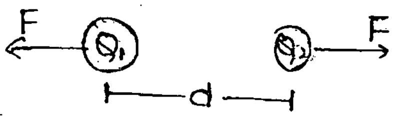
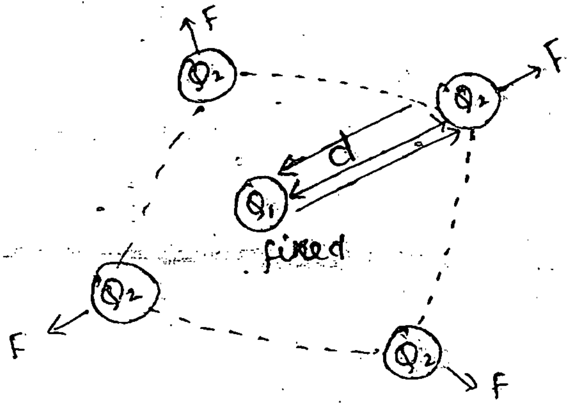
Capacitance of transmission line:

Coulombs law



$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0\varepsilon_r d^2}$$



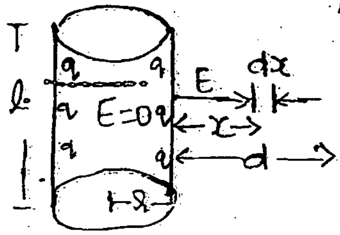
$$E = \frac{F}{Q_2} = \frac{Q_1}{4\pi\varepsilon_0\varepsilon_r d^2}$$

Voltage $dv = \frac{\text{Workdone}}{\text{charge}} = \frac{E}{Q}\,dx = \frac{F}{Q_2}\,dx$

$$\boxed{V = -\int_{d}^{r} E \cdot dx}$$

$$\boxed{C = Q/V}$$

Single tr. lines



ASCR

σ = high

$J = \sigma . E$

$E\downarrow = \frac{J}{\sigma\uparrow}$

$E \simeq 0$

q = line charge C/m

$$E = \frac{q}{2\pi \varepsilon_0 \varepsilon_r x}$$

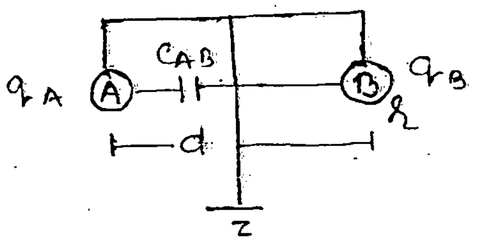
$$V = -\int_d^r E\,dx$$

$$V = -\int_d^r \frac{q}{2\pi \varepsilon_0 \varepsilon_r} \frac{dx}{x}$$

$$V = \frac{q}{2\pi \varepsilon_0 \varepsilon_r} \cdot \ln \frac{d}{r}$$

$$\boxed{C = \frac{Q}{V} = \frac{2\pi \varepsilon_0 \varepsilon_r}{\ln(d/r)}}$$

Capacitance of 1-Φ 2wire line:



At balance $q_A + q_B = 0$

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

$$V_{AB} = V_A - V_B$$

$$= \frac{q_A}{2\pi \varepsilon_0 \varepsilon_r} \ln d/r - \frac{q_B}{2\pi \varepsilon_0 \varepsilon_r} \ln(d/r)$$

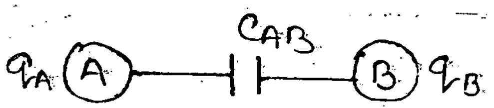
$$q_B = -q_A$$

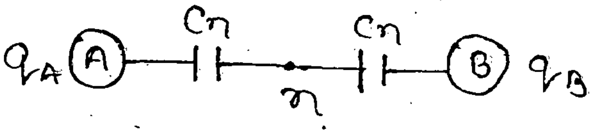
$$V_{AB} = \frac{q_A}{2\pi \varepsilon_0 \varepsilon_r} \ln(d/r)^2$$

$$V_{AB} = \frac{q_A}{\pi \varepsilon_0 \varepsilon_r} \ln(d/r)$$

$$C_{AB} = \frac{q_A}{V_{AB}} = \frac{\pi \varepsilon_0 \varepsilon_r}{\ln(d/r)}$$

capacitance to neutral:





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

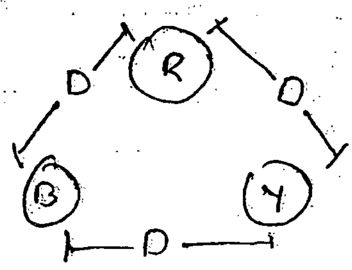
$$\boxed{C_n = 2C_{AB}}$$

$$\boxed{C_n = \frac{2\pi \varepsilon_0 \varepsilon_r}{\ln(d/r)}}$$

⊕ 3φ transposed line:

C_n = capacitance per phase ⇒ F/m/ph

$$C_n = \frac{2\pi \varepsilon_0 \varepsilon_r}{\ln \frac{(D_1 D_2 D_3)^{1/3}}{r}}$$



if $D_1 = D_2 = D_3 = D$

$$C_n = \frac{2\pi \varepsilon_0 \varepsilon_r}{\ln(D/r)}$$

(2.) Bundle conductor

$$C_n = \frac{2\pi\varepsilon_0\varepsilon_r}{\ln\left(\frac{D_m}{D_S}\right)}$$

(3.) Double ckt line:

$$C_n = \frac{2\pi\varepsilon_0\varepsilon_r}{\ln\left(\frac{D_{m1}\,D_{m2}\,D_{m3}}{D_{S1}\,D_{S2}\,D_{S3}}\right)^{1/3}}$$

(4.) $X_c = \frac{1}{2\pi f C_n}$ $\Omega/m/Ph$

(5.) $B = \frac{1}{X_c} = 2\pi f C_n$ $\mho/m/Ph$

(6.) I_c = Charging current

$= 2\pi f C_n V_{ph}$ A/m/Ph.

(7.) Reactive power (Q_{ph})

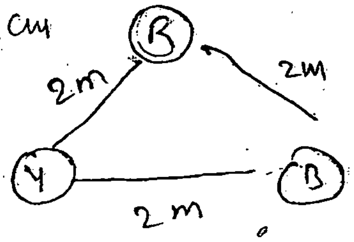
$Q_{ph} = 2\pi f C_n V_{ph}^2$ .... Vars/m/Ph

Q. $r = 1cm$ (R) (Y) (B) Horizontal-

|— 2m —|— 2m —|

$C_n = 2\pi$

Q. $r = 1cm$



Equilateral

$C_n =$

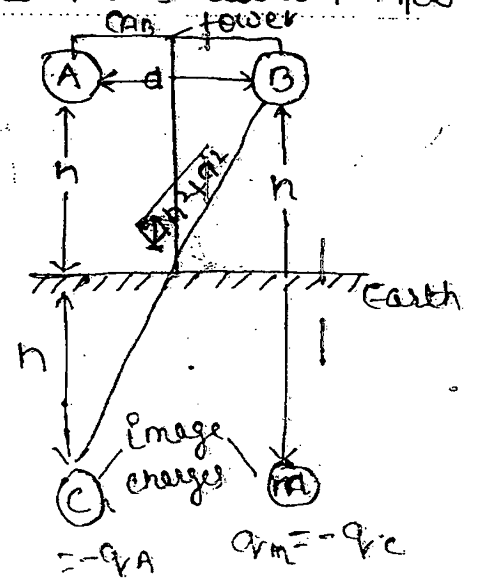
→ Effect of Earth on the capacitance b/w earth condʳ:

Earth consist of infinite no of charge carriers both +ve & -ve. This charge carrier's produces additional Electrical field so that 'C' b/w conductor ↑es. This increment causes increase in transmission line voltage which causes insulation failure.

If this increment in voltage more than critical disruptive voltage [a minᵐ voltage required to initiates 'corona'] so that corona occurs in the system for Eliminating or reducing earth Effect, The hight of the tower is ↑ed as the operating voltage is ↑ing.

Method of images:

It is the mathamatical techniques adopted from electromagnetic fields used as calculation of effect of earth on the capacitance b/w condʳ. In this method images charges are assumed below their large which have the same mag. of charges but opp. sign. the no of image charges equal to no of condʳ existing in the transmission N/w above ground.



Voltage b/w A/B

$$V_{AB} = \frac{1}{2\pi\varepsilon_0\varepsilon_r}\left[q_A \ln\frac{D_{AB}}{r} + q_B \ln\frac{r}{D_{BA}} + q_C \ln\frac{D_{CB}}{D_{CA}} + q_m \ln\frac{D_{mB}}{D_{mA}}\right]$$

At balanced

$$q_A + q_B = 0$$

$$q_A = -q_B \quad q_C = -q_A \;, \quad q_m = -q_B = q_A$$

$$D_{AB} = D_{BA} = d \;, \quad D_{CA} = D_{mB} = 2h \;, \quad D_{CB} = D_{mb} = \sqrt{4h^2+d^2}$$

$$V_{AB} = \frac{q_A}{\pi\varepsilon_0\varepsilon_r}\ln\left(\frac{d}{r\sqrt{1+\frac{r^2}{4h^2}}}\right)$$

$$\boxed{C_{AB} = \frac{q_A}{V_{AB}} = \frac{\pi\varepsilon_0\varepsilon_r}{\ln\left(\frac{d}{r\left(\sqrt{1+\frac{d^2}{4h^2}}\right)}\right)}}$$ With Earth effect

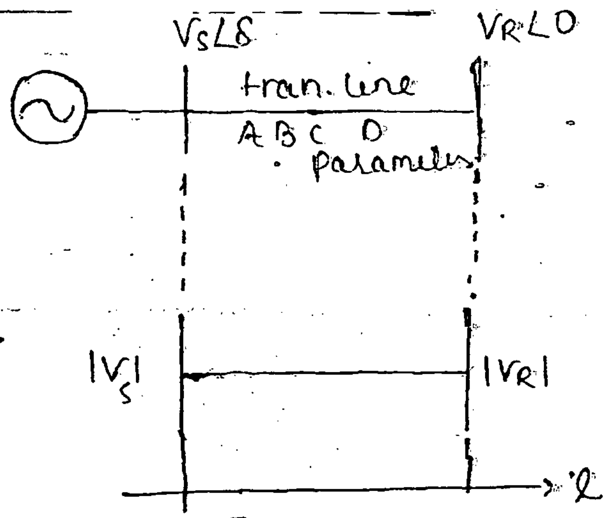
~~Note~~: By increasing high of tower

$$\frac{d^2}{4h^2} \simeq 0$$

$$\boxed{C_{AB} = \frac{\pi\varepsilon_0\varepsilon_r}{\ln(d/r)}}$$ → No Earth effect

V_L (kV)	11	33	132	220	440	765
h (m)	7	11	20	35	50	65

→ Voltage Regulation of Tr. line:



Flat voltage profile

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

V_{RNL} = No load reciving end voltage

$V_S = A V_R + B I_R$

At no load $I_R = 0$

$V_S = A V_R$

$\therefore A = \frac{V_S}{V_R} = \frac{V_S}{V_{RNL}}$

$\Rightarrow \boxed{V_{RNL} = \frac{V_S}{A}}$

V_{RFN} = Full load receiving end voltage
$= |V_R|$

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

The above Eqn applicable for All type of transmission line

~~Ex:- Short transmission~~ line $A = 1$

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

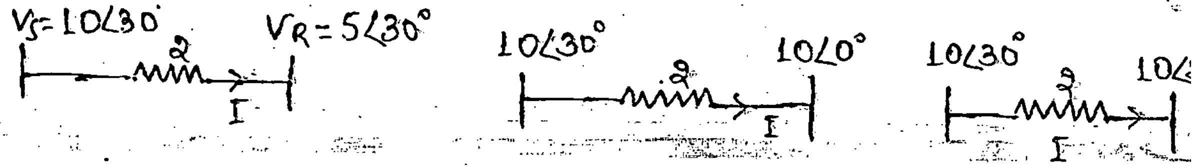
if $|V_S| = |V_R|$

$$\boxed{\% V_{REG} = 0\%}$$

$\% V_{REG} = \pm 5\%$

~~Concept~~

HAVC



$I \neq 0$ $\quad$ $I \neq 0$ $\quad$ $I = 0$

* In case of HAVC, voltage b/w sending and receiving end must have different magnitude of voltage or phase difference. then power will flow.

HVDC

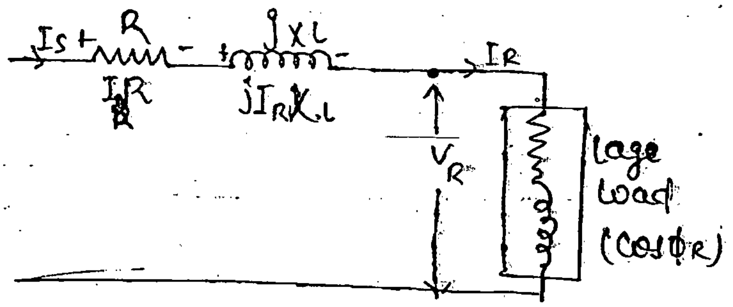
$I \neq 0$ $\quad$ $I = 0$

* For max^m power transfer due to unequal magnitude of the voltage

→ Effects of load on the voltage Regulation of the tr. line:-

(A) Short trans. line:

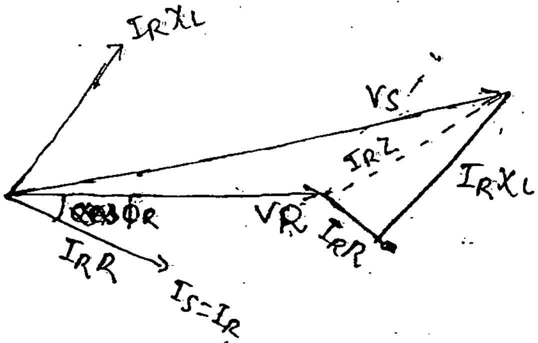
(a) lag load.



$$Z = R + jX_L$$

$$V_S = V_R + I_R Z$$

$$\boxed{V_S = V_R + I_R R + jI_R X_L}$$



From phasor diagram

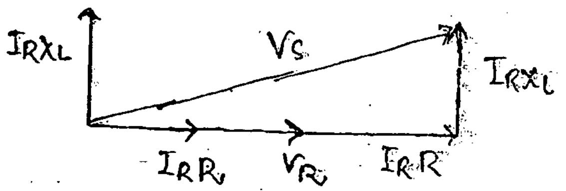
$$|V_S| > |V_R| \qquad |V_S| = +ve$$

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

$$\boxed{\% V_{REG} = +Ve}$$

↳ Peak load time

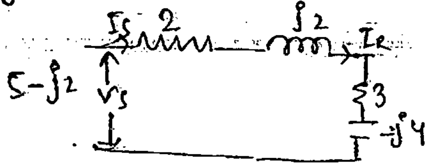
For unity power load

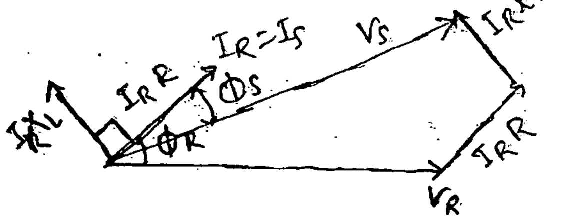


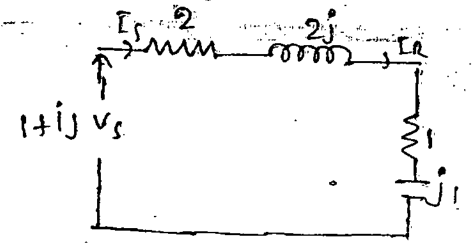
$|V_S| > |V_R|$

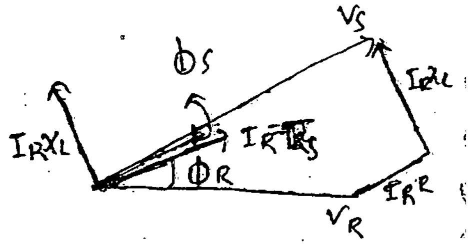
$\boxed{\% V_{REG} = +ve}$

For leading load:



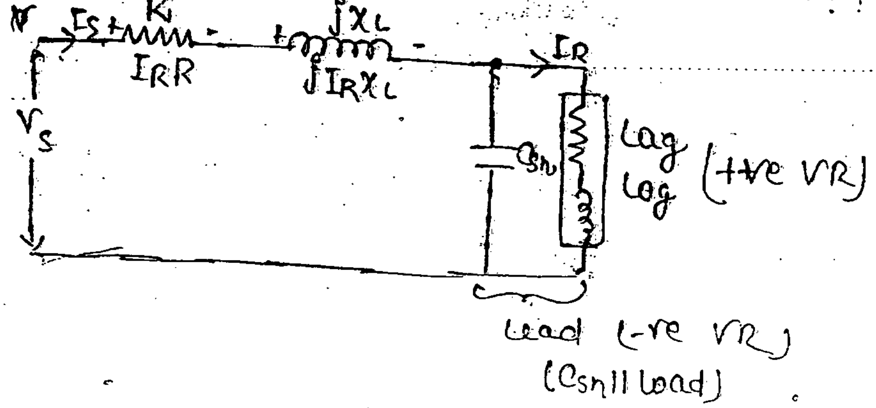






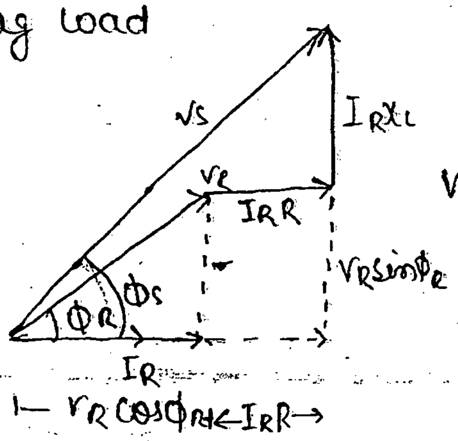
Q. Why designer using shunt capacitor during load cond^n?

Ans.



conclusion about above ckt:-

1) Lag load



$$V_S^2 = (V_R\cos\phi_R + I_RR)^2 + (V_R\sin\phi_R + I_RX_L)^2$$

$$= \cancel{V_R^2 + I^2(R^2+X_L^2) + 2I_RV_R(\cos\phi_R+\sin\phi_R)}$$

$$V_S^2 = V_R^2 + I^2(R^2+X_L^2) + 2I_RV_R(R\cos\phi_R + X_L\sin\phi_R)$$

$$I^2(R^2+X_L^2) << V_R^2$$

$$V_S^2 = V_R^2 + 2I_RV_R(R\cos\phi_R + X_L\sin\phi_R)$$

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

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

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

60A/c

$(1+x)^{1/2} = 1 + x/2$

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

$$\boxed{V_S - V_R = I_R(R\cos\phi_R + X_L\sin\phi_R)}$$

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

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

For max^m Regulation

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

$$-I_R\left[R\sin\phi_R \pm X_L\cos\phi_R)\right] = 0$$

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

$$\tan\phi_R = \frac{X_L}{R}$$

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

$\uparrow$ condn for max^m Regulation

If $Z = R + jX_L = |Z|\angle\theta$ = trans. line parameter

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

$\therefore$ P.F factor of lag load for max^m V_{REG}

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

Condition for $V_{REG} = 0$

$\phi_R = -ve$

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

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

P.F of leading load for $V_{REG} = 0\%$

$$\boxed{\cos\phi_R = \cos\left(\pi/2 - \theta\right) = \sin\theta = \frac{X_L}{Z}}$$

leading

$$\frac{V_{REG}(\text{lag})}{V_{REG}(\text{load})} = \frac{\overbrace{R\cos\phi_R + X_L \sin\phi_R}^{\text{lag angle}}}{\underbrace{R\cos\phi_R - X_L \sin\phi_R}_{\text{lead Angle}}}$$

- Calculation of P_R if $|V_S| = |V_R|$ (or) $V_{REG} = 0\%$

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

Substitute $V_S = V_R$ calculate I_R

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

Where $V_R = V_{ph} = V_L/\sqrt{3}$

$\because$ X_L, R per phase value

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

5. Procedure for cal of C_{sh} required at desired ~~Reduce~~ (Improve voltage Regulation)

(i) Calculate $|V_S|$ crossponding to new V_{REG} using:

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

(ii) calculate ϕ_2

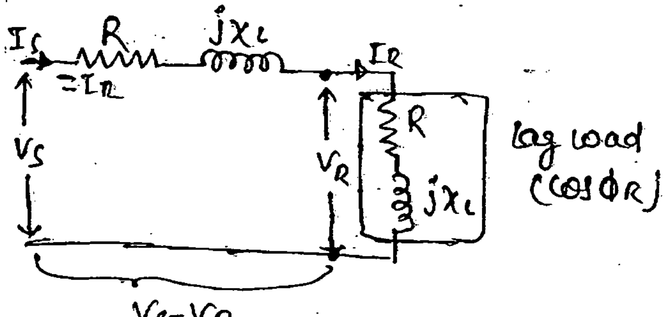
$$V_S - V_R = I_S(R\cos\phi_2 + X_L\sin\phi_2)$$

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

$$V_S V_R - V_R^2 = P_R R + P_R X_L \tan\phi_2$$

$$\boxed{\phi_2 = \tan^{-1}\left[\frac{V_S V_R - RP_R - V_R^2}{P_R X_L}\right]}$$

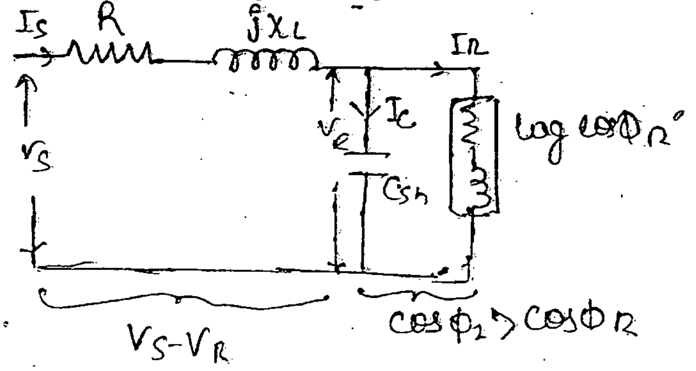
concept:



$$V_S - V_R = I_S(R\cos\phi_R + X_L\sin\phi_R)$$

$|V_R| < |V_S|$ $\quad V_{REG} \Rightarrow +ve \Rightarrow 10\%$.

to reduced the V_{REG} upto 3 to 5%. C_{sh} is used parallel to lag load



63 $\dot{V}_S - \check{V}_R = \dot{I}_S[\check{R}\cos\phi_2 + \check{X}_L\sin\phi_2]$

$$P_R = V_R I_S \cos\phi_2$$

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

$$V_S - V_R = \frac{P_R}{V_R\cos\phi_2}\left[R\cos\phi_2 + X_L\sin\phi_2\right]$$

$$V_R(V_S - V_R) = P_R R + P_R X_L \cancel{\tan\phi_2}$$

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

(3) $|I_S| = \frac{P_R}{V_R\cos\phi_2}$ V_R → perphase value

(4) $\bar{I}_S = \bar{I}_R + \bar{I}_C$

$$I_C = |I_S|\angle-\phi_2 - I_R\angle-\phi_R = |I_C|\angle 90^\circ$$

(5) $I_C = 2\pi f C_{sh} \cdot V_R$

$$C_{sh} = \frac{I_C}{2\pi f V_R}$$

workbook

Q.30 soln. given data

$V_R = 220KV$ $R = 0.15\Omega/Km/ph$ $L = 1.5923\, mH/Km/ph$

$S_R = 381\, MVA$ $\cos\phi_R = 0.8$ lag $l = 40Km$ $f = 50Hz$

Find (1.) $V_S = ?$ $P_S = ?$

(2.) $V_{REG} = ?$ $\eta\%$

Soln: $R = 0.15 \times 40 = 6\Omega$/phase

$X_L = 2\pi f L \cdot l$

$= 2\pi \times 50 \times 1.592 \times 10^{-3} \times 40 = 20\Omega$

$^{64}Z = R + jX_L = 6 + j20$

$= 20.8 \angle 73.3^\circ \Omega$

For Short tr. Line

$A = D = 1 \quad B = Z, \; C = 0$

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

$P_R = \cancel{3} S_{ph} \cdot \cos\phi_R$

$\therefore I_R = \dfrac{S_{ph} \cdot \cos\phi_R}{\sqrt{3} V_{RL} \cdot \cos\phi_R}$

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

$I_R = 1000A = I_S$

$\cos\phi_R = 0.8$ lag

$\therefore \phi_R = 36.86^\circ$

$I_R = I_S = 1000 \angle -36.86^\circ A$ ~~lag~~ lag =

(1) (a) V_S

$V_S = A V_R + B \cdot I_R$

$V_{Sph} = A \cdot V_{Rph} + B \cdot I_R$

$= 1 \cdot \dfrac{220 \times 10^3}{\sqrt{3}} + 20.8 \angle 73.3^\circ \times 1000 \angle -36.86^\circ$

$= 145.3 \angle 4.8^\circ$ KV/ph

$V_{SL} = \sqrt{3} V_{Sph}$

$= \sqrt{3} \times 145.3 \angle 4.8^\circ = 250 \angle 4.8^\circ$ KV

(b) $P_S = \sqrt{3}\, V_{SL}\, I_S \cos\phi_S$

$= \sqrt{3} \times 250 \times 10^3 \times 1000 \cos(48^\circ + 36 - 86^\circ)$

$P_S = 323\, MW$

Alternatives:

For 3ϕ short T.L

$P_L = 3 R I_R^2$

$= 3 \times 6 \times 1000^2 = 18\, MW$

$P_S = P_R + P_L$

$= 381 \times 0.8 + 18 = 323\, MW$

(2) (a) V_{REG}

$= \frac{|V_S| - |V_R|}{|V_R|} \times 100$

$= \frac{250 - 220}{220} \times 100 = 13.674\%$

(b) Effinceiny

$\eta\% = \frac{P_R}{P_S} \times 100$

$= \frac{381 \times 0.8}{323} \times 100$

$\eta\% = 94.45\%$

or $\eta\% = \frac{P_R}{P_R + P_L} \times 100 = 94.45\%$

In the previous problem calculate the capacitance required /phase for reducing VR ------

(i) – 50%   2) 25% $V_R = 220KV$

(i) V_{REG} – 50%

$$V_{REG} = 13.67 \times 50/100 = 6.835$$

$$\frac{V_S - V_R}{V_R} \times 100 = 6.835\%$$

$$\frac{V_S - 220}{200} \times 100 = 6.835$$

$$V_S = 235KV = V_L$$

$$V_{sph} = \frac{235}{\sqrt{3}} = 135.69KV$$

(2) $$\Phi_2 = \tan^{-1}\left(\frac{V_S V_R - V_R^2 - P_R \cdot R}{X_L P_R}\right)$$

$$P_{R3\text{-}\phi} = 3 \times P_{R\,ph}$$

$$P_{Rph} = \frac{P_{R\,3\phi}}{3} = \frac{381 \times 0.8}{3} = 101.6 MV$$

$$V_{S\,ph} = 135.69 \ KV/ph$$

$$V_{R\,ph} = \frac{220}{\sqrt{3}} = 127. \ KV/ph$$

$R = 6\Omega/ph$ $\Phi_2 = 13.61°$

$X_L = 20\Omega/ph$

(3) $$I_S = \frac{P_{S\,ph}}{V_{Rph} \cdot \cos\phi_2} = \frac{101.6 \times 10^6}{127 \times 10^3 \times \cos 13.61°}$$

$$|I_S| = 823.11 \angle{-13.61°}$$

(4) $I_C = I_S - I_R$

$= 823.11 \angle{-13.61^\circ} - 1000 \angle{-36.86^\circ}$

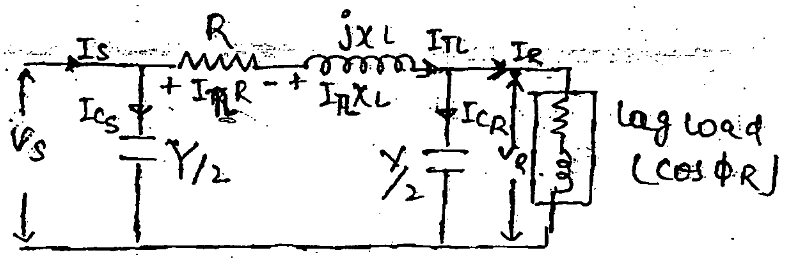
$= 405.9 \angle 90^\circ$

(5) $C_{sh} = \dfrac{I_R}{2\pi f V_{Rph}} = \dfrac{405.9}{2\pi \times 50 \times 127 \times 10^3}$

$\boxed{C_{sh} = 10.1\ \mu F}$

MEDIUM TRANSMISSION-LINE:

NOMINAL π-N/W:



Steps:

(1) V_R as Ref

(2) I_R lags V_R by ϕ_R

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

I_{CR} leads V_R by 90°

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

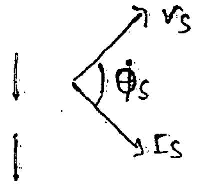
(5) $I_{TL}Z = I_{TL}R + j\, I_{TL}X_L$

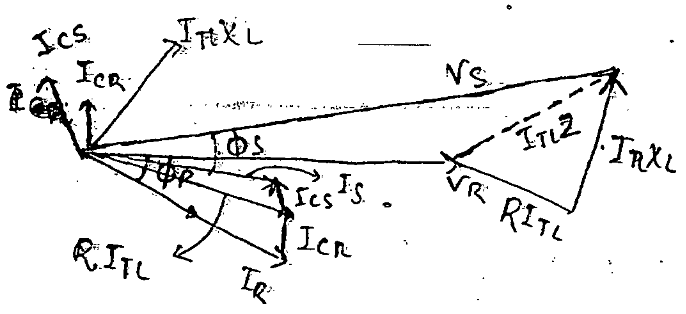
(7) $I_{CS} = V_S \cdot Y/2$ (I_{CS} leads by 90°)

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

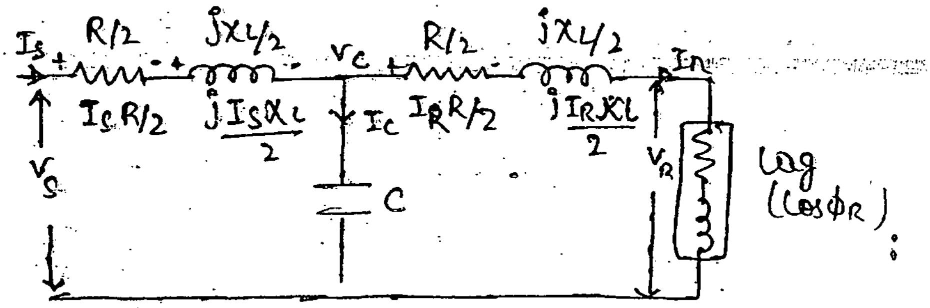
(8) $I_S = I_{CS} + I_{TL}$

(9)





Nominal T-N/W



Steps

(1) V_R as Ref

(2) I_R lags V_R by ϕ_R

(3) $IRZ/2 = I_R \cdot R/2 + j\, I_R X_L/2$

(4) $V_C = V_R + I_R Z/2$

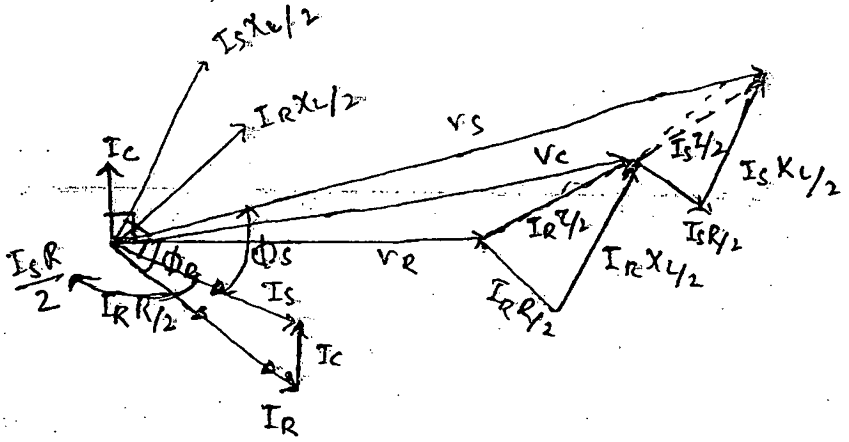
(5) $I_C = V_C Y$ (Ic lead Vc 90°)

(6) $I_S = I_C + I_R$

(7) $IZ/2 = I_S R/2 + j I_S X_L/2$

(8) $V_S = V_C + I_S Z/2$

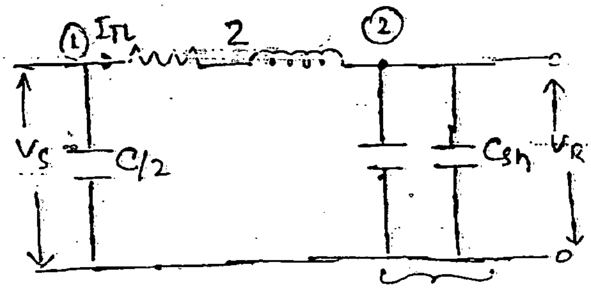
(9) $\angle \phi_S$ between V_S and I_S



- Comparision b/w Short medium line/Medium

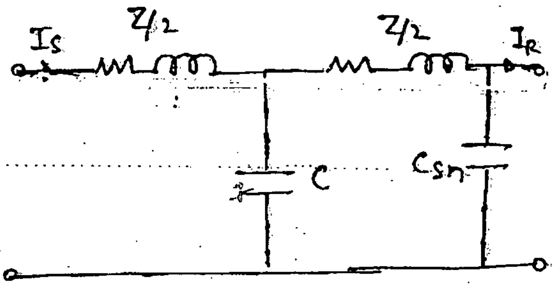
Parameter	Short	Medium
I_S	$\lvert I_S\rvert = \lvert I_R\rvert$	$\lvert I_S\rvert < \lvert I_R\rvert$ due to I_c
V_{REG}	↑	↓
P_L	↑	↓
η	↓	↑
P_S	↑	↓
$\cos\phi_S$	↓	↑

- Comparision b/w π and T-N/W



$I_{TL} = \frac{V_S - V_R}{Z}$ $\quad C_T = \frac{C}{2} + C_{sh}$

π-N/w

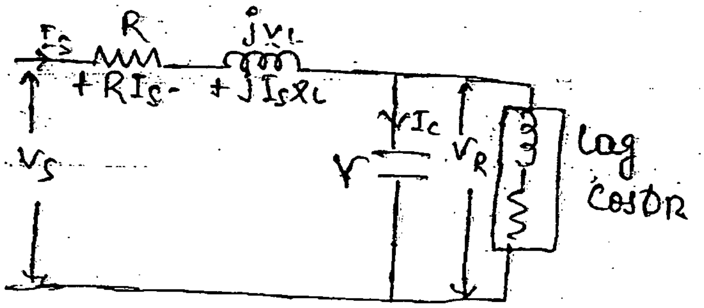


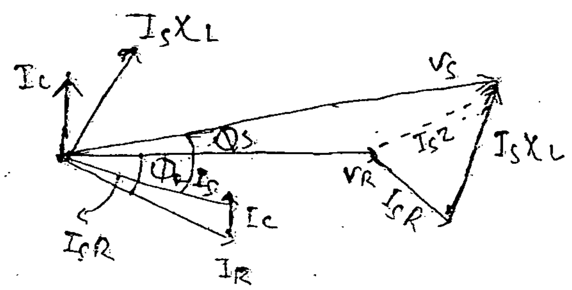
$I_S = \frac{V_S - V_c}{Z/2}$ $\quad I_R = \frac{V_c - V_R}{Z/2}$

T N/w

1) No of Nodes are two. So, no of Eqⁿ less	(i) No of Nodes = 3. No of Eqⁿ = more
2) External compensator connected can easily combine and match with line capacitance	(ii) ~~Capacitance of line is equally distributed.~~ it is Defcult to combine and matching.
3) Capacitance of line is Equally distributed both Sending & Receiving End.	(iii) It is concentrated in the centre.
4) Because of the advantages π n/w is practically used as one Eqⁿ ckt of the Trans line in the load flow analysis	(iv) For analysis the Effect of the line capacitance at the middle of the line it is used.

3) End condenser n/w





(1) Take Reference V_R

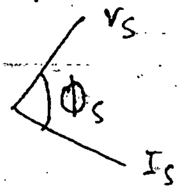
(2) I_R lags V_R by Φ_R

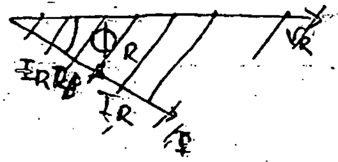
(3) $I_C = V_R \cdot jY$ ~~(I_C leads by V_R by 90°)~~

(4) $I_S = I_C + I_R$

(5) $I_S Z = I_S R + j I_S X_L$

(6) $V_S = V_R + I_S Z$

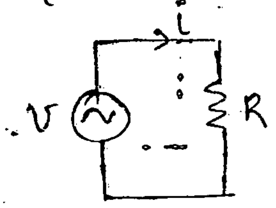




→ Power Factor:

It is degree to which a given load (R_L R_C) matches with pure resistive load

(1) R-load



$V = V_m \sin\omega t$

$i = I_m \sin\omega t$

$I_m = V_m/R$

Instantanious power

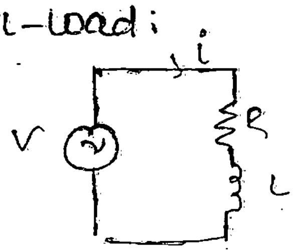
$p = v \cdot i$

$= V_m \sin\omega t \cdot I_m \sin\omega t = V_m I_m \sin^2\omega t$

$$P_{avg} = \frac{1}{2\pi}\int_0^{2\pi} V_m I_m \sin^2\omega t \, dt = \frac{V_m I_m}{2} = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}}$$

$P_{avg} = V_{Rms} \cdot I_{Rms}$

(2) RL-load:



$V = V_m \sin\omega t$

$i = I_m (\sin\omega t - \phi)$

$I_m = \frac{V_m}{Z}$

$Z = R + j\omega L$

$\phi = \tan^{-1}\left(\frac{\omega L}{R}\right)$

$P = V \cdot I$

$= V_m I_m \sin\omega t \cdot \sin(\omega t - \phi)$

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

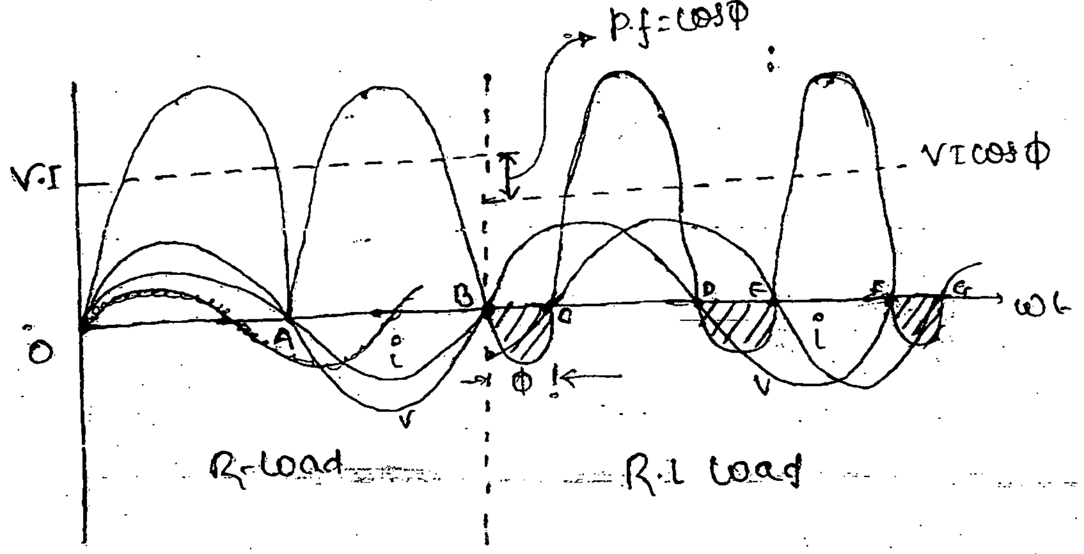
Where $P = VI\cos\phi$

$Q = VI\sin\phi$

$P_{avg} = \frac{1}{2\pi}\int_0^{2\pi} p \cdot d(\omega t)$

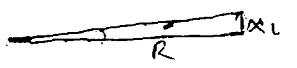
$$\boxed{P_{avg} = P = VI\cos\phi}$$

Where $\frac{V_m}{\sqrt{2}} = V$ $\quad I = \frac{I_m}{\sqrt{2}}$



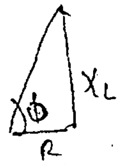
$$\boxed{\frac{P_{avg\,RL}}{P_{avg\,R}} = \frac{VI\cos\phi}{VI} = \cos\phi}$$

Concepts:



$\cos\phi\downarrow$, $\cos\phi\uparrow$

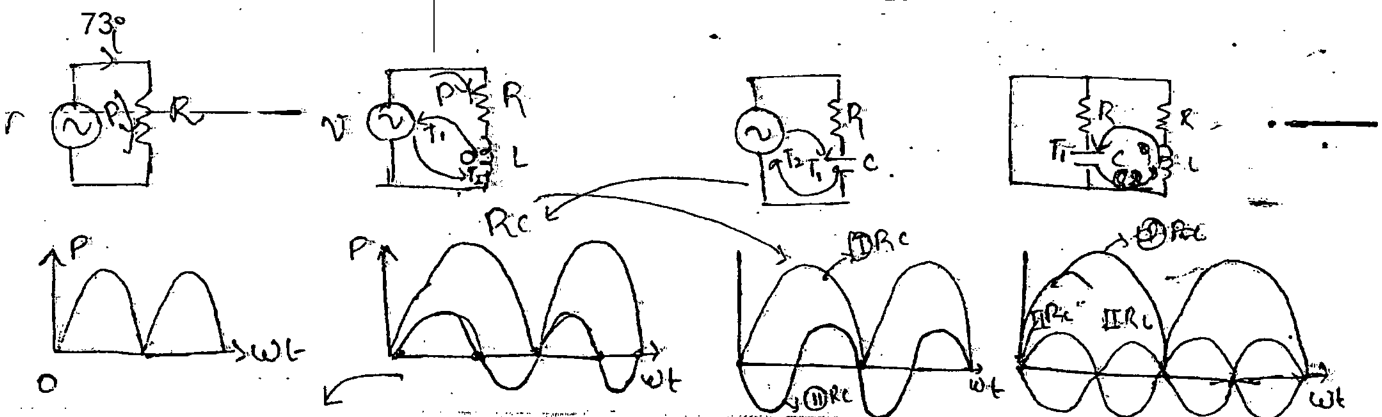
P_{avg} is max^m . $X_L\downarrow$



* Up - Resistance dominates
* down - inductor domin.

$\phi\uparrow$ $\cos\phi\downarrow$

$X_L\uparrow$ P_{av} is min^m



$$p = \underbrace{p(1-2\cos\omega t)}_{\text{I Rc}} + \underbrace{Q \sin 2\omega t}_{\text{II Rc}}$$

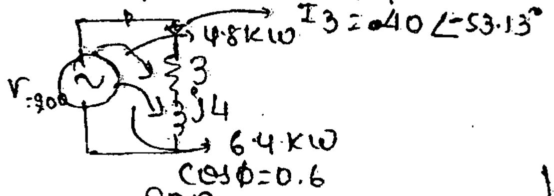
$$p = vi = \underbrace{P(1-\cos 2\omega t)}_{\text{① Rc}} \cdot \underbrace{Q \sin 2\omega t}_{\text{② Rc}}$$

	Source	Sink
L	lead vars	lag vars
C	lag vars	lead vars

Chapter 1

Q 6.

I_1'' without capacitor



Load

$$I_3 = \frac{200}{3+j4}$$

$$= 40\angle -53.13° \text{ A}$$

$$\cos\phi_3 = \cos 53.13° = 0.6 \text{ lag}$$

$$S_3 = I_3^* V^*$$

$$= 200 \times 40\angle 53.13°$$

$$= 200(40\cos 53.13° + j40\sin 53.13°)$$

$$= 200(40 \times 0.6 + j40 \times 0.8)$$

$$= 4800 + j6400$$

$P_3 = 4800$ $\quad Q_3 = 6400$

$= \cancel{4.8\text{ kW}}$ $\quad = 6.4 \text{ kVAR}$

Source (-ve for delivering)

$$I_1 = -40\angle -53.13°$$

$$S = V(-I_1^*)$$

$$= -200 \times 40\angle 53.13°$$

$$= -200(40\cos 53.13° + 40j\sin 53.13°)$$

$$= -4800 - j6400$$

$P_1 = -4.8$ kW

$Q_1 = -6.4$ kVAR

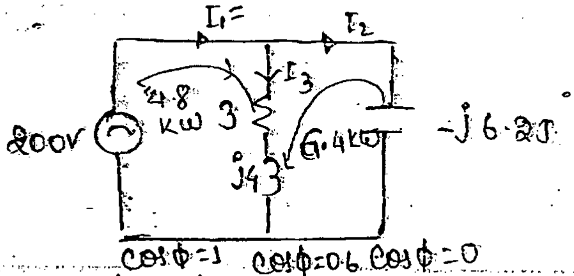
$|S_1| = \sqrt{6.4^2 + 4.8^2}$

$=$

$\cos\phi_1 = 0.6$

(2) with capacitor

(i) $X_c = -j6.25\,\Omega$



Soln. Load

$I_3 = 40\angle -53.13^\circ$

$P_3 = 4.8\ \text{KW}$

$Q_3 = 6.4\ \text{KVAR}$

$\cos\phi = 0.6\ \text{lag}$

Capacitor

$$I_2 = \frac{200}{j6.25} = 32\angle 90^\circ$$

$S_2 = V \cdot I_2^*$

$= -j6.4 \times 10^3$

$P_2 = 0$

$Q_2 = -6.4\ \text{KVAR}$

$\cos\phi_2 = 0$

Source:

$I_1 = I_2 + I_3$

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

$= 24\angle 0^\circ$

$S_1 = V_1(-I_1^*)$

$= 200(-24\angle 0)$

$= -4.8 + j0$

$P_1 = -4.8\ \text{KW}$

$\phi_1 = 0$

$\cos\phi = 1$

$$S_1 = \sqrt{P_1^2 + Q_1^2}$$
$$= 4.8\,KVA$$

(1) Capacity of the genrator reduced so the cost of the electrical energy in m+m

(2) Tr. line current reduces

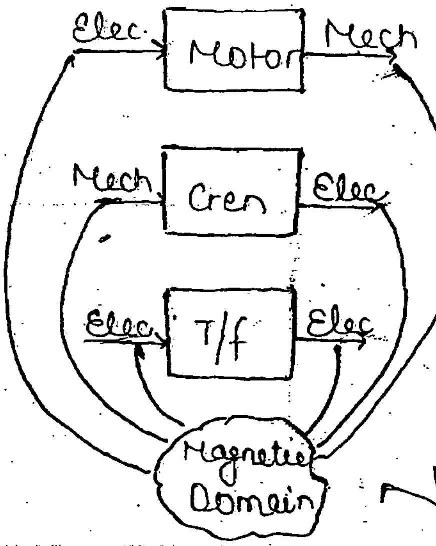
(3) Line losses reduce.

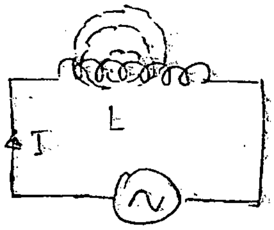
(4) Efficiency improve.

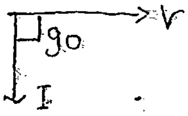
(5) Voltage regulation Improve.

(6.)

Importance of Reactive power:







$\text{Energy} = \frac{1}{2} L \cdot I^2$

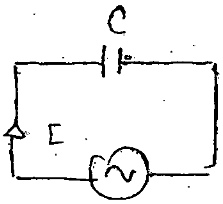
$= \text{Power} \times T$

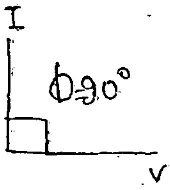
$P = VI\cos\phi$ $\quad Q = VI\sin\phi$

$P = VI\cos 90^\circ$ $\quad Q = VI\sin 90^\circ$

$P = 0$ $\quad Q = VI$

$\frac{1}{2} L I^2$



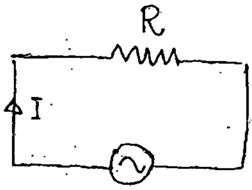


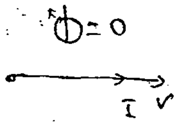
$\text{Energy} = \frac{1}{2} CV^2$

$= \text{Power} \times \text{time}$

$P = VI\cos 90^\circ$ $\quad Q = VI\sin 90^\circ$

$P = 0$ $\quad Q = VI$





$\text{Energy} = I^2 R t$

$= \text{power} \times \text{time}$

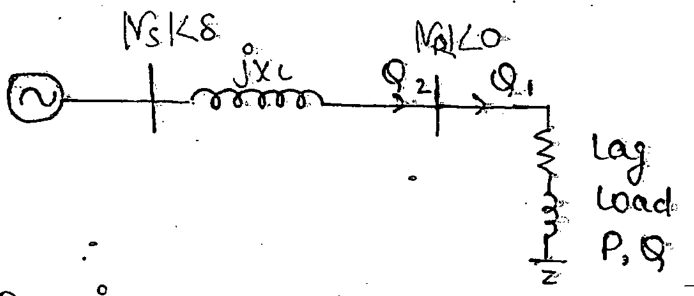
$P = VI\cos 0$ $\quad Q = VI\sin 0$

$P = VI$ $\quad Q = 0$

$P = \frac{2\pi N T}{60}$

$P \propto T$

N.B to produced trorque active power is used.



Q_1 = Reactive power demand by load

Q_2 = Reactive power supply

$Q_R = Q_1 - Q_2$

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

Assume δ is small $\cos\delta = 1$

$$\phi_R = \left|\frac{V_S V_R}{X_L}\right| - \frac{V_R^2}{X_L}$$

$$V_R^2 - V_S V_R + X_L \phi_R = 0$$

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

if $$V_R = \frac{V_S}{2} + \frac{\sqrt{V_S^2 - 4X_L\phi_R}}{2}$$

After constructed the trans. line

V_S and X_L constant

$\therefore$ only $\phi_R \propto V_R$

(a) if $\phi_R = 0 \Rightarrow Q_1 = Q_2$ $\quad V_R = V_S \quad V.R = 0\%$

(b) if $\phi_R > 0 \Rightarrow Q_1 > Q_2$ $\quad |V_R| < |V_S| = V_{Reg} = +ve$

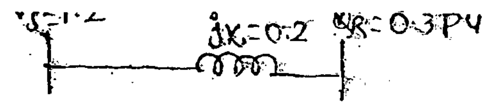
Peak load time

(c) if $\phi_R < 0 \Rightarrow Q_R < Q$ $\quad |V_R| > |V_S| \Rightarrow V_{Reg} = -ve$

$\Rightarrow$ ferrante effect

$\Rightarrow$ off peak load time

Q5. 78



$0.86 + 0.5j$
-1
$-0.14 + 0.5j$
$-0.51 \angle 105^\circ$
$0.5 \angle 90^\circ$
$0.5 \angle 15^\circ$

$\Delta V = (V_S - V_R)$

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

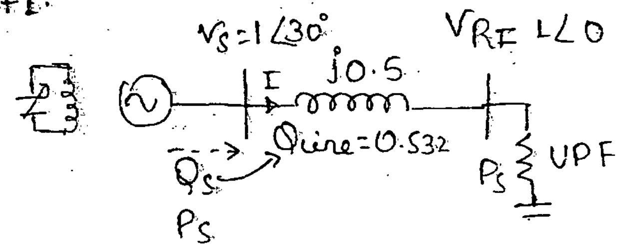
$$= \frac{1.2}{2} + \sqrt{\frac{(1.2)^2 - 4 \times 0.2 \times 0.3}{2}}$$

$$= 0.6 + \sqrt{\frac{(1.2)^2 - 0.24}{2}}$$

$$= 0.6 + \sqrt{\frac{1.44 - 0.24}{2}}$$

$= 1.147$ Ans

~~Concept 1~~



$$I = \frac{V_S - V_R}{jX} = \frac{1\angle 30^\circ - 1\angle 0}{j0.5} = \frac{0.5\angle 105}{0.5\angle 90^\circ} = 1.03\angle 15^\circ$$

$$Q_{line} = |I^2 \times X_L| = 1.03 \times 0.5 = 0.532$$

Concept 2:

$$Q_S = \frac{V_S^2}{X_L} - \frac{V_S V_R}{X_L}\cos\delta = \frac{V_S}{X_L}(V_S - V_R) \quad \cos\delta = 1$$

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

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

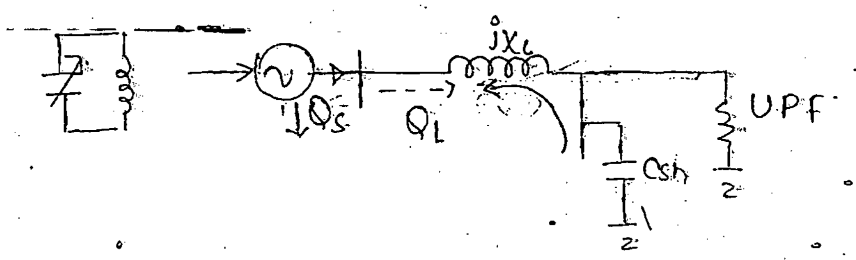
$$\boxed{Q_R \propto (V_S - V_R)}$$

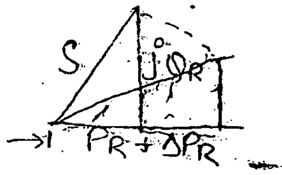
$$P_R = \left|\frac{V_R V_S}{X_L}\right| \sin\delta$$

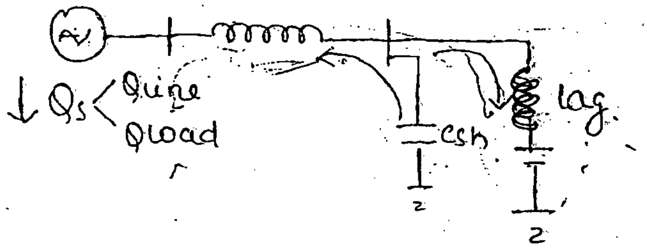
$$\boxed{P_R \propto \sin\delta}$$

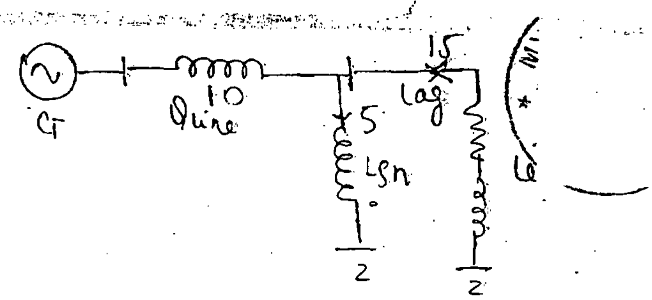
79

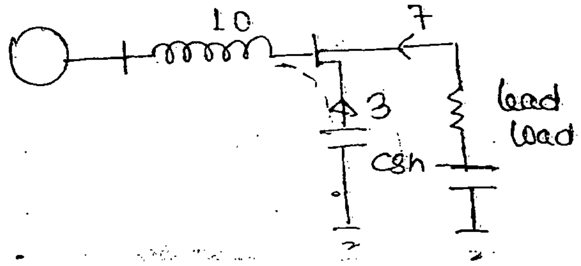
Q.3 use of compensator:







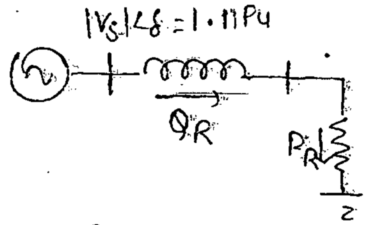




Copensator is used to reduce Reactive power to the delivered max^m active power at load

Q. A Tr. Line has reactance 0.5 PU operates at $V_R = 1\angle 0$. calculate V_S and δ for supplying loads:

Soln. (a) UPF at 1 PU active power (b) 1 PU active power at 0.8



concept

* $P_R \propto \sin\delta$
* $Q_R \propto |V_S| - |V_R|$

$$P_R = \frac{|V_S||V_S|}{X_L}$$

Soln (a) $$P_R = \frac{|V_R||V_S|}{X_L}\sin\delta$$

$$1 = \frac{V_S \cdot 1}{0.5}\cdot\sin\delta$$

$$V_S\sin\delta = 0.5 \quad \text{— (1)}$$

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

For UPF $Q_R = 0$

$$0 = \frac{\cancel{0.5}\times V_S}{0.5}\cos\delta - \frac{1}{0.5}$$

i.e. $$V_S\cos\delta = 1 \quad \text{— (11)}$$

from eqn (11) $\cancel{\cos\delta = \frac{1}{0.5}}$

$$\tan\delta = \frac{0.5}{1}$$

$$\begin{cases} \delta = 26.56 \ \underline{\underline{\text{Ans}}} \\ V_S = 1.11 \text{ P.U} \end{cases}$$

(b) $$P_R = \frac{|V_R||V_S|}{X_L}\sin\delta$$

$$1 = \frac{V_S\cdot}{0.5}\times\sin\delta$$

$$V_S\sin\delta = 0.5 \quad \text{— (1)}$$

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

$$Q_R = P_R\tan\phi = 0.75$$

$$0.75 = \left|\frac{V_S\times 1}{0.5}\right|\cos\delta - \frac{1^2}{0.5}$$

$$V_S\cos\delta = 1.375 \quad \text{— (1)}$$

$$V_S = 1.42$$

$$\delta = 20^\circ$$

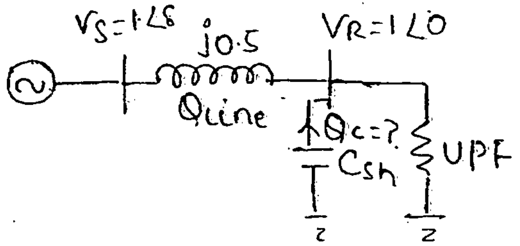
Note: With uncompensated Tr. line For suppling active & reactive power, δ and $(V_S - V_R)$ has to be maintain this is not pradically valid for continously variableload to compensate this effect ~~at~~ power factor correction device like shunt capacitor and Reactor to be installed at the load end so $|V_S|$ and $|V_R|$ can be maintained.

The reactive power burden at the Gen end is reduces so that max^m active power is delivered by generator.

Q. In the previous problem calculate the rating and type of the compensator required for maintaing $|V_S| = |V_R| = 1$ PU. for the following load.

(a) 1 P.U UPF (b) 1 PU 0.8 lag (d) 1 P.U 0.8 lead
(c) 1 P.U 0.995 lead.

Soln:-



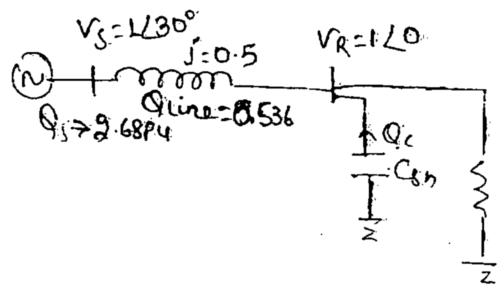
for V_S = reduce 1.11 to 1

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

$$1 = \frac{1 \times 1}{0.5} \sin\delta$$

$$\delta = 30°$$

$$Q_{line} = I^2 X_L = 0.536$$



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

$$= \frac{1^2}{0.5} - \frac{1\times 1}{0.5}\cos 30^\circ = 0.268\,\text{pu}$$

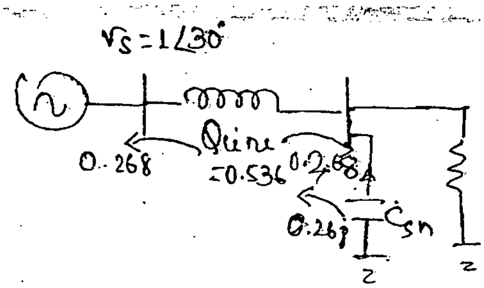
$$Q_C = 0.536 - 0.268 = 0.268\,\text{pu} \text{ supplied by } C_{sh}$$

Method II

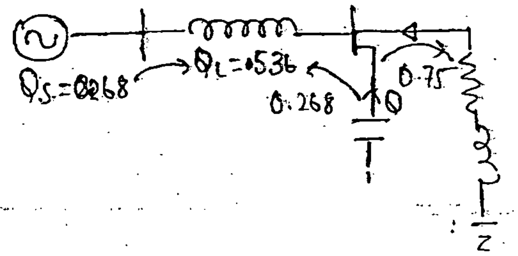
$$Q_R = \left|\frac{V_S V_R}{X_L}\right|\cos\delta - \frac{V_R^2}{X_L}$$

$$= \frac{1\times 1}{0.5}\cos 30^\circ - \frac{1}{0.5}$$

$$Q_R = -0.268\,\text{pu} = +0.268$$



(2) 1 pu 0.8 lag



$$Q_{load} = 1\times\tan(\cos^{-1}0.8) = 0.75$$

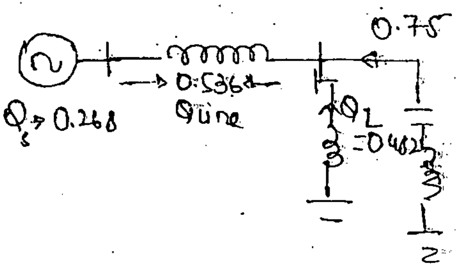
$$Q_S = 0.268$$

$$Q_L = 0.536$$

$$Q_C = (Q_{load} + Q_{line}) - Q_S$$

$$= 1.018\,\text{pu}$$

(3)



R C

$P + jQ$

$P - jQ$

$Z = R + j(X_L - X_C)$

$X_L > X_C$

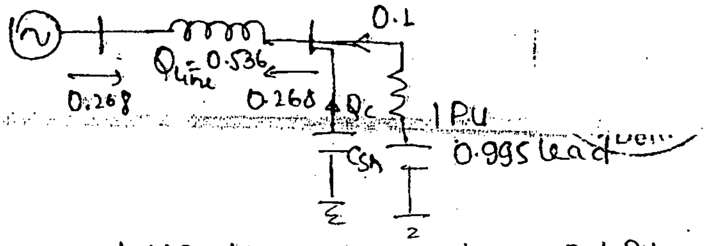
$Z = R +$

$Q_{load} = 1 \times \tan(-\cos^{-1} 0.8) = -0.75$

lead load deliver 0.75 lag vars

$Q_L = 0.75 - 0.268 = 0.482$ pu of lag vars absorbed by Lsh

(4)



$Q_{Load} = 1 \times \tan^{-1}(-\cos^{-1} 0.995) = -0.1$ PU

lead load deliver 0.1 PU of lag vars

$Q_c = 0.268 - 0.1 = 0.168$ lags vars supplied by Csh