
- Maximum demand = Sum of their individual full load capacity

30/10/14

Protection And Switchgear

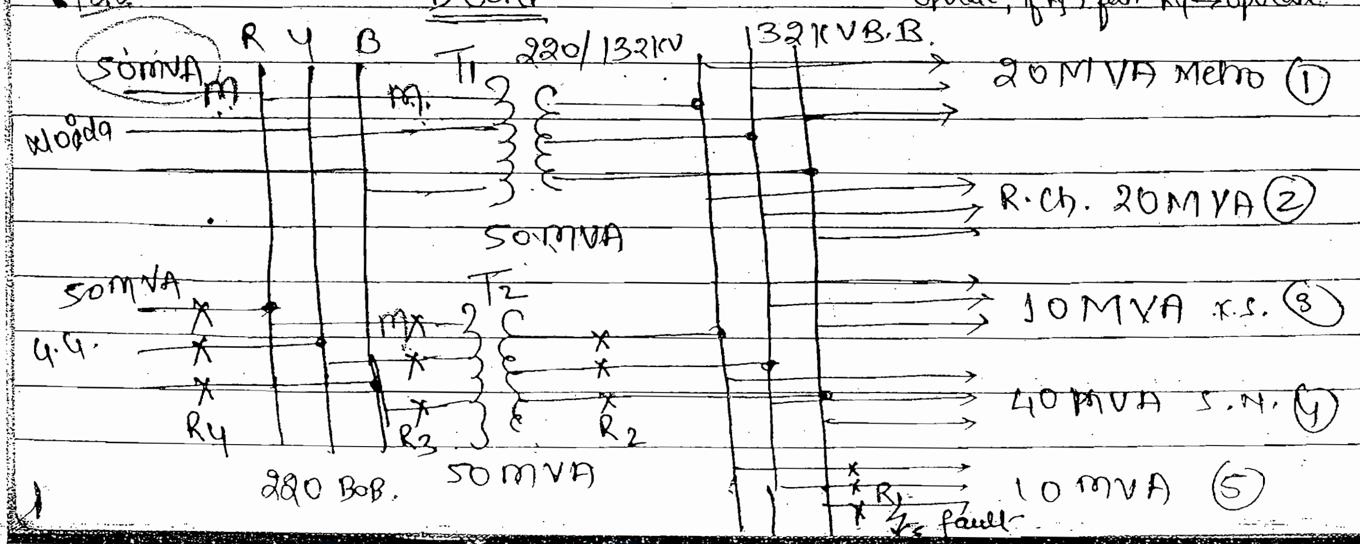


→ shown only for R phase (Next page fig).
→ We have to protect ⇒ four X-mes 220/132 KV, 220 KV Bus Bar, 132 KV Bus Bar.
→ (1) Identification of fault (2) Isolation of fault from healthy part.
→ Tr-line → SF_6, Distribution → Vacuum CB.

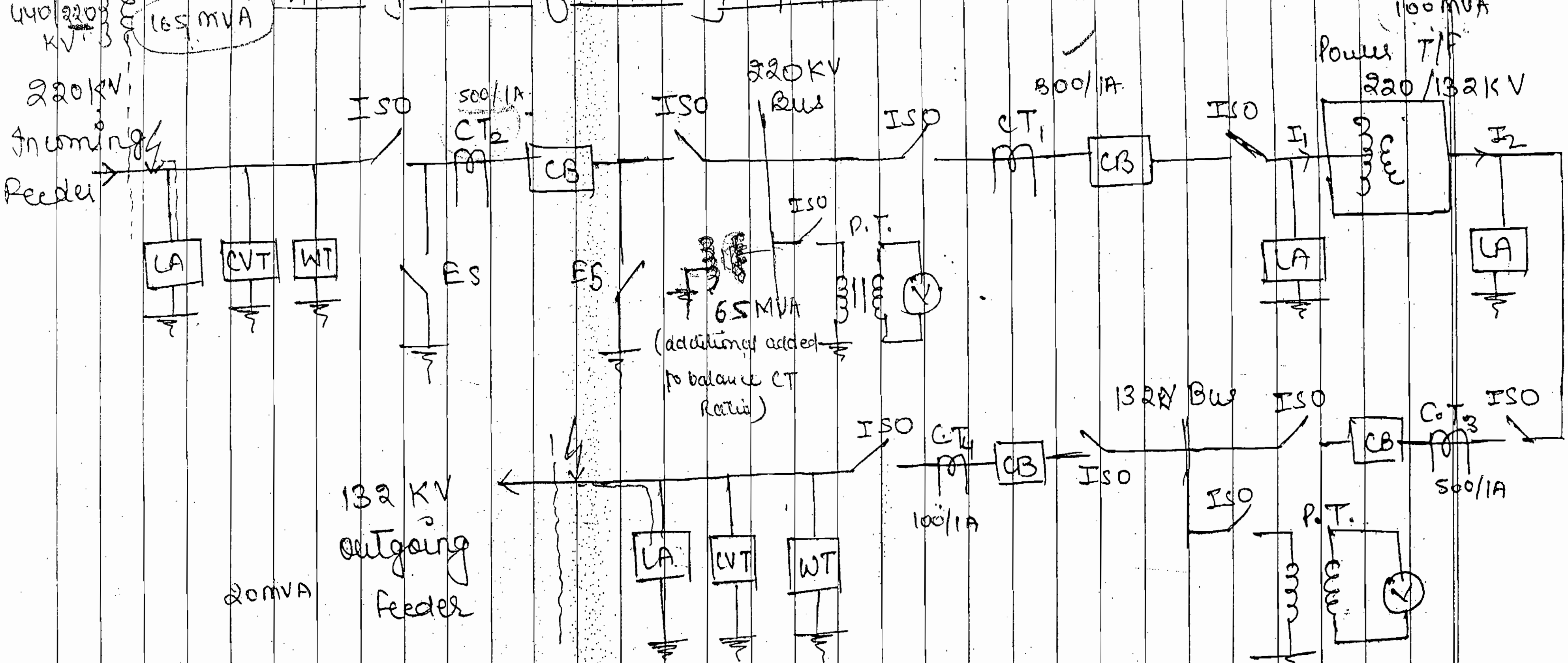
- Lock out condition :- CB donot operate, even fault is present Bcoz pressure (sufficient) is not present, if open CB get Blast
  → ex:- R_3 (operate for fault occur accross R_1)
- Non-unit protection: Identify the fault not only it's own unit (area) But also outside. (also called Backup protection)
- Unit protection:- ex:- Buchholtz Relay. which operate only in specified area

If R_1 get failed R_2 will operate, if R_2 → fail, R_3 operate, if R_3 → fail R_4 → operate.

- 100 Delhi



Arrangement of Protecting equipment In the substation



LA = Lightning Arrestor

WT = Wave trap

CVT = Cap. voltage Transformer

PT = Potential Transformer

ES = Earth Switch

CT = current Transformer

CB = Circuit Breaker.

HV CT

$\sqrt{3} V_p I_p = S$

$\sqrt{3} \times 220 \times 10^3 \times I_p = 100 \times 10^6$

$I_p = 2A$

LV CT

$I_s = 4A$

- Suppose (G.G.) generator fail, then gen. is 50 MVA and demand is 100 MVA, then area (5) and (4) are disconnected, [G_2 is fail due to fait of Relay R_1]

Date________

- Power sys N/w consisting of generators, x-mer, Bus Bars, x-line and electrical Motors etc. These equipments are to be protected from the abnormal condition like short circuit, open circuit, faults and lightning surges.

- Non-Unit Protection:- The protecting equip. like Relays, CB etc are operating for the faults within in own zone and also in the other zone equipment and faults is known as N.U.P. ex:- overcurrent and distances relays.

- Unit Protection:- The protecting equipments are operating ~~within~~ for the fault with in some physical space with in or equipments is called U.P.
ex:- Differential Relay or Buchholtz Relay

- LA: The first and last protecting device of the substation is LA used for diverting the lightening surges occur outside the substation.
- Two more LA are kept on both side of pow-x-mer for discharging the surges occur within the substatn
- LA are made of Metal oxides like - Zinc oxide, silicon caboide (SiC) which offer low resistance for the lightening surges and high Resistance for Normal voltages
- LA have impulse Ratio of unity

$$\text{Impulse Ratio} = \frac{\text{Mag. of lightening surge with high freq.}}{\text{Mag} \quad " \quad " \quad " \quad \text{low} \quad "}$$

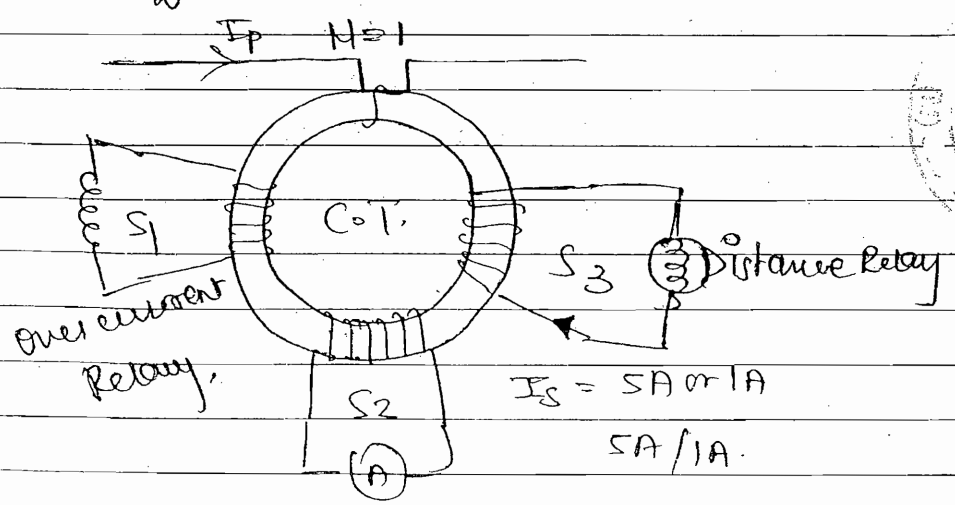
→ P.T → only in Bus Bar
⇒ CVT → each feeder.

Date________

- CVT :- It is working on principle of capacitance using for Reducing the high voltage of 220 kV / 132 kV etc. to a low voltage. The standard low voltage is of 110V. It provides voltage signal for
(i) Voltmeter.
(ii) Wattmeter and energy meter
(iii) Distance and directional Relay.
- Each phase has one CVT. The cost of CVT is less than compare to P.T.

- P.T. ⇒ It is working on principle of X-mer, used to measure high voltage. The standard secondary voltage of the P.T is 110V. It provides voltage signal for voltmeter, energy, wattmeter and Relays like directional and distance. It can used as a Back up for CVT's

- C.T :- It consist of single turn primary and multiple secondary turns with different wedge used for measuring high currents. The standard sec. current is of 1A or 5A. It provide signals for ammeter, wattmeter and energy meters, and relays like overcurrent differential, distance etc.



$I_S = 5A$ or $1A$

5A / 1A.

- Power X-mer. → 220/132 KV capacity of X-mer = 100 ~~MVA~~ Rated MVA

$I_1 = \frac{100 \times 10^6}{\sqrt{3} V_1} = \frac{100 \times 10^6}{\sqrt{3} \times 220 \times 10^3} = 262.43$ $I_2 = \frac{100 \times 10^6}{\sqrt{3} \times 132 \times 10^3} = 437.38$

Then Current value of C.T. = 300/1A in primary (CT_1)
" " = 500/1A in secondary (CT_3)

- Let 132/33KV having capacity of Xmer = 20 MVA.

$I_1 = \frac{20 \times 10^6}{\sqrt{3} \times 132 \times 10^3} = 87.4$. So value of C.T Ratio = 100/1A (CT_4)

- Suppose another power-Xmer of 165 MVA capacity 440/220 KV

$I_2 = \frac{165 \times 10^6}{\sqrt{3} \times 220 \times 10^3} = 445.6$ A

So C.T. ratio will become (CT_2) = 500/1A.

- As C.T. ratio are NOT same, CT_2 = 500/1A, CT_1 = 300/1A, to make equal we add 65 MVA capacity X-mer at Bus Bar of 220KV.

- C.B ⇒ C.B are filled with arc quenching medium like SF_6, oil, vacuum air etc so that this can be open or closed at No load or full load.

✓ This can be operated by relay or manual

- Isolator :- It must be opened or closed on No load only because it does not contain any arc quenching medium.

- Earth Switch :- It is used to discharge residual energy present in the electrical equipment

✓ It has to be open ~~enclosed~~ position under normal condition.

✓ Sequence used Before attending the maintenance of the equipment :-

(1) Open C.B under No load or full load

(2) Open Isolator under No load.

(3) Close Earth Switch

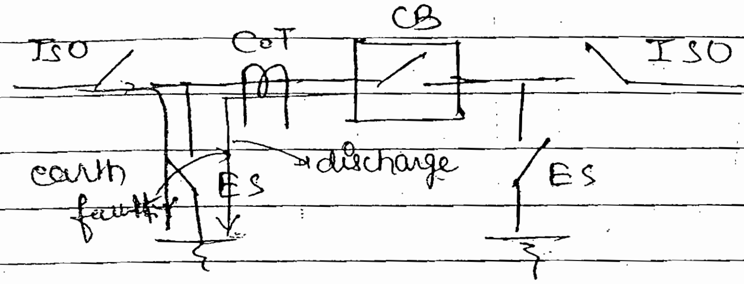
Date________

- Sequence used before charging of the equipement:

(1) open Earth switch

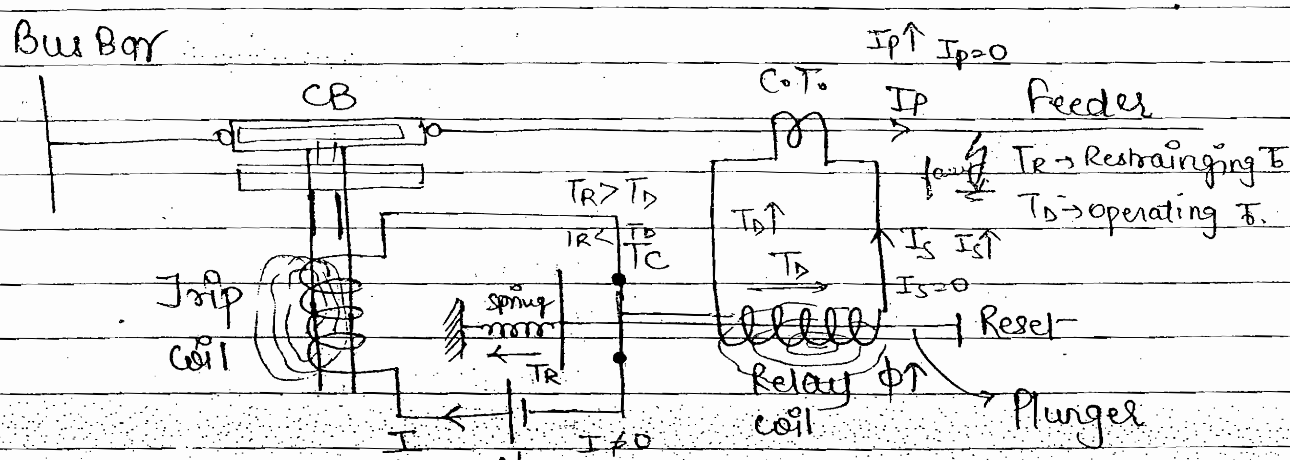
(2) Close Isolator

(3) Close CB.



After maintainance, if ES is not open and ISO → closed, intentionally created earth fault.

- Relation B/w C.B and Relays.-



T_C = Trip contacts

(1) Block (Healthy Condition)

TC → open (Normal open – N.O)

CB → close.

(2) Trip (Faulty Condition)

TC → close (Normal close – N.C)

CB → open

- After fault is removed, Mannually Reset is pressed to open the TC

Date

- How to identify which Relay get operate after the fault. In Normal condition, CB are covered, when a particular CB is get operated, it will pull down and can see the identificatn by which we get know which CoB get operate

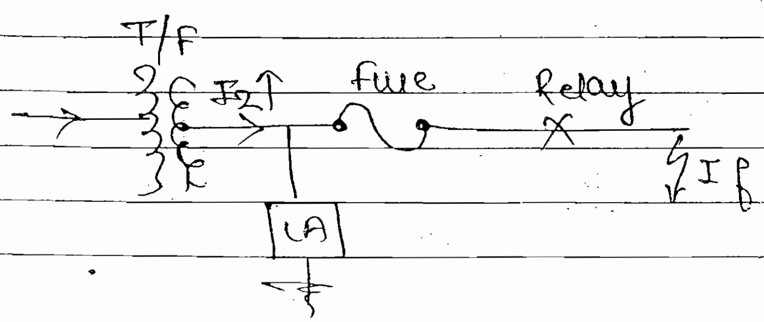
- Types of Relays:-

Depends on: PRINCIPLE	Equipment Protected	Sensing Element	Time
(1) Electromagnetic	Generator	over current	(IDMT) Inverse Definite Minimum Time
(2) Thermal	X-mer	Over Voltage	
(3) Static.	Tr-line	over flux	Very Inverse
	Bus-Bar	Over speed	
	Motor	Earth fault	Extreme Inverse
		Distance	Instantaneous.
		Directional	
		Differential	

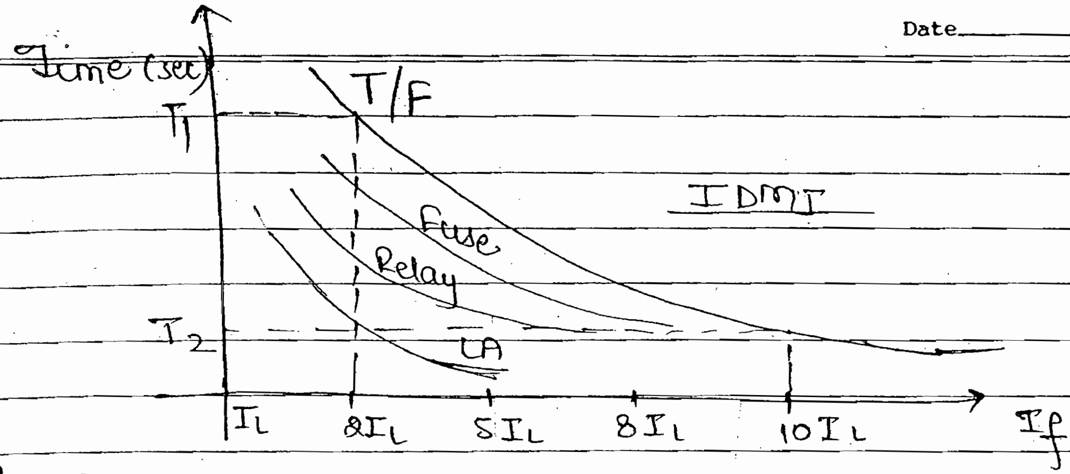
- Total fault Clearing Time =

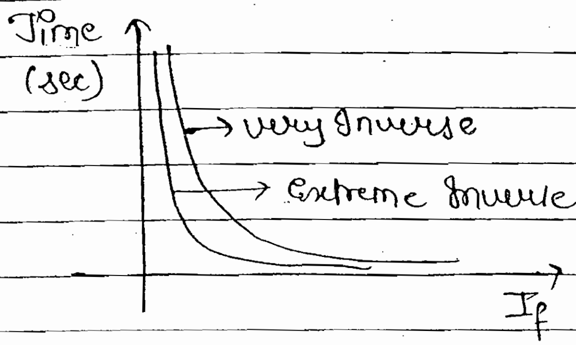
Relay Time + Circuit Breaker Mechanical operating time + Arc quenching time

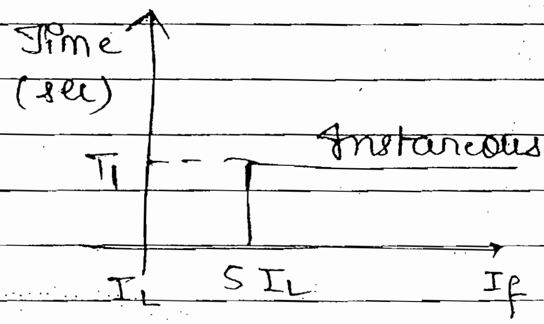
- The minimum fault clearing time required 5 to 6 cycles. (100 - 120 mili seconds)



Date________



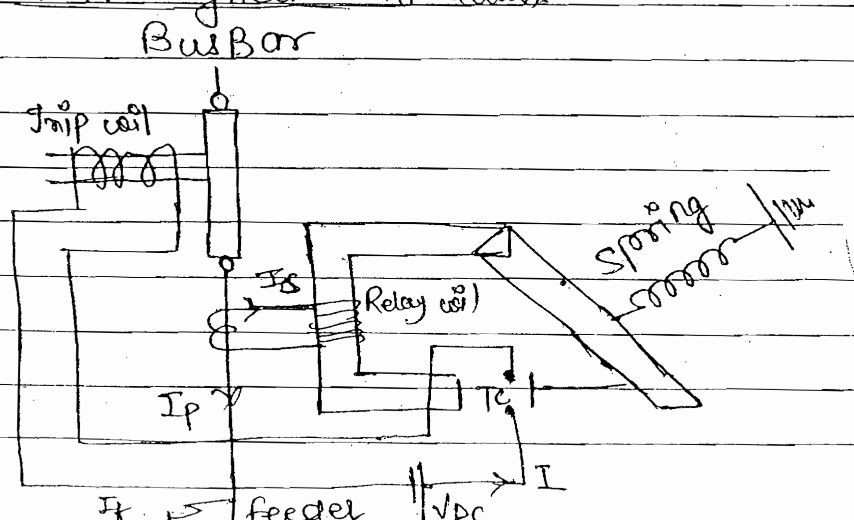




- Electromagnetic Relay:-

  - Attraction — Dependent on frequency.
  - Induction (Independent to freq.)
    - Watthour Meter, Shaded pole → IDMT → over current, Differential
    - Induction Cup → Instantaneous → Directional, Distance

Electromagnetic Attraction



Date

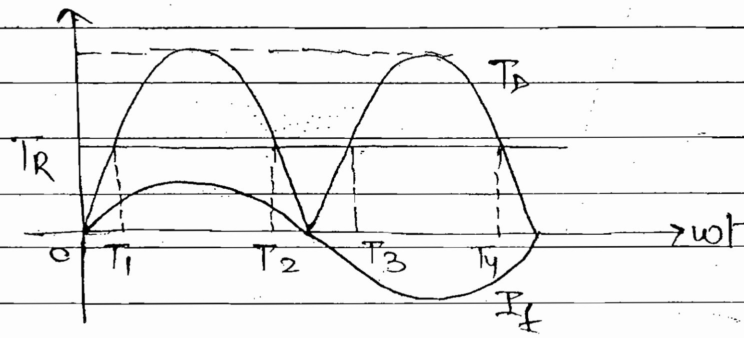
$\phi \propto I_s \propto I_p \propto I_f$. $\quad I_f = I_m \sin\omega t$

$T_D \propto I_f^2$

$\propto I_m^2 \sin^2 \omega t$

$$\boxed{T_D = \frac{K I_m^2}{2}(1-\cos 2\omega t)}$$

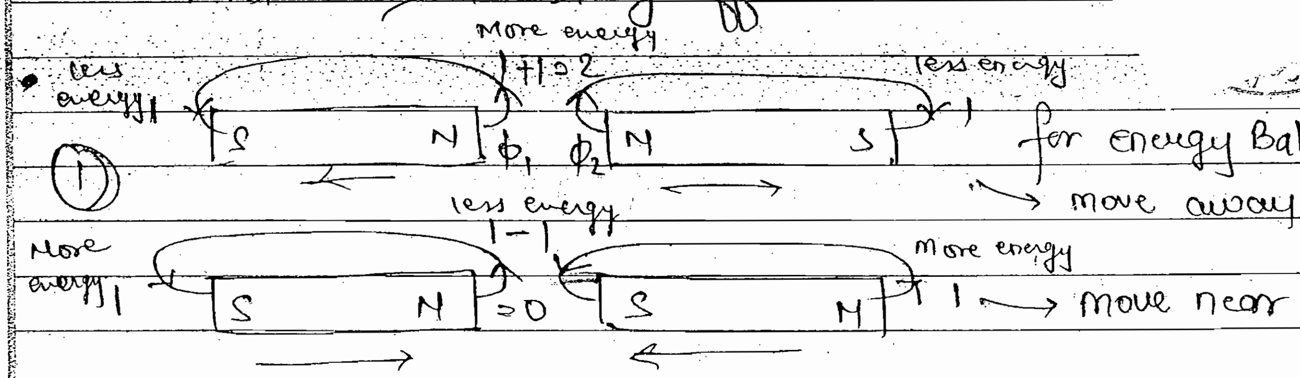
T_D = Operating / Deflecting Torque
T_R = Restraining / control Torque.

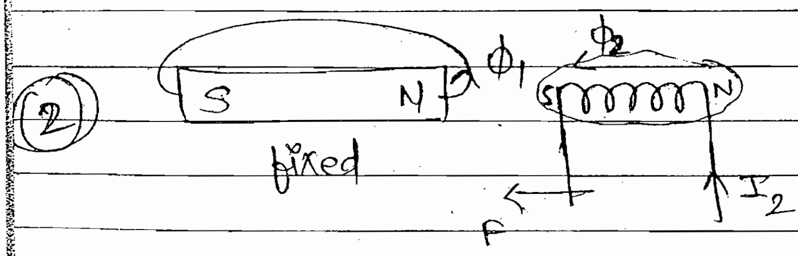


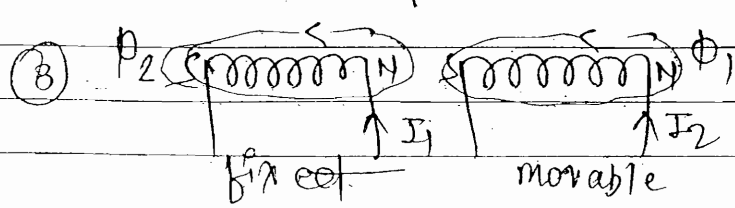
Trip: $T_D > T_R$

Block: $T_D \leq T_R$

- Attraction Type → Not in use Now.
  Problem ⇒ Doubling effect.







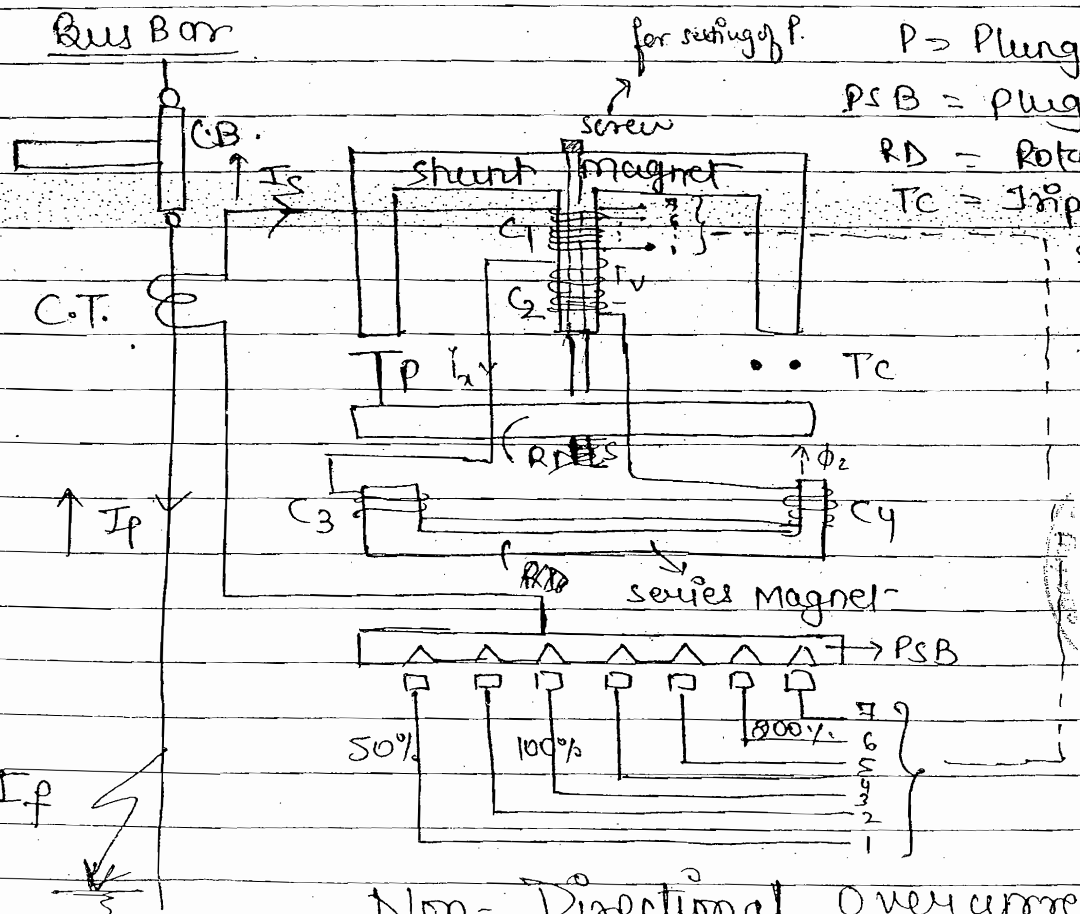
Date________

Doubling effect:- In electromagnetic attraction relay $T_D \propto (1 - \cos\omega t)$ ie in one cycle of fault current, trip contacts and closes twice, so that arcing is produce b/w the trip contacts and the plunger. This will causes overheating and demages the relay trip contacts. This effect is called doubling effect. Due to this effect electromagnetic attraction Relays are practically not used

B/w T_2 to T_3 → contact open → produce arc, after T_4 again open.

- **Electromagnetic Induction Relay**:

Watthour Meter Relay:- Problem of doubling effect can be eliminated in the electromagnetic induction Relays Hence, these are used most practically in the substation.



P ⇒ Plunger

PSB = Plug setting Bridge

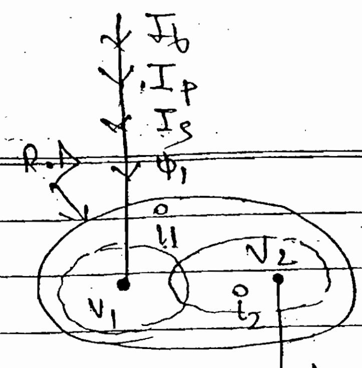
RD = Rotating Disc

TC = Trip contact

S = spring

Non-Directional Overcurrent Relay

Date________

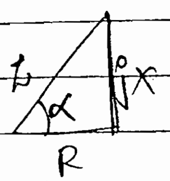


$I_f = I_m \sin\omega t$

$\phi_1 \propto I_s \propto I_p \propto I_f$

$\phi_1 = \phi_{m_1} \sin\omega t$

$V_1 = -\dfrac{d\phi_1}{dt} = \phi_{m_1}\omega \sin(\omega t - 90^\circ)$



$i_1 \propto V_1 \propto \phi_m \sin(\omega t - 90^\circ - \alpha)$

$\phi_2 = \phi_{m_2} \sin(\omega t - \theta)$

disc having same impedance

$V_2 = -\dfrac{d\phi_2}{dt} = \phi_{m_2}\omega \sin(\omega t - \theta - 90^\circ)$

$i_2 \propto V_2 \propto \phi_{m_2} \sin(\omega t - \theta - 90^\circ - \alpha)$

$T_D \propto (\phi_1 i_2 - \phi_2 i_1) \propto \phi_{m_1}\phi_{m_2}[\sin\omega t \cos(\omega t - \theta) - \cos\omega t \sin(\omega t - \theta)]$

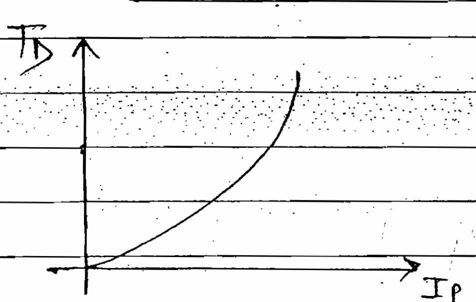
$$\boxed{T_D \propto \phi_{m_1}\phi_{m_2} \sin\theta}$$

$\phi_{m_1} \propto I_{f_1}$, $\phi_{m_2} \propto I_f$

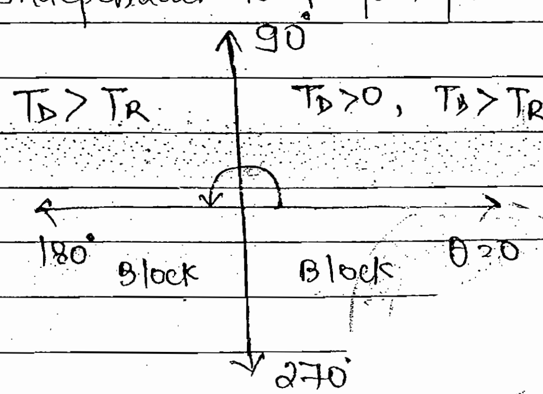
$\{\theta \rightarrow$ Impedance Angle due to C_2, C_3, C_4

$$\boxed{T_D \propto I_f^2 \sin\theta}$$

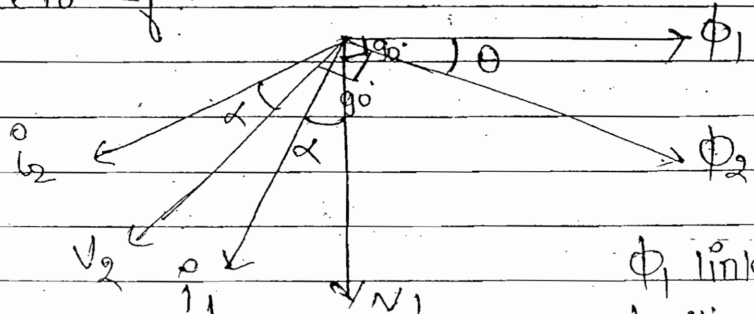
Independent to frequency.



Non-linear graph.



- ϕ_2 due i_x, i_x due to V, V due to ϕ_1, ϕ_1 due to I_s, I_s due to I_p, I_p due to I_f

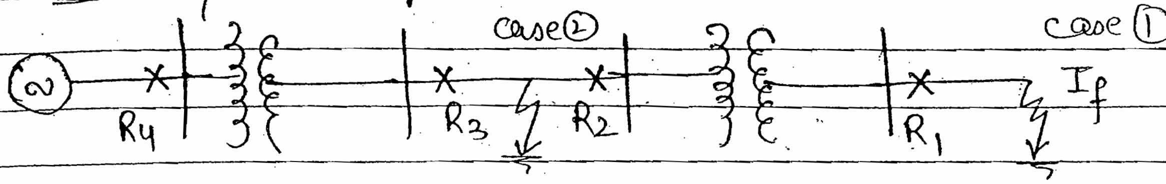


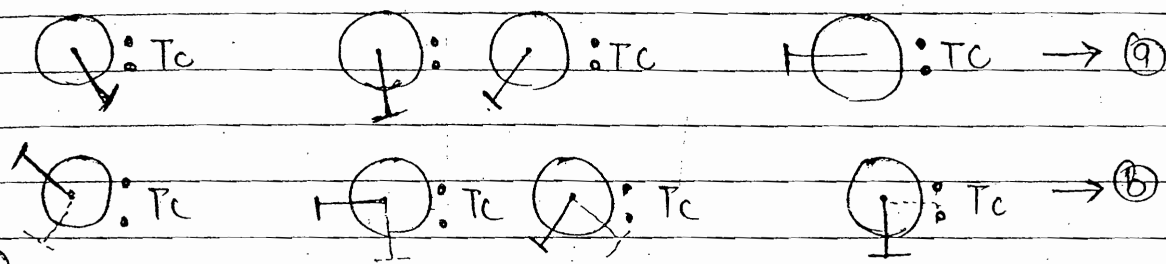
ϕ_1 link with i_2

ϕ_2 link with i_1

Time Grading

Date________





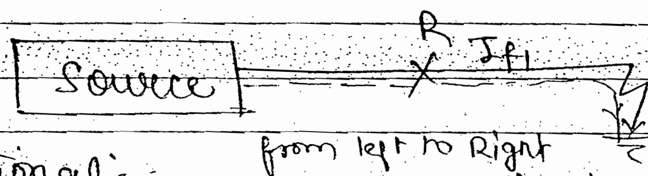
Case (1):-

(I_f value low)

In (a) condition, plunger are arranged in this manner, fault is away from source, R_4 will operate first, then R_3; R_2; R_1. Not a good sys. So arrangement is done in (b) condition manner. At fault, sequence of operating Relay → R_1, R_2, R_3, R_4. When fault occur, all relay will simultaneously operate, if R_1 get fail, than seq. of operating of Relay → R_2, R_3, R_4.

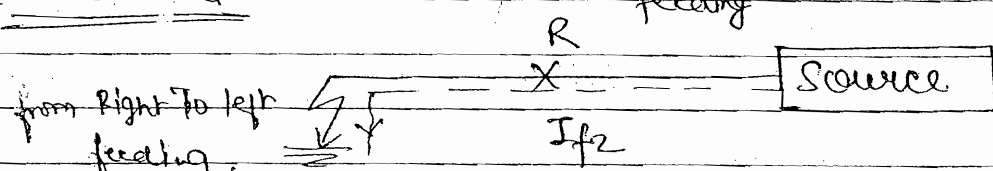
Case (2) :- If fault occur b/w R_3 & R_2, near the source, as $T_D \propto I_m^2$ fault current value is more, so R_3 will operate quickly is less time.

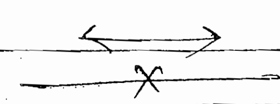
≠ fault near the soure I_f value more, away the source I_f value is low

✓ 

$$I_{f2} = -I_{f1} = I_{f1} \angle 180°$$

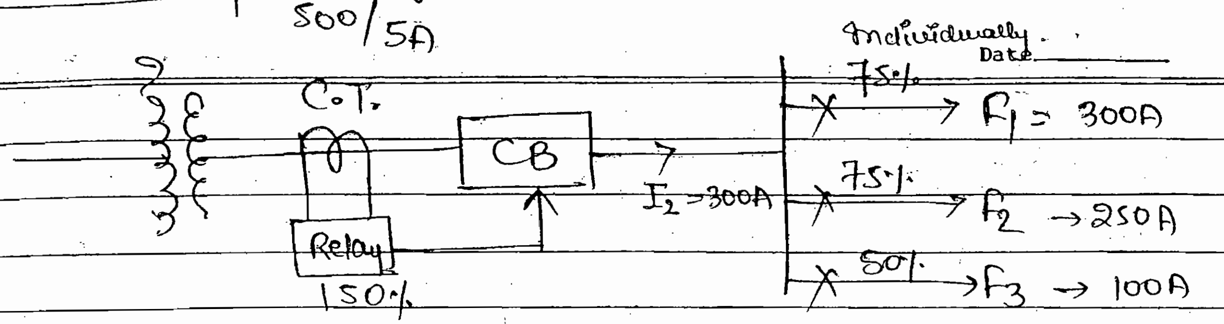
Directional:-



- Symbol Non directional Relay 

⇒ CB will operate in either direction of fault current.

Current Grading :-



PSB

250	375	500A	625	750	825	1000 A
1	2	3	4	5	6	7
50%	75%	100%	125%	150%	175%	200%

for 300A $\rightarrow$ 100% = $\frac{500}{5A}$

✓ Now added $F_2 \Rightarrow 300 + 250 = 550$ It will set to 4 Nob. = 625A (125%) $\Rightarrow$ 125% × 5 = 6.25

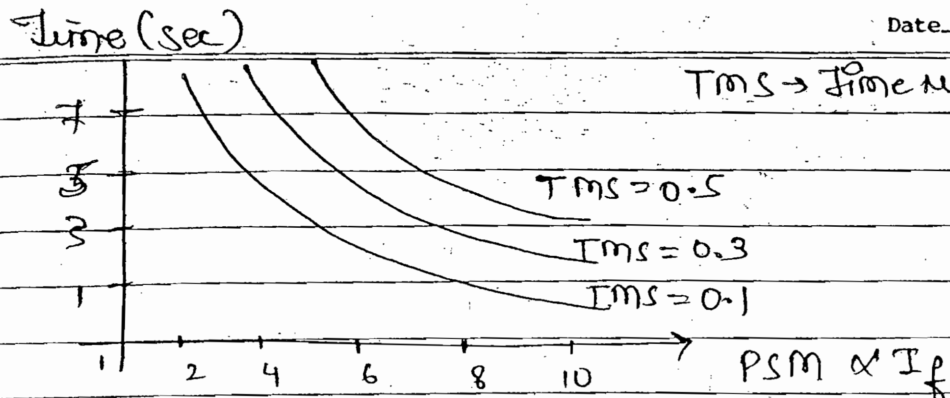
✓ Now again added a feeder F_3 of demand 100A.

Total = 300+250+100 = 650 A , set to 150%.

150% × 5A = 7.5.

Now it will get connected to nob 5.

Date________



TMS → Time multiplier setting.

IDMT (character of o/c Relay)

(1) Pick up current of Relay:-

I_{PK} = % setting of Relay × C.T Sec current

(2) Plug setting Multiplier (PSM)

$$PSM = \frac{I_f}{I_{PK} \times C.T.\ Ratio}$$

(3) Time of operation of any Relay:-

T_O = TMS × (Time Calculated from IDMT graph / Table corresponding to PSM)

(4) Time of operation of Back up Relay:-

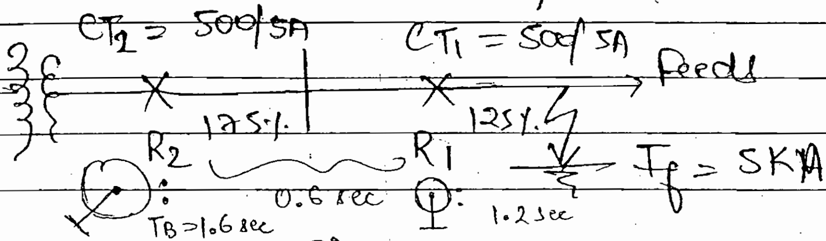
$T_B = (T_p + T_d)$

T_p = Time of operation of primary Relay

T_d = Time delay b/w Primary and Back up Relay.

Q Part of pow sys N/w is shown in the fig. The primary relay R_1 has TMS of 0.3. The time delay b/w primary and Back up relay R_1 & R_2 is 0.6 sec. Both Relays having CT Ratio of 500/5A. The IDMT character is given in the Table for the R_1 and R_2 Calculate

(i) Time of operation of Primary Relay
(ii) PSMS of Back up Relay.



PSM	10	8	5.7	4.5
Time (sec)	2	4	~~6~~ 5	8

Solution :- for Relay 1 :- $I_{PK} = \frac{125}{100} \times 5 = 6.25A$

$PSM = \frac{I_f}{I_{PK} \times CT\ Ratio} = \frac{5000}{6.25 \times \frac{500}{5}} = 8$

$T_0 = 0.3 \times 4 = 1.2$ sec.

for Relay 2 :- $I_{PK} = \frac{175}{100} \times 5 = 8.75A$

$PSM = \frac{5000}{8.75 \times \frac{500}{5}} = 5.7$

$T_0 = T_B = T_P + T_d = 1.2 + 0.6 = 1.8$ sec

Same for primary or Back up Relay.

$TMS \times 5 = 1.8$ sec.

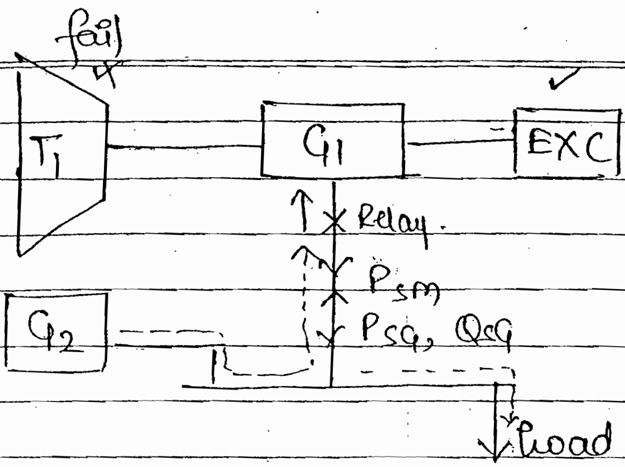
$TMS = 0.366$

31/10/14

- Directional OR Reverse Power OR Wattmetric Relay

When the prime mover get fail or stop delivering the i/p to gen. G_1, G_1 will draw the huge amount of active power from G_2 to drive the Turbine bcoz now it will work as motor bcoz it has flux. It will damage the G_1 wdg, so we use Reversal power Relay to watch the flow of power direction.

Date________



Relay → Block when power flow from G_1 to load. (Syn. Gen.)

Relay → operate when power flow from G_2 to G_1 (Syn. Motor)

- Non directional overcurrent Relay :-

  $T_D \propto \phi_{m1}\, \phi_{m2} \sin\theta.$

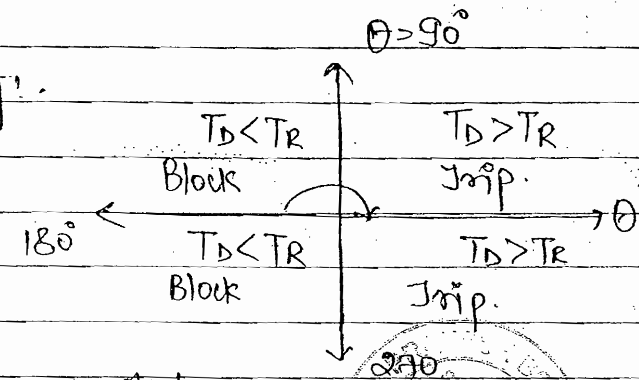
Directional / Reverse power Relay :

$\phi_{m1} \propto V \quad , \phi_{m2} \propto I$

$\sin\theta \longrightarrow \cos\theta.$

Ideal → $\boxed{T_D \propto V I \cos\theta}$

$\boxed{T_D \propto P}$



- Relay must operate Before it will start work as Motor so speed must be high.

- To get Maximum Torque θ must equal to 0°, for this V and I are in same phase, for this we use Resistive coil, (such RC arrangement).

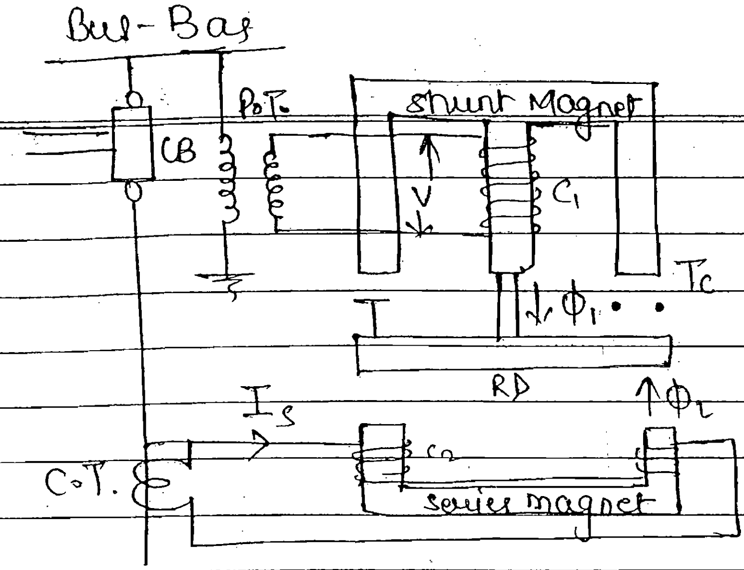
- practically :- $\boxed{T_D \propto V I \cos(\theta - \tau)}$

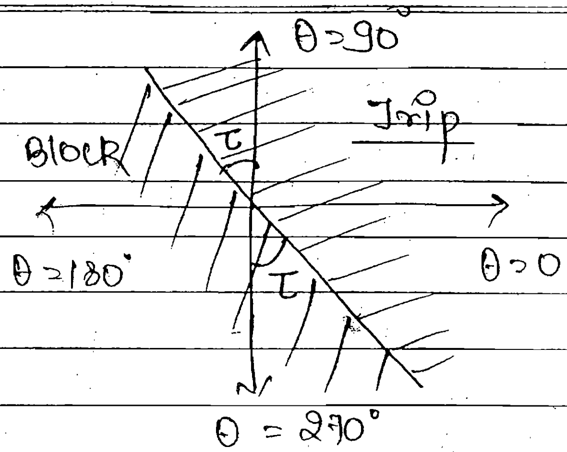
  τ = Max. Torque adjustment angle

  If $\tau = \theta \Rightarrow T_D \Rightarrow T_{Dmax} = VI$

✓ Never use $\tau = 90°$, otherwise $T_D = VI\cos(\theta - 90) = VI\sin\theta$ which is non directional condition.

Date________





$$\boxed{T_d = VI\cos(\theta - \tau)}$$

- τ value should lie b/w 0 to 90°

- We make C_1 very highly inductive. So we get now $\theta - 90$ which make $\sin\theta \Rightarrow$ ~~cos~~ $\sin(\theta - 90) = \cos\theta$)
  To make VI are in phase θ must $= 0$, (Resistive nature) for this ϕ_1 and ϕ_2 have phase displacement $= 0$, To make phase displacement we use other value τ.
  T_D max when $\theta = \tau$.

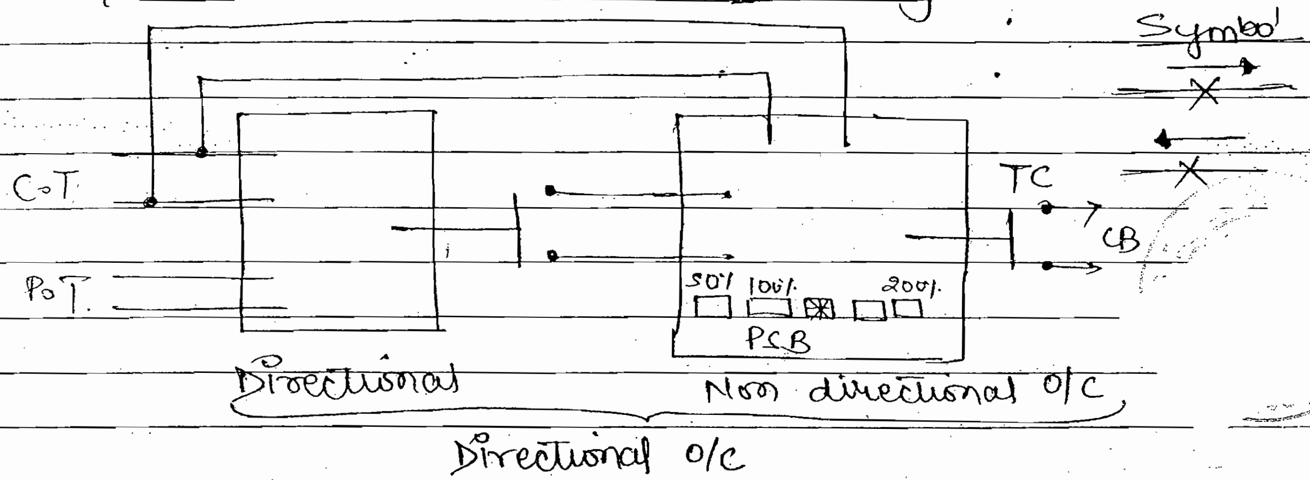
- Directional or reversal power relay is used to produce trip signal if the direction of power is reversed.
- operating T is proportional to the power. So that CT and PT o/p. are applied to the relay
- Max T is to required so that it is normally make up of induction cup structure which is working on the principle of Induction Motor.
- In watt hour Meter Relay an extra T adjustment angle is provide to get max T.

- Application (1) The Reverse power Relay used to protect generator from the failure of prime Mover (Turbine)
(2) In Normal condition if prime mover and excitation is present the syn. generator delivers more

Date

active and reactive power to the load. If the excitatn is present and prime mover is failed then the gen. absorbes active power from the other parallel gen. and start working as syn. Motor. The Turbine is working as Mechanical load for this Motor. Bcoz of huge Mass of the Turbine the motor draws heavy current which damages the wdg. To protect the gen from this abnormality, Reverse power Relay is used

• Directional Over Current Relay :-

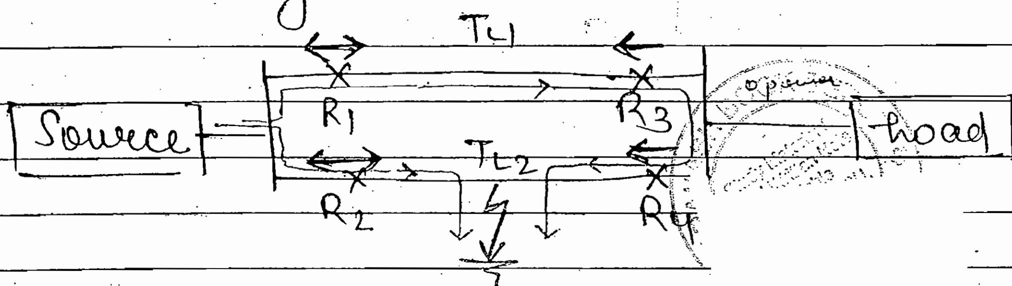


• Directional over current Relay containing Both reverse power element and non-directional over current Relay. In case of power direction is reversed the direction element operates and closes the trip contacts which initiates non-directional over current relay. This Relay checks wheather the reverse current is exceeding the PSV and produce trip signal if it is exceeding which open the CB.

• Application of Non-directional O/C & Directional O/C Relays
(1) Protection of parallel feeders :- In case of ‖ feeders Source & Relays are Non-directional O/C Relay and load and Relays

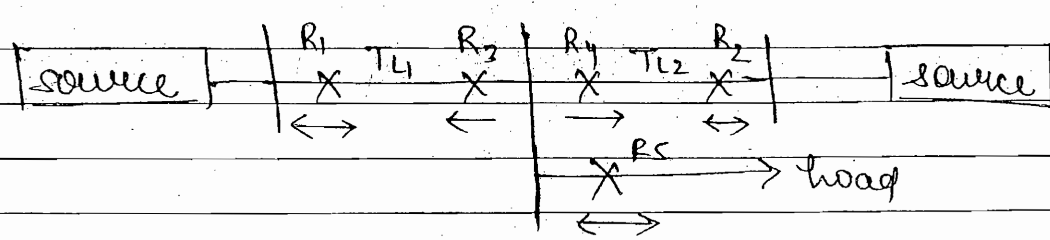
Date

are directional O/C Relays are used.
Under Normal condition power flows from source to load through the parallel feeder. If any fault is occur in one of x-line corresponding Relays operate isolating the faulty line. so that 50% of power can be transferred from the heathy line.



- Relay operate R_2 and R_4.
- If we use R_3 and R_4 also Non-directⁿ then what happen.
  If fault occur at T_{L2}, R_3 Relay get operate → Not Req.
  If we provide time delay $R_4 \Rightarrow 0.1$, $R_3 = 0.4$, Then R_4 will operate, But By this time delay if fault occur at T_{L1} then T_4 will operate which is not required. So we use directional Relay

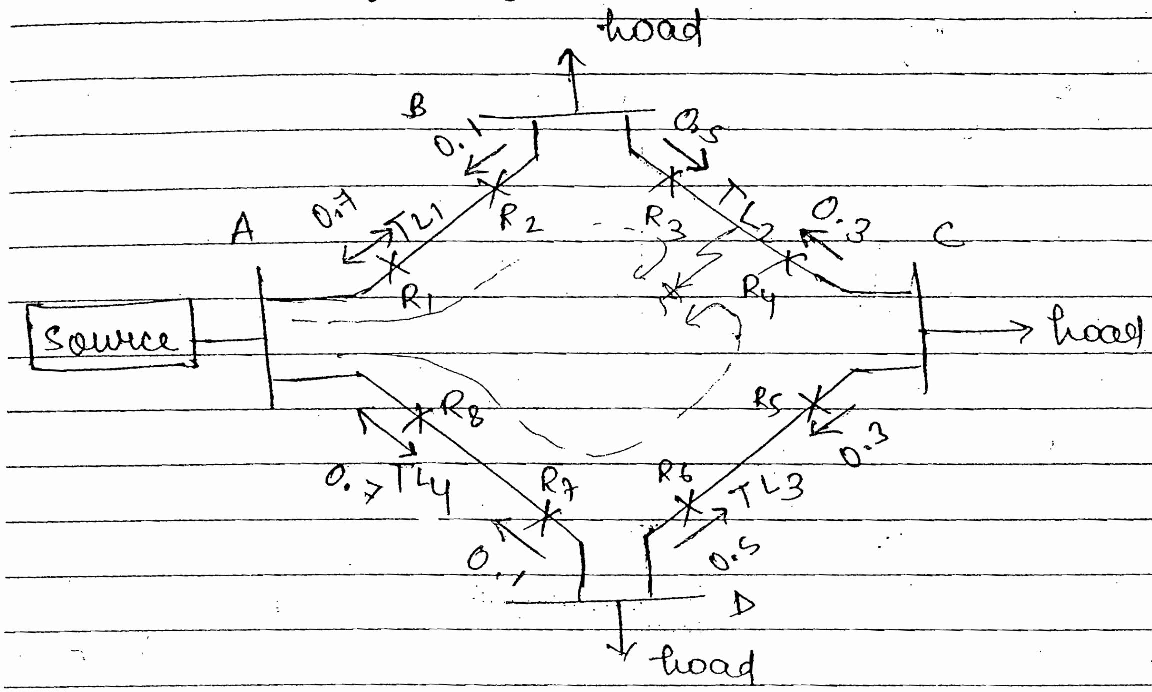
ex:-



Here R_1 and R_2 are non directⁿ. o/c Relay and R_3 and R_4 are direction O/C Relay. But in case of R_5, Bus Bar is source for load so R_5 is non-directⁿ O/C Relay.

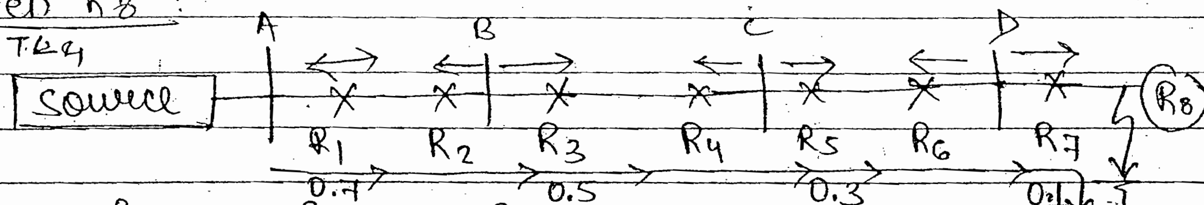
Date

Protection of Ring Distribution System:-



• Open R8 :

fault TL4

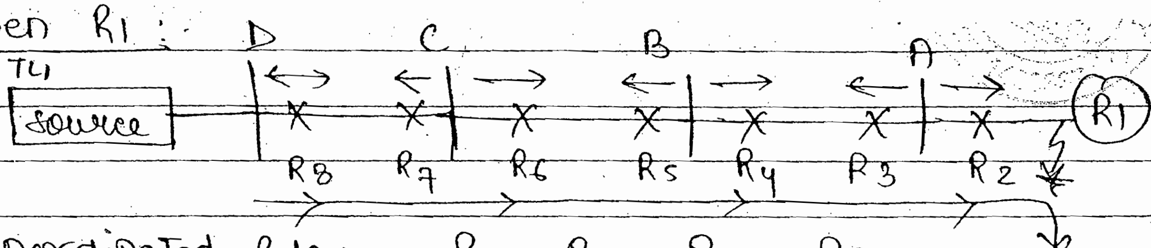


Coordinated Relays = R7, R5, R3, R1

provide time delays 0.1, 0.3, 0.5, 0.7

• Open R1 :

fault TL1



Coordinated Relays: R2, R4, R6, R8

provide time Delay:- 0.1, 0.3, 0.5, 0.7

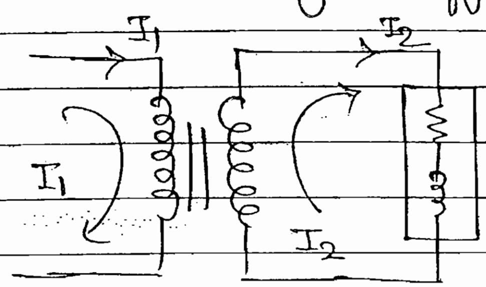
• If fault at TL2 → R4, R6, R8 and R3, R1 will operate

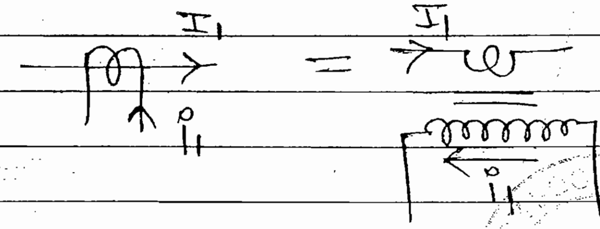
Time delay → 0.3, 0.5, 0.7   0.5, 0.7

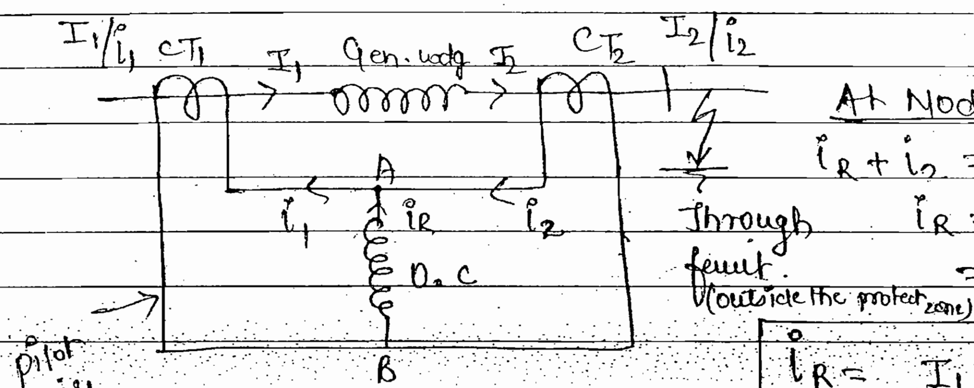
Date_______

- For protection of Ring System Non-directional relays are kept on source side, and directional Relays are kept on load side. Time grading is provided b/w the relays for complete protection of Ring System

- <u>Ordinary Differential Relay</u>:-







At Node A

$i_R + i_2 = i_1$

$i_R = \bar{i}_1 - \bar{i}_2$

$= |i_1| \angle\theta_1 - |i_2| \angle\theta_2$

$$\boxed{i_R = \frac{I_1}{CT_1 \text{ Ratio}} - \frac{I_2}{CT_2 \text{ Ratio}}}$$

OC = operating coil of Diff. Relay.

i_R = Relay current.

If CT_1 Ratio = CT_2 Ratio = C.T Ratio

$$\boxed{i_R = \frac{I_1 - I_2}{CT \text{ Ratio}}}$$

- If ① <u>Trip</u>

$i_R \neq 0$ (Ideal)

$i_R > I_0$ (Practical)

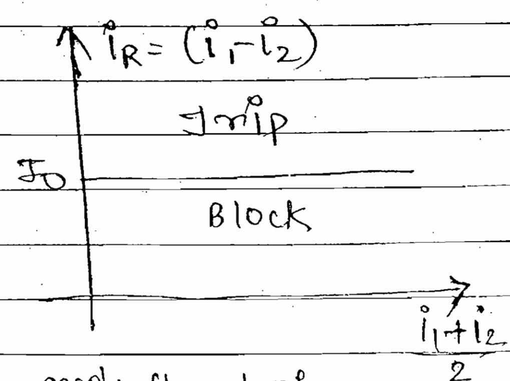
② <u>Block</u>:-

$i_R = 0$ (Ideal)

$i_R \leq I_0$ (Practical)

I_0 = Min. pick up Current of Relay

= spring Restraining Torque



graph:- Charact. of ordinary Diff. Relay.

- Power X-Mer have diff. CT Ratio B'coz of voltage step up and step-down.
- Motor and Gen. have same voltage so same CT ratio.

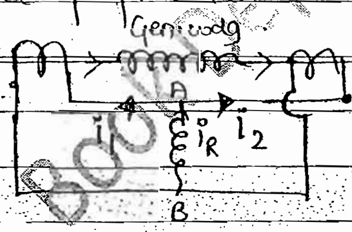
Date

- Differential Relay is a unit protectⁿ Relay, used for protection of generator, x-mer, motor wdgs and Bus Bar protection. Also used to protect x-line. This is called pilot relaying.
- If the phasor difference of two electrical sys. i.e. I & V exceeding the setting value of relay produces trip signal. This principle is used in the diff. relay.
- Through Fault:- If the fault is occurring outside the unit protection zone is called through fault.
- If the any relay is producing trip signal without any operation is called mal operatⁿ of Relay.

Imp concept

- Disadvantages of Ordinary Diff. Relay:-

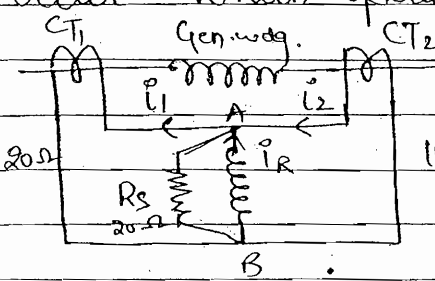
(1) If one of the sides of pilot wire is wrongly connected, Relay produces trip signal without any fault.



$i_R = (i_1 + i_2) \neq 0$

$\rightarrow$ Trip.

(2) Difference in the length or resistance of pilot wire produces potential difference across the relay coil so that $i_R \neq 0$ occurs. Which operate the relay without any fault.



To overcome this difficulty a Stabilising Resistor is connected in parallel to the Relay coil.

R_S = Stabilizing Resistor.

Date____

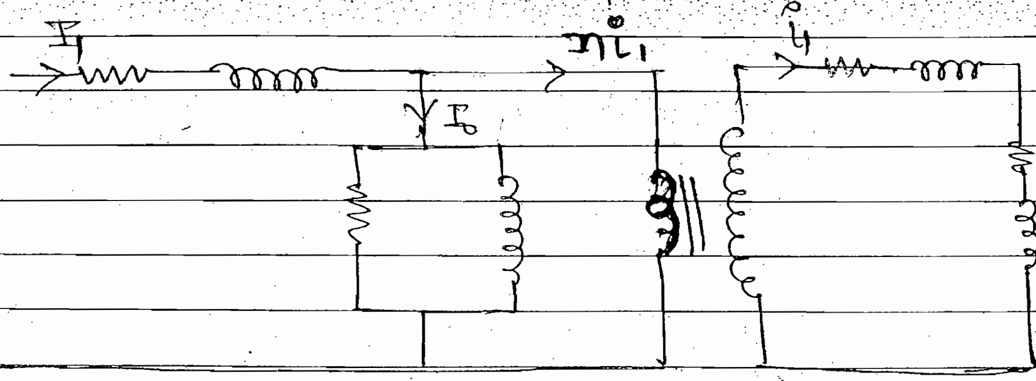
- Use ∥ resistor, Not series Becoz we can't cut the cable and place the series Resistor.

(3) If the CT of core of CT is saturated produced trip signal without any fault. But for the outside fault are through fault produce trip.

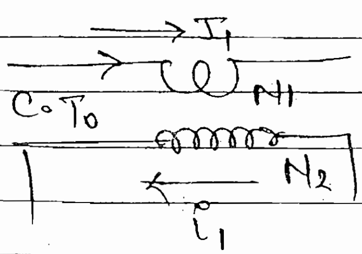
I_p	CT_1 100/1	CT_2 100/1	$i_R = i_1 - i_2$	
100	100/1	100/1	1 − 1 = 0	Block
200	200/2	200/2	2 − 2 = 0	
400	400/4	400/2	4 − 2 = 2	Trip.
600	600/6	600/2	6 − 2 = 4	

→ saturat?

(4) If CT_1 and CT_2 has different ratio and phase angle error produces trip signal without any fault. Becoz of No-load component of current phase angle and ratio error are produce.



$N_1 : N_2$



$n = \frac{N_2}{N_1}$ = Nominal Ratio

$I_1 = I_0 + n i_1$

$\frac{I_1}{i_1}$ = Actual Ratio

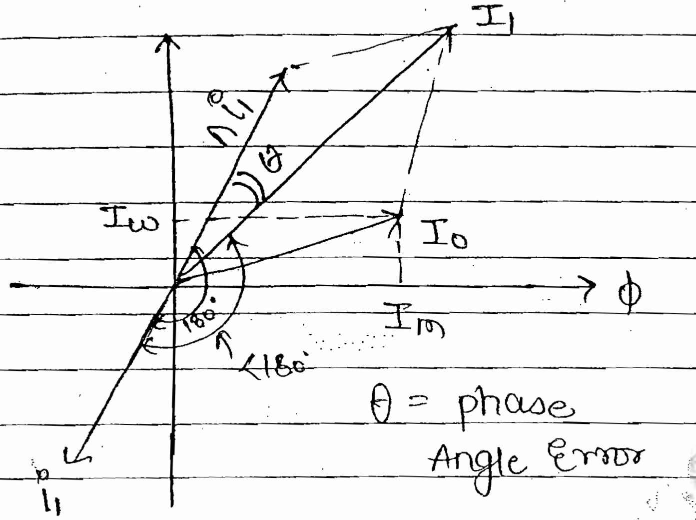
Date

$$\text{Actual Ratio} = \frac{I_1}{i_1} = n + \frac{I_0}{i_1} \leftarrow \text{Ratio Error.}$$

Suppose Ideal case.

$N_1 = 1, N_2 = 100$ $\qquad$ $I_1 = 500$; $i_1 = 5A$

$n = \frac{N_2}{N_1} = \frac{100}{1} = 100$ $\qquad$ $\frac{I_1}{i_1} = \frac{500}{5} = 100$

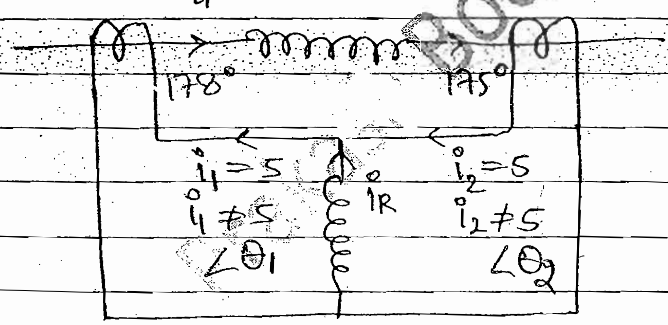


θ = phase Angle Error

When i_1 transfer to primary it become ni_1. Diff b/w ni_1 and i_1 = 180° (ideal case) But due to error it is <180°, $I_1 = ni_1 + I_0$

Error called θ

$CT_1 = \frac{500}{5} = \frac{I_1}{i_1} = 100$ (N.R) $= 101$ A.R $\qquad$ $CT_2 = \frac{I_2}{i_2} = \frac{500}{5} = 100$ (N.R) $= 99$ A.R.



But when the primary current get change $CT_1 = 101$ and $CT_2 = 99$ $i_1 \neq 5$, $i_2 \neq 5$, trip signal b/c of Ratio Error.

Suppose the angle is 178° in CT_1 side and 175° in CT_2 This causes the phase error.

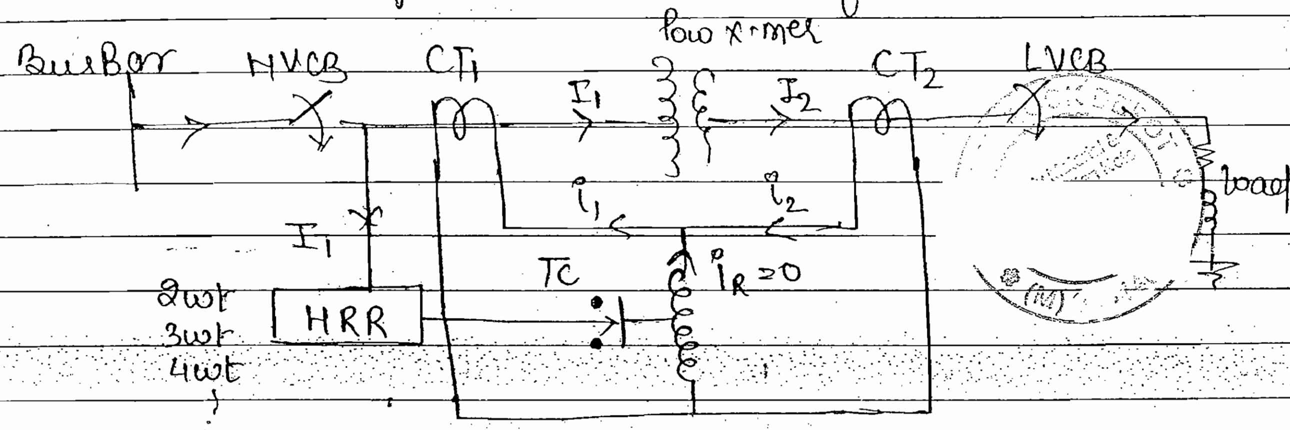
(5)

pr 1) 2) } pilot wire 3) 4) } Related to CT 5) 6) } pow x-mer

Date

(6) During initial charging time of the power-x-mer magnetic in rush current having high magnitude flows, will will causes unequal current in the primary and secondary CT's so that relay operates without any fault. To over come this difficulty harmonic restraining relay is used.

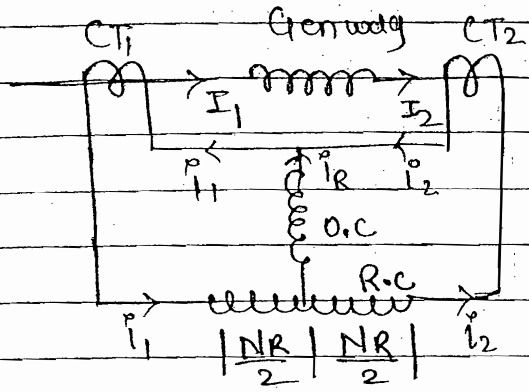
The magnetic in rush current consisting of 2, 3, 4 harmonic signals. These signals are filter by the harmonic restraining relay which will produces additional restraining torque so that relay will not operate during charging time of power x-mer.



- During charging HVCB → closed, current I_1 will flow through CT_1 and HRR, HRR produces additional restraining torque, not to operate the relay with HVCB get close. (2ωt, 3ωt, 4ωt) -- $I_1 \neq 0$, $i_1 \neq 0$ But $I_2 = 0$, $i_2 = 0$ $i_R \neq 0$, But restraining torque is not allow the ~~relo~~ CB to get open, after 10-5 minutes (charging) LVCB also close, so that $I_1 = I_2$, $i_1 = i_2$ and $i_R = 0$

Date________

% Differential / pilot wire / Merz price / Biased Scheme Relay



operating mmf $= N_o i_R$

Restraining mmf $= \frac{N_R}{2} i_1 + \frac{N_R}{2} i_2$

$= \frac{N_R}{2}(i_1+i_2)$

$N_o i_R = N_R\left(\frac{i_1+i_2}{2}\right)$

O.C = operating coil

R.C = Restraining coil.

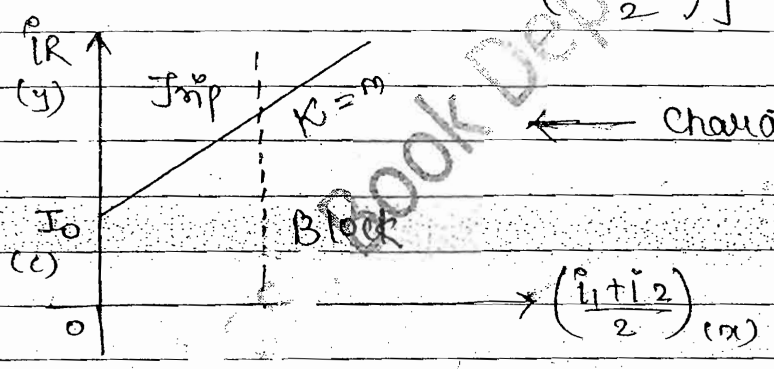
$\frac{i_R}{\left(\frac{i_1+i_2}{2}\right)} = \frac{N_R}{N_o} = K = \%$ setting

(1) Trip $\quad i_R > \left[I_o + K\left(\frac{i_1+i_2}{2}\right)\right]$; I_o = spring Torque

$y \qquad c \qquad m\,x$

; $K\left(\frac{i_1+i_2}{2}\right)$ = Restraining coil Torque

(2) Block : $i_R \le \left[I_o + K\left(\frac{i_1+i_2}{2}\right)\right]$



← Characteristic graph of % Diff. Relay.

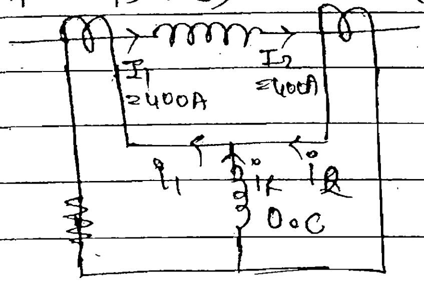
In the % Diff. Relay, During abnormal conditionals when current in R.C flow, spring torque + Restraining T also ↑ with ↑ current value so relay will not operate.

But during fault condition, fault current value is very high i_R will operate the relay as operating T is higher than (spring T + restraining T).

Date________

Solution (1) (b) Ordinary Diff $i_1 = \frac{I_1}{CT_1 \text{ Ratio}} = \frac{400}{79} = 5.06A$

$CT_1 = 400/5\ (79)$ $\quad CT_2 = 400/5\ (81)$ $\quad i_2 = \frac{I_2}{CT_2 \text{ Ratio}} = \frac{400}{81} = 4.94A$



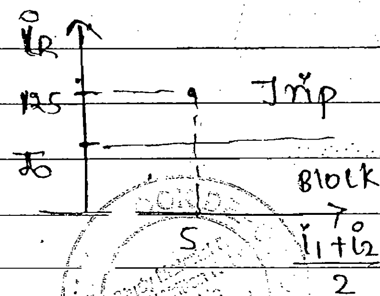
$\frac{i_1+i_2}{2} = \frac{5.06+4.94}{2} = 5$

$i_R = i_1 - i_2 = 5.06 - 4.94 = 0.125A$

$= 125\ mA$

$I_0 = 100\ mA$ (given)

$I_R = 125 \quad i_R > I_0$ (Trip)



(c) % Diff :-

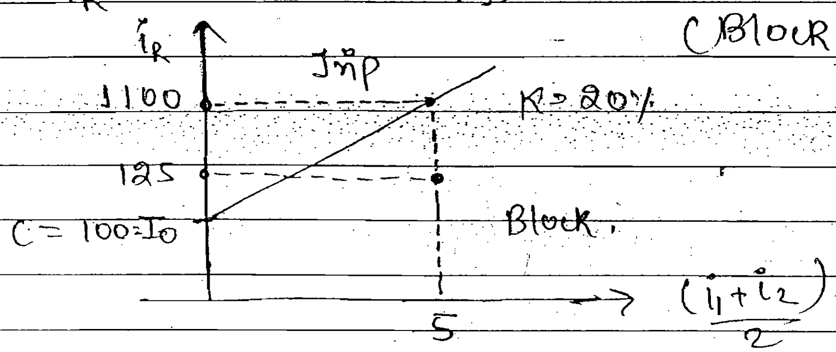
$K = 20\% = 0.2$

$I_0 + K\left(\frac{i_1+i_2}{2}\right) = 100 \times 10^{-3} + 0.2 \times 5 = 1.1A$

$= 1100\ mA$

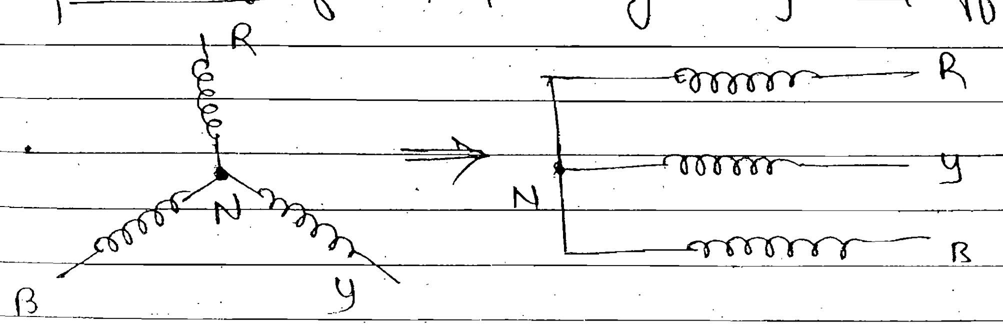
$i_R = 125\ mA < 1100\ mA$

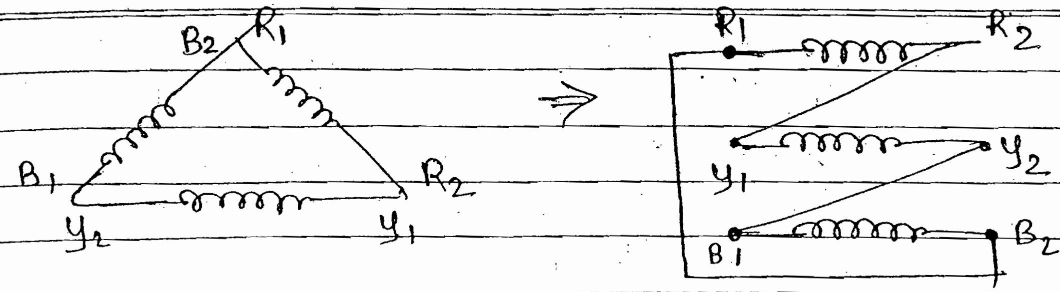
(Block)

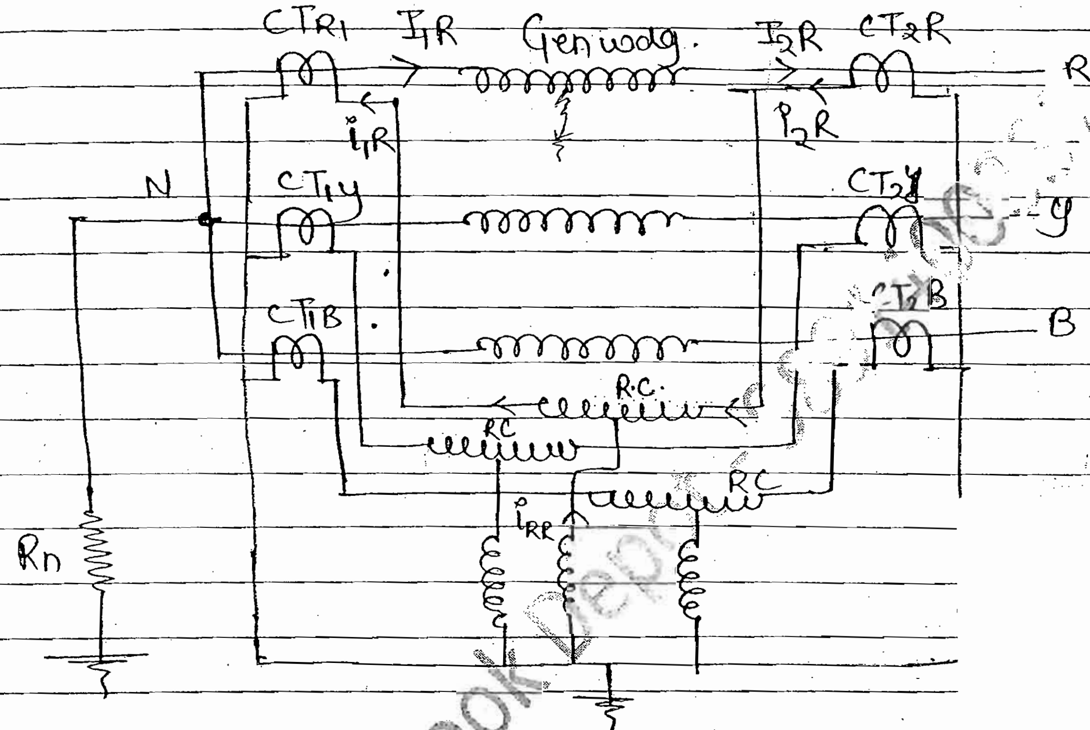


Relay current = 125 corresponding to 5 value → Block region.

• Protection of 3-ϕ Gen wdg using % Diff. Relay :-



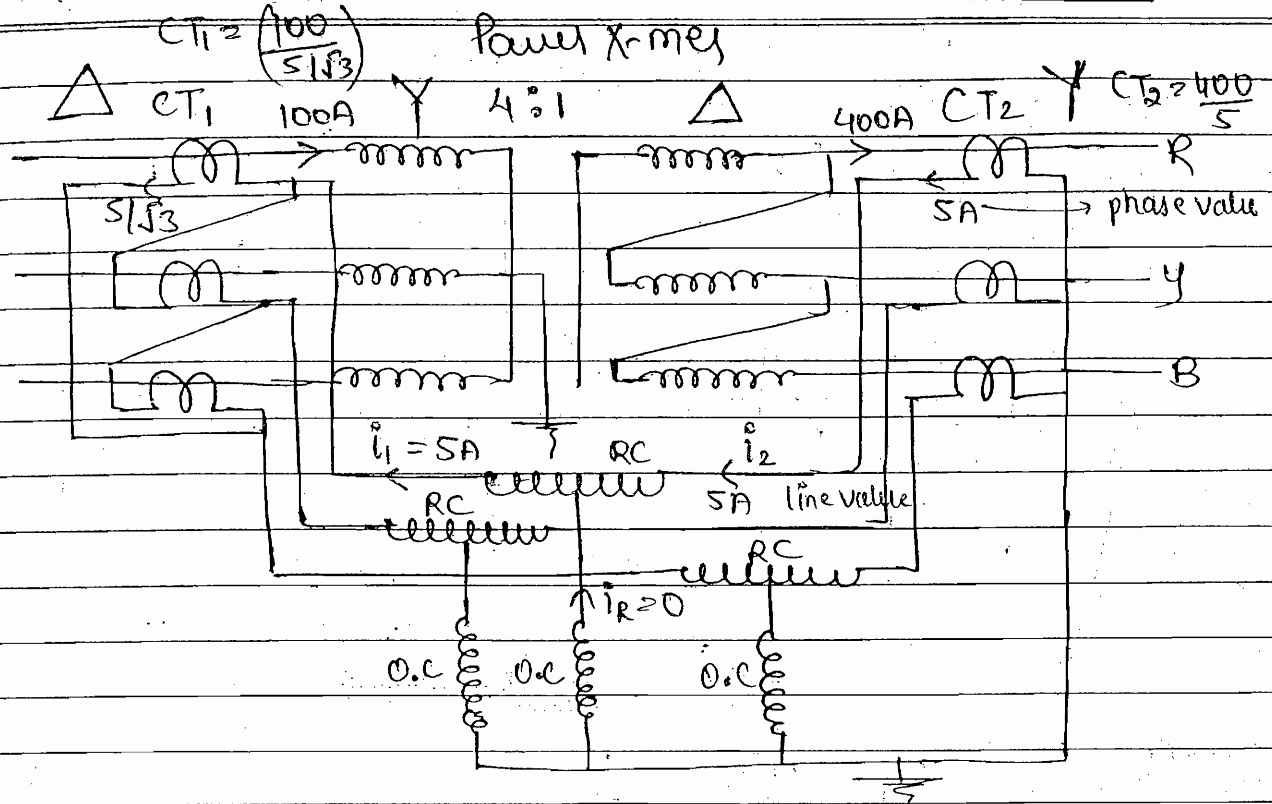


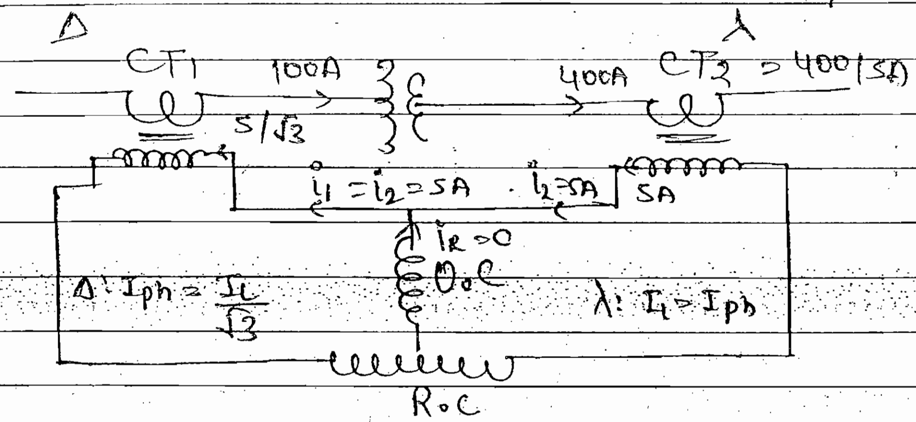


• When fault occur in any phase, for Balance condition all phase CB will get open.

✓ Protection of 3-Φ X-mer using % Diff Relay :-

POWER X-MER		CURRENT X-MER	
Primary	Secondary	CT_1	CT_2
Δ	Y	Y	Δ
Y	Δ	Δ	Y
Y	Y	Δ	Δ
Δ	Δ	Y	Y





Q A 3-φ 132/33 KV pow X-mer is protected By Merz price protection. The CT ratio on LV side of X-mer is 400/5A. Calculate the CT ratio required on the HV side of pow-xmer If the x-mer is connected

(1) Y Δ (2) Δ Y $\left(\frac{100}{5\sqrt{3}}\right):1$

Solution $132/33 = 4:1$ $CT_2 = \frac{400}{5}$ primar / secon

V_2/V_1.

$$\frac{I_2}{I_1} = \frac{V_1}{V_2} \qquad I_1 = \frac{400}{\times 4} = 100$$

Date

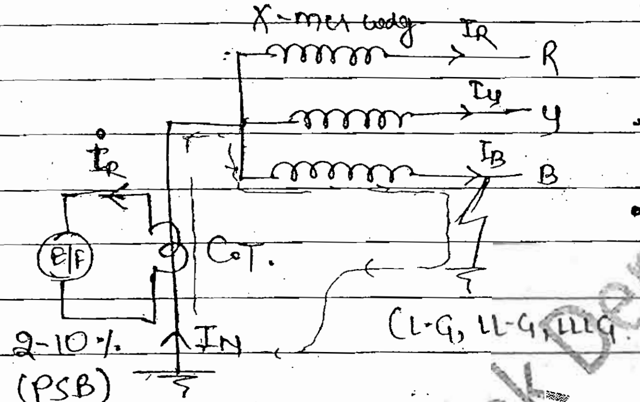
- Inside the CT, per phase values of current
- In RC line value of current used.

✓ secondary current at $CT_2 = 5\,A$. $\lambda \rightarrow I_{ph} = I_L = 5A$
we required $i_R = 0$ so i_1 also $= 5A$.

✓ $CT_1 \rightarrow \Delta$ connected so $i_1 R = \frac{5}{\sqrt{3}}$ $\quad I_{ph} = \frac{I_L}{\sqrt{3}}$: Δ.

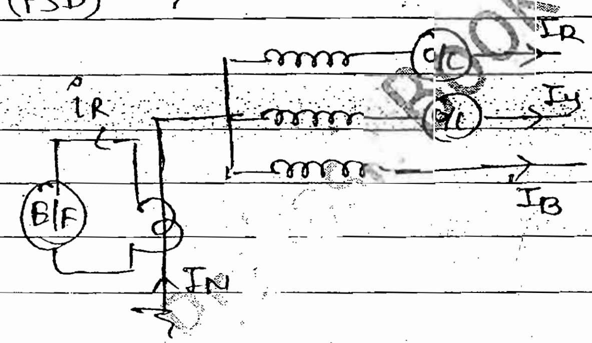
3/11/2014.

- Earth Fault Relay:-



- At No fault $I_N = 0$, $i_R = 0$
- over-current relay.
- At fault $I_N \neq$, $i_R \neq 0 \rightarrow$ trip
- only operate at Earth fault. for phase fault. O/C relay required.

S.C Fault



LG, LLG, LLLG $\} \rightarrow$ Earth fault Relay.

LL, LLL $\} \rightarrow$ 2 over/current

LL < RY, YB, BR

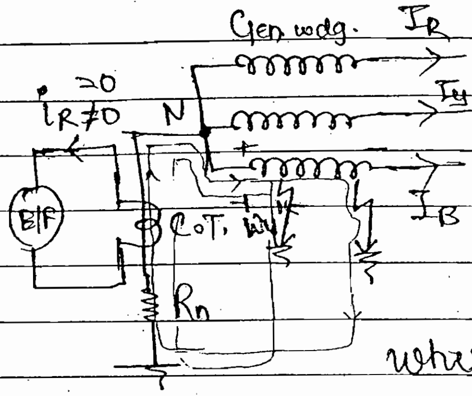
LLL → RYB

Total Relay : 3 Relays

- Earth fault relay is Basic over current or directional (Non-directional) over current relay with flexiating value b/w 2 to 10%. It is used to identify ground faults like (LG, LLG, LLLG. For complete protectn of 3-ϕ sys. the min. no. of Relays required are 3 Relays ie one earth fault relay and two over current relays.

Date

- Restricted Earth fault Relay:- (Generator)



~~% protects~~

% winding unprotected:-

$$\boxed{\%W_u = \frac{I_o R_n}{V_{ph}} \times 100}$$

where I_o = min pick up current of Relay × C.T. Ratio

R_n = Neutral Resistance.

V_{ph} = Gen. phase voltage = $V_L/\sqrt{3}$.

- $\boxed{\%\text{ wdg protected} = 100 - W_u\%}$

$$\uparrow I_f = \frac{V_{ph}}{X_{th}}\uparrow \qquad \uparrow I_f = \frac{V_{ph}}{X_{th}}\uparrow$$

- For improving sys. stability Gen. Neutral is connected to the ground through resistor i.e. Resistance grounding is used. Because of this resistance if any ground fault occur some % of wdg cannot be protected in the generator. For complete protection of gen. wdg. % diff. Relay is associated with the restricted earth fault Relay.

- At less no. of turns, less voltage induce, less I_f value, goes through R_n but $I_R = 0$, does not operate the relay.

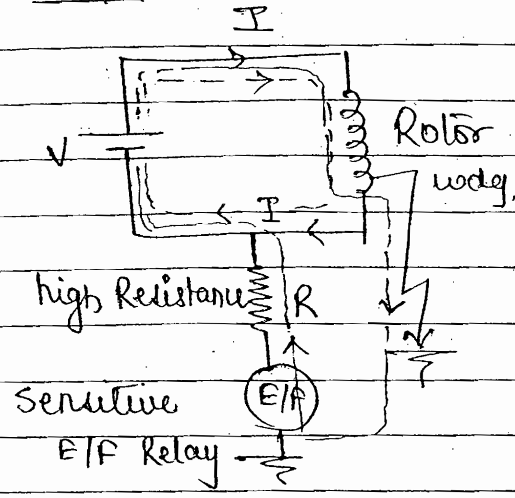
Q.8 Pg no. 66.

$$\%W_u = \frac{0.75 \times \frac{1000}{5} \times 5}{11 \times 10^3/\sqrt{3}} \times 100 = 11.8\%$$

$W_p\% = 100 - 11.8 = 88.2\%$ Ans.

Date________

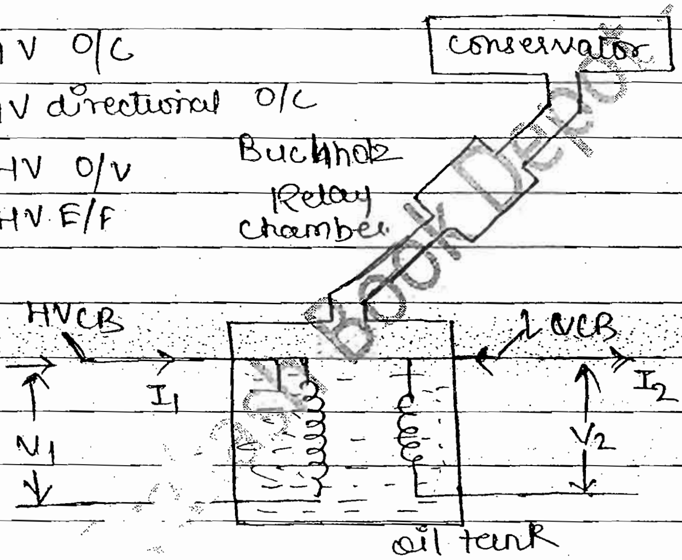
- Gen. Rotor E/F Relay:-



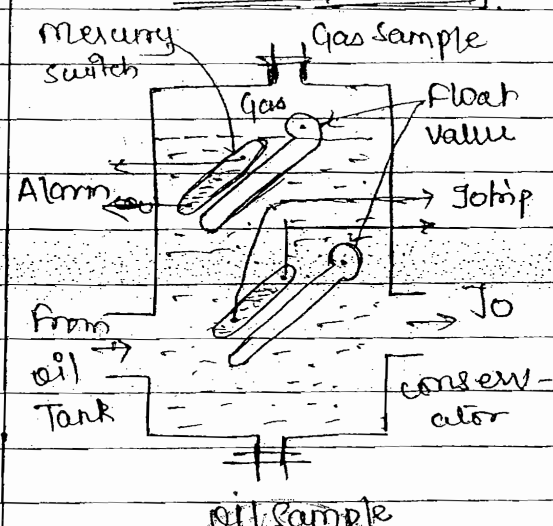
- Normal condition (Blue colour)
- At fault. (Red colour)
- Under Normal condition current do not flow through Relay due to high Resistance. If any fault (ground) occur the fault current flows through sensitive E/F relay and produces trip signal if it is exceeding the setting value of Relay.

- Protection of 3φ - x-mer:

(1) HV O/C
(2) HV directional O/C
(3) HV O/V
(4) HV E/F

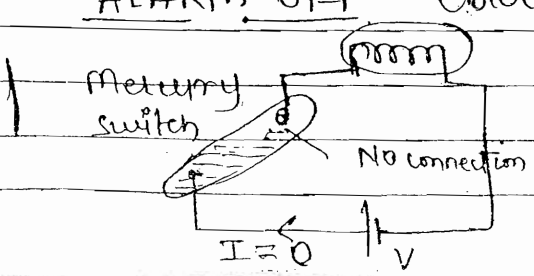


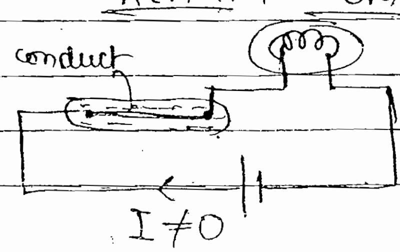
- Buchholz Relay



(5) % Diff Relay (6) Buchholtz Relay
(7) Over flux Relay (8) LV O/C
(9) LV direction O/C (10) LV O/V (11) LV E/F

ALARM OFF (Block) ALARM ON (Trip)





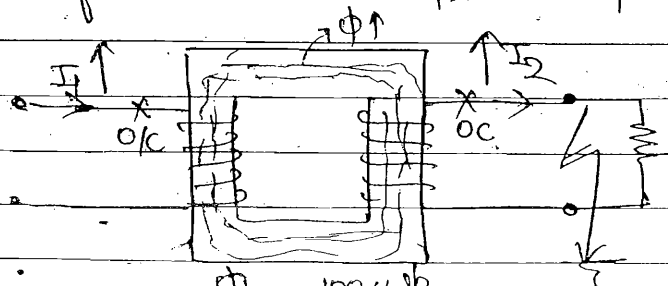
Locatⁿ of fault	Chemicals
Construction parts	C_2H_2, H_2
Winding	C_2H_2, CH_4, H_2
OLTC	CH_2, C_2H_6, H_2, CO_2
Core joints	CH_2, CH_4, H_2, CO_2

- Buchholz relay is gas actuated relay used for protection of x-mer from the internal or incipient faults
- If the intensity of fault is low value produces alarm signal initially. If the intensity of fault is very high produces trip signal By opening LV and HV C.B.
- It is most efficient for identification of internal fault But the time of operatⁿ is more and hence it is associated with % diff. Relay for complete protection of power x-mer.

- Over flux Relay :- $V = 4.44 f \phi_m N$ $\quad \phi_m \propto \left(\frac{V}{f}\right)$

(1) $V/f > 1.1$ for 2 minutes $\Rightarrow$ Trip
(2) $V/f \leq 1.1$ $\Rightarrow$ Block.

- At the rated voltage and freq. the flux produce in the x-mer is consider as 100%. If due to fault or freq. variatⁿ or internal damage to the x-mer. If the ϕ's ↑ By 10% more than the rated value the timer is set for 2 minutes. so that produces trip signal.



$\phi_m = 100\,wb$
↑ $\phi_m = 110\,wb \rightarrow 2$ minutes $\Rightarrow$ Trip

Date________

- Protection of Generator :-

STATOR FAULT :-

1) Inter-phase fault (same phase) → Split phase Relay
2) phase - phase fault → % Diff. Relay
3) Earth fault → Restricted E/F Relay.

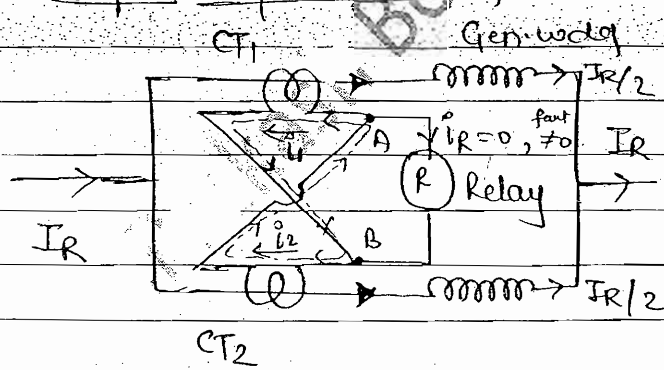
ROTOR FAULT :-

4) Rotor earth fault → Sensitive E/F Relay.

EXTERNAL FAULT :-

5) Failure of prime mover → Reverse power Relay
6) " " Excitation → Offset Mho Relay
7) " " Cooling Medium → Temp. Sensitive Relay
8) Over load → O/C Relay.
9) Over speed → Mech. Centrifugal Relay (Flyball Governor)
10) Unbalanced loading → Negative sequency Current Relay
11) Over voltage → O/V Relay.

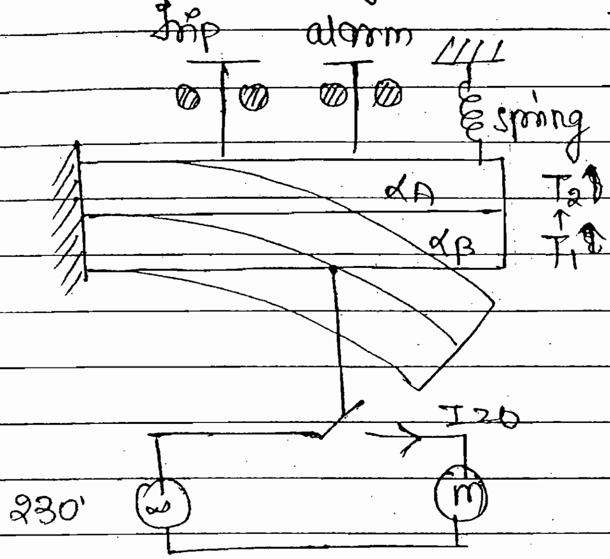
- Split - Phase Relay :



- Split phase relay is used to identify the fault occur with in the same phase of the generator.
- Two CT's are connected Back to Back. Under normal condition the current through relay is zero so that Relay → Blocks
- If any S.C or O.C fault occur at any one of 11 path potential diff. occur across the relay which produce trip signal.

Date

- **Thermal Relay :-**

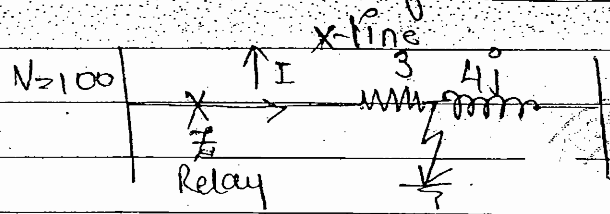


→ Thermal relay consisting of Bi-metallic strip made of Ni and chromium.

→ The thermal expansion coefficients of these metal are different so that produces Bending depending on the temp. change. This principle is used in Bi-metallic switch for :- (1) Protection of over loading of electrical motors, Gen. etc. (2) Used in MCB (3) Used in A.C, Refrigator and iron Box for temp. control.

- For high capacity gen. more than 5 MVA temp.-sensitive Relay like thermocouple, RTR are used for protectn of wdg. from the failure of cooling medium.

- **Protection of X-line using Distance Relay :-**



$Z_f = \frac{V}{I}$ Impedance seen By the Relay during fault.

Z_l = Actual or Replica Imped. of line without any fault.

= Setting value of Relay (PSB)

✓ Healthy (No fault)

$Z_l = R_l + j X_l$

$= 3 + j4$

$|Z_l| = 5$

$I = \frac{100}{5} = 20A.$

✓ Fault $I\uparrow \Rightarrow I \Rightarrow 50A.$

$Z_f = \frac{100}{50} = 2\Omega$

$\lvert Z_f\rvert \geq \lvert Z_l\rvert$ → Trip	
$\lvert Z_f\rvert < \lvert Z_l\rvert$ → Block	

Date________

- Universal Torque Equation :-

$$\boxed{T_D = K_1 I^2 + K_2 V^2 + K_3 VI \cos(\theta - \tau) - K_4}$$

where T_D = Operating time $K_1 I^2$ = O/C $K_2 V^2$ = O/V

$K_3 VI \cos(\theta - \tau)$ = Directional K_4 = Spring restraining Torque.

ex:- Over Current Relay:-

Assume $K_2 = K_3 = 0$, $T_D = K_1 I^2 - K_4$

① Trip. $T_D > 0$

$K_1 I^2 > K_4$

$I > \sqrt{\dfrac{K_4}{K_1}}$

② Block $T_D \le 0$

$K_1 I^2 \le K_4$

$I \le \sqrt{\dfrac{K_4}{K_1}}$

I = fault current , $\sqrt{K_4/K_1}$ = PSB value of o/c Relay.

(1) Impedance (Z) Relay :-

Assume $K_3 = 0$, K_4 = very small K_2 = −ve

$$T_D = \underbrace{K_1 I^2}_{\text{over current}} - \underbrace{K_2 V^2}_{\text{Restraining}}$$

Impedance Relay is a voltage Restraint over current Relay

Trip ($T_D > 0$)

$K_1 I^2 > K_2 V^2$

$\sqrt{\dfrac{K_1}{K_2}} > \left(\dfrac{V}{I}\right)$

$\sqrt{\dfrac{K_1}{K_2}} = Z_l$

$\dfrac{V}{I} = Z_f$

$\boxed{Z_l > Z_f \text{ or } Z_f < Z_l}$

Block $T_D < 0$ $\boxed{Z_f > Z_l}$

Locus of Z-Relay:-

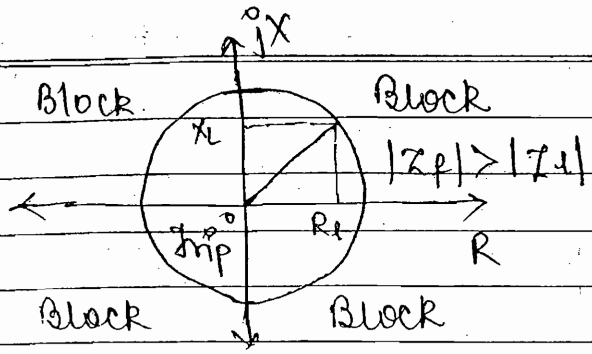
$Z_l = R_l + jX_l$

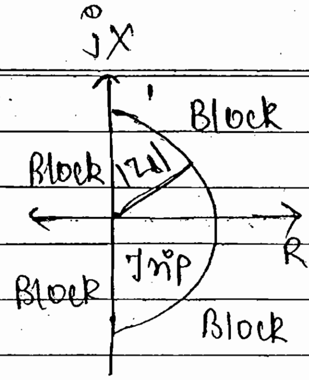
$\boxed{|Z_l|^2 = R_l^2 + X_l^2}$ — ①

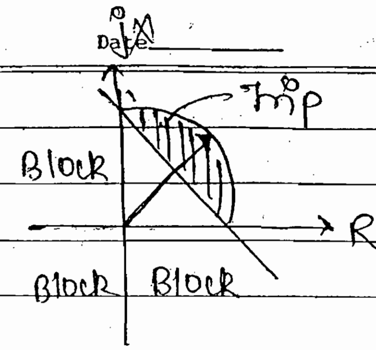
eqn ① Represents circle equation

$r^2 = x^2 + y^2$

where $r = |Z_l|$







Non-directional Z-Relay. Directional Z-Relay. Angle Impe. Relay.
→ all all qudarant. 1^{st} & 4^{th} qud. 1^{st} qu, certain appli only, if required.

(2) Reactance (X) Relay

Assume $K_2 = K_4 = 0$

$T_D = \underbrace{K_1 I^2}_{O/C} - \underbrace{K_3 V I \cos(\theta - \tau)}_{\text{restraining}}$

① Trip

$K_1 I^2 > K_3 V I \cos(\theta - \tau)$

$\frac{K_1}{K_3} > \frac{V}{I} \cos(\theta - \tau)$

Reactance Relay is a Directional Restraint over Current Relay.

Assume $\tau = 90°$, $\frac{V}{I} = Z_f$.

$\frac{K_1}{K_3} = X_1$

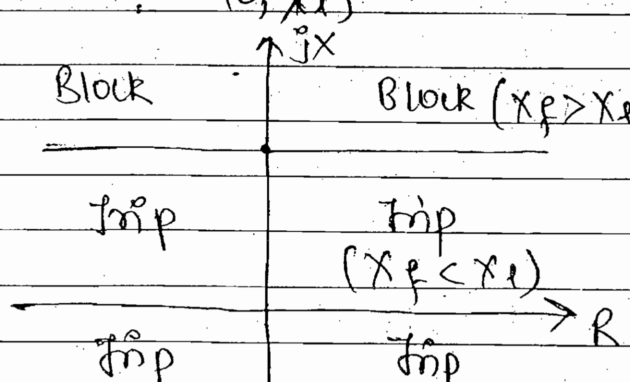
Locus of X-Relay is a straight line passing through $(0, X_1)$

$X_1 > Z_f \cos(\theta - 90°)$

$X_1 > Z_f \sin\theta$

$Z_f \sin\theta = X_f$

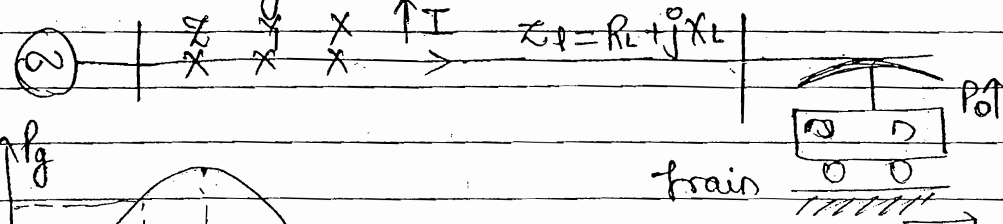
$\boxed{\begin{matrix} X_1 > X_f \\ \text{or} \\ X_f < X_1 \end{matrix}}$ → Trip.



② Block $\boxed{X_f \geq X_1}$

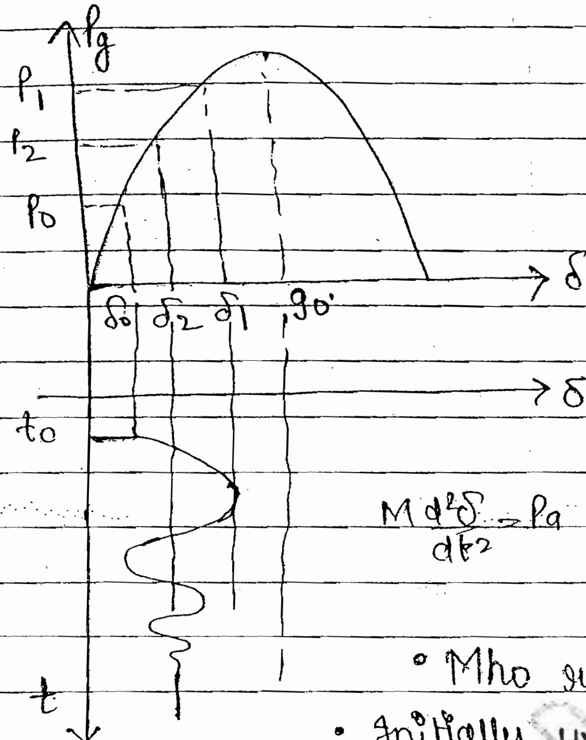
Date________

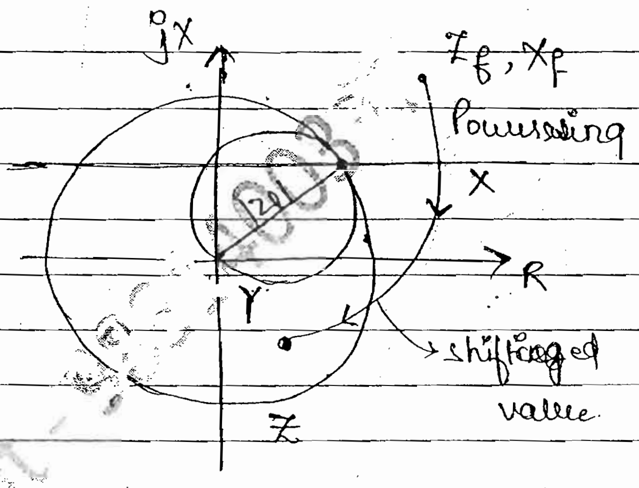
• **Power Swing :-**



$Z_f = \frac{|V| \angle \delta_0}{I \angle \theta}$

$= Z_f \angle \delta_0 - \theta$

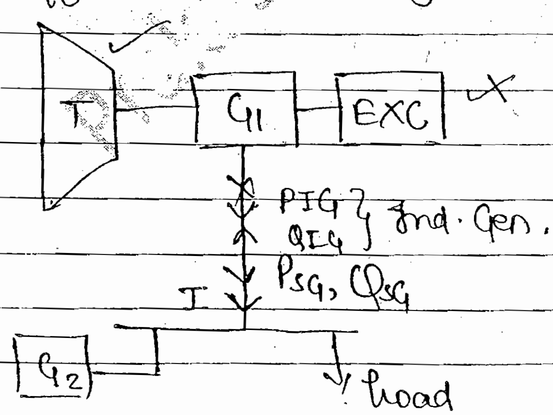


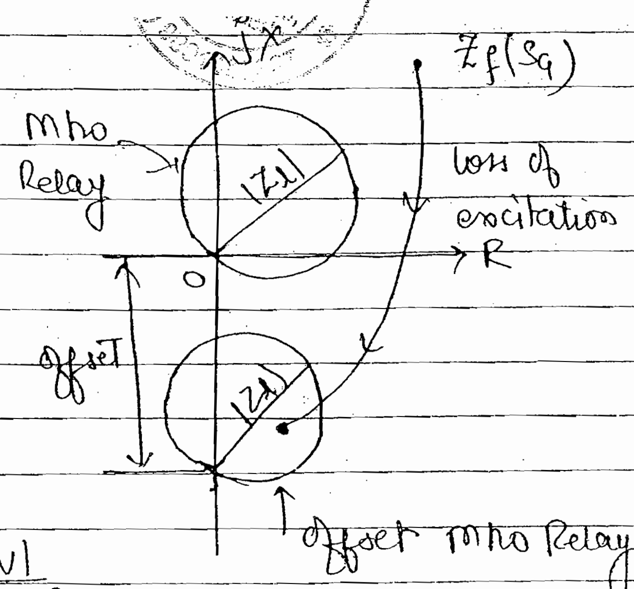


• Mho relay not produce trip during Pow swing

• Initially when demand (Train start) Po↑, δ↑, t↑ (P_1), when train attain speed, Po↓, δ↓ t↓ and oscillate, and finally settle to stable new pt. (P_2)

• **Offset Mho Relay:**



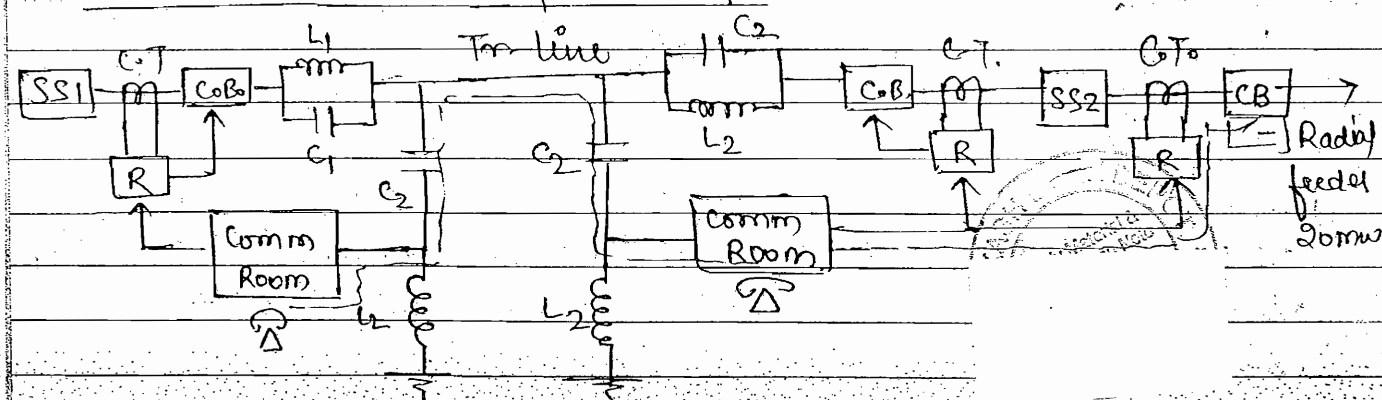


SG:	IG
$Z_f = \frac{\lvert V \rvert}{\lvert I \rvert \angle -\theta} = Z_f \angle \theta$	$Z_f = \frac{\lvert V \rvert}{\lvert I \rvert \angle \theta}$
	$= Z_f \angle -\theta$

Date ________

- Under Normal condition syn. gen. delivers active and reactive pow. to the load. If the turbine is present, excitation is failed. Then it will deliver leading VAR's and absorb lagging VAR's. And also deliver the active power. This change of Reactive power flow with-in the gen. produces unbalanced causes damage to the gen. wdg. To protect the gen. from this Offset Mho relay is used, which is basically a mho relay for which an offset is added for identificatn of loss of excitation.

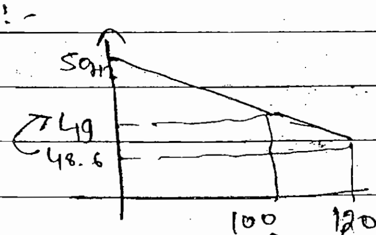
- Current Carrier Protection :-



- Line ~~trap~~ Trap = $f_1 = \frac{1}{2\pi\sqrt{L_1C_1}} \Rightarrow$ 50Hz.

- Wave Trap = $f_2 = \frac{1}{2\pi\sqrt{L_2C_2}} \Rightarrow$ Audio freq.

- Current Carrier protection is used:-
 (1) Power line carrier protection
 (2) SCADA
 (3) Load Frequency control



- It consisting of line trap and wave trap LC tuned ckt. Line trap unit offers low impedance for

Date________

power freq. and high Imp. for the communicatⁿ freq..
The wave trap unit is used low impedance for audio freq. and high Imp for power freq.

- Static Relay :-

From CT/PT → Rectifier → S_i → Comparator → S_E → Trip ckt → CB

S_{REF} [setting value of Relay] → Comparator

$$S_E = S_i - S_{REF}$$

(1) If $S_i > S_{REF} \Rightarrow S_E > 0 \Rightarrow$ Trip

(2) If $S_i \leq S_{REF}$ & $S_E \leq 0 \Rightarrow$ Block

- Advanages! :-

(1) Low power consumption. (2) store data
(3) Easily interface with comp. (4) More reliable
(5) Less maintainance. (6) Easily programmable
(7) Less Cost. (8) Occupies less space
(9) Stable operatⁿ

Date________

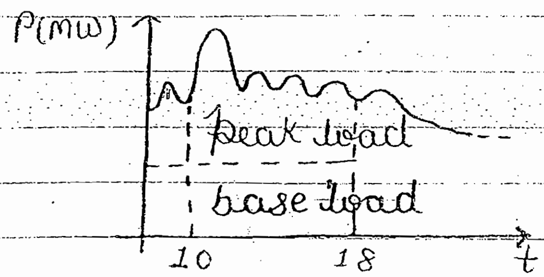
$P_L \propto (f+25)$ Corona power loss is more in HVAC compared to HVDC

Disadvantages of Corona

1) Power loss occurs
2) Produces interference to other lines.
3) Charging current increases.
4) Intensity or peak value of the lightning surge is reduced if lightning surge initiates corona ← Advantage

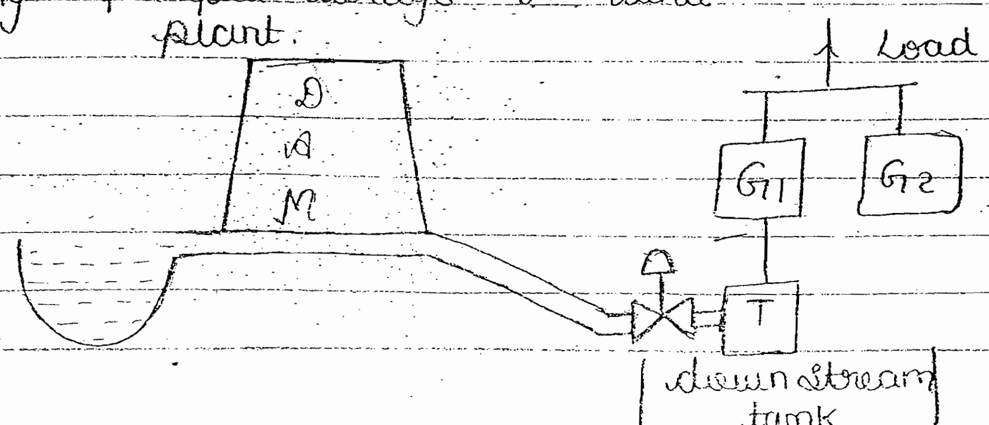
Economic / Variable load factor

S.S. →
- Hospitals (24 hrs)
- Colleges (9 A.M - 5 P.M)
- Shops (10 A.M - 10 P.M)



Base load plants	Peak load plants
1. Thermal	1. pumped storage plant
2. Nuclear	2. Hydro (Summer)
3. Run off river	3. Diesel (operating time is less)
4. Hydro	
5. Solar	
6. Wind	

fig pumped storage plant.



Pumped storage plant is also hydro plant.

→ Thermal and nuclear operaⁿ time is more (expansion) so they are used as a base load plant.

→ Depending upon availability hydro is used as base or peak load plant.

1) Plant load factor : (P_{lf})

$$P_{lf} = P_{avg}/P_{max}$$

$$= \frac{P_{avg} \times t}{P_{max} \times t}$$

$$P_{lf} = \frac{\text{area under load curve}}{(\text{Rectangular area corresponding to } P_{max})}$$

2) Plant Capacity factor (P_{cf}) →

$$P_{cf} = \frac{P_{avg}}{P_c} \qquad P_c = \text{Plant capacity}$$

$$\frac{\text{avg energy Produced in total hours}}{(\text{energy able to produce as per } P_c \text{ in total hours})}$$

$\boxed{P_{cf} < 1}$

3) Plant use factor (P_{uf})

(P_{uf})

$$P_{uf} = \frac{\text{Energy Produced in used hours}}{(\text{energy able to produce as per } P_c \text{ in used hours})}$$

$\boxed{P_{uf} < 1}$

4. Reserve Capacity R_c : $R_c = P_c - P_{max}$

$$= \frac{P_{avg}}{P_{cf}} - P_{max}$$

$$R_c = \frac{P_{avg} - P_{max} P_{cf}}{P_{cf}}$$

$$= \frac{P_{max}\left[\frac{P_{avg}}{P_{max}} - P_{cf}\right]}{P_{cf}}$$

$$= \frac{P_{max}(P_{Lf} - P_{cf})}{P_{cf}}$$

5. Demand Factor : (D_f)

$$D_f = \frac{P_{max}}{\text{Sum of connected load}}$$

$$\boxed{D_f < 1}$$

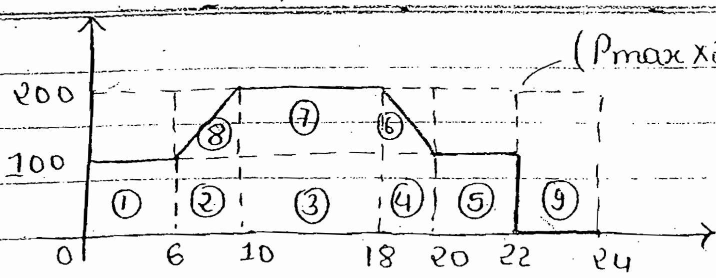
6. Diversity factor : (Div_f)

$$(Div_f) = \frac{\text{Sum of individual max demand}}{P_{max}}$$

$$\boxed{Div_f > 1}$$

Ques: A Generating Station has a plant installation capacity of 300 MW is delivering the power to the load centre. A load curve is shown in the fig calculate
(i) P_{max} (ii) Plant capacity (iii) P_{avg} (iv) P_{Lf} (v) P_{cf} (vi) P_{uf} (vii) R_c.

Solu:- $P_{max} = 200$ MW
$P_c = 300$ MW
$P_{avg} =$ Total area / Time



$$\frac{100\times 6 + 4\times 100 + 8\times 100 + 100\times 2 + 100\times 2 + 0\times 2 + \frac{1}{2}\times 100\times 4^{2} + \frac{1}{2}\times 2\times 100 + 100\times 8}{24}$$

$= 3300/24 = 137.5\ MW$

4) $P_{lf} = P_{avg}/P_{max}$

$= \frac{137.5}{200} = 0.6875 < 1$

or $\frac{P_{avg}\times 24}{P_{max}\times 24}$

$= \frac{3300}{200\times 24} = 0.6875$

$200\times 24 \rightarrow$ Total hours

5) $P_{cf} = P_{avg}/P_c = \frac{137.5}{300} = 0.4583 < 1$

or $R_{cf} = 3300/300\times 24 = 0.4583$

$24 \rightarrow$ total hours

6) $P_{uf} = \frac{3300}{300\times 22}$ (area remains same)

$22 \rightarrow$ used hours

$= 0.5 < 1$

7) $R_c = P_c - P_{max}$

$= 300 - 200 = 100\ MW$

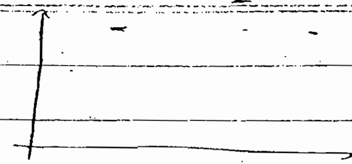
or $R_c = \frac{P_{max}(P_{lf} - P_{cf})}{P_{cf}} = \frac{200(0.6875 - 0.4583)}{0.4583}$

$= 100\ MW$

SS	connected load (kW)	Individual max demand
hospitals	50	40
colleges	40	30
shops	30	25

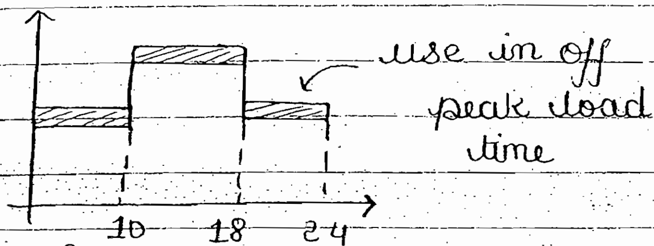
$\Sigma = 120\ P(kW)$ $\Sigma = 95$

$Df = \frac{70}{120} < 1$ $Div\ f = \frac{95}{70} > 1$

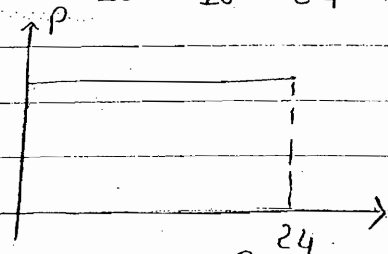


Connected load (equipments upto their full capacity)

Individual load demand is diversed. (Div f)



$P_{Lf} < 1 < 100\%$



$P_{Lf} = 1 = 100\%$

$\uparrow P_{Lf} = \frac{P_{avg}}{P_{max}\downarrow}$ $\uparrow Div_f = \frac{\Sigma Ind.\ max}{P_{max}\downarrow}$

Practically P_{Lf} more than 1 is also possible

Higher P_{Lf} is better.

Methods of Improving P_{Lf} and diversity factor

If P_{Lf} and diversity factor are higher, indicates max demand is lower so that initial investment on the electrical appliances is reduced which reduces cost of electrical energy.

Because of this reason $P_{Lf} = 1$ or higher than 1 and diversity factor > 1 is preferred.

Chem $\rightarrow$ heat $\rightarrow$ mech $\rightarrow$ elec
Boiler - Turbine Gen

Increasing industries for running their offices and industrial during off peak load time

Agricultural pumpsets are to be run during off peak load period.

Effective utilisation of sunlight by maintaining proper ventilation betwn the buildings.

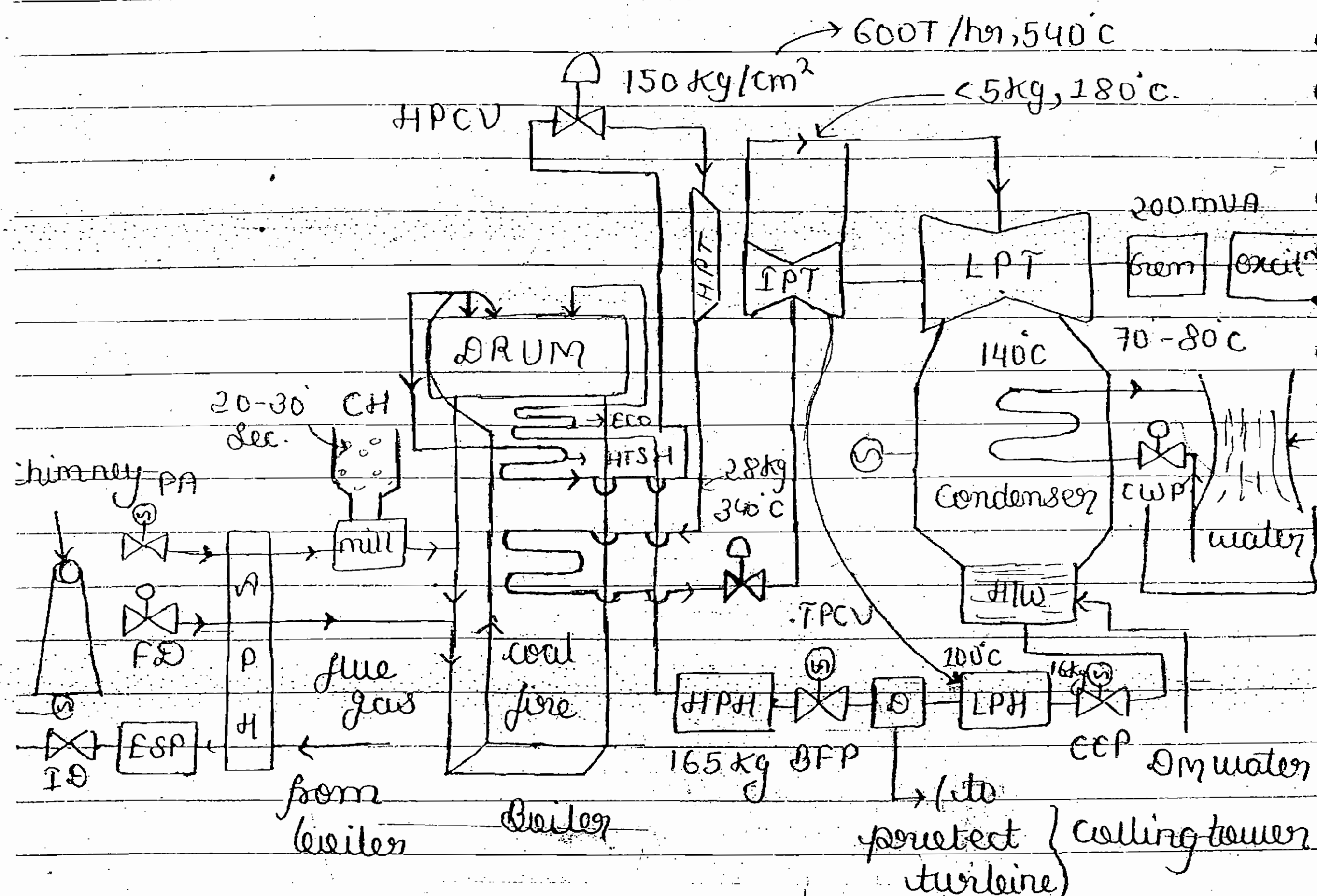
Increasing the industries for utilising high Pf loads

Power Generation

Thermal Plant

H/W → hot well
DM → Demineralised → (to avoid corrosion of boiler)
CEP → Condensate Extn. pump
CWP → circulating water pump
BFP → Boiler feed pump
LPH → Low pr heater
HPH → High Pr heater
D → Deaerator
ECO → Economiser
LPT → Low pressure turbine
IPT → Inter " "
HPT → High " "
V → vaccum pump / steam ejector
HPCV - High pr Govn. control valve
IPCV - Inter pressure " " "
HTSH - High temp super Heater
ITSH - Inter " " "
PA - Primary air

FD - forced draft
ID - Induced draught
ESP - Electrostatic Precipitator
APH - air pre heater
CH - Coal Hopper



Thermal Plant is working on the principle of Rankine Cycle. That is the process of reheating steam for improving efficiency. Thermal eff is betwⁿ 35-40%.

Anthracite - <10%.
Bituminous - 20-30%
Lignite 30-50%
Peat > 50%

(as like aerostick)

Energy of coal $\Rightarrow$ Kcal/Kg

1 unit = 1 KWh = 860 K cal heat energy.

Ex.

Bituminous :

Energy $\rightarrow$ 2 KW hr/Kg = 1720 Kcal/Kg

$\eta = 40\% = 2 \times 0.4 = 0.8$ Kwhr/Kg

1 Kg = 0.8 KWhr $\rightarrow$ 1 Kwhr = 1/0.8 = 1.25 Kg coal.

P = 200 MW , 1 day = 24 hr

energy = 200×24 = 4800 Mwhr = 4800×10^3 Kw hr

coal = $4800 \times 10^3 \times 1.25$ kg = 6000 T/day (tonnes/day)

Ash = $6000 \times \frac{200}{100}$ = 1200 T/day

(Huge amount of ash produced)

U_{92}^{235} — 1 kg = 270 000 kg coal (less requirement of coal so transportation cost is more)

$$\boxed{\eta_0 = \eta_{th} \times \eta_c}$$

$$\boxed{\eta_0 = \eta_B \times \eta_{turbine} \times \eta_g}$$

η_0 = over all η

η_B = Boiler η , η_g = Generator η

η_{th} = Heat η = boiler & thermal η.

- For protecting boiler tubes from corrosion DM water is used.

For improving η_{th}, LP and HP heaters are used so that water temp. is increased.

These heaters are of steam heaters

Deaerator is used for removal of dissolved gases from the water for protection of turbine.

BFP is the highest pressure generating pump in the thermal plant which nearly consumes 4MW electrical power & produces upto 165 kg of pressure.

Economiser used for absorbing heat from flue gases, so that water temp is increased for improvement of thermal efficiency.

Water circulates naturally from drum to boiler and again to the drum due to density difference of water and steam. In high capacity plants extra pumps is used for this purpose HTSH heater improves steam temp upto 540°C.

Steam is reheated in the ITSH for improving the thermal efficiency. This is the principle of rankine cycle.

Steam directly sent from IP turbine to LP turbine. Vaccum pump is used for absorbing steam from the L.P turbine to Condenser.

- Circulating water is used for conversion of steam into water. This water is sent to the boiler. circulating water is cooled by using cooling turbine.

- PA fan is used for conveying coal hopper from mill to boiler.

- FD fan is used to supply oxygen for proper combustion of coal.

- ID fan is used to extract flue gas from boiler

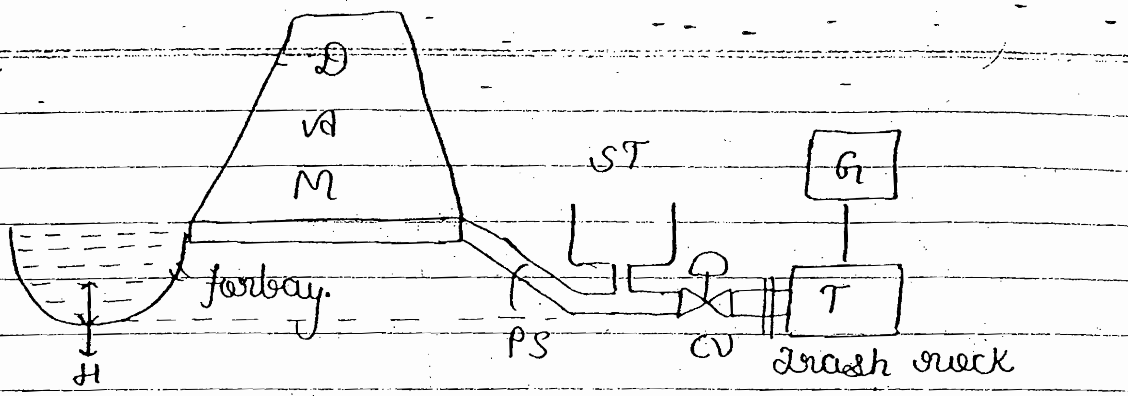
- ESP working on the principle of electrical field used for collection of ash from the flue gas. APH used to increase the PA & FD fan, air temp so that moisture from the coal is removed.

- HPCV and IPCV are used for controlling flow rate of steam into the turbine so that speed of freq. are controlled.

Hydro Power Generation

Potential $\rightarrow$ Kinetic $\rightarrow$ Mech $\rightarrow$ Elec.

PS $\rightarrow$ penstock
ST $\rightarrow$ surge tank
CV $\rightarrow$ Control valve
H $\rightarrow$ Mean water head



Electrical Power Output (P) →

1) Discharge (Q) is given -

$$\boxed{\begin{aligned} P &= 0.735\,\eta\,QWH \\ &= 9.81 \times 10^{-3}\,\eta\,QWH \end{aligned}}\ \text{KW}$$

η → plant efficiency

Q → discharge of water in m^3/sec

$= \dfrac{\text{capacity of reservoir in } m^3}{3600 \text{ sec}}$

W = density of water = 1000 Kg/m^3

H = mean water head in m.

2) Rainfall (F) is given -

$$\boxed{P = 3.14 \times 10^{-3}\,\eta\,QWH\,KAFH} \text{ --- KW}$$

η → plant η

K → yield factor (wht we get)

A → attachment area sq. km.

F → annual rainfall in mm

H → mean water head in m

$\boxed{\text{Energy} = \text{power} \times t}$

$Q\nearrow H\nearrow \rightarrow$ variable

Head (m)	Turbine
2 - 15	propeller or kaplan
15 - 70	kaplan or francis
70 - 500	francis or pelton
>500	Pelton
Pumped storage	DERIAZ

$H < 30 \rightarrow$ low head

$30 < H < 300 \rightarrow$ medium head

$H > 300 \rightarrow$ High head.