MASTER'S INTERNET

INTERNET & XEROX CENTER

Shop.no.28 & 128-130 Suryalok Complex, Gun foundry,
Abids, Hyderabad – 1
Ph: 040 - 42030795, 40047829 fax: 040-42030795

Services Offered

ApOnline Payment's, Easy Movies Booking, Railway Booking, Bus Booking, KSRTC Booking, Flight Booking, and Much More...

Name ______________________________

Course ______________________________

Subject ______________________________

Internet, Xerox, Printout, Book Printing, Fax IN/OUT, Spiral Binding, Color Print Out, Color Xerox.

* Power generation
* Per unit system
* symmetrical components
* Fault Analysis
* Power system stability
* construction of Y_{Bus} & Z_{Bus}
* Load flow studies
* Economic Aspects & Economic Load dispatch

Power system:-

It is the system which can deals with the principle of power generation & Transmission & distribution in order to supply electrical energy to various consumers on economical basis.

Economical:- The cost of energy should be minimum.

Electrical energy = Power x Time (or)

units - whr (or) Kwhr (or) unit

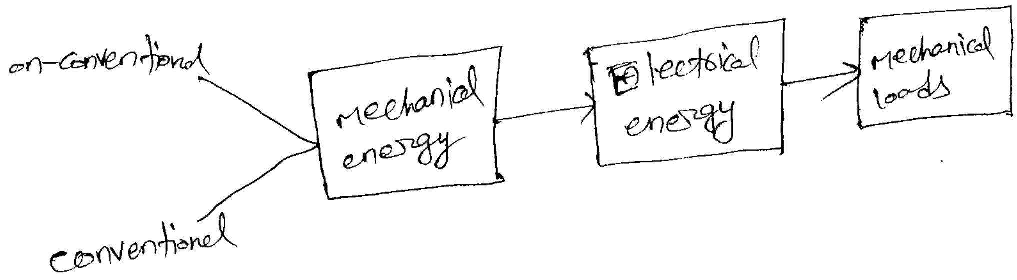
1 unit = 1000 whr (or) 1Kwhr

Electrical energy → To Produce an artificial illumination (light) in order to see the objects clearly on the assigned work
→ To drive the mechanical loads.

mechanical energy → Electrical energy → mechanical loads

↳ It is the history of PS

→ Acc to energy principle, if the available energy is transform in to another form of energy, the loss in the transformation is less & efficiency is high. Hence the cost of energy transformation less.



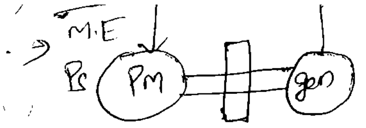
Non-conventional	Conventional
→ These are the energy sources, which are renewable (or) non-exhaustive	→ These are the energy sources, which are non-renewable (or) exhaustive
→ small capacity power generation	→ Bulk capacity power generation
→ ex:- solar energy, wind, Tidal, geothermal, biomass, magneto hydro dynamo generator (MHD)	→ ex: Thermal, Hydel, nuclear, gas, diesel.

Installed capacity 2,00,000 MW (India) as on 31-03-2012 financial year

In this 2,00,000 MW
63% Thermal,
32% Hydel
3% nuclear
2% Balance → Both conventional & non-conventional

→ except solar system, the remaining is having rotational principle for energy conversion

→ All the plants are having rotational principle the energy transformation



P_e (or) P_G (Real power)

Pm = Prime mover

P_s = mechanical i/p

P_e = electrical o/p

$P = P_s - P_e$

$\neq 0$

(at any instant)

→ In case of non conventional plant the mechanical energy is unable to control based on the load on the generator, so that an any instant of time the resultant power is not zero, hence the rotating system will experience either acceleration or deceleration. Hence the generator which is coupled should be a variable speed i.e., asynchronous generators are coupled.

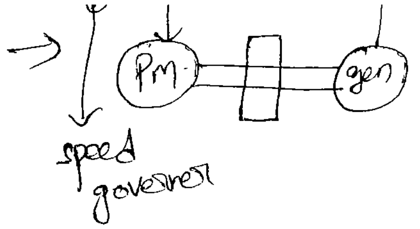
→ Rating of the system (electrical)

Power rating :— kW – Few MW

$\leq$ 5 MW

Voltage rating :— 230V, 415 V, 650V (or) 1100V,

$\underbrace{\hspace{4cm}}$ Low voltage in India



$P = P_s - P_e$

$= 0$

(at any instant)

→ In conventional plant the mech i/p is able to control based on the load on the generator, so that at any instant of time the resultant power will be zero. Hence the rotating system is neither acceleration nor deceleration, so that it can work at a constant speed. The constant (synchronous speed) speed generators are coupled with primemover.

→ Rating of system (electrical)

Power rating :— MW – 1000 MW (Thermal/nuclear)

Voltage rating :— 3.3 kV, 6.6 kV, 11kV, 13.2 kV, 22 kV max gen. vol

$\underbrace{\hspace{4cm}}$ High voltage (HV) in India

HV → upto 33kV

→ **Location of the plant:-**

most of these plants are located near to the loads because there are no much constructions to fullfill, while selecting the site for the plant.

Power generation is distributed directly to the local consumers.

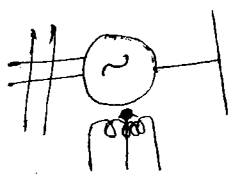
→ **Location of the plant:-**

most of these plants are located at the remote places because there are certain constants to full fill, while selecting the site for the plant.

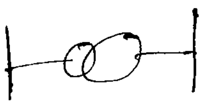
The bulk amount of power is generated at remote place and it needs to be carried out over a longer distances which is called as power transmission and then followed by distribution of the power to various consumers.

machine models:-

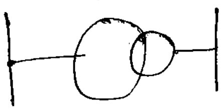
synchronous generator:-



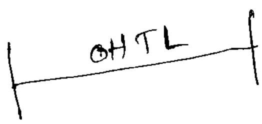
Transformer:-



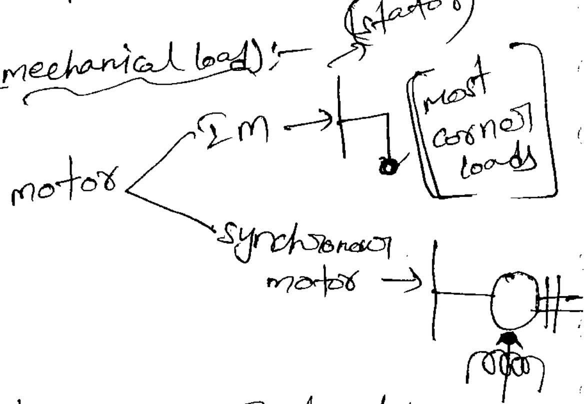
(or)



Transmission line:-

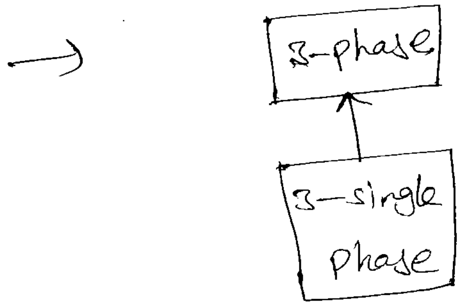


Load (mechanical load):-

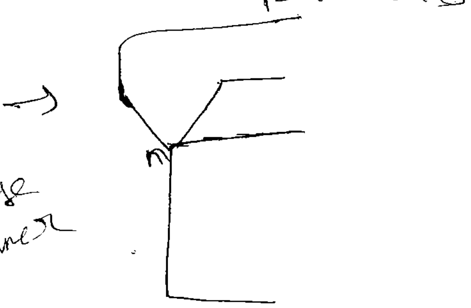


→ In order to generator the bulk amount of power & also to transmit, it is prefered have a 3-φ system. In a 3-φ syme system the 3-phases are identical, hence the electrical equipment can be represented by a single line diagram for the

3) Rolls—Gill



Y (or) Δ



→ except the consumer side, the remaining network is configured a 3-ϕ, 3wire Y to get the nutral point for the purpose of employ the relays in a phase manner i.e, phase to nutral.
In order to protect the equipment against the faults, at the consumer side it is the 3-ϕ, 4 wire in order to have 1-ϕ loads.
because of

→ A syn gen is having a rating of aparant power i.e, real power due to mechanical i/p & the reactive power due to rotor excitation voltage.

$S = 3VI$ (3-ϕ)

$V =$ phase voltage

$I =$ " current

But a $S = \frac{3V_L}{\sqrt{3}} I_L = \sqrt{3} V_L I_L$

$V = \frac{V_L}{\sqrt{3}}$

$I_p = I_L$

→ In a 3-ϕ 3wire system the voltage will be expressed as line to line ex: generator rating

250 MVA (3-ϕ)

13.2 KV (L-L)

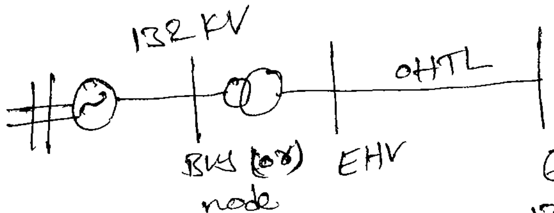
3-ϕ

50Hz

0.9 Pf lag

→ The bulk amount of amount ~~x~~ of power is generated at a remote place at high voltage. The power carrying capacity will be high, so that the loss in the transmission n/w is high.

→ The reduce the line loss, it is necessary to increase the voltage level so that the current capacity reduce by using a transformer which is of step up character.



66 KV

132 KV

220 KV

Modern EHV 400 KV

ultra high voltage - 765 KV & above in ac network

~~If the pow~~

→ For the same amount of power, if the operating voltage will increase will on certain limit, the cost of insulation will increase, so that the ~~t~~ransmission system is uneconomical.

→ The selection of the Transmission voltage in TL is an economical between

× Cost of conductor and cost of insulation

$$V = 5.5\sqrt{0.62\,l + \frac{P}{150}}\ \text{kV}$$

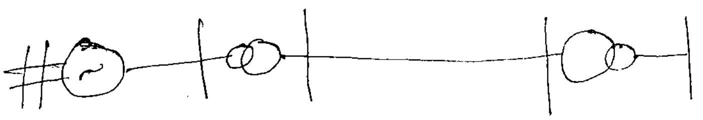
V = (L–L)

l = length of TL in km

P = Power in kw of 3-φ

Insulation ∝ Voltage
current ∝ area of cross section

→ At the end of the transmission line the voltages are very high



→ At the end of the TL there will be a step down Transformer in order to get the required voltage of consumer, is called as 'Distribution level' [$\underbrace{33\text{KV}, 11\text{KV}}_{\substack{HV \\ 3-\phi,\ 3\text{wire}}}$, $\underbrace{415\text{V or } 230\text{V}}_{\substack{LV \\ 3-\phi,\ 4\text{wire}}}$].

(1-φ consumer)

415 V → (L–L)

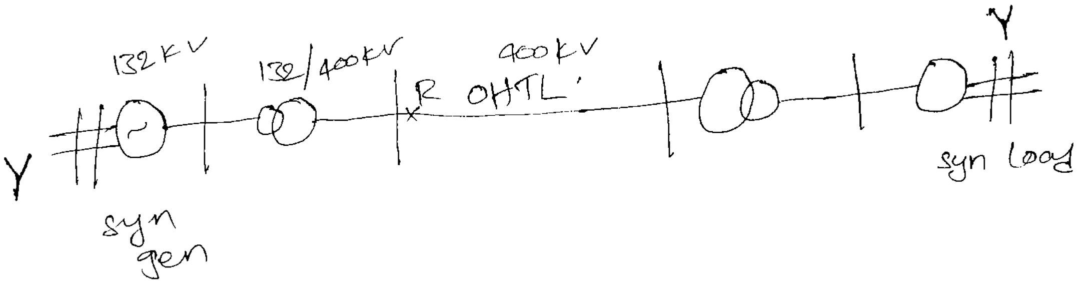
230 V → (L–n) ✓

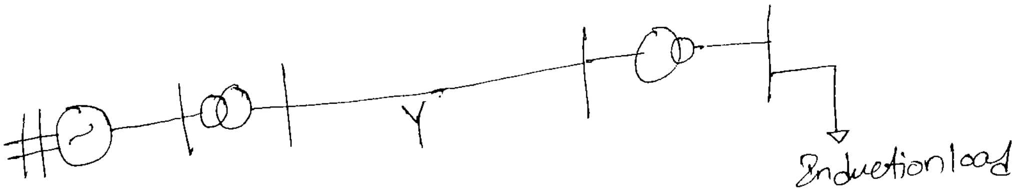
consumer:-

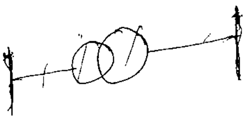
mechanical load

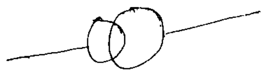
→ Im

→ synchronous motor









Y Y → Line side

(or)

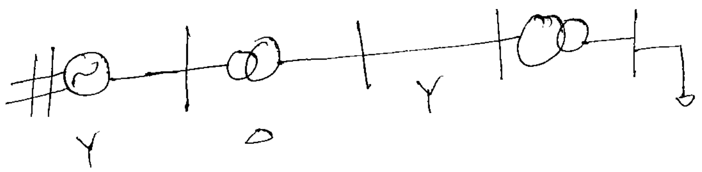
Δ Y → Line side

→ In order to employ the relays in transmission line, the line side of the transformer should be star(Y). The source side of the transformer can be either star(Y) or delta (Δ).

Y → ≥ 66 kV. → $\boxed{V_p = \frac{V_L}{\sqrt{3}}}$ ↑ cost of the insulator is reduced.

or

Δ → ≤ 33 kV → $\boxed{I_p = \frac{I_L}{\sqrt{3}}}$ → To reduce the cost of conductor



step down mechanism:-

400KV / 220KV
Y

220KV / 132KV
Y Y

132KV / 33KV
Y Y

33KV / 11KV
o Y

} Power Transmission

11KV / 415V → Distribution transform
o Y

Perunit system:-

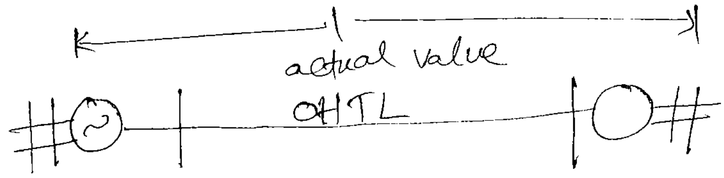
The electrical ~~equipments~~ quantities of the system deals in two ways. They are

i) Actual value — Associated with units

ii) perunit value — no units

Impedance — 20 ohms (actual)
— 1.2 (PU)

current — 100 Amp (actual)
— 4.0 (PU)



→ Ideal case

syn gen
11 KV
100 mVA

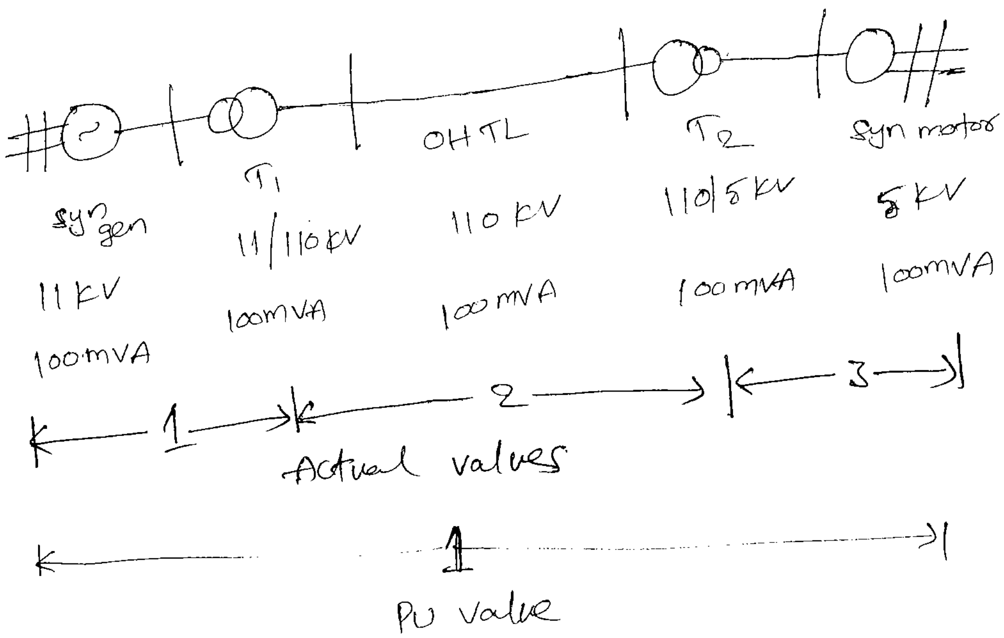
11 KV
100 mVA

syn motor
11 KV
100 mVA

$S = \sqrt{3} V_L I_L$

$$I_L = \frac{S}{\sqrt{3} V_L} = I_P$$

$$Z = \frac{V}{I}$$



→ The PU system is 1 then reduce the number of calculations. Hence time taking is less to solve the eqns.

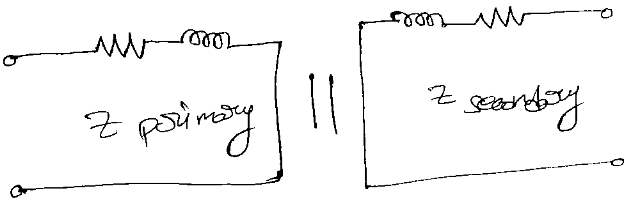
<u>Actual values</u>

→ If the given single line dia is having more than one operating voltage, the above single line diagram is represented electrically by more than one n/w there will be more than one network eqn to be solve. Hence the time taking is high to solve the eqns

<u>PU values</u>

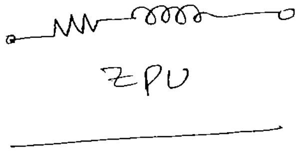
→ If the given single line dia is having more than one operating voltage, the above single line diagram, is represented 1. There will be one network eqn will be solve, hence the time taking is less to solve the eqn.

→ The impedance of transformer is not same in primary & secondary. Hence it can be represented by two networks



$Z_{pri} \neq Z_{sec}$

→ The impedance of Transformer is same in primary & secondary. Hence it can be represented by only one network saying that

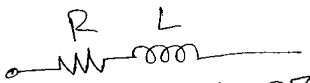


$Z_{pri} = Z_{sec}$

→ In the PU analysis the given single line diagram will be replaced by an electrical equivallent i.e., impedance (or) reactance network in a phase manner w.r.to nutral under the assumption that the existing system is a 3-φ star equivallent. Even it there is a Δ configuration it can be assumed as converted into Y equivallent. They associated electrical quantities will be expressed as PU values

Electrical equivallent:-

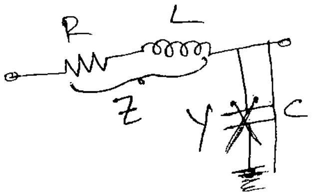
syn machine:- voltage source (stator) in series w.r.to impedance or reactance (stator)



$X = 2\pi f L$

Transformer:- Impedance (or) Reactance

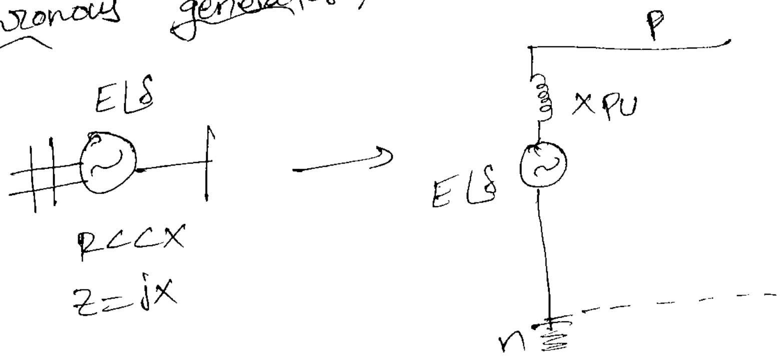
Transmission line:-



→ During the short circuit studies, stability analysis, the capacitance of the can be ignore. The TL is represented either by impedance or reactance only. In the load flow studies, in addition to impedance, the capacitance of the line can be represented in impedance form.

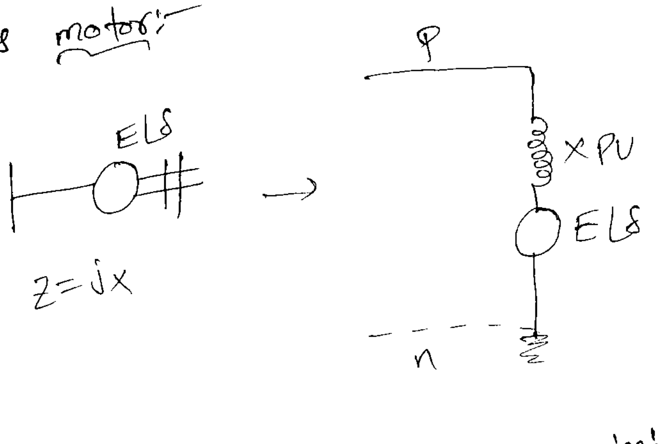
Inductive load :- It can be represented as impedance / reactance only

Synchronous generator :-

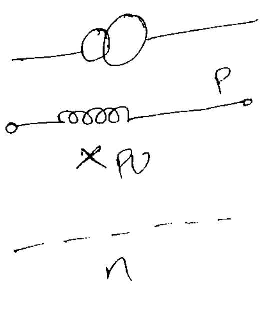


$E \rightarrow$ excitation voltage (Reactive power)
$\delta \rightarrow$ real power (rotor angle)

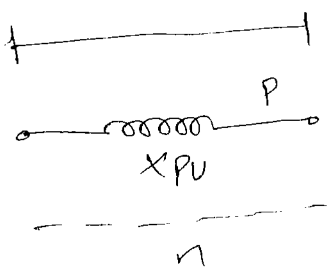
Synchronous motor :-



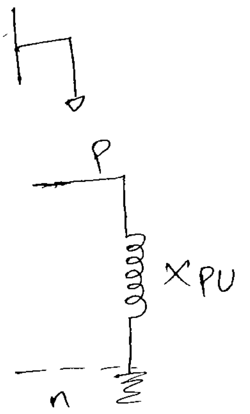
Transformer :-

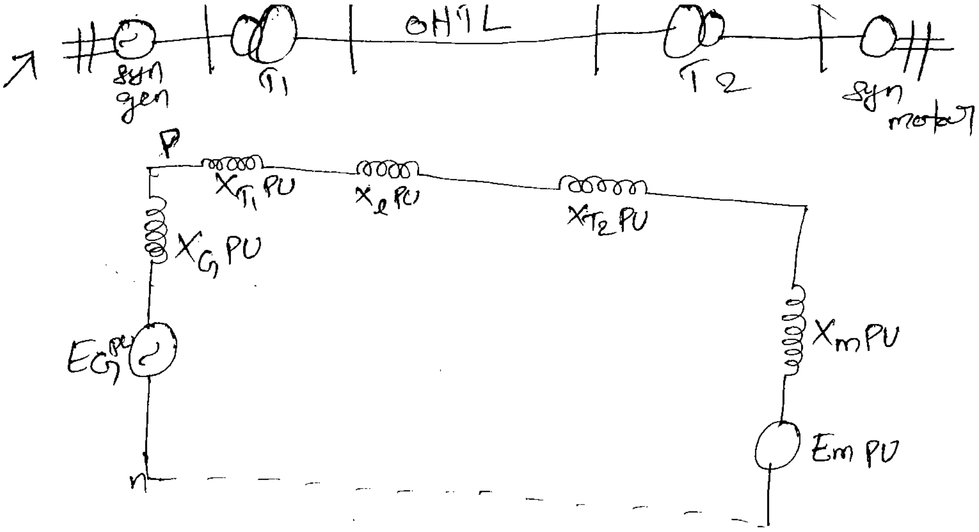


Transmission line



Inductive load





The above electrical equivalent network is having excitation voltages and impedances / reactances. The above electrical quantities are to be expressed in PU values by using the rating of the electrical system

i) voltage & current

ii) voltage & power ratings [VA (volt ampere) → apparent power]

$$\text{Per-unit value} = \frac{\text{actual quantity in the units}}{\text{Base (or) reference quantity in the same units}}$$

→ The value of the PU quantity that depends on base value, if the base value is not specified select maximum rating of equipment as the base value and do the calculations.

Synchronous generator:-

Voltage = V volts

current = I amps

Impedance = Z ohms

$$V_{PU} = \frac{V_a}{V_b}$$

→ As only one generator and the base value is not specified, consider the voltage of the generator of base value.

→ $$Z_{pu} = \frac{Z\Omega}{Z_b}$$

$$Z_b = \frac{V_b}{I_b}\Omega$$

The base impedance can be calculated by considering the voltage and the current of the alternators of the base values.

→ $$\boxed{Z_{pu} = \frac{Z\Omega}{\left(\frac{V_b}{I_b}\right)} = Z\Omega \cdot \frac{I_b}{V_b}} \rightarrow ①$$

The synchronous generator is having the rating interms of voltage and current, in Ideal case.

synchronous generator

→ Voltage = V volts
current = VA (volt-ampere)

$$\boxed{\frac{VA_b}{V_b} = I_b \text{ (Amps)}} \rightarrow ②$$

$$Z_{pu} = Z\Omega \cdot \frac{\left(\frac{VA_b}{V_b}\right)}{V_b} = Z\Omega \cdot \frac{VA_b}{(V_b)^2}$$

To produce the bulk amount of power, they alternator is having 'mVA' capacity and ~~the~~ operating voltage is 'kV.'

$$Z_{pu} = Z\Omega \cdot \frac{\left(\frac{VA_b}{10^6}\right)}{\left(\frac{V_b}{10^3}\right)^2}$$

$$\boxed{Z_{PU} = Z\Omega \cdot \frac{MVA_b}{(KV_b)^2}} \rightarrow (3)$$

(or)

$$\boxed{X_{PU} = X\Omega \cdot \frac{MVA_b}{(KV_b)^2}}$$

$3-\phi$

L-L

ϕ

ex: 12MVA, 6.6KV, 3-ϕ alternator having $X = 4\Omega$. what is the PU reactance of the alternator.

12MVA (3-ϕ) $X = 4\Omega$ (L-n)

6.6KV (L-L)

$$X_{PU} = X\Omega \cdot \frac{(MVA_b/3)}{(KV_b/\sqrt{3})^2}$$

$$= X\Omega \cdot \frac{MVA_b}{KV_b}$$

The pu reactance of the alternator is directly proportional to MVA capacity of 3-ϕ and inversely proportional to square of the operating voltage of L-L in KV.

$$X_{PU} = \frac{4 \times 12}{(6.6)^2}$$

The synchronous generator is rated as 12MVA, 6.6 KV, $X = 4\Omega$.

→ The PU reactance at $\underbrace{50\text{ MVA and } 11\text{ KV}}_{\text{Base}}$

$$X_{PU} = 4 \times \frac{50}{(11)^2}$$

→ Gen-1: 100 MVA, 11 KV, X = 5A

Gen-2: 250 MVA, 13.2 KV, X = 10

The PU reactance at $\underbrace{500\text{ MVA}}$ & 22 KV.

Base = 500 MVA, 22 KV Base

$$X_{G_1 PU} = 5 \times \frac{500}{(22)^2}$$

$$X_{G_2 PU} = 10 \times \frac{500}{(22)^2}$$

Base = 250 MVA, 13.2 KV

$$X_{G_1 PU} = 5 \times \frac{250}{(13.2)^2}$$

$$X_{G_2 PU} = 10 \times \frac{250}{(13.2)^2}$$

→ synchronous generator is rated as 210 MVA and 13.2 KV, X = 1.2 PU

The reactance of the alternator in Ω.

a) $1.2 \times \frac{210}{(13.2)^2}$ b) ✓ $1.2 \times \frac{(13.2)^2}{210}$

c) $\frac{210}{1.2 \times (13.2)^2}$ d) $1.2 \times \frac{210}{13.2}$

$$X_{PU} = X_\Omega \times \frac{MVA}{(KV)^2}$$

$$X_\Omega = X_{PU} \cdot \frac{(KV)^2}{MVA}$$

$$= 1.2 \times \frac{(13.2)^2}{210}$$

9) → $\% X = X_{PU} \times 100$

$X_{PU} = \frac{\% X}{100}$

a) $X_{PU} = X\Omega \frac{KVA}{(KV)^2}$ b) $X_{PU} = X\Omega \times \frac{(KV)^2}{MVA}$

c) $X_{PU} = X\Omega \frac{KVA \times 1000 \rightarrow VA}{(KV)^2}$ ✓d) $X_{PU} = X\Omega \frac{KVA}{1000\,(KV)^2}$

$X_{PU} = X\Omega \frac{MVA}{(KV)^2}$

$X_{PU} = X\Omega \frac{VA}{(\cancel{K}V)^2}$

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

$1 MVA = 10^6 VA$

$\cancel{= (10^3)(10^3) VA \Rightarrow 10^3 KVA}$

$= X\Omega \frac{\frac{VA_b}{10^3 \times 10^3} \rightarrow KVA}{(KV_b)^2}$

~~KVA~~ =

$= X\Omega \frac{KVA \rightarrow MVA}{1000 (KV)^2}$

→ 100 KVA, 11 KV, X = 2Ω. what is the PU value of reactance

$X_{PU} = X\Omega \frac{MVA}{(KV)^2}$

$= X\Omega \cdot \frac{100/1000}{(11)^2} \Rightarrow 2\Omega \times \frac{100}{1000\,(11)^2}$

a) $X_{PU} = X\Omega \frac{(KV)^2}{MVA}$ b) $X_{PU} = X\Omega \frac{MVA}{V^2 \rightarrow KV^2}$

✓c) $X_{PU} = X\Omega \frac{KVA \times 1000 \rightarrow VA}{V^2}$ d) $X_{PU} = X\Omega \frac{KVA}{(KV)^2}$

→ 250 MVA, 13.2 KV, X = 1.2 PU. what is the PU reactance at 500 MVA & 22 KV

$$X_{PU,new} = X_{PU old} \frac{MVA_{new}}{MVA_{old}} \left(\frac{KV_{old}}{KV_{new}}\right)^2 \rightarrow ④$$

$$X_{PU,old} = X_\Omega \frac{MVA_{old}}{(KV_{old})^2}$$

$$X_\Omega = X_{PU\,old} \times \frac{KV_{old}}{MVA_{old}}$$

$\left\{\begin{array}{l} 250\,MVA \\ 13.2\,KV \\ X = 1.2 \end{array}\right\} \rightarrow old$

$$X_{PU,new} = X_\Omega \frac{MVA_{new}}{(KV_{new})^2}$$

$$X_{PU,new} = X_{PU old} \frac{(KV_{old})^2}{MVA_{old}} \cdot \frac{MVA_{new}}{(KV_{new})^2}$$

$\left\{\begin{array}{l} 500\,MVA \\ 22\,KV \\ X_{PU} \end{array}\right\} \rightarrow new$

$$\therefore X_{PU,new} = X_{PU old} \cdot \frac{MVA_{new}}{MVA_{old}} \cdot \left(\frac{KV_{old}}{KV_{new}}\right)^2$$

$$= 1.2 \times \frac{500}{250} \left(\frac{13.2}{22}\right)^2$$

→ 100 MVA, 11 KV, X = 0.8 PU, what is the PU reactance at 210 MVA & 13.2 KV

$$X_{PU,new} = X_{PU,old} \cdot \frac{MVA_{new}}{MVA_{old}} \cdot \left(\frac{KV_{old}}{KV_{new}}\right)^2$$

$$= 0.8 \times \frac{210}{100} \times \left(\frac{11}{13.2}\right)^2$$

10)

→ The PU reactance of syn generator when the capacity and the voltage are doubled.

$$X_{PU,new} = X_{PU,old} \cdot \frac{MVA_{new}}{MVA_{old}} \cdot \left(\frac{kV_{old}}{kV_{new}}\right)^2$$

$$= 1.0 \times \frac{2}{1} \times \left(\frac{1}{2}\right)^2 \Rightarrow 0.5$$

→ The PU reactance of syn generator when the capacity and the voltage are half

$$X_{PU,new} = X_{PU,old} \frac{MVA_{new}}{MVA_{old}} \cdot \left(\frac{kV_{old}}{kV_{new}}\right)^2$$

$$= 1.0 \times \frac{2}{(1/2)} \cdot \left(\frac{1/2}{2}\right)^2 \Longrightarrow 2$$

→ The PU reactance (or) Impedance of transformer is same on both sides :-

V_p V_s

I_p I_s

$Z_{pri} \neq Z_{sec}$

$Z_{PPU} = Z_{SPU}$

Primary side

$$Z_{PPU} = \frac{Z_{P\Omega}}{Z_b}$$

$$= \frac{Z_{P\Omega}}{(V_P/I_P)}$$

select primary rating is the base

Secondary side

$$Z_{SPU} = \frac{Z_{S\Omega}}{Z_b}$$

$$= \frac{Z_{S\Omega}}{(V_S/I_S)}$$

select secondary rating is the same.

$$Z_{PPU} = \frac{Z_{P\Omega}}{Z_b} \Rightarrow \frac{Z_{P\Omega}}{(V_P/I_P)} \Rightarrow Z_{P\Omega} \cdot \frac{I_P}{V_P} \Rightarrow \frac{Z_{S\Omega}}{K^2} \cdot \frac{I_P}{V_P}$$

$\left[K = \frac{V_S}{V_P} \right.$; 'K' is called as transformer ratio

$$Z_{P\,PU} = \frac{Z_{S\Omega}}{(V_S/V_P)^2} \cdot \frac{I_P}{V_P} \Rightarrow Z_{S\Omega} \cdot \frac{V_P^2}{V_S^2} \cdot \frac{I_P}{V_P} \Rightarrow Z_{S\Omega} \cdot \frac{V_P I_P}{V_S^2} \Rightarrow Z_{S\Omega} \cdot \frac{V_S I_S}{V_S^2}$$

$$\Rightarrow Z_{S\Omega} \cdot \frac{I_S}{V_S} \Rightarrow \frac{Z_{S\Omega}}{\underbrace{(V_S/I_S)}_{Z_b}} = Z_{S\,PU}$$

→ 10 MVA, 33/11 KV, Transformer having a reactance of 0.2 PU. The reactance of the Transformer on HV side in Ω.

$$X_\Omega = X_{PU} \cdot \frac{(KV)^2}{MVA}$$

$$= 0.2 \times \frac{(33)^2}{10}$$

→ 100 KVA, 400/200 V, 1-φ transformer having a impedance of $Z = 0.01 + j0.02$ PU. The impedance of the transformer on LV side in Ω

$$\times\ \cancel{X_\Omega} = X_{PU} \cdot \frac{(KV)^2}{MVA} \quad \times$$

$$Z_\Omega = Z_{PU} \cdot \frac{V^2}{VA}$$

$$= \frac{(0.01 + j0.02)(200)^2}{100 \times 1000} \Rightarrow 0.004 + j0.008$$

→ 10 KVA, 400/800 V, 1-φ transformer $Z_{PU} = 0.01 + j0.04$ PU, the impedance of a transformer on LV side.

$$Z_\Omega = Z_{PU} \cdot \frac{V^2}{VA}$$

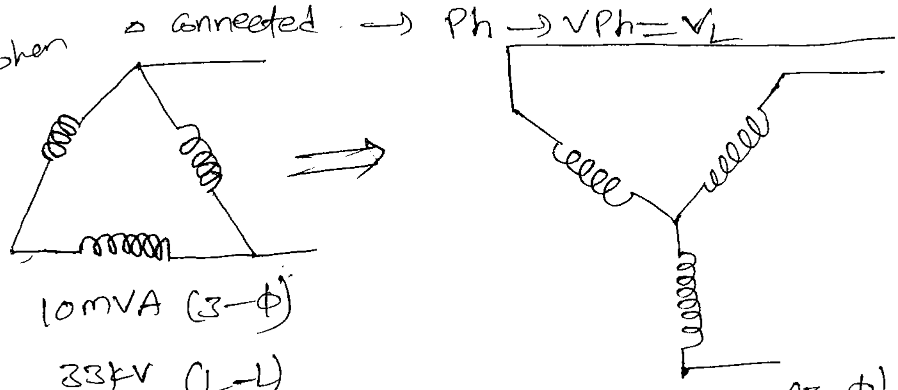
$$= \frac{(0.01 + j0.04)(400)^2}{10 \times 1000}$$

$$0.16 + j0.64$$

→ 100 kVA, 11/22 kV, 3-φ transformer is having X = 0.5 PU the reactance of the transformer in Ω on LV side

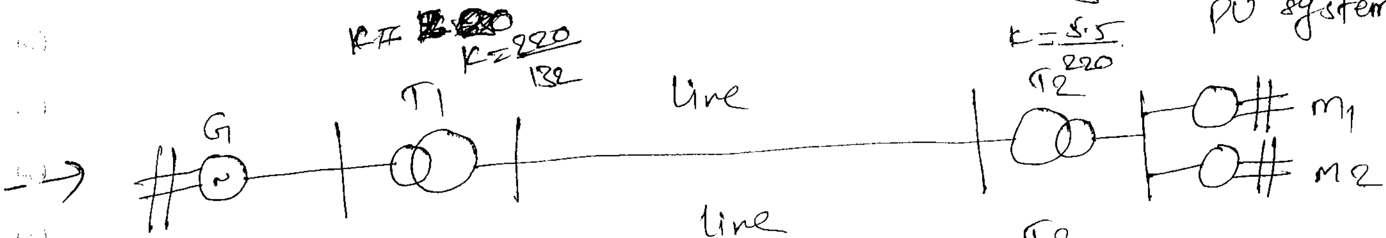
$$X_\Omega = X_{PU} \cdot \frac{(kV)^2}{MVA} = \frac{0.5 \times (11)^2}{0.1} = 605\,\Omega$$

→ when Δ connected → Ph → $V_{Ph} = V_L$



$$\boxed{X_{PU} = X_\Omega \cdot \frac{MVA}{(kV)^2_{L-L}}}$$

→

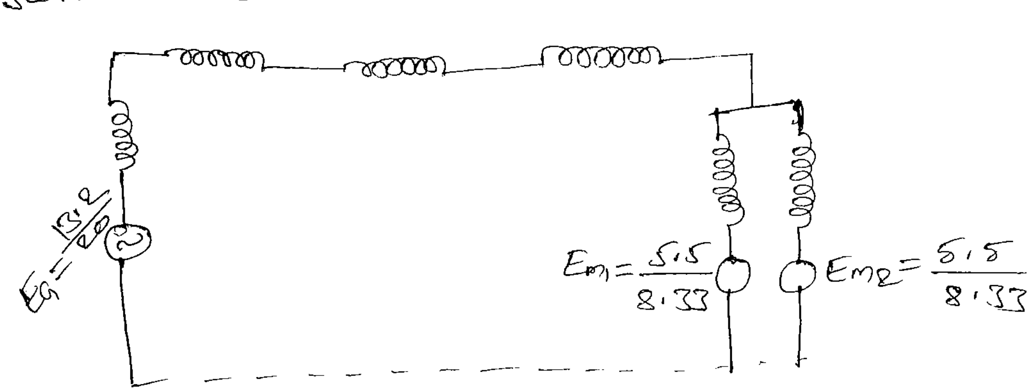


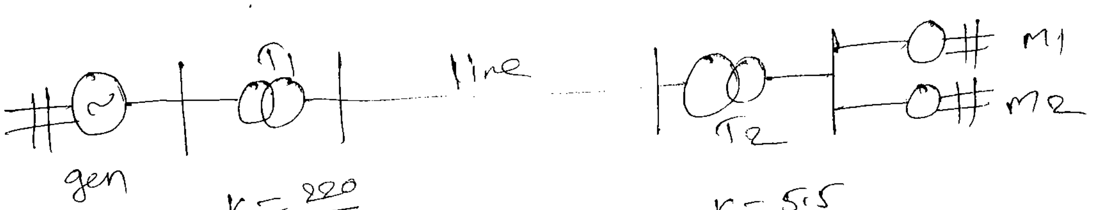
gen	T1	line	T2	m1	m2
200MVA	150MVA	150MVA	150MVA	100MVA	50MVA
13.2kV	13.2/220kV	220kV	220/5.5kV	5.5kV	5.5kV
X = 20	X = 1.2	X = 40 kΩ	X = 1.2	X = 1.0	X = 0.5

old: 200MVA, 13.2kV, X = 20

300MVA
20kV

→ draw the reactance diagram and indicate the pu values based on 300MVA and 20kV as the base values





new:

gen	T1	line	T2	m1	m2
300 MVA	300MVA	300MVA	300MVA	300MVA	300MVA
20 KV	20/333.4kv	333.4kv	333.4/8.33 kv	8.33 KV	8.33kv

$$X_{G\,pu,new} = 2.0 \times \frac{300}{200}\left(\frac{13.2}{20}\right)^2$$

$$X_{T_1(pri),new} = 1.2 \times \frac{300}{150}\left(\frac{13.2}{20}\right)^2$$

$$X_{T_1,new(sec)} = 1.2 \times \frac{300}{150}\left(\frac{220}{333.4}\right)^2$$

$$X_{line}(PU) = X_{\Omega}\,\frac{MVA}{(KV)^2} = 40 \times \left(\frac{300}{(333.4)^2}\right)$$

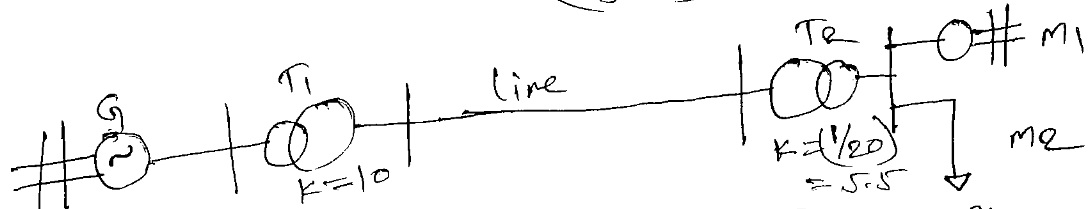
$$X_{T_2,new(P)} = 1.2 \times \frac{300}{150}\left(\frac{220}{333.4}\right)^2$$

$$X_{T_2,new(S)} = 1.2 \times \frac{300}{150}\left(\frac{5.5}{8.33}\right)^2$$

$$X_{m1,new} = 1.0 \times \frac{300}{100}\left(\frac{5.5}{8.33}\right)^2$$

$$X_{m2,new} = 0.5 \times \frac{300}{50}\left(\frac{5.5}{8.33}\right)^2$$

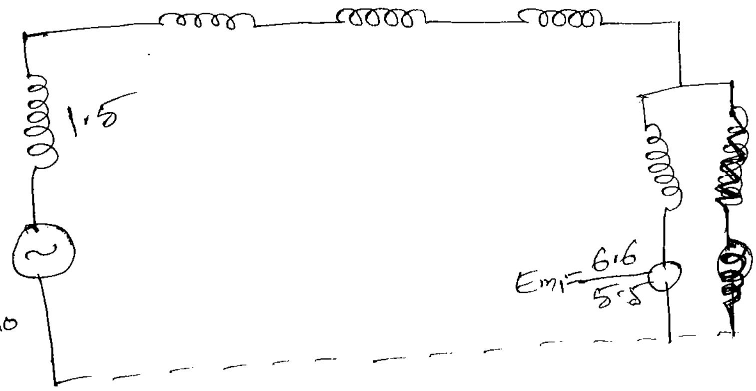
→



Gen	T1	line	T2	M1	M2
150MVA	100MVA	100MVA	100MVA	75MVA	50 MVA
11KV	13.2/132KV	132KV	132/6.6KV	6.6KV	6.6KV
X=1.5	X=1.0	X=20Ω	X=1.0	X=0.8	0.8 pf lag

draw reactance diagram & indicate pu ...

	gen	T1	line	T2	m1	m2
new	150MVA	150MVA	150MVA	150MVA	150MVA	150MVA
	11kV	11/110kV	110kV	110/5.5kV	5.5kV	5.5kV



$$X_{T_1}\,PU\,(new)\,(P) = 1.0 \times \frac{150}{100}\left(\frac{13.2}{11}\right)^2$$

$$X_{T_1}\,PU\,(S) = 1.0 \times \frac{150}{100}\left(\frac{132}{110}\right)^2$$

$$X_{line}\,(PU) = 20 \times \frac{150}{(110)^2}$$

$$X_{T_2}\,PU(P) = 1.0 \times \frac{150}{100}\left(\frac{132}{110}\right)^2$$

$$X_{T_2}\,PU(S) = 1.0 \times \frac{150}{100}\left(\frac{6.6}{5.5}\right)^2$$

$$E_{m1}\,(PU) = 0.8 \times \frac{150}{75}\left(\frac{6.6}{5.5}\right)^2$$

$$Z_{PU} = 0.\cancel{87} \times \frac{150}{(5.5)^2} = 4.32$$

$$R = Z\cos\phi = 4.32 \times 0.8$$

$$X = Z\sin\phi = 4.32 \times 0.6$$

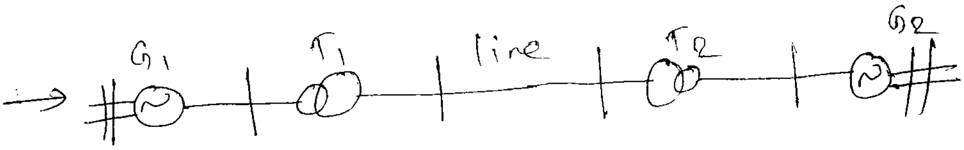
$S = 3VI$

$S = 3V \cdot \frac{V}{Z} = \frac{3V^2}{Z}$

$\Rightarrow \frac{V_L^2}{Z}$

$Z = \frac{V_L^2}{S} \Rightarrow \frac{(6.6)^2}{50}$

$Z = 0.\cancel{87}$



	G_1	T_1	line	T_2	G_2
old	150MVA	125MVA	1.25MVA	125	100MVA
	13.2KV	11/110KV	110KV	110/5.5KV	6.6KV
	$X=1.5$	$X=1.0$	$X=20\Omega$	$X=1.0$	$X=1.2$

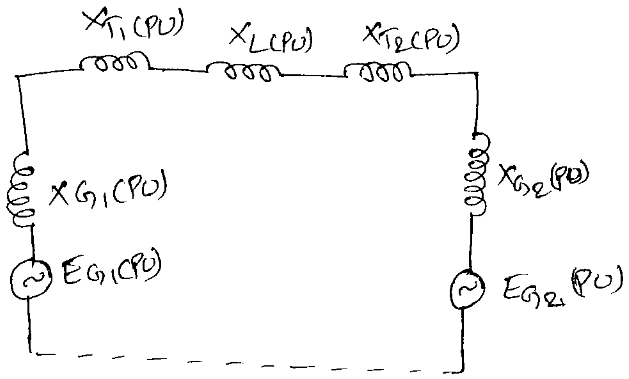
Draw the reactance 6.6KV diagram based on G_1 MVA capacity at the base MVA and base voltage of 15kV.

$MVA_b = 150\,MVA$

$KV_b = 15KV$

$K_1 = \frac{110}{11} = 10$

$K_2 = \frac{5.5}{110}$



G_1	T_1	Line	T_2	G_2
150MVA	150MVA	150MVA	150MVA	150MVA
15KV	15/150KV	150KV	150/7.5KV	7.5KV

T_1: ↓ $X_s = KX_p$ $= 10 \times 15$ $= 150KV$

T_2: $X_s = \frac{5.5}{110} \times 150$ $= 7.5$

$X_{G_1}(PU)\ new = 1.5 \times \frac{150}{150} \times \left(\frac{13.2}{15}\right)^2$

$X_{T_1(P)}\ PU, new = 1.0 \times \frac{150}{125} \times \left(\frac{11}{15}\right)^2$

$X_{T_1(S)}\ PU, new = 1.0 \times \frac{150}{125} \times \left(\frac{110}{150}\right)^2$

$X_L(PU) = 20 \times \frac{150}{(150)^2}$

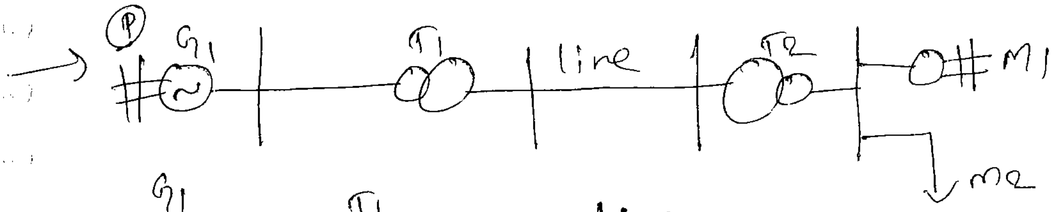
$X_{T2(P)}$ PU, new $= 1.0 \times \frac{150}{125} \times \left(\frac{110}{150}\right)^2$

$X_{T2(S)}$ PU, new $= 1.0 \times \frac{150}{125} \times \left(\frac{5.5}{7.5}\right)^2$

X_{G2} (PU), new $= 1.2 \times \frac{150}{100} \times \left(\frac{6.6}{7.5}\right)^2$

E_{G1} (PU) $= \cancel{\frac{13.2}{10}}$ $\frac{13.2}{10}$

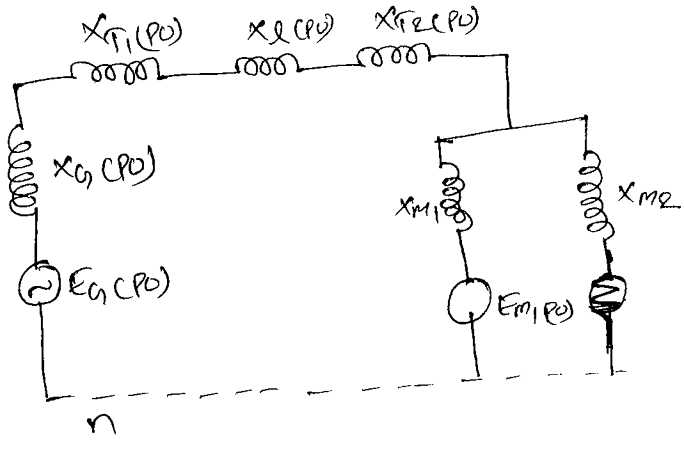
E_{G2} (PU) $= \frac{6.6}{7.5}$



G1	T1	line	T2	M1	M2
100MVA	150MVA	100MVA	150MVA	75MVA	40MW − j30MW
11KV	12/120KV	100KV	120/5.5KV	5.5KV	5.5KV
X=1.5	X=1.2	X=30Ω	X=1.2	X=0.75	

Draw the reactance diagram

$E_G = \frac{11}{12}$, $E_{m1} = \frac{5.5}{8}$



$MVA_b = 150MVA$

$KV_b(P) = 12KV$

$KV_b(S) = 120KV$

	G1	T1	Line	T2	M1	M2
new	150MVA	150MVA	150 MVA	150MVA	150 MVA	150 MVA
	12KV	12/120KV	120KV	120/8 KV	8 KV	8 KV

$X_{G}(PU), new = 1.5 \times \frac{150}{100} \times \left(\frac{11}{12}\right)^2$

$X_{T_1}(PU)\ P, new = 1.2 \left(\frac{150}{150}\right)\left(\frac{12}{12}\right)^2 = 1.2$

$X_{T_1}(S)\ PU, new = 1.2 \times \frac{150}{150} \times \left(\frac{120}{120}\right)^2 = 1.2$

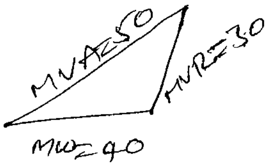
$X_l (PU) = 30 \times \frac{150}{(120)^2}$

$X_{T_2}(P)\ PU, new = 1.2 \times \frac{150}{150} \times \left(\frac{120}{120}\right)^2 = 1.2$

$X_{T_2}(S)\ PU, new = 1.2 \times \frac{150}{150} \times \left(\frac{8}{8}\right)^2 = 1.2$

$X_{m_1}(PU), new = 0.75 \times \frac{150}{75} \times \left(\frac{5.5}{8}\right)^2$

$S = \frac{V_L^2}{Z}$



$Z_1 = (5.5)^2/50 \Rightarrow 0.605\Omega$

$Z_{PU} = 0.605 \times \frac{150}{(8)^2} \Rightarrow 1.41$

$R = Z\cos\phi = 1.41 \times 0.8 = 1.128$

$X_{PU} = Z\sin\phi = 1.41 \times 0.6 = 0.846$

Symmetrical Components:-

→ The performance of the above system can be analysed by evaluating the voltage at load point.

Balanced load

$I_n = I_R\angle 0 + I_Y\angle 120 + I_B\angle 240 \Rightarrow 0$

current calculation

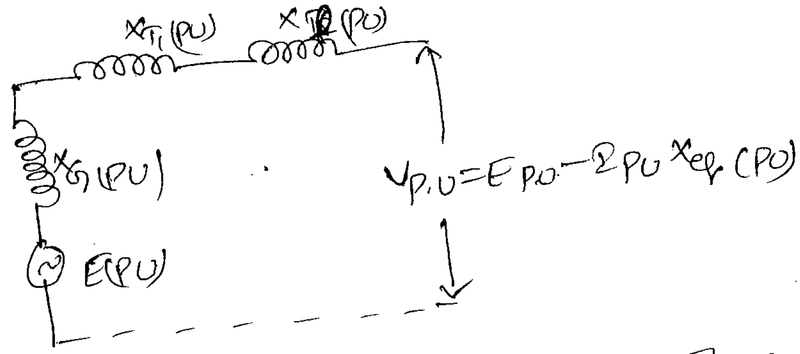
To apply KVL

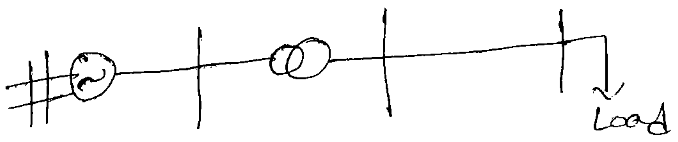
Voltage Calculation

To apply KCL

14)

→ The balanced load voltage can be calculated with the help of per phase reactance n/w along with PU value.





There is only one n/w equation to solved, inorder to evaluate

→ The time taken to be less

Unbalanced load :-

$$I_n = I_R \angle 0 + I_Y \angle 120 + I_B \angle 240$$

$$\boxed{I_n \neq 0}$$

→ Due to the occurance of fault, the unbalanced load voltage will be calculated by representing individual phase.

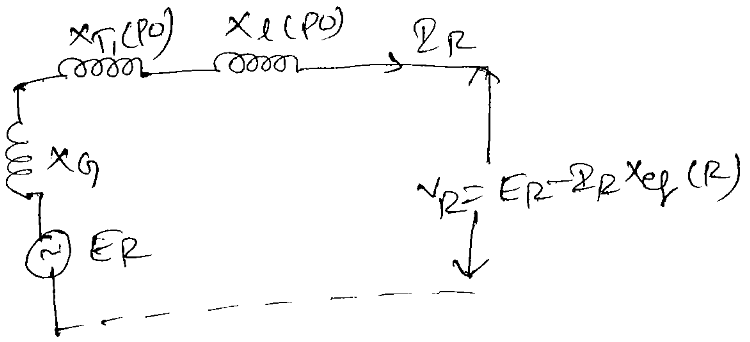
→ There are three n/w's for the 3-ϕ so that three n/w eqns to be solved

→ Hence time taking will be high inorder to calculate unbalanced load voltages.

→ similarly for Y & B phase

R Y B
(or) $\Big\}$ sequence (clock wise)
A B C

→ we have a similar concept of Y & B phase.



→ In order to reduce the time taking to evaluate the unbalanced electrical quantity of base, it is proposed to represented mathematically. Any unbalanced electrical quantity of base.

→ By a set of a 3 balanced electrical quantities

→ The set of 3 balanced electrical quantities called as symmetrical quantities (or) symmetrical components, which are namely

* +ve sequence components
* -ve "
* zero "

Voltage unbalance

three unbalanced
$$\left.\begin{aligned} V_R &= V_{R1}+V_{R2}+V_{R0} \\ V_Y &= V_{Y1}+V_{Y2}+V_{Y0} \\ V_B &= V_{B1}+V_{B2}+V_{B0} \end{aligned}\right\}$$

Vph
9 symmetrical components
↓ Balanced

Current unbalance

$$I_R = I_{R1}+I_{R2}+I_{R0}$$
$$I_Y = I_{Y1}+I_{Y2}+I_{Y0}$$
$$I_B = I_{B1}+I_{B2}+I_{B0}$$

Impedance unbalance

$$Z_R = Z_{R1}+Z_{R2}+Z_{R0}$$
$$Z_Y = Z_{Y1}+Z_{Y2}+Z_{Y0}$$
$$Z_B = Z_{B1}+Z_{B2}+Z_{B0}$$

Power unbalance

→ Power calculation will be a 3-ϕ, not a 1-ϕ (or) each ϕ

→ In a 3-ϕ system the power will be expressed as 3-ϕ

→ symmetrical components the purpose of the unbalanced electrical quantity of base

→ Hence the symmetrical quantity not used, for the representation

→ Even though there are 9 symmetrical components but they are balanced components

→ In order to reduce the no of symmetrical components, it is proposed to replace, the system components of Y & B-phase interms of R.

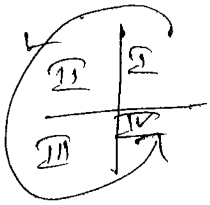
→ By using a suitable notation "K' & d, α, a"

unity magnitude & 120° phase displacement in anticlockwise direction

$K = 1\angle 120^\circ$ → vector notation

direction → anti clock wise

$K = -0.5 + j0.867$



$K^2 = 1\angle 120 \cdot 1\angle 120$

$K^2 = 1\angle 240 = -0.5 - j0.867$

$$\boxed{K^3 = 1\angle 360 = 1.0 + j0.0}$$

$K^2 + K^2 + K^3 = 1 + K + K^2 = 0$

$K^4 = K^3 \cdot K = K$

$K^5 = K^3 \cdot K^2 = K^2$

$K^6 = K^3 \cdot K^3 = K^3$

i) $a - a^2$

$0.5 + j0.867 - (-0.5 - j0.867)$

$a - a^2 = j\sqrt{3}$

$0.867 + 0.867 = 1.734 = \sqrt{3}$

ii) $a + a^2 = -1$

iii) $-a + a^2 = -j\sqrt{3}$

$0.5 - j0.867 - 0.5 - j0.867$

$= -j\sqrt{3}$

Fault:-

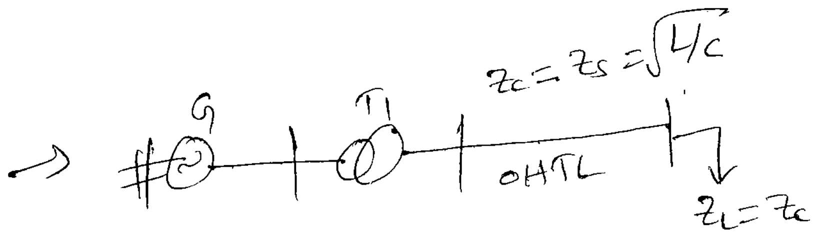
→ A fault is an abnormal condition which will result as the electrical quantities are more than rated value.

→ The occurance of fault is make the system as unbalance and also as balance

→ most of the faults are unbalanced nature.

→ The faults are more common in over head TL and less in gen

Fault
- open ckt (or) series fault
- short ckt (or) shunt fault

→ 

→ In OHTL the loading is more than SIL. So that the loss in the conductor will be high, which will be converted in to heat

→ when heat generation is high the current carrying element will get melts, which will results as the occurance of the open circuit fault.

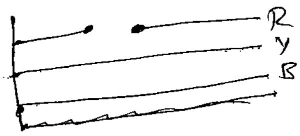
* * $\boxed{\text{Loading} > \text{SIL}}$ (surge impedance of line)

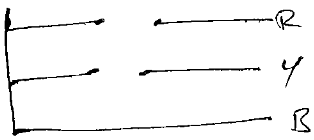
→ A short circuit fault is mainly due to failure of insulation (or) falling of the tree branches in a OHTL.

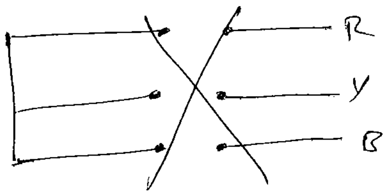
open circuit

unsymmetric (or) unbalanced

i) melting of the conductor in one phase
ii) melting of the conductor in two phases







Vo — no load voltage
↓
Rated voltage

→ open ckt in all the 3-φ's will result as, the current in the phases is zero, and there will be no load voltages
→ no load voltages are same as rated voltages. Hence there is no damage to the ~~system~~

5% ⟶ LLL & LLLG

70% faults — LG faults
15% faults — L-L
10% " — LLG

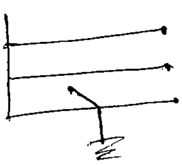
short circuit :-

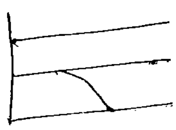
unbalanced (or) unsymmetrical faults

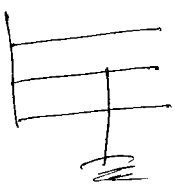
i) In the line - ground fault — 75%
ii) Line - line fault — 15%
iii) line - line - ground fault — 10%

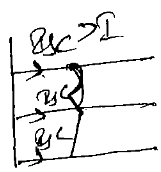
balanced (or) symmetrical faults

iv) line - line - line fault
v) line - line - line - ground fault

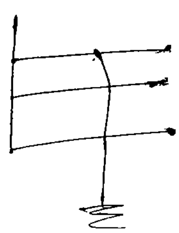








Balance currents are same in all phases.



→ short circuit in all the 3-ϕ's will result as the currents are same, but they are more than rated current, hence it should be treated as a fault.

→ The failure of insulation is more common when compared to melting of the conductor

→ Hence the Ps n/w having SC faults, when compared to oc faults

→ 95% of faults are unbalanced faults

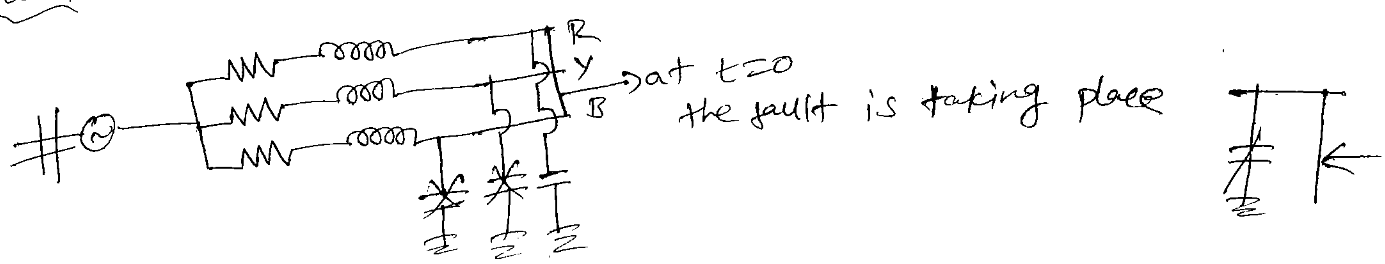
→ 5% of " " balanced "

Short circuit on TL:-

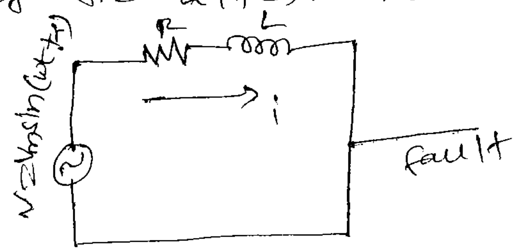
steady state condition

electrical quantities are measured interms of Rms value.

fault:-



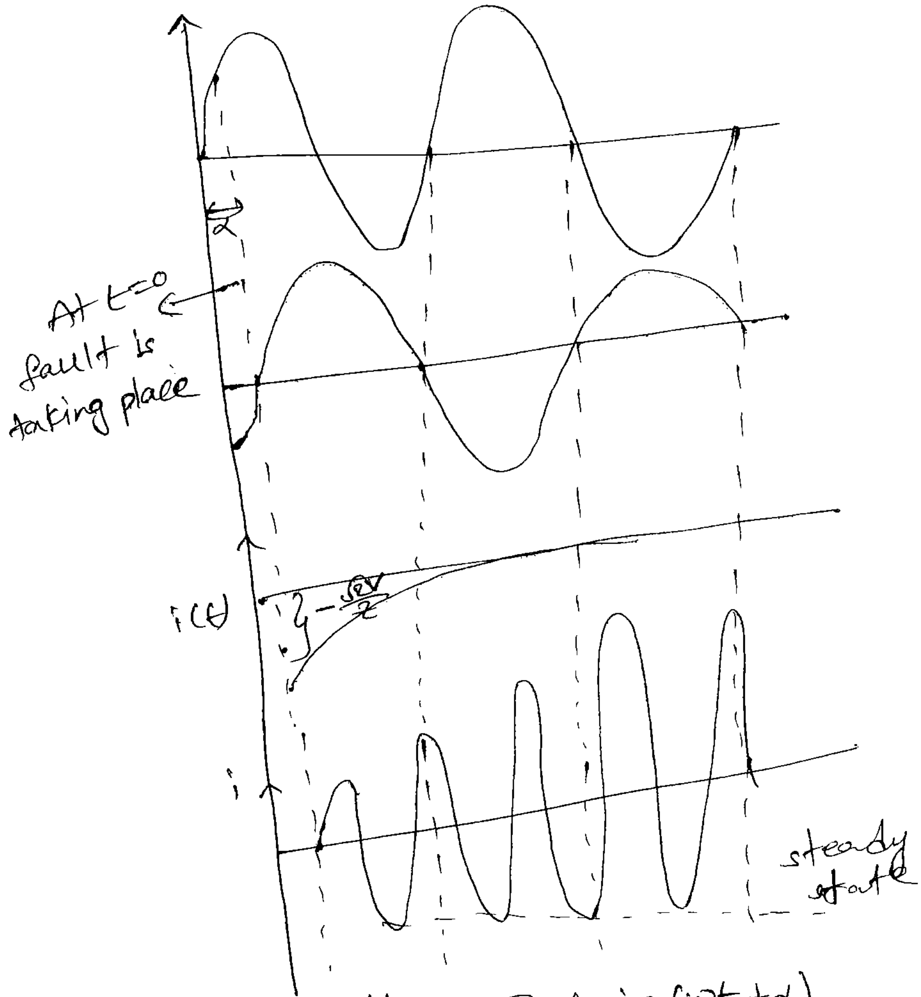
→ The TL is replaced by an RL series circuit with a constant excitation of the alternator



$v = \sqrt{2}V \sin(\omega t + \alpha)$

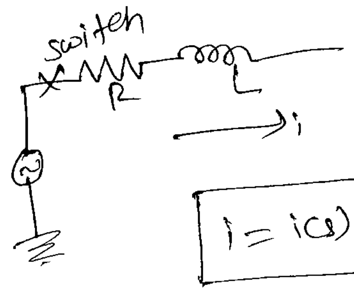
i = instantaneous current (or) momentry current

α = angle formed b/w fault point and zero cross over pt



$$Ri + L\frac{di}{dt} = \sqrt{2}V\sin(\omega t + \alpha)$$

→ The instantaneous current of the fault is similar to that of the Instantaneous of the switch closed condition.



$$\boxed{i = i(s) + i(t)}$$

i_s = symmetrical sinusoidal sc current, in fault analysis

is AC component

$$= \sqrt{2}\cdot\frac{V}{Z}\sin(\omega t + \alpha - \phi)$$

$$\phi = \tan^{-1}(X/R)$$

i(t) = Transient current (or)
exponentially decayed current (RL)
(or) DC off-set current

→ In order to calculate the DC off-set current use the initial condition of the network.

$$i(s) = 0$$

$$i(0) = i_s(0)\, e^{-t/\tau} + i_t(0) = 0$$

$$i(t) = i_t(0) = -i_s(0)\, e^{-t/\tau}$$

$$i_t = i_t(0) = -\frac{\sqrt{2}V}{Z} \sin(\alpha - \phi)\, e^{-t/\tau}$$

$$\boxed{i = \frac{\sqrt{2}V}{Z} \sin(\omega t + \alpha - \phi) - \frac{\sqrt{2}}{Z} V \sin(\alpha - \phi)\, e^{-t/\tau}}$$

→ Due to the present of DC off set value.

→ The fault current is called instantaneous current (or) momentary current

→ The fault current is also called as sub transient current because the dc off set value will be high during of the 1st cycle of the wave form.

→ The fault current is also called as surge currents, it is called surge waveform (or) unsymmetrical waveform because of the exponential component

→ The fault is an instantaneous current, but the magnitude of the current is calculated as the rms current of the sinusoidal waveform by ignoring dc offset values. The heat produced by the dc off set value is zero.

→ The Rms current of the sinusoidal waveform is to be multiplied with 1.6, inorder to include the DC off set values. while calculating the instantaneous current (or) momentary current

→ The momentary current is having a maximum value during the 1st cycle of the wave form because the DC off set value will be high during 1st cycle.

The maximum momentary current

1st cycle $\boxed{i_{mm} = \frac{\sqrt{2}V}{Z}\sin(\alpha-\phi) - \frac{\sqrt{2}V}{Z}}$

$$\phi = \tan^{-1}(X/R) = 90^\circ$$

$X >> R$

$$i_{mm} = \frac{\sqrt{2}V}{Z}\sin(\alpha-90) - \frac{\sqrt{2}V}{Z}$$

$$i_{mm} = -\frac{\sqrt{2}V}{Z}\cos\alpha - \frac{\sqrt{2}}{Z}V$$

$$i_{mm} = -\frac{\sqrt{2}V}{Z}(1+\cos\alpha)$$

if $\alpha = 0$

$$i_{mm} = -\frac{\sqrt{2}}{Z}V(1+1)$$

$\boxed{i_{mm} = -\frac{2\sqrt{2}V}{Z}}$ → Double effect

→ In a sinusoidal wave forms the momentary current is having a double effect. (or) The fault is more sevier provided that the fault is taking place at zero crossover point

→ circuit breaker of braking current expressed in terms of RMS value.

→ Heat is produced due to symmetrical currents of the component not by unsymmetrical

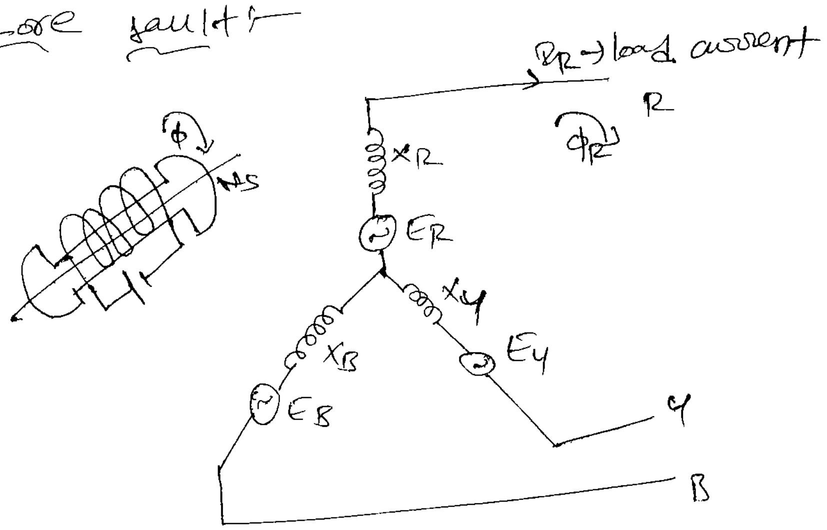
→ The braking current of the CB is also expressed in terms of RMS value, because the heat produced by the arc that mainley depends upon symmetrical sinusoidal current.

→ In transformer no need to assume the capacitance is zero, but in transmission line 'c' is zero assumed.

→ The short circuit of the transformer is similar to that of short circuit characteristics of the TL

The short circuit characteristics of the generator:—

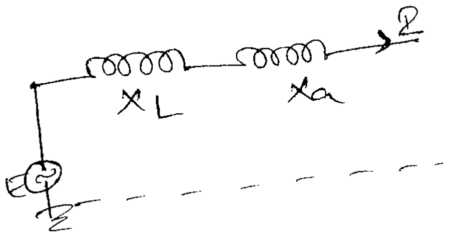
Before fault:—



→ I rotor changes, I stator changes, speed of the stator changes

→ rotor speed changes to changes the stator flux changes.

→ stator is always depends upon the load current & rotor speed.



$$\underbrace{X_s = X_d}_{} = X_l + X_a$$

↓

syn reactance (or) direct reactance (or) steady state reactance

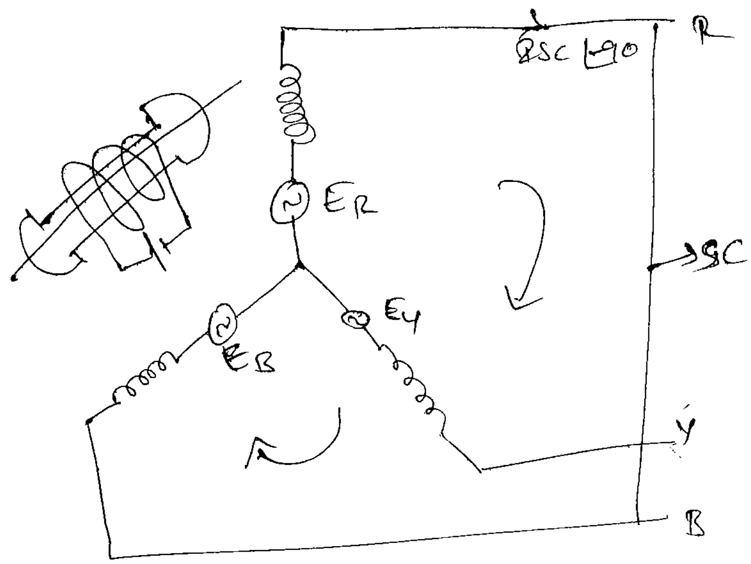
→ The rotor flux is rotating at syn speed, so that stator flux is also assumed as a rotational flux at syn speed.

→ The rotational flux of the stator will influence the rotor flux. which is called as armature reaction and it will be represented by X_a.

→ The armature winding is short ~~circuited~~ pitch winding, there will be some leakage flux and it can be represented by leakage reactance. The electrical equivalent is as shown for the current delivered.

(3)
→ stator current's are leading magnetisation takes place.

→ stator currents are lagging demagnetization takes place.



$I\angle{-36.86°}$

$I\angle{-45°}$

$I\angle{-53.13°}$

I_{SC} - purely inductive (ϕ lagging)

ϕ_{SC} - pure inductive flux

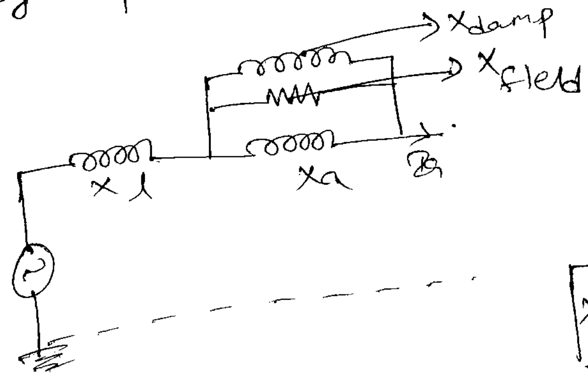
→ The load currents are inductive but the I_{SC} are purely inductive at an angle of $-90°$.

→ The flux produced by the I_{SC} is purely inductive but it is rotating with a rotor speed of the machine

→ DA will result as the rotor air gap flux is totally demagnitised due to armature effect, which will results as the syn gen is has pulled out magnitically, comfortable (or) Asynchronize.

Damper winding → To reduce oscillator

→ In order to maintain the stability of the synchronous machine, the rotor air gap is to be strengthned or the armature reaction is to be opposed with the help of the counter emf, that will produced rotor field winding & damper winding due to the flux produced by exponential current, the electrical equivalent is as shown.



1st cycle
subtransient period
subtransient reactance

$$\boxed{X_d'' = X_l + (X_a) // (X_{field}) (X_{damp})}$$

Damper winding:-

$T = L/R$

R → more → To reduce the oscillation

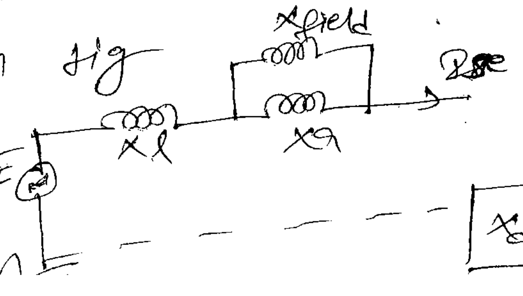
R↑ T↓

→ The damper winding is predominent with resistance and the field winding is predominent with reactance

→ Hence the time constant of the damper winding is less and field winding is high

→ so that the induced emf is disappeared from the damper winding, but it will continue at field winding but it oppose armature reaction

→ The corresponding period is transient period & the electrical eqn is as shown in fig



Transient period
Transient reactance

$$\boxed{X_d' = X_l + (X_a // X_{field})}$$

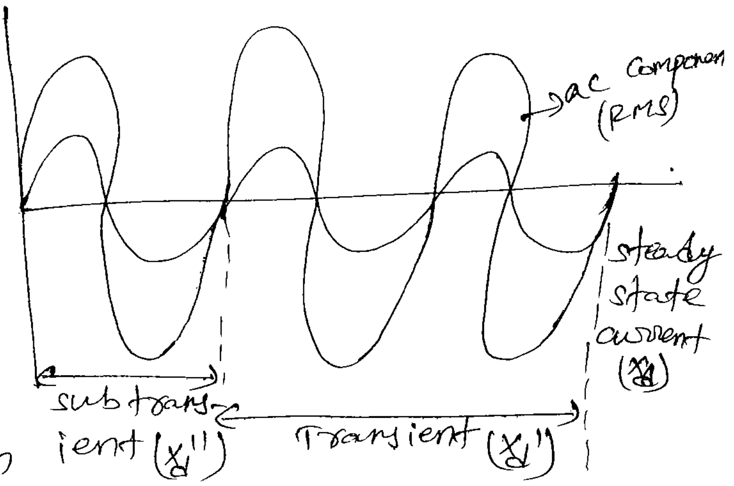
→ In order to bring the steady state condition ...

The sc fault should be isolated by using relay & ckt breaker where the time of operation of those device should be less than the time constant of the field winding.

$$\boxed{X_d'' < X_d' < X_d}$$

→ sub transient (Isc) currents are very high when compared to steady state current load (curves)

$$\boxed{I_{sc} > I_{load}}$$



In addition to the ac component there will be dc off set value which can included by multiplying the rms current of the waveform with 1.6

occurance of fault	severity of fault I_{sc}
most common (or) most frequent	less sevire
LL, LLG	
LLL, LLLG	most sevire (or) most sevire fault
less frequent (or) Rare fault	

→ which of the following fault is more sevire

a) LG
b) LLG
c) LL
d) LLL

a) LG
b) LLG
c) LLLG
d) LL

a) LG
b) ~~LLLG~~
c) LLL
d) LL

symmetrical components:-

+ve sequence components:-

→ These are the components having equal in magnitude & 120° phase displacement.

→ The ϕ sequence of these components are same as that of original phase sequence of the n/w.

-ve sequence components:-

→ These are the components having equal in magnitude and 120° phase displacement

→ The phase sequence is opposite to that of original phase sequence of that n/w.

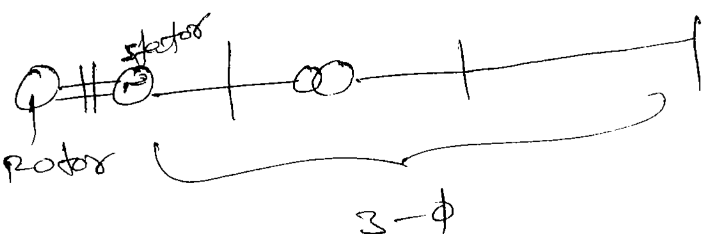
zero sequence components:-

→ These are the components having equal in magnitude without any phase displacement. If there is no phase displacement so no phase sequence to compose.

original sequence:-

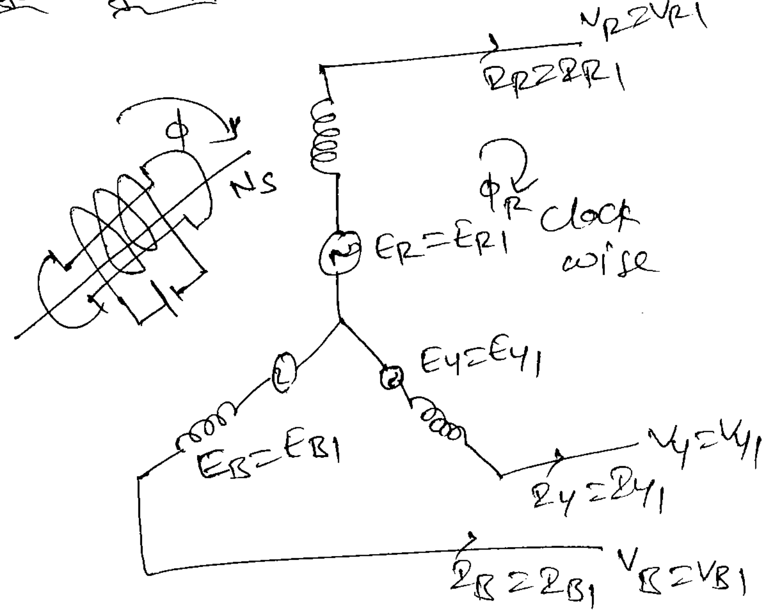
It is the sequence at which the system operating before fault.

sequence order (or) direction



→ The direction of the rotation of the rotor is refference to decide the sequence of n/w.

Before fault:-



stator ABC (or) RBY clock wise

→ The rotor of the syn generator is coupled with the primemover due to mechanical i/p the of the primemover is moves in clockwise. The flux produced by rotor also rotating in clockwise. The field winding is also rotating clock wise.

→ will produce an emf in the stator of 3-ϕ in a clockwise manner either ABC (or) RYB

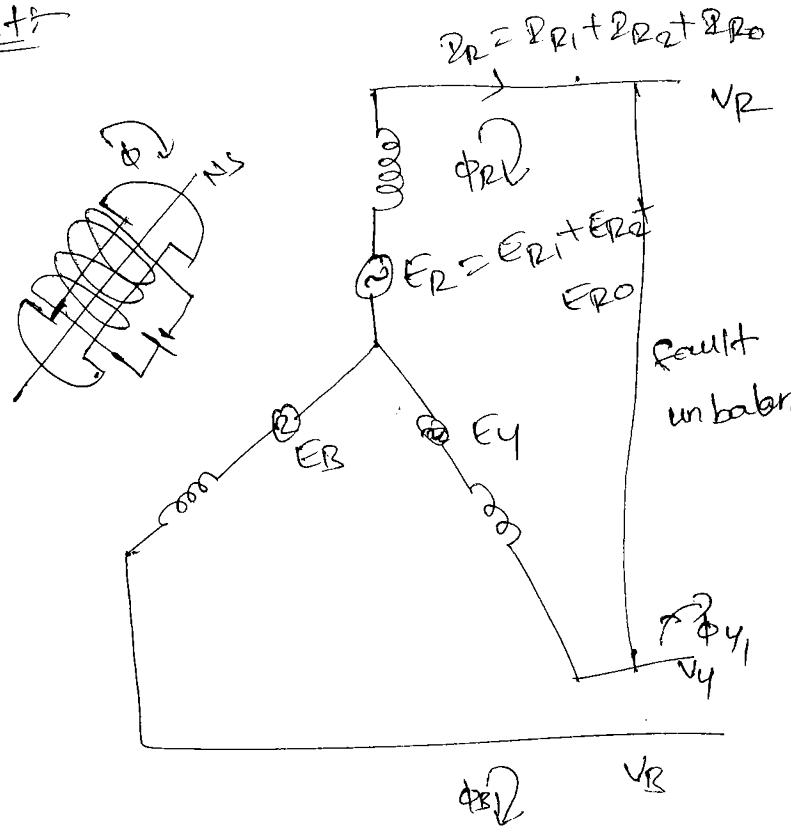
→ The induced emf in the stator will produce the current and delivered to the load in a clock wise

→ The flux of the stator current is also in a clockwise manner.

Definition:-

when ever the direction of rotation of stator flux is same as that direction of rotation of ~~stator~~ rotor flux. The corresponding sequence components of electrical quantities called as +ve sequence components of a steady state condition.

faults:



$$E_Y = E_{Y1} + E_{Y2} + E_{Y0}$$
$$E_B = E_{B1} + E_{B2} + E_{B0}$$
$$V_R = V_{R0} + V_{R1} + V_{R2}$$
$$V_Y = V_{Y0} + V_{Y1} + V_{Y2}$$
$$V_B = V_{B0} + V_{B1} + V_{B2}$$

fault
- stator (most common)
- rotor

→ The faults are more common in the stator winding & the unbalanced unbalanced faults are more.

→ The unbalanced electrical quantities are replaced by a set of 3-balanced electrical quantities

→ ~~[illegible]~~ out of which one of the component is +ve sequence component but a subtransient condition having a reactance of X_d''

→ The fault is taking place is stator winding, but the direction of rotation of the rotor is in clockwise only. So that there will be a clockwise voltages in stator windings E_{R1}.
The corresponding current is I_{R1} & the flux is ϕ_{R1} in a clock-wise

→ By the direction of rotation of the rotor flux is same as the corresponding electrical quantities are called +ve sequence components, but a. subtransient condition.

<u>Significance of +ve sequence components:</u>—

<u>Before fault</u>	<u>fault</u>	
+ve sequence	L-G LL LLG LLL	+ve sequence is exist

→ The +ve sequence components are the bases for the relay operation and also CB operation → (CB – circuit breaker)

<u>Relays & CB</u>

→ The set values of the relays will be assigned interms of +ve sequence steady state values

→ +ve sequence components are exist during any type of faults.

→ The +ve sequence subtransient current is more than steady state current because

$$\boxed{X_d'' < X_d}$$

→ so that the relay will operate if it is an application of over current relay (or) differential relay.

→ The impedance offered during the fault is less than the steady state impedance of the relay. The relay will operate.

In case of relay application

→ In case of over current relay the minimum set value employed.

→ In case of distance relays (impedance) maximum set value employed based on L-G faults, the name relay will operate the all faults.

circuit breakers:-

→ As the CB contacts are seperated an arc is developed. The braking of the arc will produce the heat. The heat reduced should able to with stand by the breaker ~~consta~~ contacts.

→ The breaker contacts are designed to withstand maximum heat, by consider 3-ϕ faults of a +ve sequence components

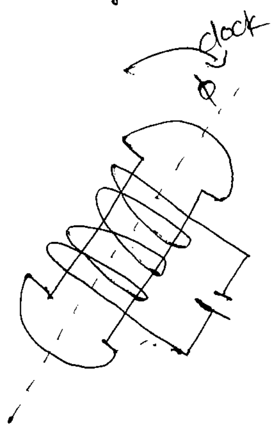
Before fault — fault

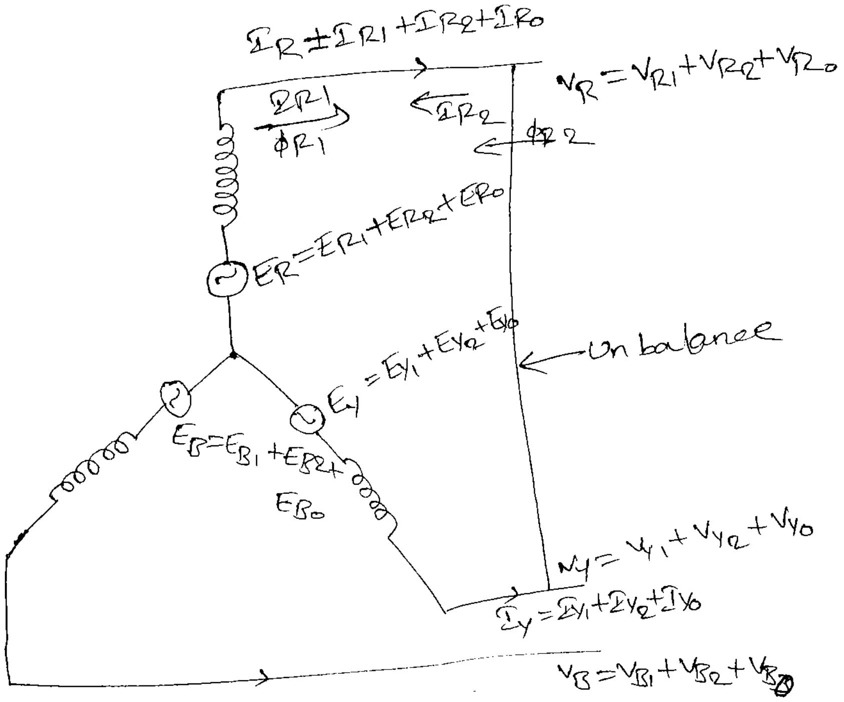
+ve sequence components — LG – relay

LLL – CB

Negative sequence components:-

If the direction of stator flux is opposite to that of direction of rotor flux, the corresponding electrical quantities are called as "Negative sequence components".





$E_{b2} = 0$	$E_{R0} = 0$
$E_{Y2} = 0$	$E_{Y0} = 0$
$E_{R2} = 0$	$E_{b0} = 0$

$E_R = E_{R1}$ Before fault (steady state)

$E_R = E_{R1}$ fault (sub-T)

+ve sequence always present

-ve sequence unbalance

Before fault

$V_R = V_{R1}$ (steady state)

fault (unbalance)

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

$V_{R2} \neq 0$

$V_{R2} > E_{R2}$ ($E_{R2} = 0$)

→ In case of a +ve sequence, there will be a induced voltage and also terminal voltage at the fault point and $E_{R1} > V_{R1}$. Hence the corresponding current is from the stator winding towards the fault.

→ In case of -ve sequence there is no induced voltage i.e., E_{R2} will be zero because the direction of the rotation of the rotor is always in clock wise. Due to unbalancing effect there will be a terminal voltage at the fault point i.e., V_{R2}. Hence $V_{R2} > E_{R2}$.

→ The corresponding current is from the fault point towards the stator, (or) the flux produced by the corresponding current is opposite to that of +ve sequence flux, (or) opposite to that of the direction of rotation of the rotor flux.

Significance of -ve sequence components:-

The flux produced by the -ve sequence component is having a relative speed of $2N_s$ w.r.t rotor, so that the rotor field winding. It will result as there will be indused Emf in the rotor field at double the syn speed (or) $2N_s$. The induced Emf in the field winding will produce the circulating current which will result as the rotor field winding will get over heated inorder to protect the rotor of the alternator against unbalan loading, a -ve seqence relay is employed.

Zero sequence components:

+ve sequence — Always

-ve sequence — unbalance

zero sequence — unbalance with ground effect

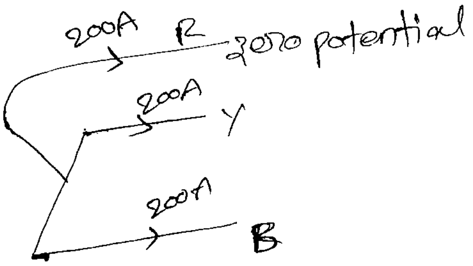
→ The zero sequence components does exist provided that the fault must be i) Grounded fault

ii) The nearest neutral of the system must be ground

In any grounded fault the current passes through ground and enter into the system from nearest neutral grounding. The ground can provide the magnitude without any displacement.

Neutral — common point of Y winding at zero (or) any other potential

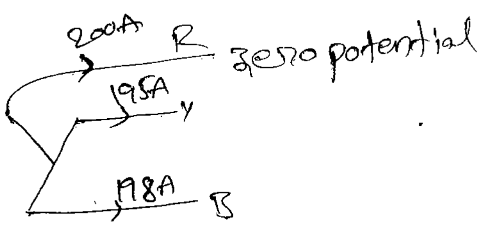
Ground — Any external surface by maintaing zero potential.



$I_n = 200\angle 0 + 200\angle 120 + 200\angle 240$

$= 0$

$V_n = 0$



$I_n = 200\angle 0 + 195\angle 120 + 198\angle 240$

$\neq 0$

$\downarrow V_R = E_R - \text{Drop} \uparrow$

$V_Y = E_Y - \text{Drop}$

$V_B = E_B - \text{Drop}$

$V_n \neq 0$

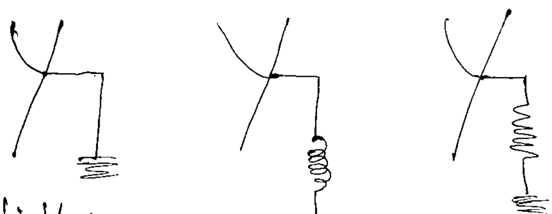
$P-n \neq P-G$

neutral $\neq$ ground

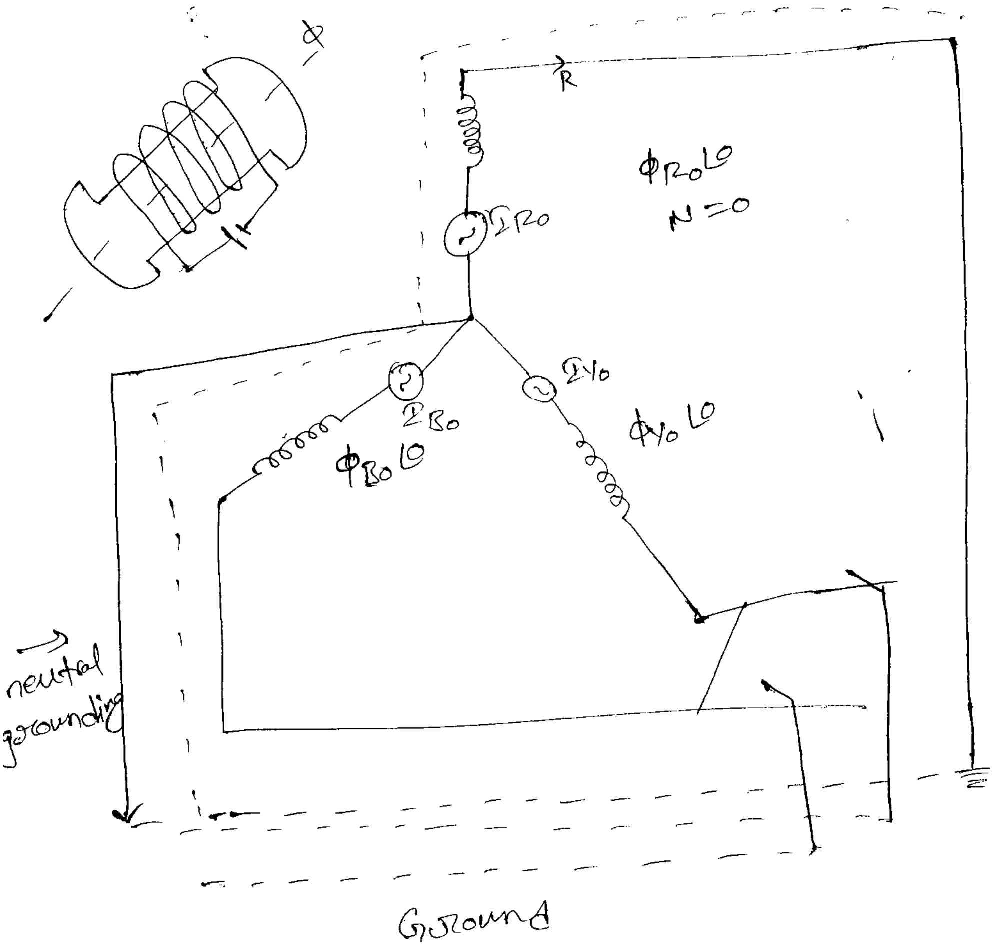
→ neutral grounding is necessary in order to divert the circulating ~~grou~~ effect to ground so that the floating of the neutral can be prevented and also the damage to any one of the phase as well as the occurrance of the shocks can be prevented.

→ The neutral grounding is also necessary to provide closed path for the fault current in case of grounded fault. Hence the neutral of the system is permanantly grounded.

→ There are three ways in grounding effect.

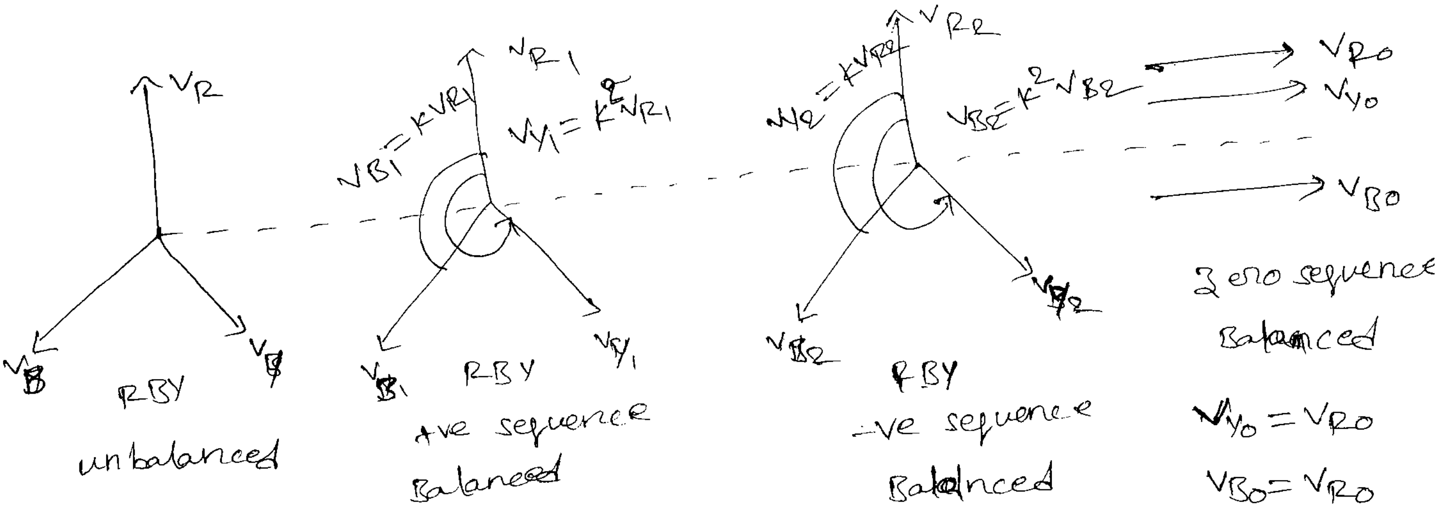


solidly grounding — neutral grounding — Reactance grounding



Significance of zero sequence components:-

The flux produced by the zero sequence components are equivalent to without any phase displacement. If there is no phase displacement, these fluxes will be treated as static fluxes. However w.r.to air gap the zero sequence component fluxes are having 120° phase displacement so that the resultant flux in the air gap will be zero. Hence there is no effect on the rotor field winding. However certain amount of zero sequence flux is in the stator winding in the form of leakage flux due to short pitch winding of the alternator hence the zero sequence components are treated as leakage components.



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

$$V_Y = V_{Y0} + V_{Y1} + V_{Y2} = V_{R0} + K^2V_{R1} + KV_{R2}$$

$$V_B = V_{B0} + V_{B1} + V_{B2} = V_{R0} + KV_{R1} + K^2V_{R2}$$

$$\underbrace{\begin{bmatrix} V_R \\ V_Y \\ V_B \end{bmatrix}}_{\text{unbalanced}} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & K^2 & K \\ 1 & K & K^2 \end{bmatrix} \begin{bmatrix} V_{R0} \\ V_{R1} \\ V_{R2} \end{bmatrix} \rightarrow \text{Balanced symmetrical components}$$

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

Calculation of symmetrical components by using unbalanced ē quantities.

I_{R0}, I_{R1}, I_{R2}

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

$$A^{-1} = \frac{\text{adj } A}{\det A} = \frac{(\text{Cofactors})^T}{\det A}$$

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

$$I_{R0} = \frac{1}{3}\left[I_R + I_Y + I_B\right]$$

$$I_{R1} = \frac{1}{3}\left[I_R + I_Y \cdot k + k^2 I_B\right]$$

$$I_{R2} = \frac{1}{3}\left[I_R + k^2 I_Y + k I_B\right]$$

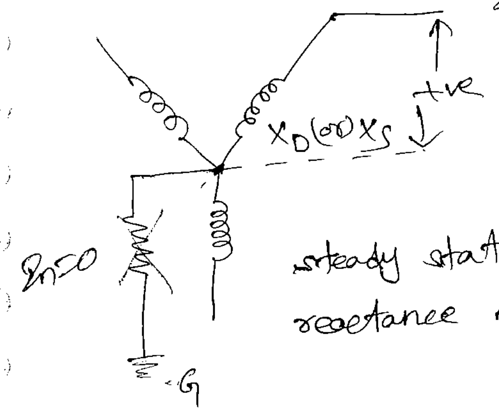
Symmetrical networks (or) sequence networks:-

The symmetrical components can be represented by an ē network and the corresponding networks are called symmetrial network, these are called "sub-transient impedance (or) reactance networks" in a phase manner (per-phase) w.r.to

i) neutral ii) ground

Before fault

$I_n = I_R + I_Y + I_B$
$= 0$



steady state
reactance network

Fault

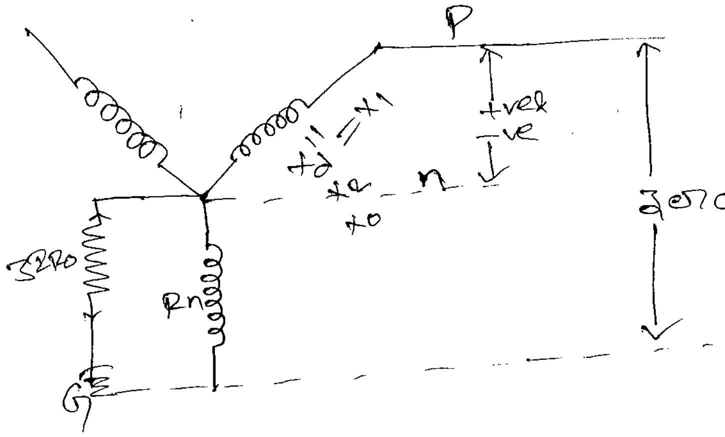
$I_n = I_R + I_Y + I_B \neq 0$

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

$I_n = I_{R0} + I_{R1} + I_{R2} + I_{R0} +$
$k^2 I_{R1} + k I_{R2} + I_{R0} + k I_{R1} +$
$k^2 I_{R2}$

$= 3I_{R0} + I_{R1}\underbrace{(1+k^2+k)}_{0} + I_{R2}\underbrace{(1+k+k^2)}_{0}$

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



→ In case of +ve & -ve sequence n/w the neutral grounding can be ignored where as in case of zero sequence the neutral grounding effect should be taken into account.

→ Any sequence network is having prefault voltage i.e. voltage before fault at the fault point in series with equivalent sub transient reactance (sub-T) which is evaluated w.r.t. fault point by replacing all the active sources with their internal reactances.

active sources:-

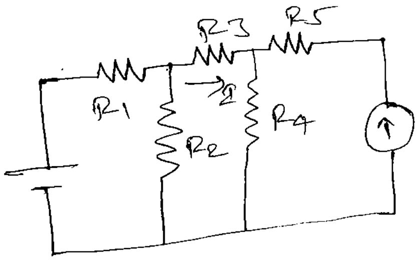
i) voltage source → short circuit

ii) current source → open circuit

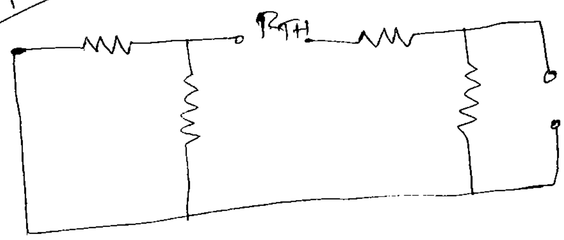
→ The power system n/w is having voltage sources due to syn machine and they can be repheed as short circuit.

→ The sequence n/w's are electrial equivalent of theviren's network.

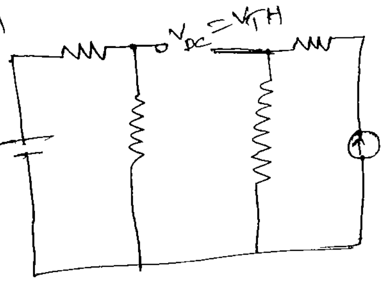
Thevinins network:-



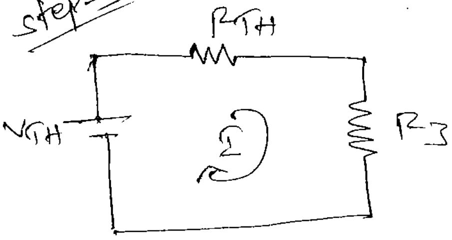
step-2



step-1



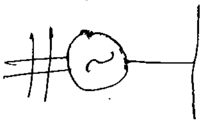
step-3



+ve sequence subtransient network:-

Before fault:-

$E_R = E_{R1}$ $V_R = V_{R1}$



$R \ll X$

$Z = jX_d$

No-load

$V_R = V_{R1} = E_{R1}$

$E_R = E_R = 13.2 kV$

$\frac{V_{R1}}{E_{R1}} = \frac{13.2}{13.2}$

Loaded

$V_R = V_{R1} < E_{R1}$

$V_R = V_{R1} = 13.0$

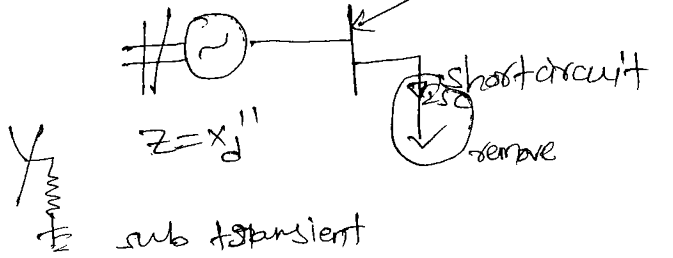
$\frac{V_{R1}}{E_{R1}} = \frac{13.0}{13.2}$

Fault:-

Voltage at the fault point = voltage before fault = Prefault voltage

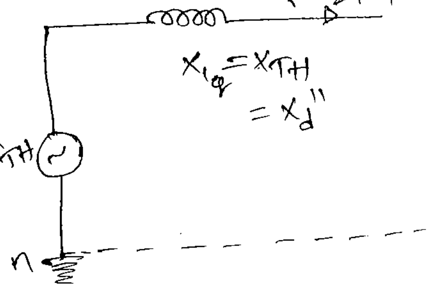
$V_{TH} = V_R = V_{R1} = E_{R1}$ (no load)

$\neq E_{R1}$ (Load)



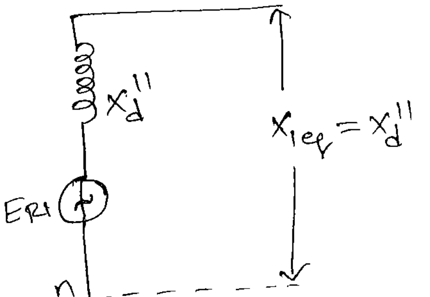
sub transient reactance

Calculation of X_{1eq}:-

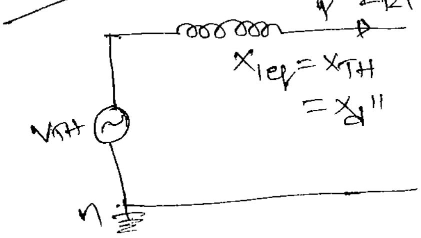


Draw the reactance diagram for a given single line diagram & evaluate the reactance to fault point by replacing the active sources.

step-1



step-2

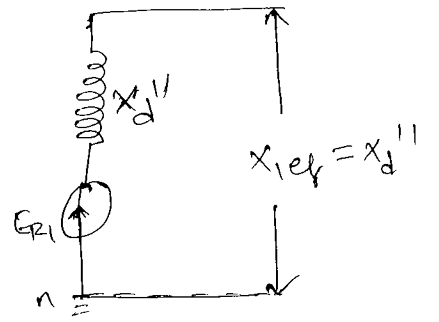


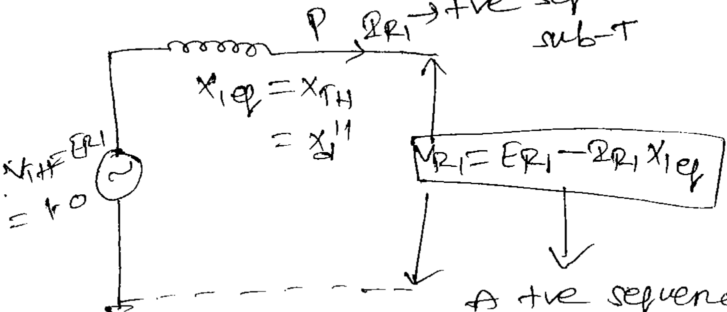
$$\uparrow I_{R1} = \frac{V_{TH}}{X_d''} = \frac{1.0}{X_d''} = \frac{0.98}{X_d''} \downarrow$$

The magnitude of the sub-T current does depends upon prefault voltage. In a no-load condition it will be 1 PU and in a loaded condition it will be less than 1 PU. The sub-T current will be high in a no-load condition of the alternator when compared to loaded alternator.

step-3

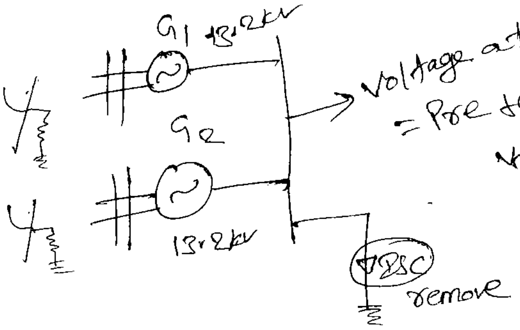
The fault current may have more than 1 n/w and by fault n/w is the symmetrical n/w should be closed rather than each n/w close seperately.





A +ve sequence sub-T network terminal voltage equation.

+ve sequence sub-T n/w:-



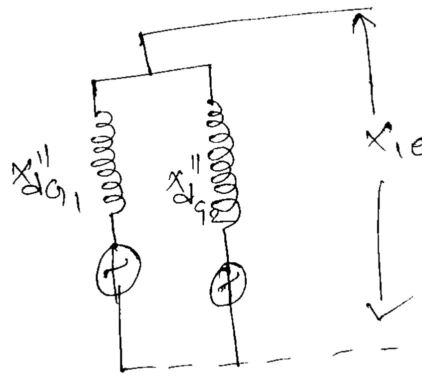
→ Voltage at the fault point = Pre fault voltage

$V_{TH} = V_P = V_{PF} = E_{R1}$ (no load)

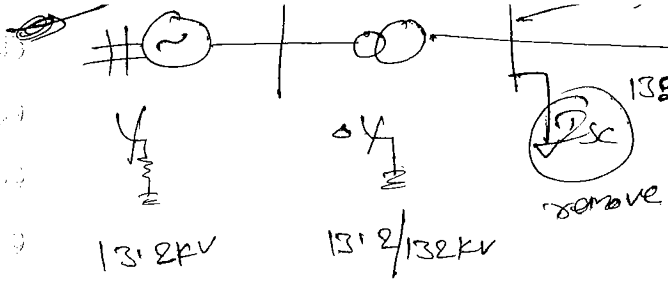
$\frac{13.2}{13.2} = 1.0$

calculation of X_{1eq}:-

step-1

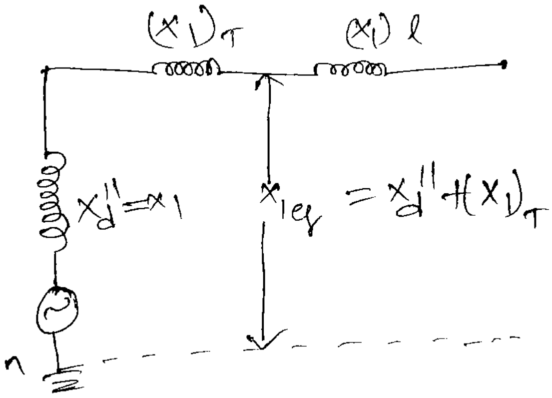


$X_{1eq} = (X''_{dG_1}) \parallel (X''_{dG_2})$



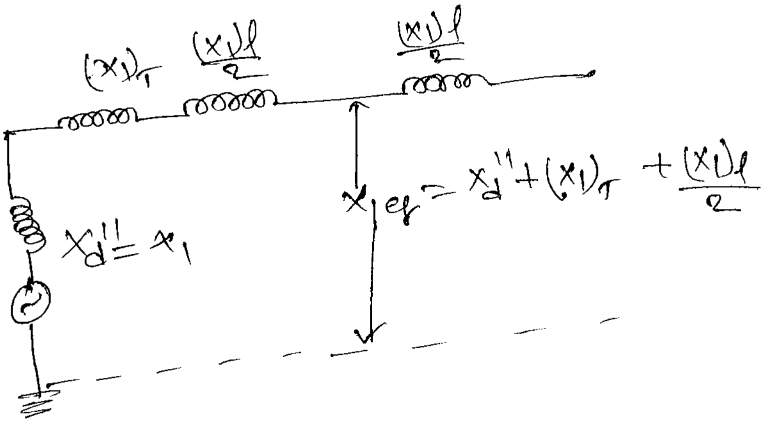
$V_R = V_{R_1} = 132$ kV (no load)
$= \frac{132}{132} = 1.0$

$\frac{128}{132} < 1.0$ (load)

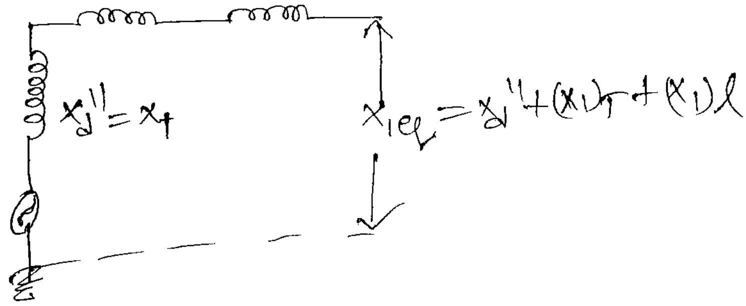


$X_{1eq} = X_d'' + (X_1)_T$

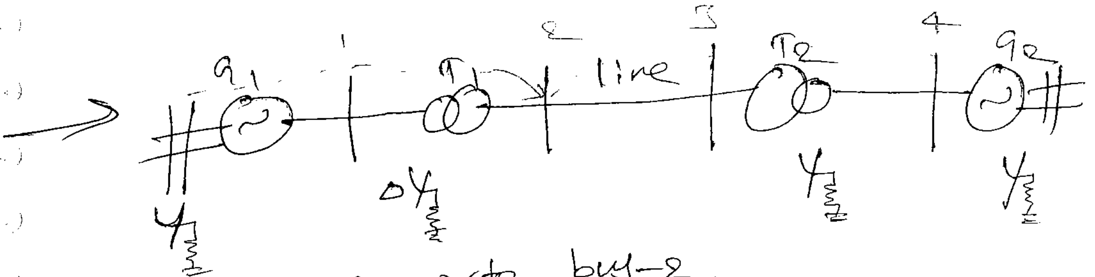
step-3



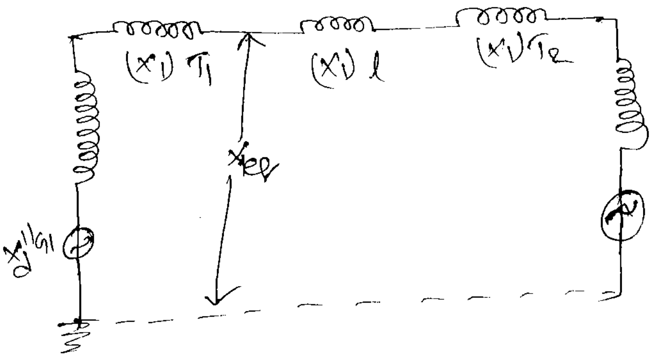
$X_{1eq} = X_d'' + (X_1)_T + \frac{(X_1)l}{2}$



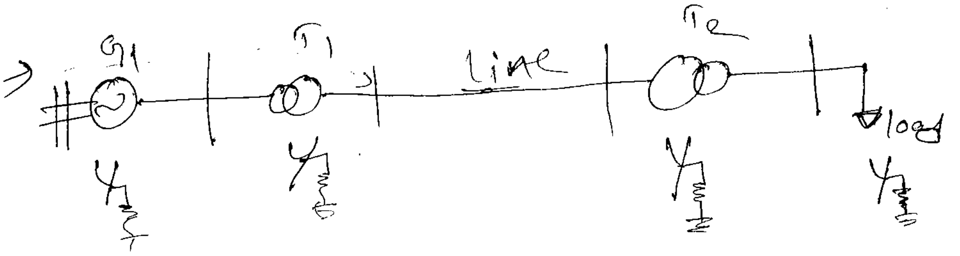
$X_{1eq} = X_d'' + (X_1)_T + (X_1)l$



calculate the the sequence x w.r.to bus-2.
equivalent



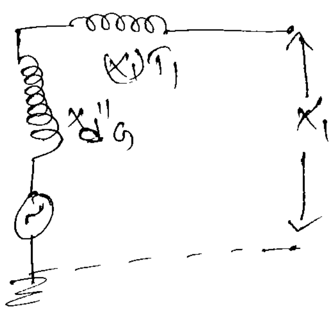
$$\Rightarrow X_{1eq} = \left[X_d'' G_1 + (X_1) T_1\right] \,//\, \left[(X_1)_l + (X_1) T_2 + X_d'' G_2\right]$$



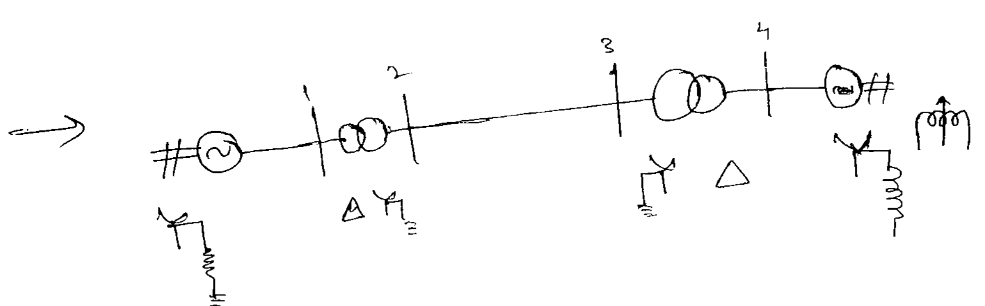
+ve seq w.r.to
calculate the x bus-2

$$V_{TH} = V_R = V_{R1} \neq E_{R1}$$
$$\angle 10$$

In the fault analysis the effect of inductive loads can be ignore while calculating equivalent reactance



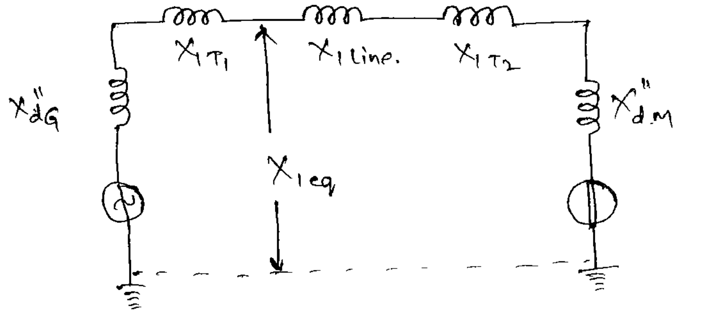
$$X_{1eq} = X_d'' G + (X_1) T_1$$



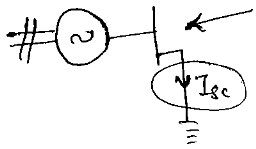
If the fault occurs, the current delivered to the load is zero.

But due to moment of inertia the rotor is still in rotational manner.

The energy stored in the rotor will be supplied to the fault point



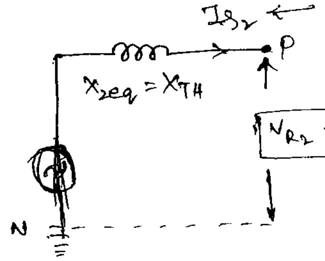
-ve sequence sub-transient network:-



Prefault voltage

$V_{TH} = V_R = V_{R2} = E_{R2} = 0$

The system is having only +ve sequence before fault so that the prefault voltage for -ve sequence and zero sequence will be zero.



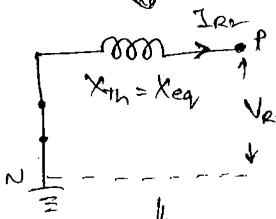
$I_{R_2} \leftarrow$ -ve sequence sub transient current

$\boxed{V_{R_2} = E_{R_2} - I_{R_2} X_{2eq}}$

-ve sequence sub-Transient network terminal voltage equation

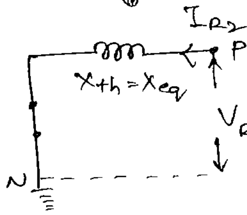
-ve sequence sub-T N/W

⇓



$V_{R_2} = -I_{R_2} X_{2eq}$

⇓

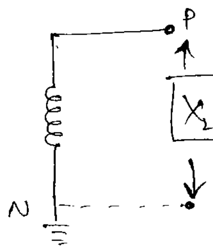


$V_{R_2} = I_{R_2} X_{2eq}$

→ In case +ve sequence the Generator is ~~series~~ represented by voltage source in series with reactance.

→ In case of -ve sequence and the zero sequence it can be represented by only reactance model

$X_{2eq} = X_{2G}$

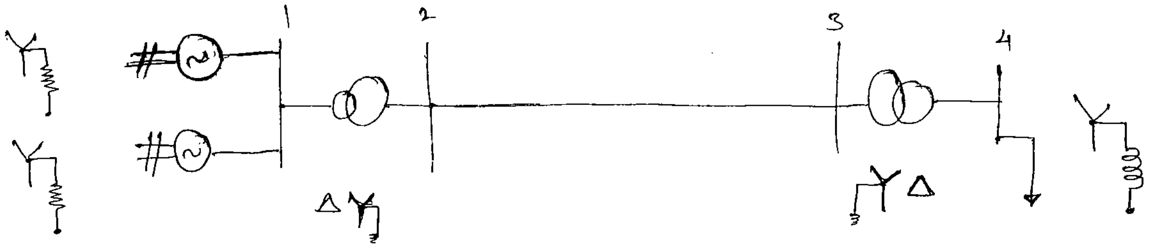


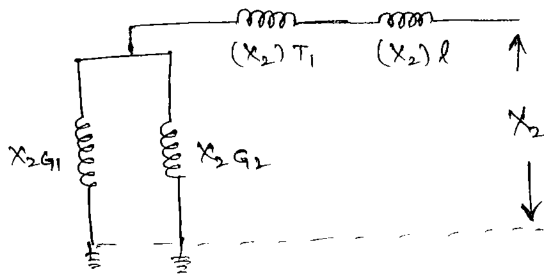
$\boxed{X_{2eq} = X_{2G}}$

Note:-

* Equavalant reactance will be same as Generator reactance.

The -ve sequence n/w is similar to that of +ve seq. N/W except that there is no prefault voltage





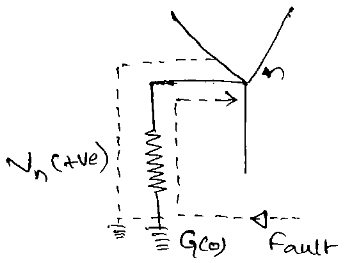
$$X_{2eq} = \left[(X_2G_1) \,||\, (X_2G_2) + (X_2)_{T_1} + (X_2)_l\right]$$

Zero-Sequence sub-transient Network :-

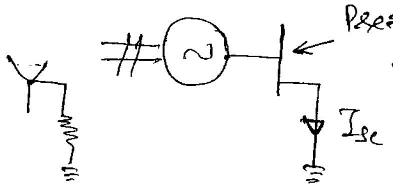
Include the neutral Grounding effect because the reference is Ground

Voltage of Neutral

$$V_n = I_n R_n = 3 I_{R0} R_N \text{ (-ve)}$$

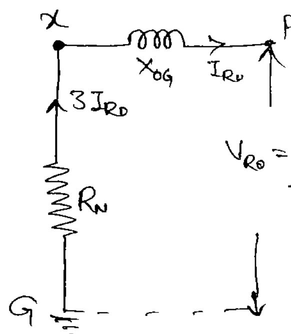


V_n(-ve) - Fault

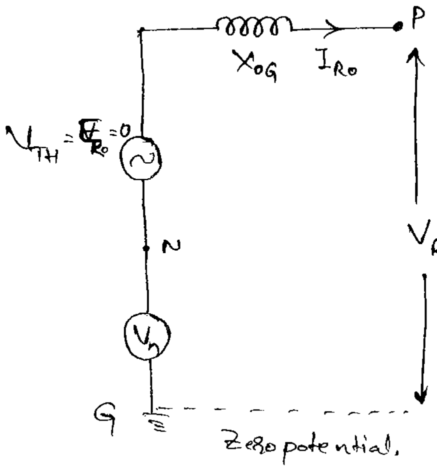


Prefault voltage

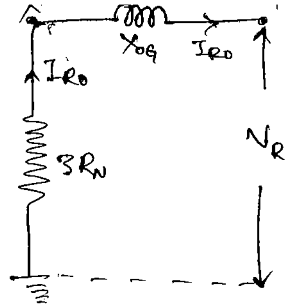
$V_{TH} = V_R = V_{R0} = E_{R0} = 0$



$V_{R0} = -3I_{R0}R_N - 3R_0X_{0G}$ ⇐



$V_{R0} = E_{R0} - V_n - I_{R0} X_G$



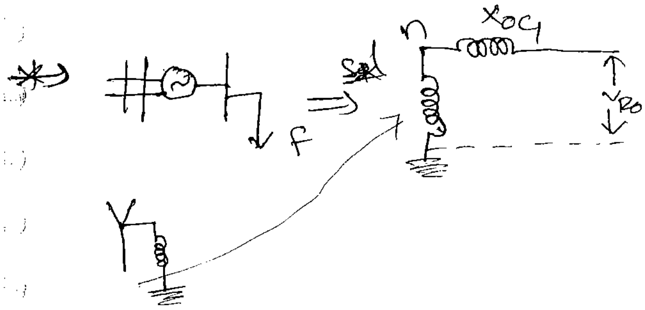
Zero - sequence sub-T network

$$V_{R0} = -I_{R0}\,3R_x - I_{R0}\,X_{0G}$$
$$= -I_{R0}\left(3R_x + jX_{0G}\right)$$
$$= -I_{R0}\,Z_{0eq} \qquad \left[\because Z_{0eq} = 3R_x + jX_{0G}\right.$$

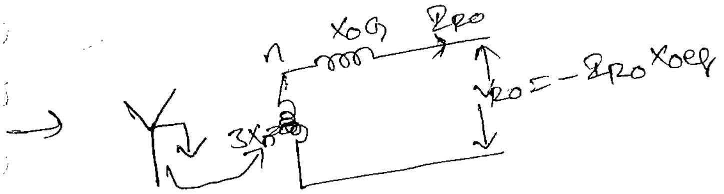
Network terminal voltage equation

$$\begin{bmatrix} V_{R0} \\ V_{R1} \\ V_{R2} \end{bmatrix} = \begin{bmatrix} 0 \\ E_{R1} \\ 0 \end{bmatrix} - \begin{bmatrix} Z_{0eq} & 0 & 0 \\ 0 & X_{1eq} & 0 \\ 0 & 0 & X_{2eq} \end{bmatrix} \begin{bmatrix} I_{R0} \\ I_{R1} \\ I_{R2} \end{bmatrix}$$

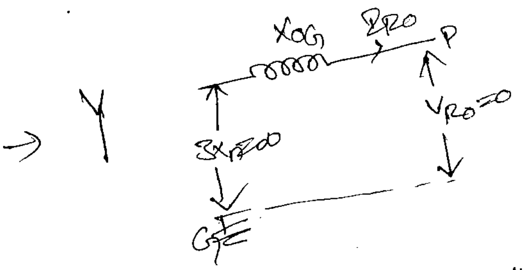
Network terminal voltage equations.

*) 

$$\therefore X_{0eq} = 3X_n + jX_{0G}$$
$$= j\left(3X_n + X_{0G}\right)$$

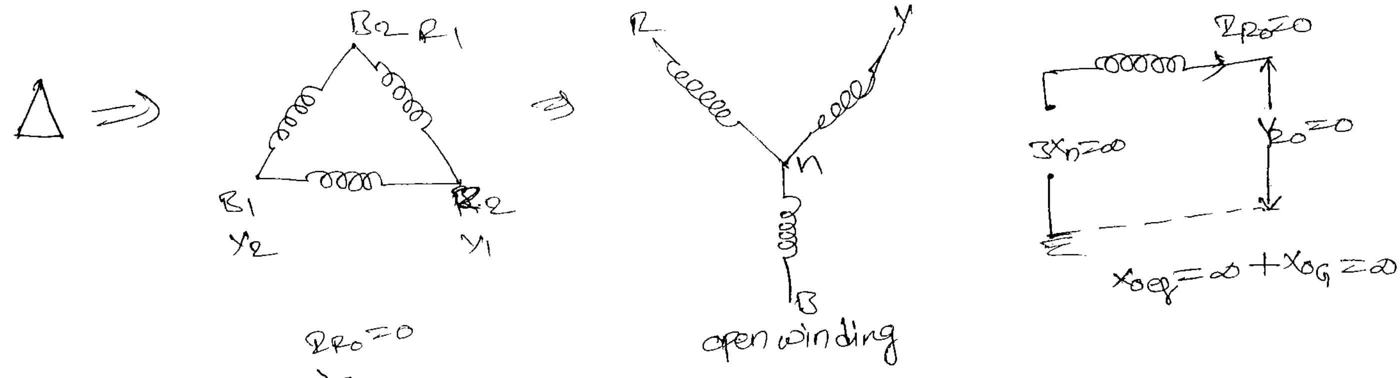
→ 

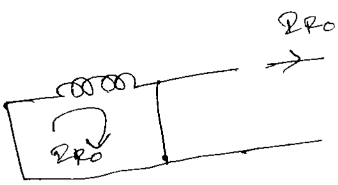
$$X_{0eq} = 0 + X_{0G}$$
$$= X_{0G}$$

→ 

$$X_{0eq} = \infty + X_{0G} = \infty$$

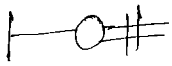
→ As the neutral grounding changes, the zero sequence reactance of n/w will also changes. However, the +ve sequence & the -ve sequence n/w reactances are remain same.



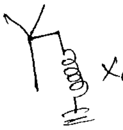


→ A star winding is open winding and if there is no current in the line. However, the delta connected winding is a closed winding b/n any two phases so that there will be a zero sequence current with in the phases but there is no current in the line.

→ Apart from the generator grounding, the neutral groundings are employed at the load side which are normally synchronous loads.

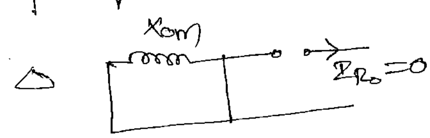


 $Z_{0eq} = 3R_n + jX_{0m}$

 $X_{0eq} = j3X_n + jX_{0m}$

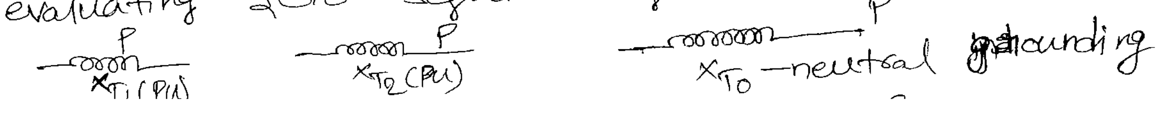
 $X_{0eq} = 0 + X_{0m} = X_{0m}$

 $X_{0eq} = \infty + X_{0m} = \infty$

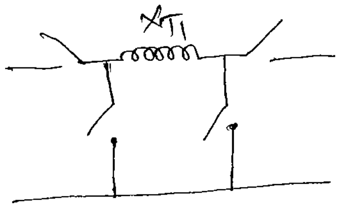


→ The neutral grounding effects are also provided in a transformer, It is a two winding system and pu reactance of the transformer on both sides will be same.

→ However the neutral grounding effect should be included by evaluating zero sequence equivallent n/w.



→ ... effect the transformer can be replaced by points mechanical equivalent with help of series-parallel switches.



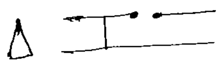
Y – open winding – series switch

Δ – closed winding – parallel/shunt switch.

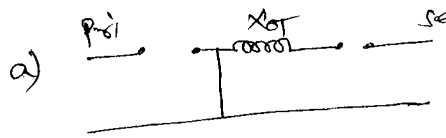

n → opened series switch i.e., $3X_n = \infty$

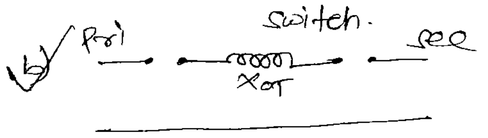

→ closed series switch i.e., $3X_n = 0$

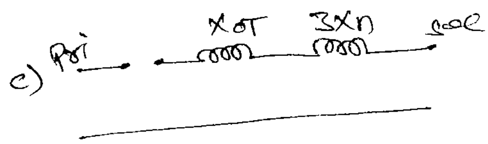

→ closed series switch i.e., $3X_n \neq 0$

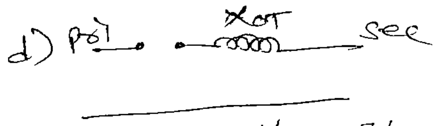

line ⇒ ||el switch is closed b/n two lines & open the line & phase switch.

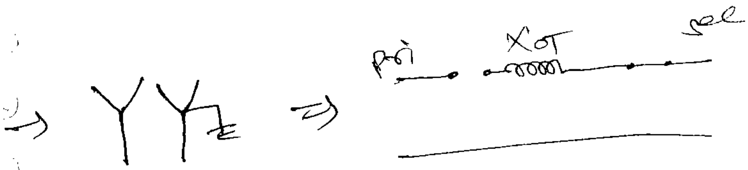
→ 

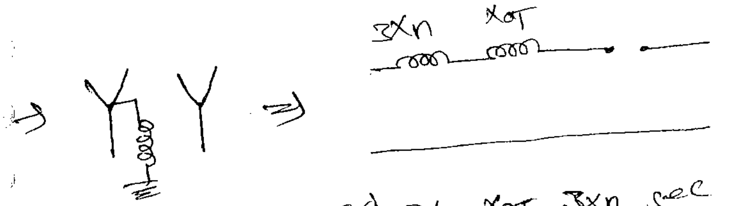


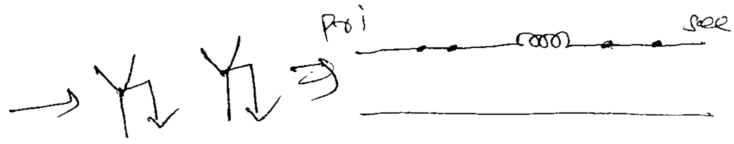


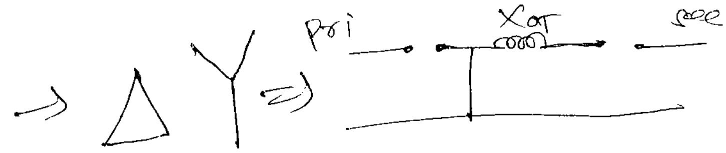


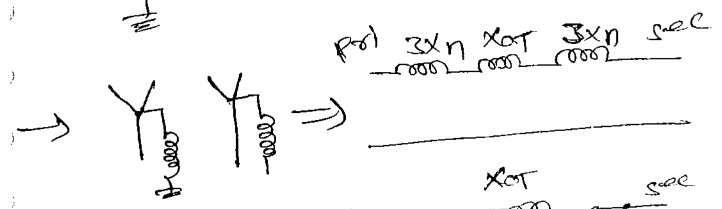




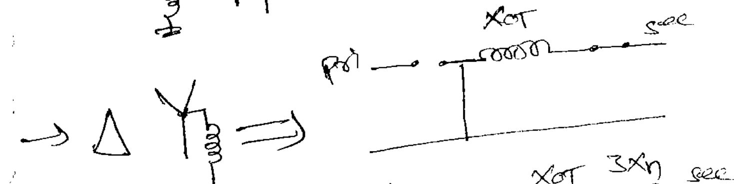


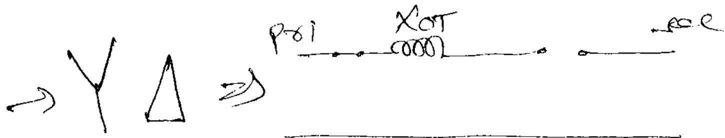


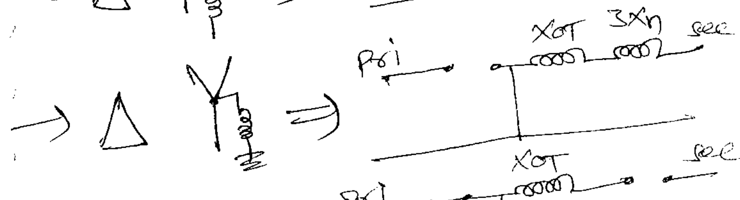


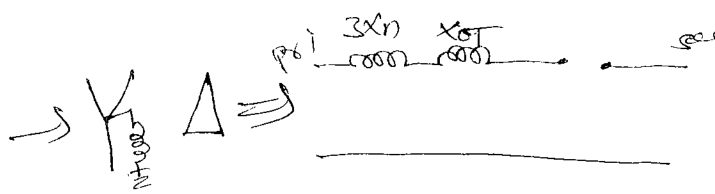


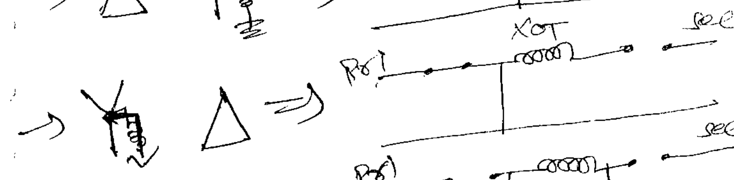
(metallic conductors are bilateral elements)

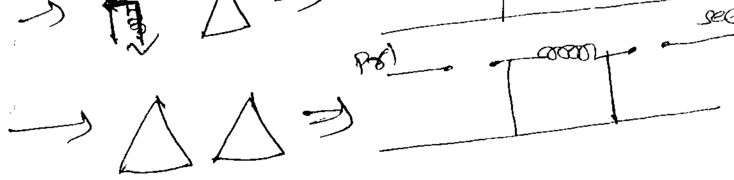












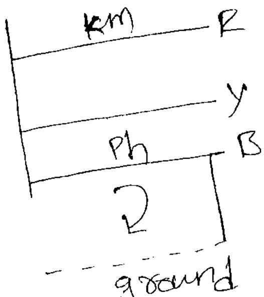
Relations among sequence reactances:-

	+ve sequence	-ve sequence	zero sequence
Transmission line	X_1	$X_2 = X_1$	$\boxed{X_0 = 3X_1}$ ** grd effect is considered
Transformer	X_1	$X_2 = X_1$	$X_0 = X_1$
Turbo machine	X_d''	$X_2 = X_d''$	$X_0 << X_d''$
salient pole machine	X_d''	$X_d'' > X_2$	$X_0 << X_d''$

(Transmission line, Transformer: reference i/p neutral) (Turbo machine, salient pole machine: ignore the grd effect)

→ Both (Transmission line and Transformer) are static devices, they are made by bi-lateral elements and the reference is neutral for +ve sequence and -ve sequence so that the reactance offered in both the directions will be same, because there is no effect of ground, ∵ reference is neutral.

→ The zero sequence components does exist provided that the fault must be grounded fault. In any grounded fault, the current passes through ground and enter into the system from nearest neutral grounding. Hence the effect of the ground should be considered while evaluating zero sequence equivalent ~~network~~ reactance, especially in the longer length of equipment i.e., transmission line and effect of the ground can be ignored in shorter length of equipments.



→ Because of the ground effect, the zero sequence reactance of the TL is a variable from time to time and it could be varied as $2.5X_1$ to $3.5X_1$ with an average of $3X_1$.

→ The sequence ...

a) Transformer b) Transmission line c) syn m/c d) Ind. m/c

→ $X_1 = X_2 = X_0 = 0.05\,\Omega$ ⇒ Transformer

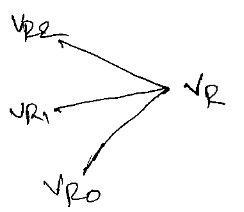
AP Genco
→ The +ve reactance of Transmission line is 0.15 pu, the zero sequence reactance is ——

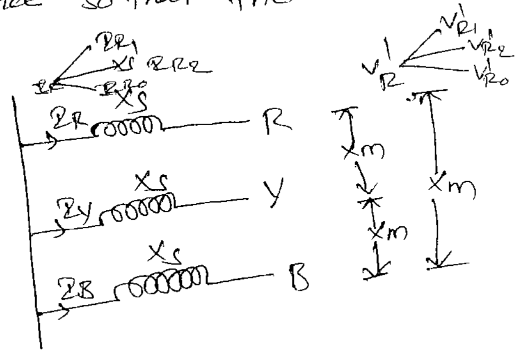
a) 0.15 b) 0.05 c) 0.45 d) 0.3

i.e) $X_1 = 0.15$

$X_0 = ?$ $X_0 = 3X_1 \Rightarrow 3(0.15) \Rightarrow 0.45$

special case:- It is assumed that the flux of one phase may also linked with the other phases, so that there will be a mutual inductance effect apart from self inductance. If a short circuit occurs, the transmission line will become unbalance so that there will be '3' sequence components.





X_s — self reactance of phase

X_m — mutual reactance of phase

(or) replaced by
$X_s \rightarrow Z_s$
& $X_m \rightarrow Z_m$

$X_{1eq} = X_s - X_m = X_{2eq}$ & $X_{0eq} = X_s + 2X_m$

+ve sequence (Apply KVL)

$V_{R1} = V'_{R1} + I_{R1}X_s + I_{Y1}X_m + I_Y X_m$

$= V'_{R1} + I_{R1}X_s + I_{R1}(\underbrace{K^2 + K}_{-1})$

$= V'_{R1} + I_{R1}\underbrace{(X_s - X_m)}_{X_{1eq}}$

$\therefore V_{R1} = V'_{R1} + I_{R1}X_{1eq}$

-ve sequence

lll'y

$V_{R2} = V'_{R2} + I_{R2}X_{2eq}$

zero sequence

$V_{R0} = V'_{R0} + I_{R0}(X_s + 2X_m)$

$= V'_{R0} + I_{R0}X_{0eq}$

→ In this special case, the effect of the ground is ignored, while calculating equivalent reactance.

→ The +ve sequence impedance of the transmission line is 16Ω and zero seq impedance of the line is 45Ω. The ~~effect~~ self impedance and the mutual impedance of the line are ____

$Z_{1eq} = Z_s - Z_m = 16\Omega$

$Z_{0eq} = Z_s + 2Z_m = 45\Omega$

(−)

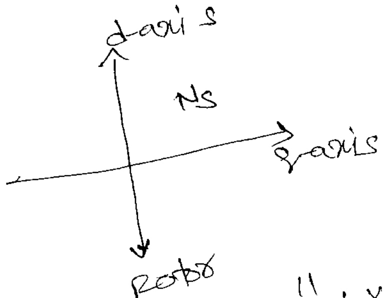
$-3Z_m = -29\Omega$

$Z_m = 9.67\ \Omega$

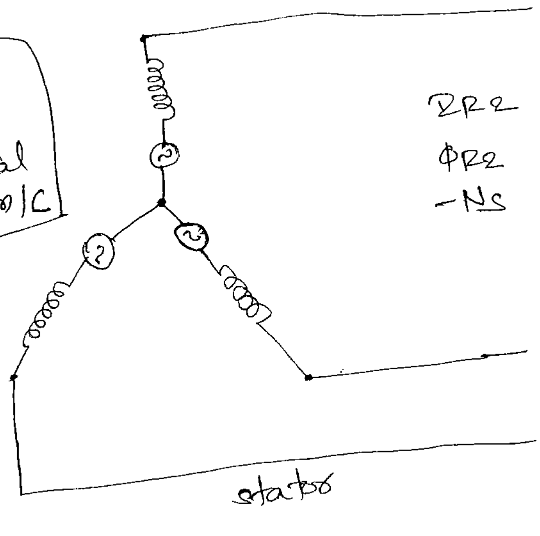
$\therefore Z_s = 16 + \frac{29}{3} \Rightarrow 25.67\Omega$

→ In case of turbo machine there will be a uniform air gap flux (∵ only two poles are present) Hence $X_2 = X_d''$

→ But in case of salient pole machine there will be a non-uniform air gap flux (∵ more than one pair of poles are present). Hence $X_2 < X_d''$



Turbo m/c (or) cylindrical rotor m/c



$X_2 = \frac{X_q'' + X_d''}{2}$

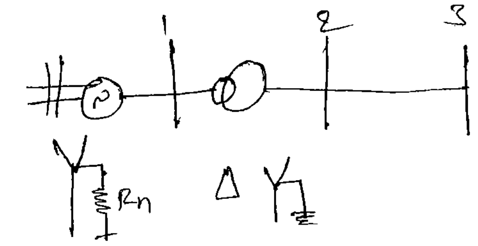
→ The flux produced by the −ve sequence component flux is having a relative speed of 2Ns, so that the −ve sequence component flux is able to cut the rotor field winding.

→ Incase of salient pole m/c, due to projected poles, the air gap flux has become non-uniform so that the −ve sequence flux that can be cut by the rotor axes are become alternatively maximum in the direct axis as well as quadrature axis. Hence the −ve sequence reactance is calculated as average reactance.

$X_2 = \frac{X_q'' + X_d''}{2} \Rightarrow \boxed{X_2 < X_d''}$

→ The flux produced by the zero sequence components currents are equal in magnitude without any phase displacement. If there is no phase displacement, there is no armature reaction effect. However, there will be a leakage flux and zero sequence reactances are treated as leakage reactances.

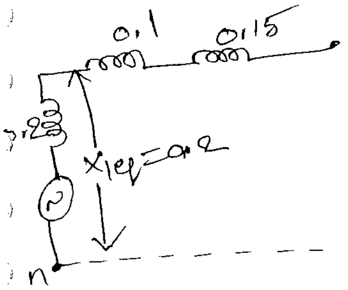
→



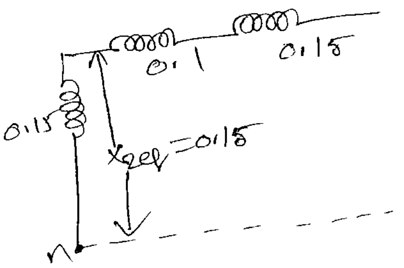
generator	Transformer	Transmission line
$X_d'' = 0.2$	$X_1 = X_2 = X_0$	$X_1 = X_2 = 0.15$
$X_2 = 0.15$	$= 0.1$	$X_0 = 0.45$
$X_0 = 0.04$		
$R_n = 0.05$		

a) calculate the equivalent reactances w.r.to bus '1'

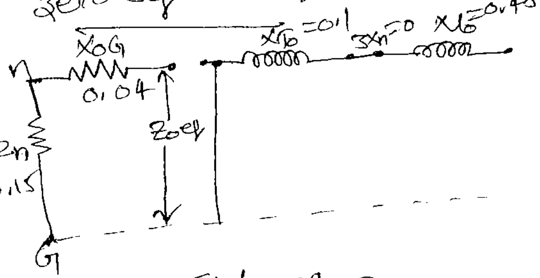
+ve sequence n/w



-ve sequence n/w



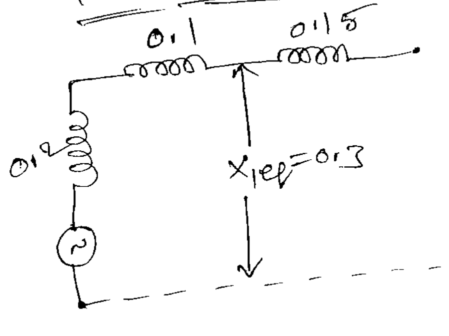
zero sequence n/w



$Z_{0eq} = 0.15 + j0.04\ \Omega$

b) calculate equivalent reactances w.r.to bus '2'.

+ve sequence network



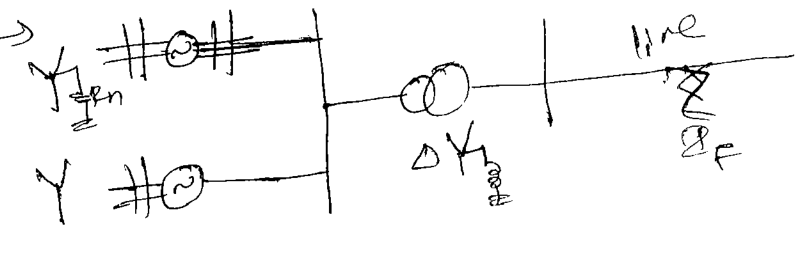
|||ly $X_{2eq} = 0.25$

$X_{0eq} = 0.1$

c) w.r.to bus '3'.

$X_{1eq} = 0.45$, $X_{2eq} = 0.4$, $X_{0eq} = 0.55$

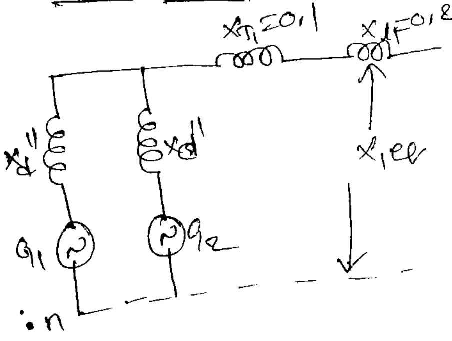
→



$G_2 = G_1$	T/f	TL
$X_d'' = 0.12$	$X_1 = X_2 =$	$X_1 = X_2 = 0.$
$X_2 = 0.1$	$X_0 = 0.1$	$X_0 = 0.6$
$X_0 = 0.04$	$X_n = 0.05$	
$R_n = 0.05$		

Calculate the equivalent reactances, if the fault occurs at the middle of the line.

+ve sequence n/w

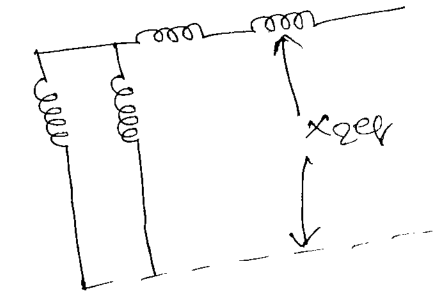


at middle fault occurs $X_{l_1} \Rightarrow \frac{X_l}{2} = \frac{0.2}{2} = 0.1$

$$X_{1eq} = 0.12 \| 0.12 + \left(0.1 + \frac{0.2}{2}\right)$$

$$= 0.06 + 0.1 + 0.1 = 0.26$$

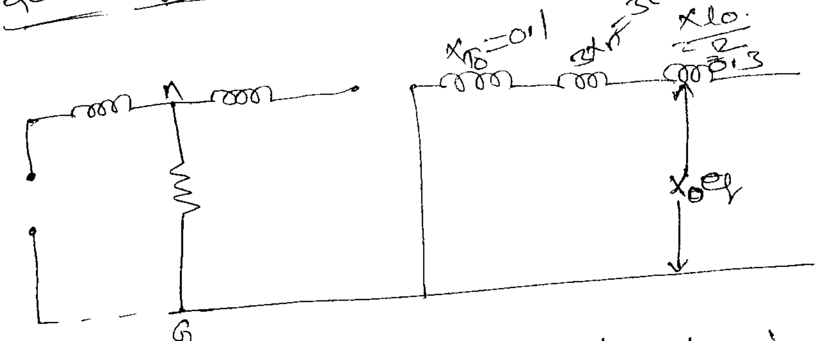
-ve sequence n/w



$$X_{2eq} = (0.1)\|(0.1) + \left(0.1 + \frac{0.2}{1}\right)$$

$$= 0.05 + 0.1 + 0.1 = 0.25$$

zero sequence n/w



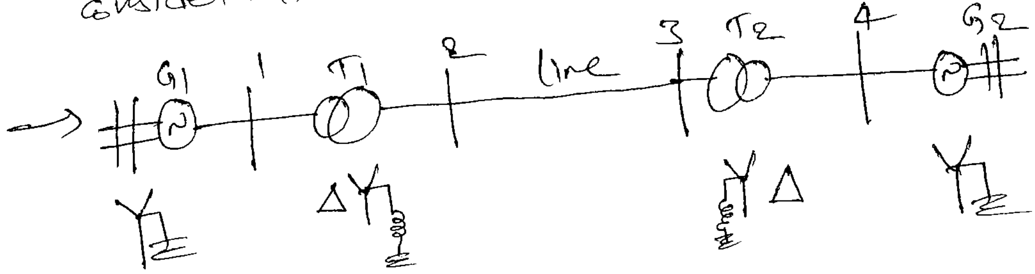
$$X_{0eq} = 0.1 + 3(0.05) + 0.3$$

$$= 0.1 + 0.15 + 0.3$$

$$= 0.55$$

If fault occurs at generator terminal

the Y generator is a open path & ignore it; only closed path should consider. Hence $Z_{0eq} = 0.15 + j0.04$



Gen-1
$X_d'' = X_2 = 0.2$
$X_0 = 0.6$

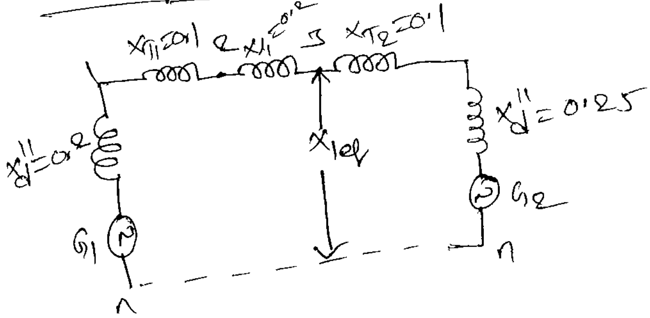
T/f-1
$X_1 = X_2 = X_0 = 0.1$
$X_n = 0.05$

T2
$X_1 = X_2 = X_0 = 0.1$
$X_n = 0.05$

Line
$X_1 = X_2 = 0.2$
$X_0 = 0.6$

Gen-2
$X_d'' = X_2 = 0.25$
$X_0 = 0.08$

+ve sequence n/w



$X_{1eq} = (0.2+0.1+0.2) \,||\, (0.35)$

$= 0.5 \,||\, 0.35$

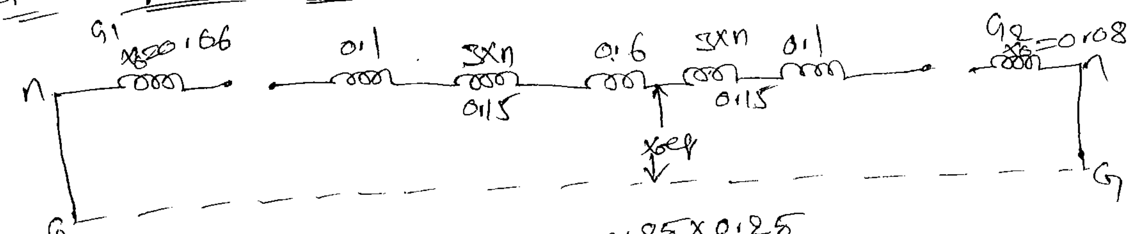
$= \dfrac{0.5 \times 0.35}{0.5+0.35}$

(∵ both generators are gives current in both directions)

-ve sequence n/w

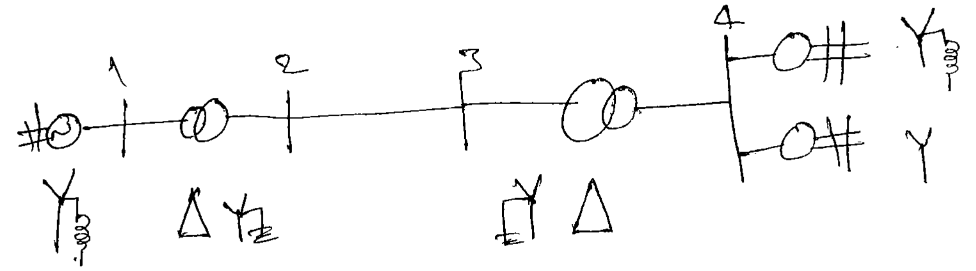
X_{2eq} = same as $X_{1eq} = \dfrac{0.5 \times 0.35}{0.5+0.35}$

zero sequence n/w:-



$X_{0eq} = 0.185 \,||\, 0.25 \Rightarrow \dfrac{0.185 \times 0.25}{0.185+0.25} = $ ——

→

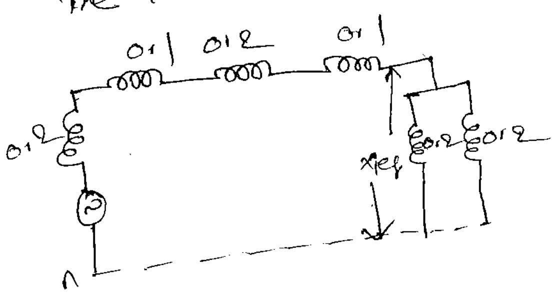


Gen	$T_2=T_1$	line	$M_1=M_2$
$X_d''=X_2=0.2$	$X_1=X_2=X_0$	$X_1=X_2=0.2$	$X_d''=X_2=0.2$
$X_0=0.06$	$=0.1$	$X_0=0.6$	$X_0=0.06$
$R_n=0.05$			$X_n=0.05$

Calculate equivalent reactances w.r.to bus '4'

+ve sequence n/w

The loads are synchronous Hence +vely should be taken into account

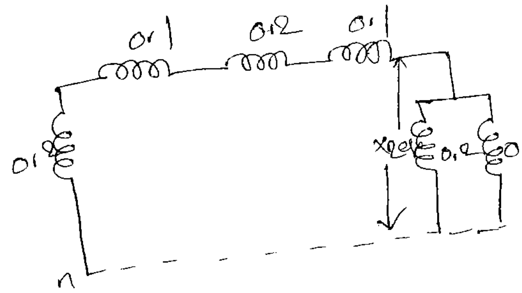


$X_{1eq} = (0.2+0.1+0.2+0.1) \,||\, (0.2 \,||\, 0.2)$

$= 0.6 \,||\, 0.1$

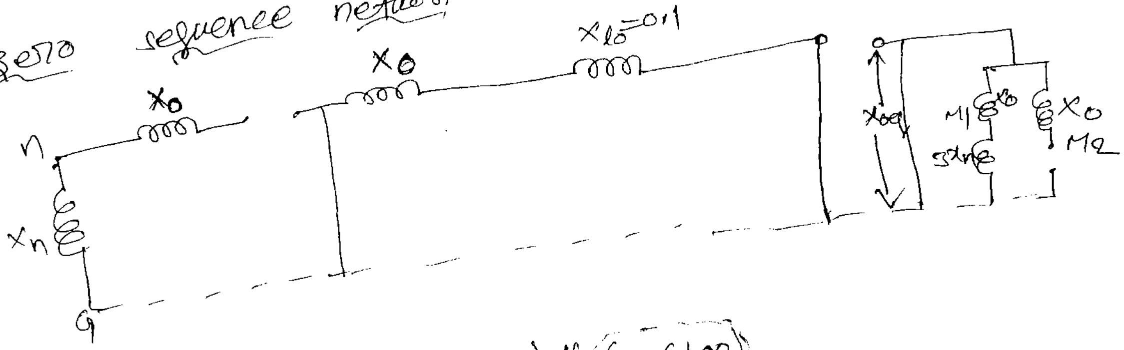
$= \dfrac{0.6 \times 0.1}{0.7}$

-ve sequence network:-



$$x_{2eq} = 0.6 // 0.1$$
$$= \frac{0.6 \times 0.1}{0.7}$$

Zero sequence network:-

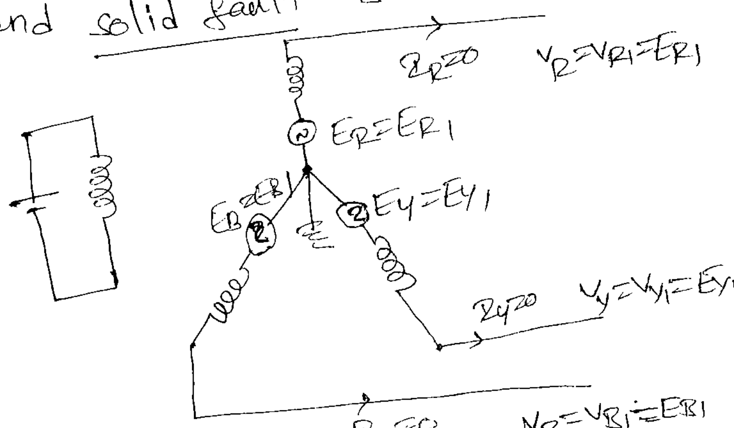


$$X_{0eq} = (0.06 + 3X_n) // (0.06 + \infty)$$
$$= 0.06 + 3(0.05)$$
$$= 0.06 + 0.15$$
$$= 0.21$$

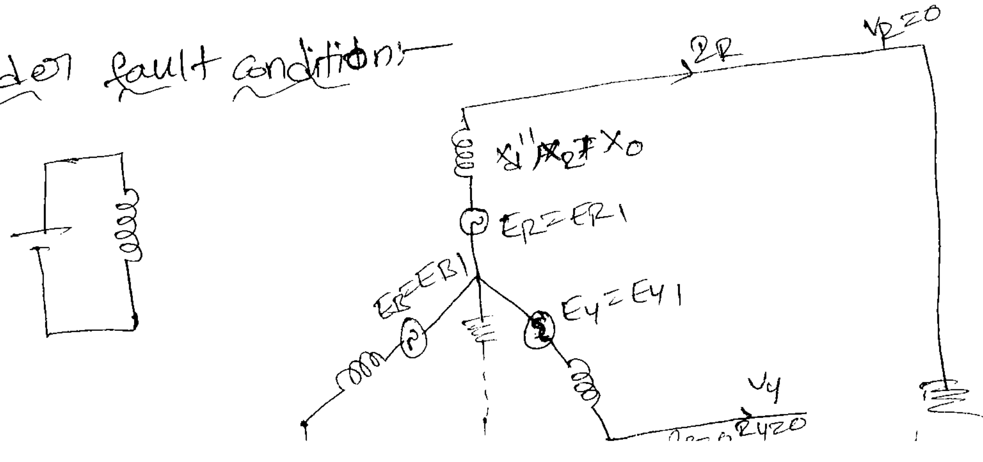
Fault analysis:-

1) Line to ground:- Alternating is working at no-load and rated voltage and solid fault is considered.

[Because at no-load, pre-fault voltage is zero. Hence it is considered as no-load.]



under fault condition:-



During fault :-

$$\left.\begin{array}{l} I_f = I_R \\ I_Y = I_B = 0 \\ V_B = 0 \end{array}\right\} \text{unbalance}$$

use the symmetrical components to steady state the system

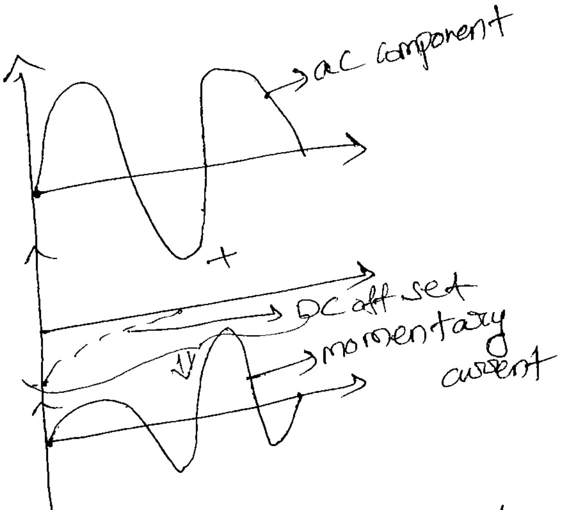
$$\left.\begin{array}{l} I_{R0} = \frac{1}{3}\left[I_R + I_Y + I_B\right] = \frac{I_R}{3} \\ I_{R1} = \frac{1}{3}\left[I_R + K I_Y + K^2 I_B\right] = \frac{I_R}{3} \\ I_{R2} = \frac{1}{3}\left[I_R + K^2 I_Y + K I_B\right] = I_R/3 \end{array}\right\} \quad I_{R0} = I_{R1} + I_{R2} + \frac{I_R}{3}$$

But $\boxed{I_f = I_R = 3I_{R0} = 3I_{R1} = 3I_{R2}}$ PU $\quad (\because I_{R0} = I_{R1} = I_{R2})$

$\Downarrow$

$\therefore$ fault current (or) substransient current (or) symmetrical sinusoidal current

(This is rms pu current.



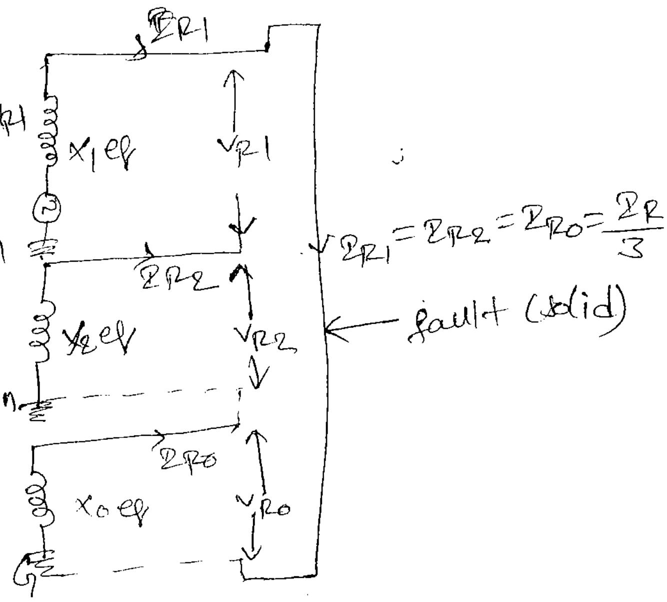
→ If they asked for momentary current, multiply the fault current (what we get) with 1.6

→ The fault is an unbalanced fault with ground so that the three sequence components are exist. In case of grounded fault the fault current should be expressed as zero sequence currents.

i.e) $I_f = I_R = 3I_{R0} \; (3I_{R1} = 3I_{R2})$

→ The fault is having 3 sequence networks and they are connected in series because the sequence currents are same.

sequence n/w for L-G fault



$X_{1eq} = X_d''$

$X_{2eq} = X_2$

$X_{0eq} = X_0$

Actual fault current:-

$$I_f(pu) = \frac{I_f(act)}{I_b} \Rightarrow \boxed{I_f(act) = I_f(pu) \times I_b}$$

$$S = \sqrt{3} V_L I_L \Rightarrow I_L = \frac{S}{\sqrt{3} V_L}$$

$$I_{ph} = I_b = I_L (Y)$$

Calculation of I_{R1} (+ve seq current):-

$$V_R = 0 = V_{R1} + V_{R2} + V_{R0}$$

$$E_{R1} - I_{R1} X_{1eq} - I_{R2} X_{2eq} - I_{R0} X_{0eq} = 0$$

$$E_{R1} = I_{R1} X_{1eq} + I_{R2} X_{2eq} + I_{R0} X_{eq} \quad (\because I_{R0} = I_{R2} = I_{R1})$$

$$E_{R1} = I_{R1} (X_{1eq} + X_{2eq} + X_{0eq})$$

$$\therefore \boxed{I_{R1} = \frac{E_{R1}}{X_{1eq} + X_{2eq} + X_{0eq}}} \text{ pu}$$

$$\therefore I_f = 3 \times \frac{E_{R1}}{X_{1eq} + X_{2eq} + X_{3eq}} \text{ pu}$$

→ The rating of the CB will be expressed interms of breaking current, which is same as fault current.

→ The CB rating will also expressed as breaking capacity, which will generally also called as symmetrical breaking capacity (∵ fault current)

$$\text{Breaking capacity} = 3V_b I_f \rightarrow I_f(\text{act})$$

$$= 3V_b I_{f\,pu} \times I_b$$

$$= \underbrace{3V_b I_b}_{(3VI)_{rated}} \times 3 \times \frac{E_{R1}}{x_{1eq}+x_{2eq}+x_{0eq}}$$

$$\therefore \text{Breaking capacity} = \text{Rated MVA} \times \frac{3\times 1.0}{x_{1eq}+x_{2eq}+x_{0eq}}$$

$$= \frac{3\,\text{base MVA}}{x_{1eq}+x_{2eq}+x_{0eq}}$$

$$\therefore \text{Breaking Capacity} = \frac{3\,\text{base MVA}}{x_{1eq}+x_{2eq}+x_{0eq}}$$

Voltage of the neutral during fault:-

$$V_n = I_n R_n$$

$$= 3I_{R0} R_n = (I_f R_n) \cdot pu$$

(or)

$$V_n = 3I_{R0} \cdot X_n \; pu$$

solid neutral $V_n = 0$ ($\because R_n$ (or) $X_n = 0$)

Actual neutral voltage ; $V_n(pu) = \frac{V_n(act)}{V_b} \Rightarrow \boxed{V_n(act) = V_n(pu) \times V_b}$ V/kV

$V_b = \frac{V_L}{\sqrt{3}}$ (Y) ($\because$ base vol $\Rightarrow$ Phase vol)

Isolated neutral (If the neutral of the alternator is removed):-

Practically it is not done

$$X_{0eq} = X_0 + \infty \Rightarrow X_{0eq} = \infty$$

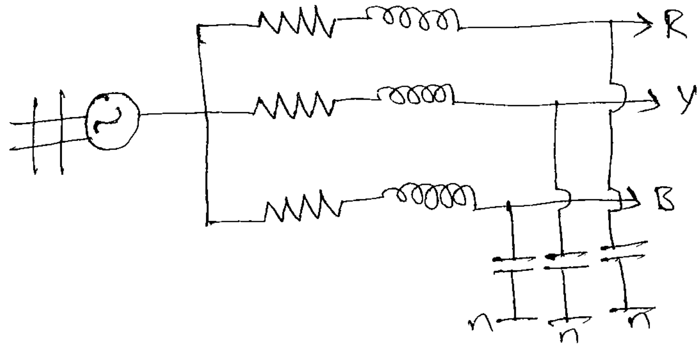
$$\therefore I_f = 3 \times \frac{E_{R1}}{x_{1eq}+x_{2eq}+\infty} = 0 \Rightarrow \boxed{I_f = 0}$$

→ In the case of an isolated neutral of an alternator, the fault current will be zero and also the vol's of other two phases is same as rated vol. Hence the faulty phase (or) other two phases are not effected.

→ However, if a synchronous generator is connected to transmission line and the LG fault occurs in a transmission line, the fault current will be zero, but the voltages of other two phases will become $\sqrt{3}V$ (due to capacitance effect) which is called as "ARCING Grounds" or "severe over voltages".

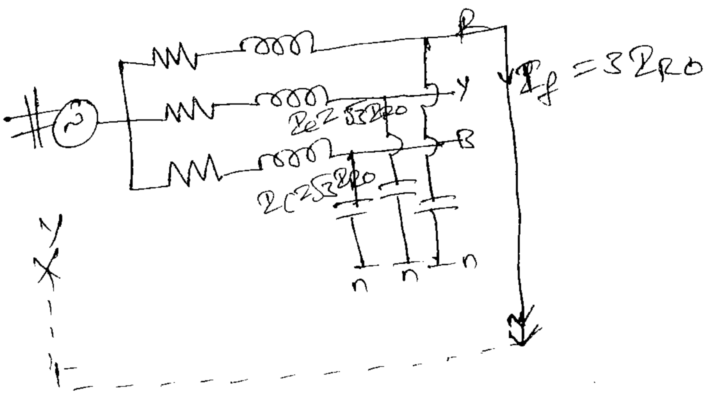
→ In a sinusoidal waveform the insulation of the winding is designed to withstand peak voltage i.e., $\sqrt{2}V$. Hence the insulation of healthy phases will be failed [i.e., flash over of insulation)

→ The ARCING grounds are due to the shunt capacitance of the line



Consider a Y-connected gen connected to TL.

Take one of the line is short circuited.



→ In order to avoid the arcing grounds, the neutral of the alternator should be connected to ground through a coil, which is known as "peterson coil" and the type of grounding is called "Resonance grounding".

→ The value of the inductance of coil, $L = \frac{1}{3\omega^2 C}$

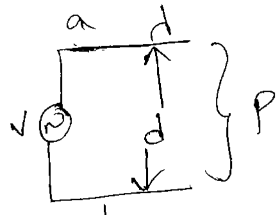
where $C = $ GD/81

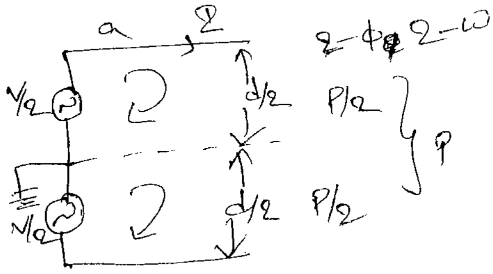
$I_n = 3I_{R0} = 3I_C$

$$\frac{V_{ph}}{X_L} = 3\times\frac{V_{ph}}{X_C} \Rightarrow \frac{1}{\omega L} = 3\times\frac{1}{1/\omega C}$$

$$\frac{1}{\omega L} = 3\omega C$$

$$\frac{1}{L} = 3\omega^2 C \Rightarrow \boxed{L = \frac{1}{3\omega^2 C}}$$



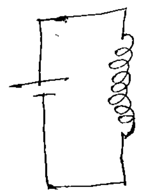


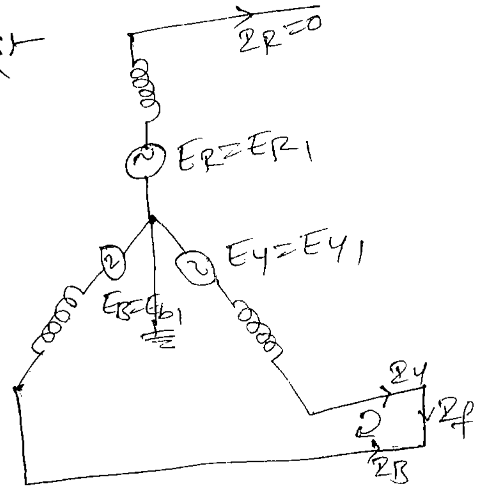
$$C_{ab} = \frac{q}{V} = \frac{\pi\varepsilon_0}{\ln\left(\frac{d}{r}\right)}$$

$$C_a = \frac{q}{\left(\frac{V}{2}\right)} = 2(q/V) = 2C_{ab}$$

⇓ cap/ph (or) cap/conductor

L-L faults:





Alternator is working at no load, rated voltage, solid fault.

During fault

$$\left.\begin{array}{l} I_f = I_Y = -I_B \\ I_f + I_B = 0,\ I_R = 0 \\ V_Y = V_B \end{array}\right\} \text{unbalance}$$

use the symmetrical components

$$I_{R0} = \frac{1}{3}\left[I_R + I_Y + I_B\right] = 0$$

$$I_{R1} = \frac{1}{3}\left[I_R + KI_Y + K^2 I_B\right] = 0$$

$$I_{R1} = \frac{1}{3}\left[0 + KI_Y + K^2(-I_Y)\right] = \frac{I_Y}{3}(K - K^2)$$

$$I_{R2} = \frac{1}{3}\left[I_R + K^2 I_Y + KI_B\right]$$

$$= \frac{1}{3}\left[0 + K^2 I_Y - KI_Y\right] = \frac{I_Y}{3}(K^2 - K)$$

$$\therefore \boxed{I_{R2} = -I_{R1}} \longrightarrow (1)$$

∴ The fault is an unbalanced fault without ground, so that there is no zero sequence components but the +ve and -ve sequence are exist.

$$V_Y = V_B$$

$$V_{Y0} + V_{Y1} + V_{Y2} = V_{B0} + V_{B1} + V_{B2}$$

$$K^2 V_{R1} + K V_{R2} = K V_{R1} + K^2 V_{R2}$$

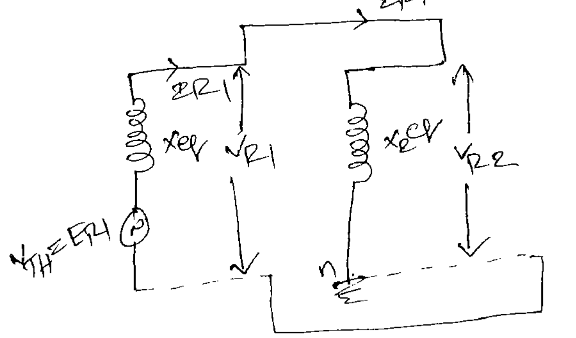
$$K^2 V_{R1} - K V_{R1} = K^2 V_{R2} - K V_{R2}$$

$$(K^2 - K) V_{R1} = (K^2 - K) V_{R2}$$

$$\therefore \boxed{V_{R1} = V_{R2}} \rightarrow (2)$$

∴ The +ve sequence and -ve sequence n/w's are connected in anti-||el

$$I_{R1} = -I_{R2}$$



Calculation of +ve sequence current

$$V_{R1} = V_{R2}$$

$$E_{R1} - I_{R1} X_{1eq} = -I_{R2} X_{2eq}$$

$$E_{R1} = I_{R1} X_{1eq} + I_{R1} X_{2eq}$$

$$\therefore \boxed{I_{R1} = \frac{E_{R1}}{X_{1eq} + X_{2eq}}} \text{ pu}$$

Calculation of fault current:-

$$I_{R1} = \frac{I_Y}{3}(K - K^2)$$

$$I_f = I_Y = \frac{3 I_{R1}}{K - K^2} = \frac{3 I_{R1}}{(-0.5 + j0.867) - (-0.5 - j0.867)} = \frac{3 I_{R1}}{j\sqrt{3}}$$

$$\therefore \boxed{I_f = I_Y = -j\sqrt{3} I_{R1} = j\sqrt{3} I_{R2}}$$

$$\boxed{I_f = I_Y = \sqrt{3} I_{R1}}$$ PU ⇒ (magnitude wise)

$$\boxed{I_f = I_y = \frac{\quad}{X_{1eq}+X_{2eq}}} \text{ pu}$$

$$I_f(\text{act}) = I_f(\text{pu}) \times I_b \text{ amp}$$

$$I_b = I_{ph} = \frac{S}{\sqrt{3}V_L}$$

Breaking capacity of the fault:-

$$\text{Breaking capacity} = 3V_b I_f$$

$$= 3V_b I_f(\text{pu}) \cdot I_b$$

$$= 3V_b I_b \cdot \frac{\sqrt{3}E_{R1}}{X_{1eq}+X_{2eq}}$$

$$\boxed{\text{Breaking capacity} = \sqrt{3} \cdot \frac{\text{Base MVA}}{X_{1eq}+X_{2eq}}}$$

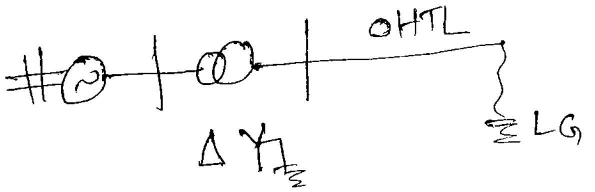
Neutral voltage during fault:-

$$V_n = I_n R_n = 3I_{R0} R_n = 0 \quad (\text{In all cases } V_n = 0)$$

$$= 3I_{R0} X_n = 3I_{R0} X_0 = 0$$

Because there is no zero sequence currents are flowing, irrespective of type of grounding $V_n = 0$

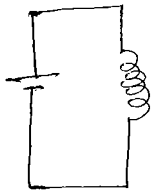
→ The L-L fault of an isolated neutral will provide the same fault current because the +ve sequence and -ve sequence components does not depends upon neutral grounding.

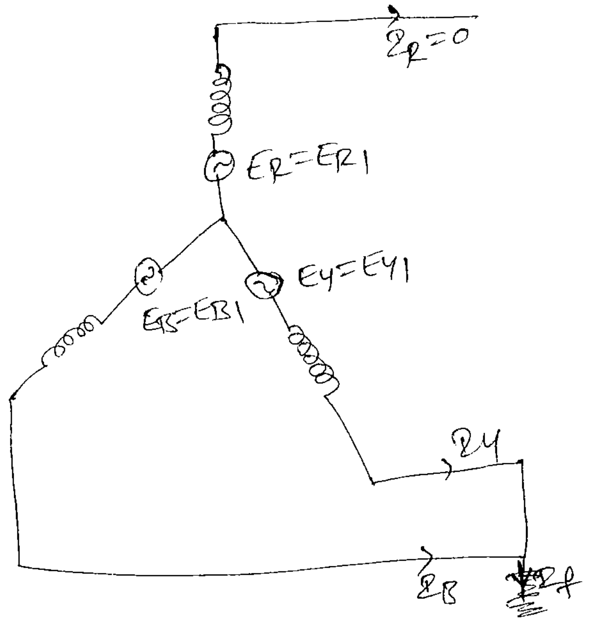
→ 

the given LG fault is referred to the generator side of the transformer it will be treated as

a) L-G b) L-L-G ✓c) L-L d) L-L-L

Double line to ground fault:-





During fault

$$\left.\begin{array}{l} I_f = I_Y + I_B \\ I_R = 0 \\ V_Y = V_B = 0 \end{array}\right\} \text{unbalance}$$

use the symmetrical components to steady the fault

$$V_{R0} = \frac{1}{3}\left[V_R + V_Y + V_B\right] = \frac{V_R}{3}$$

$$V_{R1} = \frac{1}{3}\left[V_R + kV_Y + k^2V_Y\right] = \frac{V_R}{3}$$

$$V_{R2} = \frac{1}{3}\left[V_R + k^2V_Y + kV_B\right] = \frac{V_R}{3}$$

$$\boxed{V_{R0} = V_{R1} = V_{R2} = \frac{V_R}{3}} \rightarrow (1)$$

LL { In which sc fault the n/w vols are same }
LG { In which sc fault " current " }

Calculation of +ve sequence current (I_{R1}):-

$$I_R = I_{R0} + I_{R1} + I_{R2} = 0$$

* In which sc fault sum of the '3' currents is zero → LLG

Replace I_{R0} and I_{R2} in terms of I_{R1}

$$V_{R0} = V_{R1}$$

$$-I_{R0}X_{0eq} = E_R - I_R X_{1eq}$$

$$I_{R0} = \left[\frac{I_{R1}X_{1eq} - E_{R1}}{X_{0eq}}\right]$$

$$V_{R1} = V_{R2}$$

$$E_{R1} - I_{R1}X_{1eq} = -I_{R2}X_{2eq}$$

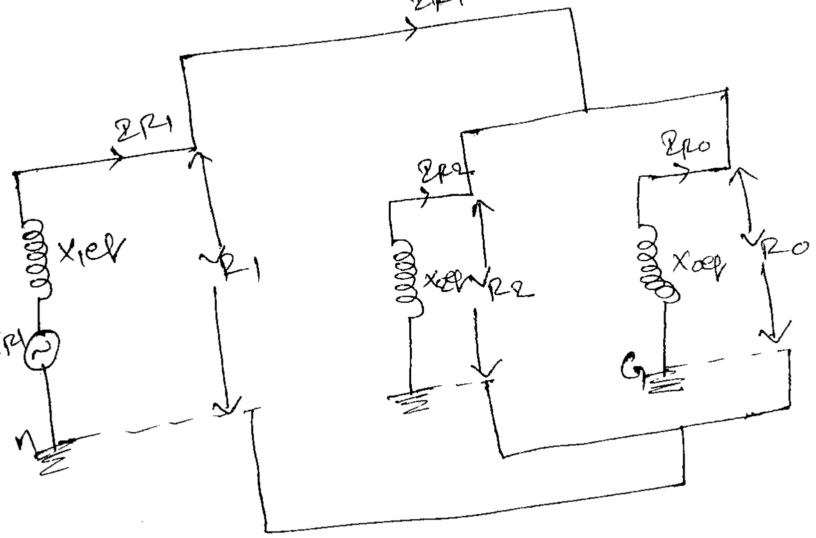
$$\left[I_{R2} = \left[\frac{I_{R1}X_{1eq} - E_{R1}}{X_{2eq}}\right]\right]$$

$$\therefore I_R = \frac{I_{R1}X_{1eq} - E_{R1}}{X_{0eq}} + I_{R1} + \frac{I_{R1}X_{1eq} - E_{R1}}{X_{2eq}} = 0$$

$$\boxed{I_{R1} = \frac{E_{R1}}{X_{1eq} + \dfrac{X_{2eq}\cdot X_{0eq}}{X_{2eq} + X_{0eq}}}} \text{ pu}$$

The fault is an unbalance with ground, so that three components are exist. The $\parallel^{el}$ combination of $-ve$ sequence and the zero sequence n/ws are connected in series with $+ve$ sequence n/w, so that the $+ve$ sequence current is divided between the $-ve$ sequence and zero sequence networks with opposite sign so that the sum of the three currents will be

$$I_{R_1} = -(I_{R_2} + I_{R_0})$$



calculation of I_f :-

$$I_f = I_Y + I_B$$

$$I_f = I_{Y_0} + I_{Y_1} + I_{Y_2} + I_{B_0} + I_{B_1} + I_{B_2}$$

$$= I_{R_0} + K^2 I_{R_1} + K I_{R_1} + I_{R_0} + K I_{R_1} + K^2 I_{R_2}$$

$$= 2I_{R_0} + I_{R_1}(K^2 + K) + (K + K^2) I_{R_2}$$

$$I_f = 2I_{R_0} - I_{R_1} - I_{R_2} \Rightarrow I_f = 2I_{R_0} + I_{R_0}$$

$$\boxed{I_f = 3I_{R_0}} \text{ pu}$$

$$I_R = I_{R_1} + I_{R_2} + I_{R_0} = 0$$

$$I_{R_0} = -I_{R_1} - I_{R_2}$$

Because of the ground effect, the fault current is a zero sequence current.

$$\boxed{I_{R_0} = -I_{R_1} \cdot \frac{X_{2eq}}{X_{2eq} + X_{0eq}}} \text{ pu}$$

$$I_f (act) = I_f \text{ pu} \times I_b \text{ amps}$$

$$I_b = I_{ph} = \frac{S}{\sqrt{3} V_L}$$

Breaking capacitance of the fault:-

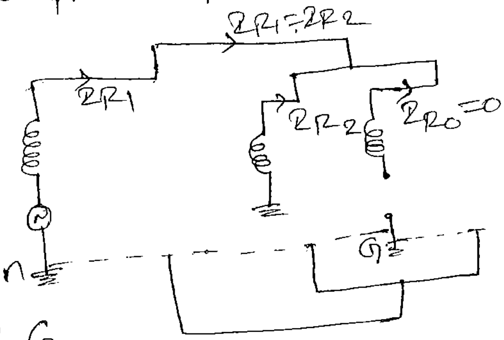
Breaking capacity $= 3V_b I_f$

neutral voltage, $V_n = I_n Z_n = 3I_{R0} Z_n$ PU

$= 3I_{R0} X_n$ PU

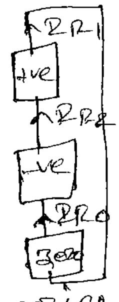
$\therefore V_n = 3I_{R0} X_0 = 0$ (solid neutral)

→ A double line to ground fault of a isolated neutral will result as the current in the ground will be zero, but there will be a short circuit current between the two phases. Hence it will be treated as L-L fault.



LG

→ The three sequence components are exist. $\boxed{I_{R0} = I_{R1} = I_{R2}}$



→ $V_{R1} + V_{R2} + V_{R0} = 0$

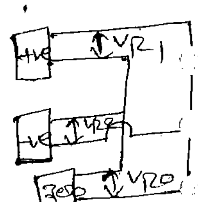
→ $I_f = 3I_{R0} = 3I_{R1}$

→ n/w's are connected in series

LLG

→ The three sequence components are exist

$I_{R0} + I_{R1} + I_{R2} = 0$

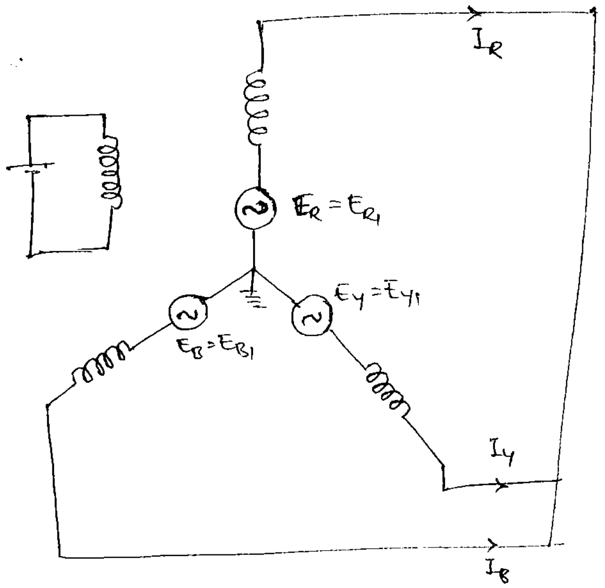


→ $V_{R1} = V_{R2} = V_{R0}$

→ $I_f = 3I_{R0} = -3I_{R1} \dfrac{X_{2eq}}{X_{2eq} + X_{0eq}}$

→ n/w's are connected in ||el

Line to Line to Line (or) Balanced (or) symmetrical fault:-



During fault:

$$\left.\begin{aligned} I_F &= I_R = I_Y = I_B \\ I_R + I_Y + I_B &= 0 \\ V_R &= V_Y = V_B \end{aligned}\right\} \text{Balanced}$$

∵ fault is a balanced fault, there is only +ve sequence components.

It can be proved by using symmetrical components

$$I_{R0} = \frac{1}{3}\left[I_R + I_Y + I_B\right] = 0$$

$$I_{R1} = \frac{1}{3}\left[I_R + KI_Y + K^2 I_B\right]$$

$$= \frac{1}{3}\left[I_R + K K^2 I_R + K^2 \cdot K I_R\right]$$

$$= \frac{1}{3}\left[I_R + K^3 I_R + K^3 I_R\right] \qquad [\because K^3 = 1$$

$$= \frac{1}{3} \times 3 I_R$$

$$\therefore I_{R1} = I_R$$

Similarly

$$I_{R2} = \frac{1}{3}\left[I_R + K^2 I_Y + K I_B\right]$$

$$= \frac{1}{3}\left[I_R + K^2 \cdot K^2 I_R + K \cdot K I_R\right] \qquad [\because K^4 = K^3 \cdot K = K]$$

$$= \frac{1}{3}\left[I_R + K I_R + K^2 I_R\right]$$

$$= \frac{1}{3}\left[1 + K + K^2\right] I_R$$

$$\therefore I_R = 0$$

$$\therefore I_F = I_R = I_{R1} \quad P.U$$

* In a 3-ϕ Short Circuit fault, the fault current is same as +ve sequence current only.

If $I_{R0} = 0 \Rightarrow V_{R0} = 0$

$I_{R2} = 0 \Rightarrow V_{R2} = 0$

$$V_{R1} = \frac{1}{3}\left[V_R + V_Y K + K^2 V_B\right]$$

$$= \frac{1}{3}\left[V_R + K V_R + K^2 V_R\right] \qquad \therefore \boxed{V_{R1} = V_{R2} = V_{R0} = 0}$$

$$= \frac{1}{3} V_R \left[1 + K + K^2\right]$$

$$\Rightarrow \boxed{V_{R1} = 0}$$

* In which fault the +ve sequence, network terminal Voltage will be zero.?

ANS: In a 3-ϕ, S.C - fault:- the +ve sequence network terminal voltage will be zero.

$V_{R_1} = 0$

$\Rightarrow E_{R_1} - I_{R_1} X_{1eq} = 0 \Rightarrow E_{R_1} = I_{R_1} X_{1eq}$

$$\therefore \boxed{I_{R_1} = \frac{E_{R_1}}{X_{1eq}} = I_F = I_R} \quad \text{P.U.}$$

(i.e, fault current is same as +ve sequence current only)

Before fault:-

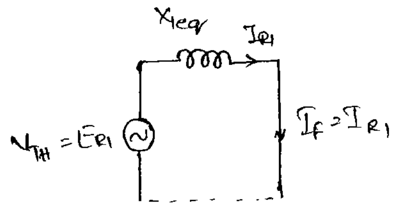
$I_R = I_{R_1} \Rightarrow$ Steady state current, here reactance is X_d

But after fault also

$I_R = I_{R_P} \Rightarrow$ Sub transient current, here reactance offered X_d''

$\Downarrow$

It is very high compared to steadystate currents $(X_d'' < X_d)$



$I_{F(act)} = I_{F(P.U)} * I_b$ Amps.

$I_b = I_{ph} = \frac{S}{\sqrt{3} V_L}$

Breaking Capacity $= 3 V_b I_F = 3 V_b I_{F(P.U)} I_b$

$= 3 V_b I_b \frac{E_{R_1}}{X_{1eq}} = \frac{\text{Base MVA}}{X_{1eq}}$

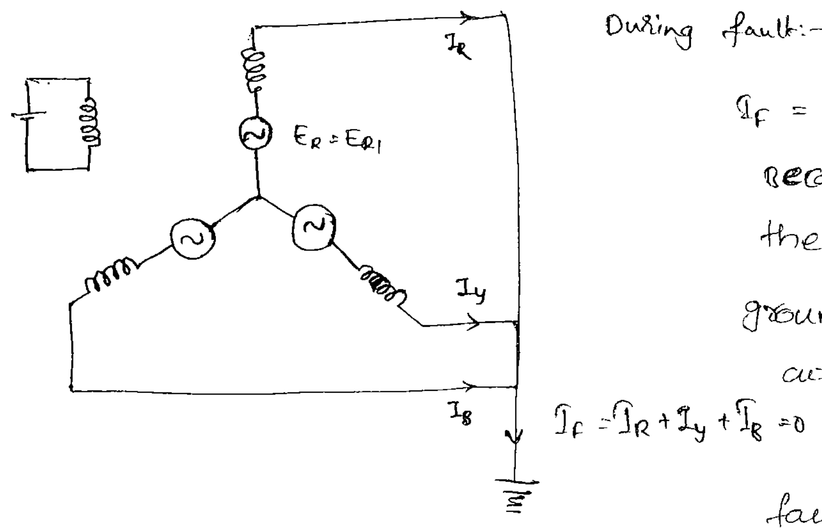
* Breaking Capacity $= \frac{\text{Base MVA}}{X_{1eq}}$

Nuetral voltage $V_n = I_N R_n = 3 I_{R_0} R_n = 0$

$= 3 I_{R_0} X_n = 0$

$= 3 I_{R_0} X_0 = 0$

like L-L fault, no zero sequence currents $\Rightarrow$ Nuetral voltage is zero., Irrespective of grounding. (A 3-ϕ S.C fault as a Isolated neutral of the alternator will result as the fault current is same., Because the +ve sequence components



During fault:-

$I_F = I_R + I_B + I_Y = 0$

Because of the balance currents, the sum of the currents in the ground will be zero, but the currents are circulated with in the phases. Hence the fault will be studied as a 3-φ fault (by ignoring ground effect)

3-φ fault:-

we know that the subtransient reactance of the alternator is very less so that the sub-transient current of the fault is high and also the short circuit MVA of the breaker is high. Hence the rating of the circuit breaker is high. so that the cost of the circuit breaker is also high.

$$I_f = I_R = I_{R1} = \frac{E_{R1}}{X_{eq}}$$

$$SC\ MVA = \frac{Base\ MVA}{X_{1eq}}$$

$$\boxed{X_{1eq} = X_d''} \qquad X_d'' < X_d' < X_d$$

> In order to reduce the cost of the circuit breaker, the rating of the circuit breaker is to be reduced by ↑ the reactance of the n/w for which the series reactors are employed.

→ series reactors are classified based on their applications.

i) Generator reactors:-

The synchronous generator is connected to the bus through a reactor.

series reactors

$$I_f = \frac{E_{R1}}{X_d''} \quad , \quad I_f = \frac{E_{R1}}{X_d'' + X_r}$$

$$SC\ MVA = \frac{Base\ MVA}{X_d''} \quad , \quad SC\ MVA = \frac{Base\ MVA}{X_d'' + X_r}$$

→ The subtransient current of the generator 8 pu. It is proposed to reduce the subtransient current by using a series reactors 5 pu. The value of the reactance of the reactor.

$$8 = \frac{1.0}{X_d''} \Rightarrow X_d'' = \frac{1.0}{8} = 0.125$$

$$I_f = \frac{E_{R1}}{X_d'' + X_r} \Rightarrow 5 = \frac{1.0}{0.125 + r}$$

$$\underline{\underline{X_r = 0.075}}$$

Modern turbo generators Z 500 MW

→ modern turbo generators does not require any series reactor, because the reactance of the generators is very high.

→ modern turbo generators does not require any series reactor, because the reactance of the generators is very high.

→ modern turbo generators reactance in pu ——

a) 1.0 b) 0.5 c) 1.5 ~~d)~~ 2.0

→ sc current of modern turbo generators in (pu) ——

~~a)~~ 0.5 b) 1.5 c) 2.0 d) 1.0

because, $I_{sc} = I_f = \frac{E_{RI}}{X_d''} = \frac{1.0}{2} = 0.5$

→ short circuit ratio (SCR) of modern turbo generators is ___

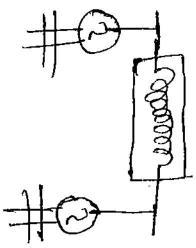
a) 0.5 b) 1.5 c) 2.0 d) 1.0

$$SCR = \frac{I_{sc}}{I} = \frac{0.5}{1} = 0.5$$

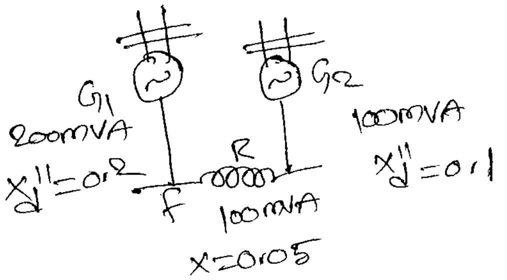
$\boxed{\therefore \text{S.C current} = SCR}$

ii) Busbar section reactor:-

The installed capacity of the generating station can be increased by having more than one generator in ||el which are connected to a common bus. Inorder to reduce the sc current, the series reactor is placed in the busbar (common to both generator) this is called bus bar reactor.



→ calculation of short circuit MVA



The short circuit MVA, if 3-ϕ fault occurs on a generator + terminal.

given reactance, by default is +ve sequence reactance

$$SCMVA = \frac{\text{Base MVA}}{X_{1eq}} = \frac{200}{X_{1eq}}$$ (take larger as base MVA)

while doing pu problems, all the quantities should be in same base, If we want to change the base, calculate remaining values for the new base and then do the problem.

there, voltage is not given, hence we considered voltage has no change.

for G_2:- $X_{new} = 0.1 \times \frac{200}{100} = 0.2$

for R:- $X_{new} = X_{pu(old)} \times \frac{kVA(new)}{kVA(old)} \times \left(\frac{kV_{old}}{kV_{new}}\right)^2$

no change i.e; $kV_{old} = kV_{new}$

$= 0.05 \times \frac{200}{100} = 0.1$

now calculate SC MVA $= \frac{200}{X_{eq}} = \frac{200}{0.2 \| 0.3} = \frac{200}{\left(\frac{0.2 \times 0.3}{0.5}\right)} =$

iii) Feeder reactors
⇓

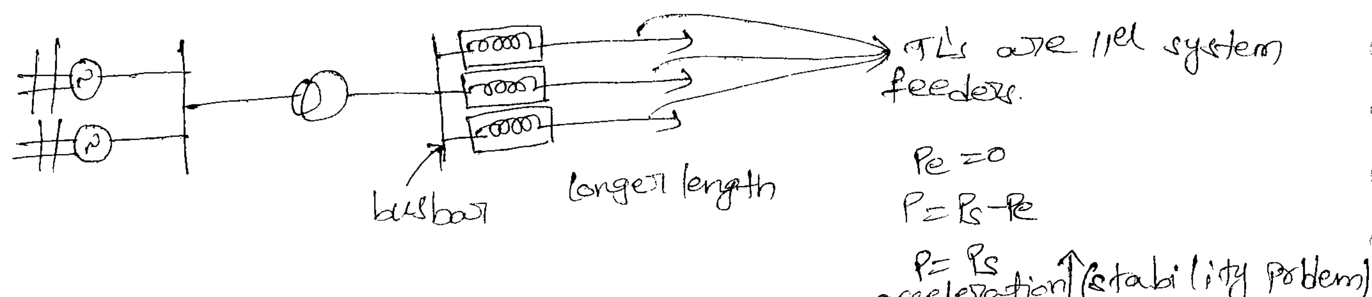
These are classified as TL reactors.

→ A feeder is a current carrying element in which the magnitude of the current throughout length is same.

→ The current carrying elements of the TL's are called as "feeders."

→ The power handling capacity in the TL is high, so that SC currents are also high.

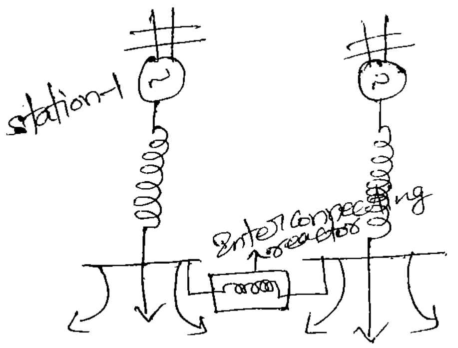
→ Inorder to reduce the sc currents a reactor is proposed (or) placed on the TL, which is called as "feeder reactor."



→ Integers
→ In general feeder reactors are placed near to the busbar

→ There are certain advantages in an interconnected power system network, so that the stations should be made as an inter connecting stations by providing an interconnecting line.

→ The inter connecting power system network is having the SC current level is high i.e., if a fault occurs in one area, the other area will also supply the current. Inorder to reduce the SC current, the inter connection can be done through reactor.



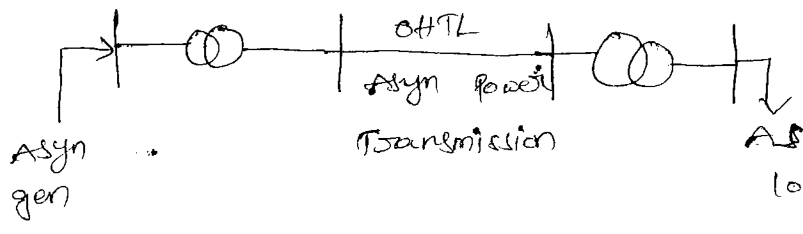
Power system stability

→ The existing power system network should maintain the stability while it is delivering the power to the load.

stability:- It is the one which is associated with the synchronous machine.

→ If the existing system is having a synchronous machine, then this system always dealing with stability criteria (i.e., to exist stability criteria atleast one synchronous m/c should be available in the system)

ex:-



It is not deals with stability criteria, since the system has no single syn m/c

But practically above like system is not present, because we preferred to use conventional m/c's (syn m/c) rather than using non-conventional m/c

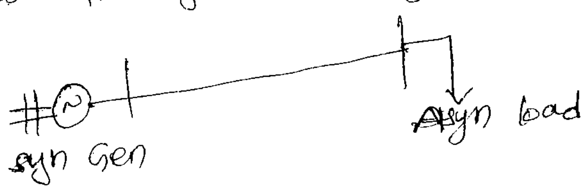
→ Inorder to produce bulk amount of power, the conventional energy sources are used.

→ At conventional energy sources, the synchronous generator are employed. Hence "AC" ~~with stability~~ power transmission is always uses synchronous generator, hence it is always associated with stability criteria.

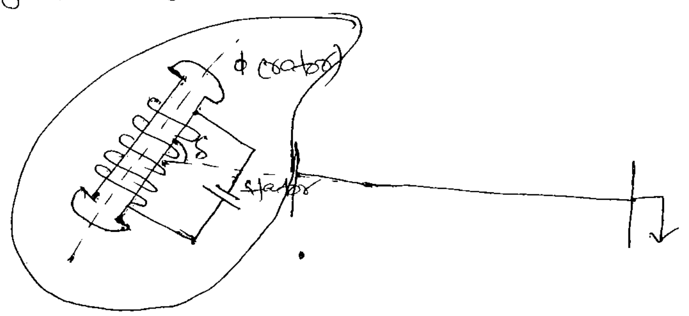
stability:- It is the property (Real power) of synchronous machine which can able to deliver maximum power to the load by maintaining synchronization with the ~~maximum~~ externally connected TL know as "Tieline".

→ stability concepts always default with real power transfer capacities.

[As power is transferred mainly from generator to load is through TL rather than transformer. Hence transformer effect is neglected on power transfer capacity. ∴ It is assumed that the load is connected directly to generator through TL only as shown in below]



→ The synchronization of syn m/c can be analysed interms of magnetic flux characterics between the stator and rotor (or) interms of the speed of the synchronous machine.



Initially

$P = P_s - P_e$

$= 0$

neither accelerate nor decelerate

$\boxed{N = N_s}$ synchronous speed.

→ If the synchronous machine working at N_s, the rotor of the generator can maintain certain angle w.r.to the stator and also the air gap flux b/n the rotor and stator is a magnetizing flux. so that the synchronization is maintained.

→ why the stability of synchronous machine is get effected?

The load on the generator is variable load. for any change in load at load side will result as the corresponding change in mechanical input is not taking place because the synchronous generator is following from the load point which ... input

maynot be equal to the electrial output. so that the speed of the synchronous machine can be changes.

The change in the speed of the synchronous machine will result as the rotor flux axes will be also changes. i.e, the angle of the rotor will be changes. If the change of the rotor angle will go beyond certain limits, the rotor air gap flux will become demagnetised so that the magnetic coupling is failed and greater generator has beame unstable.

→ These are two types of variation of load on the generators.

1) small and gradual variations of load:-

Due to variation in consumer loads → steady state characteristics ⇓ steady state stability of syn m/c.

2) sudden and large variations of load:-

Due to occurance of faults → It is a transient characteristics corresponding stability is called "transient stability".

* Generally occured faults are sc faults, hence transient stability analysis deals the stability for sc fault.

steady state stability of the synchrous m/c:-

It is the property of the syn m/c which can be able to deliver maximum power to the load by maintaining synchronization with the externally connected Tie line (TL) where the synchronous machine is having small and gradual variation of the load.

→ The frequency of oscillations made by the rotor due to change of load are very less when compared to the natural frequency of the supply, such change of load is called a small and gradual variation of the load (i.e.) rotor is making oscillatory around a fixed point angle)

→ stability analysis of a synchronous machine can be done in two ways.

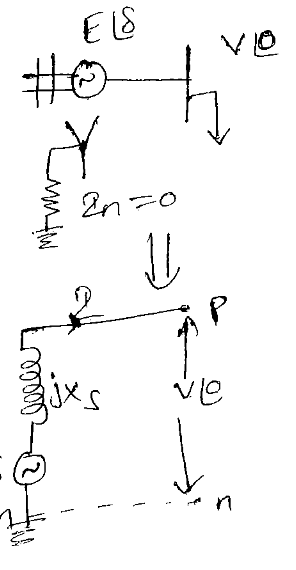
a) static model   b) Dynamic model (or) rotating model.

→ for a small and gradual variation of load, the change in the position constant of the rotor is negligible so that the position of rotor is assumed as constant. Hence the steady state stability of the synchronous machine can be analyzed with the help of the static model of the synchronous machine.

[In static model stability analysis is done w.r.to stator and
In dynamic model " " " " " rotor]

→ If the power transfer equations of impedance (or) reactance network in a phase manner w.r.to neutral point, then it is said to be "static model".

__Ideal case:-__



$Z_n = 0$ under steady state condition

$R << X$

$Z = jX_s$ = synchronous reactance (or) steady state reactance.

__Power load:-__

$$S = VI^*$$

$$= |V|\angle 0 \left[\frac{|E|\angle\delta - |V|\angle 0}{|X_s|\angle 90}\right]^*$$

$$= |V|\angle 0 \left[\frac{|E|}{|X_s|}\angle 90-\delta - \frac{|V|}{|X_s|}\angle 90^\circ\right]$$

$$= \frac{|E||V|}{|X_s|}\angle 90-\delta - \frac{|V|^2}{|X|}\angle 90$$

stability equation (i.e.) real power transfer equation to the load)

= electrical output of the generator.

$$\boxed{P_e = \frac{|E|\,|V|}{|X_s|}\sin\delta}$$

(3-ϕ ⇒ E & V are L-L voltages X_s is reactance/phase) (Power transfer in 3-ϕ)

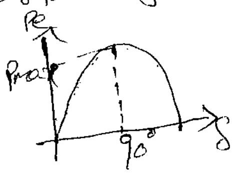
$P_e = P_{max}$ = steady state stability limit.

$$\delta = 90^\circ$$

$$P_e = P_{max} = \frac{|E||V|}{|X_s|}$$

$$P_e = \underbrace{P_{max}}_{\text{constant}} \sin\delta \text{ (or) } P_e \propto \sin\delta$$

→ The variation of power w.r.to angle 'δ' is called "power angle curve", of the Generator.



→ The steady state stability of the synchronous machine can be also analysed interms of degree of magnetic coupling between the rotor and stator (or) synchronising power.

$$\boxed{\frac{\partial P_e}{\partial \delta} = \frac{EV}{X_s}\cos\delta}$$

→ synchronous power

→ for any change of load beyond 'P_{max}' will result as, the electrical output of the generator will be reduced. (or) the synchronising power will become -ve.(i.e., $\delta > 90^\circ$) i.e.) the air gap flux has become demagnetising so that the synchronous machine has become unstable.

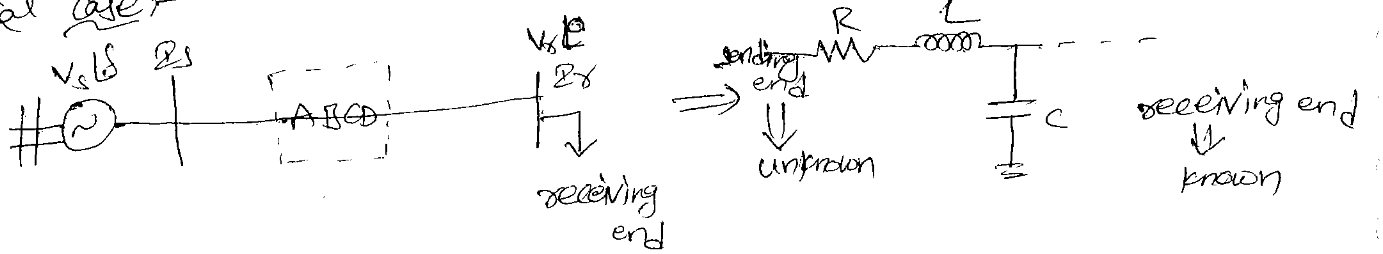
syn power | air gap flux

If $\delta > 90^\circ$ → demagnetising flux

If $\delta < 90^\circ$ ⇒ magnetising flux.

→ The concept of the steady state stability by using the static model is nothing but angle stability i.e.) if the angle can go beyond 90° due to any change of load, the synchronous machine will become unstable & if the angle is less than 90°, the synchronous machine is stable.

Practical case:-



→ we preferred to steady the n/w in ABCD parameters rather in R, L, C.

→ In a two port network analysis, the unknown electrical quantities are to be evaluated by using the known values along with the n/w parameters.

$$V_s = AV_r + BI_r \quad \text{KV/Phase}$$
$$I_s = CV_r + DI_r \quad \text{KV/Phase}$$
} these eqn's are phase eqn's.

→ Transmission line constants can be represented in two ways < Lumped (for steady state analysis) / distributed (for transient analysis) ⇓ (wave travelling phenomena)

[for short and medium TL we can't see transient state, only steady state is present, hence lumped parameters are used. But for long line we can see both transient and steady state hence we can use distributed and lumped parameters here]

→ The stability of a synchronous machine is analysed in a steady state condition, so that the transmission line is represented in a lumped manner, irrespective of transmission line (i.e) short or medium or long.

Units of ABCD parameters:-

A and D are unit less

B is an impedance (ohms)

$$\boxed{\therefore B = Z = R + jX = R + j\omega L}$$

C is an admittance (mhos)

$$\boxed{C = Y = G + jB}$$

[If Ω/km ⇒ indicates distributed (parameter) element. If simply in Ω ⇒ indicates reactance is lumped parameter]

w.k.t. in transmission line there is no leakage currents ⇒ no conductance i.e., $G = 0$

$$\therefore \boxed{C = Y = jB = j\omega C}$$

... line 'B' is capacitive susceptance

is -ve.

→ The polar form of the ABCD values of a given TL are —

$$\boxed{\begin{aligned} A &= |A|\angle\alpha \\ B &= |B|\angle\beta \\ C &= |C|\angle\eta \\ D &= |D|\angle\alpha \end{aligned}}$$

$|B| = \sqrt{R^2+X^2}$

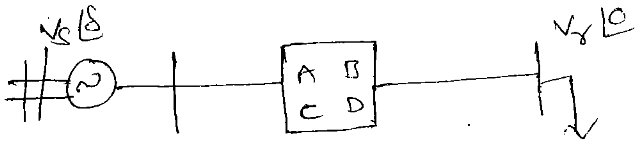
$\beta = \tan^{-1}\left(\frac{X}{R}\right)$ = impedance angle < 90°

$|C| = |\omega C|$

γ = admittance angle = 90°

In transmission line, the impedance angle of the line depends upon '$\frac{X}{R}$' ratio, As the X/R ratio is changes, the impedance angle will be changes. However the admittance angle of transmission line is 90° (always)

steady state stability:-



$V_s = AV_r + BI_r$

$I_r = \frac{V_s - AV_r}{B}$

Power at receiving end

$$S_r = V_r I_r^* = V_r\left[\frac{V_s - AV_r}{B}\right]^*$$

$$S_r = |V_r|\angle 0\left[\frac{|V_s|\angle\delta - |A|\angle\alpha\,|V_r|\angle 0^\circ}{|B|\angle\beta}\right]^*$$

$$S_r = \frac{|V_s||V_r|}{|B|}\angle\beta-\delta - \frac{|A|}{|B|}|V_r|^2\angle\beta-\alpha$$

Real power transfer eqn (or) static model.

V_s & V_r are L-L voltages, B = impedance/phase

short transmission line:-

shunt capacitance ≃ 0° $|A| = 1.0$, $\alpha = 0$, $A = 1\angle 0$

$B = Z$, $C = 0$, $D = 1\angle 0^\circ$

$$\therefore P_r = \frac{|V_s|\,|V_r|}{|B|}\cos(\beta-\delta) - \frac{1.0}{|B|}|V_r|^2\cos\beta$$

$P_r = P_{max} =$ steady state stability limit

$$\frac{dP_r}{d\delta} = 0 \Rightarrow \frac{|V_s||V_r|}{|B|}\left[-\sin(\beta-\delta)(-1)\right] - 0$$

$$\Rightarrow \sin(\beta-\delta) = 0 \Rightarrow \beta - \delta = 0 \Rightarrow \beta = \delta \;(\text{or})\; \underbrace{\delta}_{\text{variable}} = \underbrace{\beta}_{\text{fixed}}$$

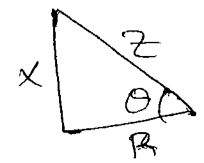
$$\therefore \delta = \beta = \tan^{-1}(X/R)$$

For a given transmission line, the '$\frac{X}{R}$' ratio is a fixed value but the power angle of the generator is a variable angle. The variable angle is allowed up to the fixed angle.

$\delta = \beta \Rightarrow$

$$P_{max} = \frac{|V_s||V_r|}{|B|} - \frac{1.0\,|V_r|^2}{|B|}\cos\beta$$

$$= \frac{|V_s||V_r|}{\sqrt{R^2+X^2}} - \frac{1.0}{\sqrt{R^2+X^2}}|V_r|^2\left(\frac{R}{\sqrt{R^2+X^2}}\right)$$



$$\left[\cos\theta = \frac{R}{Z} = \frac{R}{B} = \frac{R}{\sqrt{R^2+X^2}}\right]$$

→ If a synchronous generator is connected to the load through transmission lines, the stability of the synchronous generator is limited by the (impedance angle of the transmission line, and the impedance angle of the transmission line does depends upon 'X/R' ratio

→ In order to get the '$\frac{X}{R}$' ratio of transmission line, the steady state stability limit is to be minimized w.r.to the reactance of the line

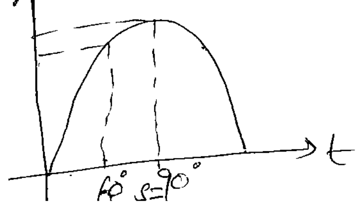
$$\frac{dP_{max}}{dX} = 0$$

$$\boxed{X = \sqrt{3}R}$$ (steady state stability limit)

$$\delta = \beta = \tan^{-1}(X/R)$$

but

$$P_{max} = \frac{|V_s||V_r|}{\sqrt{R^2+X^2}} - \frac{1}{\sqrt{R^2+X^2}}|V_r|^2 +$$



→ If $\delta < 90$, the stability generation

→ In AC systems the power transfer is mainly through reactance and this reactance is called "transfer reactance"
(for transmission lines 'X/R' ratio is more, the reactance effects are more

→ In general, the 'X/R' ratio of OHTL is transmission line > 1
" " " Direct line $\boxed{1.4T<1}$

→ The short transmission line is a special case and most of the transmission line more long line effect.

Long TL

$$P_r = \frac{|V_s||V_r|}{|B|} \cos(\beta - \delta) - \frac{|V_s|^2 |A_s|}{|B|} \cos(\beta - \alpha)$$

$$\delta = \beta = \tan^{-1}(X/R)$$

$V_r = V_{max}$ = steady state stability limit

$P_r = P_{max}$ = Steady state stability limit.

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

⇒ $R = 0, \delta = 90°$

$$R = \frac{\rho l}{a} \Rightarrow R \propto \frac{l}{a}$$

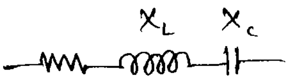
$$X = 2\pi f L$$

$$L = 0.2 \ln\left(\frac{GMD}{GMR}\right)$$

$$L \propto \ln(GMD)$$

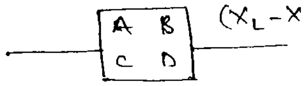
In long transmission line the operating voltage will be high. Hence the inductance of the transmission line will be increase. So that inductive reactance i.e., also ↑, the (X/R) ratio of long line will be $\sqrt{3}$. The impedance of angle of long lin. i.e., more than 60° less than 90° (or) near to 90°

* The steady state stability (S.S.S) angle of the generator is little less than 90°.

(

Reactance Value

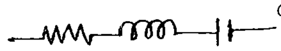
As $(X_L - X_c) \downarrow$, $\frac{X}{R} \downarrow$, $\delta \downarrow$, Stability ↑)



$(X_L - X_c)\downarrow$

Inorder to improve the stability of the Synchronous machine the power angle of the Generator is to be reduced by the impedance angle by which $(\frac{X}{R})$ ratio, is to be reduced by reducing the reactance of line by having series capacitor in the transmission line.

The long transmission line are called as Generator lines for the purpose of the stability and the Series Capacitor is called "Power system stability devices".

* ( Compensator line

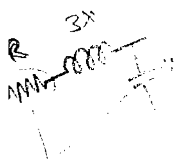
$\frac{X_L - X_c}{R}$ power system stability line.)

Practically we don't have reactance, we have capacitor series in transmission line, In long transmission line it is near to 90°. So we should improve the stability by compensator line by using series capacitor. $\frac{X}{R}$ ↑, impedance angle ↑ to reduce its Series Capacitor.

The series capacitor is employed, if the transmission is having $(\frac{X}{R})$ high. So that the stability of the system will be improved.

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

$A = 1.0 \quad B = |X|, \ \alpha = 0°, \ \beta = 90°$



$$\boxed{\begin{aligned} |P_R| &= \frac{|V_S||V_R|}{|X|}\cos(90 - \delta) \text{ (or)} \\ P_R &= \frac{|V_S||V_R|}{|X|} \cdot \sin\delta \end{aligned}}$$

we ignored. then power transfer ... equation in

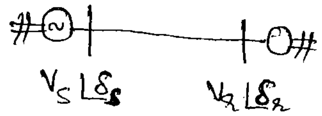
$$\delta = \beta = \tan^{-1}\left(\frac{X}{R}\right) = 90$$

$$P_R = P_{max} = SSSL = \frac{|V_S||V_R|}{|X|}$$

$$\boxed{P_R = P_{max} \cdot \sin\delta}$$

$P_R \propto \sin\delta$

$\boxed{P_R \propto \delta - 0}$ If one side sync. m/c and one side load power transmission in AC. Machine.



side

$$P_R = \frac{|V_S||V_R|}{|X|}\sin(\delta_S - \delta_R)$$

$$P_R = P_{max} \cdot \sin(\delta_S - \delta_R)$$

$\boxed{P_R \propto (\delta_S - \delta_R)}$ if w

Methods to improve steady state stability limit:—

1) operate the system ~~with~~ at higher voltages.

2) reduce the reactance of the system $\quad P_e = P_{max} \cdot \sin\delta \downarrow$

3) use the bundle conductors (or) sub conductors $\quad P_{max} = \frac{|V_s||V_R|}{|X|}$ — S.S.S.L

4) use series capacitor

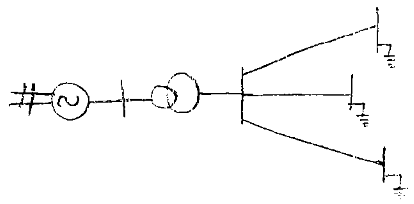
* Power transfer devices at lesser angle for steady state stability.

1. Operate the system at higher voltages:—

As the voltage level increases beyond certain limit the cost of insulation is increases so there is certain limit to increase the voltage.

2. Reduce the reactance in the system:—

a) Use parallel transmission lines:—

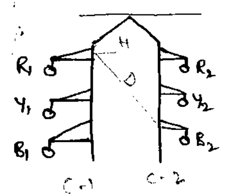


net $X_L \downarrow$ $(X = 2\pi f L \downarrow)$ the reactance $\downarrow$

b) Use double circuit line:—

These lines in place of "single circuit line"

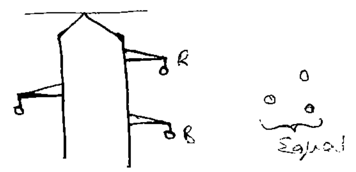
Double circuit line



$L = 0.02 \ln\left(\frac{GMD}{\text{self GMD}}\right)$

$L = 0.2 \ln\left(\frac{GMD}{GMR}\right)$

$L \propto 0.2 \ln(GMD)$



3-ϕ, 3-wire double circuit line

3-ϕ, 3-wire single circuit

3(RBY) are ideal.

As $L \downarrow$, inductive $(X) \downarrow$

By using double circuit line the self GMD value $\uparrow$ The inductive value $\downarrow$ and the inductive reactance will be $\downarrow$

(As Diagonal distance $\uparrow$, $L \downarrow$, $X \downarrow$, self inductance $\uparrow$) $\quad L = 0.2 \ln\left(\frac{GMD}{\text{self induc}}\right)$

3. Use the bundle conductors (or) Sub conductors:—

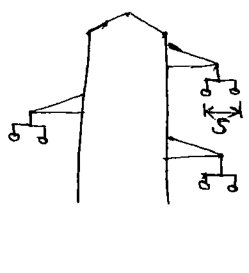
$\downarrow$ Corona, $\uparrow$ stability

$V\uparrow$ Field intensity $\uparrow$ (E/V) corona $\uparrow$

The bundle conductors are used in the transmission line for the voltage 400 kV and above. In order to reduce the corona effect. The bundle conductor is also improve the stability conditions.

$$L = 0.2 \ln\left(\frac{GMD}{\text{self induc}}\right)$$

$X \downarrow$, self inductance $\uparrow$, $L \downarrow$



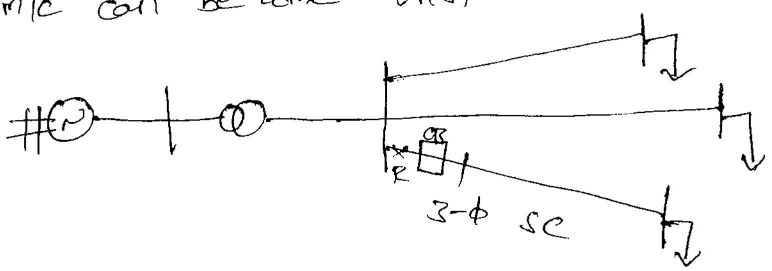
4) use series capacitors:-

If the transmission line is having high X/R ratio, the impedance angle is high. so that the stability angle is highly.

→ In order to reduce the 'δ' the impedance angle to be reduced for which series capacitors are employed.

The transient stability of the system:-

It is the property of the syn m/c to deliver maximum power to the load by maintaining synchronization with externally connected transmission line, where the syn m/c is having sudden and large variation of the load due to the occurrence of 3-φ short circuit fault on one of the ||el transmission line, for a time of few cycles only. If faults that can exist for more no of cycles, the syn m/c can be come unstable.



→ Fault clearing Time = The time up of relay + The time up of circuit breaker

→ If a short circuit occurs in of the transmission line the power transfer capacity to the load during the fault is less when compared to before fault.

P_{e1} → before fault

P_{e2} → with fault

$\boxed{P_{e2} < P_{e1}}$

$P_{e1} = \frac{EV}{X_{1eq}} \sin\delta_0 = P_{m1} \sin\delta_0$

$P_{e2} = \frac{EV}{X_{2eq}} \sin\delta = \boxed{P_{max}} \sin\delta$ ($\delta \rightarrow$ variable angle)

TSL (Transient steady limit)

$\boxed{TSL < SSSL}$

$\searrow$ steady state stability limit

special cases:-

i) If a fault occurs on a line near to the busbar, it will be assumed as fault on bus, because the voltage at the fault point is same as bus voltage. Hence the power transfer during the fault is zero

~~ii) some times they say that~~

ii) If SC occurs on the bus bar, the ~~power~~ transfer will be zero.

→ The sudden and large variation of the load will result as the change in the rotor angle will be high.

→ The transient stability of will be analise by using the rotating principles of the rotating M/C i.e., the dynamic model, which can be obtain with the help of mechanical equivalent of the syn M/C.

~~→ The steady of the~~

Dynamic model:→ study of Principles of kinematics:-

θ = angular displacement – rad

ω = angular velocity – rad/sec

α = angular acceleration – rad/sec²

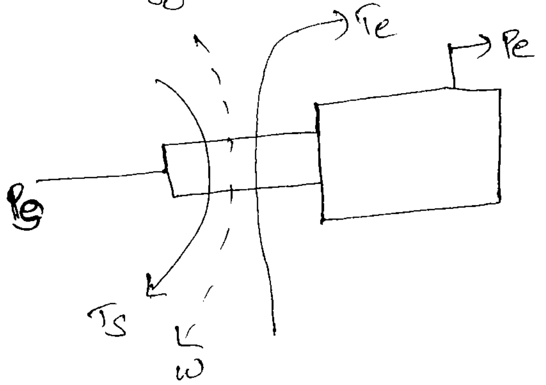
I = Inertia → kg − m²

M − moment of inertia → MJ−sec / Elec deg

H → Inertia constant → MJ/MVA

T → Torque → N−m (or) M N−m

kinetic energy stored in rotor (MJ)



$P = P_s - P_e$ ↓

= +ve

Principle of rotating m/c is acceleration, this is called "acceleration power".

$P_{acc} = T_a \omega$

T_a = acceleration torque

ω = angular velocity

rad/s

$\omega = \frac{2\pi N}{60}$

N = speed in rpm

$P_{acc} = I \alpha \omega$ $[T_a = I\alpha]$

$P_{acc} = M\alpha$ $(M = I\omega)$

M = moment of inertia (or) angular momentum

M = J-sec / mech rad

The rotor of the syn generator is mechanically coupled with the turbine and change in the rotor position will be always expressed in terms of mechanical radians.

→ when deals with the mechanical loads, the units are very high.

$$M = MJ-sec/ P/2 \times mech\ rad$$

$$= MJ-sec / elec\text{-}rad$$

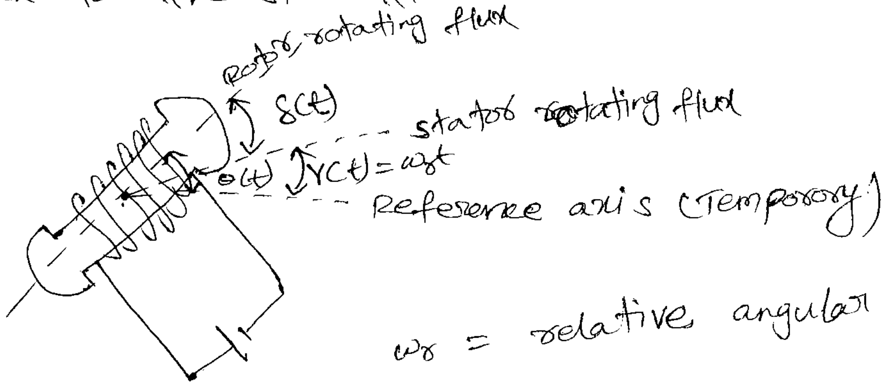
$$= MJ-sec/elec\ rad \times \frac{180}{\pi}$$

$$= MJ-sec/elec\ deg$$

$$\boxed{\alpha = \frac{d\omega}{dt} = \frac{d}{dt}\left(\frac{d\theta}{dt}\right) = \frac{d^2\theta}{dt^2} = \frac{d^2\delta}{dt^2}}$$

$$\theta = \delta$$

→ In a synchronous machine, the angular displacement made by the rotor = the rotor angle of the generator i.e., angle b/n the rotor ~~rota~~ rotating flux to the stator flux.



$$\omega_r = \text{relative angular velocity}$$

$$\theta(t) = \delta(t) + \omega_r t$$

$$\frac{d\theta(t)}{dt} = \frac{d\delta(t)}{dt} + \omega_r$$

$$\frac{d^2\theta(t)}{dt^2} = \frac{d^2\delta(t)}{dt} + 0$$

$$\boxed{\frac{d^2\theta(t)}{dt^2} = \frac{d^2\delta(t)}{dt^2} = \alpha}$$

→ For any change of load, there will be a change in the position of rotor w.r.to reference axis, but there is no change in the ref flux. Hence the relative angular velocity will be zero and the stator flux axis it self treated as refference axis. so that $\boxed{\theta(t) = \delta(t)}$

$Ma = P_{acc}$

$$\boxed{M\frac{d^2\delta(t)}{dt^2} = P_s - P_e = P_e - \frac{EV}{x_{eq}}\sin\delta}$$ → Dynamic model (or) swing equation

→ swing eqn is the one which can provide the position of the rotor wrto stator having a function of time, where the synchronous machine is having a sudden and large variation of the load due to the occurance of the fault for few cycles only.

→ The nature of the swing eqn is a non-linear differential eqn.

$$M\frac{d^2\delta(t)}{dt^2} = P_{acc} = P_e - P_s$$

$$\boxed{M\frac{d^2\delta(t)}{dt^2} = \frac{EV}{x_{eq}}\sin\delta - P_s}$$ → swing eqn.

→ The inertia of the syn m/c is also expressed as inertia constant, which is denoted by 'H.'

$$H = \frac{\text{KE stored in rotor}}{\text{Rating of syn machine}} \quad MJ/MVA$$

$$H = \frac{\frac{1}{2}I\omega^2}{S} = \frac{\frac{1}{2}(I\omega)\omega}{S} = \frac{\frac{1}{2}M 2\pi f}{S} \quad f$$

$$\boxed{M = \frac{SH}{\pi f} = \frac{SH}{180f}}$$

$\downarrow$ rad $\quad \downarrow$ deg

$\boxed{M \alpha H}$ and $\boxed{H \alpha \frac{1}{S} \text{ But } M \alpha S}$

→ A 4-pole, 100MVA syn generator is having an inertia constant of 8MJ/MVA, the KE stored in the rotor in MJ is —

$$H = \frac{\text{KE stored in rotor}}{\text{rating of m/c (S)}}$$

KE stored in rotor $= HS = 800$ MJ.

→ The inertia constant of 100 MVA gen is 5 MJ/MVA. what is the inertia constant of generator of 200 MVA capacity

$$\frac{H1}{H2} = \frac{S2}{S1}$$

$$H2 = \frac{H1\,S1}{S2} = \frac{5 \times 100}{200} = 2.5 \text{ MJ/MVA}$$

→ The inertia constant of a 400 MVA generator is 8 pu. what is the inertia constant in pu of 200MVA generator.

$$\frac{H1}{H2} = \frac{S2}{S1}$$

$$H2 = \frac{H1\,S1}{S2} = 16$$

→ The moment of Inertia of syn gen is 20 pu at 500MVA. The moment of inertia of syn gen at 100MVA capacity in pu

$$\frac{M1}{M2} = \frac{S1}{S2}$$

$$M2 = \frac{M1\,S2}{S1} = \frac{20 \times 100}{500} = 4 \text{ pu}$$

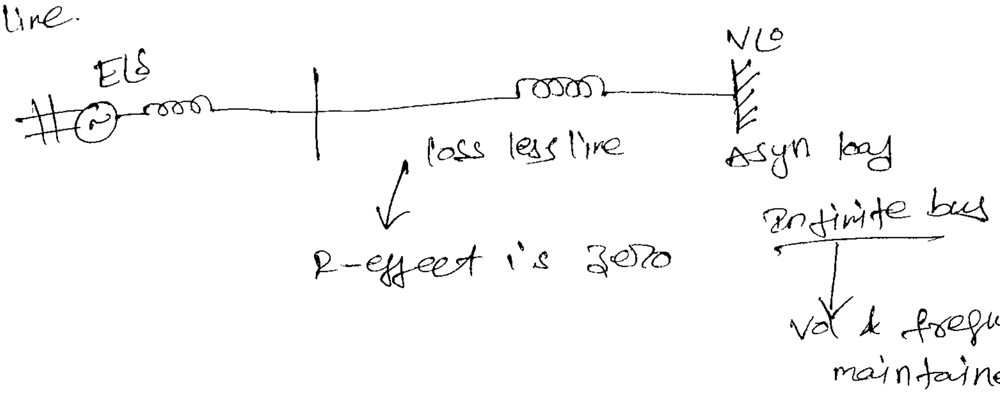
→ The transient stability of the syn m/c is analyse with the help of swing eqn

$$\frac{M d^2 \delta(t)}{dt^2} = P_a$$

→ The sol of the syn. swing eqn is required inorder to decide the stability of the syn M/C. The sol of swing eqn does depend upon the no. of M/c's that present

i) single machine system:-

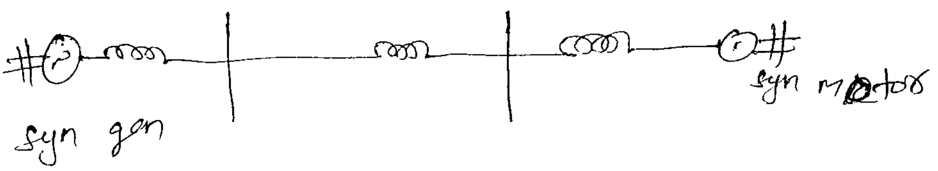
→ syn gen is connected to an infinite bus through a loss less line.



→ An infinite bus an ideal case the syn gen's are connected to the finite buses

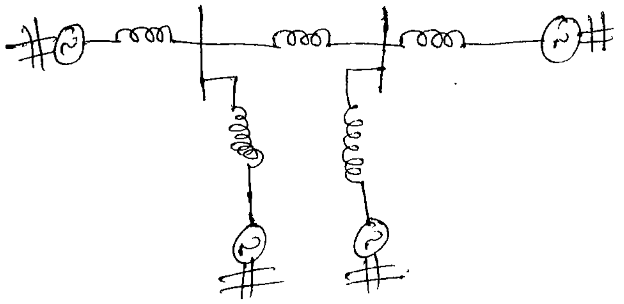
ii) Two machine system:-

→ syn generator is connected to synchronous motor through a loss less line



→ The solution of the two machine system is equal area criteria (graphical)

iii) Multy Machine system



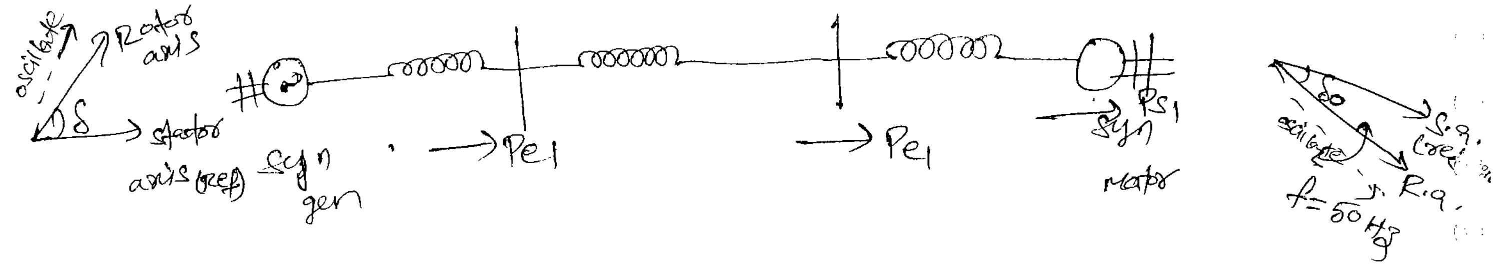
→ sol of the multy machine system is point by point method (or) step by step method (methametically)

→ sol of swing eqn is determined.

Two machine system:-

As the two machines are syn M/c & they have the stability criterion. so that the rating of two m/c's should be same. Hence the moment of inertia is same and the oscillations made by both machines are uniform. Due to the occurrence of the disturbance on any one of the machine, the M/c will start oscillation. whenever the frequency of oscillations are more than natural frequency of the supply. The syn m/c will become unstable. If one of the M/c is unstable automatically the other M/c is also unstable, Hence at any point of time the above two M/c system is replaced as single machine only because at <u>any point of time both the machines are stable (or) both the machines are unstable.</u>

→ The equal area criteria is also applicable for a single machine system i.e., synchronous generator connect to infinite bus through a loss less line.

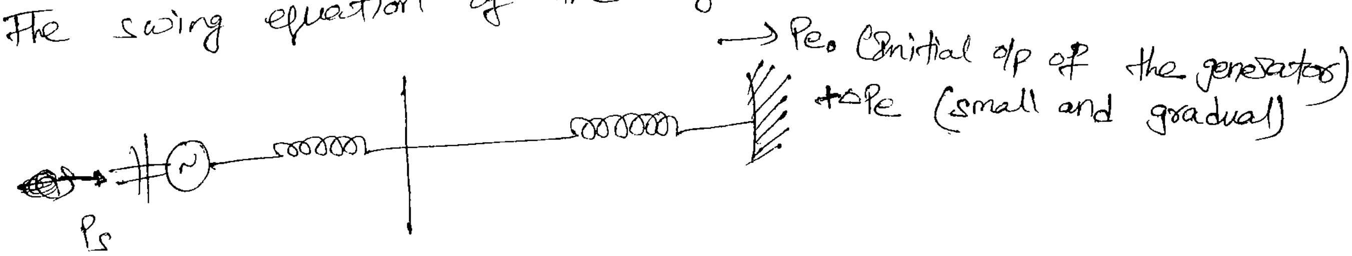


→ Initially the two machines are working in a stable condition without any oscillations. If the load on the synchronous motor is increased suddenly, there is no corresponding increased input, so that the rotor of the synchronous motor will start oscillation and if these oscillations are more than natural frequency of supply, the syn motor will become unstable (or) magnetically pulled out. As the motor has become unstable, the load on the generator will be zero. so that the syn gen will start oscillations, and these oscillations are also more than natural frequency of the supply. so that the syn gen will also unstable.

Study of steady state stability by using swing equation:-

→ For a small and gradual variation of a load, they will be certain oscillation made by the rotor and inorder to evaluate the frequency of oscillation either in rad/sec (or) Hz's.

→ The swing equation of the synchronous machine is use.



$$M\frac{d^2\delta}{dt^2} = P_a$$

53. → In order to get the frequency of oscillation, the solution of the swing equation is required. Convert the non-linear differential equation into linear differential equation by using Taylor series expansion.

ex: $f(x) = x^3+8x^2-10x+12$

$$x = x_0 + \Delta x$$

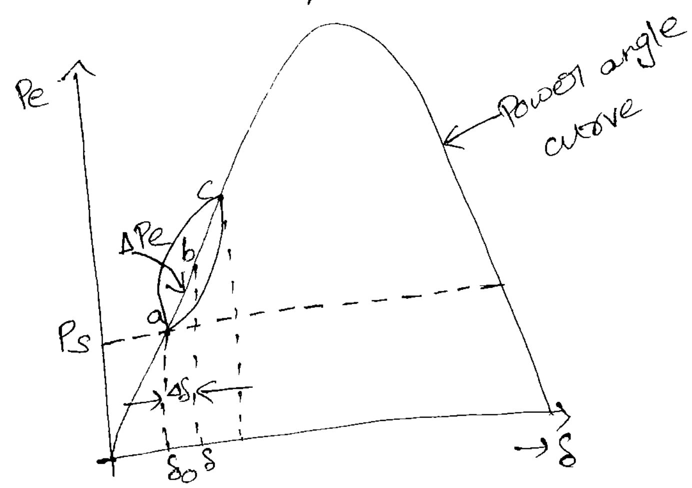
x → unknown value of the function

x_0 → initial value of the function

Δx → residual (small gradual) value of the function

$$M\frac{d^2\delta}{dt^2} = P_a$$

$$M\frac{d^2\delta}{dt^2}(\delta_0+\Delta\delta) = P_s - (P_{e0}+\Delta P_e)$$ → linear differential equation



at 'a'

$$P_s = P_{e0} = P_m \sin\delta_0$$

$$\delta_0 = \sin^{-1}\left(\frac{P_s}{P_m}\right) \text{ elec deg}$$

$$M\frac{d^2\delta}{dt^2} = P_a$$

$$M\cancel{\frac{d^2\delta}{dt^2}}(\delta_0+\Delta\delta) = \cancel{P_s} - (\cancel{P_{e0}}+\Delta P_e)$$

$\delta_0 = \delta_0$ $\quad P_s = 0$ $\quad P_{e0} = 0$

$$M\frac{d^2}{dt^2}(\cancel{\delta_0}+\Delta\delta) = -\Delta P_e = \left.\frac{-\partial P_e}{\partial\delta}\right|_{\delta_0}\Delta\delta$$

$$M\frac{d^2}{dt^2}\Delta\delta + \left.\frac{\partial P_e}{\partial\delta}\right|_{\delta_0}\Delta\delta = 0$$

$$\frac{d}{dt} = K \text{ (roots)}$$

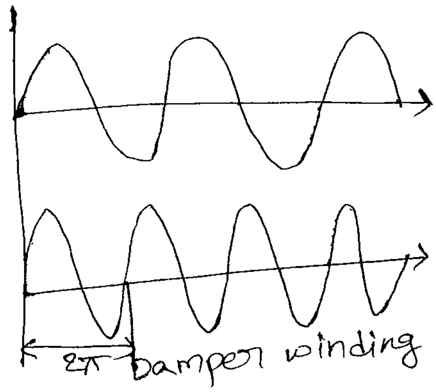
$$\left[MK^2 + \left.\frac{\partial P_e}{\partial\delta}\right|_{\delta_0}\right]\Delta\delta = 0$$

$$\boxed{K = \pm\left[\frac{1}{M}\left(\left.\frac{-\partial P_e}{\partial\delta}\right|_{\delta_0}\right)\right]^{1/2} \text{ rad/sec}}$$

→ The stability of the synchronous machine will be analyse based on the nature of roots.

case-(i):– $\frac{\partial P_e}{\partial \delta} = \frac{EV}{X} \cos\delta = +ve$, $\delta_0 < \frac{\pi}{2}$, imaginary roots without damping

→ The frequency of oscillations evaluated Provided that the syn m/c is having imaginary roots for which $\boxed{\delta_0 < \pi/2}$



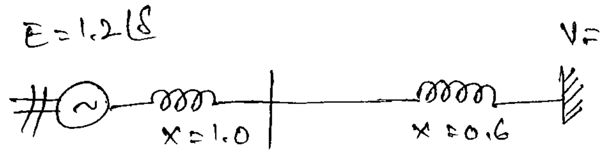
$$K = \pm \underbrace{\left[\frac{1}{M}\left(\frac{-\partial P_e}{\partial \delta}\right)\Big|_{\delta_0}\right]^{1/2}}_{2\pi} \text{ rad/sec}$$

$K = (\quad)$ Hz

case (ii):– $\frac{\partial P_e}{\partial \delta} = \frac{EV}{X} \cos\delta = -ve$, $\delta_0 > \frac{\pi}{2}$, Real roots, no oscillations (unstable)

* The steadystate stability of the synchronous machine thus depends upon the nature of roots. & The nature of roots decides by initial angle (δ_0). In case of static model also the stability of the sync. machine thus depends upon initial angle (δ_0). Hence the stedy state stability is angle stability.

*



The inertia of the constant of the machine is 4MJoul/MVA. Calculate the frequency of the Oscillations made by the M/C in Hz. If the sync. machine working at at 40% of the stability limit.

Sol:-
$$K = \pm\left(\frac{1}{M}\left(\frac{-\partial P_e}{\partial \delta}\Big|_{\delta_0}\right)\right)^{1/2}$$

$$P_s = P_{e0} = 0.4\,P_m$$

$$0.4 P_m = P_{m_0} \sin\delta_0$$

$$\delta_0 = \sin^{-1}\left(\frac{0.4 P_{m_0}}{P_m}\right)$$

$$= 23.57^\circ$$

$$\frac{\partial P_e}{\partial \delta}\Big|_{\delta_0} = \frac{EV}{X_{eq}} \cos\delta_0$$

$$= \frac{1.2 \times 1.0}{1.6} \cos 23.57^\circ$$

$$= 0.68$$

$$M = \frac{SH}{\pi F} = \frac{1.0 \times 4}{3.14 \times 50} = 0.025$$

$$K = \left[\frac{1}{0.025} \times 0.68\right]^{1/2}$$

$$= 5.21 \text{ rad/sec}$$

$$= \frac{5.21}{2\pi} \text{ Hz.}$$

Calculate the frequency of oscillations in Hz made by the rotor if the alternator is initially delivering 80% of the stability limit

$$K = \pm\left[\frac{1}{M}\left(\frac{-\partial P_e}{\partial \delta}\Big/_{\delta_0}\right)\right]^{1/2} \text{ rad/sec}$$

$$P_s = P_{e0} = 0.8 P_{m_0}$$

$$0.8 P_m = P_{m_0} \sin\delta_0$$

$$\delta_0 = \sin^{-1}\left(\frac{0.8\,P_m}{P_m}\right)$$

$$= 53.13.$$

$$\left.\frac{\partial P_e}{\partial \delta}\right|_{\delta_0} = \frac{EV}{X_{eq}} \cos\delta_0$$

$$= \frac{1.2 \times 1.0}{1.6} \cos 53.13.$$

$$= 0.45$$

$$M = \frac{SH}{\pi f} = \frac{1.0 \times 4}{3.14 \times 50} = 0.025$$

$$K = \left[\frac{1}{0.025} \times 0.45\right]^{1/2}$$

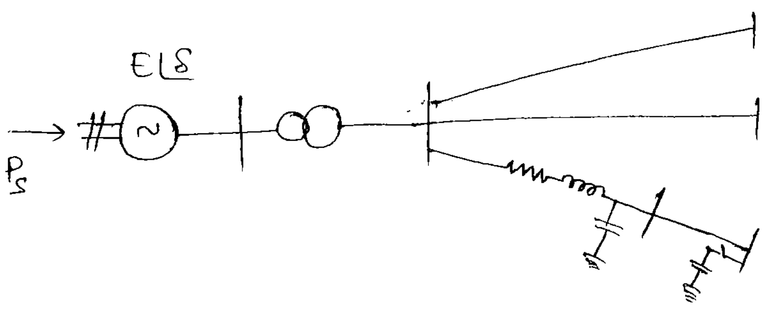
$$= 4.24 \text{ rad/sec}$$

$$= \frac{4.24}{2\pi} \text{ (Hz)}$$

$$= 0.67 \text{ Hz}$$

* In a rotating machine, the efficiency will be high at F.L condi-tion. Because the frequency of Oscillations are less so that the mechanical losses are less.

* Assumptions on the existing system for Transient stability:-



1. The shunt capacitance of the transmission line and also the resistance of the transmission line are ignored. Any external shunt elements at the buses are also ignored. The remaining network will be replaced

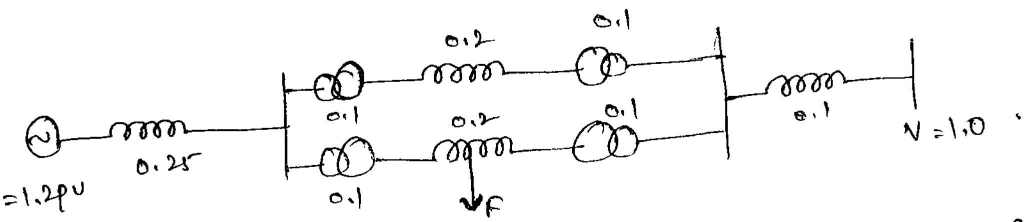
and the load by eleminating fault point.

2. The excitation voltage of the Generator and infinite bus voltage are assumed to be constant because the power transfer is mainly depends upon the reactance of the network. When compared to voltages.

$$P_e = \frac{EV}{X_{eq}} \sin\delta.$$

3. The mechanical input given to the sync. Generator is assumed as constant.

4. The force produced by the damper winding is very less. So that the effect of the damper winding can be ignored because it cannot prevent the oscillations made by the rotor.



Page-62
Q.NO-4

For the figure shown above calculate the max power transfers when the system is healty, fault occurs at the middle of the line and fault is cleared by the breaker

Sol: In the transient stability analysis, the system is having 3-ϕ fault So that there will be +ve sequence components only. In case of +ve sequence the reference is nuetral, and the neutral groundings are not necessary.

P_{e1} = Power transfer before fault. → To know initial Conditions;

P_{e2} = Power transfer capacity (during) with fault

P_{e3} = Power transfer capacity after fault → (Due to the Moment of Inertia)

The transient stability of the sync. machine thus depends upon the swinging of the machine before fault and also the swinging of the machine after fault

$$P_{e1} = \frac{EV}{X_{1eq}} \sin \delta_0 = P_{M1} \sin \delta_0$$

$$P_{e2} = \frac{EV}{X_{2eq}} \sin\delta_0 = P_{M2} \sin \delta$$

$$P_{e3} = \frac{EV}{X_{3eq}} \sin\delta_0 = P_{M3} \sin\delta$$

$P_{M1} = \frac{EV}{X_{1eq}}$ = Max. power transfer before fault

$P_{M2} = \frac{EV}{X_{2eq}}$ = Max. power transfer with ~~before~~ fault

$P_{M3} = \frac{EV}{X_{3eq}}$ = Max. power transfer after fault

X_{1eq} = Transfer reactance before fault

X_{2eq} = Transfer reactance with ~~after~~ fault

X_{3eq} = Transfer reactance after fault

In a parallel transmission lines,

for a line fault

$$\boxed{X_{2eq} > X_{3eq} > X_{1eq}}$$

$P \quad < P_{M2} < P_{..}$

$$* \; P_{M2} = \frac{\quad}{X_{2eq}} = \frac{\quad}{X_{1eq}} \cdot \frac{\quad}{X_{2eq}} = r_1 P_{M1}$$

$$\Rightarrow r_1 = \frac{X_{1eq}}{X_{2eq}} < 1.0$$

$$* \; P_{M3} = \frac{EV}{X_{3eq}} = \frac{EV}{X_{1eq}} \cdot \frac{X_{1eq}}{X_{3eq}} = r_2 P_{M1}$$

$$\Rightarrow r_2 = \frac{X_{1eq}}{X_{3eq}} < 1.0$$

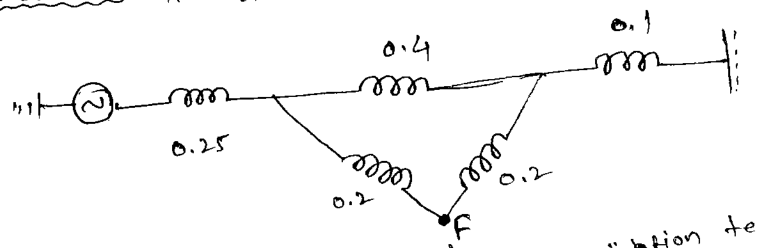
Calculations:

$$P_{M1} = \frac{EV}{X_{1eq}} = \frac{1.2 \times 1.0}{0.25 + \frac{0.4}{2} + 0.1} = 2.18 \text{ PU}$$

$$P_{M3} = \frac{EV}{X_{3eq}} = \frac{1.2 \times 1.0}{0.25 + 0.4 + 0.1} = 1.6 \text{ PU}$$

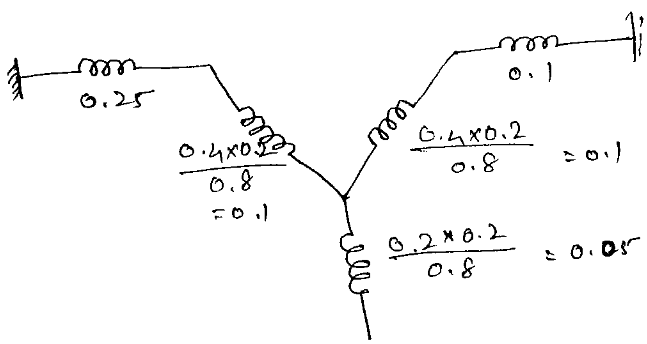
$$P_{M2} = \frac{EV}{X_{2eq}}$$

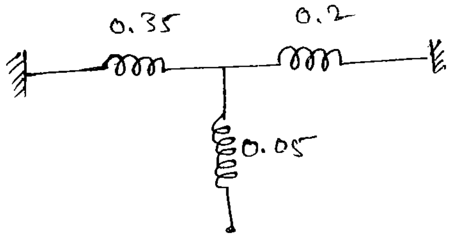
Calculation of X_{2eq}:

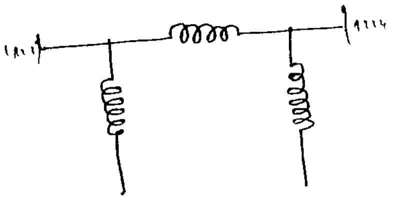


fault elimination technique

$\Rightarrow$

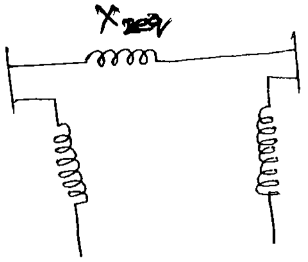






$$X_{2eq} = 0.35 + 0.2 + \frac{0.35 \times 0.2}{0.05}$$

$$= 1.95 PU$$



$$\Rightarrow \boxed{\begin{array}{c} P_{m2} < P_{m3} < P_{m1} \\ X_{2eq} > X_{3eq} > X_{1eq} \end{array}}$$

$$\Rightarrow P_{m2} = \frac{EV}{X_{2eq}} = \frac{1.2 \times 1.0}{1.95} = 0.61 PU$$

Calculate the maximum power transfers for the above single line diagram before fault, with fault and after fault may fault occurs on one of the transmission line at 60% of line length from the source

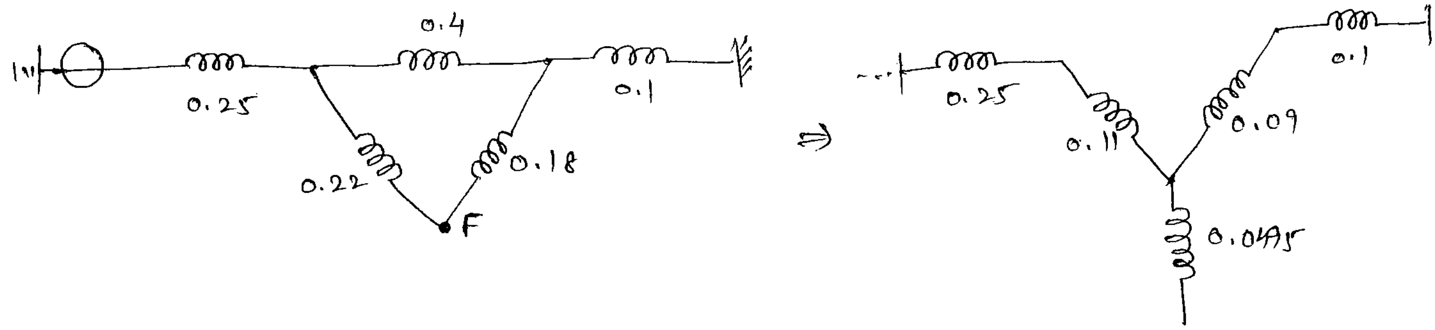
$$P_{M1} = \frac{EV}{X_{1eq}} = \frac{1.2 \times 1.0}{0.25 + \frac{0.4}{2} + 0.1} = 2.15 PU$$

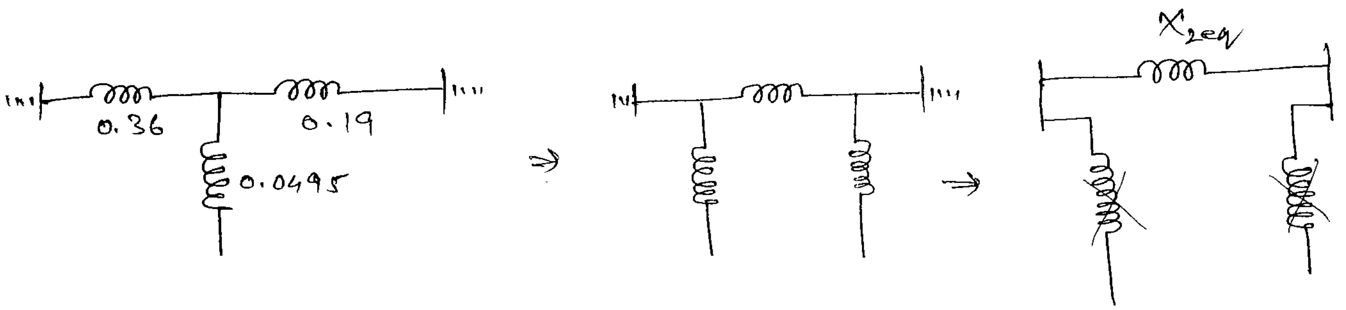
$$P_{m3} = \frac{EV}{X_{3eq}} = \frac{1.2 \times 1.0}{0.25 + 0.4 + 0.1} = 1.6 PU$$

Calculations of P_{m2}

$$P_{m2} = \frac{EV}{X_{2eq}}$$

Calculations of ~~X~~





$$X_{2eq} = 0.36 + 0.19 + \frac{0.36 \times 0.19}{0.0495} = 1.93$$

$$P_{m_2} = \frac{EV}{\cancel{X}_{2eq}} = \frac{1.2 \times 1.0}{1.93} = 0.62 \text{ PU}.$$

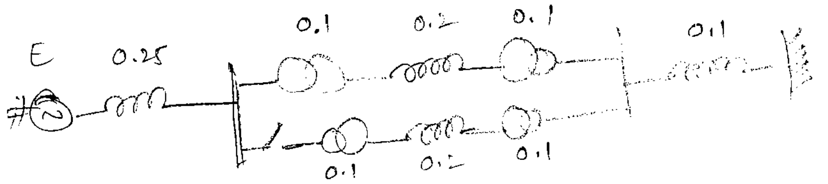
* Calculate the max. power transfers for ~~than~~ a fault occurs on a line near to bus-bar

$$P_{m_1} = \frac{EV}{X_{1eq}} = \frac{1.2 \times 1.0}{0.25 + \frac{0.4}{2} + 0.1} = 2.18 \text{ PU}$$

$P_{m_2} = 0$, $P_{e_2} = 0$ (Assumed as fault on bus-bar)

$$P_{m_3} = \frac{EV}{X_{3eq}} = \frac{1.\cancel{2} \times 1.0}{0.25 + 0.4 + 0.1} = 1.6 \text{ PU}$$

(Though it is assumed as bus fault but it is actually a line fault

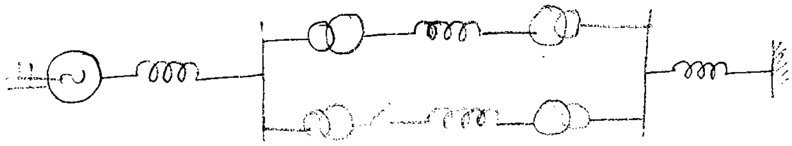


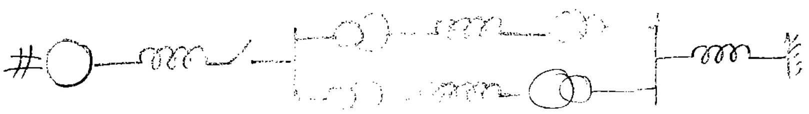
* Calculate the max. power transfer for a fault occurs on the Bus-Bar.

$$P_{m1} = \frac{EV}{X_{1eq}} = \frac{1.25 \times 1.0}{0.25 + \frac{0.4}{2} + 0.1} = 2.18\ pu$$

$P_{m2} = 0, \quad P_{e2} = 0$ [Fault is on Bus-Bar]

$$P_{m3} = \frac{EV}{X_{3eq}} = P_{m1} \quad (X_{3eq} = X_{1eq})$$





No load condition

If a fault occurs on the Bus-Bar, the sync. Gen will be isolated from parallel lines. which will result as it is working at no-load condition. In-order to avoid the no-load operation, the alternator breaker will be close at a faster rate. If the alternator breaker is close, the original network is bring back. Hence $\boxed{X_{3eq} = X_{1eq}}$

So that $\boxed{P_{m3} = P_{m1}}$

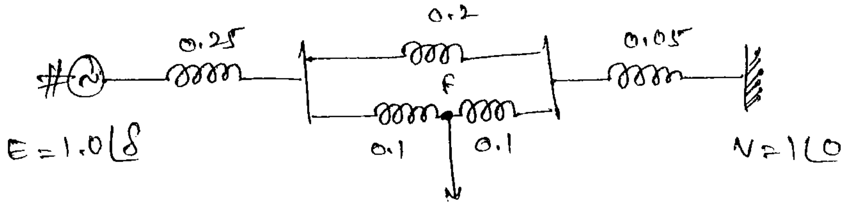
$\Rightarrow P_{m3} = P_{m1} = 2.18$ PU.

$P_{e1} \neq P_{e3}$

$P_{m1} \sin\delta \neq P_{m3} \sin\delta$

Consider the system shown in fig. ... point.

when the circuit breaker is re-closed after clearing the fault, the steady state stability limit of the restored system will be.



$$P_{m1} = \frac{EV}{X_{1eq}} = \frac{1.0 \times 1.0}{0.25 \times \frac{0.2}{2} \times 0.05} = 2.5\ pu$$

$$P_{m3} = \frac{EV}{X_{3eq}} = \frac{1.0 \times 1.0}{0.25 \times 0.2 \times 0.05} = 2.0\ pu$$

$$P_{m2} = \frac{EV}{X_{2eq}}$$

$$X_{2eq} = 1.6 \qquad \Rightarrow P_{m2} = \frac{1.0 \times 1.0}{1.6} = 0.625\ pu$$

Calculate the max. power transfered, if a fault occurs on the line near to Bus-Bar.

$$P_{m1} = \frac{EV}{X_{1eq}} = \frac{1.0 \times 1.0}{0.25 \times \frac{0.2}{2} \times 0.05} = 2.5$$

$P_{m2} = 0$, $P_{e2} = 0$ Assumed as bus fault.

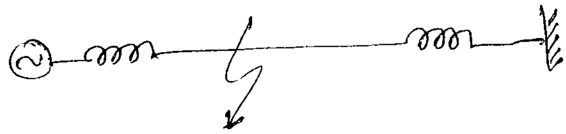
$$P_{m3} = \frac{1.0 \times 1.0}{0.25 \times 0.2 \times 0.05} = 2.0\ pu$$

Calculate the max power transfered, if a fault is on the Bus-Bar.

$$P_{m1} = \frac{EV}{X_{1eq}} = \frac{1.0 \times 1.0}{0.25 \times \frac{0.2}{2} \times 0.05} = 2.5\ pu$$

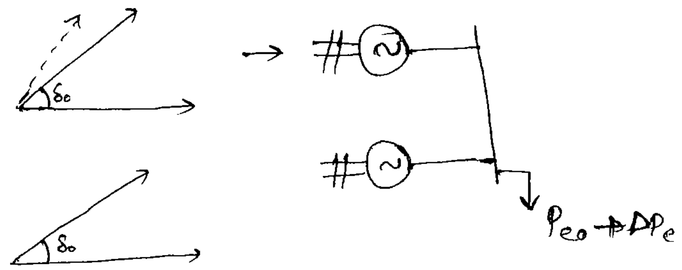
$P_{m2} = P_{e2} = 0$ (Assumed as Bus-fault)

$$P_{m3} = \frac{EV}{X_{3eq}} = P_{m1} = 2.5 \qquad (X_{3eq} = X_{1eq}).$$



* In a generating station, there will be more than one Generator is working in parallel. The Gen will having two types of operations.

1. Swinging togther :-



For any change of load, there will be a corresponding change in the rotor angles of the both machines, the change of load is shared by the two machines, the two machines are working in

$$\delta_1 = \delta_2 = \delta$$

$$P_{aeq} = P_{a1} + P_{a2}$$

$$= M_1 \cdot \frac{d^2\delta_1}{dt^2} + M_2 \cdot \frac{d^2\delta_2}{dt^2}$$

The equalent moment of inertia,

$$M_{eq} \frac{d^2\delta}{dt^2} = (M_1 + M_2)\left[\frac{d^2\delta}{dt^2}\right]$$

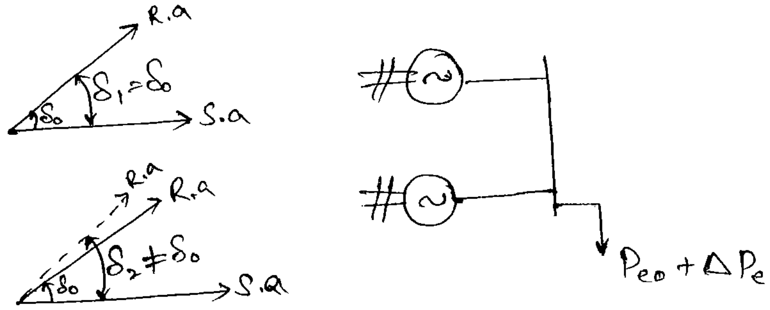
$$\boxed{M_{eq} = M_1 + M_2}$$

$$M_{eq} = M_1 + M_2 + \cdots \cdots + M_n$$

$$M = \frac{SH}{180f}$$

$$H_{eq} = H_1 + H_2 + \cdots \cdots + H_n$$

2. Do not swinging together:—



Any change of load will result as, there will be a change in a position of Rotor is one of the machine.

So that the change of load is shared by the two machines are working in the donot swinging mode.

When

$$\delta = \delta_2 - \delta_1$$

$$\frac{d^2\delta}{dt^2} = \frac{d^2\delta_2}{dt^2} - \frac{d^2\delta_1}{dt^2}$$

$$\frac{d^2\delta}{dt^2} = \frac{P_{a2}}{M_2} - \frac{P_{a1}}{M_1}$$

$$\frac{d^2\delta}{dt^2} = \frac{P_{s2} - P_{e2}}{M_2} - \frac{P_{s1} - P_{e1}}{M_1}$$

$$P_{aeq} = P_{seq} - P_{eeq}$$

$$\frac{M_1 M_2}{M_1 + M_2} \cdot \frac{d^2\delta}{dt^2} = \frac{M_1 M_2}{M_1 + M_2}\left[\frac{P_{s2} - P_{e2}}{M_2} - \frac{P_{s1} - P_{e1}}{M_1}\right]$$

$$\frac{M_1 M_2}{M_1 + M_2} \cdot \frac{d^2\delta}{dt^2} = \left(\frac{M_1 P_{s2} - M_2 P_{s1}}{M_1 + M_2}\right) - \left(\frac{M_1 P_{e2} - M_2 P_{e1}}{M_1 + M_2}\right)$$

$$P_{aeq} = P_{seq} - P_{eeq}$$

$$M_{eq} \cdot \frac{d^2\delta}{dt^2} = P_{seq} - P_{eeq}$$

$$\text{Here } M_{eq} = \frac{M_1 M_2}{M_1 + M_2}$$

$$\frac{1}{M_{eq}} = \frac{1}{M_1} + \frac{1}{M_2}$$

for n - Generators.

$$\frac{1}{M_{eq}} = \frac{1}{M_1} + \frac{1}{M_2} + \dots + \frac{1}{M_n}$$

$$\frac{1}{H_{eq}} = \frac{1}{H_1} + \frac{1}{H_2} + \dots + \frac{1}{H_n}$$

When there is a sudden and large variation at the bus, it is required to maintain the transient stability by allowing the 2-machines in a swinging together. So that the change of load will be shared by both machines and if the two machines are sharing, the disturbance in each machine are less.

$$M \cdot \frac{d^2\delta}{dt^2} = P_a$$

$$\alpha = \downarrow \frac{d^2\delta}{dt^2} = \frac{P_a}{M \uparrow} \qquad \alpha = \text{Angular accelaration,}$$

If the equavalent moment of inertia is high, the angular accelaration is less, the swinging of the machines are less, the machines are stable.

In order to get the swinging of Generators the generators which are connected to common bus should be have same size.

Generator - 1 $\longrightarrow$ Rating S_1 and H_1

Generator - 2 $\longrightarrow$ S_2 and H_2

$$S_1 \neq S_2$$

$$H_{eq} = \frac{H_1 H_2}{H_1 + H_2} \rightarrow \text{Do not swinging}$$

$\Rightarrow$ Inorder to get the swinging of two machines, the 2-Generators are bringing into a common base. (S_b).

$$H \alpha \frac{1}{S} \qquad \frac{H_1\, old}{H_2\, old} = \frac{S_b}{S_1\, old}$$

$$H_1\, new = \frac{H_1\, old \cdot S_1 old}{S_b}$$

$$H_2\, new = \frac{H_2 old \cdot S_2 old}{S_b}$$

$$H_{eq} = H_1\, New + H_2\, New$$

$$\boxed{H_i new = \sum_{i=1}^{n} \frac{H_i old \cdot S_i old}{S_b}}$$

Gen-1:- 100 MVA, 11 KV, 50 Hz, H_1 = 10 MJ/MVA

Gen-2:- 200 MVA, 11 KV, 50 Hz, H_2 = 5 MJ/MVA

The equivalent inertia of the 2-Generators is

$$H_{eq} = \frac{H_1 H_2}{H_1 + H_2}$$

$$= \frac{10 \times 5}{15}$$

$S_1 \neq S_2$ Do not Swinging.

Gen-1: 100 MVA, 11 KV, 50 Hz, $H_1 = 10\ MJ/MVA$

Gen-2: 200 MVA, 11 KV, 50 Hz, $H_2 = 5\ MJ/MVA$

The equalent inertia constant at 500 MVA common base is.

$$H_{1New} = \frac{H_{1old} \cdot S_{1old}}{S_b}$$

$$= \frac{10 \times 100}{500} = 2$$

$$H_{2New} = \frac{H_{2old} \cdot S_{2old}}{S_b}$$

$$= \frac{5 \times 200}{500} = 2$$

$$H_{eq} = H_{1New} + H_{2New} = 2 + 2 = 4\ MJ/MVA.$$

Equal Area Criteria:-

It gives the solution for swinging equation in a graphical manner inorder to study the transient stability of a single machine system.

The equal area criteria says that the area covered by the synchronous machine between the two swinging points. By the sync. machine of the first swing will be zero.

(or)

The area covered during accelaration will be equal to the area covered during decellaration by the synchronous machine during the first swing.

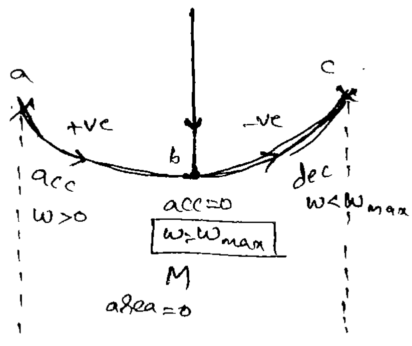
$$M \frac{d^2\delta}{dt^2} = P_a$$

Multiply on both sides by $2\frac{d\delta}{dt}$ and integrate with respect to dt

$$\int M \frac{d^2\delta}{dt^2} \cdot 2\frac{d\delta}{dt} \cdot dt = \int P_a \cdot 2\frac{d\delta}{dt} \cdot dt$$

$$\frac{d\delta}{dt} = \left[\frac{2}{M}\int P_a\, d\delta\right]^{1/2} = 0$$

The oscillations ... of synchronous machine in equal area criteria are similar to that of the oscillations made by the pendilum in the clock.



accelarating area = decelarating area

$$A_{acc} = A_{dec}$$

$$A_{acc} + A_{dec} = 0.$$

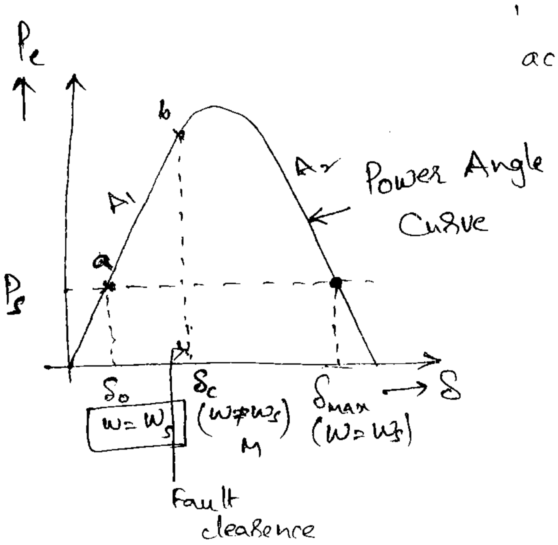
at 'a'

$$P = P_s - P_{eo}$$
$$= 0$$

Neither accelarating nor decelaration

$$\omega = \omega_s$$

$$\left.\frac{d\delta}{dt}\right|_{\delta_0} = 0.$$



A short circuit fault occurs on the generator terminal and it will be cleared by C.B. after few cycles. There will be a swinging of the machine during the fault condition which can be shown on equal area criteria.

There will be a swinging of the machine even after fault is cleared due to the moment of inertia and it will be continued

inorder to get $\boxed{\omega = \omega_s}$

$$\left.\frac{d\delta}{dt}\right|_{\delta_{max}} = 0$$

$$\boxed{\int_{\delta_0}^{\delta_{max}} P_a \, d\delta = 0.}$$

$$\Rightarrow \frac{d\delta}{dt} = \left[\frac{2}{M}\int_{\delta_0}^{\delta_{max}} P_a \, d\delta\right]^{1/2} = 0$$

* The area covered between the two swinging points is zero.

→ The equal area criteria will able to provide the angle made by the rotor at the time of fault is cleared by the C.B which is known as Critical clearing angle (δ_c).

→ Stability Analysis:— Consider the first swing of the Synchronous M/c.

a) $A_1 < A_2$ → Stable

b) $A_1 = A_2$ → Critically Stable.

c) $A_1 > A_2$ → Unstable.

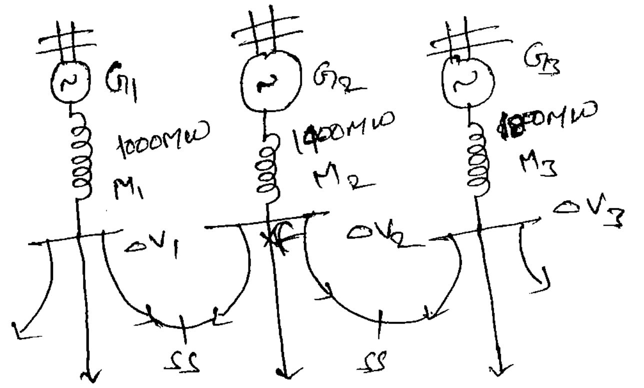
→ The stedy state stability is the angle stability, where as the transient stability in area stability

→ Due to moment of inertia, the synchronous machine is swinging even after fault is cleared inorder to get $\omega = \omega_s$. Eventhough $\delta_{max} > 90°$ but there are chances to become stable conditions because the stability will be decided by area but not angle.

→ Equal area Criteria is dealing with a single m/c. The swinging of the machine is max. during the first swing.

If the sync. machine is stable during the first swing and it could be also stable during subsequent cycles (swing).

In a multimachine system, as the size of the generating stations are not same, the swinging of the Generating stations are not uniform. Hence even though the sync. machine is stable during the first swing there are chances to become unstable in the subsequent swing. which is called as Cascade Tripping of the Generators. (or) Grid failure.



swinging descending order

1. G2 G3 G1
2. G3 G1
3. G1

Cascade tripping of alternator (or) grid failure

swinging now descending order

1. G2 G3 G1
2. G2 G3 G1
3. G2 G3 G1

$\boxed{\Delta V_2 > \Delta V_3 > \Delta V_1}$ → change in voltage at buses. The fault occurs at 'V_2'.

→ In a real time application the time up operation of the breaker is more preferred when compared to the angle made by rotor.

→ The equal area criteria is a graphical solution so that it is unable to convert the angle into time. However in a point by point method, the time up operation of the circuit breaker can be obtain, which is called as critical clearing time i.e., t_c, for a given critical angle

Applications of equal area criteria:-

i) A sudden increase mechanical input to the synchronous generator

ii) A sudden increase mechanical output on synchronous motor.

iii) Fault occurs at the middle of transmission line in a ||el TL

iv) Fault occurs on a transmission line near to bus bar in a ~~near~~ ||el TL

v) fault occurs on bus bar in a ||el transmission line. a

sudden ~~increased~~

Assumptions of equal area criteria:

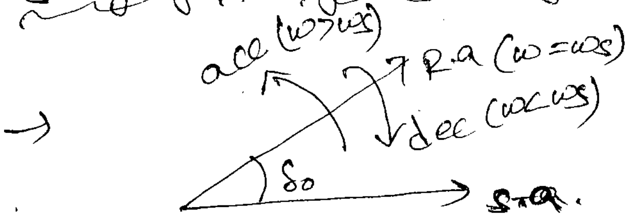
a) $P_a = 0$ and $\omega = \omega_s$ → a stable point on the curve.

Hence there is no swinging on TL.

b) $P_a \neq 0$ but $\omega = \omega_s$ (or) $P_a = 0$ but $\omega = \omega_s$ → swinging point on curve.

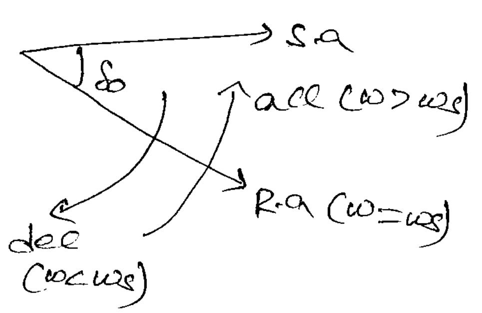
c) The effect of moment of inertia is considered on swinging of machine

swinging of synchronous generator

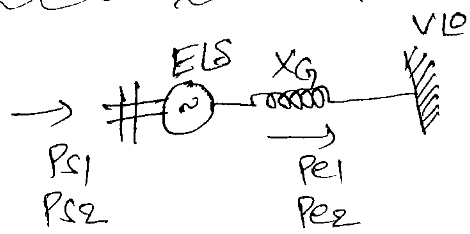


[sa → stator axis
R.a → Rotor axis]

swinging of synchronous motor



sudden increased mechanical input to synchronous generator:



P_{s1} — initial mechanical input

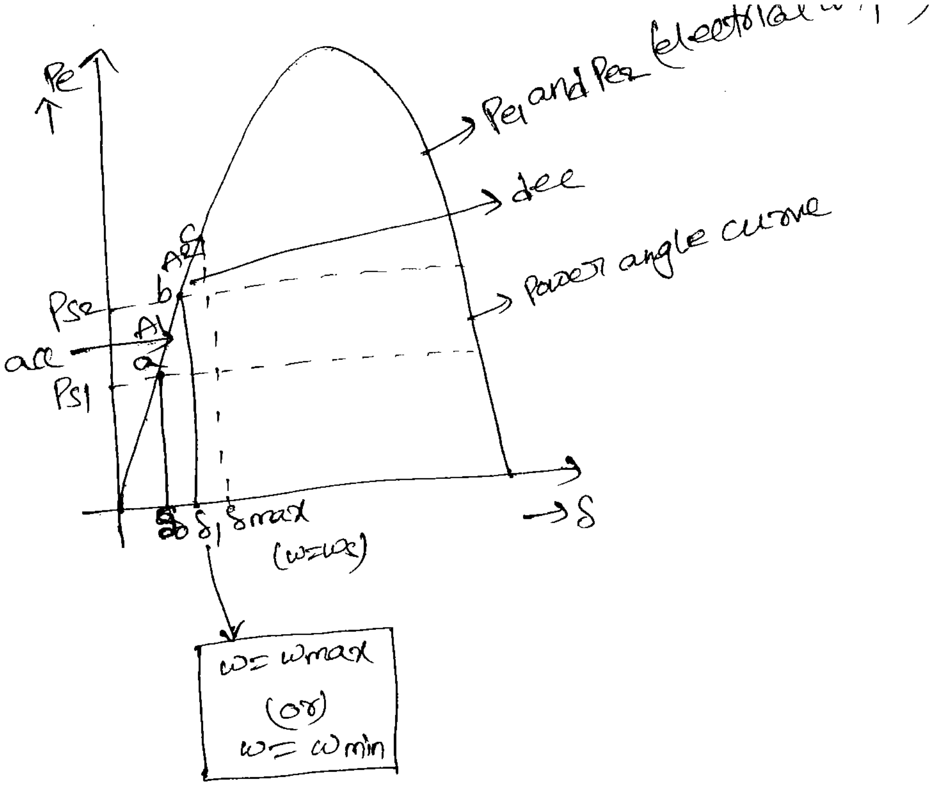
P_{s2} — increased mechanical input

P_{e1} — $\frac{EV}{X_{1eq}} \sin\delta_0 = P_{m1}\sin\delta_0$ initial e o/p

P_{e2} — $\frac{EV}{X_{2eq}} \sin\delta = P_{m2}\sin\delta$

increased electrical output

$X_G <$ $\boxed{X_{2eq} = X_{1eq}}$ $\boxed{P_{m2} = P_{m1}}$



→ The synchronous generator is supplied with a mechanical i/p of Ps1 and corresponding electrical o/p of Pe1. It is represented by poin 'a' on power angle curve.

→ The mechanical input to the synchronous generator will be increased suddenly but there is no change in the electrical output suddenly, because the moment of inertia of syn m/c does not permit the rotor angle. Hence

$$P = P_{s2} - P_{e2}$$

$$= P_{s2} - \underbrace{\frac{EV}{X_{2eq}}}_{P_{m2}} \cdot \sin\delta_0$$

$$= P_{s2} - P_{m2}\sin\delta_0 \downarrow$$

$$= +ve$$

$$= \text{acceleration}$$

→ The excess mechanical input will be stored in the form of kinetic energy of rotor.

At 'a'	$P = P_{s1} - P_{e1}$ $= P_{s1} - P_{m1} \sin\delta_0$ $= 0$	Neither acceleration nor deceleration	$\omega = \omega_s$	Stable point There is no swinging.
a to b	$P = P_{s2} - P_{e2}$ $= P_{s2} - \underline{P_{m2} \sin\delta}\downarrow$ $= +ve$	acceleration	$\omega > \omega_s$	'δ' will increases
b	$P = P_{s2} - P_{e2}$ $= P_{s2} - P_{m2} \sin\delta_1$ $= 0$	neither acceleration nor deceleration	$\omega = \omega_{max}$	swinging point Due to moment of inertia the m/c will swing further in same direction.
b to c	$P = P_{s2} - P_{e2}$ $= P_{s2} - \underline{P_{m2} \sin\delta}\uparrow$ $= -ve$	Deceleration	$\omega < \omega_{max}$ but $\omega > \omega_s$	There is a deceleration but $\omega > \omega_s$. Hence the rotor angle will further increase, because the speed of machine is deciding factor when compared to deceleration.
c	$P = P_{s2} - P_{e2}$ $= P_{s2} - \underline{P_{m2} \sin\delta_{max}}\uparrow$ $= -ve$	Deceleration	$\omega = \omega_s$	swinging point of system, the rotor angle of m/c will start decreasing. The synchronous m/c is swinging [illegible].

c to b	$P = P_{s2} - P_{e2}$ $= P_{s2} - \underline{P_{m2}\sin\delta} \uparrow$ $= -ve$	Deceleration	$\omega < \omega_s$	Rotor angle will decrease
b	$P = P_{s2} - P_{e2}$ $= P_{s2} - P_{m2}\sin\delta_1$ $= 0$	neither deceleration nor acceleration	$\omega = \omega_{min}$	swinging point. Due to moment of inertia the m/c will swing in same direction.
b to a	$P = P_{s2} - P_{e2}$ $= P_{s2} - \underline{P_{m2}\sin\delta} \downarrow$ $= +ve$	acceleration	$\omega > \omega_{min}$ but $\omega < \omega_s$	There is a acceleration but $\omega < \omega_s$. Hence the rotor angle of m/c will decrease further.

→ Due to acceleration and $\omega > \omega_s$, the swinging of m/c will be taking place. so that the rotor angle will be changes slowly.

→ The rotor angle will increase slowly so that the output of the generator increase slowly.

→ The swinging will be continue in same direction in order to get $\omega = \omega_s$, provided that the E o/p of synchronous machine should be more than mechanical input i.e., in deceleration area.

→ During the deceleration, electrical output of m/c will be more than mechanical i/p, because kinetic energy stored in rotor during acceleration will be converted into electrical output.

→ further the swinging of m/c ~~will~~ in the deceleration does depends on the swinging of m/c in acceleration.

→ with above assumptions, ~~will the~~ angle is increased up to 'c' in order to get $\omega = \omega_s$.

→ even though the syn m/c will swinging. But there will be a change in rotor angle w.r.to stator. so that the next swing of m/c will start from new point on power angle curve i.e., A1.

→ after completion of oscillation the syn m/c will be stable at 'b'. so that the speed of m/c will be a synchronous speed.

→ The above equal area criteria is a stable curve if

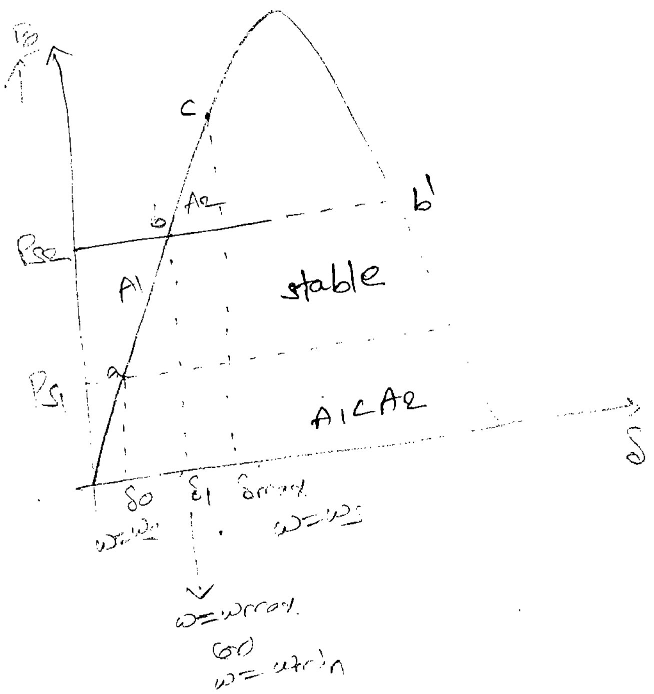
$A_1 > A_2$

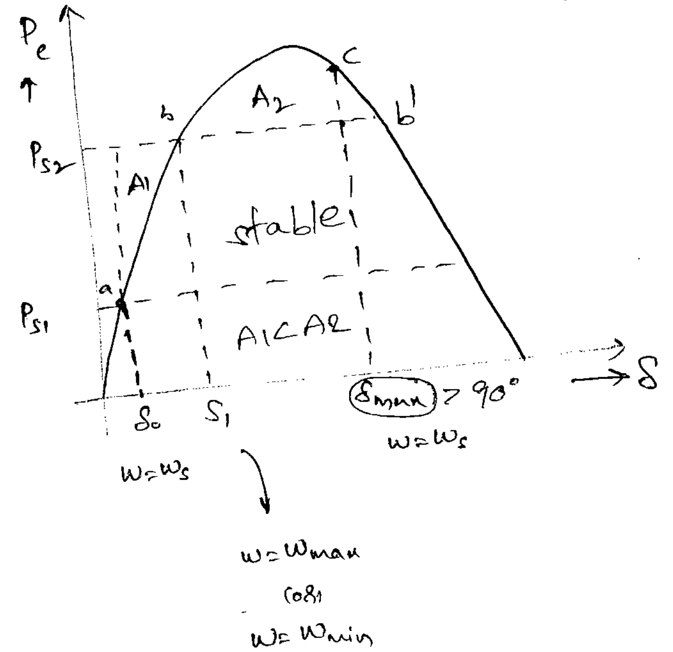
→ while comparing areas, consider critical point of the curve and then where the comparision of areas.

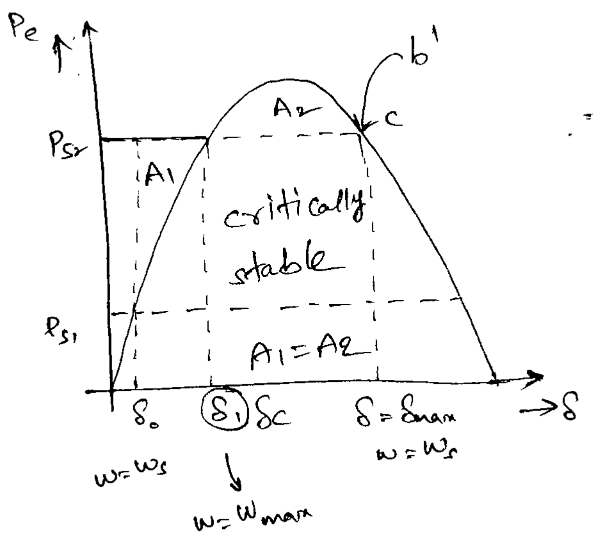
i) $\omega = \omega_s$ is obtain before critical point, $A_1 < A_2$, stable.

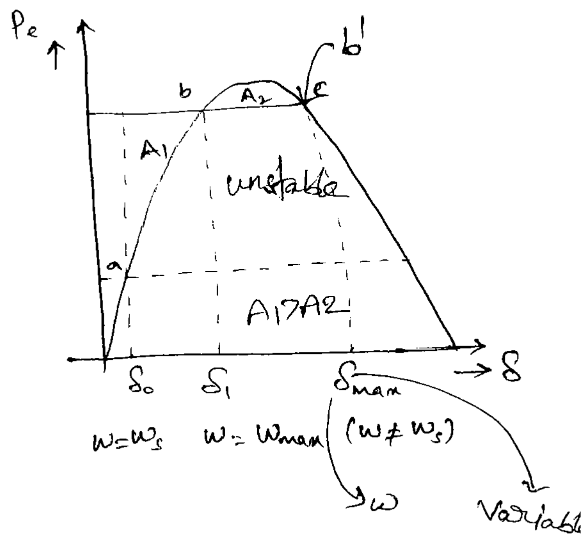
ii) $\omega = \omega_s$ is obtain at critical point, $A_1 = A_2$. critically stable

iii) $\omega \neq \omega_s$ is obtain at critical point, $A_1 > A_2$, unstable



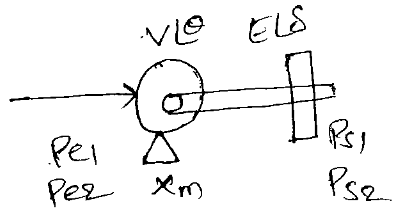






→ The purpose of equal area criteria is to calculate the critical clearing angle i.e., δ_c by considering critically stable condition i.e., $A_1 = A_2$

2) Sudden increased mechanical output on synchronous motor :-



$$P_{e1} = \frac{EV}{X_{1eq}} \sin\delta_0 = P_{m1} \sin\delta_0$$

initial electrical input

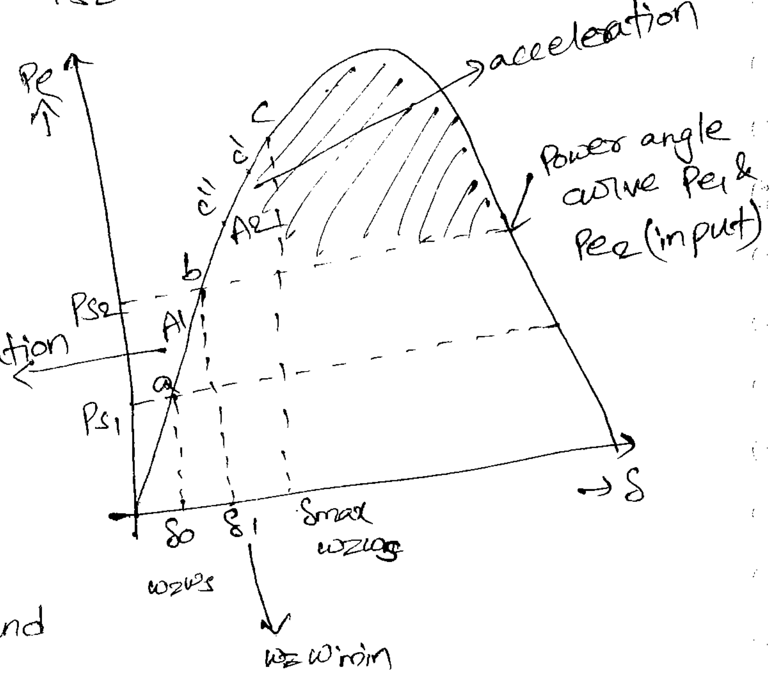
$$P_{e2} = \frac{EV}{X_{2eq}} \sin\delta = P_{m2} \sin\delta$$

increased electrical input

P_{s1} : initial mechanical output; P_{s2} : increased mechanical output.

$$\boxed{X_{1eq} = X_{2eq} = X_{eq}}$$

$$\boxed{P_{m2} = P_{m1}}$$



→ The equal area criteria of syn m/c is an image of synchronous generator.

→ The synchronous motor is supply with electrical input of P_{e1} and the mechanical output of P_{s1}. The synchronous m/c is stable at pt a' on power angle curve.

→ The load on motor is suddenly increase from P_{s1} to P_{s2}, but the electrical input will remain same. Because the moment of inertia of synchronous machine does not permit ~~the~~ a sudden change in rotor angle. Hence

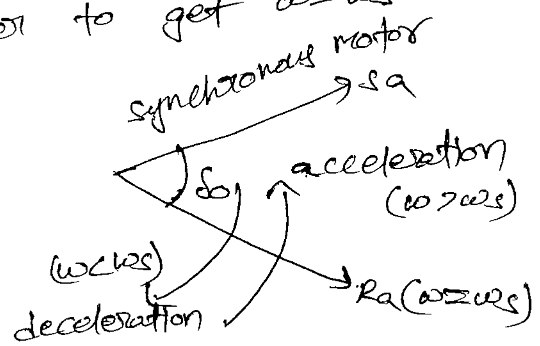
$$P = P_{e2} - P_{s2}$$
$$= P_{m2} \sin\delta_0 - P_{s2} \Rightarrow \downarrow P_{e1} - P_{s2}$$

At 'a'	$P = P_{e1} - P_{s1}$ $= P_{m1} \sin \delta_0 - P_{s1}$ $= 0$	neither acceleration nor deceleration	$\omega = \omega_s$	It is a stable point. There is no change in rotor angle
a to b	$P = P_{e2} - P_{s2}$ $= \downarrow P_{m2} \sin \delta - P_{s2}$ $= -ve$, deceleration	Deceleration	$\omega < \omega_s$	'δ' will increased
b	$P = P_{e2} - P_{s2}$ $= P_{m2} \sin \delta_1 - P_{s2}$ $= 0$	neither deceleration nor acceleration	$\omega = \omega_{min}$	swinging point. Due to moment of inertia it will swing in same direction $\boxed{\text{it means machine}}$
b to c	$P = P_{e2} - P_{s2}$ $= \uparrow P_{m2} \sin \delta - P_{s2}$ $= +ve$	acceleration	$\omega > \omega_{min}$ but $\omega < \omega_s$	There is acceleration but $\omega < \omega_s$. Hence the rotor angle will increased.
c	$P = P_{e2} - P_{s2}$ $= \uparrow P_{m2} \sin \delta_{max} - P_{s2}$ $= +ve$	acceleration	$\omega = \omega_s$	swinging point, the rotor angle of machine decreasing.

→ There is a deceleration and $\omega < \omega_s$, so that the rotor angle will be changes slowly i.e., rotor angle will increase so that the swinging of M/c will start from 'a'. Hence the electrical input will increase slowly.

→ The swinging of machine will continue inorder to get $\omega = \omega_s$ Provided that the electrical input must be more than mechanical output (acceleration region). Further the swinging of machine beyond 'b' does depends upon the swinging of m/c from a to b.

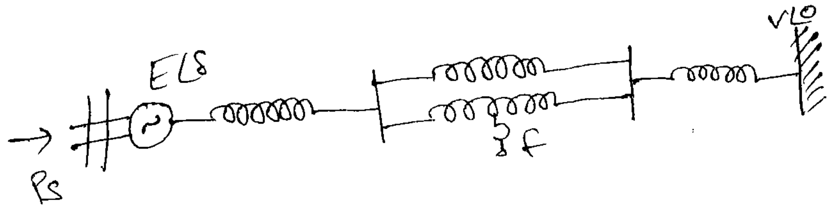
→ With the above assumptions, it is assumed that the synchronous machine is swinging up to 'c', inorder to get $\omega = \omega_s$.



→ Even though synchronous machine is oscillating but relatively there will be change in position of rotor w.r.to stator. Hence the next swing of machine will start from new point i.e., A'.

c to b	$P = P_{e2} - P_{s2}$ $= \uparrow P_{m2} \sin\delta - P_{s2}$ $= +ve$	acceleration	$\omega > \omega_s$	'δ' will decrease
b	$P = P_{e2} - P_{s2}$ $= P_{m2} \sin\delta_1 - P_{s2}$ $= 0$	neither acceleration nor deceleration	$\omega = \omega_{max}$	swinging point. Due to moment of inertia, the swinging will be in sar direction.
b to a	$P = P_{e2} - P_{s2}$ $= \downarrow P_{m2} \sin\delta - P_{s2}$ $= -ve$	Deceleration	$\omega < \omega_{max}$ but $m > \omega_s$	There is a decelerac but $\omega > \omega_s$. Hence the rotor angle will further decrease.

3)



P_s = mechanical input

$P_{e1} = P_{m1} \sin \delta_0$

electrical output before fault

$P_{e2} = P_{m2} \sin \delta$

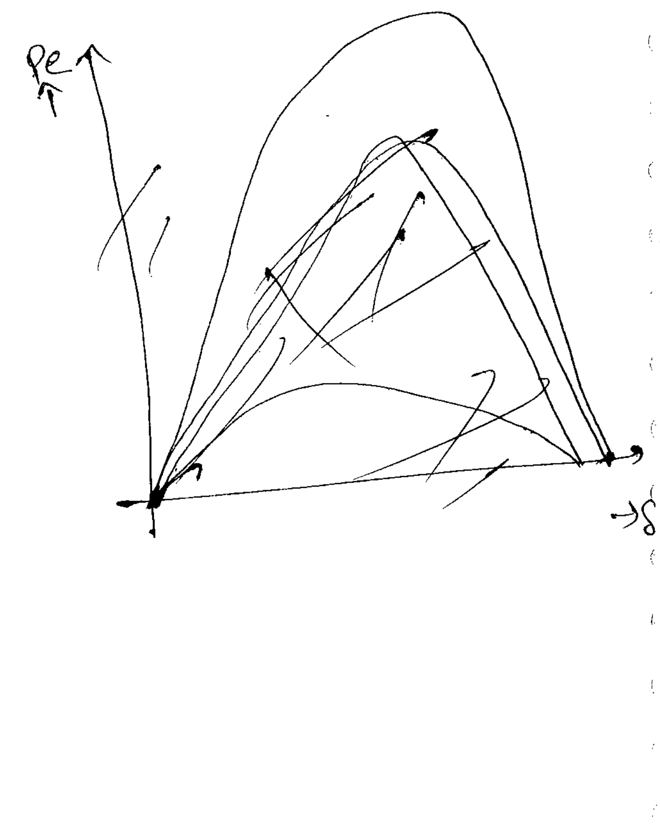
electrical output with fault

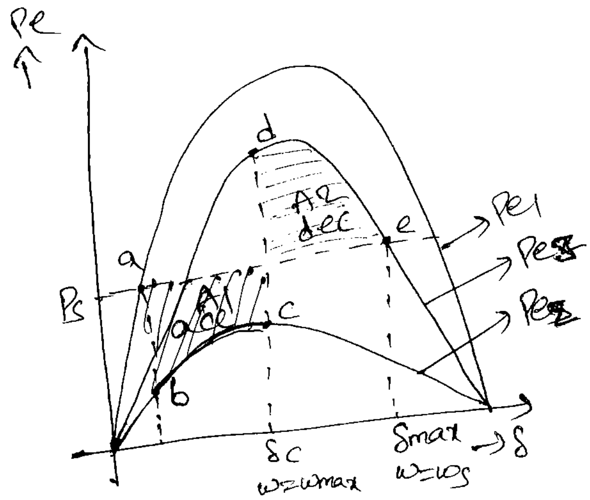
$P_{e3} = P_{m3} \sin \delta$

electrical output after fault

$X_{2eq} > X_{3eq} > X_{1eq}$

$P_{m2} < P_{m3} < P_{m1}$





→ The synchronous generator is supplied with a mechanical input of P_s and the electrical output of P_{e1}. It is represented by point 'a' on P_{e1} curve.

→ A 3-φ short circuit occurs in one of the TL at mid point of line will result as the electrical output will reduce suddenly because of change in reactance i.e., X_{eq}. However the mechanical input will remain same. It is represented by point 'b' on P_{e2} curve.

$$P = P_s - P_{e2}$$
$$= P_s - P_{m2}\sin\delta_0 \downarrow$$
$$= +ve$$
$$= \text{accelaration}$$
$$\Rightarrow \omega > \omega_s$$

→ Due to acceleration and $\omega > \omega_s$, the rotor angle of generator will increase slowly. so that the swinging of the machine will start from 'b'. The ~~swi~~

→ The swinging of machine is continue till the fault is clear (x) by breaker after few cycles. It is assumed that the fault is clear by breaker at 'c' and the corresponding angle is 'δ_c' i.e., critical clearing angle under the assemption that the equal area criteria is critically stable i.e., $A_1 = A_2$.

→ b to c $\quad P = P_s - P_{e2}$ $\quad$ acceleration $\quad \omega > \omega_s$ $\quad$ 'δ' will increase

$$= P_s - P_{m2}\sin\delta \downarrow$$
$$= +ve$$

→ If the faulty line is isolated, there will be a change in the reactance of network so that the electrical output increased suddenly, but the mechanical input will remain same. It is represented by point 'd' on P_{e3} curve.

→ Due to moment of inertia, there will be further swinging of the angle inorder to get $\omega = \omega_s$ in critical manner i.e., up to point 'e' on P_{e3} curve.

→ During the fault condition there will be acceleration and after the fault, deceleration start, hence the speed of machine will be a max speed at fault clearing point.

→ d to e $\quad P = P_s - P_{e3}$ $\quad$ deceleration $\quad \omega < \omega_{max}$ but $\omega > \omega_s$ $\quad$ There is a deceleration, but $\omega > \omega_s$. Hence the rotor angle of machine will increased.

$= P_s - P_{m3}\sin\delta \uparrow$

$= -ve$

Calculation of 'δ_c' :-

$$\int_{\delta_0}^{\delta_{max}} P_a\, d\delta = 0 \; ; \quad \int_{\delta_0}^{\delta_c} P_a\, d\delta + \int_{\delta_c}^{\delta_{max}} P_a\, d\delta = 0 \; ; \quad \int_{\delta_0}^{\delta_c} (P_s - P_{e2})\, d\delta + \int_{\delta_c}^{\delta_{max}} (P_s - P_{e3})\, d\delta = 0$$

$$\int_{\delta_0}^{\delta_c} (P_s - P_{m2}\sin\delta)\, d\delta + \int_{\delta_c}^{\delta_{max}} (P_s - P_{m3}\sin\delta)\, d\delta = 0$$

$$\left[P_s\delta + P_{m2}\cos\delta\right]_{\delta_0}^{\delta_c} + \left[P_s\delta + P_{m3}\cos\delta\right]_{\delta_c}^{\delta_{max}} = 0$$

$$\cancel{P_s\delta_c} - P_s\delta_0 + P_{m2}\cos\delta_c - P_{m2}\cos\delta_0 + P_s\delta_{max} - \cancel{P_s\delta_c} + P_{m3}\cos\delta_{max} - P_{m3}\cos\delta_c = 0$$

$$P_s(\delta_{max} - \delta_0) + P_{m2}\cos\delta_{max} - P_{m2}\cos\delta_0 = P_{m3}\cos\delta_c - P_{m2}\cos\delta_c$$

$$= \cos\delta_c (P_{m3} - P_{m2})$$

sub radians $\quad$ sub degrees

$$\boxed{\delta_c = \cos^{-1}\left[\frac{P_s(\delta_{max} - \delta_0) + P_{m2}\cos\delta_{max} - P_{m2}\cos\delta_0}{P_{m3} - P_{m2}}\right]}$$ → electrical degrees

calculation of δ_0:-

at 'a'

$P_s = P_{e1} = P_{m1} \sin\delta_0$

$\boxed{\delta_0 = \sin^{-1}\left(\frac{P_s}{P_{m1}}\right)}$ ele. deg.

$\boxed{\delta_0 (rad) = \delta_0 \times \frac{3.14}{180}}$

calculation of 'δ_{max}':-

at 'e'

$P_s = P_{e3} = P_{m3} \sin\delta_{max}$

$\delta_{max} = \sin^{-1}\left(\frac{P_s}{P_{m3}}\right)$

Any "$\sin^{-1}$" is $\leq 90°$

$P_s = P_{m3} \sin(180 - \delta_{max})$

→ In a critically stable condition, the maximum swinging angle can go beyond 90° inorder to get $\omega = \omega_s$.

$\frac{P_s}{P_{m3}} = \sin(180 - \delta_{max})$

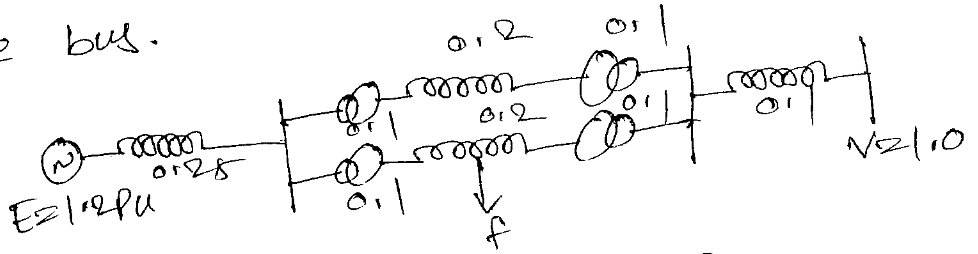
$\sin^{-1}\left(\frac{P_s}{P_{m3}}\right) = 180 - \delta_{max}$

$\boxed{\delta_{max} = 180 - \sin^{-1}\left(\frac{P_s}{P_{m3}}\right)}$ ele. deg

$\boxed{\delta_{max} (rad) = \delta_{max} \times \frac{3.14}{180}}$

~~page 62~~ Pb

→ Calculate the critical clearing angle for a fault occurs at the middle of the line for ~~above~~ below diagram where the alternator is delivering initially 1.0 PU power to the infinite bus.



$P_{m1} = 2.18$

$P_{m2} = 0.61$

$P_{m3} = 1.6$

$P_s = P_{e1} = 1.0$

$\delta_0 = \sin^{-1}\left(\frac{P_s}{P_{m1}}\right)$

$= \sin^{-1}\left(\frac{1.0}{2.18}\right) \to 27.3$

$\delta_0 (rad) = 27.3 \times \frac{3.14}{180}$

$= 0.476$

$$\delta_{max} = 180 - \sin^{-1}\left(\frac{P_s}{P_{m3}}\right) = 180 - \sin^{-1}\left(\frac{1.0}{1.6}\right) = 141.3$$

$$\delta_{max}(rad) = 141.3 \times \frac{3.14}{180} = 2.46$$

$$\therefore \delta_c = \cos^{-1}\left[\frac{P_s(\delta_{max} - \delta_0) + P_{m3}\cos\delta_{max} - P_{m2}\cos\delta_0}{P_{m3} - P_{m2}}\right] \text{ ele.deg}$$

$$= \cos^{-1}\left[\frac{1.0(2.46 - 0.476) + 1.6\cos 141.3 - 0.61\cos 27.3}{1.6 - 0.61}\right] \text{ ele.deg}$$

$$= 78.5 \text{ ele deg}$$

Pg 62

6) $P_s = P_{e1} = 1.0$

$P_{m2} = 0.4$

$P_{m1} = 1.75$

$P_{m3} = 1.25$

$$\delta_c = \cos^{-1}\left[\frac{P_s(\delta_{max} - \delta_0) + P_{m3}\cos\delta_{max} - P_{m2}\cos\delta_0}{P_{m3} - P_{m2}}\right] \text{ ele deg}$$

$$\delta_0 = \sin^{-1}\left(\frac{P_s}{P_{m1}}\right) = \sin^{-1}\left(\frac{1.0}{1.75}\right) = 34.85$$

$$\delta_0(rad) = 34.85 \times \frac{3.14}{180} = 0.608$$

$$\delta_{max} = 180 - \sin^{-1}\left(\frac{P_s}{P_{m3}}\right) \Rightarrow 180 - \sin^{-1}\left(\frac{1.0}{1.25}\right) \Rightarrow 126.86$$

$$\delta_{max}(rad) = 126.86 \times \frac{3.14}{180} = 2.21$$

$$\therefore \delta_c = \cos^{-1}\left[\frac{1.0(2.21 - 0.608) + 1.25\cos(2.21) - 0.4\cos(0.608)}{1.25 - 0.4}\right] \text{ ele deg}$$

$$= 51.9 \text{ ele deg}$$

Pg - 62

7) $P_s = 1.0$

$P_{m1} = 1.736$

$X_{1eq} = 0.72 \rightarrow$ before fault

$X_{2eq} = 3.0 \rightarrow$ with fault

$X_{3eq} = 1.0 \rightarrow$ after fault

$P_{m2} = \gamma_1 P_{m1}$ $\qquad$ $P_{m3} = \gamma_2 P_{m1}$

$= \frac{X_1}{X_2} P_{m1}$ $\qquad$ $= \frac{X_1}{X_3} P_{m1}$

$= \frac{0.72}{3.0} \times 1.736$ $\qquad$ $= \frac{0.72}{1.0} \times 1.736$

$= 0.41664$ $\qquad$ $= 1.24992$

$\therefore \delta_c =$

pg 62

8) $P_s = P_{e1} = 0.4 P_{m1}$ PU $\qquad$ $P_{m2} = \gamma_1 P_{m1}$

$X_2 = 6 X_1$ PU $\qquad$ $P_{m2} = \frac{X_1}{6X_1} P_{m1}$

$P_{m3} = 0.8 P_{m1}$ $\qquad$ $P_{m2} = 0.167 P_{m1}$

$\delta_0 = \sin^{-1}\left(\frac{P_s}{P_{m1}}\right) = \sin^{-1}\left(\frac{0.4 P_{m1}}{P_{m1}}\right) = 23.57$

$\delta_0(rad) = 23.57 \times \left(\frac{3.14}{180}\right) = 0.411$

$\delta_{max} = 180 - \sin^{-1}\left(\frac{P_s}{P_{m3}}\right) = 180 - \sin^{-1}\left(\frac{0.4 P_{m1}}{0.8 P_{m1}}\right) = 150$

$\delta_{max}(rad) = 150 \times \frac{3.14}{180} = 2.62$

$$\therefore \delta_c = \cos^{-1}\left[\frac{P_s(\delta_{max} - \delta_0) + P_{m3}\cos\delta_{max} - P_{m2}\cos\delta_0}{P_{m3} - P_{m2}}\right] \text{ ele deg}$$

$$= \cos^{-1}\left[\frac{0.4 P_{m1}(2.62 - 0.411) + 0.8 P_{m1}\cos 150 - 0.167 P_{m1}\cos 23.57}{0.8 P_{m1} - 0.167 P_{m1}}\right]$$

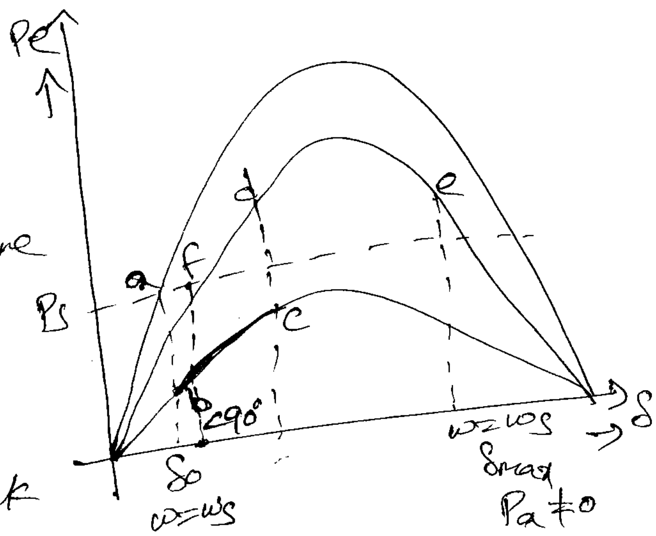
$$= \cos^{-1}\left[\frac{0.4(2.62 - 0.411) + 0.8\cos 150 - 0.167\cos 23.57}{0.8 - 0.167}\right] \text{ ele deg}$$

$= 86.58$ ele deg

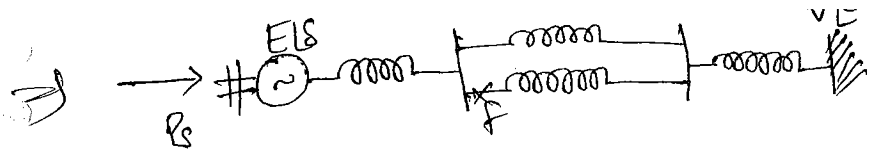
→ for a given synchronous M/c, the critical clearing angle is calculated by considering a critically stable condition. However inorder to maintain the stability, the actual angle made by rotor should be less than critical angle, otherwise the synchronous M/c will become unstable.

If actual angle = critical angle
= 86.58 ele deg

The syn M/c is swinging after the fault is clear up to the critical point inorder to get $\omega = \omega_s$ and $P_a = 0$. Hence the synchronous machine will come to a steady state condition at ≥ without any further oscillation. In a steady state condition the angle should not be more than 90°. Hence the synchronous machine is unstable



→ If the actual angle < critical angle,
critical angle is reference angle for us.
there will be a swinging of machine after fault in order to get $\omega = \omega_s$ but $P_a \neq 0$, hence the synchronous machine will swing back and it can make a further oscillations. After completing the oscillations the machine will on P_{e_3} curve. be stable at 'f', where the angle is < 90°.



P_s = mechanical input

$P_{e1} = P_{m1} \sin\delta_0$

Electrical output before fault

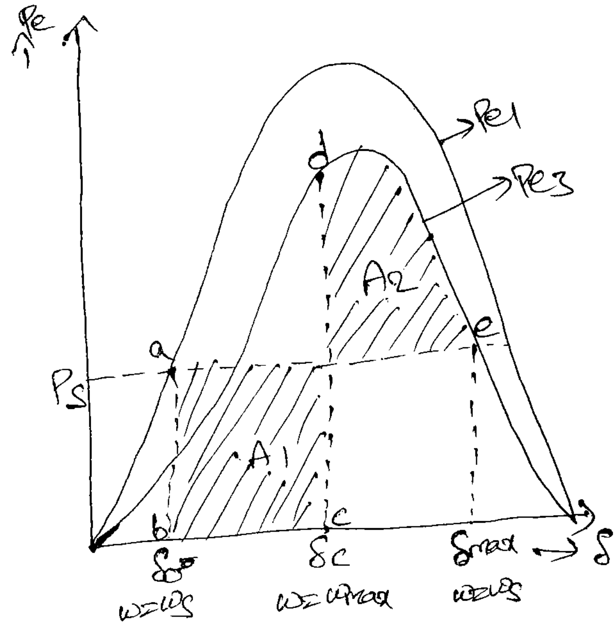
$P_{e2}=0, P_{m2}=0$

electrical output during fault

$P_{e3} = P_{m3}\sin\delta$

electrical output after fault

$\boxed{X_{3eq} > X_{1eq}}$ $\boxed{P_{m3} < P_{m1}}$



→ The synchronous generator is supplied with mechanical input of — at the ē i/p of P_{e1}, it is represented by point 'a' on 'P_{e1}' curve.

→ A 3-ϕ SC occurs in one of the transmission line near to bus bar. It will be assumed as fault on bus, because the voltage of fault point is same as bus voltage. Hence the electrical output will be zero. But the mechanical input will remain same. It is represented by point 'b' on δ-axis. Hence

$P = P_s - P_{e2}$ ($\because P_{e2}=0$)

$P = P_s$

$= +ve$

acceleration

$\omega > \omega_s$

→ Due to acceleration $\omega > \omega_s$, the rotor angle will increase so that the swinging of m/c is taking place from 'b' and it will be continue till the fault is cleared by the circuit breaker after few cycles. It is assumed that the fault is cleared by breaker at 'c' and corresponding angle is δ_c with an assemption that equal area criteria is critically stable.

→ b to c

$P = P_s - P_{e2}$
$= P_s - 0$
$= P_s$
$= +ve$

acceleration

$\omega > \omega_s$

'δ' will increase, rotor angle of M/c will increased slowly.

→ Though it is assumed as bus bar but it is a line fault so that the faulty line will be isolated, by circuit breaker which will result as the electrical o/p will increase suddenly due to change in reactance. It is represented by point 'd'. The mechanical input will remain same. Due to moment of inertia, the rotor angle will increase further inorder to get $\omega = \omega_s$ in a critical stable manner i.e., upto point 'e' on P_{e3} curve

→ d to e

$P = P_s - P_{e3}$
$= P_s - P_{m3}\sin\delta \uparrow$
$= -ve$

deceleration

$\omega < \omega_{max}$ but $\omega > \omega_s$

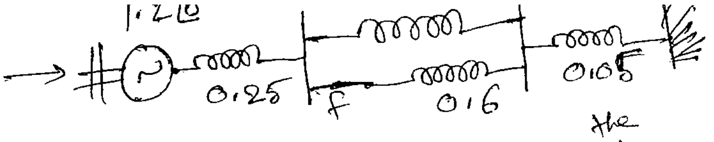
There is a deceleration but $\omega > \omega_s$. Hence the rotor angle of system will increase further.

Calculation of δ_c :-

$$\int_{\delta_0}^{\delta_{max}} P_a \, d\delta = 0 \; ; \quad \int_{\delta_0}^{\delta_c} P_a \, d\delta + \int_{\delta_c}^{\delta_{max}} P_a \, d\delta = 0 \; ; \quad \int_{\delta_0}^{\delta_c} (P_s - P_{e2}) \, d\delta + \int_{\delta_c}^{\delta_{max}} (P_s - P_{e3}) \, d\delta = 0$$

$$\int_{\delta_0}^{\delta_c} P_s \, d\delta + \int_{\delta_c}^{\delta_{max}} (P_s - P_{m3}) \, d\delta = 0$$

$$\boxed{\delta_c = \cos^{-1}\left[\frac{P_s\overbrace{(\delta_{max} - \delta_0)}^{rad} + P_{m3}\overbrace{\cos\delta_{max}}^{deg}}{P_{m3}}\right] \text{ ele deg}}$$



A 3-ϕ fault occurs one of the line near to bus bar. They alternate is delivering initially 1.0 pu power to the infinite bus. Calculate the critical clearing angle & also the critical clearing time

$P_s = P_{e1} = 1.0$

$P_{m1} = \frac{EV}{X_{1eq}} = \frac{1.2 \times 1.0}{0.25 + \frac{0.6}{2} + 0.05} = 2.0$

$P_{m2} = 0$

$P_{m3} = \frac{EV}{X_{3eq}} = \frac{1.2 \times 1.0}{0.25 + 0.6 + 0.05} = 1.33$

$\delta_0 = \sin^{-1}\left(\frac{P_s}{P_{m1}}\right) = \sin^{-1}\left(\frac{1.0}{2.0}\right) = 30^\circ$

$\delta_0(\text{rad}) = 30 \times \frac{3.14}{180} = 0.52$

$\delta_{max} = 180 - \sin^{-1}\left(\frac{P_s}{P_{m3}}\right) \Rightarrow 180 - \sin^{-1}\left(\frac{1.0}{1.33}\right) \Rightarrow 131.24$

$\delta_{max}(\text{rad}) = 131.24 \times \frac{3.14}{180} = 2.28$

(i) $\delta_c = \cos^{-1}\left[\frac{P_s(\delta_{max} - \delta_0) + P_{m3}\cos\delta_{max}}{P_{m3}}\right]$ ele deg

$= \cos^{-1}\left[\frac{1.0(2.28 - 0.523) + 1.33\cos 131.24}{1.33}\right]$

$\boxed{\delta_c = 48.38}$

(ii) conversion of critical clearing angle into critical clearing time:-

$M\frac{d^2\delta}{dt^2} = P_s - P_{e1} = P_s$

$\frac{d^2\delta}{dt^2} = \frac{P_s}{M} = \alpha$

$\frac{d\delta}{dt} = \frac{P_s}{M} \cdot t$

$$\delta = \frac{P_s}{M} \cdot \frac{t^2}{2} + A$$

the acceleration is there during the fault so that the corresponding time is consider as critical clearing time.

$$\delta_c = \frac{P_s}{M} \frac{t_c^2}{2} + A$$

use the initial condition, if $t_c = 0$ before critical clearing time

$\delta_c = \delta_0$; $\delta_0 = 0 + A$

$\delta_0 = A$

$$\delta_c = \frac{P_s}{M} \cdot \frac{t_c^2}{2} + \delta_0$$

$$\delta_c - \delta_0 = \frac{P_s}{M} \cdot \frac{t_c^2}{2}$$

rad

rad

$$t_c = \sqrt{\frac{2M(\delta_c - \delta_0)}{P_s}} \text{ sec}$$

→ consider the inertia constant of syn m/c is 5 MJ/MVA

$\delta_0 = 30°$

$\delta_0 \text{(rad)} = 0.523$

$\delta_c = 48.38$

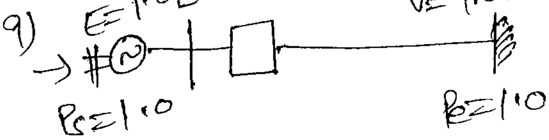
$\delta_c \text{(rad)} = 48.38 \times \frac{3.14}{180} \Rightarrow 0.84$

$M = \frac{SH}{\pi f} = \frac{1.0 \times 5}{3.14 \times 50}$ [S is PU value so we will take S = 1.0]

$$t_c = \sqrt{\frac{2 \times \frac{1.0 \times 5}{3.14 \times 50}(0.84 - 0.523)}{1.0}} \text{ se}$$

$$\boxed{t_c = 0.143 \text{ sec} = 143 \text{ msec}}$$

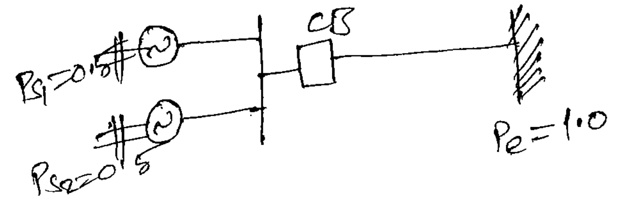
9) $E = 1.0\angle\delta$ $\quad V = 1.0\angle 0$



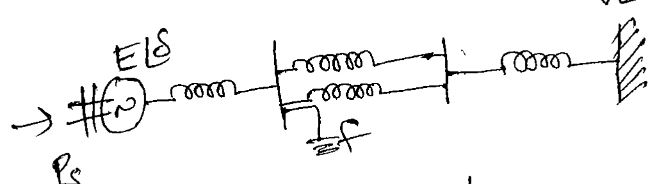
$$t_c = \sqrt{\frac{2M(\delta_0 - \delta_c)}{P_s}}$$

$t_c \propto \sqrt{M}$

Ans-(d)



Fault on bus bar:-



P_s = mechanical input

$P_{e1} = P_{m1} \sin\delta_0$

electrical output before fault

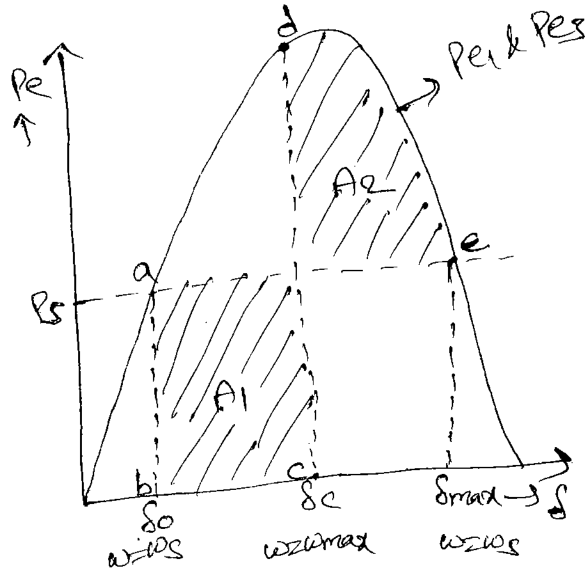
$P_{e2} = 0, \; P_{m2} = 0$

electrical output during fault

$P_{e3} = P_{m3} \sin\delta$

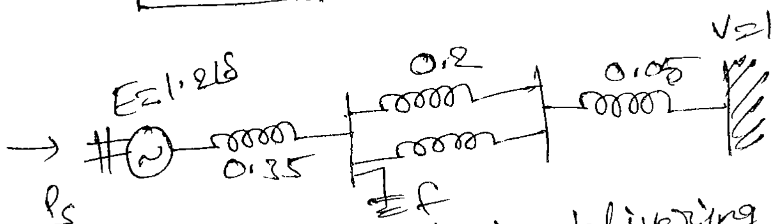
electrical output after fault

$\boxed{X_{3eq} = X_{1eq}}$ $\quad \boxed{P_{m3} = P_{m1}}$



$$\delta_c = \cos^{-1}\left[\frac{P_s(\delta_{max} - \delta_0) + P_{m3}\cos\delta_{max}}{P_{m3}}\right] \text{ ele. deg}$$

$\boxed{P_{m3} = P_{m1}}$



→ The synchronous generator is connected infinite bus through a ||el TL. It is delivering 1 pu to the infinite bus. A SC occurs on the bus bar. Calculate the critical clearing angle of the system and also critical clearing time, if the inertia constant is 4 MJ/MVA

$P_s = P_{e1} = 1.0$

$P_{m1} = \dfrac{1.2\times 1.0}{0.35+\frac{0.2}{2}+0.05} = 2.4$

$P_{m2} = 0$

$P_{m3} = P_{m1} = 2.4$

$\delta_0 = \sin^{-1}\left(\dfrac{P_s}{P_{m1}}\right) = \sin^{-1}\left(\dfrac{1.0}{2.4}\right) = 24.62$

$\delta_0 (rad) = 24.62 \times \dfrac{3.14}{180} = 0.429$

$\delta_{max} = 180 - \sin^{-1}\left(\dfrac{P_s}{P_{m1}}\right) = 180 - \sin^{-1}\left(\dfrac{1.0}{2.4}\right) = 155.3$

$\delta_{max} (rad) = 155.3 \times \dfrac{3.14}{180} = 2.71$

$\delta_c = \cos^{-1}\left[\dfrac{P_s(\delta_{max}-\delta_0) + P_{m3}\cos\delta_{max}}{P_{m3}}\right]$ ele deg

$= \cos^{-1}\left[\dfrac{(2.71-0.429) + 2.4\cos 155.3}{2.4}\right]$

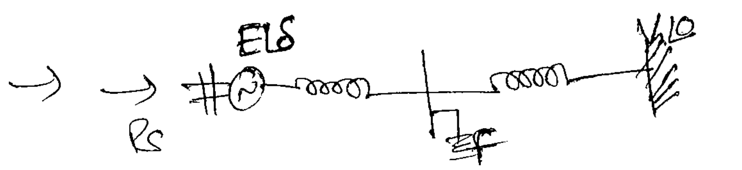
$= 87.63$

$\delta_c (rad) = 87.63 \times \dfrac{3.14}{180} = 1.52$

$t_c = \sqrt{\dfrac{2M(\delta_c-\delta_0)}{P_s}} = \sqrt{\dfrac{2\times\frac{SH}{\pi f}(\delta_c-\delta_0)}{P_s}}$

$= \sqrt{\dfrac{2\times\frac{1.0\times 4}{3.14\times 50}(1.52-0.429)}{1.0}}$

$= 0.236$ sec $= 236$ msec.



synchronous generator connected to ~~transmission line~~ infinite bus through a loss less line

P_s = mechanical input

$P_{e1} = P_{m1} \sin\delta_0$

$P_{e2} = 0$, $P_{m2} = 0$

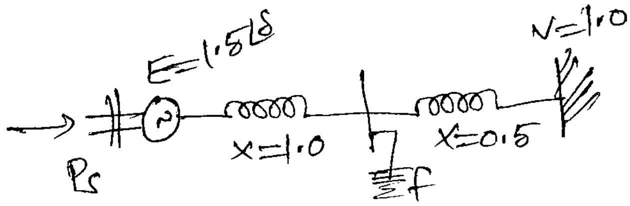
$P_{e3} = P_{m3} \sin\delta$

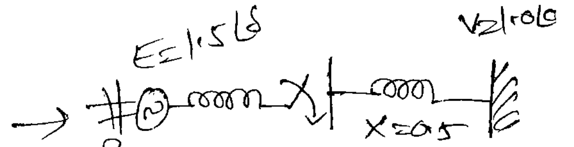
synchronous generator is connected to infinite bus through a loss less line.

$P_{m3} = P_{m1}$ $\quad X_{3eq} = X_{1eq}$

$$\delta_c = \cos^{-1}\left[\frac{P_s(\delta_{max}-\delta_0) + P_{m3}\cos\delta_{max}}{P_{m3}}\right] \text{ ele deg.}$$

→ A synchronous generator is delivering initially 0.5 pu to the infinite bus through a loss less line. The excitation voltage is 1.5 PU and infinite bus voltage is 1.0 PU. The generator reactance is 1.0 and line reactance is 0.5. A sc fault occurs on the bus bar. It is cleared by breaker at t=tc. The circuit breaker of alternator is close so that the entire n/w is restore. Calculate critical clearing angle at t=tc





$P_s = P_{e1} = 0.5$

$P_{m1} = \frac{EV}{X_{1eq}} = \frac{1.5\times1.0}{1.5} = 1$

$P_{m2} = 0$

$P_{m3} = P_{m1} = 1.0$

$\delta_0 = \sin^{-1}\left(\frac{P_s}{P_{m1}}\right) = \sin^{-1}\left(\frac{0.5}{1}\right) = 30°$

$\delta_0(\text{rad}) = 30\times\frac{3.14}{180} = 0.523$

$\delta_{max} = 180 - \sin^{-1}\left(\frac{P_s}{P_{m3}}\right) = 180 - \sin^{-1}\left(\frac{0.5}{1}\right) = 150°$

$\delta_{max}(rad) = 150 \times \frac{3.14}{180} = 2.617$

$$\delta_c = \cos^{-1}\left[\frac{P_s(\delta_{max} - \delta_0) + P_{m3}\cos\delta_{max}}{P_{m3}}\right] \text{ ele deg}$$

$$= \cos^{-1}\left[\frac{0.5(2.617 - 0.523) + 1.0\cos 150}{1.0}\right]$$

$$= 79.5^\circ.$$

Pg-71

3) $P_s = P_{e1} = 1.0$

$P_{m1} = 2.0$, $P_{m3} = 2.0$

$\delta_{max} = 110^\circ$

$\delta_{max}(rad) = 110 \times \frac{3.14}{180} = 1.91$

$\delta_0 = \sin^{-1}\left(\frac{P_s}{P_{m1}}\right) = \sin^{-1}\left(\frac{1}{2}\right) = 30^\circ$

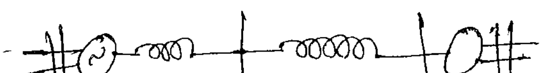
$\delta_0(rad) = 30 \times \frac{3.14}{180} = 0.523$

$$\delta_c = \cos^{-1}\left[\frac{1.0(1.91 - 0.523) + 2.0\cos 110}{2.0}\right]$$

$\delta_c = 69.14$

Pg-73

12)



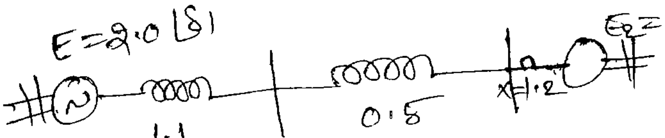
$$M\frac{d^2\delta}{dt^2} = P_a = P_s - P_{e2} = 1.0 - 0.6 = 0.4$$

$\frac{d^2\delta}{dt^2} \to \alpha$

$$\alpha = \frac{0.4}{M} = \frac{0.4}{\left(\frac{SH}{\pi f}\right)} = \frac{0.4}{\left(\frac{1.0 \times \frac{6 \times 4}{10}}{180 \times 50}\right)} \Rightarrow 1500^\circ/sec^2.$$

Pg-71

1)



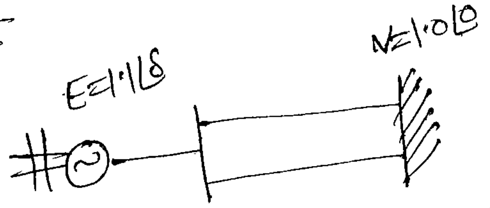
$$P_s = P_e = 0.5 = \frac{E_1 E_2}{X_{1eq}} \cancel{\sin\delta} \cdot \sin(\delta_1 - \delta_2)$$

$$0.5 = \frac{2.0\times 1.3}{2.8} \sin(\delta_1 - \delta_2)$$

$$\delta_1 - \delta_2 = 32$$

Pg-72

6)



$\delta_0 = 30°$

$P_s = P_{e1} = 1.0$

$y_{2eq} = 0.8$

$x_{2eq} = \frac{1}{0.8} = 1.25$

$P_a = P_s - P_{e2}$

$= P_s - \frac{EV}{x_{2eq}} \sin\delta_0$

$= 1.0 - \frac{1.1\times1.0}{1.25} \times \sin 30°$

$= 0.56$ PU

7) $P_a = \cancel{X}\,0$

$P_a = X\,PU = M\frac{d^2\delta}{dt^2}$

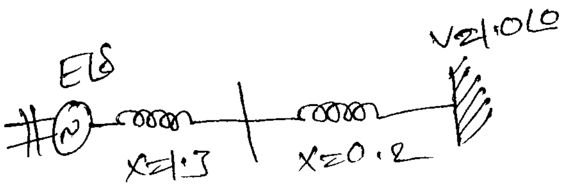
$\frac{d^2\delta}{dt^2} = \frac{X\,PU}{M} = \alpha$

$\alpha = \frac{X\,PU}{\left(\frac{SH}{180f}\right)} = \frac{X\,PU}{\left(\frac{1.0\times5}{180\times50}\right)} = 1800\,X\,PU$

$M = \frac{SH}{180f} = \frac{100\times5}{180\times50} = 0.05$

Pg-64

16)



$P_e = P_m \sin\delta$

$P_{max} = \frac{EV}{X_{eq}}$

$1.2 = \frac{E\times1.0}{1.5}$

$E = 1.2\times1.5 \Rightarrow 1.8$

Pg-65

11) $S = 20$ MVA

$H = 9$ kW-sec / kVA

$= 9$ kJ / kVA $\Rightarrow$ 9 MJ/MVA

$$H = \frac{KE \cdot S}{S}$$

$$KES = H \cdot S = 20 \times 9 = 180$$

$P_e = 16000$ kw

$P_s = 26800$ mHP

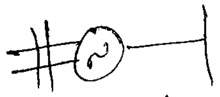
$$P_a = P_s - P_e \Rightarrow 26800 \times 0.735 - 16000 \Rightarrow 3698 \text{ kw}$$

$$P_a = T_a \cdot \omega_s \Rightarrow T_a \cdot \frac{2\pi N_s}{60}$$

$$T_a = \frac{P_a \times 60}{2\pi N_s} = \frac{3698 \times 60}{2 \times 3.14 \times 1500} \Rightarrow 23.5 \text{ KN-m}$$

pg-71

4)



500 MVA

0.8 Pf

Real power = 400 MW

$P_s = P_{e1} = 400$ MW

Fault

$$P_{e2} = 0.4 \times P_{e1} = 0.4 \times 400 = 160 \text{ MW}$$

$$P_a = P_s - P_{e2} = T_a \omega$$

$$400 - 160 = T_a \cdot \frac{2\pi N_s}{60}$$

$$T_a = \frac{(400-160) \times 60}{2 \times 3.14 \times 1500} \Rightarrow 1.528 \text{ MN-m.}$$

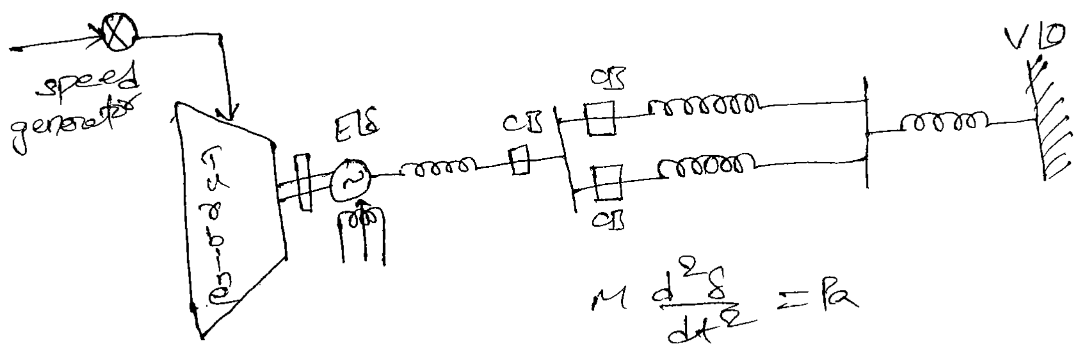
No pending

Methods to improve the Transient stability:

$$M \frac{d^2\delta}{dt^2} = P_a$$

$$A_1 < A_2$$

→ The methods which are suggested should results as the acceleration of the syn m/c will reduce. so that $A_1 < A_2$ and syn m/c is stable.



$$M \frac{d^2\delta}{dt^2} = P_a$$

i) selection of 'M' value $\qquad \frac{d^2\delta}{dt^2} = \frac{P_a}{M} = \alpha$

ii) speed of operation of CB (Time of operation)

iii) speed of operation of governer

iv) response of the excitation.

i) selection of 'M' value:-

→ If moment of inertia is high, the angular acceleration will be less. so that the swinging of m/c is less and area covered will be reduced. so that the syn m/c is stable.

→ The modern PS n/w is preferred have larger size of generators i.e., 500 MW and above.

ii) speed of operation of circuit breaker:-

→ If the time of operation of CB is less, the speed of operation of CB is high. The area covered during acceleration will be reduced so that syn m/c is stable. Hence it is prefer to install high speed CB i.e., SF6 CB.

→ Modern PS n/w is preferred have SF6 circuit breakers because the time of operation of CB is less i.e., the arc can ray at faster way due to the electro -ve characteristic i.e., it can observe the $\bar{e}$ at faster way.

iii) speed of operation of speed governor:-

$$P = P_s - P_{e2}\downarrow$$
$$= +ve$$
$$= acc\downarrow$$

→ If a short circuit occurs in one of the TL, electrical output will be reduced but the mechanical input is assumed as constant so that the syn m/c experience is acc. Inorder to reduce the acc, the mechanical input will be reduced. i.e., The time of operation of speed governor should be reduced. In order to reduce the time of operation, the speed governor should be design with electronic devices rather than mechanical system.

iv) Response of the excitation:-

$$P_{e2} = \frac{\downarrow E V}{X_{2eq}} \sin\delta$$

→ The nature of short circuit current is purely inductive which will result as the excitation voltage of alternator will be reduce. so that the electrical output will be reduced i.e., P_e.

Hence the acceleration

In order to reduce the excitation the fault in the excitation, for which voltage is in compensated. By compensating inductive current the capacitive nature of current is to be injected with help of excitation of alternator by changing excitation at a faster way i.e., fast excitation control are employed.

→ The series capacitor which is used for steady state stability is also useful for transient stability by reducing reactance of the so that the maximum power transfer will be increased. Hence electrical o/p increased and stability of syn m/c will maintain by reducing the acceleration.

methods to improve the Transient stability during unbalanced or unsymmetrical faults:-

→ which of the fault is more severe on synchronous generator terminal

a) L-G ✓ b) L-L-L c) L-L-G d) L-L

TL

$X_2 = X_1$

$X_0 = 3X_1$

L-G

$$I_f = \frac{3E_{R1}}{X_1 + X_2 + X_0} = \frac{3 \times 1.0}{X_1 + X_1 + 3X_1} = \frac{3.0}{5X_1} = \frac{0.6}{X_1}$$

L-L-L

$$\uparrow I_f = \frac{E_{R1}}{X_1} = \frac{1.0}{X_1}$$

cylindrical rotor

$X_2 = X_d''$

$X_0 << X_d''$ (leakage reactance)

$X_0 \simeq (10-20\%)$ of X_1

$X_0 \simeq 0.2X_1$

L-G

$$I_f = 3 \times \frac{E_{R1}}{x_{1eq} + x_{2eq} + x_{0eq}} = \frac{3\times 1.0}{X_d'' + X_d'' + 0.2X_d''}$$

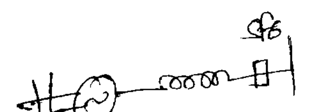
$$= \frac{3.0}{2.2X_d''} = \frac{1.36}{X_d''}$$

L-L-L

$$I_f = \frac{E_{R1}}{x_{1eq}} = \frac{1.0}{X_d''}$$

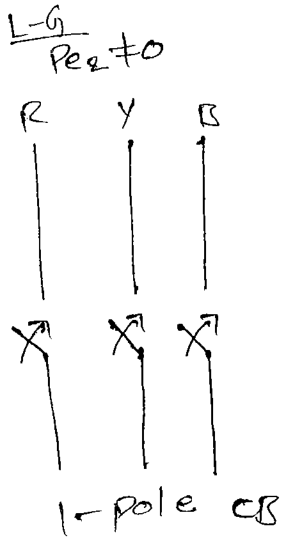
→ In TL the zero sequence reactance will 3 times +ve sequence reactance so that the line to ground fault will be less severe when compared to 3-φ fault.

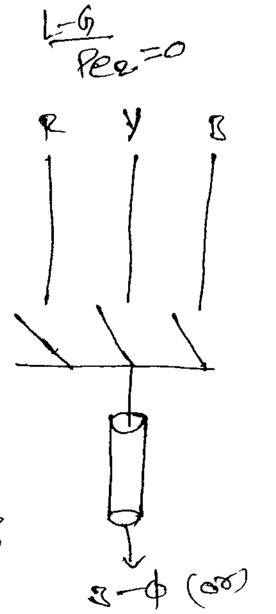
→ In case of syn gen the zero sequence reactance will be very less when compared to +ve sequence reactance so that the line to ground fault will more severe when compared to 3-φ fault.

→ 

i) use "1-pole" CB operations.

ii) use 3-pole CB operations.

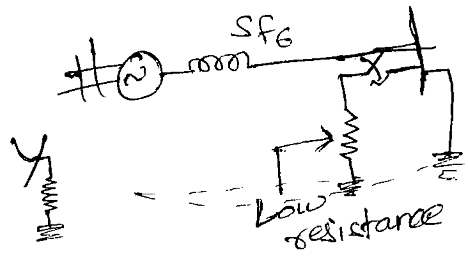




→ In order to maintain the stability for a line to ground fault, it is prefered has 1-φ CB even though the cost of the CB is high.

~~→ over dynamic res~~

ii) use dynamic resistance switching



$P = P_s - P_{e2}$

$= P_s - (P_{e2} + I_{sc}^2 R)$

$=$ acc $\downarrow$

→ If a L-G fault occurs on the terminal, the resistance will be connected to bus with help of a switching device so that the sc current will be allow thorough resistan There will be a real power loss in resistor which will result as the electrical input will increase during fault and acc will reduce so that the stability will improv

→ It is difficult to switch on the dynamic resistance as 'on' when fault occurs. However the nutral of generator is connected to ground through a resistance. In order to improve Transient stability.

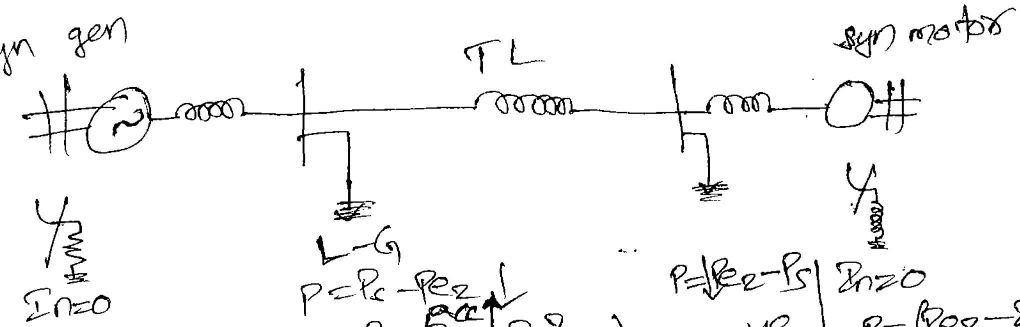
$P = P_s - P_{e2}$ I_n^2

$= P_s - (P_{e2} + I_n^2 R_n)$

$=$ acc $\downarrow$

→ The value of resistance of neutral should be low so that the fault current is allow to load.

Effect of Neutral grounding on Transient stability:-



$P = P_s - P_{e2}$ ↓ acc ↑

$P = P_s - (P_{e2} + I_n^2 R_n)$

$= acc$ ↓

$P = P_{e2} - P_s$

$= -ve$

$= dec$

$I_n = 0$

$P = (P_{e2} - I_n^2 R_n) - P_s$

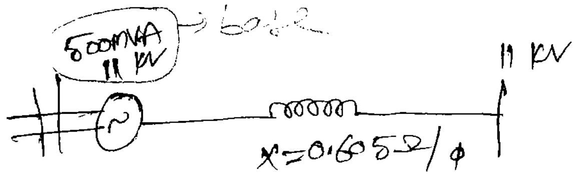
dec ↑

→ The neutral groundings are not necessary for steady state stability and also not required for faults which are not associate with ground i.e., 3-φ fault and also L-L fault. However neutral groundings are required for unsymmetrical faults i.e., L-G faults.

→ If a resistance grounding is employed, the deceleration of machine will increased, so that the m/c will become unstable. This can be overcome by using reactance grounding where the dec will not be change, but fc current will be reduced. Because the zero sequence reactance will be increased.

Pg-62

①



$E_{pu} = \frac{11}{11} = 1.0 \qquad V = \frac{11}{11} = 1.0$

$x_{pu} = x_{\Omega} \cdot \frac{MVA_b}{(kVA_b)^2} \Rightarrow 0.605 \times \frac{500}{(11)^2} \Rightarrow 2.5\Omega$

$\frac{EV}{x} = \frac{1.0 \times 1.0}{2.5} = 0.4\ PU$

pg-62

(2)

$$H_{1,New} = \frac{H_{1}\,old\; S_{1}old}{S_b} = \frac{5\times 500}{100} = 25$$

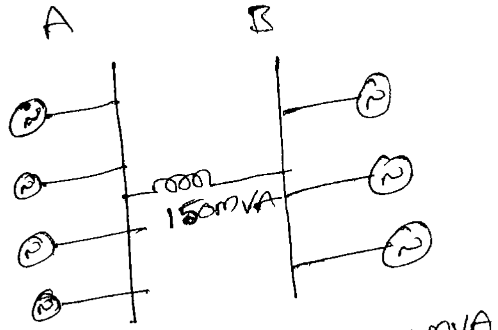
$$H_{2,New} = \frac{H_{2}old \cdot S_{2}old}{S_b} = \frac{5\times 200}{100} = 10$$

$$H_{eq} = H_{1,New} + H_{2,New}$$

$$= 25+10 \Rightarrow 35 \text{ MJ/MVA}$$

pg-62

(3)



100 MVA   200 MVA

H = 9 MJ/MVA   H = 4 MJ/MVA

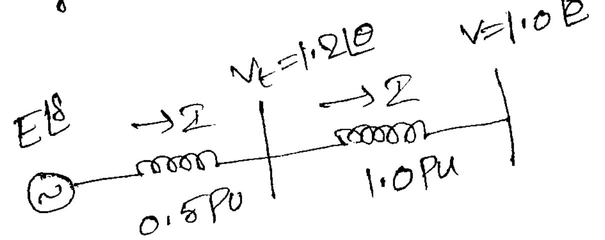
$H_{A,eq} = 36$ $H_{B,eq} = 12$

$$H_{Aeq,New} = \frac{36\times 100}{150} \Rightarrow 24 \qquad H_{Beq,New} = \frac{12\times 200}{150} \Rightarrow 16$$

$$H_{eq} = 24+16 \Rightarrow 40$$

pg-63

(10)



$$P_{max} = \frac{EV}{X_{eq}} = \frac{E\times 1.0}{1.5}$$

KVL eqn :- $E = V + I X_{eq} \Rightarrow 1.0\angle 0 + I\times 1.5\angle 90^\circ$

$$= 1.0\angle 0 + \left[\frac{1.2\angle\theta - 1.0\angle 0}{1.0\angle 90}\right]\times 1.5\angle 90$$

$$= 1.0\angle 0 + 1.8\angle\theta - 1.5$$

$$E = -0.5 + 1.8\cos\theta + j1.8\sin\theta$$

$P = P_{max}$

$\delta = \beta = \tan^{-1}\left(\frac{X}{R}\right) = 90°$

In order to get $\delta = 90°$, the real part of eqn should be zero.

$-0.5 + 1.8\cos\theta = 0$

$\theta = \cos^{-1}\left(\frac{0.5}{1.8}\right) \Rightarrow \theta = 73.87$

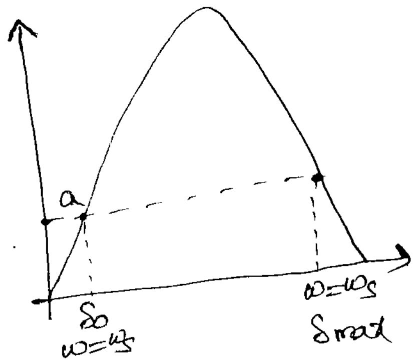
$E = 1.8 \sin 73.87 \Rightarrow 1.73 \angle 90°$

$\therefore P_{max} = \frac{1.73 \times 1.0}{1.5} \Rightarrow 1.153$

Pg-63

13) a) $P_{max} = \frac{132 \times 132}{12} \Rightarrow 1452\ MW$

b) Initially



$P_s = P_e = \frac{2}{5} P_m$

$0.4 P_m = P_m \sin\delta_0$

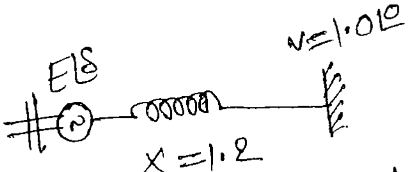
$\delta_0 = \sin^{-1}\left(\frac{0.4 P_m}{P_m}\right)$

$\delta_0 = 23.57°$

$\delta_{max} = 180 - \delta_0 \Rightarrow 180 - 23.57 \Rightarrow 156.43°$

Pg-63

12) a)



KVL

$E = V + IX$

$= 1.0\angle 0 + 1.0 \angle -36.86 \times 1.2 \angle 90$

$= 1.0\angle 0 + 1.2 \angle 90 - 36.86$

$= \cancel{1.0\angle 0 + 1.2 \angle 53.14}$

$= 1.96 \angle 29.16$

output $= VI\cos\phi$

$= 1.0 \times 1.0 \times 0.8$

$= 0.8\ PU$

$P_{max} = \frac{EV}{X} = \frac{E \times 1.0}{1.2}$

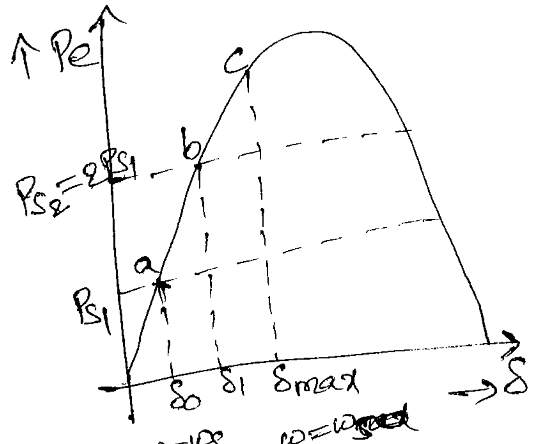
$\therefore P_{max} = \frac{EV}{X} = \frac{1.96 \times 1.0}{1.2}\ PU$

$= 1.63\ PU$

b) $E_{new} = \frac{0.8 \times 1.2}{1.0} = 0.96$ PU (∵ $E_{new} = \frac{\ }{V}$)

pg-63

14)



at 'b'

$P_{s2} = P_{e2}$

$2P_{s1} = P_m \sin\delta_1$

$2 \times 0.25 P_m = P_m \sin\delta_1$

$\delta_1 = \sin^{-1}\left(\frac{0.5 P_m}{P_m}\right)$

$\delta_1 = 30°$

pg-64

given

$H = 8$ & $S = 100$

18)

i) $KE = S \times H \Rightarrow 8 \times 100 = 800$

ii) $P_a = P_{s2} - P_{e1} \Rightarrow 80 - 50 \Rightarrow 30$

$P_a = M \frac{d^2\delta}{dt^2}$ α

$\alpha = \frac{P_a}{M} = \frac{P_a}{\left(\frac{SH}{180f}\right)} \Rightarrow \frac{30}{\left(\frac{800}{180 \times 50}\right)} \Rightarrow 337.5$ ele deg/s²

iii) 1 sec → 50 cycles

? ← 10 cycles

$\frac{10}{50} \times 1 \Rightarrow 0.2$ sec

$M \frac{d^2\delta}{dt^2} = P_a$

$\frac{d^2\delta}{dt^2} = \frac{P_a}{M} = \alpha$

$\frac{d\delta}{dt} = \alpha t$

$t \Rightarrow \Delta t$ (small)

$\omega = \alpha t$

$\Delta\omega = \alpha \cdot \Delta t$

$\left[\begin{array}{l} \omega = \frac{2\pi N}{60} \\ \Delta\omega = \frac{2\pi \Delta N}{60} \end{array}\right]$

$\frac{2\pi \Delta N}{60} = \alpha \cdot \Delta t$

$\Delta N = \frac{\alpha \Delta t \times 60}{2\pi}$

$= \frac{337.5 \times 0.2 \times 60}{2 \times 180}$

$= 11.25$ rpm

$\omega = \frac{d\delta}{dt} = \alpha t$

Int. $\delta = \alpha \cdot \frac{t^2}{2} + A$

$t \Rightarrow \Delta t$

$\Delta\delta = \alpha \frac{(\Delta t)^2}{2} + A$

use initial conditions, Before acc starts i.e., $\Delta t = 0$

$\Delta\delta = 0$ & $A = 0$

$\Delta\delta = \alpha \cdot \frac{(\Delta t)^2}{2} \Rightarrow 337.5 \times \frac{(0.2)^2}{2} \Rightarrow 6.75$ deg

Pg-64

17) $\frac{d^2\delta}{dt^2} = \frac{P_a}{M} = \alpha = \frac{20-16}{\left(\frac{SH}{\pi f}\right)} \Rightarrow \frac{20-16}{\left(\frac{20\times 9}{3.14\times 50}\right)} \Rightarrow 3.49$ rad/sec²

$\Delta\omega = \alpha \cdot \Delta t$

$= 3.49 \times 0.2 \Rightarrow 0.69$ rad/sec

$\Delta\delta = \alpha \cdot \frac{(\Delta t)^2}{2} = 3.49 \times \frac{(0.2)^2}{2} \Rightarrow 0.069$ rad

Pg-72

8) $P_s = P_{e2}$

$1.0 = \frac{EV}{X_{2eq}} \sin 130^\circ$

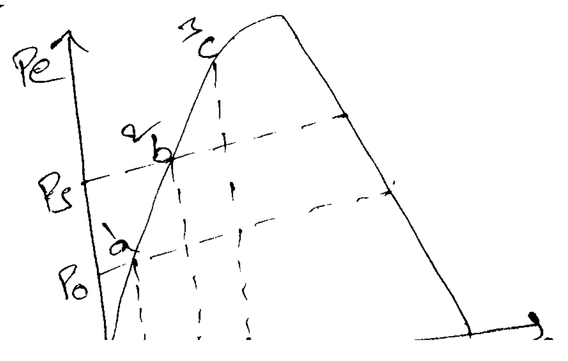
$X_{2eq} = \frac{1.0 \times 1.0}{1.0} \sin 130^\circ$

$= 0.76$ PU

$X_G + X = 0.76 - 0.1 \Rightarrow 0.66$

Pg-65

1)



$\delta_s \Rightarrow \omega = \omega_{min}$ (or) $\omega = \cancel{max}$

$\delta_{max} \Rightarrow \omega = \omega_s$

$\delta_0 \Rightarrow \omega = \omega_s$

a)

	A	B	C	D
	3	4	1	2
M ⇒	4	3	1	2

Pg-68

2) Ans — (c)

Pg-66

3) Ans — (a)

$$\alpha = \frac{P_a}{M}$$

$$\frac{d^2\delta}{dt^2} = \frac{P_a}{M} = \frac{P_s - P_e}{M} \Rightarrow P_f$$

$$= \frac{P_s - \frac{EV}{X}\sin\delta}{M}$$

Pg-~~66~~

6) Ans — (c)

Pg-66

7) same as pg-64 (18) → (iii)

Pg-67

11) Ans — (a)

Pg-67

12) Ans — (b)

Dynamic stability:-

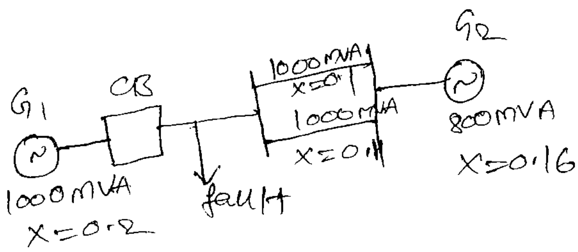
If grid failure is taking place, it is necessary to bring the units at ~~a~~ faster ~~way~~ rate inorder to restore the supply. During restoration of supply, the turbine valve opening on be done and also excitation of alternator will be also changed at a faster ~~way~~. rate.

5/10/11

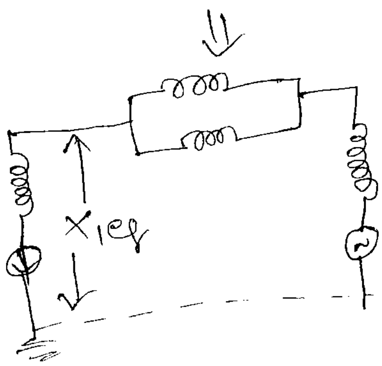
Pg-34

17)

$$SCMVA = \frac{B.MVA}{X_{1eq}} = \frac{1000}{X_{1eq}}$$



$$X_{G2} = PU\ New = 0.16 \times \frac{1000}{800} = 0.2$$



$$SCMVA = \frac{1000}{\frac{0.2 \times 0.25}{0.45}}$$

Pg-31

6) $I_f(L-G) = I_f(L-L-L)$

$I_{f\,pu} \cdot I_b = I_{f\,pu} \cdot I_b$

$$\frac{3E_{R1}}{X_1+X_2+X_0+3X_n} = \frac{E_{R1}}{X_1}$$

$$\frac{3 \times 1.0}{0.1+0.1+0.05+3X_n} = \frac{1.0}{0.1}$$

$$0.3 = 0.25 + 3X_n$$

$$X_n = \frac{0.05}{3} = 0.0167.$$

Pg-34

18) $I_f(a) = I_{f\,pu}\, I_b$

$I_{f\,pu} = 1.0$

$$1.0 = \frac{3E_{R1}}{X_1+X_2+X_0+3X_n}$$

$$0.3+0.4+0.05+3X_n = 3 \times 1.0$$

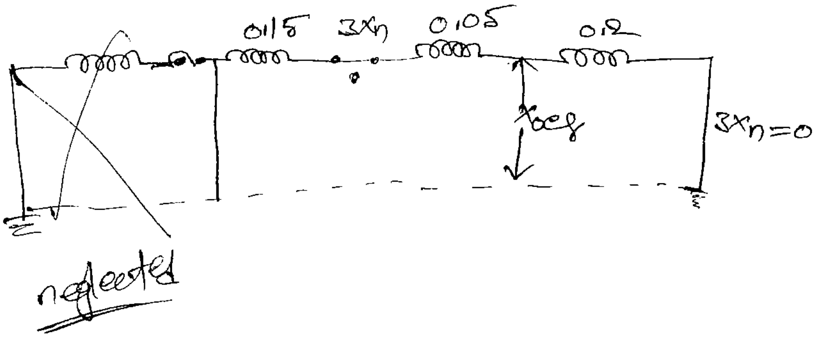
$$X_n = \frac{3-0.75}{3} \Rightarrow \frac{2.25}{3} \Rightarrow 0.75$$

$$X_{pu} = X_{\Omega} \cdot \frac{MVA_b}{(KV_b)^2}$$

$$X_{\Omega} = X_{pu} \cdot \frac{(KV_b)^2}{MVA_b}$$

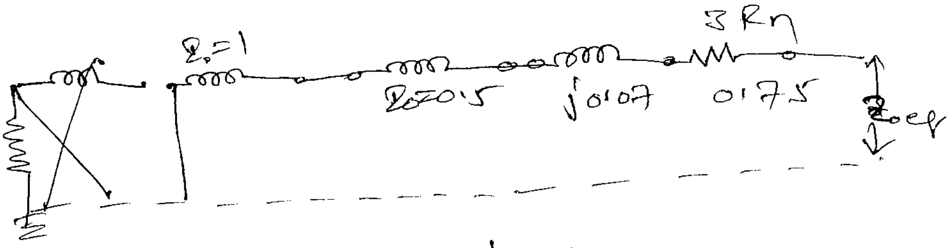
Pg-31

7) Ans – 0.1



7) pg-35

2)



$Z_{0eq} = 0.175 + j0.22$

pg-35

1) $Z_{1eq} = Z_s - Z_m = 15$

$Z_{0eq} = Z_s + 2Z_m = 48$

$-3Z_m = -33$

$Z_m = \frac{33}{3} = 11\Omega$

$Z_{1eq} = Z_s - Z_m$

$Z_s = Z_{1eq} + Z_m$

$= 15 + 11$

$= 26$

pg-32

8) $I_{a0} = \frac{1}{3}[I_a + I_b + I_c] = \frac{1}{3}[0 + 6\angle 60 + 6\angle -120]$

$= \frac{1}{3}[6\cos 60 + j6\sin 60 + 6\cos(-120) + j6\sin(-120)]$

$I_{a0} = \frac{1}{3}[6\cos 60 + j6\sin 60 + 6\cos 120 - j6\sin 120]$

$= \frac{1}{3}[6\cos 60 + j6\sin 60 + 6\cos 120 - j6\sin 120]$

$= 0$

$I_{a1} = \frac{1}{3}[I_a + kI_b + k^2 I_c] \Rightarrow \frac{1}{3}[0 + 1\angle 120 \times 6\angle 60 + 1\angle 240 \times 6\angle -120]$

$= \frac{1}{3}[6\angle 180 + 6\angle 120]$

$= \frac{1}{3}[6\cos 180 + j6\sin 180 + 6\cos 120 + j6\sin 120]$

$= \frac{1}{3}[-6 + 0 + 6(-1/2) + j6(\sqrt{3}/2)]$

$= \frac{1}{3}[-9 + j3\sqrt{3}]$

$= -3 + j\sqrt{3}$

$I_{a2} = 3 - j\sqrt{3}$

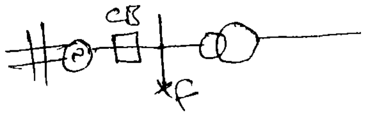
Pg-32

9) $I_{R1} = \dfrac{E_{R1}}{X_1 + X_2 + 3X_n + X_0}$

$= \dfrac{1}{0.25 + 0.25 + 3(0.05) + 0.15}$

$=$

Pg-32

10) 

$x_d'' = 19\%$ — subtransient

$x_d' = 26\%$ — Transient } +ve

$x_d = 130\%$ — SS

$I_f = I_{R1} = \dfrac{E_{R1}}{X_{1eq}} = \dfrac{1.0}{0.19} = 5.26$ PU

$I_f(a) = 5.26 \times \dfrac{110}{\sqrt{3} \times 11}$ kA $= 30.39$ kA

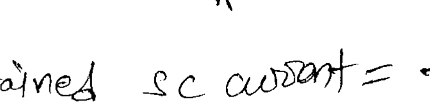
$\boxed{\text{Momentary current of the fault} = 30.39 \times 1.6}$

sustained short ckt current = steady state current

$= \dfrac{E_{R1}}{x_d} = \dfrac{1.0}{1.3} = 0.769$ PU

$= 0.769 \times \dfrac{110}{\sqrt{3} \times 11} = 0.$

P-52

25) 

i) sustained SC current $= \dfrac{E_{R1}}{x_d} = \dfrac{1.0}{1.0} = 1.0$

$= 1.0 \times \dfrac{7.5}{\sqrt{3} \times 12.0} \approx 0.313$ kA

ii) $I_f = I_{R1} = \frac{E_{R1}}{X_d''} = \frac{1}{0.09} = 11.11\ PU$

$= 11.11 \times 0.313 \Rightarrow 3.48\ KA$

iv) $3.48 \times 1.6 = 5.568$

iii) Peak value of sinusoidal current $= \sqrt{2} \times$

v) Interrupting current $= \frac{E_{R1}}{X_d'} = \frac{1.0}{0.15} \times 1.2$ (∵ dc effect thats why 1.2)

$= 8PU$

$= 8 \times 0.313\ KA \Rightarrow 2.504\ KA$

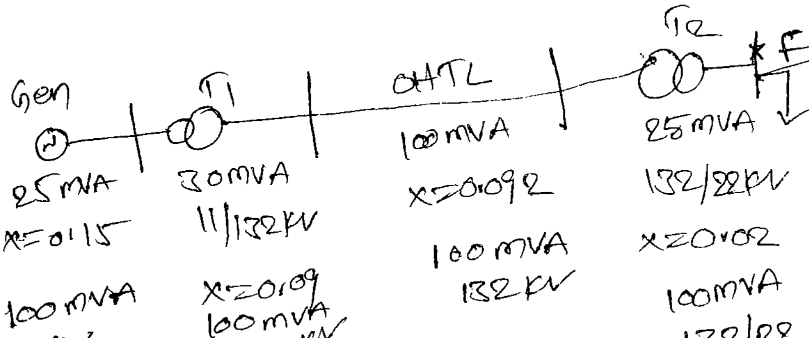
vi) Interrupting MVA $= \frac{B\,MVA}{X_d'} \times 1.2$

$= \frac{7.5}{0.15} \times 1.2 \Rightarrow 60$

$= 3 \times \frac{13.8}{\sqrt{3}} \times 8 \times 0.313 \Rightarrow 59.85$

Pg-53

26)



→ Prefault voltage $= \frac{22}{22}$

$= 1V$

$I_f = I_R = I_{R1} = \frac{E_{R1}}{X_{1eq}}$

$X_{G,new} = 0.15 \times \frac{100}{25}$

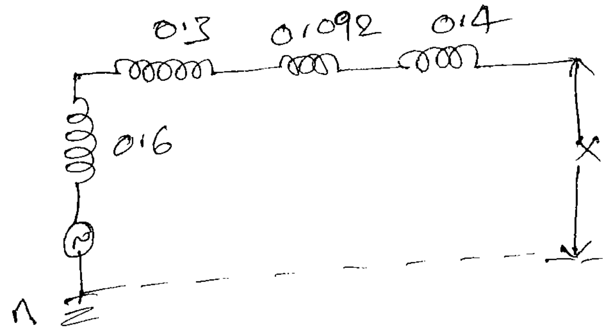
$= 0.6$

$X_{T2\,PO,new} = 0.02 \times \frac{100}{5} \times \left(\frac{132}{132}\right)^2$

$= 0.4$

$X_{T1\,PO,new} = 0.09 \times \frac{100}{30} \left(\frac{11}{11}\right)^2$

$= 0.3$



$\therefore I_f = I_R = I_{R1} = \frac{E_{R1}}{X_{1eq}} = \frac{1.0}{1.392} \Rightarrow 0.718$ PU

$I_f(a) = 0.718 \times \frac{100}{\sqrt{3} \times 22} \Rightarrow 1.88$ KA

fault apparent power =

SC MVA = $\frac{B.MVA}{X_{1eq}}$

$= \frac{100}{1.392} \Rightarrow$

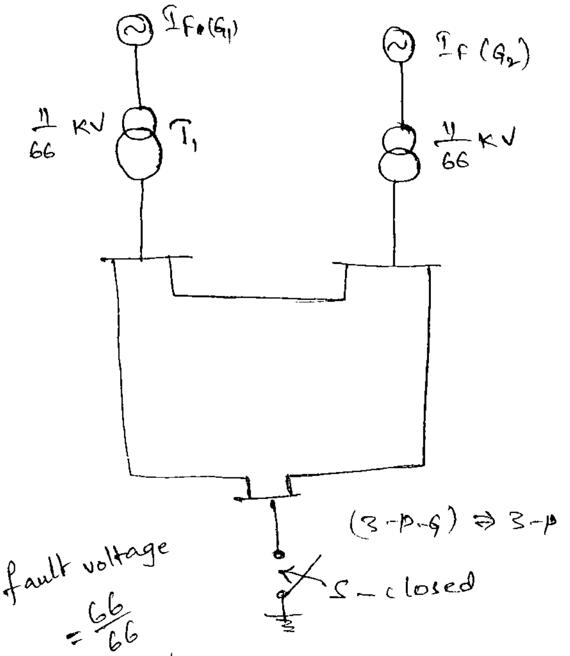
The current supplied by gen in PU → 0.718

" " " " in KA → $0.718 \times \frac{100}{\sqrt{3} \times 11}$

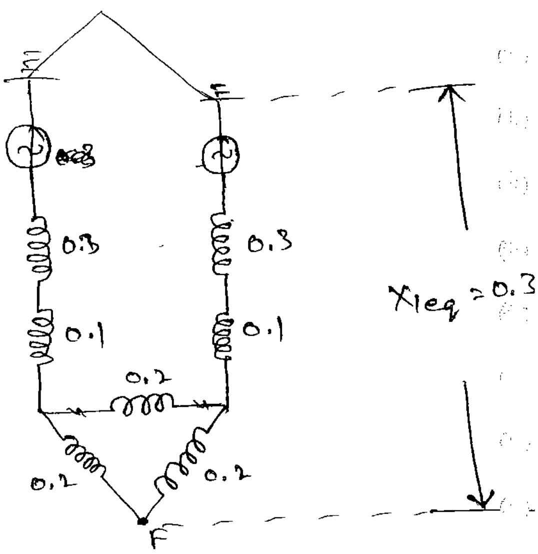
$= 3.76.$

Pg-51

19)



Pre fault voltage $= \frac{66}{66}$
$= 1.0$ V



$* \; I_F = \frac{E_{R1}}{X_{1eq}} = \frac{1.0}{X_{1eq}} = \frac{1.0}{0.3} = 3.33$ PU

$* \; I_F(a) = 3.33 \times \frac{100}{\sqrt{3} \times 66}$ KV $= 2.91$

$I_F(G_1) = I_F \times \frac{0.6}{1.2} = \frac{3.33}{2} = 1.67$ PU

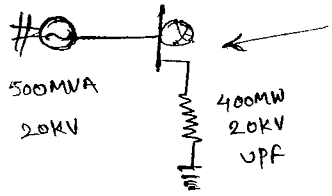
$I_F(G_1) = 1.67 \times \frac{100}{\sqrt{3} \times 11}$ KA

$\Rightarrow I_F(G_1) = 8.76$ KA

$I_F(G_2) = 1.67 \times \frac{100}{\sqrt{3} \times 11}$

$= 8.76$ KA

4) Pg. 52



Pre fault voltage $= \frac{20}{20} = 1.0$

Generator voltage $(E_G) = V_t + \text{Drop}$

$= 1.0\angle 0 + I_{pu} X_{eq}$

$= 1.0\angle 0 + I_{pu} \times 0.2\angle 90^\circ$

$= 1.0\angle 0^\circ + 0.8\angle 0^\circ \times 0.2\angle 90^\circ$

$= 1.0 + j\,0.16$

$$I_{pu} = \frac{\text{Actual Current}}{\text{Base Current}}$$

$$= \frac{400\times 10^6/(\sqrt{3}\times 20\times 10^3\times 1.0)}{\left(\frac{500\times 10^6}{\sqrt{3}\times 20\times 10^3}\right)} = 0.8\angle 0^\circ$$

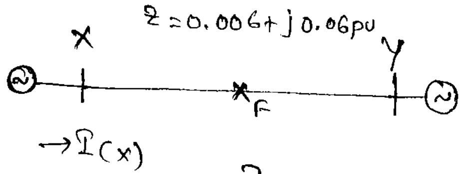
$$I_{F(G)} = \frac{1.0+j0.16}{j0.2}$$

$$= 0.8 - j5$$

$$P = \sqrt{3}\, V_L I_L \cos\phi \longrightarrow I_L = \frac{P}{\sqrt{3}\, V_L \cos\phi}$$

$$S = \sqrt{3}\, V_L I_L \longrightarrow I_L = \frac{S}{\sqrt{3}\, V_L}$$

Pg-37 8, 9, 10)



$$\frac{Z_L}{2} = 0.003 + j0.003$$

$$Z_{s1} = Z_{s2} = 0.001 + j0.001$$

9)

$$I_F = \frac{E_{R1}}{Z_{1eq}} = \frac{1.0}{\frac{0.04+j0.04}{2}} = \frac{1.0}{0.02+j0.02} = \frac{1.0\angle -84.26}{\sqrt{(0.02)^2+(0.02)^2}}$$

$= 49.75$ PU

$$I_F = 49.75 \times \frac{100}{\sqrt{3}\times 100} = 7.18\,KA$$

$$I_x = \frac{7.18}{2} = 3.59\text{ KA (RMS)}.$$

8)

50 cycles $\longrightarrow$ 1 sec

1 cycle $\longrightarrow \frac{1}{50}$

$360^\circ \longrightarrow \frac{1}{50}$

$84.3^\circ \longrightarrow$?

$$t = \frac{84.3}{360} \times \frac{1}{50} = 4.682\text{ ms}$$

10) $$I_F = \frac{3E_{R1}}{Z_{1eq} + Z_{2eq} + Z_{0eq}}$$

$$= \frac{3 \times 1.0}{0.002 + j0.02 + 0.002 + j0.02 + 0.006 + j0.06}$$

$$= \frac{3 \times 1.0}{0.01 + j0.1}$$

$$= 29.85 \text{ P.U}$$

$$I_{(x)} = \frac{29.85}{2} = 14.93 \text{ PU}$$

Pg - 51

21).

L - L - L

$$I_{F(G)} = I_{FPU} \; I_b$$

$$319 = \frac{E_{R1}}{X_{1PU}} \times I_b$$

$$319 = \frac{1.0 \times 350}{X_{1PU}}$$

$$X_{1PU} = \frac{350}{319} = 1.09 \text{ P.U}$$

L - L

$$I_{F(G)} = I_{FPU} \; I_b$$

$$I_{F(G)} = \frac{\sqrt{3} \times E_{R1}}{X_1 + X_2} \times 350$$

$$X_1 + X_2 = \frac{1.732 \times 1.0 \times 350}{435}$$

$$X_2 = (\quad) - X_1$$

$$= 0.29$$

L - G

$$I_{F(G)} = I_{FPU} \times I_b$$

$$I_{F(G)} = \frac{3 \times E_{R1}}{X_1 + X_2 + X_0} \times 350$$

$$X_1 + X_2 + X_0 = \frac{3 \times 1.0 \times 350}{659}$$

$$X_0 = (\quad 1 - X_1 - X_2$$

$$=$$

8) Pg-41

L-L-L

$I_F = I_R = I_{R1} = \frac{E_{R1}}{X_{1pu}}$

$X_{1pu} = \frac{E_{R1}}{I_F} = \frac{1.0}{-j5} = j0.2$

$X_{1\Omega} = 0.2 \times \frac{(11)^2}{50}$

L-L

$I_{R1} = \frac{E_{R1}}{X_1 + X_2}$

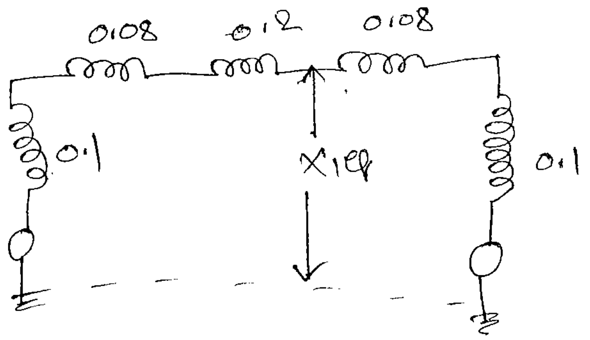
$X_1 + X_2 = \frac{1.4}{-j4} = j0.25$

$X_2 = j0.05$

$X_{2\Omega} = 0.05 \times \frac{(11)^2}{50}$

10) Pg-41

$I_F = I_R = I_{R1} = \frac{E_{R1}}{X_{1eq}} = \frac{1.0\angle 0}{\frac{(0.1+0.08+0.2)\times 0.18}{0.38+0.18}}$



$= -j8.187$

Pg-41

12) L-L

$I_{R1} = \frac{E_{R1}}{X_1 + X_2} = \frac{E_{R1}}{2X_1}$

$X_1 = \frac{E_{R1}}{2I_{R1}} = \frac{2\times 10^3}{2\times 1400} = 0.71\Omega$

$X_2 = 0.71\Omega$

L-L-G

$I_{R1} = \frac{E_{R1}}{X_1 + \frac{X_2 \cdot X_0}{X_2 + X_0}}$

$2220 = \frac{2\times 10^3}{0.71 + \frac{0.71 X_0}{0.71 + X_0}}$

Pg-44

29) Ans - LLG faults.

$V_{R0} = V_{R1} = V_{R2} = \frac{V_R}{3}$

$V_R = 3V_{R0}$

$= 3\times 0.237$

$= 0.7$

Pg-36

5,6)

5) $SCMVA = \frac{BMVA}{Z_1 PU} = \frac{\cancel{BMVA}}{Z_1 \Omega \cdot \frac{\cancel{BMVA}}{(KV)^2}}$

$$Z_1 \Omega = \frac{(KV)^2}{SCMVA}$$

$$= \frac{(220)^2}{4000} \Rightarrow 12.1\ \Omega$$

6) L-G

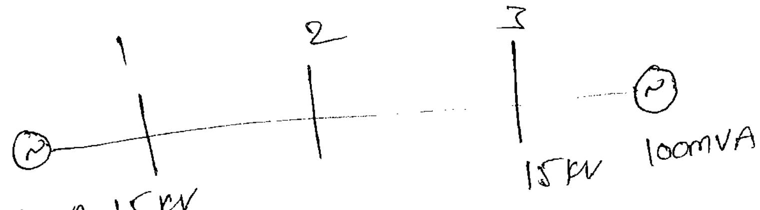
$$SCMVA = \frac{BMVA}{Z_1 PU + Z_2 PU + Z_0 PU}$$

$$= \frac{\cancel{BMVA}}{(Z_1 \Omega + Z_2 \Omega + Z_0 \Omega)\ \frac{B\cancel{MVA}}{(KV)^2}}$$

$$Z_1 \Omega + Z_2 \Omega + Z_0 \Omega = \frac{3(KV)^2}{SCMVA} \Rightarrow \frac{3(220)^2}{5000} \rightarrow 4.84$$

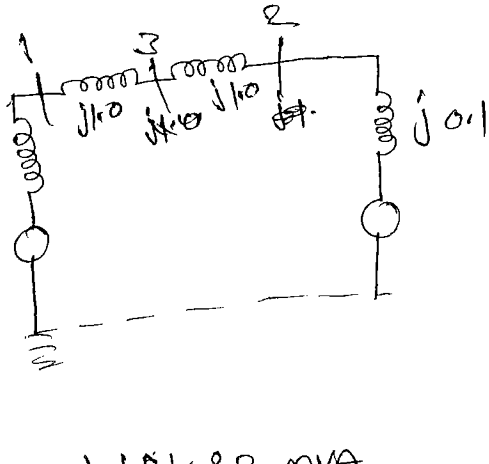
Pg-38

13, 14)

13) 

$$X_{G_1} PU_{New} = 0.25 \times \frac{100}{250} \times \left(\frac{15}{15}\right)^2$$

$$= 0.1$$



$$X_{l_1} PU = 0.225 \times \frac{100}{(15)^2}$$

$$= j1.0$$

14) $SCMVA = \frac{BMVA}{X_{1eq}} \Rightarrow \frac{100}{j0.55} \Rightarrow 181.82\ MVA$

Pg-48

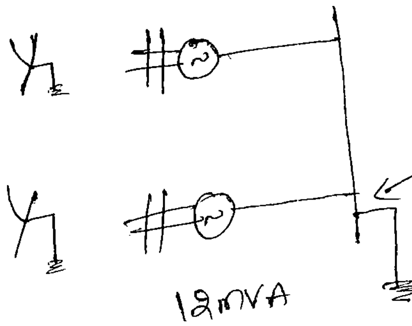
4) $I_n = 3I_{R0} = 3 \times 2.4 = 7.2\ PU$

$V_n = I_n X_n = 7.2 \times 0.05 = 0.36$

pg-48

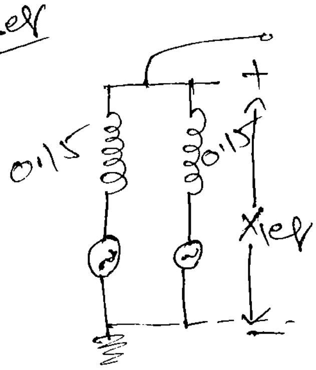
6)

a)

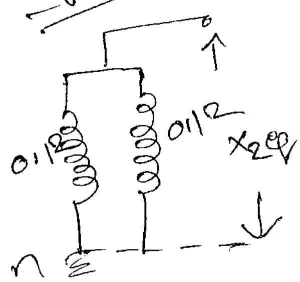


Prefault voltage $= \frac{6.6}{6.6} = 1.0$

+ve seq

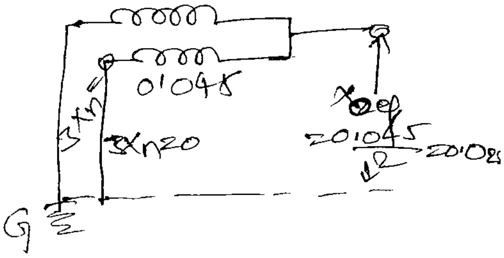


-ve seq



$X_{2eq} = \frac{0.12}{2} = 0.06$

zero seq

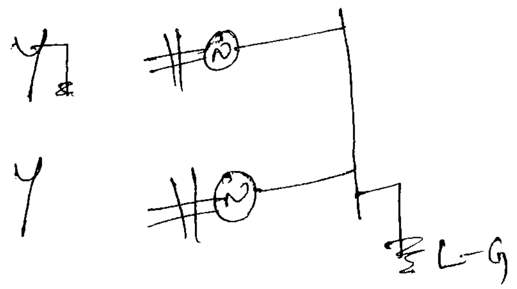


$X_{0eq} = \frac{0.045}{2} = 0.0225$

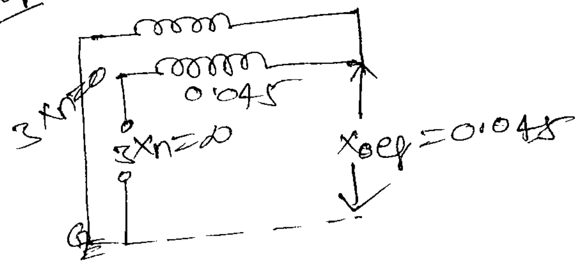
$$I_f = \frac{3 \times E_{R1}}{X_{1eq} + X_{2eq} + X_{0eq}} = \frac{3 \times 1.0}{0.075 + 0.06 + 0.0225} = 19.04\ PU$$

$$\boxed{I_{f(a)} = 19.04 \times \frac{12}{\sqrt{3} \times 6.6}\ kA}$$

b)



zero seq



$X_{0eq} = 0.045$

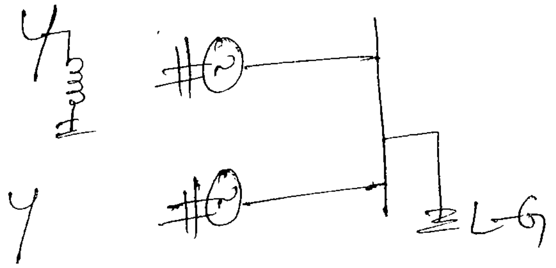
+ve & -ve seq's are same.

$$I_f = \frac{3E_{R1}}{X_{1eq} + X_{2eq} + X_{0eq}} = \frac{3 \times 1.0}{0.075 + 0.06 + 0.045} = 16.67\ PU$$

$$\boxed{I_{f(a)} = 16.67 \times \frac{12}{\sqrt{3} \times 6.6}\ kA}$$

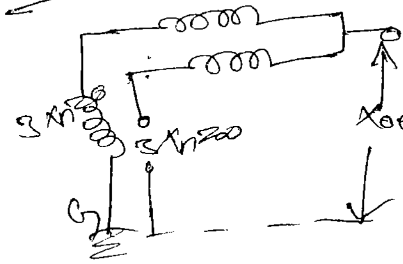
$\boxed{\begin{matrix} V_n = 0 \\ V_n = 0 \end{matrix}}$

c)



+ve & -ve seq's are same

zero seq



$X_{0eq} = 0.045 + 3X_n$
$= 0.045 + 3(0.05)$
$= 0.195$

$$I_f = \frac{3 \times E_{R1}}{X_{1eq} + X_{2eq} + X_{0eq}}$$

$$= \frac{3 \times 1.0}{0.075 + 0.06 + 0.195} = 9.09\ PU$$

$$I_f(a) = 9.09 \times \frac{12}{\sqrt{3} \times 6.6}\ KA$$

$V_n = I_n X_n$

$= 3 I_{R0} X_n$

$= 9.09 \times 0.05\ PU$

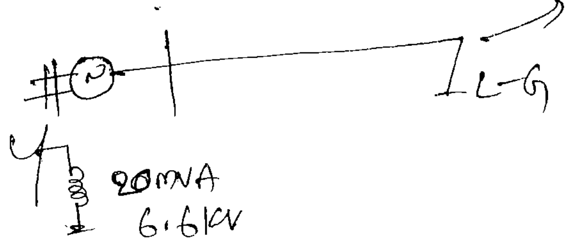
$= 0.45\ PU$

~~actual neutral voltage~~ actual neutral voltage.

$$V_n = 0.45 \times \frac{6.6 \times 10^3}{\sqrt{3}}\ \text{volts}$$

Pg-38

3)



$\text{Prefault voltage} = \frac{6.6}{6.6} = 1.0$

$V_n = I_n X_n = 3 I_{R0} X_n = I_f X_n$

$$I_f = \frac{3 E_{R1}}{X_{1eq} + X_{2eq} + X_{0eq}}$$

$$= \frac{3 \times 1.0}{j0.2 + j0.2 + \underbrace{3(0.05) + 0.04 + 0.3}_{}}$$

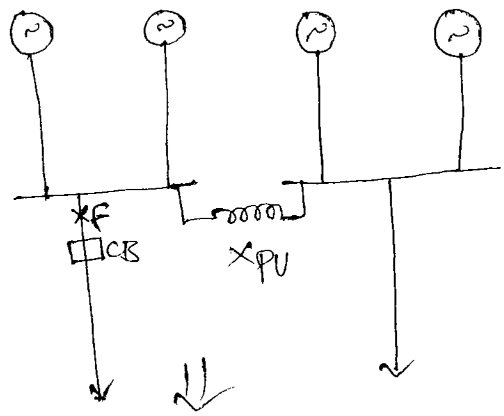
$$= \frac{3\times1.0}{0.89} \Rightarrow 3.37\,PU$$

$$V_n = I_f \cdot X_n = 3.37 \times 0.05\,PU$$

$$\text{actual voltage} = 3.37 \times 0.05 \times \frac{6.6\times10^3}{\sqrt{3}} \Rightarrow 642.2\,V$$

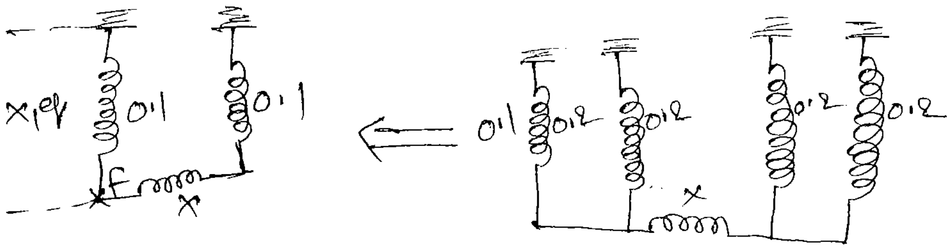
pg-32

11) $$SC\ MVA = \frac{B.MVA}{X_{1eq}}$$



$$1500 = \frac{100}{X_{1eq}}$$

$$X_{1eq} = \frac{100}{1500}$$



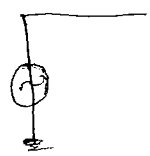
$$\frac{(0.1)(0.1+x)}{0.2+x} = \frac{100}{1500}$$

$$x = 0.1$$

pg-34

15) $I_f = \frac{E_{R1}}{X_{1eq}} \Rightarrow \frac{1.0}{X_{1eq}}$

The grid is represented as a voltage source in series with negligeble reactance.



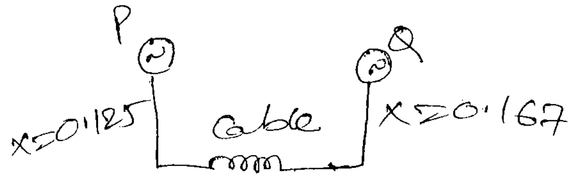
$$X_{1eq} = 0.1 \,||\, (0.1 + 0.06)$$

$$= \frac{1}{0.06}$$

$$= 15\,PU$$

pg-25)

45) $SC\,MVA = \frac{BMVA}{X_1 eq}$



$X_{pu} = 0.4 \times \frac{100}{(11)^2} = 0.33$

$\therefore SC\,MVA = \frac{BMVA}{X_1 eq} = \frac{100}{\left[\frac{(0.125)(0.497)}{0.125+0.497}\right]}$

pg-25

46, 47)

46) $\frac{3 \times 1.0}{0.2+0.2+0.08} \Rightarrow -j6.25\ PU$

47) $I_f = \sqrt{3}\, I_{R1}$

$= -j4.33\ PU$

pg-26

51) $BMVA = 100\,MVA$, $X_0 = 5\%$, $X_d'' = X_1 = X_2 = 20\%$, L-G fault

$I_f = \frac{3E_{R1}}{X_0 + X_1 + X_2 + 3X_n}$

$= \frac{3 \times 1.0}{0.2+0.2+0.05+3(0.08)} \Rightarrow 4.34\ PU$

$I_f(a) = 4.34 \times \frac{100}{\sqrt{3} \times 20}$ kA

$= 12.55$ kA

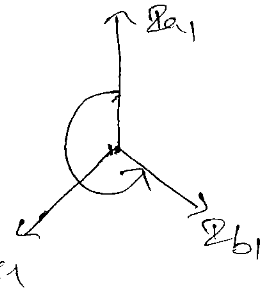
pg-26

52) Ans - 100A

pg-45

60) $I_{a1} = 33.33\angle 0$

$I_{b1} = k^2 I_{a1}$



∴ current in phase 'b' is

$33.33\angle 240°$

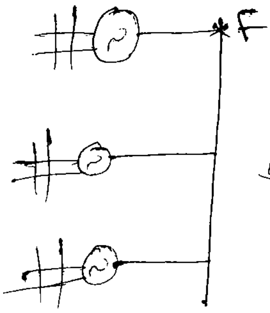
current in phase 'c' is $33.33\angle 120°$

pg-44)

31)

$$SCMVA = \frac{BMVA}{X_{1}pu} = \frac{BMVA}{X_1\Omega} \not+ \frac{BMVA}{(kV)^2}$$

$$= \frac{BMVA}{X_1\Omega \times \frac{BMVA}{(kV)^2}}$$



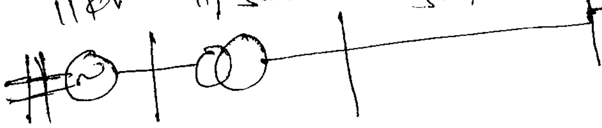
$$X\Omega = \frac{(kV)^2}{SCMVA} = \frac{400\times10^3}{20\times10^9} = 8\Omega + 12$$

$$SCMVA = \frac{(kV)^2}{X\Omega} = \frac{400\times10^3\times400\times10^3}{\left(\frac{20\Omega\times10}{30}\right)}$$

$$= \frac{40\times4}{\left(\frac{10\times20}{30}\right)} \Rightarrow 24\ GVA$$

pg-48

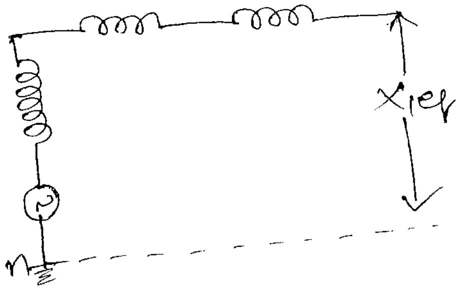
3)

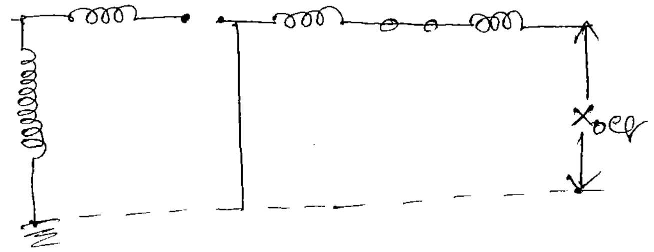


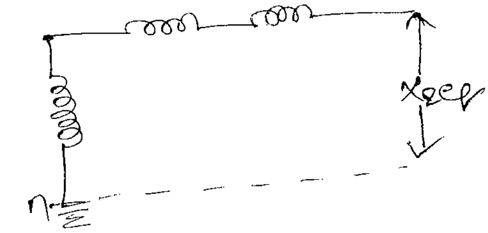
→ Prefault voltage $= \frac{34.5}{33} = 1.045$

ΔY

$$I_f = \frac{3\times E_{R1}}{X_{1eq} + X_{2eq} + X_{0eq}}$$







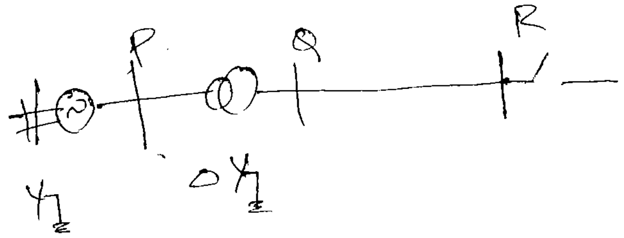
$$\therefore I_f = \frac{3 \times 1.045}{0.25 + 0.22 + 0.2} \Rightarrow 4.67\,PU$$

$V_n = 0$

Total actual current $= 4.67 \times \frac{\quad}{\sqrt{3}3}$

P-49

7)



Fault ~~current~~ at P

$$I_f = \frac{3 \times E_{R1}}{X_1 + X_2 + X_0 + 3X_n}$$

$$= \frac{3 \times 1.0}{0.1 + 0.1 + 0.05 + 0}$$

$= 12\,PU$

$$I_f(a) = 12 \times \frac{50}{\sqrt{3} \times 13.2}\ kA$$

$= 26.24\ kA$

Fault at Q

$$I_f = \frac{3 \times 1.0}{0.2 + 0.2 + 0.1}$$

$= 6\,PU$

$$I_f(a) = 6 \times \frac{50}{\sqrt{3} \times 66}\ kA$$

$= 2.624\ kA$

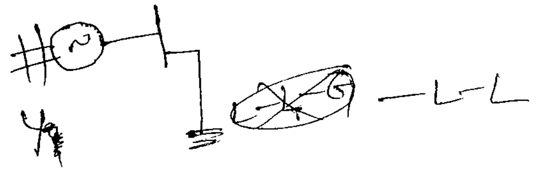
Fault at R

$$I_f = \frac{3 \times 1.0}{0.23 + 0.23 + 0.19} \Rightarrow 4.61\,PU$$

$$I_f(a) = 4.61 \times \frac{50}{\sqrt{3} \times 66}$$

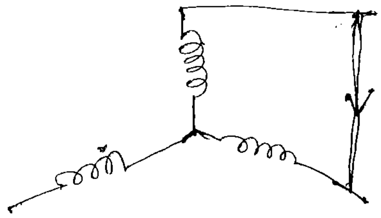
pg-50

17)



$$I_f = \sqrt{3} I_{R1} = \sqrt{3} \times \frac{E_{R1}}{X_1 + X_2}$$

$$= 1.732 \times \frac{1.0}{0.3 \times 0.2} \Rightarrow 3.464 \text{ PU}$$



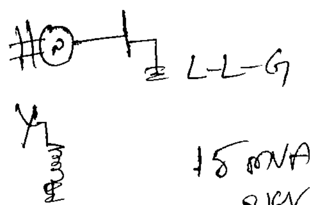
$$I_f(a) = 3.464 \times \frac{15}{\sqrt{3} \times 13.2} \text{ KA}$$

$$= 2.272 \text{ KA}$$

The limiting value of the line current is nothing but the maximum value of the current in the line, which is same as fault current.

pg-50

13)



15 MVA
13.2 kV

current through ground = fault-current

$$= 3I_{a0}$$

$$I_{a0} = -I_{a1} \cdot \frac{X_{2eq}}{X_{2eq} + X_{0eq}}$$

$$I_{a1} = \frac{E_{a1}}{X_{1eq} + \left(\frac{X_{2eq} * X_{0eq}}{X_{2eq} + X_{0eq}} \right)}$$

I_{R1} + $E_{a1} = \frac{13.9}{13.2} = 1.053$

$$I_{a1} = \frac{1.053 \angle 0}{0.2 + \frac{0.2 \times 0.23}{0.43}}$$

$$= 3.43 \angle -90^\circ \text{ PU}$$

$$I_{a0} = -3.43 \angle -90^\circ \times \frac{0.2}{0.43}$$

$$= 1.59 \angle 90^\circ$$

$I_{a2} = 1.83 \angle 90°$

current through ground $= 3 \times 1.59 \times \frac{15}{\sqrt{3} \times 13.2} = 3.1295$ KA

current in phase-B

$I_b = I_{b0} + I_{b1} + I_{b2}$

$= I_{a0} + k^2 I_{a1} + k I_{a2}$

$= 1.59 \angle 90 + 1 \angle 240 \times 3.43 \angle -90 + 1 \angle 120 \times 1.83 \angle 90$

$= 1.59 \angle 90 + 3.43 \angle 150 + 1.83 \angle 210$

current in phase - c

$I_c = I_{c0} + I_{c1} + I_{c2}$

$= I_{a0} + k I_{a1} + k^2 I_{a2}$

$= 1.59 \angle 90 + 1 \angle 120 \times 3.43 \angle -90 + 1 \angle 240 \times 1.83 \angle 90$

$= 1.59 \angle 0 + 3.43 \angle 30 + 1.83 \angle 330$

pg-52

22) $V_{a1} = \frac{1}{3}[V_{an} + k V_{bn} + k^2 V_{cn}]$

$= \frac{1}{3}[100 \angle 0 + 1 \angle 120 \times 60 \angle 60 + 1 \angle 240 \times 60 \angle 120]$

$= \frac{1}{3}[100 + 60 \angle 180 + 60 \angle 360]$ (neglected)

$= 33.3 \angle 0$

$I_{a1} = \frac{V_{a1}}{X_{a1}}$

$= \frac{33.33 \angle 0}{X_s - X_n}$

$= \frac{33.33 \angle 0}{7 \angle 90}$

P-36

4) $I_a = \frac{10\angle 0}{2\angle 90} = 5\angle -90$

$I_b = \frac{10\angle -90}{3\angle 90} = 3.33\angle -180$

$I_c = \frac{10\angle 120}{4\angle 90} = 2.5\angle 30$

$I_{a1} = \frac{1}{3}[I_a + kI_b + k^2 I_c]$

$= \frac{1}{3}[5\angle -90 + 1\angle 120 \times 3.33\angle -180 + 1\angle 240 \times 2.5\angle 30]$

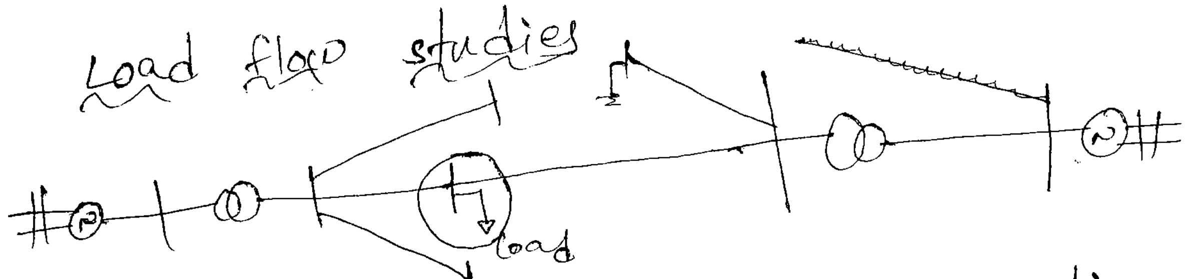
$= \frac{1}{3}[5\angle -90 + 3.33\angle -60 + 2.5\angle 270]$

$= 3.5\angle 81^\circ$

Pg-36

7) Ans - c

Load flow studies



The performance of the above system will be analise electrically by evoluating by unknown electrical quantity i.e., the voltage at load point provided that the system is working in a steady state condition.

~~The load~~ A load flow study is one which can provide the solution for unknown electrical quantities of a larger interconnected power system network along with certain

Inequality constraints, provided that the system is working in a steady state condition.

i) Voltage at the load point:-

$$V_{p\,min} \leq V_p \leq V_{p\,max}$$

'p' is a representation of Bus

$(p = 1, 2, --- n)$

ii) The reactive power generation of the generator:-

$$Q_{p\,min} \leq Q_p \leq Q_{p\,max}$$

iii) The tap setting of the tap changing T/f:-

$$t_{p\,min} \leq t_p < t_{p\,max}$$

where 't_p' → Tap ratio.

The unknown ē quantities will be applied by solving the n/w eqns which are developed either by using KCL technique (or) KVL techniques, because the n/w elements are represented in a lumped manner due to study state condition of n/w.

Purpose of the load flow study:-

The load on the system is increasing year to year (or) annually. so that the performance of system is steady by conducting the load flow study. If performance is poor, it is necessary to improve the performance by planning the power system.

Power system plannings :-

i) Addition of a new system to be existing system

ii) ~~each~~ enchancing the capacitor of the existing system i.e.,

~~iii)~~ conversion of single ckt line to double ckt line.

→ The load flow studies are ~~x~~ conducted in a steady state condition of the n/w. so that there is a balanced load on the system hence the n/w parameters are expressed through a single line diagram.

→ In a steady state condition there is a small gradual variation of the load. However during the load flow study, the change in the load is assumed to be zero for a shorter interval of time i.e., 5 to 10 minutes.

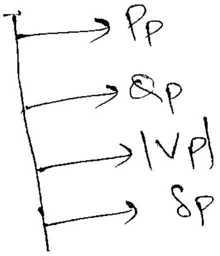
Basic requirements to start the load flow studies :-

i) Develop suitable network equations for the unknown electrial quantities by using KCL (or) KVL

ii) ~~used~~ use any one of the iterative method to set the solution of the above network equations.

→ In order to reduce the memory requirement to store the n/w data, it is preferable to develop the n/w equations by using KCL technique i.e., the admitance form of a load (or) a bus.

<u>Node or bus:-</u>



out of the four e. quantities, two of them are known values and two of them are unknown values. The unknown electrical quantities can evaluating by using known values along with admitance form of the network.

<u>Bus classification:-</u>

Bus name	known value	unknown values
Load bus	P_p and Q_p	$\|V_p\|$ and δ_p
Generator bus	P_p and $\|V_p\|$	Q_p and δ_p
SLACK bus (or) reference bus	$\|V_p\|$ and δ_p	P_p and Q_p

→ The power system n/w is having basically either load buses (or) generator buses. Out of which, most of the buses are load buses.

Importance of slack bus

→ In a balanced condition the demand + loss = generation.

→ During the load flow studies, the power at the bus will be substituted as $P_p = \Sigma P_{PG} - \Sigma P_{Pd}$ and also

$$Q_p = \Sigma Q_{PG} - Q_{Pd}$$

→ by ignoring the loss ~~in~~ the transmission n/w under the assumption that the losses are very less. ~~At~~ the end of the load flow study, the loss in the transmission line is to be included by balancing the equation.

$$\Sigma P_{PG} - \Sigma P_{Pd} = P_L$$

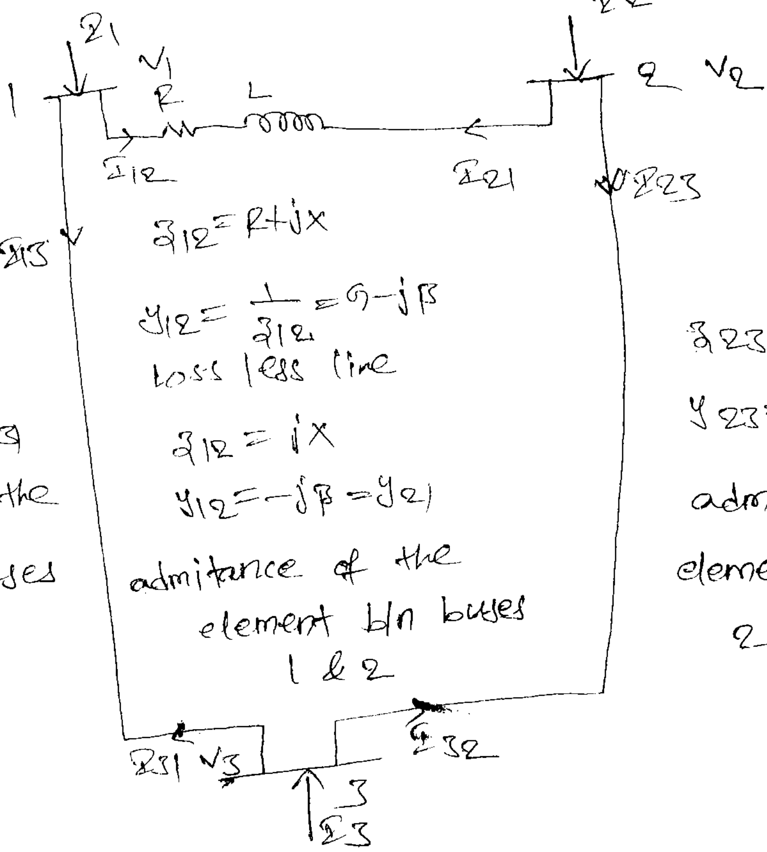
$$\Sigma Q_{PG} - \Sigma Q_{Pd} = Q_L$$

→ If the loss is included, the generation capacity to be increase

→ In load flow studies, the loss in transmission system is assign for one of the generator rather than distributing for all the generators. The generator bus is one which is assigned with loss is to be treated as a slack bus or reference bus.

→ The rotor angle of slack bus is assumed to be zero so that the rotor angles of other generators will be measured w.r.to the slack bus.

node (or) bus admitance network equation:-



$z_{13} = jx$

$y_{13} = -jB = y_{31}$

admittance of the element b/n buses 1 & 3

$z_{23} = jx$

$y_{23} = -jB = y_{32}$

admittance of the element b/n buses 2 & 3

At bus 1

$I_1 = I_{12} - I_{13}$

$= (V_1 - V_2)y_{12} + (V_1 - V_3)y_{13}$

$= (y_{12} + y_{13})V_1 - y_{12}V_2 - y_{13}V_3$

$I_1 = Y_{11}V_1 + Y_{12}V_2 + Y_{13}V_3 \rightarrow (1)$

Y_{11} = Total self admitance of bus-1 $= y_{12} + y_{13}$

Y_{12} = Total mutual admitance of buses 1 & 2 $= -y_{12}$

Y_{13} = Total mutual admitance of buses 1 & 3 $= -y_{13}$

→ The total self admitance is nothing but sum of the admitance of the elements which are connect to the respecto bus and there will be more than one element.

→ Total mutual admitance is nothing but mutual admitance b/n any buses with a opposite sign and there is one mutual admittance b/n any mutual admittance

At bus 2

$I_2 = I_{21} + I_{23}$

$I_2 = (V_2 - V_1) y_{21} + (V_2 - V_3) y_{23}$

$I_2 = -y_{21} V_1 + (y_{21} + y_{23}) V_2 - y_{23} V_3$

$I_2 = Y_{21} V_1 + Y_{22} V_2 + Y_{23} V_3$

$Y_{21} = -y_{21} = Y_{12} \rightarrow$ Total mutual admitance b/n 2 & 1

$Y_{22} = y_{21} + y_{23} \rightarrow$ Total self admitance bus 2 $\rightarrow$ It is not equal to Y_{11}

$Y_{23} = -y_{23} \rightarrow$ Total mutual admitance b/n 2 & 3

At bus 3

$I_3 = I_{31} + I_{32}$

$= (V_3 - V_1) y_{31} + (V_3 - V_2) y_{32}$

$= -y_{31} V_1 - y_{32} V_2 + (y_{31} + y_{32}) V_3$

$I_3 = Y_{31} V_1 + Y_{32} V_2 + Y_{33} V_3$

$Y_{31} = -y_{31} \rightarrow$ mutual admitance

$Y_{23} = -y_{32} \rightarrow$ mutual admitance

$Y_{33} = y_{31} + y_{32} \rightarrow$ self admitance, It is not equal to Y_{11} & Y_{22}

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix}$$

$$\boxed{I_{BUS} = Y_{BUS} \cdot V_{BUS}}$$

Y_{BUS} = Bus admitance matrix

$$Y_{BUS} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix}_{3\times3}$$

→ The impedance of the elements are converted into admitance and then constructed bus admitance matrix.

→ for a 'n' bus system the current at bus 'P' is

current at bus P

$$I_p = \sum_{q=1}^{3} Y_{pq} \cdot V_q$$

$p=1$ | $p=2$ | $p=3$

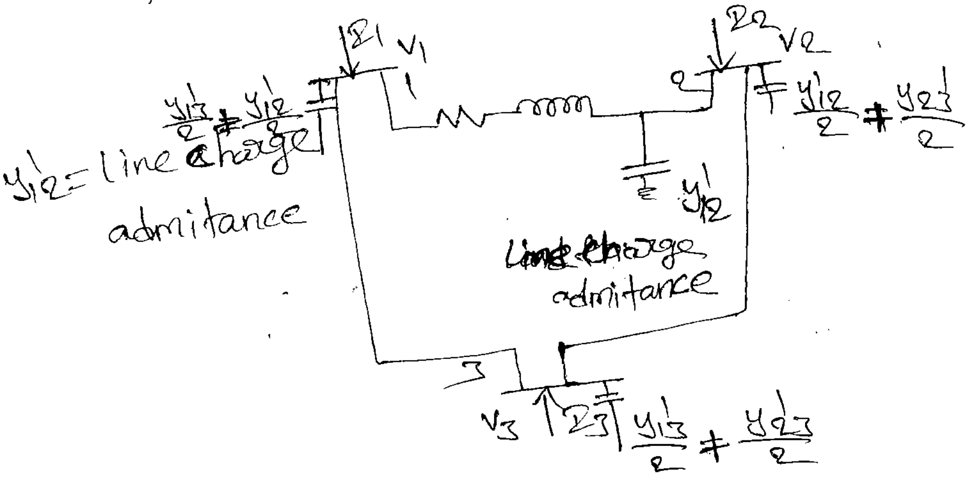
$$I_1 = \sum_{q=1}^{3} Y_{1q} \cdot V_q \qquad I_2 = \sum Y_{2q} \cdot V_q \qquad I_3 = \sum Y_{31} \cdot V_q$$

$q=1$

$$I_1 = \sum Y_{11} \cdot V_1$$

→ ~~for a n-bus system the current at bus p~~

→ The addition of shunt capacitance of line



→ The shunt capacitance of TL b/n any two buses is represented by line charge admitance y'_{12}. During the load flow study, the effect of the shunt capacitance of the line will be replaced as half line charge admitance at respective buses. so that the TL will be replaced as an equivalent of π-model.

→ The half line charge admitance at each bus will be added to the total self admitance of respective buses.

$$\downarrow Y_{11} = y_{12} + y_{13} + \frac{y'_{12}}{2} + \frac{y'_{13}}{2}$$

$$\downarrow Y_{22} = y_{21} + y_{23} + \frac{y'_{12}}{2} + \frac{y'_{23}}{2}$$

$$\downarrow Y_{33} = y_{31} + y_{32} + \frac{y'_{13}}{2} + \frac{y'_{23}}{2}$$

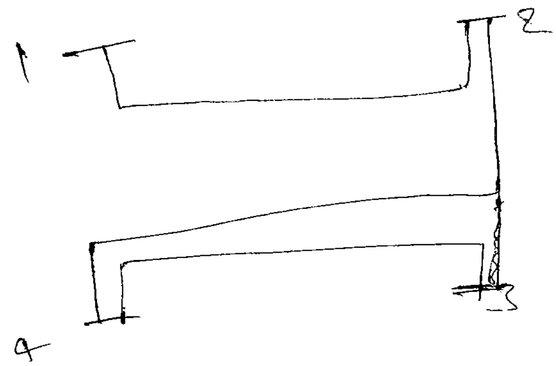
$$Y_{12} = -y_{12} = Y_{21}$$

$$Y_{23} = -y_{23} = Y_{32}$$

$$Y_{13} = -y_{13} = Y_{31}$$

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & 0 \\ Y_{31} & 0 & Y_{33} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix}$$

→ In interconnecting system, each bus is having a minimum of one TL so that all the self elements are present, but sum of the mutual elements can be made as zero.

⇒ 

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & 0 & 0 \\ Y_{21} & Y_{22} & 0 & Y_{24} \\ 0 & 0 & Y_{33} & Y_{34} \\ 0 & Y_{42} & Y_{43} & Y_{44} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix}$$

$$I_{BUS} = Y_{BUS} \cdot V_{BUS}$$

→ As the no. of buses are increases, the size of the PS n/w is increased, but the no. of element which are became zero are gradually increase and non-zero elements are gradually reduced. In a larger power system n/w, most of the elements are zero. In any matrix, if most of the elements are zero, the above matrix is called SPARSE MATRIX.

→ The Y-bus matrix of PS n/w is also called as SPARSE MATRIX. So, that the memory required inorder to store the n/w data of Y-bus elements will be reduced. Hence it is prefer to develop the n/w eqn's of the load flow studies by using admittance form of the system rather than, it is called as impedance

→ The power system n/w is having 20 buses. The Y-bus matrix of system is 80% sparse. The minimum number of TL required to make the system as inter connecting system.

$Y_{BUS} = 20 \times 20 = 400$

zeros − $0.8 \times 400 = 320$

non-zeros − $0.2 \times 400 = 80$

self $= 20$

mutual $= 60$

→ The no. of Transmission lines is mutual elements devided by '2'

$$\text{lines} = \frac{\text{mutual}}{2} = \frac{60}{2} = 30$$

→ The PS n/w is having 100 buses. The Y-bus of system is having 90% sparse. The min no. of TL required to make the system as inter connecting system 450

$Y_{BUS} = 100 \times 100 = 10000$

zeros $= 0.9 \times 10000 = 900$

non-zeros $= 10000 \times 0.1 = 1000$

no. of

→ The Y-bus matrix is also called symmetric matrix. so that the memory requirement will be further n/w in order to store the n/w data, because it is required to store either upper triangular elements (or) lower triangle element only.

$\cancel{Y_{11} = y_{12} + y_{13} + \frac{y_{12}'}{2} + \frac{y_{13}'}{2}}$

$Y_{21} = -y_{12}$

$\cancel{Y_{31} = -y_{12}}$

$Y_{11} = y_{12} + y_{13} + \frac{y_{12}'}{2} + \frac{y_{13}'}{2}$

$Y_{12} = -y_{12}$

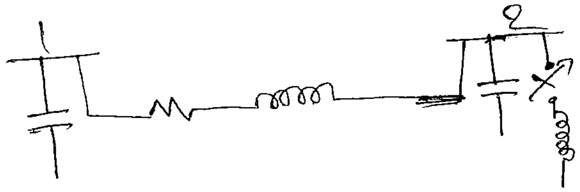
$Y_{13} = -y_{13}$

$Y_{11} + Y_{12} + Y_{13} = 0$

→ If there are no shunt elements in buses the sum of element in the row will becomes zero. so that the determinant of the matrix will be zero and such a matrix is called as singular matrix.

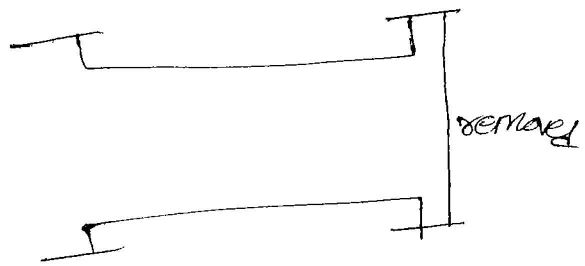
Addition of any external shunt elements:-

→ Any external shunt inductor is connect to bus will be added to the total self admitance of respective bus. As the inductor is a -ve suseptance so that the total self admitance of respective bus will increase in its' magnitude.



→ In case of external shunt capacitor the total self admitance of respective bus will reduce in its magnitude

→ If a TL is removed b/n any two buses, the mutual elements of the respective buses will be zero and also the total self admitance of the respective buses will reduce in its magnitude.



→ Bus code	Line impedance in PU (z_{pq})	Line charge admitance in PU (y'_{pq})
1-2	$z_{12} = 0.2 + j0.4$	$j0.16 = y'_{12}$
2-3	$z_{23} = 0.1 + j0.2$	$j0.08 = y'_{23}$
1-3	$z_{13} = 0.05 + j0.1$	$j0.04 = y'_{13}$

construct the Y-bus

$Z_{12} = 0.2 + j0.4$

$$y_{12} = \frac{1}{z_{12}} = \frac{1}{0.2+j0.4} \times \frac{0.2-j0.4}{0.2-j0.4}$$

$$= \frac{0.2-j0.4}{(0.2)^2+(0.4)^2} \Rightarrow \frac{0.2}{(0.2)^2+(0.4)^2} - \frac{j0.4}{(0.2)^2+(0.4)^2}$$

$y_{12} = 1 - j2$

$|||^{ly}$ $y_{23} = 2 - j4$

$y_{13} = 4 - j8$

$Y_{12} = y_{12} = -1 + j2 = Y_{21}$

$Y_{13} = -y_{31} = -4 + j8 = Y_{31}$

$Y_{23} = -y_{23} = -2 + j4 = Y_{32}$

$y_{11} = y_{12} + y_{13} + \frac{y_{12}'}{2} + \frac{y_{13}'}{2}$

$= 1 - j2 + 4 - j8 + \frac{j0.16}{2} + \frac{j0.04}{2}$

$= 5 - j9.9$

$$\therefore Y_{bus} = \begin{bmatrix} 5-j9.9 & -1+j2 & -4+j8 \\ -1+j2 & 3-j5.88 & -2+j4 \\ -4+j8 & -2+j4 & 6-j11.94 \end{bmatrix}$$

$Y_{22} = y_{21} + y_{23} + \frac{y_{12}'}{2} + \frac{y_{23}'}{2}$

$= 1 - j2 + 2 - j4 + \frac{j0.16}{2} + \frac{j0.08}{2}$ ~~notes~~

$= 3 - j5.88$

$Y_{33} = y_{31} + y_{32} + \frac{y_{13}'}{2} + \frac{y_{32}'}{2}$

$= 4 - j8 + 2 - j4 + \frac{j0.04}{2} + \frac{j0.08}{2}$

$= 6 - j11.94$

→

Bus code	Line impedance in pu	half line charg. admitance in pu
1-2	$z_{12} = 0.2 + j0.4 \rightarrow y_{11} =$	$j0.16$
2-3	$z_{23} = 0.1 + j0.2 \rightarrow y_{22} =$	$j0.08$
1-3	$z_{13} = 0.05 + j0.1 \rightarrow y_{33} =$	$j0.04$

$Y_{11} = y_{12} + y_{13} + \frac{y_{12}'}{2} + \frac{y_{13}'}{2} = 1 - j2 + 4 - j8 + j0.16 - j0.4 \Rightarrow 5 - j9.8$

$Y_{22} = y_{21} + y_{23} + \frac{y_{12}'}{2} + \frac{y_{23}'}{2} = 1 - j2 + 2 - j4 + j0.16 + j0.08$

$= 3 - j5.76$

$Y_{33} = y_{31} + y_{32} + \frac{y_{13}'}{2} + \frac{y_{32}'}{2} = 4 - j8 + 2 - j4 + j0.04 + j0.08$

$= 6 - j11.88$

$Y_{12} = y_{12} = -1+j2 = y_{21}$

$Y_{23} = -y_{23} = -2+j4 = y_{32}$

$Y_{13} = -y_{31} = -4+j8 = y_{31}$

$$\therefore Y_{BUS} = \begin{bmatrix} 5-j9.8 & -1+j2 & -4+j8 \\ -1+j2 & 3-j5.76 & -2+j4 \\ -4+j8 & -2+j4 & 6-j11.88 \end{bmatrix}$$

→ Bus code | admitance in PU

Bus code	admitance in PU
1-2	$y_{12} = 2.0 - j8.0$
2-3	$y_{23} = 0.5 - j1.0$
2-4	$y_{24} = 1 - j4$
4-1	$y_{14} = 1.5 - j3.0$

find the diagonal elements of Y_{BUS}

$Y_{11} = 3.5 - j11 \rightarrow y_{12} + y_{14}$

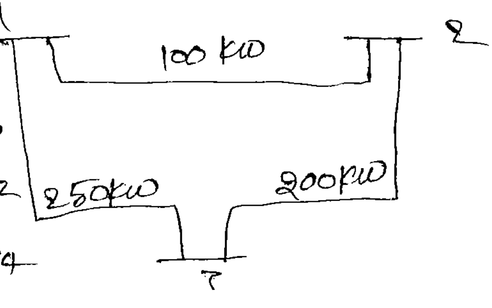
$Y_{22} = 3.5 - j13 \rightarrow y_{12} + y_{23} + y_{24}$

$Y_{33} = 0.5 - j1.0 \rightarrow y_{23}$

$Y_{44} = 2.5 - j7 \rightarrow y_{24} + y_{41}$

→ A Transmission line is having series impedance of $j0.001$ PU/km and a line charge admitance of $j0.0016$ PU/km

construct the Y_{bus} of the given bus system.



Bus code	Line imp in PU	Line charge adm in PU
1-2	$z_{12} = j0.001 \times 100 = j0.1$	$y_{12}' = j0.0016 \times 100 = j0.16$
2-3	$z_{23} = j0.001 \times 200 = j0.2$	$y_{23}' = j0.0016 \times 200 = j0.32$
1-3	$z_{13} = j0.001 \times 250 = j0.25$	$y_{13}' = j0.0016 \times 250 = j0.4$

$z_{12} = j0.001 \times 100 = j0.1 \rightarrow y_{12} = -j10$

$z_{23} = j0.001 \times 200 = j0.2 \rightarrow y_{23} = -j5$

$z_{13} = j0.001 \times 250 = j0.25 \rightarrow y_{13} = -j4$

$$Y_{BUS} = \begin{bmatrix} -j13.72 & j10 & j4 \\ +j10 & -j14.76 & j5 \\ j4 & j5 & -j8.64 \end{bmatrix}$$

Pg 73

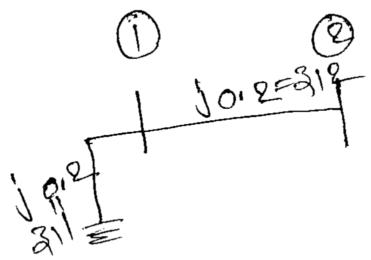
3) $Y_{23} = j10$

$y_{23} = -Y_{23} = -j10$

$z_{23} = \frac{1}{y_{23}} = \frac{1}{-j10} \Rightarrow j0.1$

Pg 74

4)



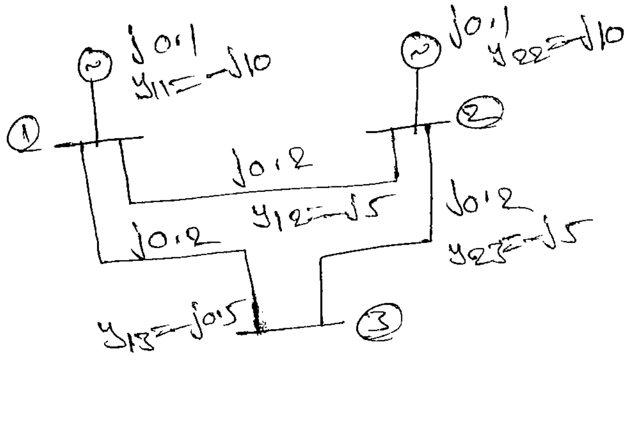
$y_{11} = -j5$

$y_{12} = -j5$

$\therefore Y_{BUS} = \begin{bmatrix} -j10 & 5 \\ 5 & -5 \end{bmatrix}$

Pg 75

10)



$Y_{11} = -j20$

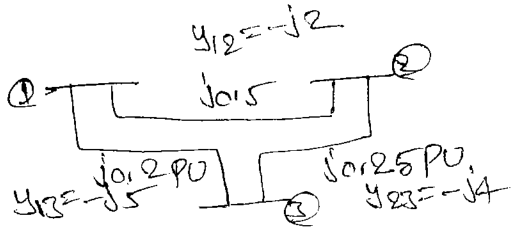
$Y_{22} = -j20$

$Y_{33} = -j10$

$Y_{12} = Y_{23} = Y_{13} = j5$

Pg 77

20)



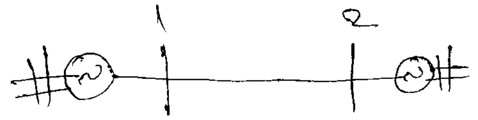
$Y_{11} = -j2 - j5 = -j7$

$Y_{22} = -j2 - j4 = -j6$

$Y_{33} = -4j - j5 = -j9$

pg-78

27)



$Y_{12} = j10$

$y_{12} = -j10$

$Z_{12} = j0.1$

$Y_{11} = y_{11} + y_{12} = -j30$

$y_{11} = -j30 - y_{12}$

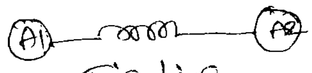
$= -j30 - (-j10)$

$= -j20$

$Z_{11} = \frac{1}{y_{11}} = \frac{1}{-j20} = j0.05$

pg-78

29)



Ans: (d)

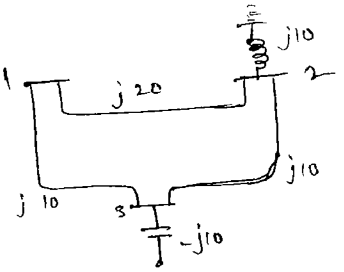
The problem will have two ~~sa~~ slack buses. one → A1
Two → A2

Y_{BUS} of the 3-Bus system is given as

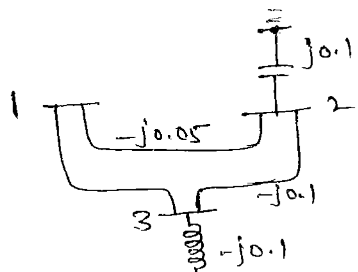
$$Y_{BUS} = \begin{bmatrix} -j30 & j20 & j10 \\ j20 & -j20 & j10 \\ j10 & j10 & -j30 \end{bmatrix}$$

Draw the reactance diagram and indicate p.u values.

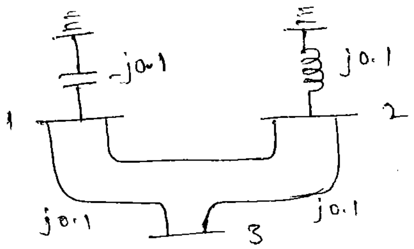
a)



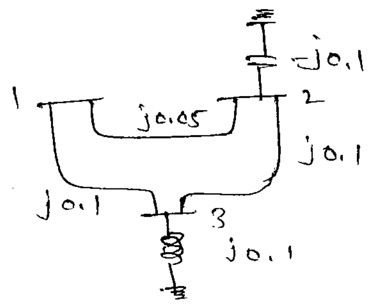
b)



c)



d)



Solⁿ: $Z_{12} = \frac{1}{y_{12}} = \frac{1}{-j20} = j0.05$

$Z_{13} = \frac{1}{y_{13}} = \frac{1}{-j10} = j0.1$

Bus 2 and 3 are having shunt elements.

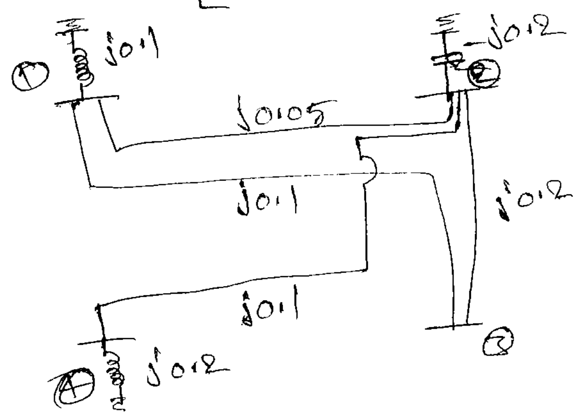
$$Y_{Bus} = \begin{array}{c} \begin{bmatrix} -j30 & j20 & j10 \\ j20 & -j30 & j10 \\ j10 & j10 & -j30 \end{bmatrix} \end{array} \begin{array}{l} \rightarrow 0 \\ \rightarrow \neq 0 \text{ (Cap) } \quad Y_{22} \\ \rightarrow \neq 0 \text{ (Indu) } \quad Y_{33} \end{array}$$

⇒ If ~~[illegible]~~ sum of elements is not zero & it is a +ve susceptance and it will be treated as shunt capacitor.

⇒ If the sum of elements in the row is not zero and it is a -ve suseptance, it will be treated as shunt inductor.

$$\rightarrow Y_{Bus} = j\begin{bmatrix} -40 & 20 & 10 & 0 \\ 20 & -30 & 5 & 10 \\ 10 & 5 & -15 & 0 \\ 0 & 10 & 0 & -15 \end{bmatrix}$$

Draw the reactance diagram and indicates PU values.



sum of the elements in 1^{st} row ≠ 0

" " " 2^{nd} row ≠ 0

" " " 3^{rd} row = 0

" " " 4^{th} row ≠ 0

$y_{11} = -j10$ → shunt inductor

$y_{22} = j5$ → shunt capacitor

$y_{33} = -j5$ → shunt inductor

$$\rightarrow \quad Y_{Bus} = j\begin{bmatrix} -50 & 20 & 10 & 10 \\ 20 & -30 & 5 & 0 \\ 10 & 5 & -20 & 10 \\ 10 & 0 & 10 & -15 \end{bmatrix}$$

A TL b/n bus 2 & 3 is removed, the modified Y_{bus} is

$$Y_{Bus} = j\begin{bmatrix} -50 & 20 & 10 & 10 \\ 20 & \overset{-25}{-30} & \overset{0}{\cancel{5}} & 0 \\ 10 & \overset{0}{\cancel{5}} & \overset{-15}{-20} & 10 \\ 10 & 0 & 10 & -15 \end{bmatrix}$$

with original values $\begin{cases} y_{22} = -5 \\ y_{33} = +5 \end{cases}$

$$Y_{22} = y_{21} + y_{22} + y_{23} + y_{24}$$
$$= 20 - 5 + 0 + 0$$
$$= -25$$

$$Y_{33} = y_{31} + y_{32} + y_{33} + y_{34}$$
$$= 10 + 0 + 5 - 10$$
$$= -15$$

→ $Y_{BUS} = j\begin{bmatrix} -30 & 20 & 10 \\ 20 & -40 & 20 \\ 10 & 20 & -35 \end{bmatrix}$ A TL b/n 1&3 is removed, the modified Y_{BUS} is

$$Y_{BUS} = j\begin{bmatrix} \overset{-20}{\cancel{-30}} & 20 & \overset{0}{\cancel{10}} \\ 20 & -40 & 20 \\ \underset{0}{\cancel{10}} & 20 & \underset{-25}{\cancel{-35}} \end{bmatrix}$$

→ $Y_{BUS} = \begin{bmatrix} -30 & 10 & 20 & 10 \\ 10 & -40 & 10 & 20 \\ 20 & 10 & -50 & 10 \\ 10 & 20 & 10 & -40 \end{bmatrix}$ the buses where ~~they~~ having shunt elements

a) 1 & 2 b) 3 & 4

c) 1 & 3 c) 2 & 4

$$Y_{BUS} = \begin{bmatrix} -30 & 10 & 20 & 10 \\ 10 & -40 & 10 & 20 \\ 20 & 10 & -50 & 10 \\ 10 & 20 & 10 & -40 \end{bmatrix} \begin{matrix} \neq 0 \\ = 0 \\ \neq 0 \\ = 0 \end{matrix}$$

∴ The buses 1&3 are having shunt elements.

→ $Y = \begin{bmatrix} -30 & 10 & 20 & 10 \\ 10 & -40 & 10 & 20 \\ 20 & 10 & -50 & 10 \\ 10 & 20 & 10 & -40 \end{bmatrix}$ the buses 1 & 3 are having shunt elements

a) Ind, cap b) cap, Ind

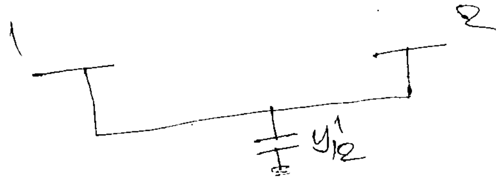
c) Ind, Ind d) cap, cap

$$\boxed{\begin{array}{l} \text{Ind} \to \text{inductor} \\ \text{cap} \to \text{capacitor} \end{array}}$$

1) PS-I

$$Y = j\begin{bmatrix} -15 & 10 & 5 \\ 10 & -18 & 10 \\ 5 & 10 & -13 \end{bmatrix}\begin{matrix} \\ \rightarrow j2 \\ \rightarrow j2 \end{matrix}$$

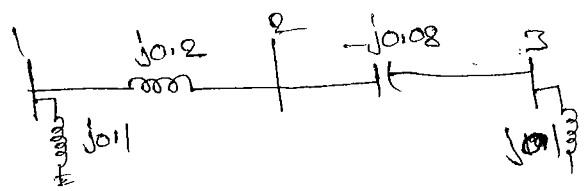
$$\frac{y'_{12}}{2} + \frac{y'_{13}}{2} = j2$$



$$\frac{y'_{12}}{2} + \frac{y'_{23}}{2} = j2$$

$$\frac{y'_{13}}{2} + \frac{y'_{23}}{2} = j2$$

$$y'_{12} = \frac{y'_{12}}{2} + \frac{y'_{12}}{2} = j1 + j1 = j2$$

→ 

The marked parameters are PU reactances, construct the Y_{BUS} of the system

$y_{11} = -j10$

$y_{12} = -j5$

$y_{23} = j12.5$

$y_{33} = -j10$

$$\therefore Y_{BUS} = \begin{bmatrix} -j15 & j5 & 0 \\ j5 & j7.5 & -j12.5 \\ 0 & -j12.5 & j2.5 \end{bmatrix}$$

Bus-impedance matrix:

$I_{BUS} = Y_{BUS} \cdot V_{BUS}$

$V_{BUS} = Y_{BUS}^{-1} \cdot I_{BUS}$

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

$\boxed{Z_{BUS} = Y_{BUS}^{-1}}$ ⟶ Bus impedance matrix

The elements of the Y_{BUS} are used for the purpose of load flow studies. However the elements of the Z_{BUS} are used for the calculation of SC currents either at the buses (or) b/n any two buses.

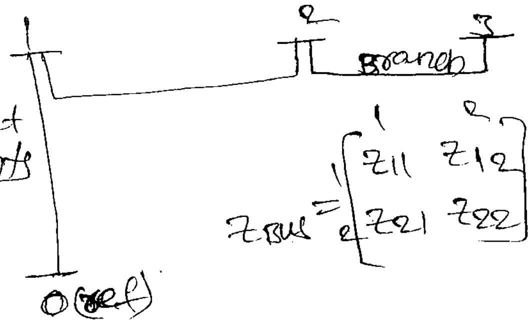
→ The bus impedance matrix can be obtain by considering Y_{Bus}^{-1}.
However the elements of Z_{bus} are not accurate, because while constructing Y_{bus} for load flow studies the shunt elements of the system are taken. where as during the sc studies, the shunt capacitance of line ~~(or)~~ any ~~external~~
→ ~~while constructing for load~~
shunt element are to be ignored. Hence, the construction of Z_{bus} can be done seperately.

Construction of 'Zbus':-

while constructing the z-bus, add one element at a time from any one of bus and complete the addition of all elements in a given bus system. ~~and~~

case (i):- If the addition of the element ~~thats~~ does creat a new bus & to existing system, the above element is called a branch. The size of the Zbus is increased by 1. It is required to evoluate the elements of extra row and extra column with out effecting the elements of original Zbus.

→ while constructing the Zbus, one of the element bus is taken as ~~reference~~ that the elements of the reference bus will be zero.



$$Z_{Bus} = \begin{array}{c|cc} & 1 & 2 \\ \hline 1 & Z_{11} & Z_{12} \\ 2 & Z_{21} & Z_{22} \end{array}$$

$$Z_{Bus} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & Z_{11} & Z_{12} & Z_{13} \\ 2 & Z_{21} & Z_{22} & Z_{23} \\ 3 & Z_{31} & Z_{32} & Z_{33} \end{array}$$

mutual elements

$Z_{qi} = Z_{pi}$

$i = 1, 2, 3, \ldots m$

$\neq q$

self elements

$Z_{qq} = Z_{pq} + Z_{pq,pq}$

$Z_{pq,pq}$ = impedance of added elements.

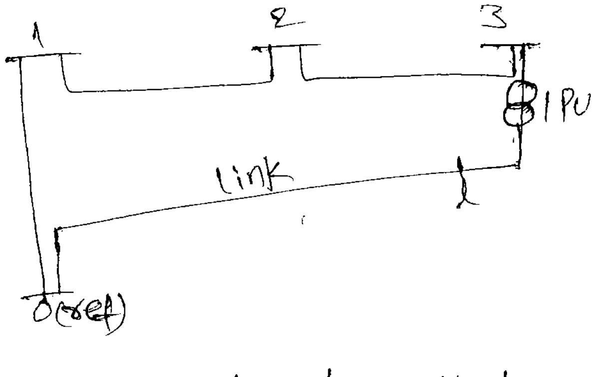
'p' is not a reference bus

If 'p' is a reference bus $Z_{qi} = 0$, $Z_{pi} = 0$

$Z_{qq} = Z_{pq,pq}$, $Z_{pq} = 0$

case (ii):- If the added elements does not creat any new bus to the existing system, the above element is called as a 'link'. The size of the Zbus will remain same. However it is required to modify all the elements of original Zbus inorder to include the effect of the impedance of the link element

$$Z_{BUS} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \end{array}\begin{array}{c} \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \begin{bmatrix} Z_{11} & Z_{12} & Z_{13} \\ Z_{21} & Z_{22} & Z_{23} \\ Z_{31} & Z_{32} & Z_{33} \end{bmatrix} \end{array}$$



→ In order to include the effect of the link element so that all the elements of original Zbus is modified, connect a voltage source having 1PU in series with added element & a temporary bus is created which is called as bus.

→ The size of the Z_{bus} is increased by 1 temporarily, because of link effect

$$Z_{BUS} = \begin{array}{c|cccc} & 1 & 2 & 3 & l \\ \hline 1 & Z_{11} & Z_{12} & Z_{13} & Z_{1l} \\ 2 & Z_{21} & Z_{22} & Z_{23} & Z_{2l} \\ 3 & Z_{31} & Z_{32} & Z_{33} & Z_{3l} \\ l & Z_{l1} & Z_{l2} & Z_{l3} & Z_{ll} \end{array}$$

mutual elements

$Z_{li} = Z_{pi} - Z_{qi}$
$i = 1, 2, \ldots n$
$\neq l$

self elements

$Z_{ll} = Z_{pl} - Z_{ql} + Z_{plpl}$

'p' is not reference bus.

Z_{plpl} = impedance of link element which is added

If 'p' is a reference bus $Z_{li} = -Z_{qi}$, $Z_{pi} = 0$

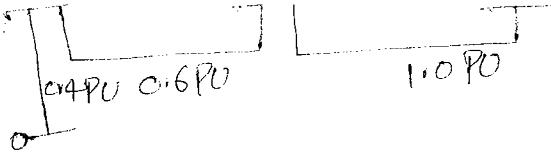
$Z_{ll} = -Z_{ql} + Z_{plpl}$, $Z_{pl} = 0$

→ In order to get the original size of the bus, the temporary bus is to be eliminated by short circuiting the voltage source

$$\underset{3\times3}{Z_{BUS,(new)}} = \underset{3\times3}{Z_{BUS}(old)} - \frac{\underset{3\times1}{(Z_{li})}(Z_{lj})_{1\times3}}{Z_{ll\,1\times1}} \quad 3\times3$$

$$= \begin{bmatrix} & & \\ & & \end{bmatrix}_{3\times3}$$

→ construct the Z_{BUS}



step 1:- Add element 1 having an impedance of 0.4 PU from the bus '0' (ref. bus). so that it will creat a new bus i.e, Bus-1, it is a branch.

$p=0$ & $q=1$

$$Z_{BUS} = \begin{array}{c c} & \begin{array}{cc} 0 & 1 \end{array} \\ \begin{array}{c} 0 \\ 1 \end{array} & \begin{bmatrix} Z_{00} & Z_{01} \\ Z_{10} & Z_{11} \end{bmatrix} \end{array}$$

mutual elements

$Z_{qi} = Z_{pi}$

$Z_{1i} = Z_{0i}$

$i=0$

$Z_{10} = Z_{00} = 0 = Z_{01}$

self elements

$Z_{qq} = Z_{pq} + z_{pq\,pq}$

$Z_{11} = Z_{01} + z_{0101}$

$= 0 + 0.4$

$= 0.4$

$$\therefore Z_{BUS} = \begin{array}{c c} & \begin{array}{cc} 0 & 1 \end{array} \\ \begin{array}{c} 0 \\ 1 \end{array} & \begin{bmatrix} 0 & 0 \\ 0 & 0.4 \end{bmatrix} \end{array} \Rightarrow \begin{array}{c c} & 1 \\ 1 & \begin{bmatrix} 0.4 \end{bmatrix} \end{array}$$

step 2:- Add element to having an impedance of 0.6 PU from Bus-1, so that it will creat a new bus i.e, Bus-2. It is a branch.

$P=1, q=2$

$$Z_{BUS} = \begin{array}{c c} & \begin{array}{cc} 1 & 2 \end{array} \\ \begin{array}{c} 1 \\ 2 \end{array} & \begin{bmatrix} Z_{00} & Z_{01} \\ Z_{10} & Z_{11} \end{bmatrix} \end{array} \qquad Z_{BUS} = \begin{array}{c c} & \begin{array}{cc} 1 & 2 \end{array} \\ \begin{array}{c} 1 \\ 2 \end{array} & \begin{bmatrix} 0.4 & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \end{array}$$

mutual elements

$Z_{qi} = Z_{pi}$

$Z_{21} = Z_{11}$

$i=1$

$Z_{21} = Z_{11} = 0.4 = Z_{12}$

self elements

$$Z_{qq} = Z_{pq} + z_{pq,pq}$$

$$Z_{22} = Z_{12} + z_{12,12}$$

$$= 0.4 + 0.6$$

$$= 1.0$$

$$\therefore Z_{BUS} = \begin{array}{c} \\ 1 \\ 2 \end{array}\begin{array}{c} \begin{array}{cc} 1 & 2 \end{array} \\ \begin{bmatrix} 0.4 & 0.4 \\ 0.4 & 1.0 \end{bmatrix} \end{array}$$

step-3:- Add element 3 having an impedance of 1 PU from bus-2, so that it will creats a new bus i.e, Bus-3. It is a branch.

$$Z_{BUS} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \end{array}\begin{array}{c} \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \begin{bmatrix} 0.4 & 0.4 & Z_{13} \\ 0.4 & 1.0 & Z_{23} \\ Z_{31} & Z_{32} & Z_{33} \end{bmatrix} \end{array}$$

mutual elements:-

$$Z_{qi} = Z_{pi}$$

$$Z_{3i} = Z_{2i}$$

$$i = 1$$

$$Z_{31} = Z_{21} = 0.4 = Z_{13}$$

$$i = 2$$

$$Z_{32} = Z_{22} = 1.0 = Z_{23}$$

self elements:-

$$Z_{qq} = Z_{pq} + z_{pq,pq}$$

$$Z_{33} = Z_{23} + z_{23,23}$$

$$= 1.0 + 1.0$$

$$= 2.0$$

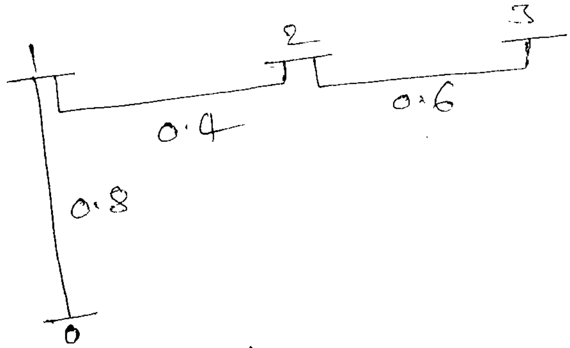
$$\therefore Z_{BUS} = \begin{bmatrix} 0.4 & 0.4 & 0.4 \\ 0.4 & 0.4 & 1.0 \\ 0.4 & 1.0 & 2.0 \end{bmatrix}$$

→ The Y-Bus matrix is not a full matrix it is a sparse matrix whereas the ZBUS matrix is a full matrix, hence the memory requirement to store the n/w data for the ZBUS will be high whereas for a Y-Bus it will be less.

step-1 $Z_{BUS} = \begin{array}{cc} & 1 \\ 1 & \begin{bmatrix} 0.4 \end{bmatrix} \end{array}$

step-2 $Z_{BUS} = \begin{array}{cc} & \begin{array}{cc} 1 & 2 \end{array} \\ \begin{array}{c} 1 \\ 2 \end{array} & \begin{bmatrix} 0.4 & 0.4 \\ 0.4 & 1.0 \end{bmatrix} \end{array}$

step-3 $Z_{BUS} = \begin{array}{cc} & \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \end{array} & \begin{bmatrix} 0.4 & 0.4 & 0.4 \\ 0.4 & 1.0 & 1.0 \\ 0.4 & 1.0 & 2.0 \end{bmatrix} \end{array}$

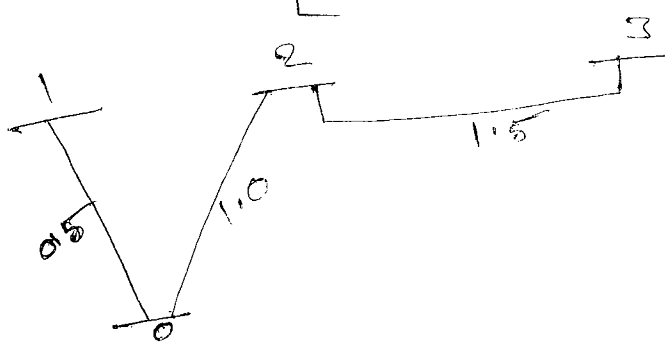
→ 

Construct the ZBUS

i) $Z_{BUS} = 1 \begin{bmatrix} 0.8 \end{bmatrix}$

ii) $Z_{BUS} = \begin{bmatrix} 0.8 & 0.8 \\ 0.8 & 1.2 \end{bmatrix}$

iii) $Z_{BUS} = \begin{bmatrix} 0.8 & 0.8 & 0.8 \\ 0.8 & 1.2 & 1.2 \\ 0.8 & 1.2 & 1.8 \end{bmatrix}$

→ 

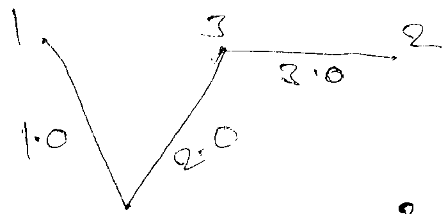
i) $Z_{BUS} = \begin{array}{c|c} & 1 \\ \hline 1 & [0.5] \end{array}$, $Z_{BUS} = \begin{array}{c|c} & 2 \\ \hline 2 & [1.0] \end{array}$

ii) $Z_{BUS} = \begin{array}{c|c} & \begin{matrix} 1 & 2 \end{matrix} \\ \begin{matrix} 1 \\ 2 \end{matrix} & \begin{bmatrix} 0.5 & 0 \\ 0 & 1.0 \end{bmatrix} \end{array}$

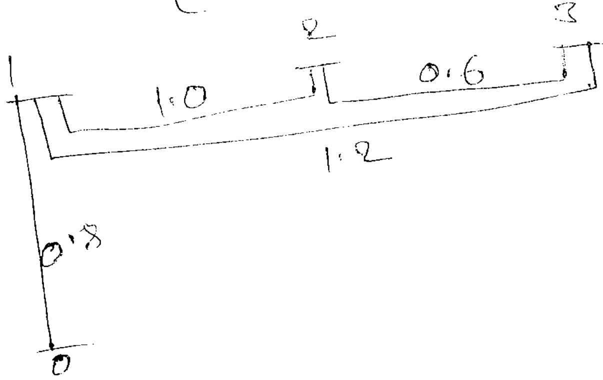
iii) $Z_{BUS} = \begin{array}{c|c} & \begin{matrix} 1 & 2 & 3 \end{matrix} \\ \begin{matrix} 1 \\ 2 \\ 3 \end{matrix} & \begin{bmatrix} 0.5 & 0 & 0 \\ 0 & 1.0 & 1.0 \\ 0 & 1.0 & 2.5 \end{bmatrix} \end{array}$

pg-79

2)



$Z_{BUS} = \begin{array}{c|c} & \begin{matrix} 1 & 2 & 3 \end{matrix} \\ \begin{matrix} 1 \\ 2 \\ 3 \end{matrix} & \begin{bmatrix} 1 & 0 & 0 \\ 0 & 2 & 2 \\ 0 & 2 & 5 \end{bmatrix} \end{array} \Rightarrow \begin{array}{c|c} & \begin{matrix} 1 & 2 & 3 \end{matrix} \\ \begin{matrix} 1 \\ 3 \\ 2 \end{matrix} & \begin{bmatrix} 1 & 0 & 0 \\ 0 & 5 & 2 \\ 0 & 2 & 2 \end{bmatrix} \end{array}$

→ 

construct the Zbus

$Z_{BUS} = \begin{bmatrix} 0.8 & 0.8 & 0.8 \\ 0.8 & 1.8 & 1.8 \\ 0.8 & 1.8 & 2.4 \end{bmatrix}$

Step-4: Add element-4 having an impedance of 1.2 PU b/n Bus 1 & 3. It does not creat a new bus, It is a link

$P = 1$ & $q = 3$

$$Z_{BUS} = \begin{bmatrix} 0.8 & 0.8 & 0.8 & Z_{1l} \\ 0.8 & 1.8 & 1.8 & Z_{2l} \\ 0.8 & 1.8 & 2.4 & Z_{3l} \\ 0 & -1.0 & -1.6 & Z_{4l} \end{bmatrix}$$

$$= \begin{bmatrix} 0.8 & 0.8 & 0.8 & 0 \\ 0.8 & 1.8 & 1.8 & -1.0 \\ 0.8 & 1.8 & 2.4 & -1.6 \\ 0 & -1.0 & -1.6 & Z_{ll} \end{bmatrix}$$

$Z_{li} = Z_{pi} - Z_{ql}$

$= Z_{ll} - Z_{pl} - Z_{ql} + Z_{plpl}$

$Z_{ll} = Z_{1l} - Z_{3l} + Z_{1l1l}$

$= 0 + 1.6 + 1.2$

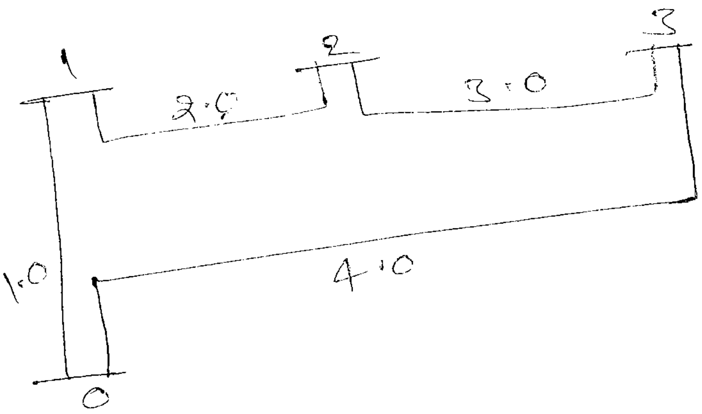
$= 2.8$

$$\therefore Z_{BUS} = \begin{bmatrix} 0.8 & 0.8 & 0.8 & 0 \\ 0.8 & 1.8 & 1.8 & -1.0 \\ 0.8 & 1.8 & 2.4 & -1.6 \\ 0 & -1.0 & -1.6 & 2.8 \end{bmatrix}$$

$$Z_{BUS\,mod} = Z_{BUS\,old} - \frac{[Z_{li}][Z_{li}]}{Z_{ll}}$$

$$= \begin{bmatrix} 0.8 & 0.8 & 0.8 \\ 0.8 & 1.6 & 1.8 \\ 0.8 & 1.8 & 2.4 \end{bmatrix} - \frac{\begin{bmatrix} 0 \\ -1.0 \\ -1.6 \end{bmatrix} \begin{bmatrix} 0 & -1.0 & -1.6 \end{bmatrix}}{2.8}$$

$$= \begin{bmatrix} 0.8 & 0.8 & 0.8 \\ 0.8 & 1.8 & 1.8 \\ 0.8 & 1.8 & 2.4 \end{bmatrix} - \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1/2.8 & \frac{1.6}{2.8} \\ 0 & \frac{1.6}{2.8} & 2.56/2.8 \end{bmatrix}$$

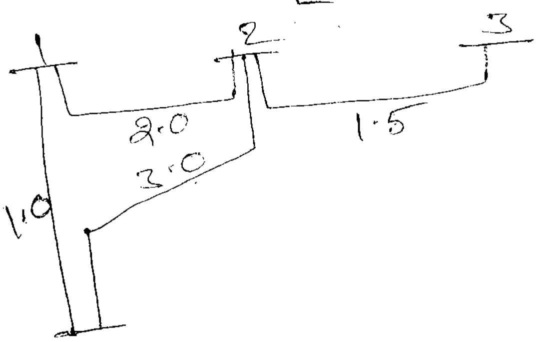


$$Z_{BUS} = \begin{bmatrix} 1.0 & 1.0 & 1.0 & Z_{l1} \\ 1.0 & 3.0 & 3.0 & Z_{l2} \\ 1.0 & 3.0 & 6.0 & Z_{l3} \\ 0 & -4.0 & -5.0 & Z_{ll} \end{bmatrix}$$

$$Z_{BUS} = \begin{bmatrix} 1.0 & 1.0 & 1.0 & -1.0 \\ 1.0 & 3.0 & 3.0 & -3.0 \\ 1.0 & 3.0 & 6.0 & -6.0 \\ -1.0 & -3.0 & -6.0 & Z_{ll} \end{bmatrix}$$

$$Z_{li} = Z_{pi} - Z_{qi}$$
$$= Z_{0i} - Z_{3i}$$
$$= -Z_{3i}$$

$$Z_{BUS}\ mod = \begin{bmatrix} 0.9 & 0.7 & 0.4 \\ 0.7 & 2.1 & 1.2 \\ 0.1 & 1.2 & 2.4 \end{bmatrix}$$



$$Z_{Bus} = \begin{array}{c} 1 \\ 2 \end{array}\begin{bmatrix} 1.0 & 1.0 \\ 1.0 & 3.0 \end{bmatrix}$$

$$Z_{Bus} = \begin{array}{c|ccc} & 1 & 2 & l \\ \hline 1 & 1.0 & 1.0 & -1.0 \\ 2 & 1.0 & 3.0 & -3.0 \\ l & -1.0 & -3.0 & 6 \end{array}$$

$$Z_{Bus,mod} = \begin{bmatrix} 1.0 & 1.0 \\ 1.0 & 3.0 \end{bmatrix} - \frac{\begin{bmatrix} -1.0 \\ -3.0 \end{bmatrix}\begin{bmatrix} -1.0 & -3.0 \end{bmatrix}}{6}$$

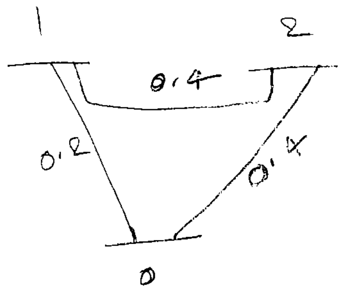
$$= \begin{bmatrix} 1.0 & 1.0 \\ 1.0 & 3.0 \end{bmatrix} - \begin{bmatrix} 1/6 & 3/6 \\ 3/6 & 9/6 \end{bmatrix}$$

$$= \begin{bmatrix} 0.833 & 0.5 \\ 0.5 & 1.5 \end{bmatrix}$$

$$Z_{Bus} = \begin{bmatrix} 0.833 & 0.5 & 0.5 \\ 0.5 & 1.5 & 1.5 \\ 0.5 & 1.5 & 3.0 \end{bmatrix}$$

pg-80

5)

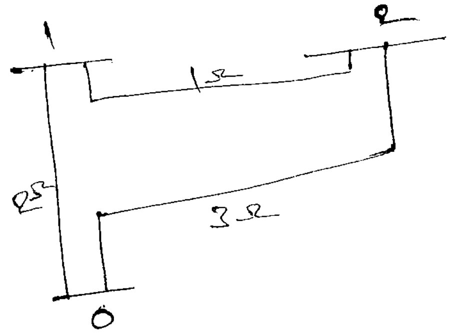


$$Z_{Bus} = \begin{array}{c|ccc} & 1 & 2 & l \\ \hline 1 & 0.2 & 0.2 & -0.2 \\ 2 & 0.2 & 0.6 & -0.6 \\ l & -0.2 & -0.6 & 1.0 \end{array}$$

$$Z_{Bus,mod} = \begin{bmatrix} 0.2 & 0.2 & -0.2 \\ 0.2 & 0.6 & -0.6 \\ -0.2 & -0.6 & 1.0 \end{bmatrix} - \begin{bmatrix} 0.04 & 0.12 \\ 0.12 & 0.36 \end{bmatrix}$$

Pg-80

10)

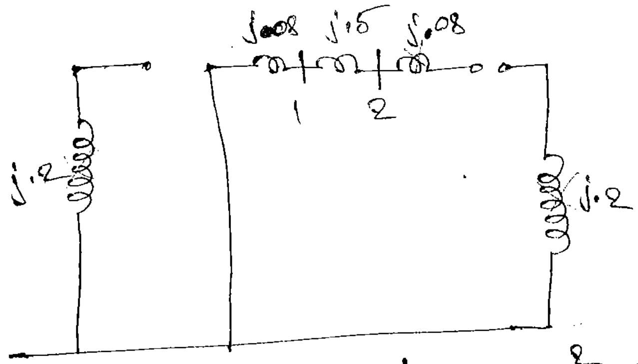


$$Z_{BUS} = \begin{bmatrix} 2 & 2 & -2 \\ 2 & 3 & -3 \\ -2 & -3 & 5 \end{bmatrix}$$

$$Z_{BUS} = \begin{bmatrix} 2 & 2 \\ +2 & 3 \end{bmatrix} - \begin{bmatrix} 4/5 & 6/5 \\ 6/5 & 9/5 \end{bmatrix}$$

Pg-85

40)



$$Z_{BUS} = \begin{array}{c c} & \begin{array}{cc} 1 & 2 \end{array} \\ \begin{array}{c} 1 \\ 2 \end{array} & \begin{bmatrix} j0.08 & j0.08 \\ j0.08 & j0.58 \end{bmatrix} \end{array}$$

→ The Z-bus of a 4-bus power system n/w is as

$$Z_{BUS} = \begin{array}{c c} & \begin{array}{cccc} 1 & 2 & 3 & 4 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \end{array} & \begin{bmatrix} j0.3435 & j0.2860 & j0.2723 & j0.2277 \\ j0.2860 & j0.3408 & j0.2586 & j0.2414 \\ j0.2723 & j0.2586 & j0.2791 & j0.2209 \\ j0.2277 & j0.2414 & j\,2209 & j0.2791 \end{bmatrix} \end{array}$$

An element having an impedance of j.2Ω is connected b/n bus-2 and the reference bus. The values of Z_{22new} and Z_{23new} of the modified Z_{BUS}

$$Z_{ei} = Z_{pi} - Z_{qi}$$
$$= -Z_{qi}$$
$$= -Z_{qi}$$

$$
Z_{BUS} = \begin{bmatrix}
j0.3435 & j0.2860 & j0.2723 & j0.2277 & -j0.2860 \\
j0.2860 & j0.3408 & j0.2586 & j0.2414 & -j0.3408 \\
j0.2723 & j0.2586 & j0.2791 & j0.2209 & -j0.2586 \\
j0.2277 & j0.2414 & j0.2209 & j0.2791 & -j0.2414 \\
-j0.2860 & -j0.3408 & -j0.2586 & -j0.2414 & -j0.5408 \, (Z_{ll})
\end{bmatrix}
$$

$$Z_{ll} = Z_{pl} - Z_{ql} + Z_{plpl}$$

$$= Z_{0l} - Z_{2l} + Z_{0l0l}$$

$$= 0 + j0.3408 + j0.2$$

$$= j0.5408$$

$$Z_{22,new} = Z_{22\,old} - \frac{Z_{l2} Z_{l2}}{Z_{ll}}$$

$$= j0.3408 - \frac{(-j0.3408)(-j0.3408)}{j0.5408}$$

$$= j0.3408 - j\frac{(0.3408 \times 0.3408)}{0.5408}$$

$$= j0.126$$

$$Z_{23,new} = Z_{23\,old} - \frac{Z_{l2} Z_{l3}}{Z_{ll}}$$

$$= j0.2586 - \frac{(-j0.3408)(-j0.2586)}{j0.5408}$$

$$= j0.095$$

pg-25

48) $I_f = I_R = I_{R1} = \frac{E_{R1}}{Z_{22}} = \frac{1.0}{j0.2} = -j5$

pg-25

50)

Q-86

3, 4) ③ Before fault

$V_1^1 = 1.0$

$V_2^1 = 1.0$

$V_3^1 = 1.0$

During fault

$V_1^2 = I_f Z_{12}$
$= +0.33 PU$

$V_2^2 = 0$

$V_3^2 = I_f Z_{23}$
$= 0.67$

Post fault

$V_1^3 = V_1^1 - V_1^2$
$= 0.67$

$V_2^3 = V_2^1 - V_2^2$
$= 1.0 - 0 = 1.0$

$V_3^3 = V_3^1 - V_3^2$
$= 0.33$

$$I_f = I_2 = \frac{V_2^2}{Z_{22}} = \frac{V_2^1}{Z_{22}}$$

$$= \frac{1.0}{j0.24}$$

$$= -j4.16$$

$V_1^2 = -j4.16 \times (j0.08)$
$= 0.33 PU$

$V_1^3 = 1.0 - 0.33$
$= 0.67$

$V_3^2 = I_f \times Z_{23}$
$= -j4.16 \times (j0.16)$
$= 0.67$

$V_3^3 = V_3^1 - V_3^2$
$= 1.0 - 0.67$
$= 0.33$

④ $I_1 = \dfrac{V_1^2}{Z_{11}} = \dfrac{0.33}{j0.16}$

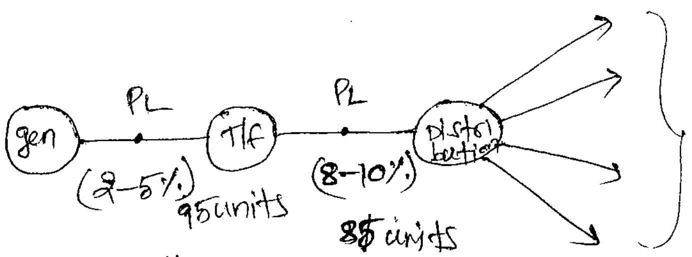
Economical operations

minimize the cost/unit/annum of electrical energy generation so that the cost/unit/annum of electrical energy consumed by the consumer is also minimised.

Energy = power × time (whr (or) kwhr (or) units)

1 unit = 1000 whr (or) 1 kwhr.

Thermal station:-



consumers → uneconomical

Rs ~~5~~/unit

4/unit

Rs ~~4~~/units

3/unit

100 units

Rs ~~3~~/unit

2/unit

$$\text{Cost/unit/annum} = \frac{\text{Fixed cost/annum} + \text{running cost/annum}}{\text{number of units generated in a year}}$$

Fixed cost:- Cost required in order to establish the plant

a) cost of land

$$\text{FC/annum} = \frac{FC}{\text{life of plant}}$$

b) cost of buildings

c) cost of machinary equipment

d) salaries of the management

e) Interest on borrowings and also Insurance charges.

f) depreciation charges.

It is the value of equipment in Rs/annum × due to cohere & care of the equipment, thatsall amount is called fixed cost.

Runing costs:-

a) cost of fuel

b) wages to the workmen (labour)

→ cost required to run the plant (or) to produce the energy.

c) maintainance cost

HP = 50Y
NP = 25Y
TP = 20Y
GP = 15Y
RCC = 100Y

→ The running cost perannum in same ~~an running~~ period ~~due~~ to ~~a~~ one year

(or)

→ The running cost per annum in same an running period due to a one period.

→ The cost/unit will be minimised certain factors in ~~electronic~~ electronic operation.

Connected load:- The arithmatic sum the ratings of e-appliances of a new consumer.

Installed capacity:- Arithmatic sum of the ratings of the generator which are connect to a common bus, the installed capacity 2,00,000 W as on 31/3/2012.

maximum load/maximum demand:- It is highest amount power that can be consume at any instant time over a specified period.

Day ~~at~~ what time

month → At which day

year → which month

The power is generated by a syn M/C and it is having a stability criteria. Inorder to maintain the stability should be less than installed capacity.

The maximum = Installed capacity − maximum load

$$ML < IC$$

$$\text{reserve} = IC - ML$$

$$= +ve \text{ (store)}$$

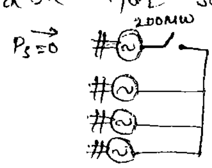
average load → PA is nothing but no. of units consumed to total no. of ~~...~~ hrs.

$$\boxed{aL > ML > IC}$$

Firm Power:- It is the amount of power which is available even during emergency condition. It is called Back up supply.

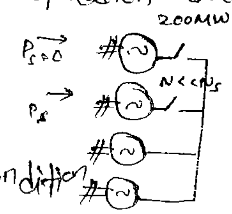
Ex:- Diesel Generators.

Cold Reserve:- It is the amount of power available for service but not operation. Service means repair.



Hot Reserve:- It is the amount of power available for operation but not service

In order to reduce the time for synchronization It is kept ~~the~~ corto at hot condition So that power can be generated in paster way



* The Hydal and Gas plants are the fast sync. units. So that they not to get Hot reserve.

* The thermal plant is a slow synchronisation so that it can be kept at hot

* The Nuclear plant is neither shutdown nor hot because the power generation is a critical one due to Nuclear fusion and it is difficult to control inorder to change the power generation. Hence it is working as a constant load.   Ex:- Thermal plant

Spinning Power:— It is the amount of power available at the busbar and deliver to the load by using transmission lines

* Load Factor:—

$$\text{Load Factor (or) Plant load function} = \frac{\text{Avg. load}}{\text{Max load (or) Max. demand}} = \frac{\text{Avg. Load (Actual Energy Generated)}}{\text{Max (Total no. of load hours)}}$$

< 1.0 (or) $< 100\%$.   24 (or) 8760.

The load factor is define in a dialy manner or annual. If it is daily 24. In order to minimise the cost of energy, the load factor of the plant should be high.

PLF = 60%.

PLF = 80% ← Most Economical.

If the avg. load of the plant is almost equals to max. load, there will be effective utilization of mech. energy. So that the amount of fuel reduced

The fuel cost is reduced, the running cost of the system is reduced and finally the cost per unit is minimised

* The nuclear plant is the one, which can maintain highest load factor among other plants i.e., 80 % and above because the variation of the load on the plant is very less so that over load is high

* In case of thermal plant there is variation of load, then the load factor will be around 60 % to 70%.

* Diversity Factor :-

$$\text{Diversity factor} = \frac{\text{Arithimatic sum of max loads of the consumer}}{\text{Simultanious max load on the system.}}$$

> 1.0

* A simultanious max load on the system should be less than arithimatic sum of max loads of the consumers.

* In order to minimise the cost of energy, the diversity factor of the system should be high

Diversity factor = 130%

= 145% ← Most Economical.

The selection of installed capacity is based on the simultanious max. load on the system. If the simultanious max. load is less, the diversity factor will be high and also the ~~sel~~ selection of installed capacity will be reduced. If the installed capacity is reduced, the fixed cost is reduced so that the cost of energy will be minimise.

Cost = Fixed cost + Running cost

(Diversity Factor + Load Factor)

* In order to minimise the cost of energy, both the load factor and diversity factor should be high.

Ex:-

Consumers	Connected load	Max. load
A	300KW	280KW
B	350KW	330KW
C	400 KW	370KW
		980

Time	8-10	16-18	12-14
8-10	280	220	210
16-18	300	330	280
12-14	320	300	370
	900	850	860.

$$\text{Diversity Factor} = \frac{980}{900}$$

$$>1$$

At the system is having more consumers, it is difficult to have individual timings inorder to get the max. load. Hence there will be more than one consumer having one max. load at any perticular time which is result as the simultaneous load on the system will increases. so that it is difficult to reduce the physical cost by using the diversity factor. However the cost of the system is ↑ by using load factor by minimising the fuel cost of the system.

Plant capacity factor:-

Average load of the plant to the installed capacity

$$<1.0$$

$$PLF = \frac{AL}{ML}$$

reserve = +ve

system is stable

$$PCF < PLF$$

because $IC > ML$

$PCF = PLF$

$ML = IC$

Reserve $= 0$

system is critical stable

ex A 200 MW line is having the plant capacity factor and the plant load factor are 50% & 60% respectively. max. load on the plant in MW is

$$\frac{PCF}{PLF} = \frac{ML}{IC}$$

$$\frac{0.5}{0.6} = \frac{ML}{200}$$

$$ML = \frac{5}{6} \times 200 \Rightarrow 166.67 MW$$

ex A 100 MW generator is having a plant capacity factor and the plant load factor are 90% & 50% respectively. The reserve capacity of the plant in MW is

$$\text{reserve} = \text{Installed capacity} - \text{Maximum load}$$

$$= 100 - 80$$

$$= 20 MW$$

ex A 100 MW generator is supplying a consumer loads of 40 MW, 45 MW and 35 MW the simultaneous load on the system is 95 MW the diversity factor of the system is

$$DF = \frac{40+45+35}{95} \Rightarrow 1.26$$

→ A 100 MW generator is having a load of 50 MW for 12 hrs and a load of 90 MW for remaining 12 hrs in a day. The no. of units of that generated in a day

$$\text{no. of units} = 50\times12 + 90\times12$$
$$= 12\times140$$
$$= 12\times14$$
$$= 168\times10^4 \text{ kWhr}$$

→ A generator is having a load of 20 MW for 12 hrs & 40 MW for 6 hrs in a day. The capacity of the generator is 50 MW. the load factor of the generator in a day

$$PLF = \frac{20\times12+40\times6}{40\times24}$$

$$= \frac{240+240}{960} \Rightarrow \frac{480}{960} \Rightarrow 0.5$$

$$PCF = \frac{20\times12+40\times6}{50\times24} \Rightarrow \frac{480}{1200} \Rightarrow 0.4$$

$$PCF = \frac{\text{actual energy generated}}{\text{maximum possible energy that can be generated based on installed capacity.}}$$

< 1.0

$$\text{plant utilisation factor} = \frac{\text{actual energy generated}}{IC\times(\text{actual no. of hrs does the plant is utilized})}$$

exp Gen — 100 MW

0–3 hrs — 30 MW

3–6 hrs — 60 MW

6–9 hrs — 80 MW

9–12 hrs — 50 MW

$\boxed{\text{12–15 hrs — 70 MW}}$ → repair

15–18 hrs — 90 MW

18–21 hrs — 40 MW

$$PCF = \frac{3(30+60+80+80+110+70+40+20)}{100 \times 24}$$

$$= 0.55$$

$$\text{plant utilisation factor} = \frac{3(30+60+80+50+0+90+40+20)}{100 \times 24}$$

$$= 0.4625$$

$\boxed{PCF \neq PUF}$ $\boxed{PUF < PCF}$

→ The average load and the maximum load on the system are increasing so that the generation capacity should be also increased. How much amount of generation capacity should be added optimally will be decided by PCF, and the selection of the size of the unit is optimally decided by PUF.

$$PUF = \frac{\text{maximum load on the plant}}{\Sigma C} = \frac{\left(\frac{ML}{av}\right)}{\left(\frac{\Sigma C}{av}\right)} = \frac{(1/PLF)}{(1/PCF)}$$

$$PUF = \frac{PCF}{PLF}$$

$$\boxed{PCF = PUF \times PLF}$$

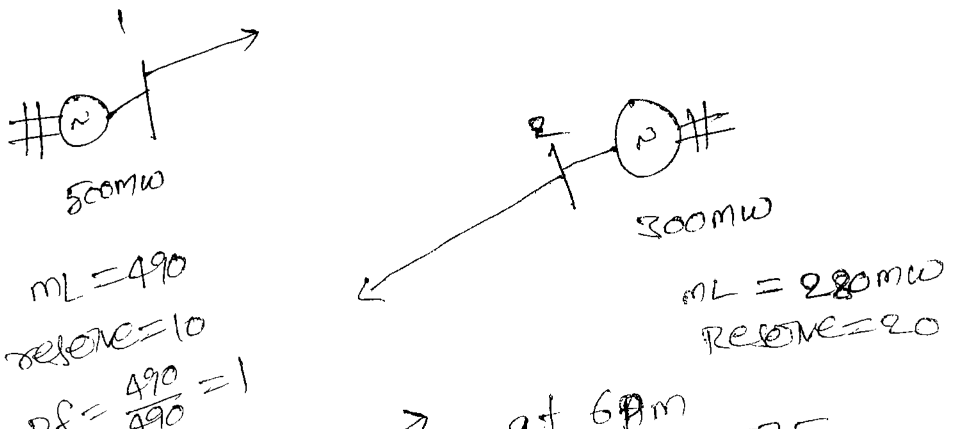
Demand factor:-

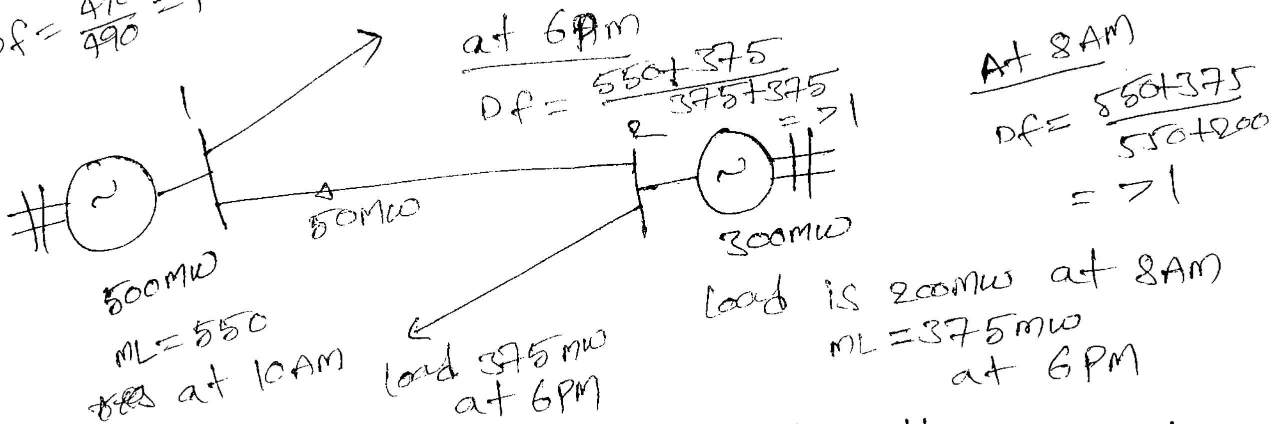
$$\text{Demand factor} = \frac{\text{max demand}}{\text{connected load}}$$

$$< 1.0$$

Advantages of the interconnected load connection system:-

i) Reliability of supply is high
ii) exchange of peak loads
iii) no need to maintain reserve capacity
iv) Diversity factor can be more than 1
v) The cost of generator can be minimized by utilizing small capacity olden plants to meet the peak load.

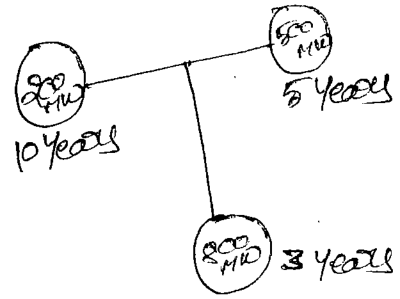




→ If a fault occurs in one area, the other area is able to contribute the power to the faulty area so that the realiability of supply increased.

→ The peak load of one area is shared by other area provided that there is no peak load in both the areas at same time.

→ In case of isolated system the Df is 1
more than 1



Load = 1800 MW

1400 MW – 2hrs

1100 MW –

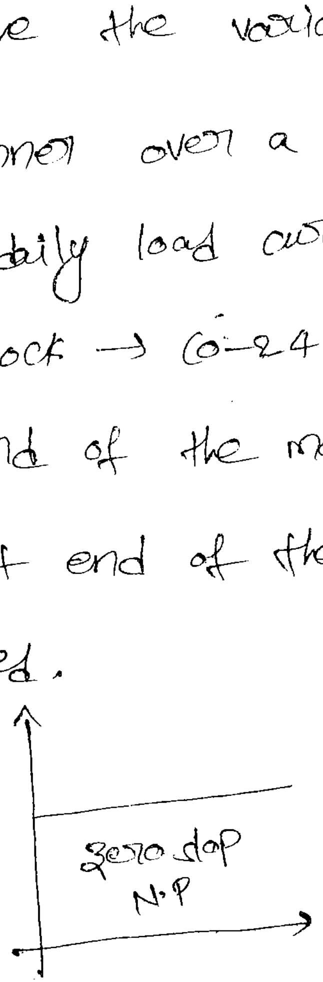
Graphical ~~representation~~

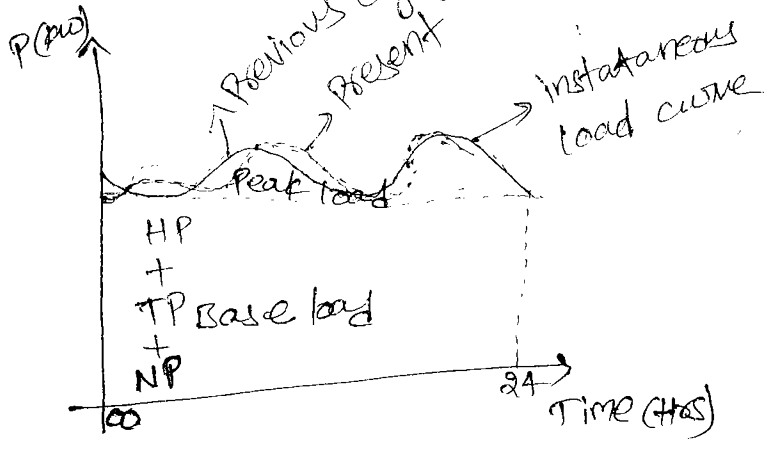
Load curve:

A give the variation of load w.r.to time in a graphical manner over a specified period. In a real time application is daily load curve.

clock → (0–24 hrs)

At the end of the month, the monthly load curve can be applied, at end of the year, the monthly load curve can be applied.





→ The load which will be ~~dry~~ those through out the day, is considered as base load.

→ The load which will be suddenly rise for a short interval, is considered as peak load.

non conventional

solar
wind
Tidal
Biomass
MHD

$\Big\}$ Peak load

geo thermal → Base load

conventional

Thermal
nuclear $\Big\}$ base load
Hydel → base (or) peak
gas → Peak
Diesel → back up (or) standby

→ The base load plants will operate through out the day.

→ In order to know the no. of hrs does the peak load plant will operate, the cost eqn of the plants are required.

$$\text{cost} = FC + RC$$
$$= Rs/kw + \text{Paise}/kwhr$$

FC – fixed cost → energy
RC – running cost → installed capacity

$$\text{cost } C_1 = Rs\, a_1/kw + \text{Paise } b_1/kwhr \rightarrow \text{Base load}$$
$$\text{cost } C_2 = Rs\, a_2/kw + \text{paise } b_2/kwhr \rightarrow \text{Peak load}$$

$$\boxed{a_1 > a_2 \quad \text{but } b_1 < b_2}$$

→ A base load plant is operate where the fixed cost is high and the running cost will be less. In case of peak load plant, the fixed cost is less & the running cost is high.

overall cost $c = c_1 + c_2$

→ In order to get the no. of hrs at peak load time, the overall cost of the system is to be minimised wrto the generation of peak load plant.

$\frac{dc}{dP} = 0$ (P is of peak load)

no. of hrs $\boxed{h = \left(\frac{a_1 - a_2}{b_2 - b_1}\right) \times 100}$

→ The following information can be ~~abtained~~ from load curve

i) Area = $P \times t$ = no. of units consumed

ii) Peak point = max load

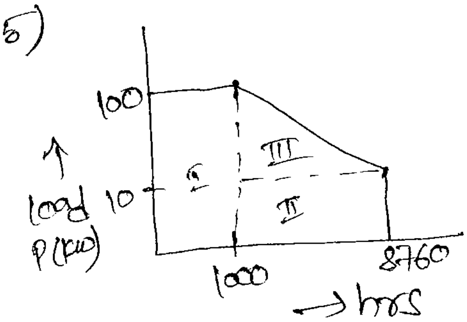
iii) avg load = $\frac{\text{Area}}{\text{no. of hrs}}$

iv) PLF = $\frac{aL}{ML}$

→ The load curve of system is basis for load forecasting i.e, the power generation requirements for tomorrow will be forecasted by taking the today values of the basic values with certain variations (or)

Pg-11

5)



ML = 100

$$AL = \frac{1000 \times 1000 + 10 \times 7760 + \frac{1}{2} \times 7760 \times 90}{8760}$$

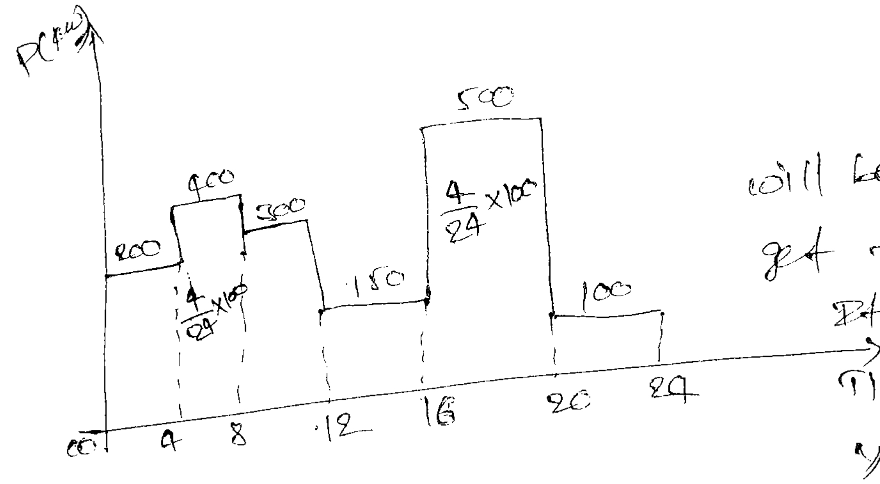
= 60.13 kW

Load factor = $\frac{60.13}{100} \times 100 \Rightarrow 60.13\%$

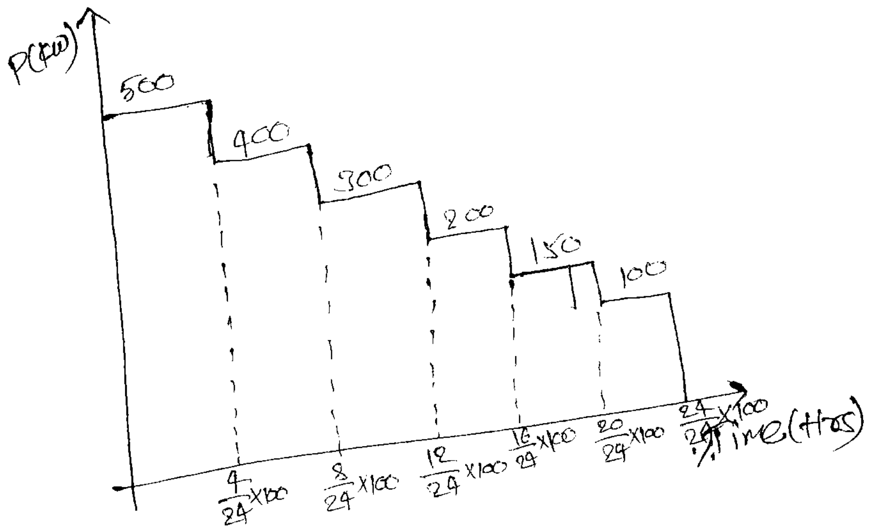
units = 10^5 ... no. of units = 100000 + 77600 + 349200

= 526800 kW hr

= 526.8 MWhr.

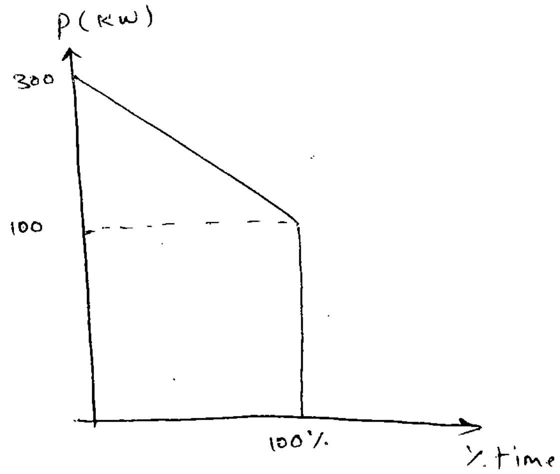
→ 

The load curve of system will be rearrange in order to get the load duration curve. It gives the variation of the load w.r.to % of time and the loads are rearrange in descending order.



3-10-12

* Daily Load duration curve of the system as shown. The no. of units that are produced



Sol:-

No. of units = Area

$= \frac{1}{2}bh + bh$

$= (\frac{1}{2}\times24\times200) + (24\times100)$

$= 2400 + 2400$

$= 4800$ units.

Average load $= 200$ $\quad (\because \frac{4800}{24} = 200)$

Load factor $= \frac{200}{300} = 0.67$

Another Method.

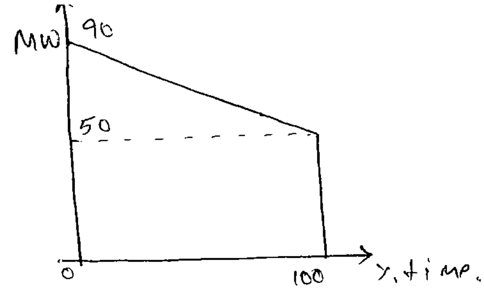
Avg. load $= \frac{1}{2}[300+100]$

$= 200$ kW

Units $= 200\times24$

$= 4800$ Units.

13). Capacity factor = 70%



$\Rightarrow$ Reserve capacity = ?

Average load $= \frac{1}{2}[90+50] = 70$ MW

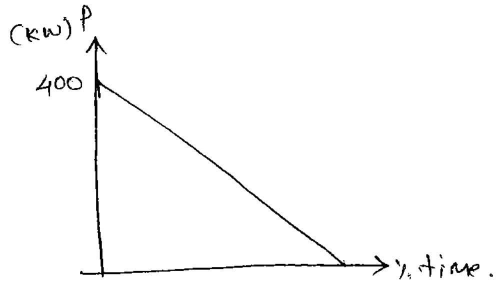
Installed capacity $= \frac{70}{0.7} = 100$

Reserve capacity = Installed capacity − Max. load

$= 100 - 90$

$= 10$ MW.

Q. The annual load duration curve of the system is as shown. The number of units that are generated ___.



Sol:-

No. of units $= \frac{1}{2} bh$

$= \frac{1}{2} \times 8760 \times 400$

$= 876 \times 2$

$= 1752$ ~~units~~ MWhr.

(or)

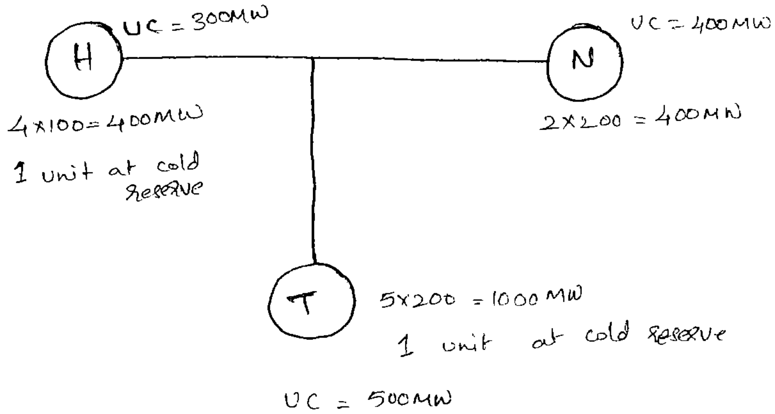
Avg. load $= \frac{1}{2}[400+0] = 200$

units $= 200 \times 8760$ units

* Minimisation of fuel cost :— (Economic load dispatch)

1. Pre load dispatch (or) Unit commitment :—

Select optimally the required no. of Generating units from the available units inorder to meet the demand over a specified period



Demand = 1200MW

UC − Unit Commitment

2. Online load dispatch:—

Allocate the existing load among the optimally selected units in such away that the total fuel cost of the system is to be minimised from time to time i.e., Hour to Hour basis

Load Cycle:—

00 - 03 Hrs $\rightarrow$ 600 MW $\Rightarrow$ 400(N) + 200 (H) + 0(Th)

Fuel cost is minimised.

03 - 06 hrs $\rightarrow$ 900 MW $\Rightarrow$ 400(N) + 300(H) + 200(Th)

Fuel cost is minimised.

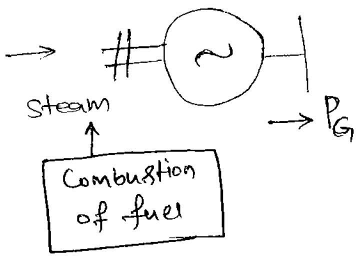
06 - 09 hrs $\rightarrow$ 1100 MW $\Rightarrow$ 400(N) + 300(H) + 400 (Th)

Fuel cost is minimised.

09 - 12 hrs $\rightarrow$ 1000 MW $\Rightarrow$ 400(N) + 300(H) + 300 (Th)

Fuel cost is minimised.

* Fuel cost equation:—



$$F = \frac{1}{2}\alpha P_G^2 + \beta P_G + \gamma \quad Rs/hr$$

(Non-linear simultanious equation)

α, β and γ are called +ve Real Co-efficients

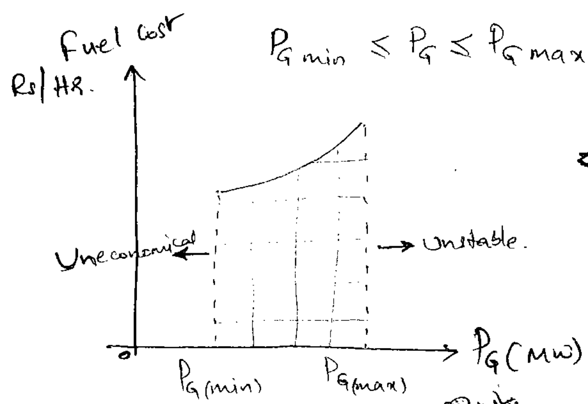
Cost of Fuel $\Rightarrow$ $C = \frac{1}{2}\alpha P_G^2 + \beta P_G + \gamma$ Rs/hr.

For n-Generations:—

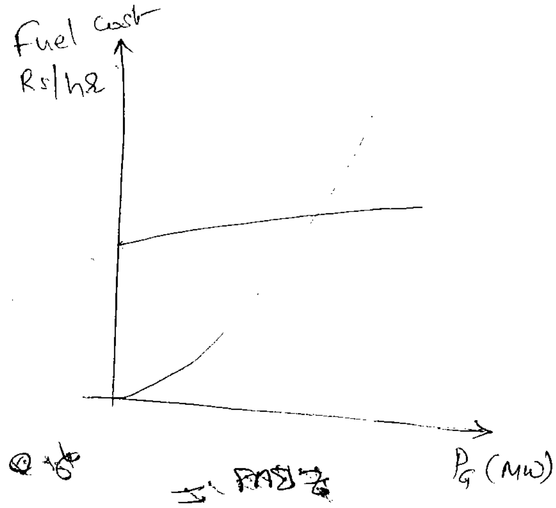
$$F_i = \frac{1}{2}\alpha_i P_{G_i}^2 + \beta_i P_{G_i} + \gamma_i \quad Rs/hr$$

$(\alpha = 1, 2, 3 \ldots n)$

$P_{G\,min} \leq P_G \leq P_{G\,max}$



$\Leftarrow$



→ For a load ... machine is stable but the cost of generation will be high so that it is "uneconomical"

→ The fuel cost of the Generator is to be differentiated with respect to generation capacity in order to minimise the fuel cost of the system which is called as "Incremental fuel Cost".

$$\frac{dF}{dP_G} = \text{Incremental fuel Cost } (Rs/hr/MW) \rightarrow Rs/MWHR$$

$$= \alpha P_G + \beta \ Rs/MWHR$$

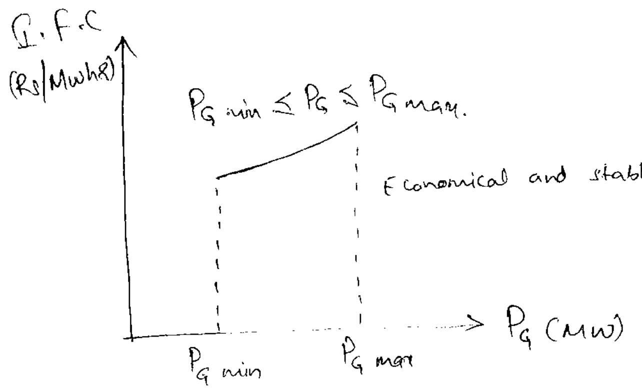
$$\frac{dc}{dP_G} = \alpha P_G + \beta \ Rs/MWHR.$$

$$\frac{dF_i}{dP_{Gi}} = \alpha_i P_{Gi} + \beta_i \ Rs/MWHR$$

$$(i = 1, 2, 3 \ldots n)$$

α → slope of the Incremental fuel Cost Curve

β → Interception of the Incremental Fuel Cost Curve



Q. Minimise the total fuel cost of n-Generating units which are optimally selected in such away that the demand of the system is equal to total power Generation. Transmission line losses are ignored

$$\text{Min } F_T = F_1 + F_2 + \ldots + F_n = \sum_{i=1}^{n} F_i$$

Subjected

$$P_d = P_{G1} + P_{G2} + P_{G3} + \ldots + P_{Gn} = \sum_{i=1}^{n} P_{Gi}$$

Constrained Minimisation

and

$$P_L = 0$$

In order to get the solution for the above problem, convert the Constrained minimisation in to Unconstrained minimisation by forming Auxilary function (F).

Auxilary function F = main function + λ (Constraint)

λ = Legrangian Multiplier

$$F = \sum_{i=1}^{n} F_i + \lambda\left(P_d - \sum_{i=1}^{n} P_{Gi}\right) \quad \text{(Unconstrained)}$$

Minimise the Auxilary function w. r. to Generation inorder to get the solution for the problem.

$$\frac{dF}{dP_{Gi}} = \frac{d}{dP_{Gi}} \sum_{i=1}^{n} F_i + \lambda\left(\frac{dP_d}{dP_{Gi}} - \frac{d}{dP_{Gi}} \sum_{i=1}^{n} P_{Gi}\right) = 0.$$

$$\frac{d}{dP_{Gi}}(F_1 + F_2 + F_3 + \dots + F_n) + \lambda\left(\frac{dP_d}{dP_{Gi}} - \frac{d}{dP_{Gi}}(P_{G1} + P_{G2} + P_{G3} + \dots + P_{Gn})\right) = 0.$$

Suppose: $F_1 = \frac{1}{2}\alpha P_{G1}^2 + \beta P_{G1} + \gamma$

$$\frac{dF_1}{dP_{G2}} = 0.$$

$$\Rightarrow \frac{dF_i}{dP_{Gi}} + \lambda(0 - 1) = 0$$

Units of Legrangian Multiplier is Rs/MWHR.

$$\boxed{\frac{dF_i}{dP_{Gi}} = \lambda \quad \text{Rs/MWHR}}$$

$$\boxed{\frac{dF_1}{dP_{G1}} = \frac{dF_2}{dP_{G2}} = \frac{dF_3}{dP_{G3}} = \dots = \frac{dF_n}{dP_{Gn}} = \lambda} \quad \text{Rs/MWHR}$$

If the demand on the system = Generation, in order to minimise the fuel cost of the system, the optimal generation capacity can be obtained provided that the I.F.C of all units should be same and is equal to λ.

Pg-7

1. Fuel cost Eqn: $F = 0.12 P_G^2 + 20P_G + 40$ Rs/HR.

Capacity = 200 MW.

$$\frac{dF}{dP_G} = 0.24 P_G + 20 \quad \text{Rs/MWhR.}$$

75% of the capacity = 200×0.75 = 150 MW.

$$\Rightarrow F = 0.12(150)^2 + 20(150) + 40 \quad \text{Rs/HR}$$

$$\frac{dF}{dP_G} = 0.24(150) + 20 \quad \text{Rs/MWhR.}$$

Formulae:-

Fuel cost/day = Fuel cost/HR × 24

Fuel cost/annum = Fuel cost × 8760

Fully loaded = 200MW

$$\Rightarrow F = 0.12(200)^2 + 20(200) + 40 \quad \text{Rs/HR}$$

$$\frac{dF}{dP_G} = 0.24(200) + 20 \quad \text{Rs/MWHR}$$

Q. The cost function of a 50 MW Generator $F(P_i) = 0.02 P_i^2 + 53P_i + 225$ Rs/HR when 100% loading is applied the incremental fuel cost is

a) 55 Rs/HR b) 53 Rs/MwHR c) ✓ 55 Rs/MwHR d) 53 Rs/HR.

PG-7

2. Fuel cost $F_1 = 0.2 P_1^2 + 30 P_1 + 60$ Rs/HR

$F_2 = 0.15 P_2^2 + 20P_2 + 80$ Rs/HR.

Legrangian Multiplier = 120.

$$\frac{dF_1}{dP_{G1}} = \frac{dF_2}{dP_{G2}} = \lambda = 120$$

$$\Rightarrow 0.4P_1 + 30 = 0.3P_2 + 20 = 120$$

$$P_1 = \frac{120-30}{0.4} = 225\text{MW} \qquad P_2 = \frac{120-20}{0.3} = 333.3 \text{ MW}$$

Power recieved by the load

$P_D = P_1 + P_2$

$= 225 + 333.3$

$= 558.3$ MW

PG-8
8.

$I_{c1} = 0.1 P_1 + 8.0$ $\qquad$ $P_W = 100\ MW.$

$I_{c2} = 0.15 P_2 + 3.0$

$\Rightarrow$ ANS: $\underline{\underline{C}}$ ✓

PG-7
3.

$$\frac{dF_1}{dP_1} = 0.1 P_{G_1} + 20 \ \text{Rs/MWHR} \qquad \frac{dF_2}{dP_2} = 0.12 P_2 + 16 \ \text{Rs/MWHR}$$

$$P_1 + P_2 = 150 \rightarrow (1)$$

$$\frac{dF_1}{dP_1} = \frac{dF_2}{dP_2}$$

$$0.1 P_1 + 20 = 0.12 P_2 + 16$$

$$P_1 = \frac{0.12 P_2 + 16 - 20}{0.1} = 1.2 P_2 - 40 \rightarrow (2)$$

$$1.2 P_2 - 40 + P_2 = 150$$

$$2.2 P_2 = 190$$

$$P_2 = \frac{190}{2.2} = 86.36\ MW$$

$$P_1 = 63.64\ MW$$

$$\Rightarrow \lambda = \frac{dF_1}{dP_1} = 0.1(63.64) + 20$$

$$= 26.36 \ \text{Rs/MWHR.}$$

PG-8
7.

$$P_1 + P_2 = 600 \rightarrow (1)$$

$$\frac{dC_1}{dP_1} = \frac{dC_2}{dP_2}$$

$$0.012 P_1 + 8 = 0.018 P_2 + 7$$

$$P_1 = \frac{0.018 P_2 + 7 - 8}{0.012} = 1.5 P_2 - 83.3 \rightarrow (2)$$

From (1) & (2) $\quad P_1 = 326.6\ MW$

$\quad P_2 = 273.33\ MW.$

Pg-10
18. $F_1 = 0.2P_1^2 + 30P_1 + 100$ Rs/Hr $20 \leq P_1 \leq 80$

$F_2 = 0.25P_2^2 + 40P_2 + 150$ Rs/Hr $40 \leq P_2 \leq 100.$

$\Rightarrow P_1 = 83.33MW$, $P_2 = 46.67MW$

$\Downarrow$ 80MW $\Downarrow$ 50MW.

Pg-14
20. Ans: A, 20MW

Pg-12
8. P_1, P_2 are Unknowns

$40^{MVA} - 5\%$. $60^{MVA} - 5\%$.

$P_1 - ?$ $P_2 - x$

$\frac{40}{P_1} = \frac{5}{x} \Rightarrow x = \frac{5P_1}{40}$ $x = \frac{5P_2}{60}$

$\Rightarrow \frac{5P_1}{40} = \frac{5P_2}{60}$

$\Rightarrow P_1 = \frac{2}{3} P_2$

$P_1 + P_2 = 80$

$\frac{2}{3} P_2 + P_2 = 80$

$\frac{5}{3} P_2 = 80$

$\Rightarrow P_2 = 32MW$

$P_1 = 48MW$.

*. The I.F.C of 2-Generators.

$$\left.\begin{aligned} \frac{dF_1}{dP_{G1}} &= 0.2P_{G1} + 20 \\ \frac{dF_2}{dP_{G2}} &= 30 \end{aligned}\right\} \text{Rs/MW Hr.}$$

$100 \leq P_i \leq 175$ MW

$i = 1, 2$

The load on the system is 300MW. The losses are ignored. The Generation schedules are ___

The Incremental Fuel Cost of G_2 is 30 Rs/MwHr and it is constant, irrespective of Generation. Hence the value of P_2 will be selected from the limits. Select higher limit for P_2 i.e., 175 MW and the balance will be assign for P_1 i.e., $P_1 = 125MW$.

Pg-16
2.

$I_{c1} = 20 + 0.3P_1$, $I_{c2} = 30 + 0.4P_2$, $I_{c3} = 30.$

So $P_3 = 300$ MW (Highest limit)

$P_1 + P_2 = 400 \rightarrow (1)$

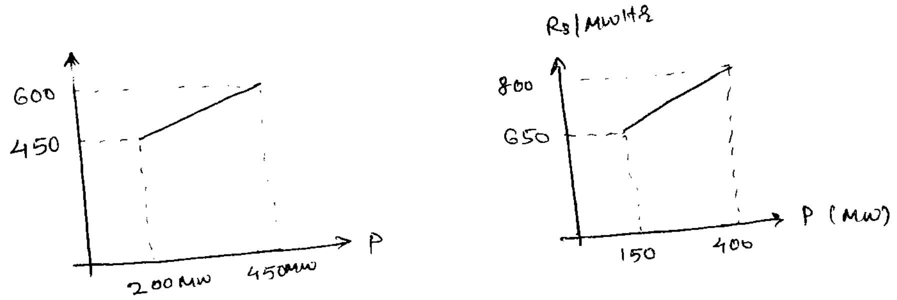
$20 + 0.3P_1 = 30 + 0.4P_2$ $(\because I_{c1} = I_{c2} \neq I_{c3})$.

$0.3P_1 - 0.4P_2 = 10 \rightarrow (2)$

From (1) & (2)

$P_1 = 242.86$ MW , $P_2 = 157.14$ MW .

Pg-16
1.



Load = 700 MW

Gen A = 450 MW $(\because$ Less cost)

Gen B = 250 MW

Pg-8
9.

$P_d = P_G + P_G = 2P_G$

Gen. A will share more than P_G $(\because$ cost is less after P_G for A) .

Pg-7
4.

$F_1 = 0.15P_1^2 + 20P_1 + 30$ Rs/HR

$F_2 = 0.2P_2^2 + 16P_2 + 20$ Rs/HR.

$0.3P_1 + 20 = 0.4P_2 + 16$

$\Rightarrow P_1 + P_2 = 100$ $\rightarrow P_1 + P_2 = 200$

$P_1 = 51.42$ MW $P_1 = 108.57$ MW

$P_2 = 48.58$ MW $P_2 = 91.43$ MW

$F_1 = (0.15(51.42)^2 + 20(51.42) + 30 + 0.2(48.58)^2 + 16(48.58) + 20) \times 12$

Pg-7
5.

$P_{G1} = -120 + 60 I_{c1} - 2.5 I_{c1}^2$

$P_{G2} = -140 + 40 I_{c2} - 2 I_{c2}^2$

$P_{G3} = -90 + 50 I_{c3} - 1.5 I_{c3}^2$

Load = 500 MW,

For optimum generation $I_{c1} = I_{c2} = I_{c3} = \lambda$

$P_{G1} + P_{G2} + P_{G3} = P_d = 500$

$F_T = -120 + 60\lambda - 2.5\lambda^2 - 140 + 40\lambda - 2\lambda^2 - 90 + 50\lambda - 1.5\lambda^2 = 500$

$\Rightarrow -6\lambda^2 + 150\lambda - 850 = 0.$

$\Rightarrow \lambda = 8.68 , 16.32.$

The I.F.C of the system should be less

$\Rightarrow \lambda = 8.68.$

$P_{G1} = -120 + 60(8.68) - 2.5(8.68)^2 = 212.44$ MW

$P_{G2} = -140 + 40(8.68) - 2(8.68)^2 =$

$P_{G3} = -90 + 50(8.68) - 1.5(8.68)^2 =$

—.

Pg-17.
2.

$\frac{dF_1}{dP_1} = 0.1P_1 + 20$ Rs/MwHr

$\frac{dF_2}{dP_2} = 0.12P_2 + 15$ Rs/MwHr.

Most economical Division

$P_1 + P_2 = 300 \rightarrow (1)$

$\frac{dF_1}{dP_1} = \frac{dF_2}{dP_2}$

$0.1P_1 + 20 = 0.12P_2 + 15 \rightarrow (2)$

$\Rightarrow P_1 = 140.9$ MW

$P_2 = 159.1$ MW.

Total fuel cost $= F_T = F_1 + F_2 = \frac{0.1 P_1^2}{2} + 20P_1 + r_1 + \frac{0.12 P_2^2}{2} + 15P_2 + r_2$

$F_T = 0.05(140.9)^2 + 20(140.9) + 0.06(159.1)^2 + 15(159.1) + r_1 + r_2$

$F_T = Rs\ 7715.9 + r_1 + r_2\ Rs/Hr.$

Equal load:

$P_1 = P_2 = 150.$

$F_T = 0.05(150)^2 + 20(150) + 0.06(150)^2 + 15(150) + r_1 + r_2$

$= Rs\ 7725 + r_1 + r_2\ Rs/Hr.$ — Uneconomical.

Saving $= 7725 - 7715.9$

$= 9.1\ Rs/Hr.$

Saving/Annum $= 9.1 \times 8760 =$

Model:-2

Minimise the total fuel cost of n- Generating units which are optimally selected in such a way that the demand and transmission line loss equal to total power generation.

$$\left.\begin{aligned} \text{Min } F_T &= F_1 + F_2 + F_3 + \dots + F_n \\ &= \sum_{i=1}^{n} F_i \\ &\text{subjected to} \\ P_d + P_L &= P_{G1} + P_{G2} + P_{G3} + \dots + P_n \\ &= \sum_{i=1}^{n} P_{Gi} \end{aligned}\right\} \text{Constrained minimisation.}$$

P_L = Transmission Line loss

For a given demand, if the loss in the system is included the generation capacity will increase so that the fuel cost of the system will increase. Hence the transmission line loss should be express a function of Generation

$$P_L = \sum_{i=1} \sum_{j=1} P_{Gi} B_{ij} P_{Gj}$$ (Non-linear ...)

P_{Gi} = Generation of i^{th} Unit

P_{Gj} = Generation of j^{th} unit

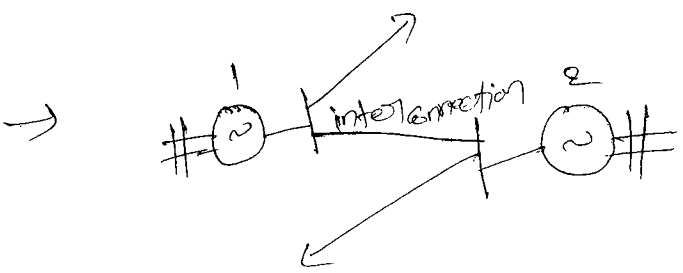
n = no. of Generating units (or) No. of buses.

B_{ij} = Loss Co-efficient between i and j units

$\frac{1}{MW}$ (or) MW^{-1}

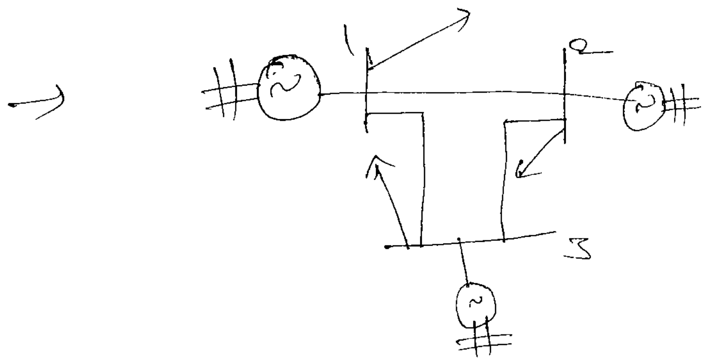
Two bus system:-

The powersystem n/w is interconnected system



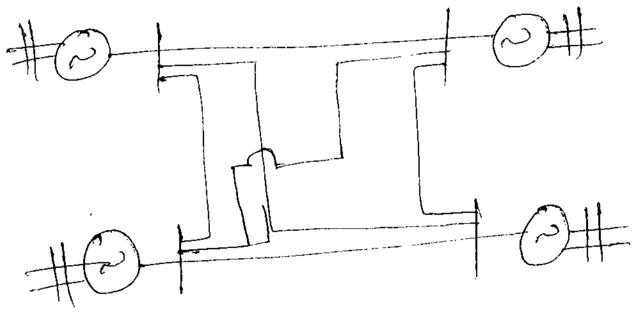
$$P_L = B_{11} P_{G1}^2 + P_{G1} B_{12} P_{G2} + P_{G2} B_{21} P_{G1} + B_{22} P_{G2}^2$$

→ ∴ The system is dealing with 4 loss coefficients



$$P_L = B_{11} P_{G1}^2 + P_{G1} B_{12} P_{G2} + P_{G1} B_{13} P_{G3} + P_{G2} B_{21} P_{G1} + B_{22} P_{G2}^2 + P_{G2} B_{23} P_{G3} +$$
$$P_{G3} B_{31} P_{G1} + P_{G3} B_{23} P_{G2} + B_{33} P_{G3}^2$$

∴ The system is dealing with 9 loss coefficients

→ 

∴ The will dealing with 16 loss coefficients.

→ If you have a n-bus system there will be n^2 loss coefficients.

→ As the size of the power system n/w increases by increasing the number of buses, the number of loss coefficients will increase. so that the loss in the transmission n/w will increase for a given demand. Hence the generation capacity will increase and the fuel ~~cost~~ cost of the system will increase.

→ In order to reduce the fuel cost of the system, the generation capacity is to be reduce by reducing the line loss for which sum of the loss coefficients can be made as zero. The loss coefficients can be made as zero provided that there should be allign, i.e., use minimum no. of line but make the system as interconnecting system.

→ As the size of the power system n/w is increases, the no. of loss coefficients which are became zero will ↑ where as non-zero loss coefficients will ↓. In a larger power system n/w most of the loss coefficient will be zero and there will be few loss coefficients will be zero, so that the loss in the system will be reduce and generation capacity will reduce.

loss coefficients:-

1) self loss coefficients $(j=i) \rightarrow B_{ii}$ (or) B_{jj}

2) mutual loss coefficients $(j \neq i) \rightarrow B_{ij}$ (or) B_{ji}

→ most of the mutual loss coefficients are zeros where as most of the self loss coefficients are not zeros.

→ In mutual loss coefficients $B_{ij} = B_{ji}$ where as in self loss coeffients $B_{ii} \neq B_{jj}$

→ The mutual loss coefficients magnitude is less where as the magnitude of the self loss coefficients is more.

→ The self loss coefficients are assigned ~~with~~ with +ve sign where as mutual loss coefficients are assigned with -ve sign

→ which of the following relations are correct regarding the loss coefficients.

a) $B_{11} = B_{22} = 0.006$, $B_{12} = B_{21} = 0.004$

b) $B_{11} = 0.006$, $B_{12} = B_{21} = 0.004$, $B_{22} = 0.002$

c) $B_{11} = 0.006$, $B_{12} = B_{21} = 0.002$, $B_{22} = 0.004$

d) $B_{11} = 0.004$, $B_{12} = B_{21} = -0.001$, $B_{22} = 0.002$

→ In TL $\quad P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} P_{Gi} B_{ji} P_{Gj}$

The Transmission line loss with the function of the generation capacity ~~load~~ if the generation changes, the loss in the system is also changes. so that the loss in variable generation however the demand of the system changes.

→ If the generation changes the loss in the system will be changes but the loss coefficient will not change.

* Auxilary function (F) = main function + λ (constant)

$$F = \sum_{i=1}^{n} f_i + \lambda\left(P_d + P_L - \sum_{i=1}^{n} P_{Gi}\right) \quad \text{(unconstrained)}$$

$$\frac{dF}{dP_{Gi}} = \frac{d}{dP_{Gi}}\sum_{i=1}^{n} f_i + \lambda\left(\frac{dP_d}{dP_{Gi}} + \frac{dP_L}{dP_{Gi}} - \frac{d}{dP_{Gi}}\sum_{i=1}^{n} P_{Gi}\right) = 0$$

$$\frac{d}{dP_{Gi}}(f_1 + f_2 + \cdots + f_i + f_n) + \lambda\left[\frac{dP_d}{dP_{Gi}} + \frac{dP_L}{dP_{Gi}} - \frac{d}{dP_{Gi}}(P_{G1} + P_{G2} + \cdots P_{Gi} + P_{Gn})\right] = 0$$

$$\frac{df_i}{dP_{Gi}} + \lambda\left(0 + \frac{dP_L}{dP_{Gi}} - 1\right) = 0$$

$\frac{df_i}{dP_{Gi}}$ → IFC (incremental fuel cost) (M/hr)

$\frac{dP_L}{dP_{Gi}}$ → Incremental TL loss (no units)

$$\therefore \frac{df_i}{dP_{Gi}} = \lambda\left[1 - \frac{dP_L}{dP_{Gi}}\right]$$

$$\Rightarrow \frac{df_i}{dP_{Gi}} \times \frac{1}{1 - \frac{dP_L}{dP_{Gi}}} = \lambda$$

$$\frac{df_i}{dP_{Gi}} L_i = \lambda$$

$$L_i = \frac{1}{1 - \frac{dP_L}{dP_{Gi}}}$$ = Penality factor of i^{th} unit (no units)

For n-generators

$$\boxed{\frac{df_1}{dP_{G1}} L_1 = \frac{df_2}{dP_{G1}} L_2 = \cdots\cdots = \frac{df_n}{dP_{Gn}} L_n = \lambda}$$

economical operation (practical case)

→ The most economical generations can be obtain in order to minimise the total fuel cost of the system provided that ~~the~~ the product of the incremental fuel cost of Penalty factor ~~are~~ are all same and is equal to Legrangian multiplier.

→ IFC in Rs/MWhr

$$\frac{df_1}{dP_{G1}} = \frac{df_2}{dP_{G2}} ------ = \frac{df_n}{dP_{Gn}} = \underset{\text{less}}{\lambda} \rightarrow \text{Rs/MWhr} \quad \text{(Ideal case)}$$

→ If the loss in the system is increases, the legrangean multiplier value is ↑ i.e., λ and it can be understand by multiplying the IFC with penalty factor.

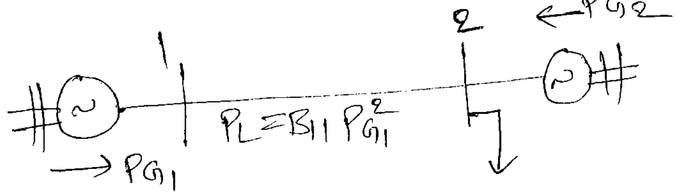
→ And The value of the penalty factor will be always ≥1

→ If the loss is included in the system, the 'λ' value will be high, but it is a practical model. Hence it is consider as most economical operation when compared to loss less problem.

$$\boxed{\frac{df_1}{dP_{G1}}L_1 = \frac{df_2}{dP_{G2}}L_2 ---- \frac{df_n}{dP_{Gn}}L_n = \lambda} \rightarrow \text{Penalty factor method}$$

→ The generation capacity can be also apply ~~int~~ the state of iterative m/d but the time taking for iterating m/d will be high. In order to taking the iterating m/d to obtain the generating capacities, the penalty factor m/d is proposed.

Special cases:-

⇒ 

→ The load of system i.e., both plant-1 & 2 are located at plant-2.

→ which of the following conditions are correct regarding loss coefficients

a) $B_{11} \neq B_{12} \neq 0$, $B_{21} = B_{22} = 0$

b) $B_{11} = B_{22} = 0$, $B_{12} = B_{21} \neq 0$

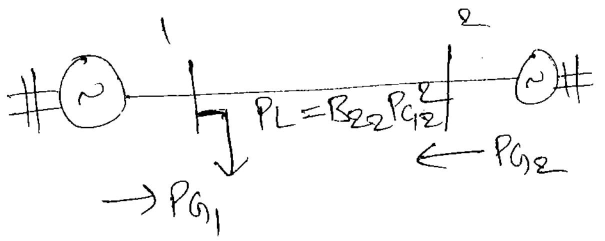
c) $B_{11} = B_{12} = B_{21} = 0$, $B_{22} \neq 0$

d) $B_{11} \neq 0$, $B_{12} = B_{21} = B_{22} = 0$

$$P_L = B_{11} P_{G1}^2 + P_{G1} B_{12} P_{G2} + P_{G2} B_{21} P_{G1} + B_{22} P_{G2}^2$$ → for 2-bus system

→ In the above diagram the loss is contributed by "P_2" will be zero. But so that the loss coefficients which are associated with P_2 unless zero. There will be a loss coefficient due to P_1 because the power generated by P_1 through TL as a self loss.

$$P_L = B_{11} P_{G1}^2$$

⇒ 

→ which of the following conditions are correct regarding loss coefficients

a) $B_{11} \neq B_{12} \neq 0$, $B_{21} = B_{22} = 0$

b) $B_{11} = B_{22} = 0$, $B_{12} = B_{21} \neq 0$

c) $B_{11} = B_{12} = B_{21} = 0$, $B_{22} \neq 0$

d) $B_{11} \neq 0$, $B_{12} = B_{21} = B_{22} = 0$

→ In above problem penalty f...

a) $L_1 = L_2 = 1.0$

c) $L_1 \neq L_2 \neq 1.0$

b) $L_1 = 1.0, L_2 \neq 1.0$ ✓

d) $L_1 \neq 1.0, L_2 = 1.0$ ✓

$$\left.\begin{aligned} L_2 &= \frac{1}{1-\frac{dP_L}{dP_{G_2}}} = \frac{1}{1-0} = 1 \\ L_1 &= \frac{1}{1-\frac{dP_L}{dP_{G_1}}} = \frac{1}{1-2B_{11}P_{G_1}} > 1.0 \end{aligned}\right\} \text{for } 1^{st} \text{ problem}$$

$$\left.\begin{aligned} L_1 &= \frac{1}{1-\frac{dP_L}{dP_{G_1}}} = \frac{1}{1-0} = 1 \\ L_2 &= \frac{1}{1-\frac{dP_L}{dP_{G_2}}} = \frac{1}{1-2B_{22}P_{G_2}} > 1.0 \end{aligned}\right\} \text{for } 2^{nd} \text{ problem}$$

$$\boxed{\frac{df_1}{dP_{G_1}} L_1 = \frac{df_2}{dP_{G_2}} = \lambda} ; \quad \boxed{\frac{df_1}{dP_{G_1}} = \frac{df_2}{dP_{G_2}} L_2 = \lambda}$$

for 1^{st} problem — for 2^{nd} problem

→ The penalty factor m/d does provide the solution for the generation capacities provided that the problem is specified with 'λ'.

→ By evaluating the generation capacities, the loss in the system will be evaluated and the power recieved by load will be also evaluated i.e., $P_d = \Sigma P_G - P_L$

→ If the demand of the system is specified and it will be shared by the generators which are existing. The optimal generator capacities are to be evaluated.

→ And also the loss in the system will be evaluated. The iterative m/d can give the solution. But the time taking is high. ~~An~~

→ An alternating solution is ~~also~~ proposed inorder to calculate generation capacity which is an approximate solution only. i.e., The losses are include a system but not coordinated. ~~when~~

Two bus system:

$$P_{G_1} + P_{G_2} - P_L = P_d \rightarrow \text{known}$$

$$P_{G_1} + P_{G_2} - [B_{11} P_{G_1}^2 + 2B_{12} P_{G_1} P_{G_2} + B_{22} P_{G_2}^2] = P_d \Rightarrow ①$$

Loss coeffients are also given

P_{G_1} & P_{G_2} are unknowns

→ Consider the problem as a loss less problem in order to solve the above equation i.e., $\frac{df_1}{dP_1} = \frac{df_2}{dP_2}$

$$\alpha_1 P_{G_1} + \beta_1 = \alpha_2 P_{G_2} + \beta_2$$

$$\boxed{P_{G_1} = \frac{\alpha_2 P_{G_2} + \beta_2 - \beta_1}{\alpha_1}}$$

$$P_{G_2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$(P'_{G_2} \text{ and } P''_{G_2})$$

$$\Downarrow$$

$$(P'_{G_1} \text{ and } P''_{G_1})$$

$$\boxed{P'_{G_1} + P'_{G_2} - P_d = P_L \rightarrow 25\,MW}$$

$$P''_{G_1} + P''_{G_2} - P_d = P_L \rightarrow 80\,MW$$

Pg-8

10) $\frac{df}{dP} = 0.002P + 18$

$\frac{dP_L}{dP} = 0.2$

$\frac{df}{dP} \cdot L = \lambda$

$(0.002P+18) \times \frac{1}{1-\frac{dP_L}{dP}} = 25$

$(0.002P+18) = 25(1-0.2)$

$P = \frac{25 \times 0.8 - 18}{0.002}$

$\therefore P =$

Pg-9

12) $\frac{df_1}{dP_1} \cancel{L_1} = \frac{df_2}{dP_2} L_2 = \lambda$

$400 \times 1.25 = \lambda$

$500 = \lambda$

Pg-9

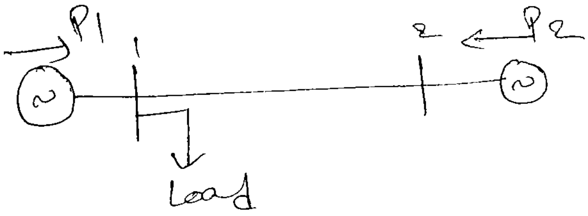
15) $P_L = B_{11} P_1^2 + 2B_{12} P_1 P_2 + B_{22} P_2^2$

$= (0.001)(150)^2 + 2(-0.0008)(150)(100) + (0.002)(100)^2$

$=$

Pg-9

16)



$P_L = B_{22} P_2^2$

$L_1 = 1.0$, $L_2 = \frac{1}{1-\frac{dP_L}{dP_{G_2}}} = \frac{1}{1-2B_{22}P_2}$

$= \frac{1}{1-2 \times 10^{-3} \times 100}$

$= \frac{1}{1-0.2} \Rightarrow 1.25$

pg-10

17)

pg-9

11)

$P_d = 260MW$

$P_L = B_{11} \cdot P_{G1}^2$

$10 = B_{11}(100)^2$

$B_{11} = 10^{-3}$

$P_1 + P_2 - P_L = P_d = 260$

$P_1 + P_2 - B_{11}P_1^2 = 260$

$P_1 + P_2 - 0.001P_1^2 = 260 \rightarrow ①$

$$\frac{dC_1}{dP_1} = \frac{dC_2}{dP_2}$$

$0.02P_1 + 16 = 0.04P_2 + 20$

$$P_2 = \frac{0.02P_1 + 16 - 20}{0.04} \Rightarrow 0.5P_1 - 100 = P_2$$

sub in ①

$P_1 + 0.5P_1 - 100 - 0.001P_1^2 = 260$

$1.5P_1 - 0.001P_1^2 = 360$

$-0.001P_1^2 + 1.5P_1 - 360$

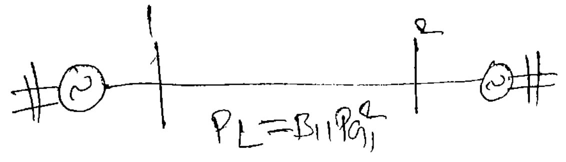
$$P_1 = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$P_1 = 1200mw$ and $300mw$ ✓

$P_2 = 500MW$ & $P_2 = 50MW$ ✓

Pg-

13)



$$\left[\begin{array}{l} 10 = B_{11} \times (100)^2 \\ B_{11} = 10^{-3} \end{array}\right]$$

$$\frac{df}{dP_1} L_1 = \frac{df_2}{dP_2} L_2 = \lambda = 25$$

$L_2 = 1.0$

$$\frac{df_2}{dP_2} = 25$$

$$0.06 P_2 + 19 = 25$$

$$P_2 = \frac{25-19}{0.06} \Rightarrow 100\text{MW}$$

$$\frac{df_1}{dP_1} L_1 = \lambda = 25$$

$$\frac{df_1}{dP_1} \times \frac{1}{1 - \frac{dP_L}{dP_1}} = 25$$

$$\frac{df_1}{dP_1} \times \frac{1}{(1 - 2B_{11}P_1)} = 25$$

$$\frac{df_1}{dP_1} = 25(1 - 2B_{11}P_1)$$

$$0.01P_1 + 17 = 25(1 - 2B_{11}P_1)$$

$$0.01P_1 + 17 = 25(1 - 2 \times 10^{-3} P_1)$$

$$0.01P_1 + 25 \times 2 \times 0.001 P_1 = 25 - 17$$

$$\therefore P_1 = 133.3\text{MW}$$

$$\therefore P_d = P_1 + P_2 - P_L$$

$$= 133.3 + 100 - B_{11}P_1^2$$

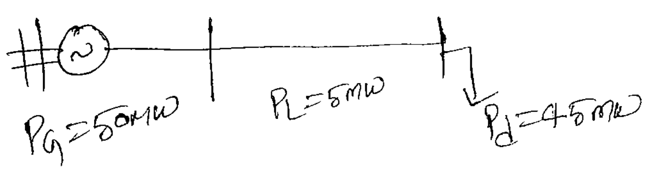
$$= 133.3 + 100 - 0.001(133.3)^2$$

$$= 133.3 + 100 - 17.76$$

$$= 215.5\text{MW}$$

Pg-15

23)

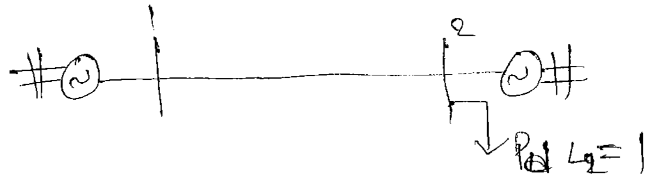


$$\frac{df}{dP_G} \cdot L = \lambda$$

$$L = \frac{1}{1 - \frac{dP_L}{dP_G}} = \frac{1}{1 - \frac{P_L}{P_G}} = \frac{1}{1 - 5/50} = 1.1$$

The load is contributed by one of the generator to be constant ~~so~~ that the demand is the loss in the TL is constant, there is no incremental loss. But there will be a loss to generation.

24)



$$L_1 = \frac{1}{1-\frac{dP_L}{dP_G}} = \frac{1}{1-3/8} = 1.6$$

→ $\frac{df}{dP} = (0.4P+1)$ Rs/mwh, the load on the system is 8mw & loss is 2mw the cost received by generator in Rs/mwhr.

$$\frac{df}{dP} L = \lambda$$

$$\frac{df}{dP} \times \frac{1}{1-\frac{dP}{dP_G}} = \lambda$$

$$\frac{df}{dP_G} \times \frac{1}{1-\frac{P_L}{P_G}} = \lambda \Rightarrow (0.4\times10+1) \times \frac{1}{1-2/10} \Rightarrow 6.25 \text{ Rs/Mwh}$$

21) $\frac{df}{dP} \cdot L = \lambda$

$$0.1\times(10+3) \times \frac{1}{1-1/10} = 1.11\times4 \Rightarrow 4.414$$

25) $\frac{dC_1}{dP_1} L_1 = \frac{dC_2}{dP_2} L_2$

$$10000 \times \frac{1}{1-\frac{dP_L}{dP_1}} = 12500\times1$$

$$\frac{dP_L}{dP_1} = 1 - \frac{10000}{12500}$$

$P_1 = 0.2$

$P_L = 0.5(0.2)^2$

$= 0.02$

$P_L = 0.1P \Rightarrow 0.02$

$\frac{dP_L}{dP_G} = 2B_{11}P_1$

$P_1 + P_2 = 22+20 \Rightarrow 42$

$P_d = 40$

$P_1 = 2$

$P_L = 0.1\times22 \Rightarrow 2.2$

$P_1 + P_2 = 20+22 \Rightarrow 42$

$P_d = 40$

$P_L = 2$

$P_L = 0.1\times20$

$= 2.$

26) If the generating ... compared to generator which are away from the load.

Load flow studies (Iterative method):-

Gauss method:-

Load bus $\longrightarrow$ known P_p & Q_p; unknown $|V_p|$ & δ_p

current at bus P

$$I_p = \sum_{q=1}^{n} Y_{pq} \cdot V_q = Y_{pp} V_p + \sum_{\substack{q=1 \\ \neq p}}^{n} Y_{pq} \cdot V_q$$

$$Y_{pp} \cdot V_p = I_p - \sum_{\substack{q=1 \\ \neq p}}^{n} Y_{pq} \cdot V_q$$

$$V_p = \frac{1}{Y_{pp}} \left[I_p - \sum_{\substack{q=1 \\ \neq p}}^{n} Y_{pq} V_q \right]$$

power at Bus P

$$S_p = V_p I_p^* = V_p^* I_p = P_p - JQ_p$$

$$I_p = \frac{P_p - JQ_p}{V_p^*}$$

$$V_p = \frac{1}{Y_{pp}} \left[\frac{P_p - JQ_p}{V_p^*} - \sum_{\substack{q=1 \\ \neq p}}^{n} Y_{pq} V_q \right] \rightarrow \text{non-linear simultaneous eqn.}$$

$$= a \pm Jb$$

$$|V_p| = \sqrt{a^2 + b^2}, \quad \delta_p = \tan^{-1}(b/a)$$

generator bus $\longrightarrow$ known P_p & $|V_p|$; unknown Q_p & δ_p

current at bus P

$$I_p = \sum_{q=1}^{n} Y_{pq} V_q = Y_{pp} V_p + \sum_{\substack{q=1 \\ \neq p}}^{n} Y_{pq} V_q$$

$$Y_{pp} V_p = I_p - \sum_{\substack{q=1 \\ \neq p}}^{n} Y_{pq} V_q$$

Power at bus p

$$S_p = V_p^* I_p = P_p - jQ_p$$

$$Q_p = -Im(V_p^* I_p)$$

$$Q_p = -Im(V_p^* \sum_{q=1}^{n} Y_{pq} V_q)$$

generator bus:-

$$Q_p = -Im(V_p^* \sum_{q=1}^{n} Y_{pq} V_q)$$

$$V_p = \frac{1}{Y_{pp}}\left[\frac{P_p - jQ_p}{V_p^*} - \sum_{\substack{q=1 \\ \neq p}}^{n} Y_{pq} V_q\right] = a \pm jb$$

$$\delta_p = \tan^{-1}(b/a)$$

Algorithm for gauss method:-

step-1:- Assume initial voltages for all the buses as flat voltages i.e., $V_p = 1.0 + j0.0$, except for slack bus

step-2:- set the convergent creteria at $|\Delta V_p|$ max at the bus

$|\Delta P|_{max} < \epsilon$ (ϵ is a set values)

step-3:- Initiate the iteration count as $K=0$

step-4:- Initiate the bus count at $P=1$

step-5:- Check is it a slack bus → yes - go to step 7 / → no - go to next step

for a slack bus real & reactive

step-6:- It is a load bus. Calculate the voltage at the bus

$$V_p^{k+1} = \frac{1}{Y_{pp}}\left[\frac{P_p - jQ_p}{(V_p^k)^*} - \sum_{\substack{q=1 \\ \neq p}}^{n} Y_{pq} V_q^k\right] = a \pm jb$$

Calculate, $\Delta V_p = |V_p^{k+1}| - |V_p^k|$ & go to next step.

step-7:- check the bus count $P = n$ → no - advance the bus count as $P = P+1$, go to step-5 / → yes - all the buses are

i.e.) $|\Delta V_p|_{max} < \epsilon$ — are the initial values, advances the initial as $k = k+1$, go to step-4
↳ yes – convergent step.

The unknown values will be assigned at iterated values.

* Disadvantages:—

1. The load flow studies are varied out by constant. For next bus calculation.

* Gauss-seidal method:—

Step: 5:— check is it a slack bus → Yes – Go to step-8; No – Go to next step.

Step: 6:— check is it a gen. bus → No – next step; Yes

calculate,

$$Q_p^{k+1} = -\mathrm{Im}\,(V_p^k)^* \sum_{q=1}^{n} Y_{pq} V_q^k$$

&

$$V_p^{k+1} = \frac{1}{Y_{pp}}\left[\frac{P_p - JQ_p}{(V_p^k)^*} - \sum_{\substack{q=1 \\ \neq p}}^{n} Y_{pq} V_q^k\right] = a \pm jb$$

$$\delta_p = \tan^{-1}(b/a) \rightarrow \text{Go to step-8.}$$

Step: 7:— Calculate $\Delta V_p = |V_p^{k+1}| - |V_p^k|$, Replace V_p^k by V_p^{k+1}

Step: 8:— Check is bus count $p = n$ → No – advance the bus count as $p = p+1$, go to step-5; Yes – all the buses are counted, go to next step.

→ In case of Generator bus magnitude of 'V' is a known value. So that the residual voltage V_p^{k+1} will be "0". i.e., ΔV_p (step-6)

Step: 9:— Check for convergent criteria (i.e.,) is $|\Delta V_p|_{max} < \epsilon$ → No – divergent; Y – Convergent, Stop.

→ P ____ & angle of generator bus, the magnitude of Voltage 'δ' of load bus are evaluated

→ In order to reduce no. of iterations further because Gauss-seidel method will become a fast convergent method, the acceleration....

Modification of step: 7:— it is a load bus

Calculate the voltage at the bus

$$V_p^{k+1} = \frac{1}{Y_{pp}}\left[\frac{P_p - jQ_p}{(V_p^k)^*} - \sum_{\substack{q=1\\ \neq p}}^{n} Y_{pq} V_q^k\right] = a \pm jb$$

$$V_p^{k+1}\ \text{all} = V_p^k + \alpha\left(V_p^{k+1} - V_p^k\right)$$

α = accelaration factor → Optimal → 1.6

$\Delta V_p = V_{p\,acc}^{k+1} - V_{p\,acc}^{k}$, Replace V_p^k by $V_{p\,acc}^{k+1}$

→ The load flow studies are conducted with certain constant in which one of the constant is the reactive power of generation i.e., $Q_{p\,min} \leq Q_p \leq Q_{p\,max}$ at V_{pp} (constrained by).

Modification of step: 6:—

check is it a Gen. Bus → No → steps
→ Yes.

Replace V_p^k by V_p specified

Calculate $Q_p = -\,\text{Im}\,(V_{psp})^* \sum_{\substack{q=1\\ \neq p}}^{n} Y_{pq} V_q^k$.

If the calculated Q_p of the constrained Generator bus has became convergent with reactive power limits, the constrained gen-bus will be treated as Gen-Bus only. If the calculated Q_p has become ~~divedgnt~~ divergent with the Q_p limits, the constrained Gen-bus will be assumed as load bus.

Q_p calc $< Q_p$ min → Yes – Divergent – Load bus

$Q_p = Q_p$ min

$P_p = P_p$

Replace V_p & eqn by $(V_p^k = 1.0)$

Calculate

$$V_p^{k+1} = \frac{1}{Y_{pp}}\left(\frac{P_p - jQ_p}{V_p^*} - \sum_{q=1}^{n} Y_{pq} V_q^k\right]$$

→ If actual value is given

$$\Delta V_p = V_{p(act)}^{k+1} - V_{p(act)}^{k}$$

replace V_p^k by actual voltage.

step-8:-

Is $Q_{Pcal} > Q_{p\,measured}$ → yes - divergent, load bus

$Q_p = Q_{p\,max}$

$P_p = P_p$

go to step-5

$Q_p = Q_{Pcal}$

$$V_p^{k+1} = \frac{1}{Y_{pp}}\left[\frac{P_p - jQ_p}{V_{p(spec)}} - \sum_{\substack{q=1\\ \neq p}}^{n} Y_{pq} V_q^k\right] = a + jb$$

$$\delta_p = \tan^{-1}(b/a)$$

NEWTON-RAPHSON'S METHOD:-

load flow equations:-

Power at bus p

$$S_p = V_p^* I_p = P_p - jQ_p$$

$$P_p - jQ_p = V_p^* \sum_{q=1}^{n} Y_{pq} V_q$$

$$V_p = e_p + jf_p$$

$$Y_{pq} = G_{pq} - jB_{pq}$$

$$V_q = e_q + jf_q$$

$$S_p = P_p - jQ_p = \sum_{q=1}^{n} (e_p - jf_p)(G_{pq} - jB_{pq})(e_q + jf_q) \quad \text{[rectangular co-ordinates]}$$

$$P_p = \sum_{q=1}^{n} \left\{ e_p(e_q G_{pq} + f_q B_{pq}) + f_p(f_q G_{pq} - e_q B_{pq}) \right\} \rightarrow ①$$

$$Q_p = \sum_{q=1}^{n} \left\{ f_p(e_q G_{pq} + f_q B_{pq}) - e_p(f_q G_{pq} - e_q B_{pq}) \right\} \rightarrow ②$$

$$|V_p|^2 = |e_p|^2 + |f_p|^2 \rightarrow ③$$

$$V_p = \frac{1}{Y_{pp}}\left[\frac{P_p - jQ_p}{V_p^*} - \sum_{\substack{q=1\\ \neq p}}^{n} Y_{pq} V_q\right]$$

$$Q_p = -\text{img } V_p^* \sum_{q=1}^{n} Y_{pq} V_q .$$

⇒ In case of gauss-seidal method, the unknown electrical circuit of the buses will be expressed of a non-linear simultaneously function of the known value of the buses. In case of NR-method the specified electrical quantities of the buses are expressed a non-linear simultaneous function of unknown electrical quantities of the buses.

→ Out of the three equations each bus required only 2-equations i.e., for a load bus the real & reactive power and for generator bus P_p & V.

∴ If requires the solution of (2n−2) load flow equations only. By solving one of the bus is slack bus.

→ In order to get solutions of unknown electrical quantity n/w, cannot non-linear ——— by using a Taylor series expression.

Taylor series expansion:— (Mathematical model)

$$\text{known}\begin{cases} y_1 = f_1(x_1 - - - - x_n) \\ \vdots \\ y_n = f_n(\underbrace{x_1 - - - x_n}_{\text{unknown}}) \end{cases}\Bigg\}\ \text{non-linear}$$

$$\left.\begin{aligned} y_1 &= f_1(x_i + \Delta x_1 - - - - x_n^a + \Delta x_1) \\ &\vdots \\ y_n &= f_n(x_i + \Delta x_1 - - - x_n^o + \Delta x_n) \end{aligned}\right\}\ \text{Linear simultaneously}$$

$$y_1 = f_1(x_i \cdots x_n) + \frac{\partial f_1}{\partial x_1}\bigg|_{x_1^0} \Delta x_1 + \cdots + \frac{\partial f_1}{\partial x}\bigg|_{x_n^0} \Delta x_n$$

$\underbrace{f_1(x_i \cdots x_n)}$ evaluated value with initial guess

$$\begin{bmatrix} y_1 - f_1(x_1^0 \cdots x_n^0) \\ \vdots \\ y_n - f_n(x_1^0 \cdots x_n^0) \end{bmatrix} = \begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \cdots & \frac{\partial f_1}{\partial x_n} \\ \vdots & & \vdots \\ \frac{\partial f_n}{\partial x_n} & \cdots & \frac{\partial f_n}{\partial x_n} \end{bmatrix}_{(x_1^0 \cdots x_n^0)} \begin{bmatrix} \Delta x_1 \\ \vdots \\ \Delta x_n \end{bmatrix}$$

$$\begin{bmatrix} \Delta y_1 \\ \vdots \\ \Delta y_n \end{bmatrix} = B = J \quad C$$

B → known residual matrix

J → Jacobian matrix

C → unknown residual matrix

→ In case of NR method the value of the residual is to be added to the initial value inorder to get the solution of the unknown electrical quantity.

1) construct the elements of matrix B with the initial values of the unknown quantity.

Δy = specified − evaluated values.

2) check for convergent i.e, $|\Delta Y|_{max} < E$ → no divergent go to next step; → yes

$x_i = x_i$

$\vdots$

$x_n^1 = x_n^0$

3) calculate $C = J^{-1} B$

$x_1^1 = x_1^0 + \Delta x_1$

$\vdots$

$x_n^1 = x_n^0 + \Delta x_n$

Use the above values as the initial values & go for next iteration & it will be continue till the problem will become convergent

$$\begin{bmatrix} P_{2(spec)} - P_{2\,cal} \ (\Delta P_2) \\ \vdots \\ P_{n(spec)} - P_{n\,cal} \ (\Delta P_n) \\ Q_{2(spe)} - Q_{2\,cal} \ (\Delta Q_2) \\ \vdots \\ Q_{n(spe)} - Q_{n\,cal} \ (\Delta Q_n) \\ |V_2|^2_{spe} - |V_2|^2_{cal} \ (\Delta|V_2|^2) \\ \vdots \\ |V_n|^2_{spe} - |V_n|^2_{cal} \ (\Delta|V_n|^2) \end{bmatrix} = \begin{bmatrix} \frac{\partial P_1}{\partial e_1} \cdots \frac{\partial P_2}{\partial e_n} & \frac{\partial P_2}{\partial f_2} \cdots \frac{\partial P_2}{\partial f_n} \\ J_1 & J_2 \\ \frac{\partial P_n}{\partial e_2} \cdots \frac{\partial P_n}{\partial e_n} & \frac{\partial P_n}{\partial f_2} \cdots \frac{\partial P_n}{\partial f_n} \\ \frac{\partial Q_2}{\partial e_2} \cdots \frac{\partial Q_2}{\partial e_n} & \frac{\partial Q_2}{\partial f_2} \cdots \frac{\partial Q_2}{\partial f_n} \\ J_3 & J_4 \\ \frac{\partial Q_n}{\partial e_n} \cdots \frac{\partial Q_n}{\partial e_n} & \frac{\partial Q_n}{\partial f_2} \cdots \frac{\partial Q_n}{\partial f_n} \\ \frac{\partial |V_2|^2}{\partial e_2} \cdots \frac{\partial |V_2|^2}{\partial e_2} & \frac{\partial |V_2|^2}{\partial f_2} \cdots \frac{\partial |V_2|^2}{\partial f_n} \\ J_5 & J_6 \\ \frac{\partial |V_n|^2}{\partial e_2} \cdots \frac{\partial |V_n|^2}{\partial e_n} & \frac{\partial |V_n|^2}{\partial f_2} \cdots \frac{\partial |V_n|^2}{\partial f_n} \end{bmatrix} \begin{bmatrix} \Delta e_2 \\ \vdots \\ \Delta e_n \\ \Delta f_2 \\ \vdots \\ \Delta f_n \end{bmatrix}$$

$B(2n-2)\times 1$ $\qquad (e_2^0, \cdots e_n^0, f_2^0 \cdots f_n^0)$ $\qquad C(2n-2)\times 1$

$J(2n-2)\times(2n-2)$

for Bus P

$$\begin{bmatrix} \Delta P_p \\ \Delta Q_p \\ \Delta |V_p|^2 \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \\ J_5 & J_6 \end{bmatrix} \begin{bmatrix} \Delta e_p \\ \Delta f_p \end{bmatrix}$$

→ A power system n/w is having 14 buses out of which there are 3-voltages controlled buses. The load flow studies are conducted by NR-method, the size of the Jacobian matrix is

$= (14\times 2) - 2 \Rightarrow 26 - 3$

$= 23 \times 23$

→ The power system network is having 20 buses out of which there are 5-generator buses & 3 shunt capacitor buses. The size of the Jacobian matrix of NR-method. The external shunt

$\Rightarrow [(2n-2)-m-l] \times [(2n-2)-m-l]$

$\Rightarrow [(2\times20-2)-5-3] \times [(2\times20-2)-5-3]$

$\Rightarrow 30\times30$

→ A Powersystem n/w having 300 buses out of which there are 20 generator buses, 25 Q P support buses & 15 shunt 'L' buses. The load flow studies are conducted by NR-method. The size of the Jacobian matrix is

$l = 25+15 = 40$

$\Rightarrow [(2n-2)-m-l] \times [(2n-2)-m-l]$

$\Rightarrow (300\times2-2)+20-25-15$

remove

538×338

540×540

fast N-R method:-

The elements of the Jacobian matrix are changes at the initial values are changes so that it is required to calculate the inverse of Jacobian matrix in every iteration which will results as the time taking is very high. In order to reduce the time taking it is proposed to have fast NR-method.

power at bus P

$$S_p = V_p^* I_p = V_p^* \sum_{q=1}^{n} Y_{pq} V_q = \sum_{q=1}^{n} |V_p| \angle -\delta_p |Y_{pq}| \angle \theta_{pq} |V_q| \angle \delta_q$$

$$S_p = P_p - jQ_p = \sum_{q=1}^{n} |V_p| |Y_{pq}| |V_q| \angle -(\delta_p + \theta_{pq} - \delta_q)$$

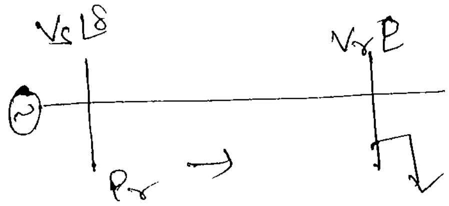
$$P_p = \sum_{q=1}^{n} |V_p| |Y_{pq}| |V_q| \cos(\delta_p + \theta_{pq} - \delta_q) \rightarrow ①$$

$$Q_p = \sum_{q=1}^{n} |V_p| |Y_{pq}| |V_q| \sin(\delta_p + \theta_{pq} - \delta_q) \rightarrow ②$$

The above equation says that the speified electrical quantities of the buses are to be expressed as a non-linear

of unknown electrical quantities in a polar co-ordinates for a generator bus the 'Pp' is consider & for a load bus the real & Qp is able to get the solution of unknown electrical quantities.

$$\begin{bmatrix} \Delta P_p \\ \Delta Q_p \end{bmatrix} = \begin{bmatrix} J_1 & 0 \\ 0 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta_p \\ \Delta V_p \end{bmatrix}$$



→ In ac system the amount of real power transfer differential eqn's depends up on the di and the angle on both where as the Q points does depends on the of the voltage, the change in real power doesn't depends on change in voltage & Change in Qp doesn't depends on change of angle. ∴ $J_2 = 0$ & $J_3 = 0$

→ Half of the elements in the Jacobian matrix have become zero. so that the time taken to evaluates the J will be reduced.

∴ It is preferred to have text NR-method. By developing the load flow eqn's by using polar quantities.

check for convergent criteria:-

step-9:-

no - divergent

yes - convergent

$$\delta_p^{k+1} = \delta_p^k$$

$$|V_p|^{k+1} = |V_p|^k$$

Fast decoupled NR method:-

The linear factor eqns are developed with a polar form with the following assumptions in the n/w so that the elements of J_1 & J_4 will remain same in all iterations so that the time taken for calculation of J^{-1} is reduced.

1) The 'R' in the TL is ignored
2) The phase shifting of T/f in Δ-Y T/f can be ignored
3) The shunt capacitor of TL & any external shunt elements at the buses i.e., shunt capacitor and inductor will be ignored.
4) The effect of the changing Tf can be ignored.

Gauss-seidal method	NR method
→ It gives the solution for (n-1) non-linear simultaneous eqns.	→ It gives the solution for (2n-2) non-linear load flow eqn's.
→ The convergent criteria is a linear interms of bus voltage $\Delta V_p = V_p^{k+1} - V_p^k$	→ The convergent criteria is a linear interms of power $\Delta P_p = P_{p\,spec} - P_{p\,cal}$ (or) $\Delta Q_p = Q_{p\,spec} - Q_{p\,cal}$
→ It is very easy to programing the load flow eqn's due to rectangular conditions. ∴ The memory usage is less	→ It is difficult to programming the Load flow eqn's due to polar coordinates ∴ The memory usage will be high.

→ The time taken ~~is~~ for each iteration is less	→ The time taken for each iteration is high
→ The no. of iterations required to get convergent criteria will be more & also depends on size of the powersystem network	→ The no. of iterations required to get the convergent criteria is limited of 3-5 & it is independent on the size of Powersystem network
→ Total time taken to get the convergent criteria is high	→ Total time taken to get the convergent criteria is low
→ acceleration factors are proposed	→ acceleration factors are not ~~necess~~ necessory.
→ The change in the selection of slack bus will effect convergent criteria	→ The convergent criteria will not affected by changing selection of slack bus
→ unreliable convergent criteria	→ Reliable convergent criteria
→ not recommended for a larger system but can be used for a smaller sytems	→ used for a larger power system network.

1) TS-2

TRANSMISSION & DISTRIBUTION

→ Basic concepts of transmission

→ Transmission line constants

→ steady state performance of transmission lines

→ wave travelling phenomenon (or) Transient performance of lines

→ voltage control (or) Power factor correction

→ concept of Corona

→ over head line insulator

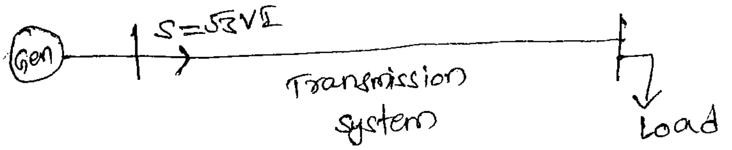
→ under ground cables

→ HVDC transmission

→ Distribution system

Basic concepts of transmission:-

Transmission system means 3-ϕ transmission



The characteristics of transmission line:-

→ The power loss should be as low as possible

→ The impedance of transmission line should be low value.

→ Ratings of the transmission line are voltage rating and MVA limit

→ MVA limit is 3-ϕ capacity

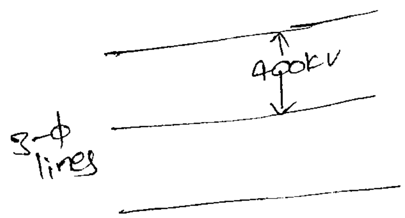
→ If the MVA limit of the transmission line is less than the power carry by transmission line then there will be some damage for the transmission line

→ what is voltage rating of 3-φ power system?

a) L-L peak value   b) L-L rms value ✓

c) phase peak value   d) phase rms value

ex:



MVA limit = 1000MVA

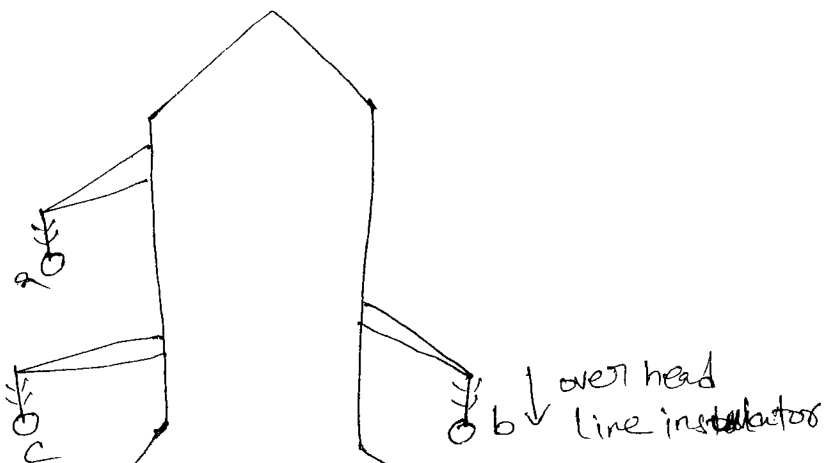
→ current carrying capacity ∝ a (area of cross-section of conductor.

Different types of conducting materials:-

Ag, Cu, Al, Au, etc

→ 'Al' is ~~performed~~ preffered to manufacture the transmission line because of its low cost.

Insulation ∝ voltage



$$= \frac{400\,kV}{\sqrt{3}} \times \sqrt{2}$$

→ Insulator is provided based on phase voltage of the system

→ phase voltage is taken in peak value.

7

Types of over voltages:-

i) switching surges   ii) Lightning surges

→ surge is nothing but a transient (or) sudden change.

→ switching surges will occur in a system during switching periods such as connecting a Transmission line to the generator.

→ Lightning surge will occur due to the discharge of cloud to the conducting parts (transmission lines) on the earth.

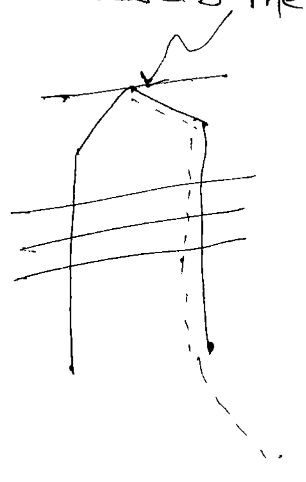
→ Lightning surge is always in the form of currents (KA).

→ Due to the injection of charges into transmission line the line will experience the lightning over voltage.

→ The lightning surge value is very high compared to switching surge value.

→ The designing of over head line insulation is difficult and costly for the lightning surges, so the lightning surges effect will be avoided on the transmission line by using a ~~drum~~ ground wire.

→ The lightning will occur only on the top most part of system, so a ground wire is placed on the top of the tower to obserb the lightning discharge



→ The ground wire is directly connected to tower

→ The overhead line insulators will be design based on switching surges (per phase peak value)

Classification of transmission voltages:-

i) High voltage (HV) transmission — 11KV, 33KV

ii) Extra high voltage (EHV) transmission — 66KV, 132KV, 220KV

iii) Modern extra high voltage (MVHV) — 400KV

iv) ultra high voltage (UHV) — 765KV and above

→ Based on distance of power transfer the transmission voltage level is selected.

→ If the length of TL is less than 500km then AC transmission is economical. ($l < 500km$)

If the $l > 500$ km then $\underbrace{\text{DC transmission}}_{\text{HVDC}}$ is economical

→ If the AC voltage is greater than 1000V then that voltage is called as high voltage AC (HVAC), acc to ~~IS~~ AC

→ The dc voltage is >1200 then that voltage is called high voltage dc, acc to ~~IS~~ IS

→ The distribution system voltage levels are 230V (1-φ) & 440V (3-φ)

Necessity of very high voltage power transfer:-

Apparent power ~~I~~ $S = \sqrt{3} V_L I_L$

$$I_L = \frac{S}{\sqrt{3} V_L}$$

as V_L is low, I_L is high } for constant power transfer

$I_L \propto a$

→ As $I_L \uparrow$ then $a \uparrow \Rightarrow$ Area of cross section, size of the conductor and cost will become high.

$$\text{Power loss} = 3I_L^2 R$$

'R' is the resistance of line

$$I_L \propto a^2, \quad R \propto 1/a$$

$$\text{Power loss} \propto a^2 \cdot \frac{1}{a}$$

$$\boxed{P_{loss} \propto a}$$

→ P_{loss} is more

→ efficiency of transmission system $= \dfrac{\text{output}}{\text{output} + \text{losses}}$

→ efficiency is less.

→ for EHV, MEHV, UHV power transfers, the line to line voltage value is high, current will be low for constant power transfer.

$$I_L \propto a$$

→ $I_L \uparrow \Rightarrow$ area of cross section of conductor is low

size and cost of conductor will low

$$\text{Power loss} = 3I_L^2 \cdot R$$

$$\boxed{P_{loss} \propto a}$$

→ Power loss is low and efficiency is high

→ By using these voltage levels there may not be any appreciable decrement in cost of the system but the efficiency of transmissio system will become a high value.

Feeder:-

feeder is a conductor which will carry a constant amount of current through out its length (or) constant current density.

$$J = I/a$$

ex: Transmission line.

Distributor:-

Distributor is a conductor which will carry different amount of currents at different places, nothing but variable current density.

ex: Distribution lines

→ The feeder will be designed based on current carrying capability (or) Power loss

→ The distributor will be design based on the voltage drop in the system.

→ Due to the low voltage profile the performance of the load will be poor, is called poor performance of the load.

Case (1):-

For same length, same material, same power transfer, same

If the voltage is increased by 'n' times what will happen to area of cross section of conductor

Initial case → $V_1, I_1, \cos\phi$

final case → $V_2, I_2, \cos\phi$

$P_1 = \sqrt{3}\ V_1 I_1 \cos\phi$

$P_2 = \sqrt{3}\ V_2 I_2 \cos\phi$

$V_2 = nV_1$

$P_1 = P_2$ (∵ power transimission is same)

$\sqrt{3} V_1 I_1 \cos\phi = \sqrt{3} V_2 I_2 \cos\phi$

$$\frac{V_1}{V_2} = \frac{I_2}{I_1}$$

$$\frac{1}{n} = \frac{I_2}{I_1}$$

$$\boxed{I_2 = I_1 \cdot \frac{1}{n}}$$

current will be reduced by 'n' times

$I_2 \propto a_2$, $I_1 \propto a_1$

$$\boxed{a_2 = \frac{1}{n} \cdot a_1}$$

Area of cross section is reduced by 'n' times

Power loss $\propto a$

$$\boxed{P_{loss\,2} = \frac{1}{n} \cdot P_{loss\,1}}$$

P_{loss} is also be reduced by 'n' times

case (2) :- for feeder

for same length, same material, same power transmission, same power loss.

If the voltage is increased by 'n' times what will happen to area of cross section of conductor

$P_{loss1} \overset{<}{=} P_{loss2}$

$$\left\{ \begin{aligned} V_2 &= n \cdot V_1 \\ \frac{V_2}{V_1} &= n \end{aligned} \right.$$

$P_{loss1} = 3 I_1^2 R_1$

Power $P_1 = \sqrt{3} V_1 I_1 \cos\phi$

$$I_1 = \frac{P_1}{\sqrt{3} V_1 \cos\phi}$$

$$P_{loss1} = 3 \left(\frac{P_1}{\sqrt{3} V_1 \cos\phi} \right)^2 R_1$$

$$= \frac{P_1^2}{V_1^2 \cos^2\phi} \cdot R_1$$

$$P_{loss1} \propto \frac{R_1}{V_1^2}$$

$$P_{loss1} \propto \frac{1}{a \cdot V^2}$$

$$aV^2 \propto \frac{1}{P_{loss}}$$

aV^2 is constant

$$\frac{a_1 V_1^2}{a_2 V_2^2} = \text{constant (1)}$$

$$\frac{a_1}{a_2} = \frac{V_2^2}{V_1^2} \quad \left[\begin{aligned} \because V_2 &= n \cdot V_1 \\ \frac{V_2}{V_1} &= n \end{aligned} \right]$$

$$\frac{a_1}{a_2} = n^2$$

$$\boxed{a_2 = \frac{1}{n^2} a_1}$$

efficiency is constant

Case (3) :- for distributor

for same length, same material, same power transmission, same voltage drop

If the voltage is increased by 'n' times, what will happen to

$V_2 = n V_1 \Rightarrow \frac{V_2}{V_1} = n$

Initial case $\rightarrow I_1, V_1, R_1 \Rightarrow$ PU voltage drop $= \frac{I_1 R_1}{V_1}$

final case $\rightarrow I_2, V_2, R_2 \Rightarrow$ PU voltage drop $= \frac{I_2 R_2}{V_2}$

for same voltage drop, $\frac{I_1 R_1}{V_1} = \frac{I_2 R_2}{V_2}$

$\boxed{I_1 R_1 = \frac{I_2 R_2}{n}} \Rightarrow \boxed{I_2 R_2 = n \cdot I_1 R_1}$

absolute voltage drop is incremented by 'n' times

same power, $V_1 I_1 = V_2 I_2$

$I_1 = \frac{V_2}{V_1} I_2$

$\boxed{I_1 = n I_2}$

$I_2 R_2 = n^2 \cdot I_2 \cdot R_1$

$\boxed{R_2 = n^2 \cdot R_1}$

The resistance of the distributor is increased by 'n^2' times

Then a/ttim

$\frac{1}{a_2} = n^2 \cdot \frac{1}{a_1}$

$\boxed{a_2 = \frac{1}{n^2} \cdot a_1}$

Area of cross section is reduced by 'n^2' times

G-2009 $\rightarrow$ For the transmission voltage 'V', what will be the power loss proportionality.

a) V b) V^2 c) $1/V$ d) $1/V^2$

$S = \sqrt{3} V_L I_L$

$I_L = \frac{S}{\sqrt{3} V_L}$

$P_{loss} = 3 \cdot I_L^2 R$

$P_{loss} \propto I_L^2$

$\propto (S^2/3 \cdot V_L^2)$

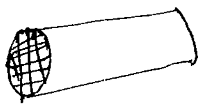
$P_{loss} \propto \frac{1}{(\text{Voltage})^2}$

$P_{loss} \propto \frac{1}{V^2}$ [$\because$ 'S' is constant]

Types of conductors used for transmission lines

1) solid conductor
2) stranded conductor
3) composite stranded conductor
4) Bundle conductor

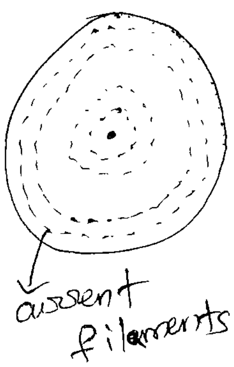
1) solid conductor:-



→ A single piece of conductor will act as solid conductor/transmission line. line.

→ It is made up of only one material either cu or Al

→ manufacturing of solid conductor is simple



for ac supply the current distribution is non-uniform through out the surface of the conductor

Skin effect:-

It is the tendency of alternating current to be concentrated on the surface of conductor. (skin)

→ The current value goes on reduces towards the centre of conductor

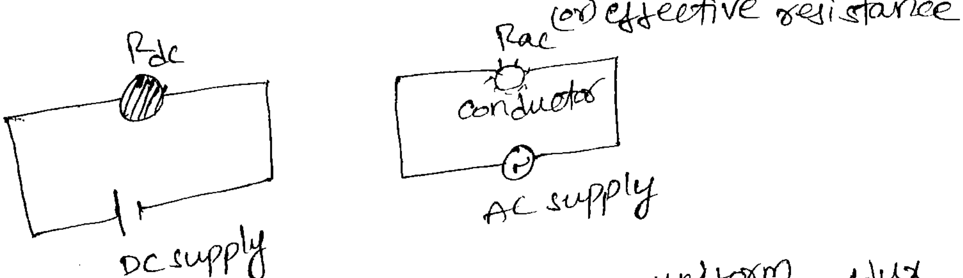
→ non-uniform distribution of current will called cause non-uniform

→ skin depth is the radius of conductor measured from surface of the conductor up to which the current is non zero

→ resistance of conductor (or) effective resistance $= \frac{\text{Power loss } (I^2R)}{I^2}$

→ DC resistance of the conductor $= \frac{\rho l}{a}$

$$R_{dc} = \frac{\rho l}{a}$$



uniform flux distribution

non-uniform flux distribution

→ The flux linkages at the middle of the conductor is high so that the internal inductance of the conductor will become more such that the current concentration at the middle of the conductor will be low (or) zero.

→ on the surface of the conductor the flux linkages are low such that the external inductance will be a low value. so the current will be concentrated on the surface of the conductor

$$\boxed{R_{ac} > R_{dc}}$$

→ Due to skin effect the area of cross section offered for the current is low, so that the resistance value will become high

Let us take 'a'' = effective area of cross section of conductor (ac supply)

$$\boxed{R_{ac} = \frac{\rho l}{a'}} \; ; \; \boxed{a' < a}$$

skin effect α $\mu_r \times$ frequency i.e.,

$$\boxed{\text{skin effect} \; \alpha \; \mu_r f \cdot a}$$

where 'a' is physical cross section area

Disadvantages of skin effect:-

i) Power is more

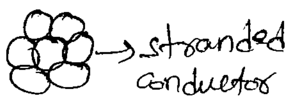
ii) voltage drop is more

2) Stranded conductors:-

A number of strands which are having less cross-section area are taken and these are twisted together to form a stranded conductor.

→ skin effect is low for the stranded conductors compared to solid conductor

→ The selection of no of ~~stan~~ strands depends upon the current carrying capability of the transmission line.



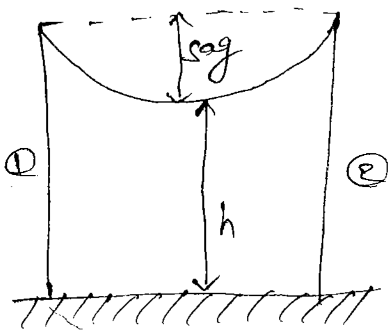
→ The manufacturing of stranded conductor is difficult compared to solid conductor

→ The stringing of stranded conductor is easy compared to solid conductor, so travelling/transporting of stranded conductor

→ The tensile strength of stranded conductor is low compared to solid conductor

$$sag \propto \frac{1}{T}$$ where 'T' is Tensile strength.

→ sag value is high for the stranded conductors.



→ If the sag value is high then the clearance provided for the conductor from the ground(h) will become low.

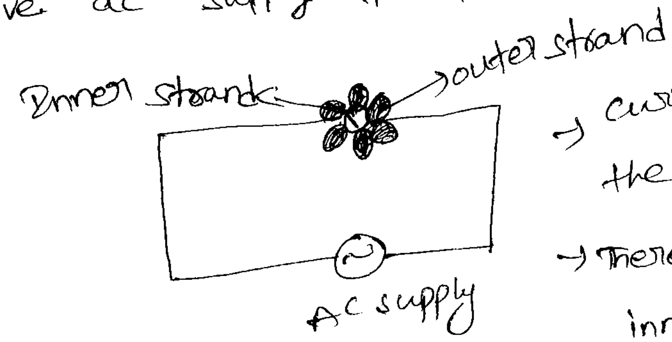
→ To reduce the sag value the tensile strength has to be increased

→ so, this is done by using composite stranded conductor

→ All strands are made by Al, that conductors are called as

All Aluminium conductor (AAC)

→ To give ac supply to the AAC



→ currents will be concentrated at the outer strands.

→ There is no current flow in inner strand.

→ The middle strag (or) Inner strag will be replaced by another material, which will have high tensile strength, so that the tensile strength of total conductor will be increased and sag will be reduced.

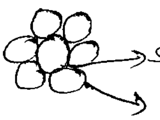
3) Composite stranded conductor

→ The inner strag will be replaced by a stell strand the resultant conductor is called as composite stranded conductor.

→ The ineffective strands (the strands which are not carrying the current) will be replaced by the strands which will have high tensile strength.

→ The resultant conductor is called

→ Two materials are used to form the conductor, is called composite stranded conductor.



→ Composite stranded conductor ⇒ ACSR

→ ACSR conductor will have high tensile strength, sag of line will be less because sag $\propto \frac{1}{T}$

→ skin effect is also reduced for ther by using ACSR conductor.

$R_{ac} > R_{dc}$

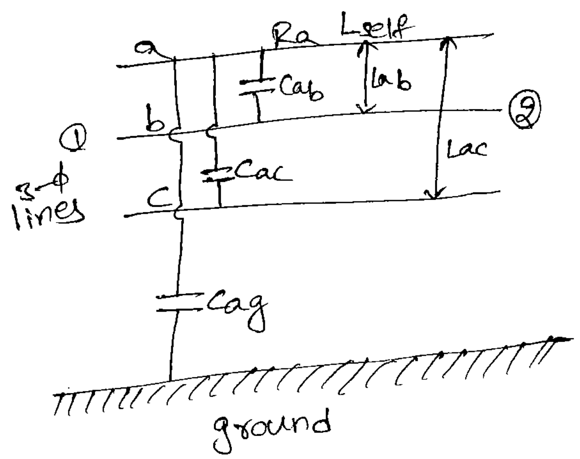
$R_{ac} = K \cdot R_{dc}$

K = factor of skin effect

= 1.6 for solid conductor

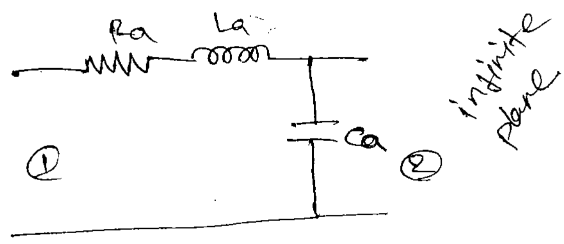
$K < 1.6$ for ACSR conductor and stranded conductor.

equivalent diagram of Transmission line



$C = \frac{\epsilon A}{d}$

a-phase equivalent circuit



La → equivalent inductance of phase-a and it is the combination of self and mutual inductance.

Conditions for formation of capacitance:-

i) They should be atleast two conducting bodies

ii) The conducting bodies should be displaced by some distance with a dielectric material.

iii) There should be some finite voltage difference between two conducting bodies.

→ The capacitance between phase conductor and ground is negligeble, because the distance between phase conductor and ground is high.
[As $c = \frac{\epsilon A}{d}$ then $d\uparrow$ & $c\downarrow$]

→ The electric field intensity at the middle of the conductor will be zero so there is no existance for self capacitance.

→ 'Ca' is the equivalent capacitance of a-phase

→ Resistance 'Ra' depends on length, area of cross section, nature of material and skin effect of the conductor.

→ The self Inductance depends on area of cross section of the conductor.

→ The mutual inductance depends on the distance between the a-phase conductor and other conductors in the system.

→ capacitance depends on ~~a-phase~~ distance between a-phase conductor and other conductors in the system.

mathematical concepts:-

GMR :- Geometric mean radius

→ It is used to calculate self inductance

→ GMR is the effective radius measured from centre of the conductor to circumferance or surface of the conductor.

r = actual radius of conductor

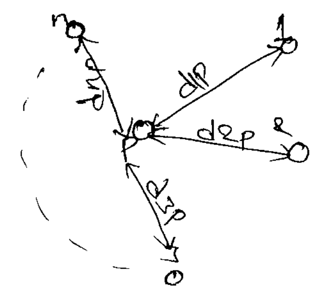
effective radius $= r' < r$ after considering skin effect

$$\boxed{GMR = r' = 0.7788r}$$

GMD:- Geometrical mean distance

→ It is the ~~geo~~ used to calculate mutal inductance and capacitance

→ 'n' no of conductors are placed in the space of 'p' conductor



→ GMD of conductor 'p' is

$$GMD_p = \sqrt[n]{d_{1p} d_{2p} \cdots d_{np}}$$

→ GMD is the effective distance of the conductor measured from all the conductors in the space.

→ There are two configurations for the conductors arrangement.

1) symmetrical configuration

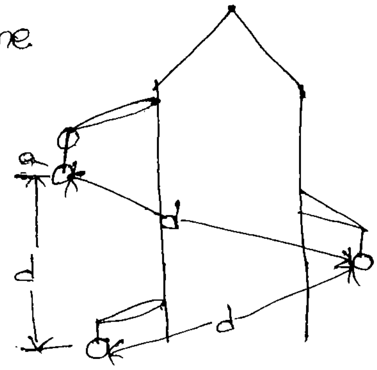
2) Asymmetrical " /unsymmetrical configuration

symmetrical configuration:-

→ The distance between the conductors is same

→ This is also called as equilateral spacing

→ The distance between each conductor is 'd' and the radius between each conductor is 'r'.



$GMR_a = r' = 0.7788r$

$GMR_b = r'$

$GMR_c = r'$

→ GMR of the system $[GMR_{system}] = \sqrt[3]{GMR_a \cdot GMR_b \cdot GMR_c}$

$GMR = \sqrt[3]{r' \cdot r' \cdot r'}$

$GMR = r' = 0.7788r$

$$\boxed{GMR = GMR_a = GMR_b = GMR_c}$$

$GMD_a = \sqrt{d \times d} = d$

$GMD_b = r'$

$GMD_c = r'$

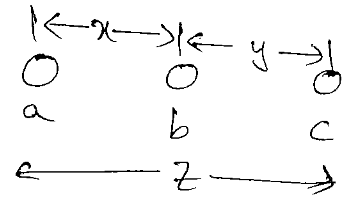
$GMD_{sys} = \sqrt[3]{GMD_a \cdot GMD_b \cdot GMD_c}$

$= \sqrt[3]{d \cdot d \cdot d}$

$= d = GMD_a = GMD_b = GMD_c$

→ In equilateral spacing the GMD is nothing but the distance between conductors.

Asymmetrical configuration:-



radius of each conductor is r

$GMR = GMR_a = GMR_b = GMR_c = r' = 0.7788r$

$GMD_a = \sqrt{xz}$

$GMD_b = \sqrt{xy}$

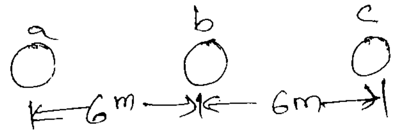
$GMD_c = \sqrt{yz}$

$GMD = \sqrt[3]{GMD_a \cdot GMD_b \cdot GMD_c}$

$= \sqrt{\sqrt{xy} \cdot \sqrt{yz} \cdot \sqrt{xz}}$

$= \sqrt[3]{xyz}$

→ GMD for the unsymmetrical configuration is the geometric mean of all the distances.

→ 

which are unsymmetrically space, radius of the conductor is 2cm. what is the GMR & GMD

$GMR = r' = 0.7788 \times r$

$= 0.7788 \times 2\ cm \Rightarrow 1.554\ cm$

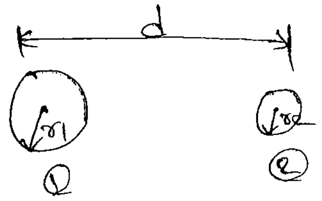
$GMD = \sqrt[3]{6 \times 6 \times 12}$

$= 6 \times (2)^{2/3}$

$= 7.55\ m$

→ A 1-φ 2wire system having two conductors with radius 2cm & 1cm respectively. If the two conductors are displaced by 0.5m distance. what is the GMD & GMR of the system.

$d = 0.5m$



$r_1 = 2cm$ $r_2 = 1cm$

$$\left.\begin{aligned} GMD_1 &= 0.5m \\ GMD_2 &= 0.5m \end{aligned}\right\} \quad GMD = \sqrt{0.5 \times 0.5} = 0.5m$$

$GMR_1 = r_1' = 0.7788 \times 2\ cm$

$GMR_2 = r_2' = 0.7788 \times 1\ cm$

$$GMR = \sqrt{(0.7788)^2 \times 2 \times 1}\ cm$$

$$= 0.7788\sqrt{2}\ cm$$

$$= 1.10cm$$

For 3-φ system

$$L = 2 \times 10^{-7} \ln\left(\frac{GMD}{GMR}\right) H/m$$

$$C = \frac{2\pi \varepsilon_0 \varepsilon_r}{\ln\left(\frac{GMD}{r}\right)}$$

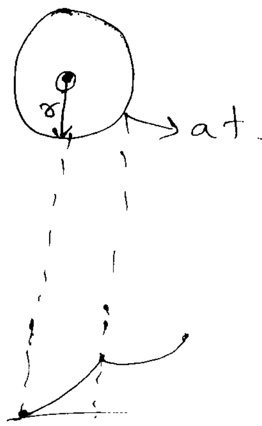
→ for EHV lines the selection of conductor depends on current carrying capacity.

→ for MEHV and UHV transmission lines the selection of conductor depends on corona.

→ To reduce the corona bundle conductors are preferreble

4) Bundle conductors:-

→ It is also called as subconductor system



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

Here
r = radius of conductor
V = voltage applied to conductor
d = distance b/n conductor & ground.

→ In the electric field intensity is high compared to dielectric strength of the air then there will be an ionization on the surface of conductor, this is called as 'corona'.

→ Corona will happen at fine and sharp points where dielectric field intensity is high

→ corona will be experienced as noise and ionisation (light) which is creating energy loss in the power transmission.

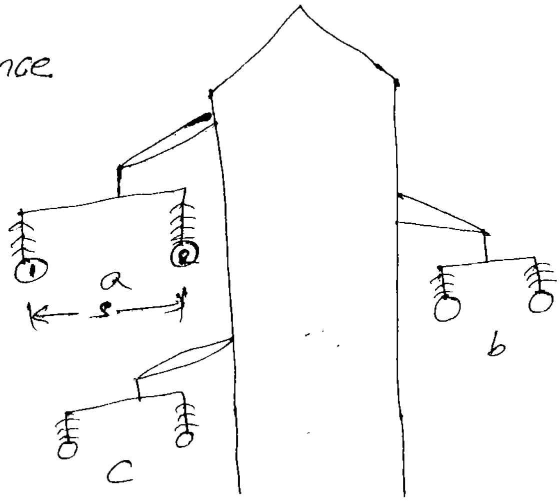
→ The transmission efficiency will become less due to corona

→ To reduce the corona loss we will use bundle conductors.

→ for 3-φ conductor electric field intensity $E = \frac{V_{ph}}{GMR \ln\left(\frac{GMD}{GMR}\right)}$

→ Reducing system voltage
→ Increasing GMR (or) self distance
→ " GMD (or) Increasing the distance between conductors.

Bundle conductor configuration:-

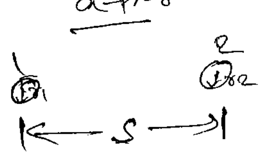


→ To calculate the self inductance of a-phase the mutual linkages between ① & ② sub conductors will be considered.

→ The distance b/n ① & ② subconductors is spacing 's'.

→ The areas of subconductors ① & ② will be same and these too are displaced by a spacing 's', which is greater than radius of sub. conductor. i.e.) $\boxed{s > r}$

→ Each subconductor is an ACSR conductor.



r_1, r_2 → radii of sub conductors

→ self $GMD_1 = \sqrt{r_1' \times s}$

self $GMD_2 = \sqrt{r_2' \times s}$

self $GMD_a = \sqrt{\text{self } GMD_1 \cdot \text{self } GMD_2}$

$= \sqrt{\sqrt{(r_1' \times s)}\sqrt{(r_2' \times s)}}$

If $r_1 = r_2$

~~self GMD~~ self GMD_a of a-phase $= \sqrt{r' \times s}$

self GMD$_2$ $= \sqrt{r_2' \times s}$

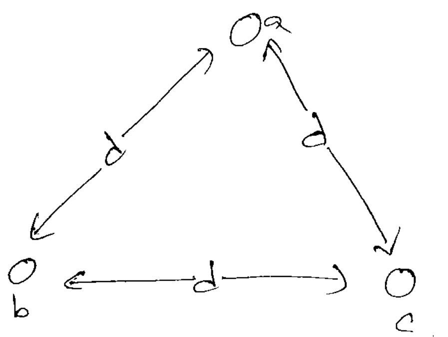
→ The effect of spacing is neglected in the calculation of GMD

GMD $= d$

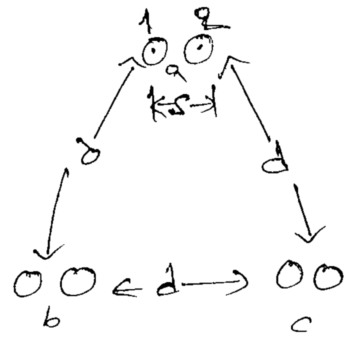
self GMD $= \sqrt{r' \times s}$ where 'r' is radius of sub conductor

electric field intensity $E = \dfrac{V_{ph}}{\text{self GMD} \ln\left(\dfrac{\text{GMD}}{\text{self GMD}}\right)}$

→ The self GMD for bundle conductors is greater than the GMR of normal conductor system.



⇒



radius of conductor $= r$

GMR $= r'$

radius of semiconductor-1 $= r_1$

" " -2 $= r_2$

self GMD $= \sqrt{r_1' \cdot s} \Rightarrow \sqrt{\frac{r'}{\sqrt{2}} \times s} \Rightarrow \sqrt{r' \cdot s/\sqrt{2}}$

→ conductor size depends upon current carrying capacity

$I \propto a$

$I = I_1 + I_2$

I = current in normal conductor system

I_1 & I_2 = current carrying by subconductors

$a = a_1 + a_2$

$\pi r^2 = \pi r_1^2 + \pi r_2^2$

$r^2 = r_1^2 + r_2^2$

for n-sub conductor system) $r^2 = r_1^2 + r_2^2 + \cdots + r_m$

→ sub conductors radii is same $r_1 = r_2 = \cdots = r_n$

$$r^2 = n \cdot r_1^2$$

$$\boxed{r_1 = r/\sqrt{n}}$$

for two subconductor system

$$\boxed{r_1 = r/\sqrt{2}}$$

for bundle conductors

$$L = 2\times10^{-7} \ln\left[\frac{GMD}{self\,GMD}\right] \Rightarrow self\,GMD = \sqrt{r_1' \times s}$$

$$C = \frac{2\pi\varepsilon_0\varepsilon_r}{\ln\left(\frac{GMD}{self\,GMD}\right)} \Rightarrow self\,GMD = \sqrt{r_1 s}$$

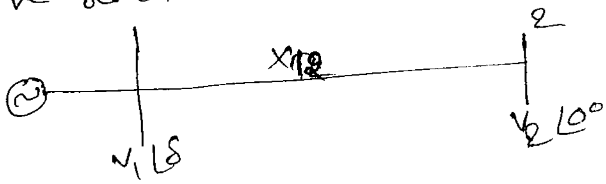
Advantages of bundle conductors:–

1) Inductance value is less ⇒ Voltage drop is less in the transmission lines

2) capacitance " increasing ⇒ reactive power supplied by TL will become high

→ As inductance

3) The inductive reactance is low



Power transfer $P_{12} = \frac{V_1V_2}{X_{12}} \sin\delta$

→ To maintain the stability of system the δ value should be as low as possible.

→ as P_{12} is constant and X_{12} got reduced.

⇒ $\frac{V_1V_2}{X_{12}}$ will increased

→ $\sin\delta$ has to be reduced to maintain 'P_{12}' as constant.

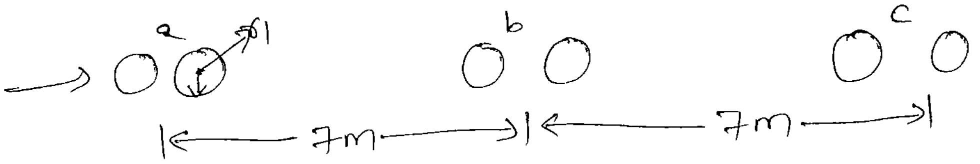
→ δ will be reduced and the system will become more stable

4) characteristic impedance is $Z_c = \sqrt{\frac{L}{C}}$

as $L \downarrow$ $C \uparrow \Rightarrow Z_c \downarrow$

→ Ideal loading $= \frac{V^2}{Z_c}$

Ideal loading value will increasing



and $r_1 = 1\,cm$

$GMD = \sqrt[3]{7 \times 7 \times 14} \Rightarrow 8.817\,m$

self GMD_a = self GMD_b = self GMD_c = $\sqrt{r_1' \cdot s}$

self GMD $= \sqrt{1 \times 0.7788 \times 20}$ cm $\Rightarrow 3.94\,cm$

what is the radius of normal conductor. If the bundle conductor configuration is converted into normal conductor configuration.

Radius of subconductor, $r_1 = r/\sqrt{n}$

radius of single conductor, $r = r_1 \cdot \sqrt{n}$

$= r_1 \cdot \sqrt{2}$

$= 1 \times \sqrt{2} \Rightarrow 1.414$

GMR of single conductor configuration, $GMR = r'$

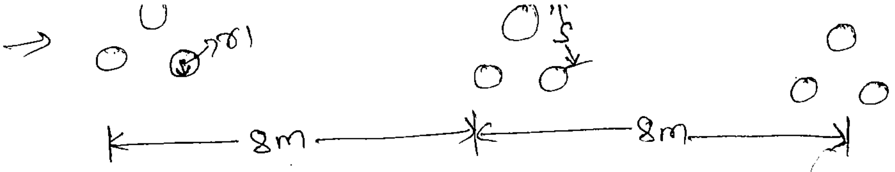
$= 0.7788 \times \sqrt{2}$

$= 1.101\,cm$

$GMD = \sqrt[3]{7 \times 7 \times 14}$

$= 8.817\,m$

b)



radius of subconductor, $r_1 = 2\,cm$, spacing $(S) = 25\,cm$

self GMDa

$$\text{self } GMD_1 = \sqrt[3]{r_1' \times s \times s}$$

$$\text{self } GMD_2 = \sqrt[3]{r_1' \times s \times s}$$

$$\text{self } GMD_3 = \sqrt[3]{r_1' \times s \times s}$$

$$\text{self } GMD_a = \sqrt[3]{\text{self } GMD_1 \cdot \text{self } GMD_2 \cdot \text{self } GMD_3}$$

$$= \sqrt[3]{r_1' \times s \times s}$$

$$= \sqrt[3]{0.778 \times 2 \times 25 \times 25}$$

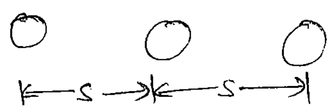
$$= 9.90\,cm$$

$$\text{self } GMD_a = \text{self } GMD_a$$

$$= 9.90\,cm$$

$$GMD = \sqrt[3]{8 \times 8 \times 16} \Rightarrow 10.07\,cm$$

Phase-a



$r_1 = 1.5\,cm$

$s = 30\,cm$

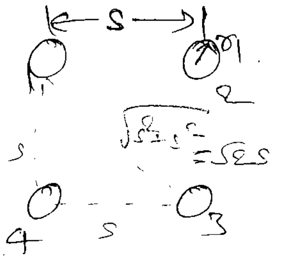
$$\text{self } GMD_1 = \sqrt[3]{r_1' \times s \times 2s}$$

$$\text{self } GMD_2 = \sqrt[3]{r_1' \times s \times s}$$

$$\text{self } GMD_3 = \sqrt[3]{r_1' \times 2s \times s}$$

$$\text{self } GMD = \sqrt[3]{\text{self } GMD_1 \cdot \text{self } GMD_2 \cdot \text{self } GMD_3}$$

$$= \cancel{11.46\,cm}\ 12.81\,cm$$



$r_1 = 1\,cm$

$s = 20\,cm$

self $GMD_1 = \sqrt[4]{r_1' \times s \times \sqrt{2}s \times s}$

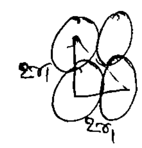
self GMD_2 = self GMD_3 = self GMD_4 = self GMD_1

$= \sqrt[4]{r_1' \times s \times \sqrt{2}s \times s}$

$= 9.68\,cm$

self $GMD = 9.68\,cm$

radius of each sub conductor, $r_1 = 1\,cm$



$\sqrt{(2r_1)^2 + (2r_1)^2}$

$\sqrt{4r_1^2 + 4r_1^2}$

$\sqrt{8}r_1$

self $GMD_1 = \sqrt[4]{r_1' \times 2r_1 \times \sqrt{8}r_1 \times 2r_1}$

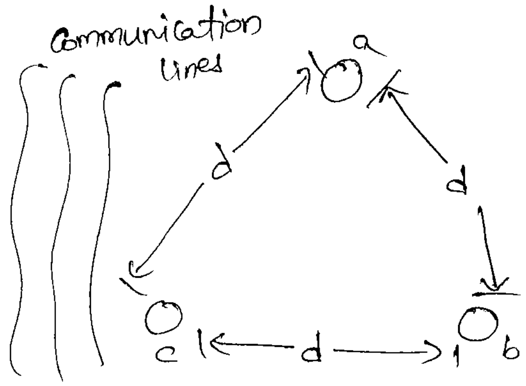
$= 1.72\,cm$

self GMD_1 = self GMD

$= 1.72\,cm$

Radio interference:-

It is the effect of power transmission lines on communication system



$L_a = 2 \times 10^{-7} \ln\left(\frac{GMD_a}{GMR_a}\right)$ H/m

$L_a = L_b = L_c$

fluxes $|\phi_a| = |\phi_b| = |\phi_c|$

$\phi_a = |\phi_a| \angle 0°$

$\phi_b = |\phi_b| \angle -120°$

$\phi_c = |\phi_c| \angle 120°$

$GMD_a = GMD_b = GMD_c$

$GMR_a = GMR_b = GMR_c$

→ The resultant flux produced by the power transmission lines will interact with communication system and there will be some emf induced in communication lines.

→ The effect of the emf some current will be circulated in the communication line, such that the communication signal will get distrubed, this is called radio interference.

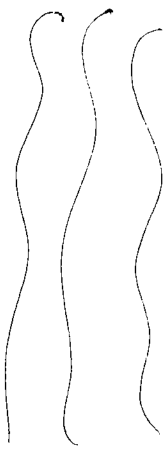
→ resultant flux in case of symmetrical configuration

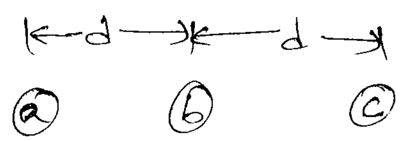
$$\phi_R = \phi_a + \phi_b + \phi_c \Rightarrow 0 \Rightarrow \text{no radio interference}$$

→ $GMD_a = \sqrt{d \times 2d}$

$GMD_b = \sqrt{d \times d}$

$GMD_c = \sqrt{d \times 2d}$





All the GMD's are not same.

but $GMD_a = GMD_c$ so

Inductance of GMD_a and Inductance of GMD_c are same.

i.e, $L_a = L_c \neq L_b$

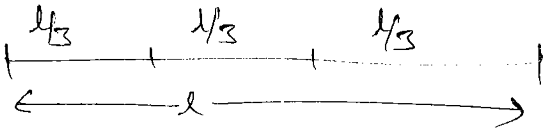
$|\phi_a| = |\phi_c| \neq |\phi_b|$

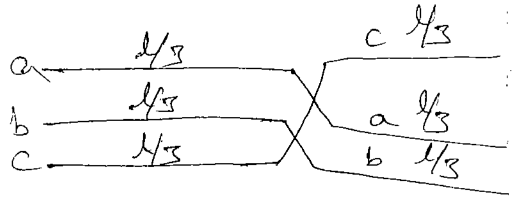
$\phi_r = |\phi_a| \angle 0^\circ + |\phi_b| \angle -120^\circ + |\phi_c| \angle 120^\circ \neq 0$

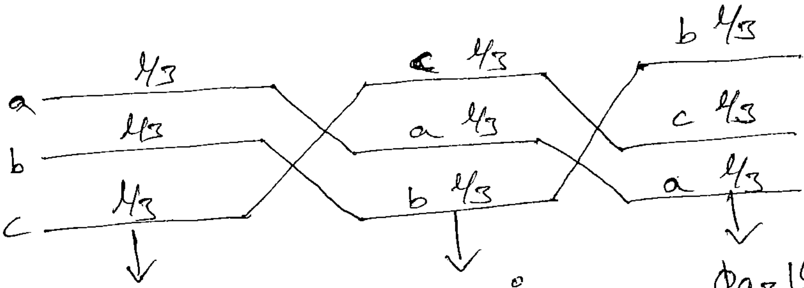
there is some resultant flux produced by the system

→ for unsymmetrical configuration $\phi_R \neq 0 \Rightarrow$ radio interference is present here.

→ To avoid radio interferance effect transposition of transmission line is done.







$\phi_{a_1} \angle 0^\circ$	$\phi_{a_2} \angle 0^\circ$	$\phi_{a_3} \angle 0^\circ$
$\phi_{b_1} \angle -120^\circ$	$\phi_{b_2} \angle -120^\circ$	$\phi_{b_3} \angle -120^\circ$
$\phi_{c_1} \angle 120^\circ$	$\phi_{c_2} \angle 120^\circ$	$\phi_{c_3} \angle 120^\circ$

Resultant flux, $\phi_r = (\phi_{a_1} + \phi_{a_2} + \phi_{a_3}) \angle 0^\circ + (\phi_{b_1} + \phi_{b_2} + \phi_{b_3}) \angle -120^\circ + (\phi_{c_1} + \phi_{c_2} + \phi_{c_3}) \angle 120^\circ$

$= \phi_{ar} \angle 0^\circ + \phi_{br} \angle -120^\circ + \phi_{cr} \angle 120^\circ$

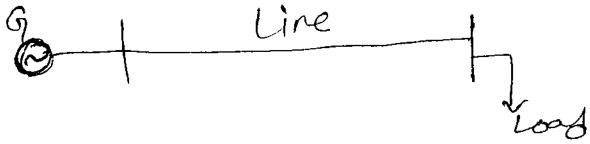
$\phi_{ar} = \phi_{br} = \phi_{cr}$

$\phi_r = 0$

→ In unsymmetrical configuration the voltages at the terminal of TL will become unbalanced. To make the voltages as balance the transposition for the transmission line is done.

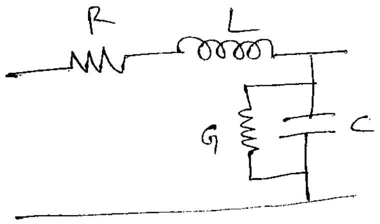
→ reducing the radio Interferance.

Transmission line constants/ Transmission line calculations:-



single line diagram of a 3-φ system

equivalent circuit of line:-



→ 'G' is the shunt conductance of TL
→ It is due to leakage current flowing through over head line insulator.

→ Leakage current value is very low, in the order of 'µA'.

⇒ 'G' value is very low and it is neglected.

$G \cong 0$

→ for the steady state performance analysis of TL R, L, C elements will be considered. where as for the transient analysis R, L, C, G elements will be considered.

→ Insulators will have -ve temperature coefficients and conductors will have +ve temperature coefficients.

→ In insulators the temperature increases then the resistance of the insulator will be reduced. so we have consider 'G' in the transient analysis.

Calculation of resistance:-

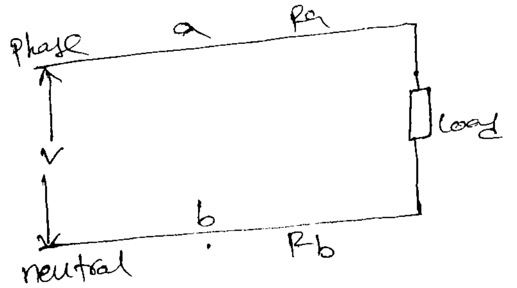
Resistance, $R = \frac{\rho l}{a}$ → dc resistance

effective resistance of TL $= \frac{\text{Powerloss } (I^2R)}{I^2}$

effective resistance → Ac resistance (R_{ac})

$R_{ac} > R_{dc}$ (or) $R_{ac} = 1.6 R_{dc}$ → Due to skin effect

1-ϕ, two wire Transmission line:-

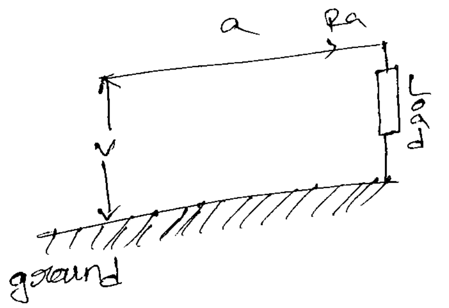


→ Loop resistance of 1-ϕ resistance, $R_{ab} = R_a + R_b$

→ If a, b conductors are identical, then $R_a = R_b$ *

⇒ loop resistance $R_{ab} = 2R_a$

1-ϕ, single wire system:-



Loop resistance, R_{ab} = R_a + earth resistance

$R_{ab} \cong R_a$

→ for 3-ϕ system the resistance is taken in per phase. i.e., R/Ph

→ R/Ph is represented in Ω/km.

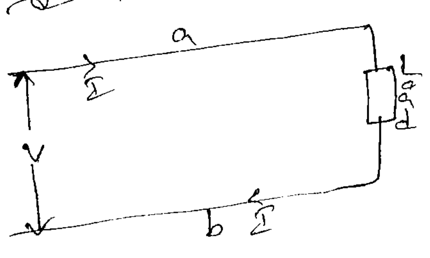
→ The resistance value is independent of configuration of conductors.

Calculation of Inductance:-

$$\text{Inductance} = \frac{\text{magnetic flux linkages}}{\text{current}}$$

$$\boxed{L = \frac{\lambda}{I}}$$ where 'λ' is magnetic flux linkage.

single-ϕ, 2 wire system:-



Infinite plane

→ A conductor will have a finite amount of internal inductance irrespe-
ctive of size of conductors and the presents of other conductors.

→ Internal flux linkages, $\lambda_{int} = \frac{\mu_0 \mu_r}{8\pi} \cdot I$

→ Internal inductance, $L_{int} = \frac{\lambda_{int}}{I} = \frac{\mu_0 \mu_r}{8\pi}$ H/m

→ External inductance depends on size of the conductor and the presents of other conductors in the space, so the external flux linkages $\lambda_{ext} = \frac{\mu_0 \mu_r}{2\pi} \ln(d/r)$

r → radius of conductor.

d → distance b/n two conductors.

external inductance, $L_{ext} = \frac{\lambda_{ext}}{I}$

$= \frac{\mu_0 \mu_r}{2\pi} \ln\left(\frac{d}{r}\right)$

→ Inductance of p-a (or) conductor-a, $L_a = L_{int} + L_{ext}$

$$L_a = \frac{\mu_0 \mu_r}{2\pi}\left[\frac{1}{4} + \ln\left(\frac{d}{r}\right)\right]$$

→ for external inductance $\mu_r = 1$

$$L_a = \frac{\mu_0 \mu_r}{8\pi} + \frac{\mu_0}{2\pi} \ln\left(\frac{d}{r}\right)$$ → ACSR conductor

$$= \frac{4\pi \times 10^{-7} \times \mu_r}{8\pi} + \frac{4\pi \times 10^{-7}}{2\pi} \ln\left(\frac{d}{r}\right) \text{ H/m}$$

$$= 0.5 \times 10^{-7} \mu_r + 2 \times 10^{-7} \ln\left(\frac{d}{r}\right) \text{ H/m}$$

$\boxed{L_a = 0.05 \mu_r + 0.2 \ln(d/r) \text{ mH/km}}$ → ACSR conductor

→ AAC

→ for AAC (or) solid conductor, $L_a = 0.05 + 0.2\ln(d/r)$ mH/km

$$= 0.2\left[\frac{0.05}{0.2} + \ln(d/r)\right] \text{ mH/sec}$$

$$= 0.2\left[\frac{1}{4} + \ln(d/r)\right] \text{ mH/sec}$$

$$L_a = 0.2\left[\ln(e)^{1/4} + \ln(d/r)\right]$$

$$= 0.2\left[\ln\left(\frac{d \cdot e^{1/4}}{r}\right)\right]$$

$$= 0.2\ln\left(\frac{d}{r \cdot e^{-1/4}}\right) \text{ mH/sec} \rightarrow 0.2\ln\left(\frac{d}{0.7788r}\right) \text{ mH/sec}$$

$$= 0.2\ln\left(\frac{d}{r'}\right) \text{ mH/sec}$$

$$L_a = 2\times10^{-7}\ln\left(\frac{d}{r'}\right) \text{ H/m}$$

$$= \underbrace{2\times10^{-7}\ln\left(\frac{1}{r'}\right)}_{\text{self inductance}} - \underbrace{2\times10^{-7}\ln\left(\frac{1}{d}\right)}_{\text{mutual inductance}}$$

loop inductance, $L_{ab} = L_a + L_b$

→ The two conductors are identical, $L_a = L_b \Rightarrow L_{ab} = 2L_a$

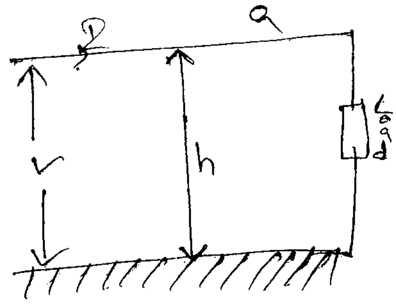
$$L_{ab} = 4\times10^{-7}\ln\left(\frac{d}{r'}\right) \text{ H/m}$$

1-φ, single wire system :-

$r \rightarrow$ radius

$$L_a = 2\times10^{-7}\ln\left(\frac{h}{r'}\right) \text{ H/m}$$

where 'h' is height of the conductor



$L_{ab} = L_a +$ Inductance of earth
↓
neglected because radius of earth is very high.

$L_{ab} \simeq L_a$
$= 2\times10^{-7} \ln\left(\frac{h}{r}\right) H/m$

→ for 3-φ system / 3-φ transmission line inductance is taken in per phase manner.

→ $L/ph = 2\times10^{-7} \ln\left(\frac{GMD}{GMR}\right) H/m$

as $r \rightarrow$ constant , $L \alpha \ln(d)$

→ As distance b/n the conductors will increase then the inductance will be increased.

→ As distance b/n conductors will be an optimum value such that the inductance will be low.

→ As the distance is increasing the self inductance is constant and the mutual inductance is reducing with effect of this the resultant inductance is increasing. This inductance is called as +ve sequence inductance.

i.e +ve sequence inductance = self inductance − mutual inductance

i.e, $L_1 = L_s - L_m$

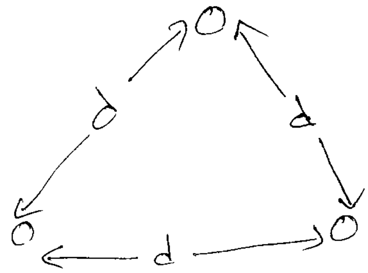
→ Inductive reactance, $X = 2\pi f L \; \Omega/m$

→ The inductive reactance and resistance of the transmission line are compare to decide impedance angle of TL.

$\frac{X}{R} > 1$ for the TL

$\frac{X}{R} < 1$ for the distribution line

→



3-ϕ
symmetrical
configuration

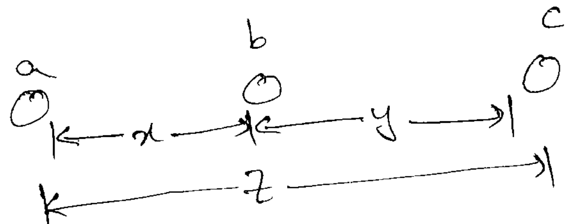
$GMD = d$

$GMR = r'$

$$L_{ph} = 2\times10^{-7} \ln\left(\frac{d}{r'}\right) \; H/m$$

$L_a = L_b = L_c \Rightarrow$ voltages are balanced at the end of line

→



$GMR_a = GMR_b = GMR_c = r'$

$$L_a = 2\times10^{-7} \ln\left(\frac{GMD_a}{GMR_a}\right) \; H/m$$

$GMD_a = \sqrt{xz}$

$$L_b = 2\times10^{-7} \ln\left(\frac{GMD_b}{GMR_b}\right) \; H/m$$

$GMD_b = \sqrt{xy}$

$$L_c = 2\times10^{-7} \ln\left(\frac{GMD_c}{GMR_c}\right) \; H/m$$

$GMD_c = \sqrt{yz}$

The inductance represented in per phase equivalent diagram is average of L_a, L_b, L_c.

$$L_{Ph} = \frac{L_a + L_b + L_c}{3}$$

$$= \frac{2\times10^{-7}}{3} \ln\left[\frac{GMD_a \cdot GMD_b \cdot GMD_c}{GMR_a \cdot GMR_b \cdot GMR_c}\right]$$

$$= 2\times10^{-7} \ln\left[\frac{\sqrt[3]{GMD_a \cdot GMD_b \cdot GMD_c}}{\sqrt[3]{GMR_a \cdot GMR_b \cdot GMR_c}}\right]$$

$$= 2\times10^{-7} \ln\left(\frac{GMD}{GMR}\right) \text{ H/m}$$

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

$$GMR = r'$$

Calculation of capacitance:

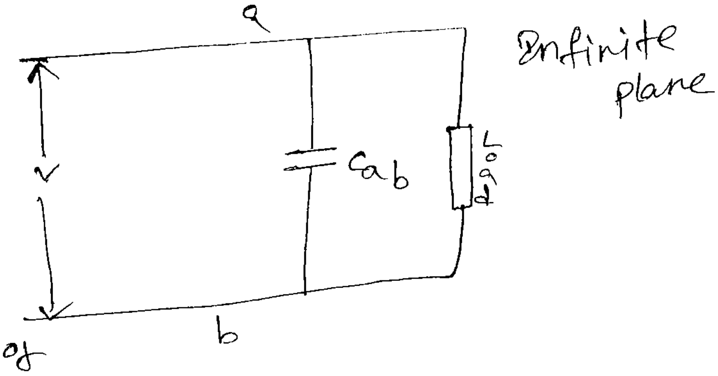
$$\text{capacitance} = \frac{\text{electric flux linkages}}{\text{voltage}}$$

$$C = \frac{\text{charge}}{\text{voltage}}$$

$$\boxed{C = \frac{q}{V}}$$

1-ϕ, 2wire system:

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



'r' is radius of conductor

$\varepsilon_r \rightarrow$ relative permitivity of space ~~free~~ air for air $\varepsilon_r = 1$

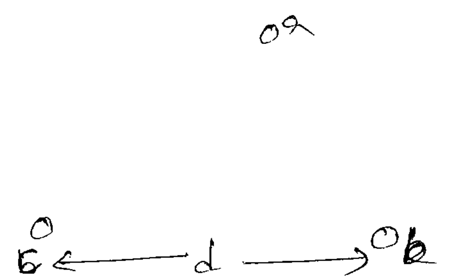
$$C_{ab} = \frac{2\pi \varepsilon_0 \varepsilon_r}{\ln (d/r)}$$

→ for 3-φ system the capacitance per phase i.e.,

$$C/ph = \frac{2\pi \varepsilon_0 \varepsilon_r}{\ln (d/r)} = \frac{2\pi \varepsilon_0 \varepsilon_r}{\ln \left(\frac{GMD}{r}\right)}$$

→ There is no effect of skin effect in the calculation of capacitance.

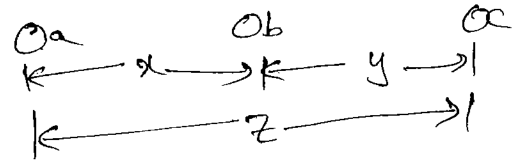
→ for symmetrical configuration,



GMR's, GMD's for all conductors is same.

$$C_a = C_b = C_c = C/ph$$

→ for unsymmetrical configuration,



GMD's are different. so,

C_a, C_b, C_c will be different

$$C_{ph} = \frac{C_a + C_b + C_c}{3} = \frac{2\pi \varepsilon_0 \varepsilon_r}{\ln \left(\frac{GMD}{r}\right)}$$

→ for bundle conductor $\quad C/ph = \dfrac{2\pi \varepsilon_0 \varepsilon_r}{\ln \left[\dfrac{GMD}{\text{self GMD}}\right]}$

Actual radius of conductor is taken for its calculation.

→ capacitive reactance/ph (X_c/Ph) $= \frac{1}{2\pi f C}$ Ω

→ The reactances of inductance and capacitances will not be compares.

X_L/Ph → series element

X_c/ph → shunt element

→ The electro magnetic energy stored in the inductor will be compared with the electro static energy stored in the capacitor.

→ If r = constant and 'd' is increased

$$C \propto \frac{1}{\ln(d)}$$

As $d\uparrow$ $C\downarrow$ ⇒ electric flux linkages will reduce.

→ As length of the transmission line increases then resistance will increases and inductance will increased and inductive reactance will also increased and capacitance will increased ($X_L = 2\pi f L$)

and capacitive reactance ($X_C = \frac{1}{2\pi f L}$) will reduced.

→ charging current for transmission line,

$$I_c = \frac{V}{X_c}$$

$$= V \cdot 2\pi f \cdot C$$

$$I_c \propto V \cdot f \cdot C$$

If length of line is increasing then the charging current will also increases.

→ The charging current will cause the injection of reactive power into system. i.e., the source is required to supply less amount of reactive power.

→ The inductor will absorb the reactive power from the system.

→ If the self inductance of transmission line is K mH/km, If the distance b/n transmission lines is doubled, what will be the self inductance value.

$$L_s = 2\times10^{-7}\ln\left(\frac{1}{GMR}\right)$$

GMR is independent of distance b/n conductors.

⇒ self inductance is independent of distance b/n conductors

⇒ L_s is " " " "

$L_s = K$ mH/s

→ A 3-φ TL is supplying a power of 150 MVA with a voltage 110 kV. The power loss in the transmission system is 15 MW

$$\text{Resistance} = \frac{3\text{-}\phi \text{ Power loss}}{3\cdot I_L^2}$$

$$S = \sqrt{3}\, V_L \cdot I_L$$

$$I_L = \frac{150}{\sqrt{3}\times110\text{kV}} = 787.2\text{A}$$

$$R = \frac{15\times10^6}{3\times(787.2)^2} \Rightarrow 24.2\,\Omega$$

$R/ph = 8.06\,\Omega$

→ ① equilateral spacing ← 4m →

② ← 4m → ← 4m →

a) $C_1 = C_2, L_1 = L_2$ b) $L_1 > L_2, L_1 \ldots$

c) ✓ $C_1 > C_2, L_1 < L_2$ d) none of the above

GMR value is same in both cases

$GMD_1 = 4m$

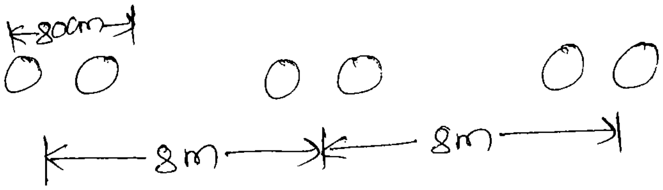
$GMD_2 = \sqrt[3]{4 \times 4 \times 8} \Rightarrow 5.03m$

$GMD_3 \neq$ $L \propto \ln(GMD)$

$\Longrightarrow L_2 > L_1$ (or) $L_1 < L_2$

$C \propto \frac{1}{\ln(GMD)} \Longrightarrow C_2 < C_1$ (or) $C_1 > C_2$

→ what is the inductance/km/ϕ of the 400 kV bundle conductor system shown below. The diameter of each subconductor is 5cm



$$L/Ph = 2 \times 10^{-7} \ln\left[\frac{GMD}{\text{self } GMD}\right] \text{ H/m}$$

$GMD = \sqrt[3]{8 \times 8 \times 16} \Rightarrow 10.07m$

self GMD_a = self GMD_b = self GMD_c

self $GMD = \sqrt{r_1' \times s}$

$r_1 = \frac{5}{2} cm \Rightarrow 2.5cm$

* $s = 80 cm$

self $GMD = \sqrt{0.7788 \times 2.5 \times 80} \text{ cm} \Rightarrow 12.487 cm$

$$L/Ph = 2 \times 10^{-7} \ln\left[\frac{10.07}{12.487 \times 10^{-2}}\right] \text{ H/m}$$

$= 2\times10^{-7} \times 4.39$ H/m

$= 0.2 \times 4.39$ mH/km

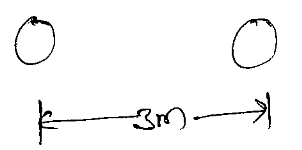
$L/Ph = 0.878$ mH/km

$C/Ph = (2\pi \varepsilon_0) \Big/ \left[\ln\left(\frac{GMD}{self\,GMD}\right)\right]$ (F/m)

self GMD $= \sqrt{r_1 \times s} \Rightarrow \sqrt{2.5\times 80}$ cm $\Rightarrow 14.14$ cm

$$C/Ph = \frac{2\pi\varepsilon_0}{\ln\left(\frac{10.07}{14.14\times10^{-2}}\right)} \text{ F/m} \Rightarrow 13\times10^{-12} \text{ F/m} \Rightarrow 13 \text{ nF/km}$$

→ A 1-ϕ, two conductors transmission line is operating at 50 Hz with the distance b/n two conductors is 3m and diameter of each conductor is 20mm. If the conductors is made up of cu. what is the inductance per phase per kilometer.



diameter = 20mm
radius = 10mm

$L_{ph} = 2\times10^{-7} \ln(d/r') $ H/m

$= 2\times10^{-7} \ln\left(\frac{3}{0.7788\times10\times10^{-3}}\right)$ H/m

$= 1.19$ mH/km

→ If the conductors are made up of steel which is having a relative permiability of 50, then what is the loop inductance from the previous problem

$\mu_r = 50$

loop inductance, $L_{ab} = L_a + L_b$

$$= 2L_a$$

$$= 2L/Ph$$

$$L/Ph = \frac{\mu_0 \mu_r}{8\pi} + \frac{\mu_0 \mu_r}{2\pi} \ln\left(\frac{d}{r}\right)$$

$$= \left[\frac{\mu_0}{8\pi} + \frac{\mu_0}{2\pi} \ln(d/r)\right] \mu_r$$

$$L/Ph = \mu_r \times 1.19 \text{ mH/km}$$

$$= 50 \times 1.19 \text{ mH/km} \Rightarrow 59.5 \text{ mH/km}$$

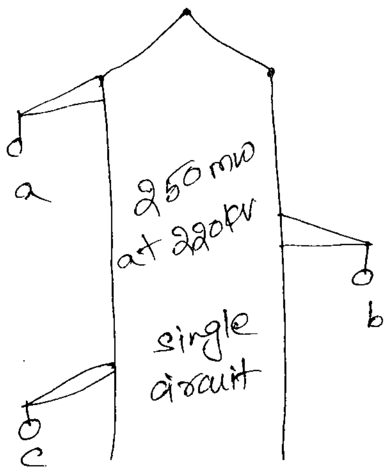
$$\text{loop inductance} = 2L/Ph$$

$$= 2 \times 59.5 \text{ mH/km}$$

$$= 0.119 \text{ H/km}$$

Double circuit transmission line:-

Purpose:- To increase (or) enhance the power transfer capability of system



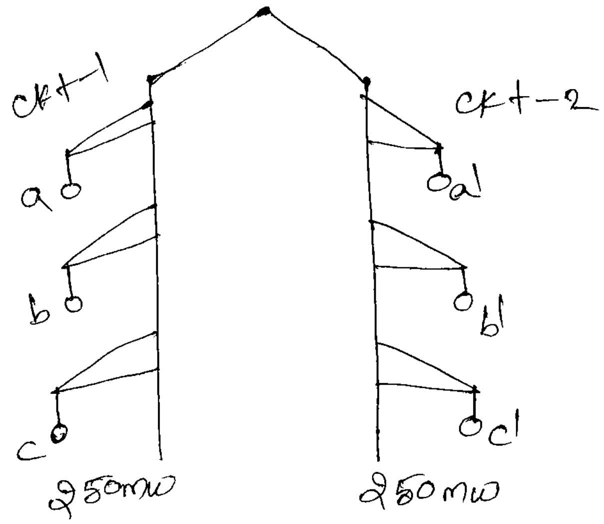
→ To increase the power transfer capability, i) the conductors has to be replaced by new conductors which will have more cross section area.

ii) Going for the new transmission system to transfer the extra amount of power

iii) placing another 3-ϕ system on the same tower.

→ Always the tower will design to bear double circuit lines self $GMD_a = \sqrt{r' \times d_{aa'}}$

$GMD_a = \sqrt[4]{d_{ab} \times d_{ac} \times d_{ab'} \times d_{ac'}}$



self $GMD_b = \sqrt{r' \times d_{bb'}}$

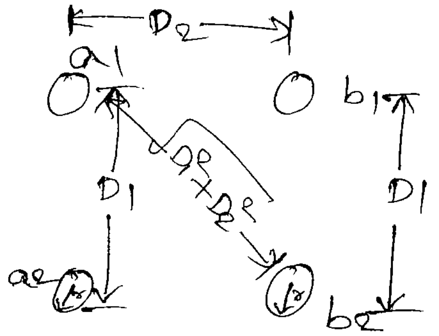
$GMD_b = \sqrt[4]{d_{ba} \times d_{bc} \times d_{ba'} \times d_{bc'}}$

$r \rightarrow$ radius of each conductor

self $GMD_c = \sqrt{r' \times d_{cc'}}$

$GMD_c = $ ~~$d_{ca} \times d$~~

→ A 1-φ, double circuit line is shown below which will have a_1, a_2 → forward conductors, b_1, b_2 → return conductors, what is the total inductance per km



$D_1 = 1m$

$D_2 = 2m$

$r = 1cm$

$L/Ph = 2 \times 10^{-7} \ln \left[\frac{GMD}{self\ GMD}\right]$ H/m

$GMD_{a_1} = \sqrt[3]{D_1 \times D_2 \times \sqrt{5}}$

$\Rightarrow \sqrt[3]{1 \times 2 \times \sqrt{5}} \Rightarrow 1.64m$

~~self~~ $GMD_{a_1} = \sqrt{D_2 \times \sqrt{5}} \Rightarrow \sqrt{2 \times \sqrt{5}} \Rightarrow 2.11\ m$

self $GMD_{a_1} = \sqrt{r' \times D_1} \Rightarrow \sqrt{0.7788 \times 1 \times 10^{-2} \times 1\ m} \Rightarrow 0.088m$

$L_{a_1} = 2 \times 10^{-7} \ln \left(\frac{2.11}{0.088}\right)$ H/m

$= 0.635$ mH/km

$L_{a2} = L_{a1} = 0.635\ mH/km$

$$L_a = \frac{L_{a1} + L_{a2}}{2} \Rightarrow \frac{0.635 + 0.635}{2} \Rightarrow 0.635\ mH/km$$

Inductance of b1 & b2 is same as that of La1 & La2

$\therefore L_{b1} = L_{b2} = 0.635\ mH/km$

$$L_b = \frac{L_{b1} + L_{b2}}{2} \Rightarrow 0.635\ mH/km$$

Loop inductance/Total inductance $L_{ab} = L_a + L_b$

$$= 2 \times 0.635\ mH/km$$

$$= 1.27\ mH/km$$

steady state performance of transmission lines:-

→ Performance analysis is done to know whatever the equipment is working satisfactorily or not.

→ we have two performance indices for any apparatus

1) efficiency

2) regulation
- static regulation
- dynamic regulation

→ static regulation is for the devices which will give electrically energy as o/p and this is also called as voltage regulation.

ex: synchronous generator, transformer, transmission line

→ dynamic regulation is for the apparatus which gives mechanical energy as o/p and this is also called as speed regulation

ex: motor: for syn motor speed regulation is zero

→ for IM, the speed regulation is nothing but slip%.

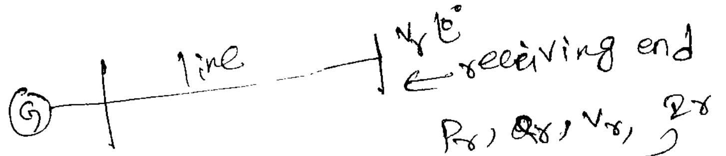
efficiency:-

→ Power efficiency = $\frac{\text{o/p power}}{\text{i/p power}} = \frac{\text{o/p power}}{\text{o/p power} + \text{losses}}$

→ Losses = cu loss + corona loss + shunt conductance loss

→ By using Bundle conductors corona loss will be reduced.

→ The value of loss due to conductance is neglected.



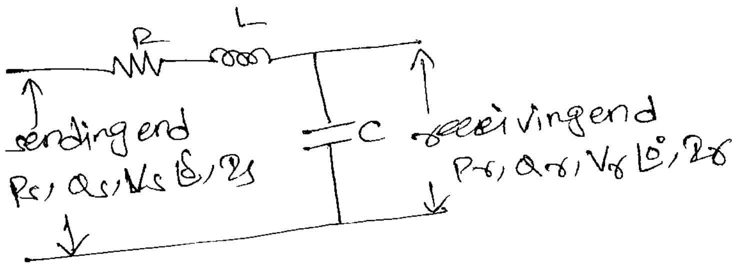
← receiving end

$\underbrace{P_r, Q_r, V_r, \delta_r}$ → known values.

↑ sending end

$\underbrace{P_s, Q_s, V_s, \delta_s}$

unknown values.



→ efficiency, $\eta = \frac{P_r}{P_r + \text{losses}} \times 100$

$\eta = \frac{P_r \text{ (3-}\phi\text{ power)}}{P_r + 3I_r^2 R} \times 100$

→ Bundle conductors will

i) increases efficiency of TL

ii) reduces corona loss

iii) reduces characteristic impedance

a) 1, 2 correct b) 2, 3 correct

c) ✓ 1, 2, 3 correct d) none of the above

Voltage regulation of transmission line:

→ This is difference b/n no-load and full load voltages of TL at the recieving end when full load is Thrown off.

→ It is taken as a % of full load Voltage.

$$\boxed{\%\ \text{voltage regulation} = \frac{\text{NL Voltage} - \text{FL Voltage}}{\text{FL Voltage}} \times 100}$$

Condition for calculating voltage regulation:-

1) voltages are taken as magnitudes

ii) voltages regulation is calculated at a perticular P.f

iii) There should not be any change in sending end voltage from NL to FL condition.

FL voltage → $|V_r|$

NL voltage → $|V_{r0}|$

$$\boxed{\%\text{Reg} = \frac{|V_{r0}| - |V_r|}{|V_r|} \times 100}$$

PU voltage regulation $= \dfrac{|V_{r0}| - |V_r|}{|V_r|}$

classification of transmission line:-

→ classification is done based on physical length of transmission line for a perticular frequency (50 Hz / 60 Hz)

→ Based on physical length will have three types of TL

1) short line → < 80 km (< 50 miles)

2) medium line → 80 < l < 160 km (50 to 100 miles)

3) long TL → > 160 km (> 100 miles)

→ short and medium lines are called electrically short lines and long line is electrically long line.

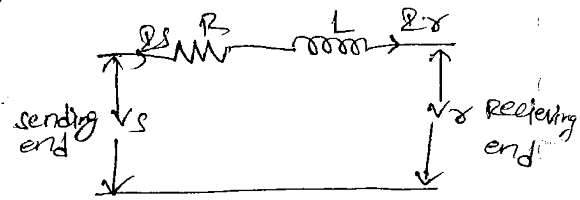
→ for the steady state analysis short and medium lines are represented in lumped parameters.

→ Long line represented in distributed parameter model

→ The wave travelling analysis is done on long TL. for steady state analysis the LT line will be represented as approximate lumped parameter model.

short transmission line:-

Lumped parameter model having only R and L elements.



$C \simeq 0$, because length of line is low.

$I_s = I_r$

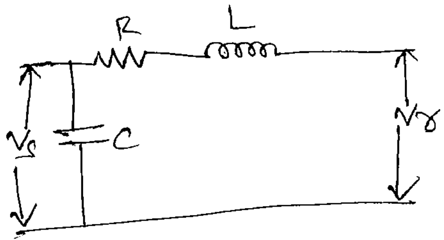
medium transmission line:-

Lumped model having R, L, C elements.

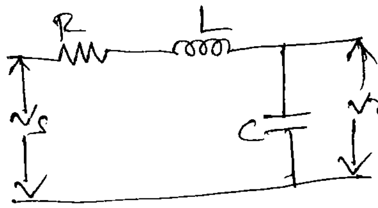
→ Acc to placement (position) of 'C' in the equivalent ckt, there are 4 types of medium line rep

1) sending end (or) source end capacitor model
2) Receiving end (or) Load " "
3) nominal-T network
4) " -π "

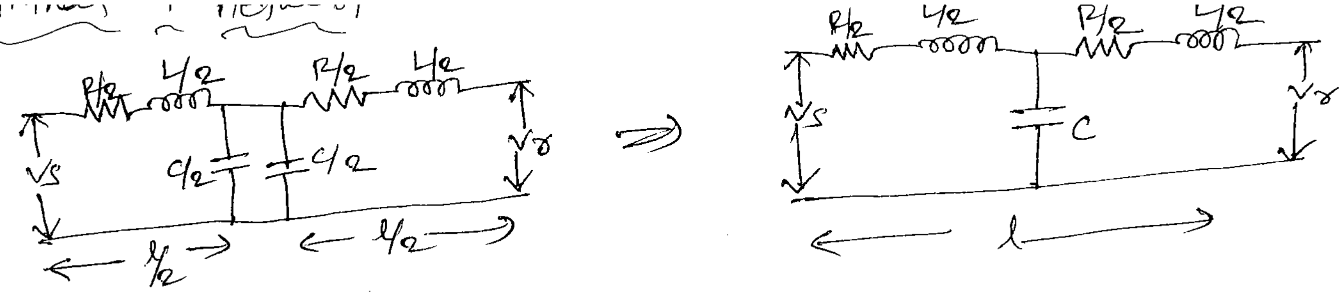
sending end capacitor model



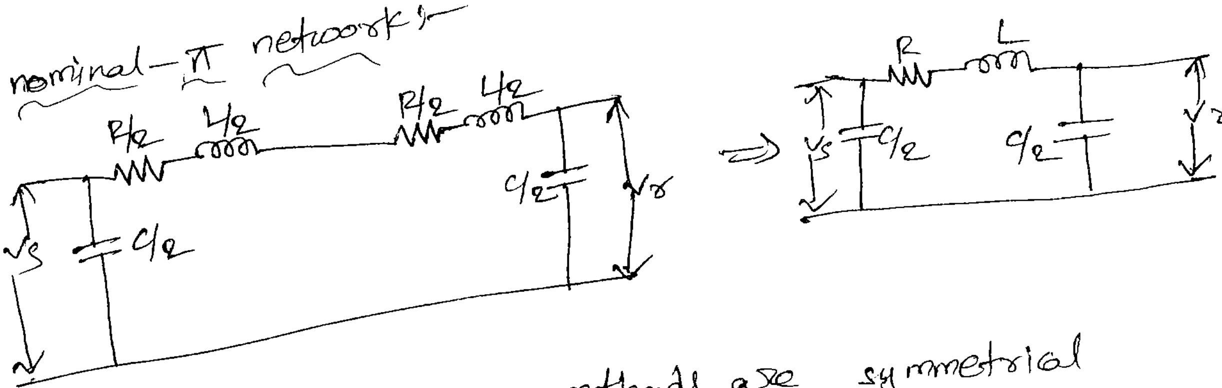
Receiving end capacitor model



nominal-T network:-



nominal-π network:-



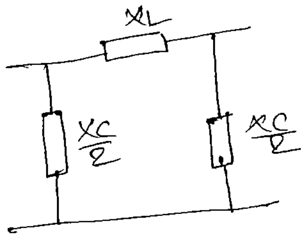
→ nominal-T & nominal-π methods are symmetrial

→ conversion of nominal-T n/w into nominal-π by using Y-Δ conversion will not give exact nominal-π n/w & vice versa

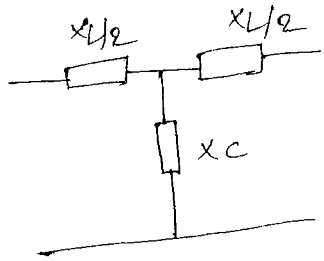
→ Among these two n/w's (T, π), the nominal-π n/w is possible, because the nominal-T n/w will create another node in the system which such that the size of Y-bus becomes high as well as the analysis of the system will become difficult.

→ A 120km TL having an inductive reactance and capacitive reactance as X_L, X_C resp. which of the following n/w is prefrable for load flow analysis.

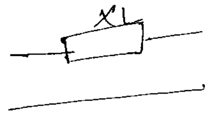
a)



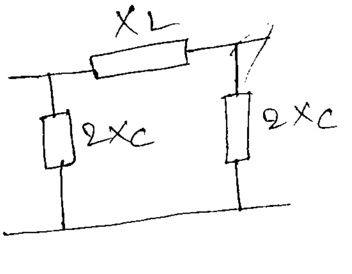
b)



c)



d) ✓



$l = 120$ km = medium TL ⇒ c) is eliminated because it is used for STL

among a), b), d) ⇒ b) is not prefered only nominal π is prefered.

∴ among a & d, d) is the correct option

∵ In nominal-π n/w, capacitance is devided by '2' means, capacitance reactance become double. $C_1 \to C/2$

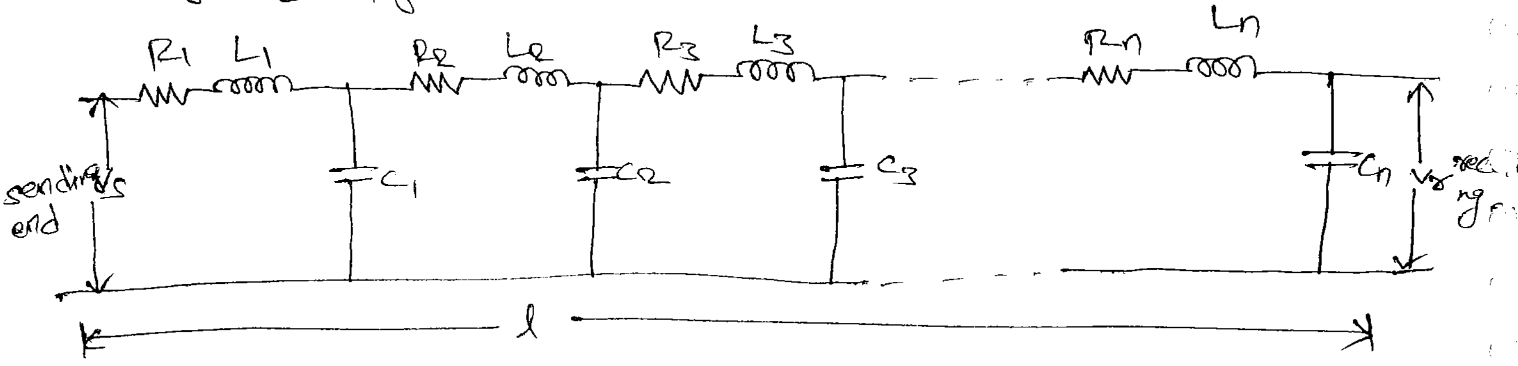
$$\left(X_{C_1} = \frac{1}{\omega C_1} = \frac{1}{\omega C/2} = \frac{2}{\omega C} = 2X_C\right.$$

Long Transmission line:-

Distributed parameter model consists of R, L, C elements.

l → length of line is devided into n-no of sections

* each section will be represented in lumped form, all the sections are cascaded together.



* This model is used for transient -T & equivalent -π n/w's

* For steady state analysis equivalent -T & equivalent -π n/w's

→ equivalent -π represent is used for the TL having a length of

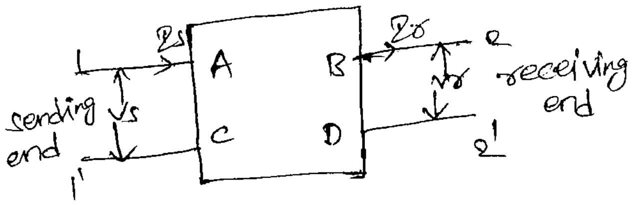
a) 50 km b) 150 km c) 250 km d) none of the above

→ To avoid the difficulty in analyzing the TL based on KCL and KVL or n/w eqns the TL constant are A, B, C, D constant are introduced.

ABCD constants

→ These are defined for two port n/w model

→ Port will have two terminals.



V_s, I_s → unknown quantities

V_r, I_r → known quantities

→ The relation between unknown and known parameters will give ABCD parameters.

$$\boxed{\begin{aligned} V_s &= AV_r + BI_r \\ I_s &= CV_r + DI_r \end{aligned}}$$

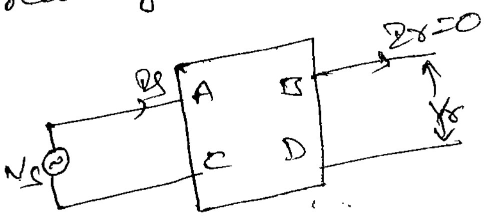
$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

→ ABCD parameters are known as Transmission line parameters

(Y & Z parameters are used to find Y-bus & Z-bus in load flow analysis)

Calculation of A, B, C, D values / parameters :-

→ If receiving end port is open circuited



Put $I_r = 0$

$V_s = AV_r$ & $I_s = CV_r$

$$\boxed{A = \frac{V_s}{V_r}} \qquad \boxed{C = \frac{I_s}{V_r}}$$

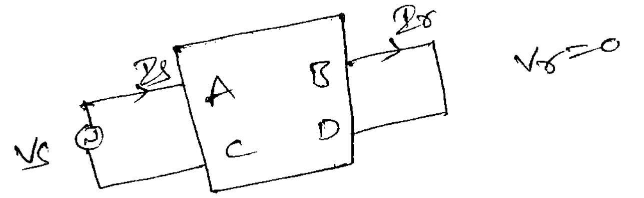
↳ It has no units   ↳ units are mho (or) siemens.

A → reverse voltage gain of the line.

$C \rightarrow$ open circuit admittance.

$\rightarrow \frac{A}{C} = \frac{V_s/V_r}{I_s/V_r} = \frac{V_s}{I_s}$ $\therefore \boxed{\frac{A}{C} = \frac{V_s}{I_s}} \rightarrow$ open circuit impedance of line.

$\rightarrow$ If the receiving end port is short circuited



I_r = short circuit in TL

from ABCD parameters eqns

$V_s = BI_r$ $\qquad$ $I_s = DI_r$

$\boxed{B = \frac{V_s}{I_r}}$ $\rightarrow$ units - Ω $\qquad$ $\boxed{D = \frac{I_s}{I_r}}$ $\rightarrow$ no units

$D \rightarrow$ reverse current gain of line

$B \rightarrow$ short circuit impedance

$\frac{B}{D} = \frac{V_s/I_r}{I_s/I_r} = V_s/I_s \Rightarrow \boxed{\frac{B}{D} = \frac{V_s}{I_s}} \rightarrow$ SC impedance of line, Z_c

$\rightarrow$ multiplying $\frac{A}{C}$ & $\frac{B}{D}$, we get

$\Rightarrow \frac{A}{C} \times \frac{B}{D} = \left(\frac{V_s}{I_s}\right)^2 \Rightarrow \boxed{\frac{V_s}{I_s} = \sqrt{\frac{A}{C}\cdot\frac{B}{D}}} \rightarrow$ characteristics impedance of line, Z_c

$\rightarrow$ for symmetrical n/w, A=D; for reciprocal n/w, AD-BC=1

$\rightarrow$ reciprocal n/w are as bilateral n/w i.e, which offers same impedance in either sides. These n/w's follow reciprocity theorem.

$\rightarrow$ Transmission line is a bilateral & reciprocal n/w which will follow the reciprocity theorem.

→ for symmetrical n/w's; characteristic impedance, $Z_c = \sqrt{\frac{B}{C}}$

$$= \sqrt{\frac{\text{sc impedance}}{\text{oc admittance}}}$$

$$Z_c = \sqrt{(\text{sc impedance}) \times (\text{oc Impedance})} = \sqrt{Z_{oc} \cdot Z_{sc}}$$

∴ characteristic impedance is the geometric mean between oc & sc impedances of Transmission line.

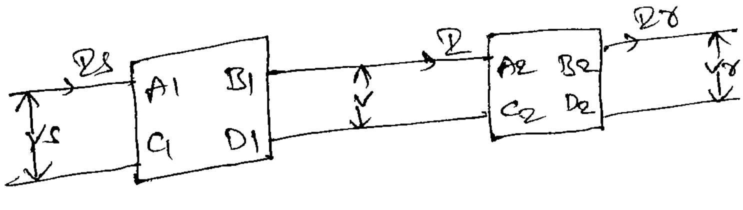
→ The open & short circuit impedances of transmission lines are $100\,\Omega$, $100\,\Omega$ respectively. what is the characteristic impedance of line.

$$Z_c = \sqrt{100 \times 100} = 100\,\Omega$$

→ The open circuit impedance of the transmission line is $900 \angle 40^\circ\,\Omega$. The short circuit impedance is $400 \angle 10^\circ\,\Omega$. what is the characteristic impedance of transmission line.

$$Z_c = \sqrt{400 \times 900 \angle 50} = 600 \angle 25^\circ\,\Omega$$

Cascaded transmission lines (ABCD parameters):-



$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} V \\ I \end{bmatrix} \rightarrow \text{for TL-1} \rightarrow (1)$$

$$\begin{bmatrix} V \\ I \end{bmatrix} = \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix} \rightarrow \text{for TL-2} \rightarrow (2)$$

for cascaded lines, ABCD parameters are taken as $A_0 B_0 C_0 D_0$ resp

$$\therefore \begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A_0 & B_0 \\ C_0 & D_0 \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix} \rightarrow (3)$$

from eqns ① & ②

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix} \rightarrow ④$$

Compare ③, ④

$$\begin{bmatrix} A_o & B_o \\ C_o & D_o \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix} \rightarrow ④$$

$A_o = A_1A_2 + B_1C_2$; $B_o = A_1B_2 + B_1D_2$

$C_o = C_1A_2 + D_1C_2$; $D_o = C_1B_2 + D_1D_2$

If the two lines are identical, $A_1 = A_2$, $B_1 = B_2$, $C_1 = C_2$ & $D_1 = D_2$

$\therefore A_o = A_1^2 + B_1C_1$; $B_o = A_1B_1 + B_1D_1 = B_1(A_1 + D_1)$

$C_o = C_1A_1 + D_1C_1 \Rightarrow C_1(A_1 + D_1)$; $D_o = C_1B_1 + D_1^2$

If the lines are symmetrical, $A_1 = D_1$ & $A_1D_1 - B_1C_1 = 1$

(or) $A_2 = D_2$ $\rightarrow A_1^2 = 1 + B_1C_1$

$B_1C_1 = A_1^2 - 1$

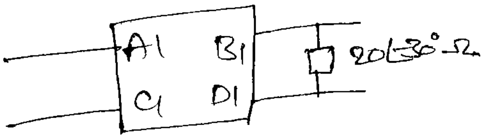
$= D^2 - 1$

$$\therefore \boxed{\begin{aligned} A_o &= A_1^2 + A_1^2 - 1 = 2A_1^2 - 1 \\ B_o &= 2A_1B_1 \\ C_o &= 2A_1C_1 \\ D_o &= 2A_1^2 - 1 \end{aligned}}$$

→ for two identical symmetrical lines cascaded

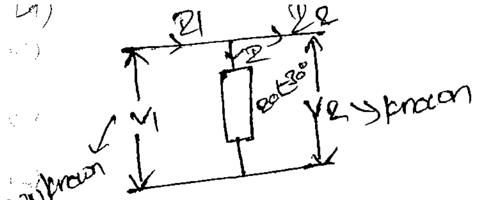
$\therefore \boxed{A_1 = D_1}$

→ The ABCD parameters of a n/w are 1, $10\angle 30°$, 0, 1 resp. If an impedance of $20\angle 30°$ is connected at the end of the n/w, what will be the resultant ABCD parameters.



$$\begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} = \begin{bmatrix} 1 & 10\angle 30° \\ 0 & 1 \end{bmatrix}$$

$I_1 = I + I_2$



but $I = \frac{V_2}{Z} = \frac{V_2}{20\angle 30^\circ} = 0.05\angle 30^\circ V_2$

$\therefore I_1 = 0.05\angle 30^\circ V_2 + I_2$

$V_1 = V_2$

(Compare)

$$\left.\begin{aligned} V_1 &= A_2V_2 + B_2I_2 \\ I_1 &= C_2V_2 + D_2I_2 \end{aligned}\right\} \text{ \& } \begin{aligned} V_1 &= V_2 \\ I &= 0.05\angle 30^\circ V_2 + I_2 \end{aligned}$$

$A_2 = 1,\ B_2 = 0,\ C_2 = 0.05\angle 30^\circ,\ D_2 = 1$

∴ Resultant ABCD parameters & $A_0 B_0 C_0 D_0$

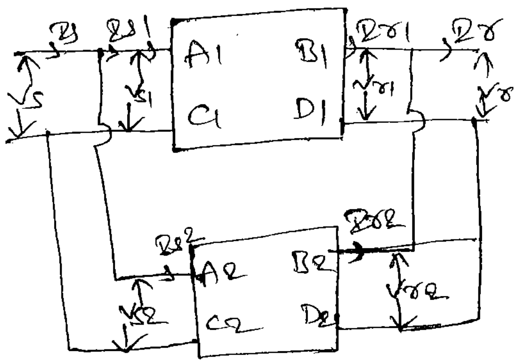
$$\begin{bmatrix} A_0 & B_0 \\ C_0 & D_0 \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix}\begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 10\angle 30^\circ \\ 0 & 1 \end{bmatrix}\begin{bmatrix} 1 & 0 \\ 0.05\angle 30^\circ & 1 \end{bmatrix}$$

$$\begin{bmatrix} A_0 & B_0 \\ C_0 & D_0 \end{bmatrix} = \begin{bmatrix} 1+0.5\angle 60^\circ & 10\angle 30^\circ \\ 0.05\angle 30^\circ & 1 \end{bmatrix}$$

∴ cascading two symmetrical networks may result as either symmetrical or unsymmetrical networks.

Two lines are connected in parallel:—



$V_S = V_{S1} = V_{S2}$ (connected in ||el)

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

& $I_S = I_{S1} + I_{S2}$

$I_R = I_{R1} + I_{R2}$

For line-1

$V_S = A_1V_R + B_1I_{R1} \rightarrow (1)$

$I_{S1} = C_1V_R + D_1I_{R1} \rightarrow (2)$

For line-2

$$V_s = A_2 V_r + B_2 I_{r2} \rightarrow (3)$$

$$I_{s2} = C_2 V_r + D_2 I_{r2} \rightarrow (4)$$

$(1) \times B_2 + (3) \times B_1 \Rightarrow$ $V_s B_2 + V_s B_1 = A_1 B_2 V_r + B_1 B_2 I_{r1} + A_2 B_1 V_r + B_1 B_2 I_{r2}$

$$\Rightarrow V_s (B_1 + B_2) = (A_1 B_2 + A_2 B_1) V_r + B_1 B_2 \underbrace{(I_{r1} + I_{r2})}_{I_r}$$

$$V_s (B_1 + B_2) = (A_1 B_2 + A_2 B_1) V_r + B_1 B_2 I_r$$

$$V_s = \left(\frac{A_1 B_2 + A_2 B_1}{B_1 + B_2}\right) V_r + \left(\frac{B_1 B_2}{B_1 + B_2}\right) I_r$$

Compare above eqn with $V_s = A_0 V_r + B_0 I_r$

$$A_0 = \frac{A_1 B_2 + A_2 B_1}{B_1 + B_2} \; ; \quad B_0 = \frac{B_1 B_2}{B_1 + B_2}$$

If the two lines are symmetrical and ~~#~~ that the resultant line of ||el combination is also symmetrical

$A_1 = D_1$ & $A_0 = D_0$

for reciprocal n/w, $A_1 D_1 - B_1 C_1 = 1$ & $A_0 D_0 - B_0 C_0 = 1$

$$\Downarrow$$

$$B_0 C_0 = A_0 D_0 - 1$$

$$C_0 = \frac{A_0 D_0 - 1}{B_0}$$

$$\therefore A_0 = D_0 = \frac{D_1 B_2 + D_2 B_1}{B_1 + B_2}$$

$$C_0 = (C_1 + C_2) + \frac{(A_1 - A_2)(D_2 - D_1)}{B_1 + B_2}$$

If both lines are identical, $A_1 = A_2$ & $B_1 = B_2$ & $C_1 = C_2$ & $D_1 = D_2$

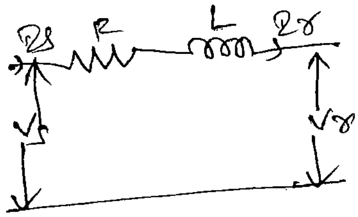
$$A_0 = \frac{2 A_1 B_1}{2 B_1} = A_1$$

$$B_0 = \frac{B_1^2}{2 B_1} = \frac{B_1}{2}$$

$$C_0 = 2C$$

$$D_0 = D_1$$

short transmission line:-



By KVL

$V_s = I_s(R+j\omega L)$

but $I_s = I_r$

$V_s = I_r R + I_r j\omega L$

$\Rightarrow V_s = V_r + Z\cdot I_r$

$I_s = 0\cdot V_r + I_r$

$$\therefore \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$$

voltage regulation of short transmission line:-

$$\%\text{ vol reg} = \frac{|V_{ro}| - |V_r|}{|V_r|} \times 100\%$$

no-load vol $\Rightarrow |V_{ro}| = \dfrac{|V_s|}{|A|}$ $\left(\because \text{ under no load } I_r = 0,\ V_s = A V_{ro} \Rightarrow |V_{ro}| = \dfrac{|V_s|}{|A|}\right)$

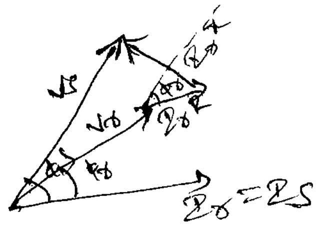
$$\boxed{\%\text{ vol regulation} = \frac{|V_s| - |V_r|}{|V_r|} \times 100\%}$$

Phasor diagram:-

Consider the eqn $V_s = I_r \underset{R+jX}{Z} + V_r$ & let 'I_r' as reference i.e., $I_r\angle 0°$

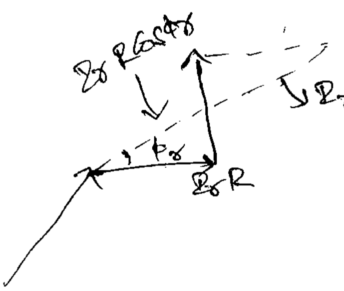
∴ load is lagging load with a powerfactor of $\cos\phi_r$

∴ $V_r\angle\phi_r$



$\phi_s \rightarrow$ power factor angle at sending end

Always $\boxed{\text{sending end pf} < \text{receiving end pf}}$ for STL $(\because \phi_r < \phi_s \Rightarrow \cos\phi_r < \cos\phi_s)$



By neglecting difference b/n ϕ_s & ϕ_r

$V_s \simeq V_r + I_r R\cos\phi_r \pm I_r X\sin\phi_r$

+ for lagging load

− for leading load

$\Rightarrow V_s - V_r = I_r R\cos\phi_r \pm I_r X\sin\phi_r$

$\therefore$ vol reg $= \dfrac{|V_s|-|V_r|}{|V_r|} = \dfrac{I_r R\cos\phi_r \pm I_r X\sin\phi_r}{|V_r|}$

$= \dfrac{I_r R}{|V_r|}\cos\phi_r \pm \dfrac{I_r X}{|V_r|}\sin\phi_r$

$= \dfrac{R}{\left(\dfrac{|V_r|}{I_r}\right)}\cos\phi_r + \dfrac{X}{\left(\dfrac{|V_r|}{I_r}\right)}\sin\phi_r$

↳ [represents PU i.e. 'V_r' value w.r.t base value i.e. ref value I_r]

$\therefore$ Vol reg = (PU resistance) $\cos\phi_r \pm$ (PU resistance) $\sin\phi_r$

$\therefore \boxed{\%\text{ vol reg} = \%R\cos\phi_r \pm \%X\sin\phi_r}$

note:-

→ Lagging power factor loads will have always +ve vol reg

→ Leading pf loads may have +ve or -ve or zero vol reg i.e. for vol reg = 0, the receiving end pf is leading but the sending end pf is unity

* for small values of leading pf loads we get +ve reg i.e. V_r may or may not $> V_s$
* for large values of leading loads $V_r \neq V_s \Rightarrow$ we get -ve reg i.e. $V_r > V_s$
* at some value of leading loads $V_r = V_s \Rightarrow$ we get vol reg = 0 that means
* at that time sending end pf must be 1

→ To get max amount of regulation (+ve)

% vol reg = $\%R\cos\phi_r + \%X\sin\phi_r$ (lagging loads)

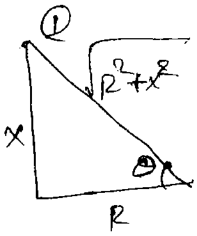
for fixed amount of current (or) load magnitude,

condition for maximum reg, is

$\Rightarrow \dfrac{d}{d\phi_r}(\%\text{vol reg}) = \%R(-\sin\phi_r) + \%X\cos\phi_r = 0$

$\Rightarrow \tan\phi_r = \dfrac{\%X}{\%R}$

i.e. $\tan\phi_r = \dfrac{X}{R}$ of transmission line



where 'θ' is the impedance angle of TL

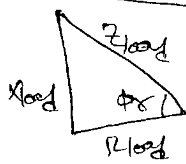
$\tan\theta = X/R$

$\therefore \tan\phi_r = \tan\theta$

$\boxed{\phi_r = \theta}$ → condition for max reg

$\therefore \phi_r = \theta \Rightarrow$ load pf angle / impedance angle of load = impedance angle of TL

② where ϕ_r = load pf angle (or) impedance angle of load



$\tan\phi_r = \dfrac{X_{load}}{R_{load}}$ i.e. If the $\dfrac{X}{R}$ ratio's of load & TL is same then the vol reg will be max.

$\therefore$ max vol reg (%) $= \%R\cos\phi_r + \%X\sin\phi_r$

$= \%R\cos\theta + \%X\sin\theta$

from ① $\cos\theta = \dfrac{R}{\sqrt{R^2+X^2}}$ &

$\sin\theta = \dfrac{X}{\sqrt{R^2+X^2}}$

→ % max vol reg $= \%R\dfrac{\%R}{\sqrt{(\%R)^2+(\%X)^2}} + \%X\dfrac{\%X}{\sqrt{(\%R)^2+(\%X)^2}}$

$\therefore \Rightarrow \dfrac{(\%R)^2+(\%X)^2}{\sqrt{(\%R)^2+(\%X)^2}} \Rightarrow \underbrace{\sqrt{(\%R)^2+(\%X)^2}}_{\%Z}$

maximum value of regulation is %Z

condition for zero voltage regulation:-

It will occur at leading power factor loads

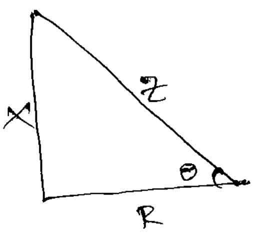
$\%$ voltage regulation $= \%R \cdot \cos\phi_r - \%X \sin\phi_r$

" " $= 0$

$\%R \cos\phi = \%X \sin\phi_r$

$$\tan\phi_r = \frac{\%R}{\%X}$$

$= \frac{R}{X}$ ratio of transmission line impedance.



impedance $\triangle^{le}$ of line

$$\tan\theta = \frac{X}{R}$$

$$\frac{R}{X} = \cot\theta$$

at zero regulation, $\tan\phi_r = \cot\theta$

$$\tan\phi_r = \tan(90-\theta)$$

$$\phi_r = 90-\theta$$

condition for zero voltage regulation is $\phi_r + \theta$.

$$\boxed{\phi_r + \theta = 90^\circ \text{ (or) } \frac{\pi}{2}}$$

If $\cos\phi_r = 1$, receiving end Pf $= 1$, then

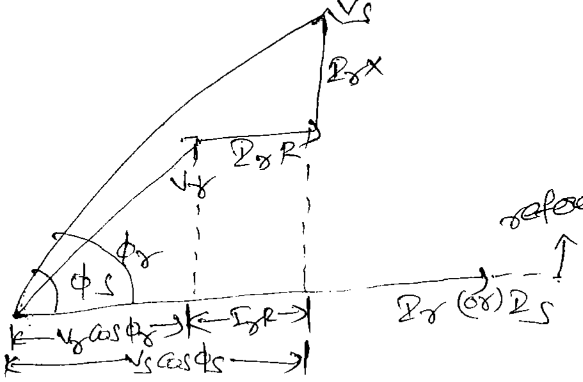
voltage regulation $= (\%R) \times 1 + (\%X) \times 0$

$= \%R$

where $I_r R$

$V_s \cos\phi_s = V_r \cos\phi_r + I_r \cdot R$

sending end Pf, $\cos\phi_s = \dfrac{V_r \cos\phi_r + I_r R}{V_s}$



→ what is the value of Pf at zero voltage regulation, if 'X/R' ratio of transmission line is unity.

$\frac{X}{R} = 1$

Condition for zero regulation, $\tan\phi_r = \frac{R}{X}$

$\tan\phi_r = 1 \Rightarrow \phi_r = 45°$.

Power factor, $\cos\phi_r = \cos 45° = 0.707$ (leading)

→ The voltage regulation of a short transmission line having %X = 3% and %R = 1% is zero. If the recieving end power factor is 0.9487 leading. what will be the sending end Pf.

$\% X = 3\%$

$\% R = 1\%$

$\cos\phi_r = 0.9487$ leading

$V.\,reg = 0$

$\cos\phi_s = \frac{V_r \cos\phi_r + I_r R}{V_s}$

for zero voltage regulation, $\frac{|V_s| - |V_r|}{|V_r|} = 0$

$|V_s| = |V_r|$

$\cos\phi_s = \frac{|V_r|}{|V_s|}\cos\phi_r + \frac{I_r R}{|V_s|}$

$\boxed{\cos\phi_s = \cos\phi_r + \text{PU resistance}}$ → for short transmission line

$= 0.9487 + 0.01$

$= 0.9587$ (leading)

→ The value of voltage regulation for a short transmission line having %X = 3% and %R = 1% is zero. If the recieving end pf is 0.9 (leading) in this case. what will be the sending end pf.

$\cos\phi_r = 0.9$

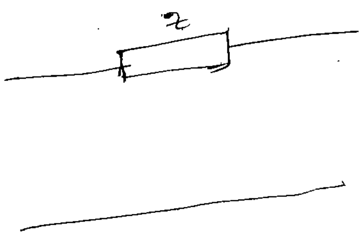
$\phi_r = 25.84°$

$\theta = \tan^{-1}(X/R) \Rightarrow \tan^{-1}(3/1) \Rightarrow 71.56°$

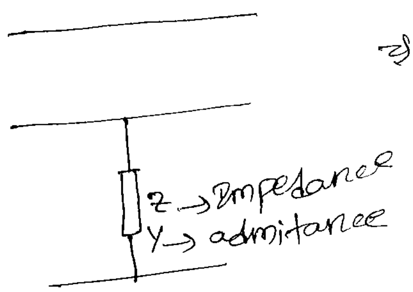
$\phi_r + \theta = 71.56 + 25.84$

$= 97.4°$

It is not condition for zero regulation. so invalid

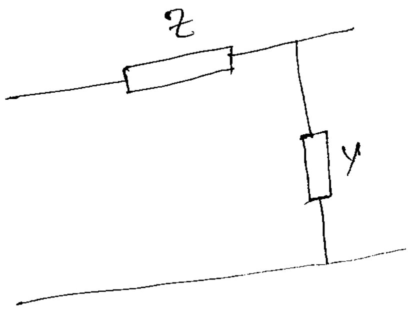
→ 

$$\Rightarrow \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$$

→ 

$$\Rightarrow \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 1/Z & 1 \end{bmatrix}$$

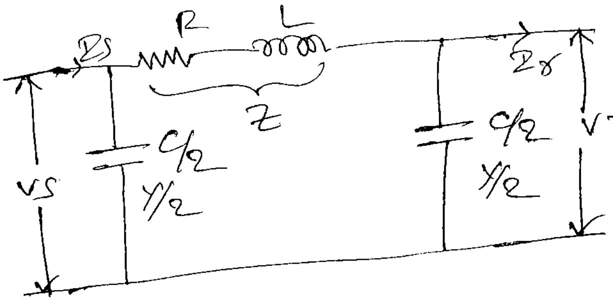
$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix}$$

→ 

$$\Rightarrow \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1+ZY & Z \\ Y & 1 \end{bmatrix}$$

Nominal π-network for the medium transmission lines :-



Z → series impedance of transmission line
Y → shunt admitance of transmission line

$$Y = \frac{1}{X_C} = \omega C$$

$$\begin{bmatrix} 1 & 0 \\ Y/2 & 1 \end{bmatrix} \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y/2 & 1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$$

for nominal-π n/w

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z \\ Y/2 & 1+\frac{ZY}{2} \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y/2 & 1 \end{bmatrix}$$

$$\frac{Y}{2} + \frac{Y}{2}\left(1+\frac{ZY}{2}\right)$$
$$\frac{Y}{2}\left[2+\frac{ZY}{2}\right]$$
$$Y\left[1+\frac{ZY}{4}\right]$$

$$= \begin{bmatrix} 1+\frac{ZY}{2} & Z \\ Y\left(1+\frac{ZY}{4}\right) & 1+\frac{ZY}{2} \end{bmatrix}$$

A = D ⇒ symetrical n/w

$$AD - BC = \left(1+\frac{ZY}{2}\right)^2 - ZY\left(1+\frac{ZY}{4}\right)$$

$= 1$ → n/w is reciprocal

→ ABCD values are always complex values and these are calculated per phase.

→ V_s, I_s & V_r, I_r the ABCD standard eqn are always per phase values.

// for medium line

$A \rightarrow |A| \angle\alpha \rightarrow \alpha = 0°-10°$

$B \rightarrow |B| \angle\beta \rightarrow \beta = \tan^{-1}(X/R) = 70°-90°$

$C \rightarrow |C| \angle\gamma \rightarrow \gamma = 90°$

$D \rightarrow |D| \angle\alpha \rightarrow \alpha = 0°-10°$

→ The B constant /parameter will represent series impedance of T.L.

→ 'C' value will represent the total admitance of the transmission line

$-jX_C \rightarrow$ reactance

susceptance $= \frac{1}{-jX_C} \rightarrow +j \cdot \frac{1}{X_C} \rightarrow jb \rightarrow b\angle 90° \rightarrow$ admitance

Voltage regulation of medium line:-

$$\text{Voltage regulation} = \frac{|V_{r0}| - |V_r|}{|V_r|}$$

$|V_{r0}|, |V_r| \rightarrow$ NL and full load voltages repectively

when $I_r = 0$, $V_s = A \cdot V_r |_{I_r = 0}$

$$V_s = A \cdot V_{r0}$$

$$V_{r0} = \frac{V_s}{A}$$

$$|V_{r0}| = \left|\frac{V_s}{A}\right|$$

$$\text{Voltage regulation} = \frac{\left|\frac{V_s}{A}\right| - |V_r|}{|V_r|}$$

As $|A| < 1$, voltage regulation of medium line is +ve.

→ The recieving end voltage of the medium end at no load or light load conditions is greater than the rated recieving end voltage / sending end voltage. This effect is called as "ferranti effect"

$$|V_{ro}| = \left|\frac{V_s}{A}\right| \Rightarrow |V_{ro}| > |V_s| \rightarrow \text{Ferranti effect}$$

→ The main cause for Ferranti effect is the consideration of capacitance (or) charging current given by the capacitance.

→ A medium transmission line has $A = 0.98\angle 2^\circ$ and $B = 100\angle 85^\circ\ \Omega$. At a perticular condition the magnitudes of sending end and recieving end voltages are 220 kv. what is the value of regulation in PU approximately.

a) 0.01 b) 0.02 c) 0.03 d) insufficient data

$$\text{voltage regulation} = \frac{\left|\frac{V_s}{A}\right| - |V_r|}{|V_r|}$$

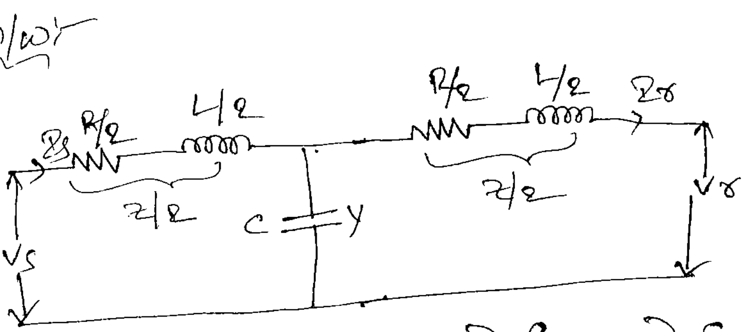
$$= \frac{|V_s|}{|A||V_r|} - \frac{|V_r|}{|V_r|}$$

$$= \frac{1}{|A|} - 1 \qquad (\because |V_s| = |V_r| \text{ given})$$

$$= \frac{1}{0.98\angle 2^\circ} - 1$$

$$= 0.0204 \Rightarrow 0.02$$

Nominal 'T' n/w



$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z/2 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} \begin{bmatrix} 1 & Z/2 \\ 0 & 1 \end{bmatrix}$$

nominal 'T'

$$= \begin{bmatrix} 1+\frac{ZY}{2} & Z\left(1+\frac{ZY}{4}\right) \\ Y & 1+\frac{ZY}{2} \end{bmatrix}$$

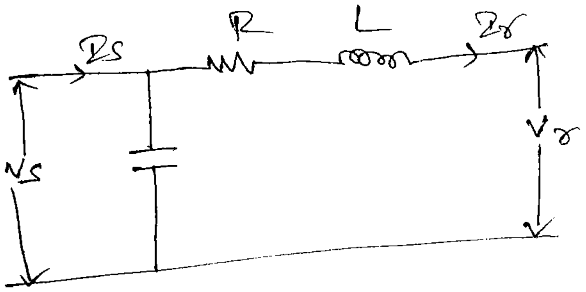
$A = D \rightarrow$ symmetrical n/w

$AD - BC = 1 \Rightarrow$ Reciprocal n/w

$$\text{voltage regulation} = \frac{|V_{r0}| - |V_r|}{|V_r|}$$

$$= \frac{\left|\frac{V_S}{A}\right| - |V_r|}{|V_r|}$$

Sending end capacitor model:—

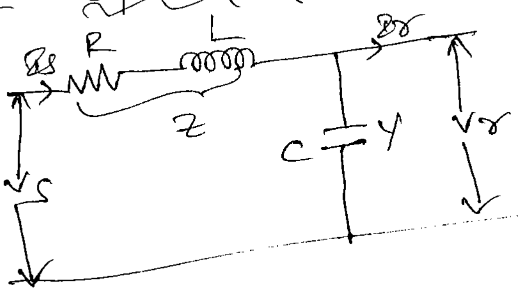


$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \Rightarrow \begin{bmatrix} 1 & Z \\ Y & 1+ZY \end{bmatrix}$$

→ $A \neq D \Rightarrow$ n/w is unsymmetrical & $AD - BC = 1 \rightarrow$ n/w is reciprocal

→ In case of sending end capacitor model $|A| = 1$. So, there is no ferranti effect under no-load condition.

Recieving end capacitor model:—



$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} \Rightarrow \begin{bmatrix} 1+ZY & Z \\ Y & 1 \end{bmatrix}$$

$|A| < 1 \Rightarrow$ ferranti effect is considered.

$A \neq D \rightarrow$ unsymmetrical n/w

$AD - BC = 1 \rightarrow$ reciprocal n/w

→ The generalised circuit constant of a 3-φ 220kV medium length TL are $A = 0.936$ at an angle $0.98°$ i.e., $A = 0.936 \angle 0.98°$, $B = 142 \angle 76.4° \Omega$, $C = (-5.18 + j914) \times 10^{-6}$ ℧. If the load at receiving end is 50MW at 220kV with a power factor of 0.9 lagging. what is the line to line sending end voltage.

$$V_s = AV_r + BI_r$$

$$V_r = \frac{220kV}{\sqrt{3}} \angle 0°$$

$$I_{rL} = \frac{P_r}{\sqrt{3} \cdot V_{rL} \cos\phi}$$

$$= \frac{50MW}{\sqrt{3} \times 220kV \times 0.9} \Rightarrow 145.79A$$

$$\phi_r = \cos^{-1}(0.9)$$

$$= 25.84° \text{ (lagging)}$$

$I_r = \cancel{145.23 \angle 25.84°}$

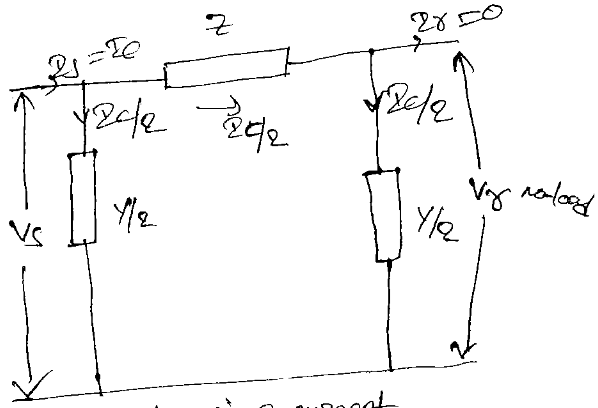
$$I_r = 145.79 \angle -25.84° \text{ A}$$

$$V_{sph} = (0.936 \angle 0.98)\left(\frac{220}{\sqrt{3}}\right) - (142 \angle 76.4°)(145.79 \angle -25.84)$$

$V_{sphLS} =$

→ A 220kV, a ... long transmission line has A = D = ...

$B = 55\angle 65^\circ \ \Omega/ph$, $C = 0.0005\angle 80^\circ$ S/ph, what is the charging current of transmission line



$I_c \rightarrow$ charging current

charging current is the sending end current under no-load condition

$I_s = C \cdot V_r \big|_{I_r = 0}$

$I_c = C \cdot V_{r0}$

under no-load condition, $V_{r0} = \frac{V_s}{A}$

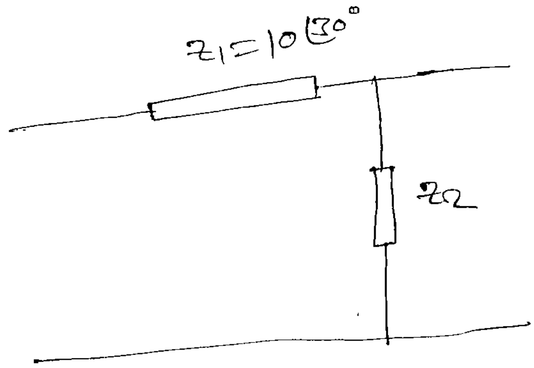
$$V_{r0} = \left| \frac{(220kV/\sqrt{3})}{0.96\angle 3^\circ} \right| \Rightarrow 132.29\ kV$$

magnitude of charging current

$I_C = 0.0005 \times 132.29\ kA$

$= 66.15\ A$

→ Two n/w's are connected in cascade as shown in fig, with usual notations the equivalent ABCD constants are obtained even that $C = 0.025\angle 45^\circ$ then what is the value of Z_2.



$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z_1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 1/Z_2 & 1 \end{bmatrix}$$

$C = \frac{1}{Z_2}$

$Z_2 = \frac{1}{C} \Rightarrow \frac{1}{0.025\angle 45^\circ}$

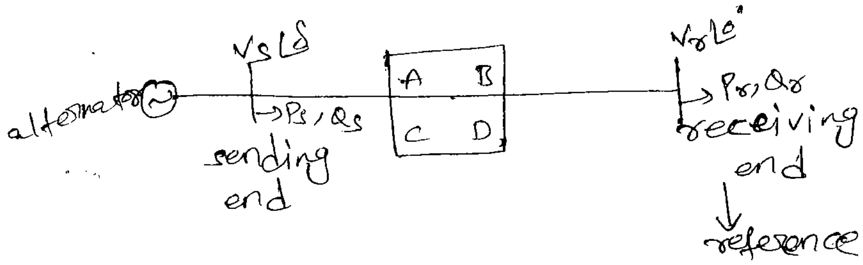
$\downarrow$

capacitive impedance

$= 40\angle -45^\circ$

Power transfer equations:-

Let us consider a Transmission line having ABCD parameters

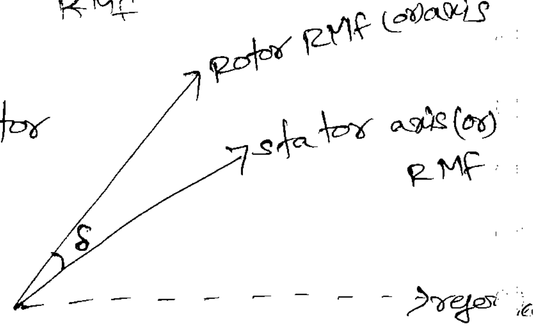


→ sending end voltage is leading with receiving end voltage by an angle 'δ'

δ → Terminal voltage angle of alternator (or) Power angle of alternator

→ Power angle of the alternator is the angle between stator rotating magnetic field and rotor rotating magnetic field.

$\underbrace{\text{rotating magnetic field}}_{\text{RMF}}$ and rotor $\underbrace{\text{rotating magnetic field}}_{\text{RMF}}$

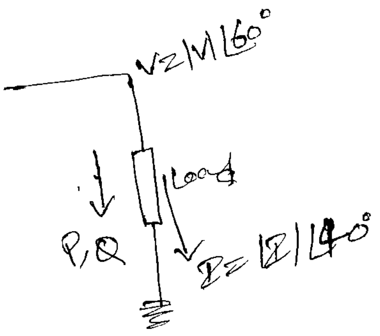


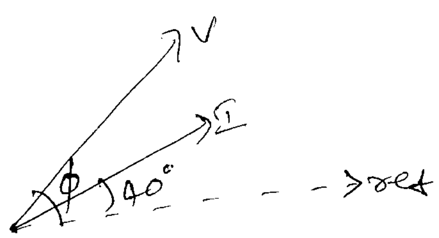
→ If $\delta > 90^\circ$ (electrical angle) then the stator and rotor magnetic fields are linkable.

→ $\delta > 90^\circ$, the magnetic locking b/n stator and rotor axis will be gone such that the alternator comes to unstable (or) looses its synchronism.

→ Always $\delta < 90^\circ$, to make alternator as stable.

→





Let us assume, $S = VI$

$$= |V|\angle 60^\circ \cdot |I|\angle 40^\circ$$

$$= |V||I|\angle 100^\circ$$

$$= |S|(\cos 100 + j\sin 100)$$

$$= |S|[-0.1736 + j0.9848]$$

$\therefore$ It is invalid because real power taken by load is negative. Let us assume, $S = V^* I$

$$= |V|\angle -60^\circ \cdot |I|\angle 40^\circ$$

$$= |S|\angle -20^\circ$$

$$= |S|[\cos 20 - j\sin 20]$$

$$= |S|[0.9396 - j0.34]$$

$\therefore$ It is also invalid calculation because reactive power is becoming -ve.

Let $S = VI^*$

$$= |V|\angle 60^\circ \cdot |I|\angle -40^\circ$$

$$= |V||I|\angle 20^\circ$$

$$= |S|[\cos 20 + j\sin 20]$$

$$= |S|[0.9396 + j0.34]$$

$\therefore$ It is valid because P & Q are positive.

→ from ABCD constants, $V_s = AV_r + BI_r$

receiving end current, $I_r = \dfrac{V_s - A \cdot V_r}{B}$

Receiving end complex power, $S_r = V_r \cdot I_r^*$

$V_r = |V_r| \angle 0^\circ$ $\qquad B = |B| \angle \beta$

$V_s = |V_s| \angle \delta$

$A = |A| \angle \alpha$

$$S_r = |V_r| \angle 0 \left[\frac{|V_s| \angle \delta - |A| \angle \alpha \cdot |V_r| \angle 0}{|B| \angle \beta} \right]^*$$

$$= |V_r| \left[\frac{|V_s|}{|B|} \angle \delta - \beta - |V_r| \frac{|A|}{|B|} \angle \alpha - \beta \right]^*$$

$$= |V_r| \left[\frac{|V_s|}{|B|} \angle \beta - \delta - \frac{|A|}{|B|} |V_r| \angle \beta - \alpha \right]$$

$$P_r + jQ_r = \frac{|V_s||V_r|}{|B|} \angle \beta - \delta - \frac{|A|}{|B|} |V_r|^2 \angle \beta - \alpha$$

$$P_r = \frac{|V_s||V_r|}{|V|} \cos(\beta - \delta) - \frac{|A|}{|B|} |V_r|^2 \cos(\beta - \alpha)$$

$$Q_r = \frac{|V_s||V_r|}{|B|} \sin(\beta - \delta) - \frac{|A|}{|B|} |V_r|^2 \sin(\beta - \alpha)$$

→ If V_s, V_r are line to line voltages ~~then~~ the eqns will result into 3-ϕ power. If these values are per phase then P_r, Q_r will be per phase.

Condition for maximum Power transfer:-

$\frac{dP_r}{d\delta} = 0$ to get the condition

$$\frac{|V_s||V_r|}{|B|} \left[-\sin(\beta - \delta) \right] (-1) - 0 = 0$$

$\sin(\beta - \delta) = 0$

$\beta - \delta = 0$; $\boxed{\beta = \delta}$ → condition for maximum power transfer

*) Value of maximum power, $P_{r\,max} = \frac{|V_s||V_r|}{|B|} - \frac{|A|}{|B|}|V_r|^2 \cos(\beta-\alpha)$ MW

→ The reactive power to be supplied by alternator during $P_{r\,max}$.

$$Q_r \Big|_{\delta=\beta} = -\frac{|A|}{|B|}|V_r|^2 \sin(\beta-\alpha)$$

reactive power is −ve, during maximum power transfer the reactive power ~~&~~ is becomes −ve that means the load at the receiving end should be a leading load which is a hypothetical case i.e., impractical because most of the loads in the power system lagging loads. so alternator will not be operated ~~alternated~~ at maximum power condition.

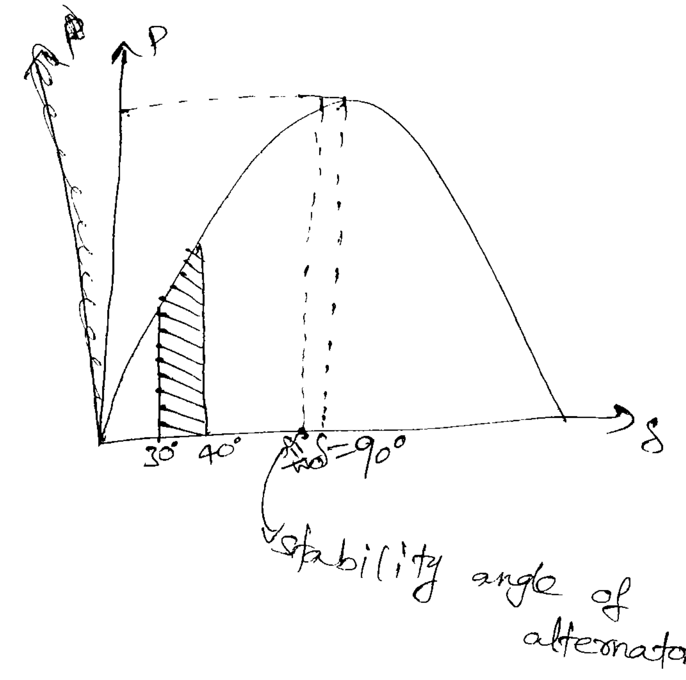
Power angle curve:–

30–40° → operating angles

$\delta = 90°$, $\delta = \beta$ → stability angles

$\delta = 90°$ → Ideal case

$\delta = \beta$ → Practical case



Short transmission line:–

$|A| = 1$, $\alpha = 0°$

$|B| = |Z|$, $\beta = \tan^{-1}\frac{X}{R} = \theta$.

$$P_r = \frac{|V_s||V_r|}{|Z|}\cos(\theta-\delta) - \frac{|A|}{|B|}|V_r|^2 \cos(\theta)$$

Assume high '$\frac{X}{R}$' ratio (or) $\frac{X}{R} >> 1$, $\theta = \tan^{-1}(X/R) \cong 90°$; $|Z| = \sqrt{R^2+X^2}$

$|Z| \cong |X|$

$$\underbrace{P_r = \frac{|V_s||V_r|}{|X|}\sin\delta \;;\; Q_r = \frac{|V_s||V_r|}{|X|}\cos\delta - \frac{1}{|X|}|V_r|^2}_{\text{approximated real \& reactive powers for any line}}$$

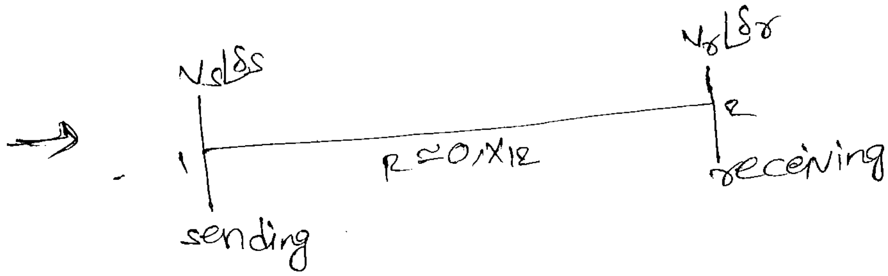
→ condition for maximum power transfer, $\frac{dP_r}{d\delta} = 0$

$$\frac{|V_s||V_r|}{|X|} \cos\delta = 0 \Rightarrow \boxed{\delta = 90^\circ} \rightarrow \text{stability angle of alternator}$$

→ value of maximum power, $P_{r\,max} = \frac{|V_s||V_r|}{|X|}$ → steady state stability limit of alternator

→ At maximum power transfer condition i.e.,

at $P_{r\,max}$, $Q_r = -\frac{|V_r|^2}{|X|}$

→ 

$$P_{12} = \frac{V_s \cdot V_r}{X_{12}} \sin(\delta_s - \delta_r)$$

$$Q_{12} = \frac{V_s \cdot V_r}{X_{12}} \cos(\delta_s - \delta_r) - \frac{V_r^2}{X_{12}}$$

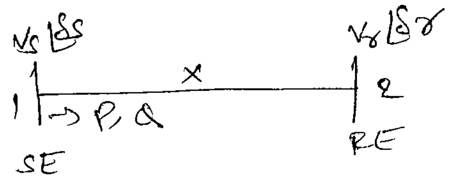
$$= \frac{V_r}{X_{12}} \left[V_s \cos(\delta_s - \delta_r) - V_r \right]$$

→ if $(\delta_s - \delta_r) = -ve$ then real power will flow from receiving end to sending end but the reactive power flow direction is unaltered, (or) independent of $(\delta_s - \delta_r)$.

→ The real power will flow from leading voltage terminal to lagging voltage terminal. The reactive power will flow from higher magnitude voltage terminal to lower magnitude voltage terminal.

→ To make the alternator as more stable, the power angle should be as low as possible.

→



$$P = \frac{V_s V_r}{X} \sin(\delta_s - \delta_r) \quad ; \quad Q = \frac{V_r}{X}\left[V_s \cos(\delta_s - \delta_r) - V_r\right]$$

→ If $(\delta_s - \delta_r) = +ve$, 'P' flows from bus ① to bus ②

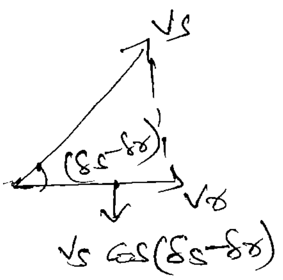
→ If $(\delta_s - \delta_r) = -ve$, 'P' flows from bus ② to bus ①

→ Real powers will flow from leading voltage terminal to lagging vol terminal.

→ 'Q' flow is independent of sign of $(\delta_s - \delta_r)$

if $V_s \cos(\delta_s - \delta_r) > V_r$ then 'Q' will flow from bus ① to bus ②

if $V_s \cos(\delta_s - \delta_r) < V_r$ then 'Q' will flow from bus ② to bus ①



→ Reactive power will flow from higher magnitude vol terminal to lower magnitude vol terminal when the two voltages are taken on the same reference.

→ A transmission line having sending end & recieving end vol's has $V_s = 1\angle 300°$ pu & $V_r = 1\angle 240°$ pu then

a) TL is unstable ✓b) TL is stable

c) no comment on stability d) none of the above

$(\delta_s - \delta_r) = 300 - 240° = 60° < 90°$

↓ ∴ It is stable

load angle of TL

real power flows from sending end to recieving end, because $\delta_s > \delta_r$

reactive power flows from ~~sen~~ receiving end to sending end

$\because V_r > V_s \cos(\delta_s - \delta_r)$

$V_r = 1\,PU$, $V_s = 1\,PU$, $\delta_s = 300^\circ$, $\delta_r = 240^\circ$

$(\delta_s - \delta_r) = 60^\circ \Rightarrow \cos(\delta_s - \delta_r) = \cos 60^\circ = 0.5\,PU$

$\therefore \underbrace{1\,PU}_{V_r} > \underbrace{0.5\,PU}_{V_s \cos(\delta_s - \delta_r)}$

$\therefore$ system is operating at leading P.f

→ A short transmission line having $X = 3\%$ with a voltage regulation to 1.8%, ~~$MVA_b = 1MVA$, $V_b = 33\,kV$~~ If the line is operating at light load condition, what is the reactive power taken by load on the base of 1 MVA, 33 kV?

Given data $X = 3\%$, Vol reg $= 1.8\%$, $MVA_b = 1\,MVA$, $V_b = 33\,kV$

line is operating at light load condition (i.e) Power taken by load is very less)

$P = P_{max} \sin\delta$ where $P_{max} = \frac{V_s V_r}{X}$

(Under no-load condition, real power, P taken by load is zero)

under light load condition, $P \simeq 0$ (negligible)

from above eqn $P \propto \sin\delta$

$\delta \approx \sin'$

$P \propto \delta$

as $P \simeq 0 \Rightarrow \delta \simeq 0$ under light load condition

Reactive power, $Q = \frac{V_r}{X}\left[V_s \cos\delta - V_r\right]$

$\delta = 0$ $Q = \frac{V_r}{X}(V_s - V_r) \rightarrow (1)$

vol reg for short TL $\Rightarrow \frac{V_s - V_r}{V_r} = 0.018$ (given)

$V_s - V_r = 0.018 \times V_r \rightarrow (2)$

sub (2) in (1)

$Q = \frac{V_r}{X}(0.018 V_r) \Rightarrow \frac{0.018\, V_r^2}{X}$

Given output voltage

but it is absolute value, take V_r in pu value.

$$V_r(pu) = \frac{33kV}{33kV} = 1\,pu$$

$$\therefore Q = \frac{1^2 \times 0.018}{0.03} \quad (\because x' = 3)$$

$$Q_{pu} = \frac{0.018}{0.03} = 0.6\,pu$$

$$Q(MVAR) = Q_{pu} \times MVA_b = 0.6 \times 1\,MVA = 0.6\,MVAR$$

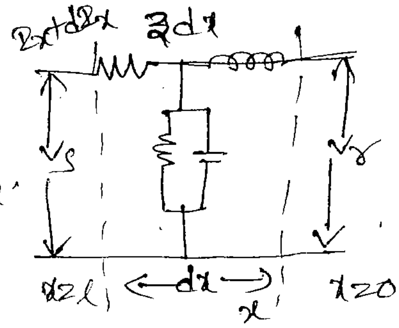
$$\therefore Q(MVAR) = 0.6\,MVAR.$$

Reg. Rigorous solution for long transmission line's / ABCD parameters of long line :—

take the receiving end side as reference point

Hence at the end of the transmission line $x=0$ length and at the sending end

$x = l$ which is the length of TL



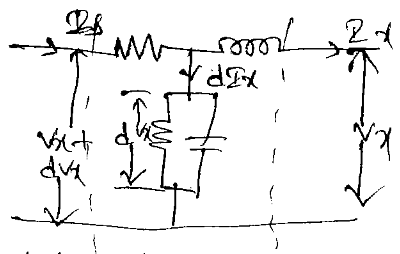
Consider a small section 'dx' on long line

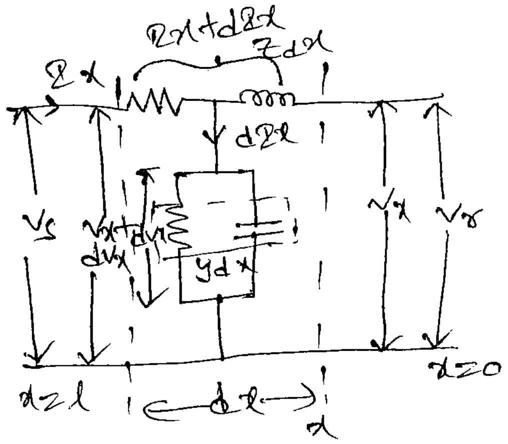
series impedance in the 'dx' section is '$z\,dx$'

$z \to$ impedance/km

shunt admittance in 'dx' section $y\,dx$

$y \to$ admittance/km





voltage drop in 'dx' section,

$$dV_x = (I_x + dI_x)\,z\,dx$$

$$= I_x z\,dx + \underbrace{z\,dx\,dI_x}_{\text{very small neglected}}$$

$$dV_x = I_x z\,dx$$

$$\frac{dV_x}{dx} = I_x z \longrightarrow (1)$$

current through shunt admittance, $dI_x = V_x y dx$

$$\frac{dI_x}{dx} = yV_x \rightarrow ②$$

Differentiate eqn ① w.r.to 'dx'

$$\frac{d^2V_x}{dx^2} = z\frac{dI_x}{dx}$$

from eqn ② $\frac{dI_x}{dx} = yV_x$

$$\frac{d^2V_x}{dx^2} = V_x z y$$

$$\therefore \frac{d^2V_x}{dx^2} = V_x yz \rightarrow ③$$

III'ly differentiate eqn ② w.r.to 'dx'

$$\frac{d^2I_x}{dx^2} = y\frac{dV_x}{dx}$$

from eqn ① $\frac{dV_x}{dx} = I_x z$

$$\frac{d^2I_x}{dx^2} = yzI_x$$

$$\therefore \frac{d^2I_x}{dx^2} = I_x yz \rightarrow ④$$

solution of eqns ③ & ④ will give vol & currents at point 'x' on the TL. Roots of differential eqn's ③ & ④ are same and is $= \pm\sqrt{zy}$

$\sqrt{zy}$' is called as "propagation constant of transmission line"

$$\boxed{\gamma = \sqrt{zy}}$$

Boundary conditions, at $x=0$, $V_x = V_R$, $I_x = I_R$

at $x=l$, $V_x = V_S$, $I_x = I_S$

$$\boxed{\begin{aligned} V_x &= \cosh\gamma x \cdot V_R + Z_c \sinh\gamma x \cdot I_R \\ I_x &= \frac{1}{Z_c}\sinh\gamma x \cdot V_R + \cosh\gamma x \cdot I_R \end{aligned}}$$

at $x=l$,

$$V_s = \cosh\gamma l \cdot V_R + Z_c \sinh\gamma l \cdot I_R$$

$$I_s = \frac{1}{Z_c}\sinh\gamma l \cdot V_R + \cosh\gamma l \cdot I_R$$

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \underbrace{\begin{bmatrix} \cosh\gamma l & Z_c \sinh\gamma l \\ \frac{1}{Z_c}\sinh\gamma l & \cosh\gamma l \end{bmatrix}}_{\text{exact ABCD parameters of long transmission line}}$$

$\because A=D \Rightarrow$ long line is symmetrical
($\cosh \gamma l$)

$AD-BC=1 \Rightarrow$ long line is reciprocal (or) passive n/w

Approximate ABCD parameters of long TL:

expand $\cosh\gamma l$ & $\sinh\gamma l$ by using Taylor's or Mc-Claurens theorem

$$\cosh\gamma l = 1 + \frac{(\gamma l)^2}{2!} + \underbrace{\frac{(\gamma l)^4}{4!} + \cdots}_{\text{higher order terms (neglected)}}$$

$$\cosh\gamma l = 1 + \frac{(\gamma l)^2}{2!}$$

$$\therefore A = D = \cosh\gamma l = 1 + \frac{(\gamma l)^2}{2!} = \frac{1 + (\sqrt{zy}\cdot l)^2}{2!} = 1 + \frac{zyl^2}{2!} = \frac{1 + (\sqrt{zl \cdot yl})^2}{2!}$$

$zl \to Z$ total impedance

$yl \to Y$ total admittance

$$A = D = 1 + \frac{(\sqrt{ZY})^2}{2} = 1 + \frac{ZY}{2}$$

$$\boxed{A = D = 1 + \frac{ZY}{2}} \to \text{approximate value of long TL}$$

$$\sinh\gamma l = \gamma l + \frac{(\gamma l)^3}{3!} + \underbrace{\frac{(\gamma l)^5}{5!} + \cdots}_{\text{higher order terms neglected}}$$

$\gamma l \to$ less value $\Rightarrow \frac{(\gamma l)^5}{4} \Rightarrow$ very very less

$$= \gamma l + \frac{(\gamma l)^3}{3!} \quad (\because |\gamma l| < 1)$$

sub $\gamma = \sqrt{zy}$ & simplify

$\gamma = \sqrt{zy}$

z/km $y$km

very low values

$$B = Z_c \sinh\gamma l \qquad C = \frac{1}{Z_c}\sinh\gamma l$$

$$B = Z\left(1 + \frac{ZY}{6}\right) \qquad C = \frac{1}{Z_c}\left(1 + \frac{ZY}{6}\right)$$

$$C = Y\left(1 + \frac{ZY}{6}\right)$$

$$\therefore \boxed{B = Z\left(1 + \frac{ZY}{6}\right)} \quad \& \quad \boxed{C = Y\left(1 + \frac{ZY}{6}\right)}$$

approximate values of B & C for long line.

→ Match the following

List-1	List-2
A	$142 \angle 86^\circ$
B	$0.005 \angle 90^\circ$
C	$0.98 \angle 0.9^\circ$
D	

A $\angle$ range 0 to 10° ; select the value with in the ranges
↓
mag ≃ 1

$\therefore A = 0.98 \angle 0.9^\circ$ & $A = D \Rightarrow D = 0.98 \angle 0.9^\circ$

$B \Rightarrow$ load impedance ; (it should be very high, hence the drop across it will be more

$\therefore B = 142 \angle 86^\circ$

$C \angle 90^\circ$ ← & by neglecting shunt conductance angle $= 90^\circ$
↓
magnitude should be very low at angle $\simeq 90^\circ$

$\therefore C = 0.005 \angle 90^\circ$

→ If the length of the line increases, what will happend to ABCD parameters

$$\boxed{\begin{array}{l}\text{in LTL} \\ A = |A| \angle \alpha \\ D = |D| \angle \alpha\end{array}}$$

$A = 1 + \frac{ZY}{2}$ If $l \uparrow$ $ZY \uparrow$

$\therefore l \uparrow (A = D)$? $\Rightarrow$ magnitude of A ↓ angle ↑

||ly for D also mag ↓ angle ↑

$B = |B| \angle \beta$ where $\beta = \tan^{-1}(X/R)$

If $l \uparrow$, $X \uparrow$ & $R \uparrow$ in same proportion
⇓ $\therefore \beta$ value almost constant
& $|B|$ also ↑ hence if $l \uparrow \Rightarrow$ no change in 'γ'

$C = |C| \angle \gamma \to \simeq 90^\circ$ ... change w.r.to length of the

34) <u>for example</u> If $Z = 142 \angle 86^\circ$, $Y = 0.0005 \angle 90^\circ$

$A = 1 + \frac{ZY}{2}$; $\frac{ZY}{2} = 0.035 \angle 176^\circ$

$|A = 1 + \frac{ZY}{2} = 1 + 0.035 \angle 176^\circ = 0.96 \angle 0.14$

assume length is ↑ by 1.2 times ⇒ new $\frac{ZY}{2} = \frac{(1.2Z)(1.2Y)}{2} = \frac{(1.2)^2 ZY}{2}$

new $\frac{ZY}{2} = (1.2)^2 \times 0.035 \angle 176^\circ \Rightarrow 0.0504 \angle 176^\circ$

$A_{new} = 1 + 0.504 \angle 176^\circ = 0.94 \angle 0.21$

i.e.) as $l \uparrow \Rightarrow |A| \downarrow, \alpha \uparrow$

as $l \uparrow \Rightarrow |B| \uparrow$, $\beta \simeq$ constant ($\because \frac{X}{R} \simeq$ constant, because X & R values will be ↑ in the same proportion wrt length of the line)

as $l \uparrow \Rightarrow |C| \uparrow$, '$\gamma$' no change (or) $\gamma =$ constant

as $l \uparrow \Rightarrow |D| \downarrow, \alpha \uparrow$

→ A 50 km transmission line (STL) having pu resistance and reactances as 0.04 & 0.05 pu. If the pf of the load is 0.8 leading what will be the vol reg.

given data $R_{pu} = 0.04$, $X_{pu} = 0.05$, $\cos\phi_R = 0.8$ leading

<u>for STL</u>

vol reg $= R_{pu} \cos\phi_R - X_{pu} \sin\phi_R$ (leading load $\angle$)

$= 0.04 \times 0.8 - 0.05 \times 0.6$

$= 0.002$ pu

$\therefore$ % vol reg $= 0.2\%$

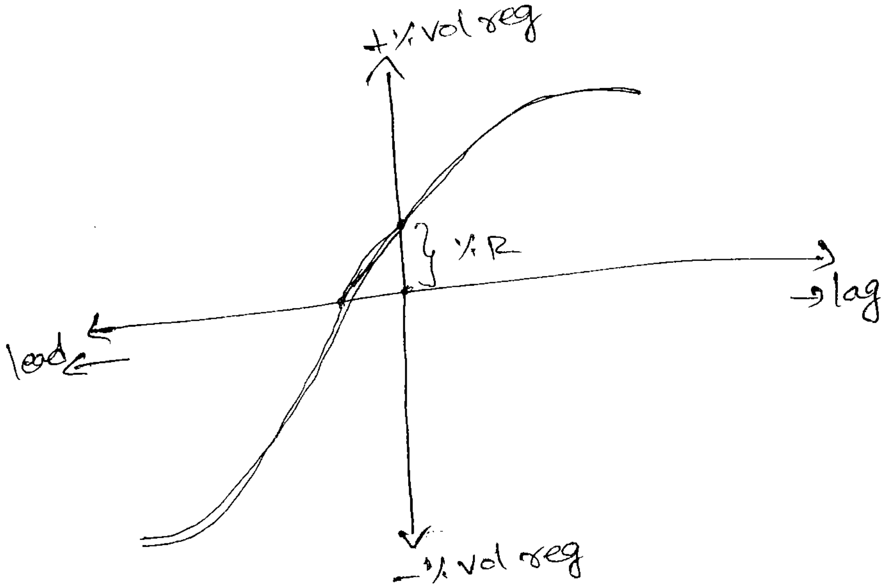
[for leading loads, all the '3' i.e. +ve & −ve & zero regulations are possible

for " ", if +ve reg comes; definitely it should be < % R_{pu}

(here % V.R. = 0.2% (+ve) ⇒ It should be < % R_{pu}

$R_{pu} = 0.04 \Rightarrow$ % $R_{pu} = 4\%$ $\therefore 0.2\% < 4\%$ ✓)]

Voltage regulation diagram:-



→ from above diagram

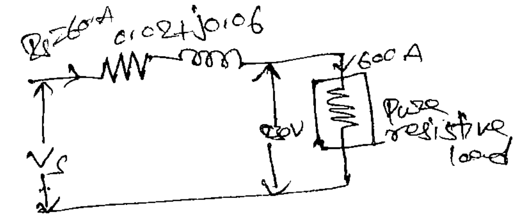
* The vol reg for leading pf loads will always less than %R of TL

* At unity pf the vol reg is equal to %R

→ A 1-φ, TL has a series impedance of 0.02+j0.06 Ω. (TL) It is connected to a 600A pure resistive load operating at a vol of 230V. find out the power loss, sending end pf & sending end voltage?

Given data $R = 0.02 + j0.06\,\Omega$, $I_L = 600\,A$, $V = 230\,V$ } Pure resistive load

1-φ TL



$\therefore P_{loss} = I_L^2 R$

$= (600)^2 \times 0.02$

$= 7.2\,kW$

Take I as reference

$\therefore I_L = 600\angle 0^\circ$

$V_L = 230\angle 0^\circ$

$V_s = V_L + I_L \cdot Z$

$= [600\angle 0 (0.02 + j0.06)] + 230\angle 0^\circ$

$= 244.67\angle 8.46^\circ\,V$

sending end current is same as load current, since it is a series circuit

$\therefore I_s = 600 \angle 0°$

sending end

Pf angle = angle b/n V_s & I_s = 8.46°

$\therefore$ Pf = cos 8.46 ⇒ 0.989 lagging

$\therefore$ sending end Pf = 0.989 lagging

Actually the load is pure resistive, due to nature of TL (having R & L), sending end voltage leads by angle of 8.46° by current. Hence the sending end, i.e.) source is supplying some reactive power, it will be dropped across the line impedance.

$\therefore$ eventhough load is resistive, Pf still lagging due to impedance

reactive power supplied by source = $I_L^2 \times X_{line}$

$= 600^2 \times 0.06$

= 21 KVAR

→ ABCD parameters of a Transmission line, $A = 0.89 \angle 0.9°$, $B = 200 \angle 86°$ Ω/Ph, $C = 0.001 \angle 90°$ Ʊ/Ph. The line is on no-load and supplied by 765 kV. Find the receiving end voltage, sending end current and no load power loss

ABCD standard eqns

$V_s = AV_r + BI_r$

$I_s = CV_r + DI_r$

at no load condition, $I_r = 0$ ⇒ (I_s = charging current)

$V_s = AV_r$ & $I_s = CV_r$

receiving end voltage, at no-load $V_r = \frac{V_s}{A}$

$V_r = \frac{765 \text{ kV (L-L)}}{0.89 \angle 0.9}$

$\left(V_{r(Ph)} = \frac{765}{\sqrt{3} \times 0.89 \angle 0.9°} \right) =$

Here, find simply voltage ⇒ $V_{(L-L)}$

$$\therefore V_{r(L-L)} = \frac{765\,kV(L-L)}{0.89 \times \angle 0.9^\circ} = \frac{765\angle 0^\circ}{0.89\angle 0.9^\circ}$$

$$V_{r(L-L)} = 859.5\angle -0.9^\circ\ kV$$

sending end current,

$$I_s/ph = C \cdot V_r/ph$$

$$= (0.001\angle 90^\circ)\ \frac{859.5}{\sqrt{3}}\angle -0.9^\circ\ kA$$

$$I_s/ph = 0.496\angle 89.1^\circ\ kA$$

↳ charging current of TL

Power loss = i/p power − o/p power

no-load power loss = i/p power under no-load − 0

$$= \sqrt{3}\, V_s I_s \cos\phi_s$$

$$= \sqrt{3} \times 765K \times 0.496K \cos(89.1^\circ)$$

$$= 10.32\ MW$$

$V_s\angle 0^\circ$

$I_s\angle 89.1^\circ$

$\phi_s = 89.1^\circ$ leading

P.f of the source, $\cos\phi_s = \cos 89.1$

$= 0.015$ leading under no-load condition

→ A long less TL has a series reactance of 100 Ω and the sending end & receiving end voltages are 410 kV & 400 kV resp. what will be the max power transfer by the TL and what is the load angle of TL if 1000 MW power is transferred.

$X = 100\Omega$, $V_s = 410\ kV$, $V_r = 400\ kV$

load angle of TL = ?

if 1000 MW power is transferred

Max power transfer = ?

max power, $P_{max} = \frac{V_s V_r}{X} = \frac{\quad}{100} = 1640 MW$

Power transfer $P = P_{max} \sin \delta$

load angle of TL $\delta = \sin^{-1}\left(\frac{P}{P_{max}}\right) = \sin^{-1}\left(\frac{1000}{1640}\right)$

$\delta = 37.57^\circ$

→ for a 400kV TL the max power transfer is P (MW). If the transfer voltage is changed to 200kV. what is the new max power transfer of TL ?

at 400kV, $P_{max} = P$ w.k.T., $P_{max} = \frac{V_s V_r}{X}$

at 200kV, $P_{max} = ?$ The difference in V_s, V_r is very less (hence neglected)

i.e.) $V_s \simeq V_r$

$$P_{max} = \frac{V_s^2}{X}$$

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

$$\frac{P_{max2}}{P_{max1}} = \frac{V_2^2}{V_1^2} = \frac{(200)^2}{(400)^2} \Rightarrow P_{max2} = P/4$$

∴ maximum power transfer is reduced by '4' times

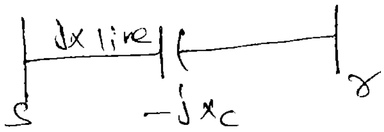
**. 'P_{max}' is also called as "steady state stability limit".

hence to ↑ (improve) the stability, Vol ↑ed.

→ steady state stability limit will be ↑ i) by increasing the o/p (or) Vol

ii) by ↓ing the reactance of TL

→ The maximum power transfer capability of a Transmission line is 'P' MW. If a series capacitor of reactance value 60% line reactance is added. what is the new power transfer capability of the line by assuming sending end & receiving end vol's as same



$P_{max} = P \rightarrow$ for a reactance of X_{line}

equivalent reactance, $X_{eq} = X_{line} - X_C$

$X_C = 60\%$ of X_{line}

$= 0.6 X_{line}$

$\therefore X_{eq} = 0.4 X_{line}$

$$P_{max}(new) = \frac{V_s \cdot V_r}{X_{eq}} = \frac{V_s \cdot V_r}{0.4 X_{line}}$$

here $\frac{V_s \cdot V_r}{X_{line}} = P$ (with out series capacitor)

$$P_{max}(new) = \frac{P}{0.4} = 2.5 P \text{ MW}$$

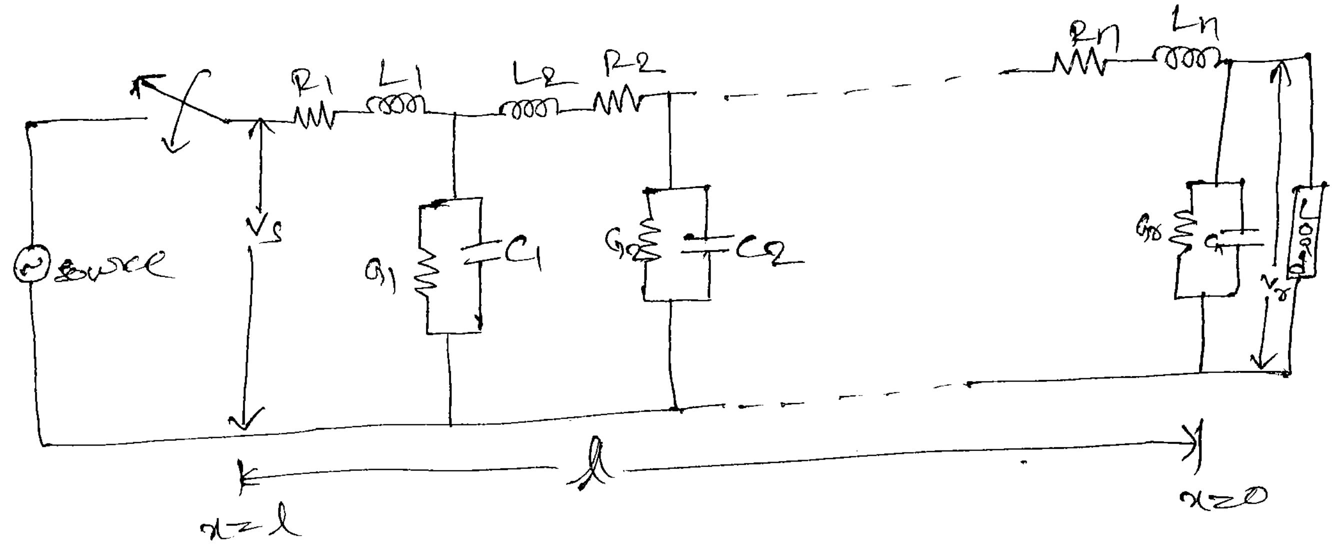
$\therefore$ series capacitor will improve the stability of the system. so it is called as "stability contool device".

Transient analysis on transmission line :-

→ This is done only on long line which is represented in distributed parameter model

→ All the parameters 'R, L, C & G' will be considered

l → length of the line, devided into 'n' section.



$R_1 = R_2 = - - - R_n = R/\text{km}$ ...

$L_1 = L_2 = - - - L_n =$ inductance/km $= L$

$C_1 = C_2 = - - - C_n =$ capacitance/km $= C$

$G_1 = G_2 = - - - G_n =$ shunt conductance/km $= G$

when the switch is getting closed, both vol & current waves will be released on to transmission line.

→ If the time constants of series and shunt sections of transmission line is same in each part of line, then that line is called as "distortion less line".

∴ i.e., there is no change in wave shape (either in vol (or) current)

→ series time constant, $\frac{L_1}{R_1}$ = shunt time constant, $\frac{C_1}{G_1}$ $\Rightarrow L_1 G_1 = R_1 C_1$

for sec - 1

$\Rightarrow \boxed{RC = LG}$

→ If $R=0$, $G=0$ then that Transmission line is called as lossless TL

→ Lossless TL is also called as "unattenuated line".

→ If either $R \neq 0$ (or) $G \neq 0$ then that TL is called as "lossy line" (or) attenuated line.

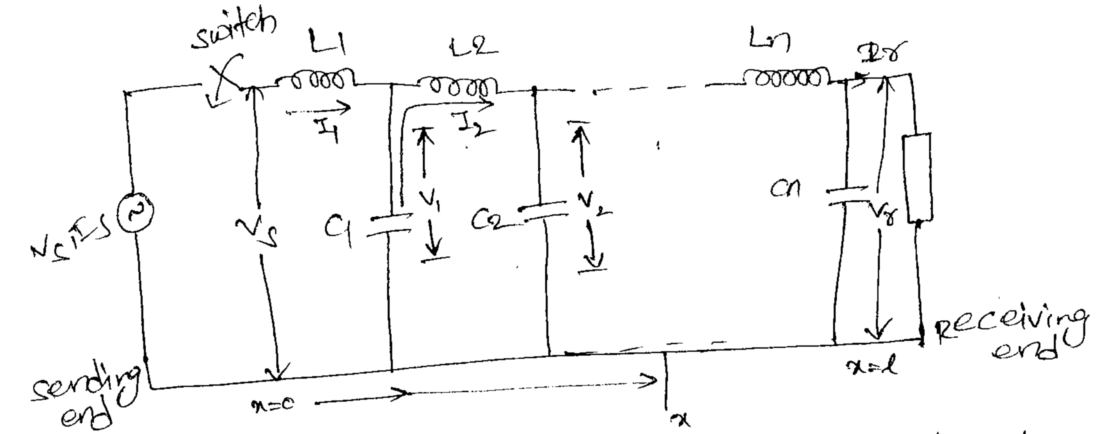
⇓

i.e., in the attenuated lines, the magnitudes of voltage and current will be reduced as the wave propagates throughout the transmission line

→ If the voltage and current is same throughout the length of the line, then that line is called as "Infinite line" i.e., $l = \infty$, [physically it does not exist and hence it has no physical meaning]

But. source will feel that the length of line is "∞"

wave propogation in loss-less line :- ($R=0$, $G=0$, in each section)



→ when ever the switch is getting closed V, I waves are propogated by means of electric and magnetic fields.

→ electric fields → static energy
magnetic fields → magnetic energy

The placement of inductane in the transmission line is to represent reactive power taken by transmission line.

The significance of capacitance is to represent the reactive power supplied by transmission line.

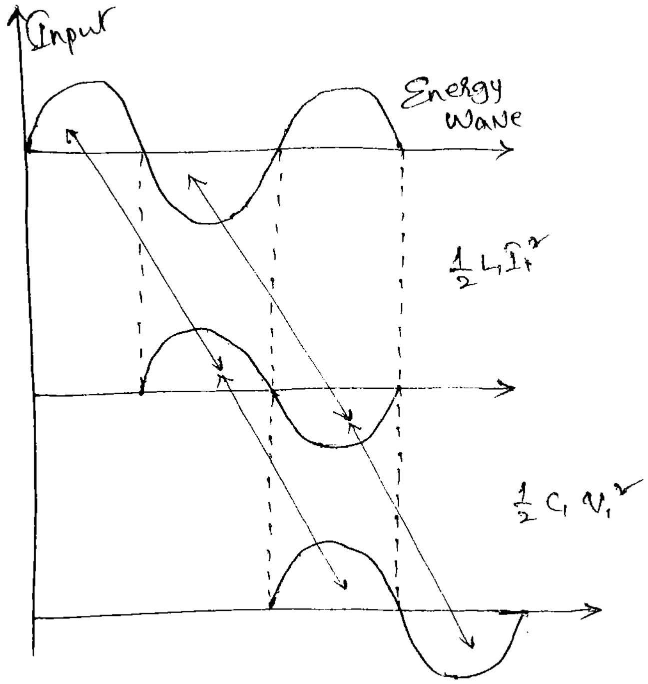
The Combined significance of L, C in equivalent diagram is to study the wave propogation in Long transmission lines.

whenever the switch is getting closed the inductor L_1 will be charged to an energy of $\frac{1}{2}L_1 I_1^2$ (Magnetic). The energy stored in L_1 will be discharged to C_1 by means of electrostatic energy $(\frac{1}{2}C_1V_1^2)$

The energy stored in C_1 will be dischaged to L_2. The same argument will be followed throughout the length of line

$$\frac{1}{2}L_1I_1^2 = \frac{1}{2}C_1V_1^2$$ (No-Energy loss in transmission line)

(Valid for each section because the line



$$\frac{1}{2}L_1I_1^2 = \frac{1}{2}V_1^2C_1$$

$$\frac{V_1^2}{I_1^2} = \frac{L_1}{C_1}$$

$$\frac{V_1}{I_1} = \sqrt{\frac{L_1}{C_1}} = Z_c$$

$\Downarrow$

Surge Impedance (OR) characteristic Impedance.

⇒ Surge Impedance is the ratio of voltage and current at each and every point of the line when the wave is propagat

$$Z_c = \frac{V}{I} = \sqrt{\frac{L}{C}} \quad \text{(loss-less line)}$$

L → Inductance per unit length.

C → Capacitance per unit length.

Surge Impedance is the impedance offered by transmission line during surge conditions. [Switching or lightening]

* Velocity of Wave propagation:—

Magnetic flux linkages upto point 'x' on the transmission line.

x-means x-KM.

$$\Psi = L_1I_1 + L_2I_2 + \dots + L_xI_x$$

Each section will carry same amount of current.

$$\therefore \Psi = LIx$$

$$(I_1 = I_2 = \dots = I_x = I)$$

Voltage developed in transmission line,

$$V = \frac{d\Psi}{dt} \quad \text{(According to faraday's 2}^{nd}\text{ law of EMI).}$$

$$V = LI\frac{dx}{dt}$$

$$\boxed{V = LI\, v} \longrightarrow (1)$$

v = velocity of wave $\left(\frac{dx}{dt}\right)$

Electric flux linkages up to point 'x' (x - km)

$$\lambda = C_1V_1 + C_2V_2 + \dots + C_xV_x$$

$$V_1 = V_2 = \dots = V_x = V$$

$$\therefore \lambda = CVx$$

Current, $I = \frac{d\lambda}{dt}$

$$\Rightarrow I = CV\frac{dx}{dt}$$

$$\Rightarrow \boxed{I = CV \cdot v} \longrightarrow (2)$$

v = velocity of wave $\frac{dx}{dt}$

Multiply (1) & (2) Equations.

$$VI = VI \cdot LC \cdot v^2$$

$$\boxed{v = \frac{1}{\sqrt{LC}}}$$

$L \rightarrow$ per km Inductance

$C \rightarrow$ per km Capacitance

$$L = 2\times10^{-7}\, Ln\left(\frac{GMD}{GMR}\right) \ H/m$$

The wave will be propagated only on surface of conductor. So only external inductance will be considered for velocity of wave

$$L = \frac{\mu_0\mu_r}{2\pi}\, ln\left(\frac{GMD}{r}\right) \ H/m \longrightarrow \text{External Inductance.}$$

for any conductor made by any material.

$$C = \frac{2\pi\epsilon_0\epsilon_r}{Ln\left(\frac{GMD}{r}\right)} \ F/m$$

$$v = \frac{1}{\sqrt{\frac{\mu_0\mu_r}{2\pi}\cdot ln\left(\frac{GMD}{r}\right)\cdot\frac{2\pi\epsilon_0\epsilon_r}{ln\left(\frac{GMD}{r}\right)}}} \Rightarrow \boxed{v = \frac{1}{\sqrt{\mu_0\mu_r\epsilon_0\epsilon_r}}}$$

for overhead (OH) line which is made up of Al (or) Cu material

$\mu_r = 1$ for Al (or) Cu

$\epsilon_r = 1$ for Air.

$$v = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

$= 2.99 \times 10^8$ m/s

$= 3 \times 10^8$ m/s (light velocity)

$= 3 \times 10^5$ km/s (loss-less line)

for attenuated line or lossy line

$v = 2.5 \times 10^5$ KM/s to 2.8×10^5 KM/s.

for Under Ground (UG) Cable, conductor is made by Al (or) Cu

$\mu_r = 1.0$, $\epsilon_r > 1$

$$v = \frac{1}{\sqrt{\mu_0 \epsilon_0 \epsilon_r}} = \frac{1/\sqrt{\mu_0 \epsilon_0}}{\sqrt{\epsilon_r}} = \frac{3 \times 10^5}{\sqrt{\epsilon_r}} \text{ KM/s.}$$

v (cable) < v (OH line)

for steel conductor the velocity of wave travelling is less compared to Alluminium conductor.

Propegation Constant (γ) :-

It will measure the changes in voltage, current waves when the wave is propegating through the transmission line.

$$\text{Changes} \begin{cases} \text{Decrement in magnitude of wave } (V, I) \\ \text{Physical displacement of wave } (V, I). \end{cases}$$

For transmission line, $\gamma = \sqrt{zy}$

$z = r + j\omega l$, per KM series impedance

$y = g + j\omega c$, per KM shunt admittance.

$\gamma = \sqrt{(r + j\omega L)(g + j\omega c)}$

$= \alpha + j\beta$

$\alpha \rightarrow$ Attenuation Constant

units $\rightarrow$ Neper/KM

$\beta \rightarrow$ Phase Constant or Quadrature Component

Units $\rightarrow$ radians/km.

α - will represent changes in the magnitude of the wave,

β - will represent physical displacement of the wave.

<u>For loss-less line:</u> $r = 0$, $g = 0$

$\gamma = \sqrt{(j\omega L)(j\omega C)}$

$= j\omega\sqrt{LC}$

$= j\beta$

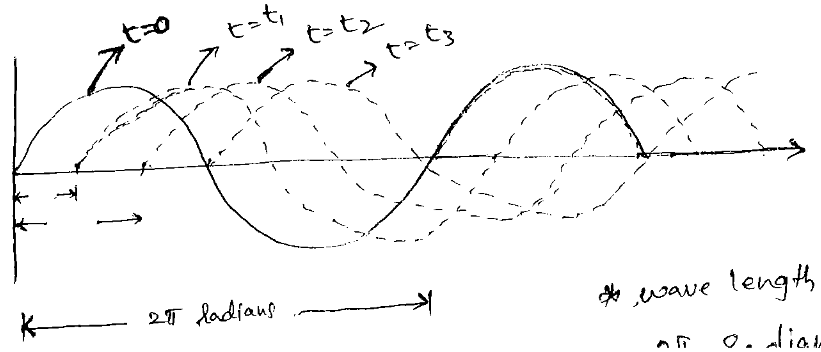
Attenuation constant, $\alpha = 0$

phase constant, $\beta = \omega\sqrt{LC}$

* Wave length (λ) for Transmission line:

Spacial period occupied by wave (or),

period after which the wave is going to be repeated.



* wave length of the sinusoidal wave is

2π radians

wave length of line(λ)

$\beta \cdot \lambda = 2\pi$

wave length of transmission line

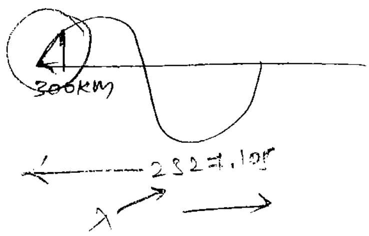
$$\Rightarrow \boxed{\lambda = \frac{2\pi}{\beta}}$$

A 300 km length TL having the quadrature component of 0.0027 rad/km, what is the ratio between physical length and wave length of TL

wave length, $\lambda = \frac{2\pi}{\beta} = \frac{2\pi}{0.0027}$ km $= 2327.105$ KM

physical length, $l = 300$ KM

$l : \lambda = 300 : \frac{2\pi}{0.0027} = 0.1289 : 1$



what is the wavelength of a loss less line which is operating at 400 kV, 50 Hz..

wave length, $\lambda = \frac{2\pi}{\beta} = \frac{2\pi}{\omega\sqrt{LC}} = \frac{2\pi v}{\omega}$; $\left(v = \frac{1}{\sqrt{LC}} \right)$

$\lambda = \frac{1}{f\sqrt{LC}}$ $\left(\because \lambda = \frac{2\pi v}{2\pi f} \right.$

$\lambda = \frac{v}{f} = \frac{3 \times 10^5 \text{ KM/s}}{50}$

$= 6000$ KM.

Surge Impedance or Characteristic Impedance (or) Natural Impedance:-

$\Rightarrow \frac{V}{I}$ value at any point of line during surge condition (or) Transients

$\Rightarrow$ Impedance offered for surges (or) Transients.

For attenuated line / Lossy lines $\rightarrow$ $Z_c = \sqrt{\frac{z}{y}}$

$z = r + j\omega L$ /km

$y = g + j\omega C$ /km.

$$Z_c = \sqrt{\frac{r + j\omega L}{g + j\omega C}} \quad \begin{matrix} \rightarrow \tan^{-1}\left(\frac{\omega L}{r}\right) & \text{[Angle for Numerator]} \\ \rightarrow \tan^{-1}\left(\frac{\omega C}{g}\right) & \text{[Angle for denominator]} \end{matrix}$$

$$\tan^{-1}\left(\frac{\omega C}{g}\right) > \tan^{-1}\left(\frac{\omega L}{r}\right)$$

$g \rightarrow$ almost zero.

$$\boxed{Z_c = |Z_c| \angle -\theta}$$

$$\theta = \frac{\tan^{-1}\left(\frac{\omega C}{g}\right) - \tan^{-1}\left(\frac{\omega L}{r}\right)}{2}$$

Characteristic impedance is capacitive in nature.

Characteristic impedence is independent of length of line and it depends on frequency [surge]

For Loss-less line:

$$r = 0 \quad , \quad g = 0$$

$$Z_c = \sqrt{\frac{j\omega L}{j\omega C}} = \sqrt{\frac{L}{C}}$$

* characteristic impedance is pure resistive and it is independent of length of line and frequency (Surge).

For loss-less line (Overhead line):

$Z_c = (300 - 400)\,\Omega \rightarrow$ range.

Typical value of Z_c is $400\,\Omega$

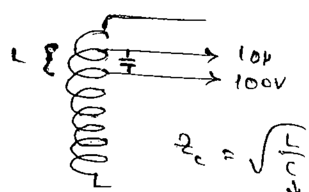
For loss-less line (Underground line):

$Z_c = (40 - 80)\,\Omega \rightarrow$ range

Typical value of $Z_c = 40\,\Omega$

Due to the inter-turn capacitance in the T/F winding, a surge impedence will be offered by the winding which is a very high value. because capacitance is very low

So for T/F, $Z_c = (1000 - 5000)\,\Omega$

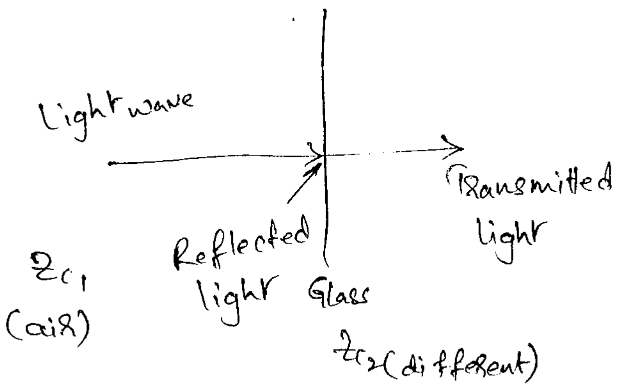


$$Z_c = \sqrt{\frac{L}{C}}$$
$\downarrow$
low val.

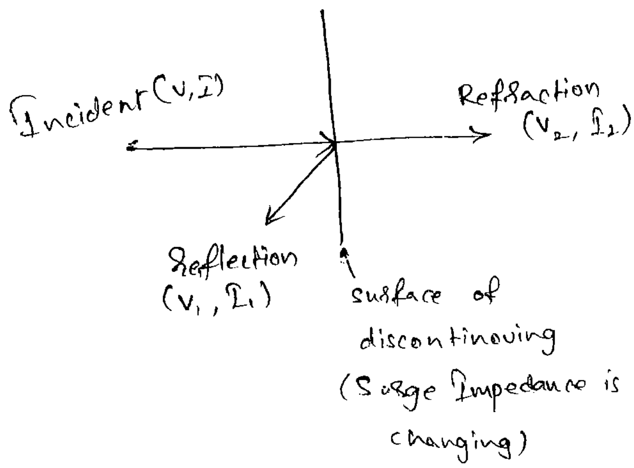
Lumped loads will have a high ... ideally infinite.

Ex:- Lumped load is transformer.

* Wave travelling in Transmission lines:

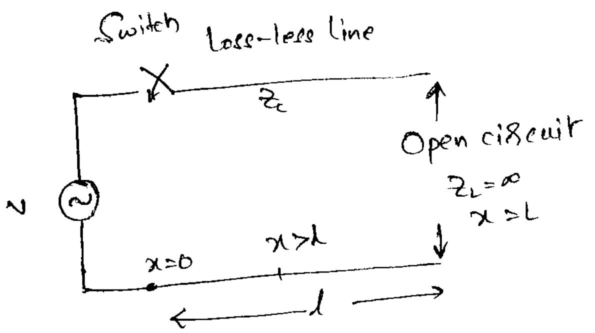


The wave will experience reflections when the wave is entering from one medium to a different medium, which are having different surge impedances.



If the surge impedance of the load and surge impedance of transmission line are same then there is no reflections at the junction point.

* Wave travelling in open circuit line:-



Z_c is pure resistive but it won't create any loss in the transmission line. The resistive propertie due to L and C only.

Time taken by the wave to reach at the end of the transmission line, $T = \frac{l}{v}$

Prob:- for 400KM, 400KV line how much time will be taken by wave to reach end of the line.

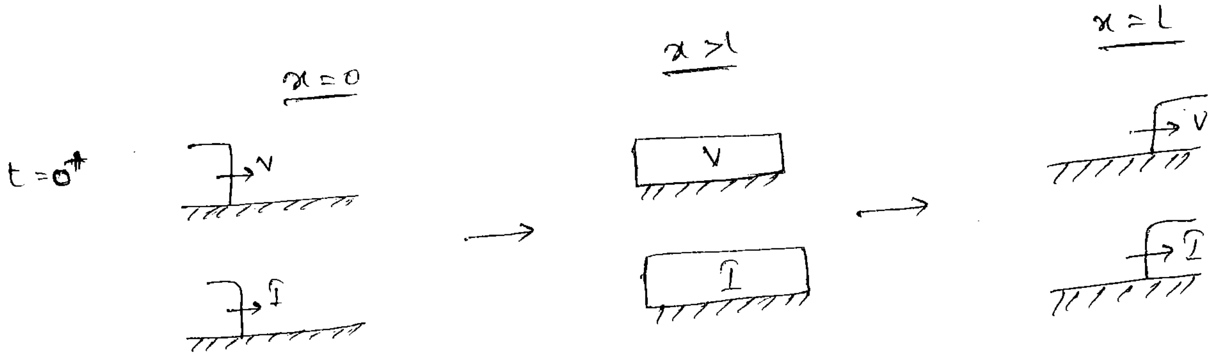
Sol:- $T = \frac{l}{v} = \frac{400km}{3\times10^5 \, KM/s} = 1.333 \, ms$

Incident voltage $\longrightarrow$ V (known) $\Big\}$ $\rightarrow$ Switching Surges.
Incident Current $\longrightarrow$ $I = \frac{V}{Z_c}$

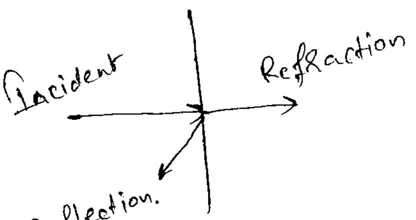
for lightening surges incident current value is known and the voltage value $V = I \cdot Z_c$

At the recieving end, we know the refracted current. i.e., $I_2 = 0$. At the sending end we know the refracted voltage i.e., $V_2 = V$.

~~Ap~~ At positions $x = 0$, $x > l$, $x = l$.



Refraction (V_2, I_2) = Inciden (V, I) + Reflection (V, I_1)

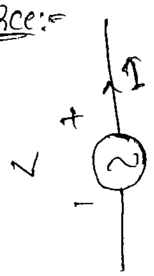


$V_2 = V + V_1$ [Refracted voltage]

$I_2 = I + I_1$ [Refracted current]

$\Rightarrow$ To make current at the open circuit as zero, a minus I - amount of current will be reflected at the end of Transmission line.

Source:-

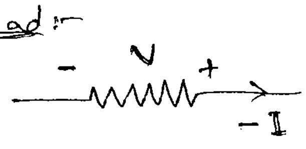


If $V \rightarrow +ve$, $I \rightarrow +ve$ [leaving from +ve terminal]

If $V \rightarrow -ve$, $I \rightarrow -ve$

If $V \rightarrow +ve$ then $I \rightarrow -ve$

Load:-



If $V \rightarrow -ve$ then $I \rightarrow +ve$

with respect to $-I$ reflected current a positive amount of voltage $+V$ will be injected in to the transmission line.

Incident $\rightarrow V, I$

$t = T$ About to reach the end line

T = Time taken to reach the end of the line.

Refracted current, $I_2 = 0$ (known)

Reflected current, $I_1 = I_2 - I$

$\Rightarrow \boxed{I_1 = I}$

Reflected voltage $V_1 = +V$

Now refracted voltage $(V_1) + V = (+V) + V = 2V$

Ferranti Effect [Because the sending end voltage $= V$, but the recieving end voltage $= 2V$.

This is the maximum value of switching over voltage is double the rated voltage. This is also called as Doubling Effect.

Doubling Effect with respect to voltage.

Co-efficient of current refraction:

$$I_{refraction} = \frac{\text{Refracted Current}}{\text{Incident Current}}$$

$$= \frac{I_2}{I} = 0 \rightarrow \text{Co-efficient of current refraction.}$$

Co-efficient of Current reflection

$$I_{reflection} = \frac{\text{Reflected current}}{\text{Incident Current}}$$

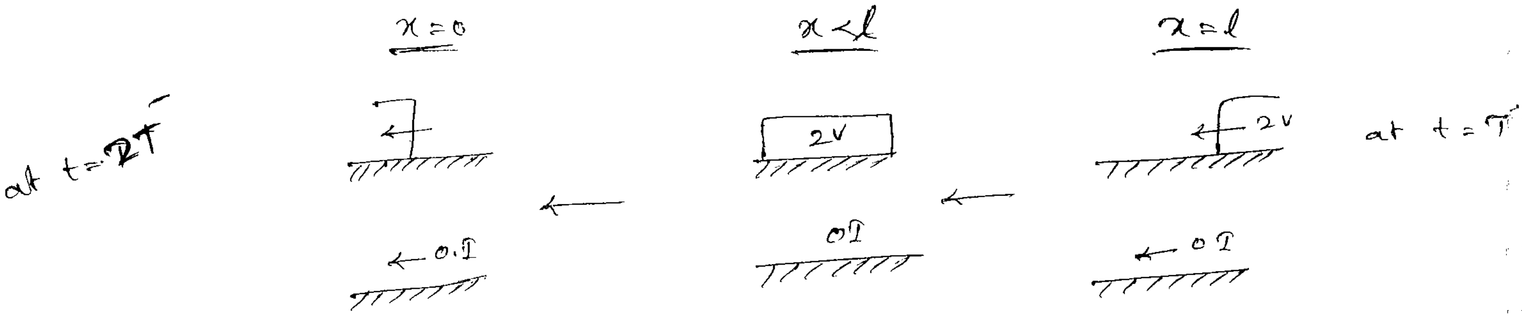
$$= -1 \rightarrow \text{Co-efficient of current reflection.}$$

Co-efficient of voltage reflection:

$$V_{reflection} = \frac{\text{reflection voltage}}{\text{Incident Voltage}} = \frac{V}{V} = 1$$

Co-efficient of voltage refraction:

$$= \frac{\text{refraction voltage}}{\text{Incident voltage}} = \frac{2V}{V} = 2$$



under this condition Refracted voltage, $V_2 = V$

Reflected voltage, $V_1 = V_2 - \text{incident}$

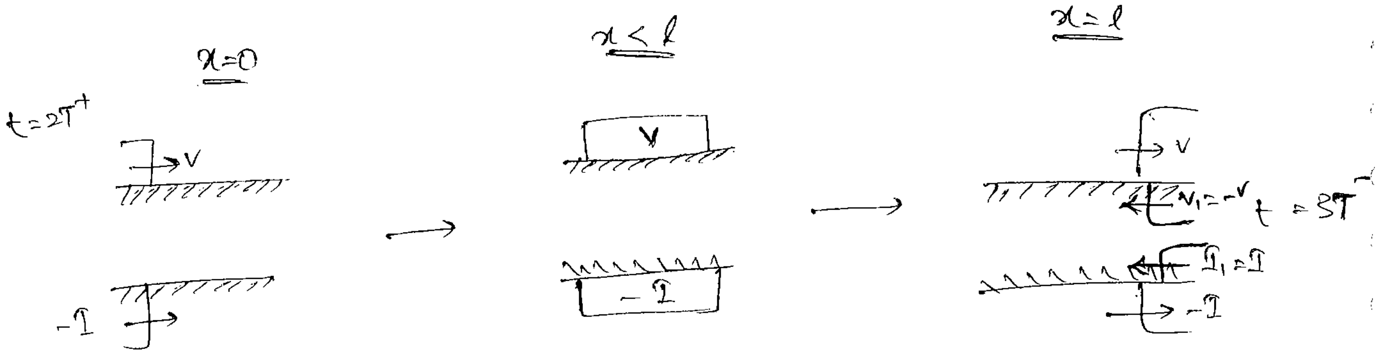
$\Rightarrow V_1 = V - 2V = -V$

Reflected current $I_1 = -I$

Refracted current $I_2 = I_1 + \text{incident}$

$I_2 = -I + 0$

$I_2 = -I$



Refract current $\boxed{I_2 = 0}$

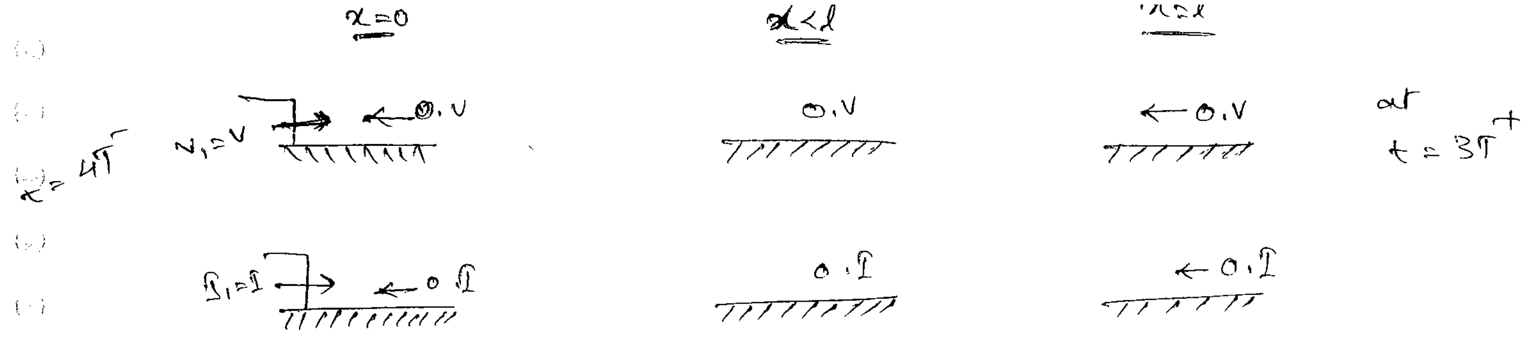
Incident current $= -I = I_1$

Reflected $= 0 - (-I) = I$

Reflected voltage $V_1 = -V$

Incident voltage $= V$

$V_2 = V_1 + \text{Incident} = 0.$



Refracted Voltage $V_2 = V$

Incident $= V_1 = 0$

Reflected $= V - 0 = V$

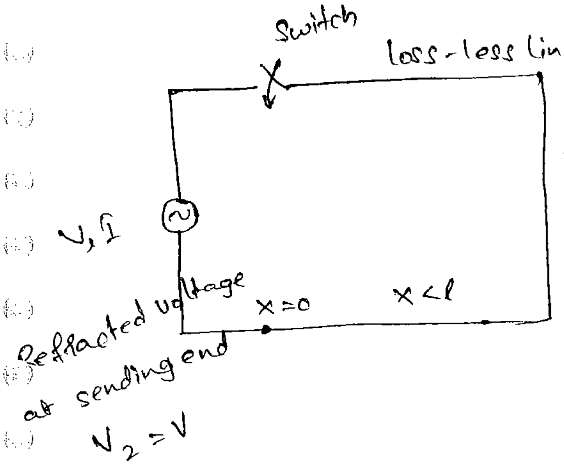
Reflected current $= I = I_1$

Incident current $= 0$

Refracted $= I + 0 = I$

After then first cycle will be repeated.

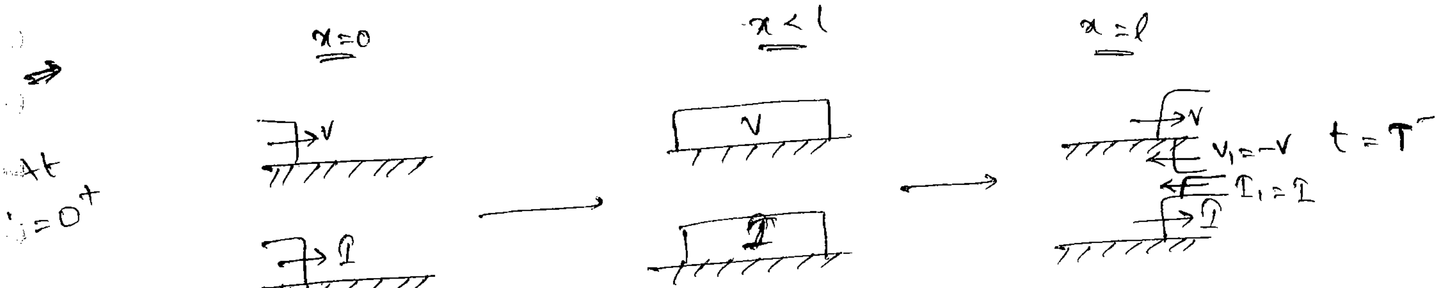
* Short-circuit line :-



Short circuit

$Z_L = 0$

Refracted voltage at recieving end $V_2 = 0$.



Refracted voltage at the end of the Line $V_2 = 0$

Incident Quantities $\longrightarrow V, I$

Reflected voltage at the end of the line $V_1 = V_2 - V$

$\Rightarrow V_1 = -V$ ($\because V_2 = 0$.

reflected current $I_1 = +I$

refracted current $I_2 = I_1 + I$

$= 2I$. ($\because I_1 = I$).

Co-efficient of Voltage Refraction

$$V_{refraction} = \frac{V_2}{V} = 0 \quad (\because V_2 = 0).$$

Co-efficient of voltage reflection

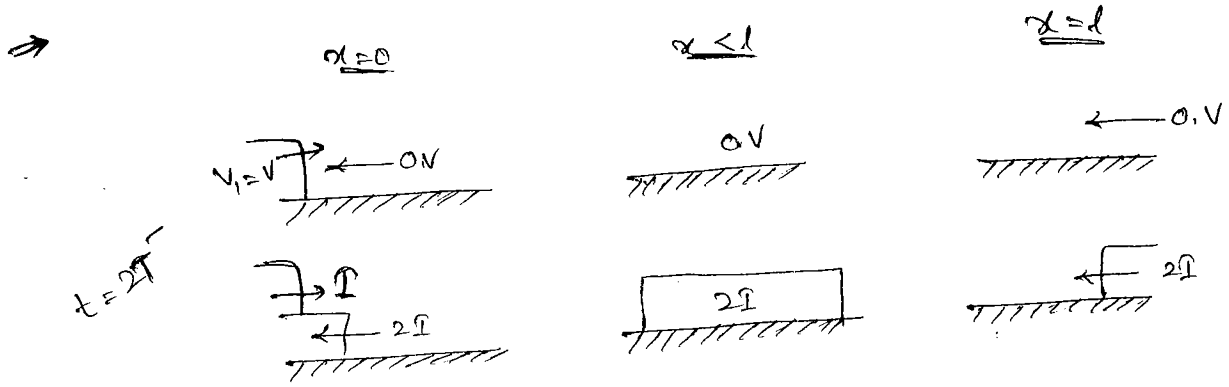
$$V_{reflection} = \frac{V_1}{V} = -1 \quad (\because V_1 = -V)$$

Co-effient of current refraction

$$I_{refraction} = \frac{I_2}{I} = 2 \quad (\because I_2 = 2I)$$

Co-effient of current reflection

$$I_{reflection} = \frac{I_1}{I} = 1 \quad (\because I_1 = I)$$



Refracted voltage $V_2 = V$

Reflected voltage $V_1 = V_2 - \text{incident}$

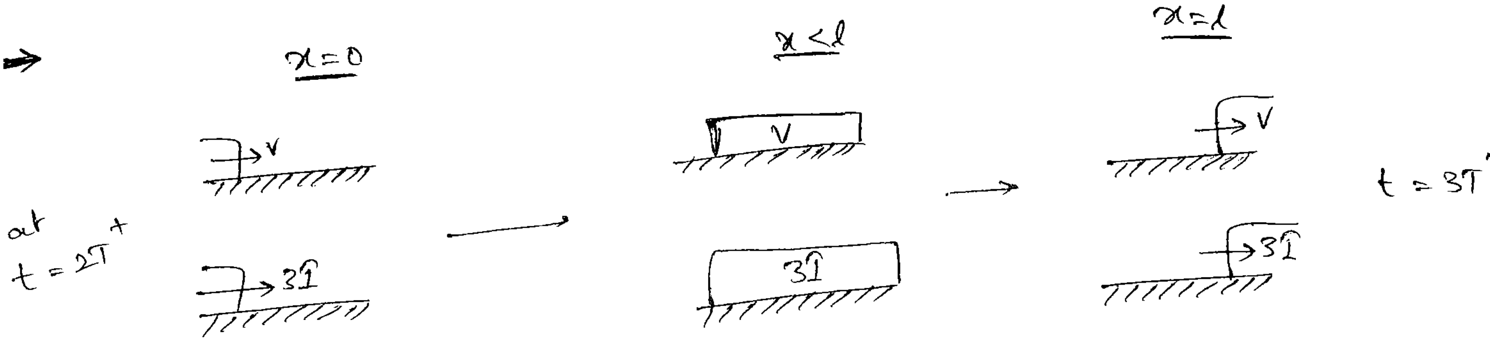
$= V - 0 = V$

Reflected Current $I_1 = I$

Refracted current $I_2 = I_1 + \text{Incident}$

$= I + 2I$

$= 3I.$



Refracted Voltage $V_2 = 0,$

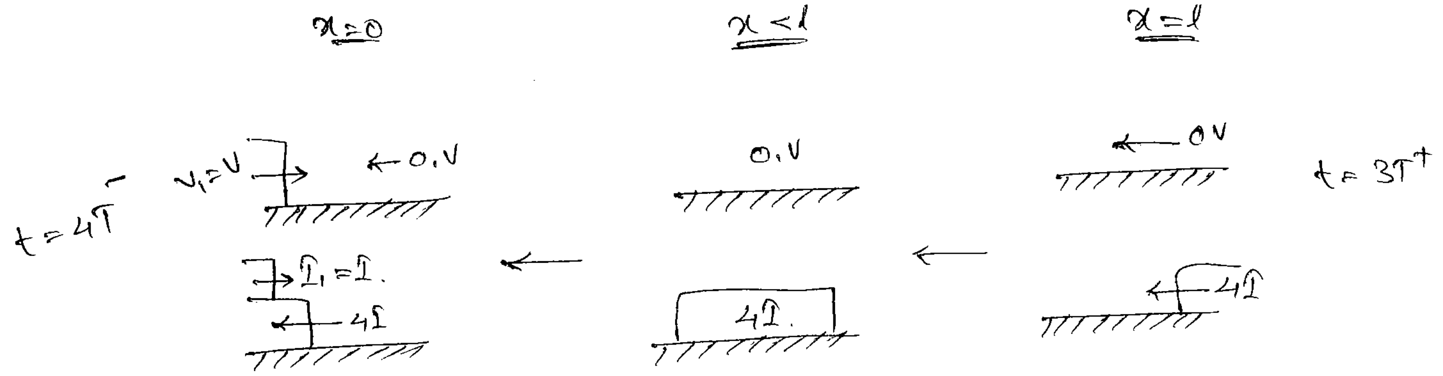
$\Rightarrow$ reflected voltage $V_1 = V_2 - \text{incident}$

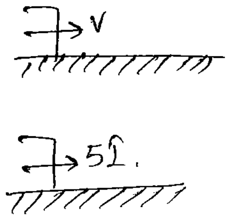
$= 0 - V$

Reflected current $I_1 = I.$

Refracted current $I_2 = I_1 + \text{incident}$

$= I + 3I$

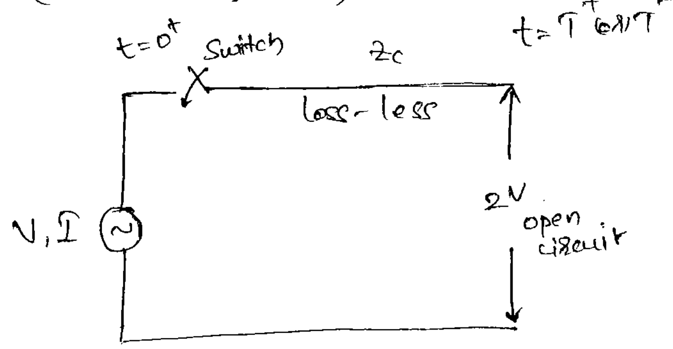


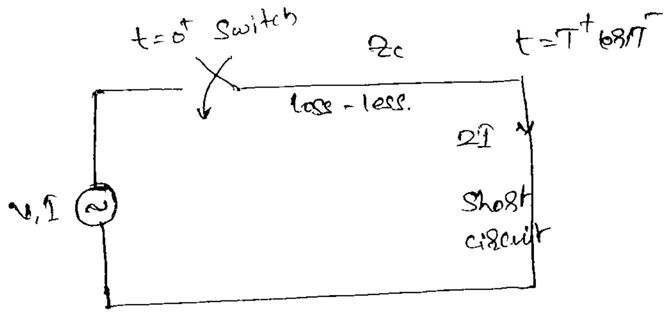


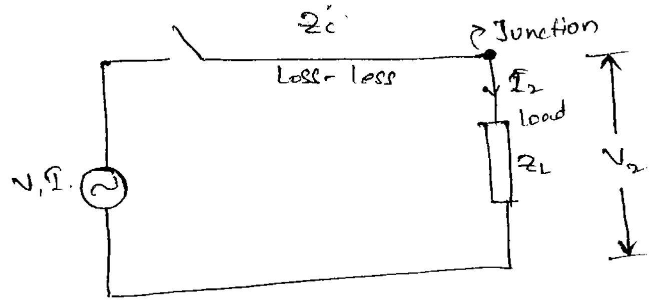
→ Due to practical limitations current is limited to $4I$.

* Electrical Equivalent diagram for wave travelling analysis:—

$(t = T^+$ or $T^-)$







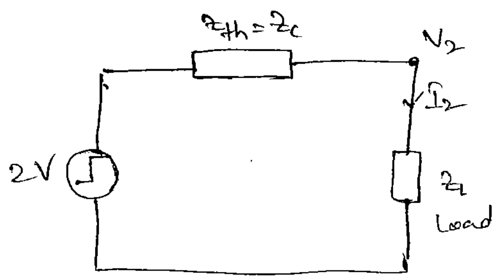
V_2, I_2 → Refracted or Junction Voltage and Current.

Thevinen's voltage (under open circuit)
$V_{th} = 2V$ (2 times the incident voltage).

Norton's current (under short circuit) $Z_L = 0$
$I_n = 2I$.

Thevinen's Impedance, $Z_{th} = \frac{V_{th}}{I_n} = \frac{2V}{2I} = Z$

Thevinen's Equivalent Circuit:



→ This circuit is used to calculate only only refracted Quantities V_2, I_2

Reflected Quantities (V_1, I_1) will be calculated as:

Reflected Quantitie (V_1, I_1) = Refracted Quantitie (V_2, I_2) − Incident Quantitie (V, I)

⇒ Refracted Voltage $V_2 = 2V \cdot \frac{Z_L}{Z_L + Z_c}$.

Co-efficient of refracted voltage, $\boxed{V_{refraction} = \frac{2Z_L}{Z_L + Z_c}}$

⇒ Reflected Voltage, $V_1 = V_2 - V$

$$\Rightarrow V_1 = 2V \cdot \frac{Z_L}{Z_L + Z_c} - V$$

$$V_1 = V\left[\frac{2Z_L - Z_L - Z_c}{Z_L + Z_c}\right] = V\left[\frac{Z_L - Z_c}{Z_L + Z_c}\right]$$

Co-efficient of reflected voltage,

$$\Rightarrow V_{reflection} = \frac{V_1}{V} = \frac{Z_L - Z_c}{Z_L + Z_c}$$

⇒ Refracted current, $I_2 = \frac{2V}{Z_L + Z_c}$ $\quad (V = I Z_c)$

$$I_2 = I \cdot \frac{2Z_c}{Z_L + Z_c}$$

Co-efficient of refraction current,

$$I_{refraction} = \frac{I_2}{I} = \frac{2Z_c}{Z_L + Z_c}$$

⇒ Reflected current, $I_1 = I_2 - I$

$$= \frac{2Z_c}{Z_L + Z_c} \cdot I - I$$

$$I_1 = -I\left[\frac{Z_L - Z_c}{Z_L + Z_c}\right]$$

Co-efficient of reflected current,

$$I_{reflection} = \frac{I_1}{I} = -\left(\frac{Z_L - Z_c}{Z_L + Z_c}\right)$$

* A transmission line having a surge impedance of 500Ω is terminated by different values of resistances. Find out the co-efficients of voltage reflection and refractions.

i, 0Ω, ii, 200Ω, iii, 500Ω iv, 1000Ω v, ∞Ω

Sol:- i, $Z_L = 0\Omega$, $Z_c = 500\Omega$

$$v_{reflection} = \frac{Z_L - Z_c}{Z_L + Z_c} = \frac{0-500}{0+500} = -1v$$

$$v_{refraction} = \frac{2Z_L}{Z_L+Z_c} = \frac{2\times 0}{0+500} = 0\ v$$

ii, $Z_L = 200\Omega$, $Z_c = 500\Omega$

$$v_{reflection} = \frac{Z_L - Z_c}{Z_L + Z_c} = \frac{200-500}{200+500} = -0.428$$

$$v_{refraction} = \frac{2Z_L}{Z_L+Z_c} = \frac{2\times 200}{200+500} = 0.572$$

iii, $Z_c = 500\Omega$, $Z_c = 500\Omega$

$$v_{reflection} = \frac{Z_L - Z_c}{Z_L + Z_c} = \frac{500-500}{500+500} = 0$$

* characteristic impedence of Transmission line

$$v_{refraction} = \frac{2Z_L}{Z_L+Z_c} = \frac{2\times 500}{500+500} = 1$$

* This Type of line is called as Infinite line or Flat line

* The reflection will be ze[ro] for Infinite line or Flat li[ne]

iv, $Z_L = 1000\Omega$, $Z_c = 500\Omega$

$$v_{reflection} = \frac{Z_L - Z_c}{Z_L + Z_c} = \frac{1000-500}{1000+500} = 0.333$$

$$v_{refraction} = \frac{2Z_L}{Z_L+Z_c} = \frac{2\times 1000}{1000+500} = 1.3333$$

v, $Z_L = \infty\Omega$, $Z_c = 500\Omega$

$$v_{reflection} = \frac{Z_L - Z_c}{Z_L + Z_c} = \frac{1 - Z_c/Z_L}{1 + Z_c/Z_L} = 1$$

$$v_{refraction} = \frac{2Z_L}{Z_L+Z_c} = \frac{2}{Z_c/Z_L + 1} = 0 \quad \left(\because \frac{Z_c}{Z_L} = 0\right).$$

Note:

$$-1 \leq v_{reflection} \leq 1 \quad (\swarrow Z_L = 0\Omega, \ \searrow Z_L = \infty)$$

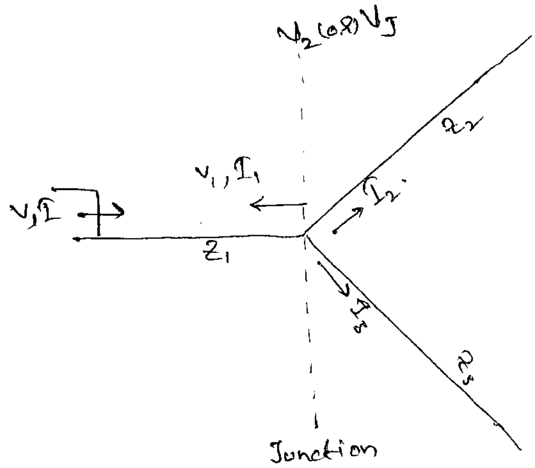
$$-1 \leq i_{reflection} \leq 1 \quad (\swarrow Z_L = \infty, \ \searrow Z_L = 0)$$

$$0 \leq v_{refraction} \leq 2 \quad (\swarrow Z_L = 0, \ \searrow Z_L = \infty)$$

$$0 \leq i_{reflection} \leq 2 \quad (\swarrow Z_L = \infty, \ \searrow Z_L = 0.)$$

* Wave travelling in Bifercated lines:-

* Bifercated line also called as Parallel line (or) forked line.

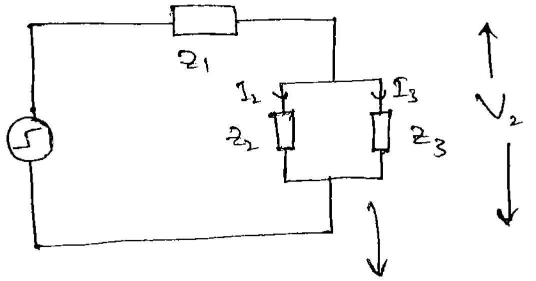


$V, I \rightarrow$ Incident

$V_1, I_1 \rightarrow$ Reflected

$V_2, I_2, I_3 \rightarrow$ Refracted.

Electrical equivalent circuit:-



$$Z_{eq} = \frac{Z_2 Z_3}{Z_2 + Z_3}.$$

⇒ Refracted Voltage

$$V_2 = 2V \cdot \frac{Z_{eq}}{Z_{eq} + Z_1}$$

$$= 2V \cdot \frac{\frac{Z_2 Z_3}{Z_2 + Z_3}}{Z_1 + \frac{Z_2 Z_3}{Z_2 + Z_3}}$$

Refracted Voltage $\boxed{V_2 = 2V \cdot \frac{Z_2 Z_3}{\ldots}}$ →

⇒ Reflected Voltage $V_1 = V_2 - V$

$$V_1 = V\left[\frac{2Z_2 Z_3}{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1} - 1\right]$$

$$V_1 = V\left[\frac{Z_2 Z_3 - Z_1 Z_2 - Z_1 Z_3}{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1}\right]$$

⇒ Refracted current

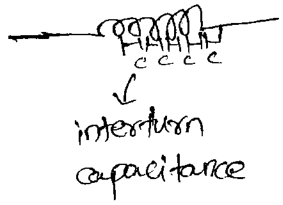
$$I_2 = \frac{V_2}{Z_2}, \quad I_3 = \frac{V_2}{Z_3}.$$

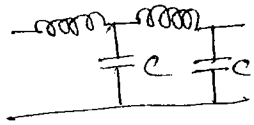
⇒ Reflected current

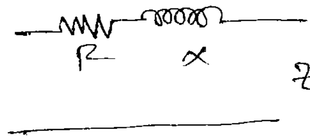
I_1 = Reflected - Incident

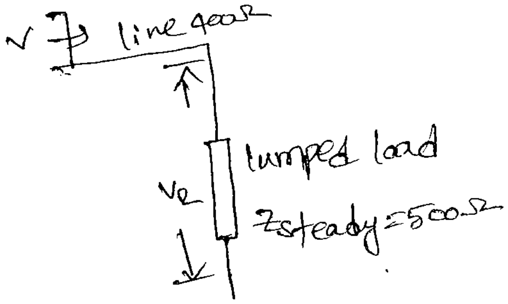
$= (I_2 + I_3) - I_1$

→ A transmission line having a surge impedance of 400Ω is terminated by a lumped load having a steady state impedance of 500Ω. what is the voltage is appeared across load after 1st wave travelling period.









$Z_{surge} > Z_{steady}$

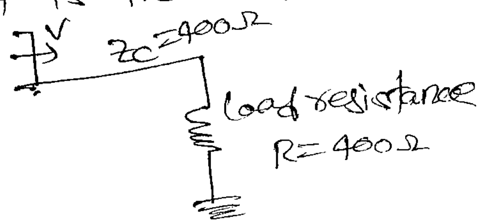
V_R = refracted voltage $= 2V\left[\frac{Z_L}{\quad}\right.$

→ surge impedance of a system is always greater than steady state impedance.

→ Lumped load means, the physical length of the load is less & the surge impedance of the lumped load is very high ideally it is infinite (it acts as a OC)

→ The voltage across the lumped load is 2V

→ what is the reflection coefficient for the following diagram



$Z_L = Z_C$

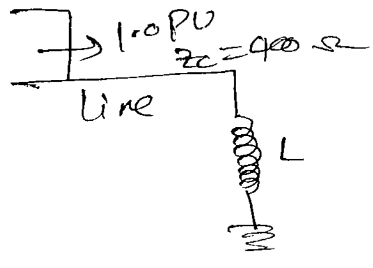
It is a matched line | infinite line | flat line

no reflection at junction.

reflection $= I$ reflection $= 0$

V refraction $= I$ refraction $= 1$

→ what is the voltage across productor after 1st wave travelling period.



a) 1 PU b) 2 PU ✓ c) -1 PU d) 0 PU

$Z_c(L) = \sqrt{\frac{L}{C}} = \sqrt{\frac{L}{0}}$

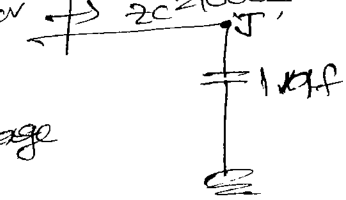
$Z_c(L) = \infty$

L-acts as OC for surges.

voltage across inductor $V_L = 2$ PU

→ for perticular inductor the voltage across the inductor will be less than the 2PU because surge impedance is not exactly equal to infinite.

→ what is the voltage & currents at point J.



$Z_c(C) = \sqrt{\frac{L}{C}} = \sqrt{\frac{0}{1\mu F}} = 0$

capacitor acts as short circuit voltage

Voltage at J $(V_J) = 0$ (refracted)

refracted (or) Junction current

I_2 (or) $I_S = 2I$

Incident current, $I = \frac{V}{Z_c} = \frac{1K}{100} = 10A$

I_L (or) $I_J' = 20A$

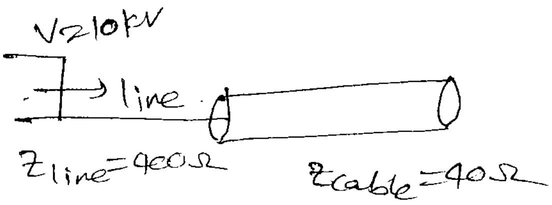
→ A transmission line having a surge impedance of 400Ω is connected to a cable of surge impedance 40Ω. If a surge voltage of 10 kV is injected on the transmission line. what is the voltage expressed by cable.

Z_c (cable) = 40Ω

Z_c (line) = 400Ω

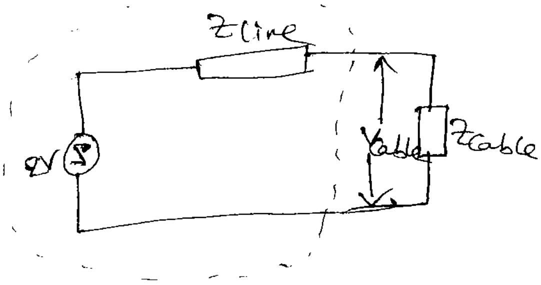
surge voltage (V) = 10 kV

Vcable = ?



refracted voltage = Vcable

$$\left.\begin{aligned} V_{th} &= 2V \\ Z_{th} &= 2I \end{aligned}\right\} \quad Z_{15} = \frac{V}{I} = Z_c$$



$$V_{cable} = 2V * \frac{Z_{cable}}{Z_{cable} + Z_{line}}$$

$$= 2 * 10 * \frac{40}{40+400} \Rightarrow 1.818\,kV$$

→ The magnitue of surge voltage will be reduced by cable connection. so cable is called as <u>surge absorber</u>.

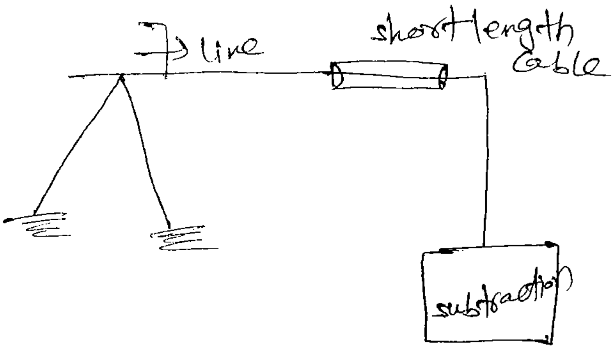
→ If a short length is connected between dead end tower and substation at the end of TL, the surge wave is entering from transmission line to cable then which of the following quantities will be reduced.

a) velocity of wave propagation

b) steepness in voltage wave form

c) magnitude of surge voltage

d) all the above



~~V(OH)~~

velocity

$V(\text{OH line}) = 3 \times 10^5$ km/s

$V(\text{cable}) = \dfrac{3 \times 10^5}{\sqrt{\varepsilon_r}}$ km/s

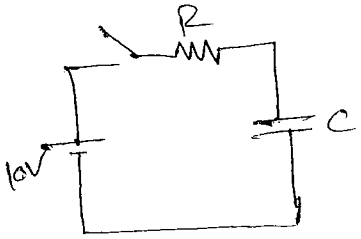
always $\varepsilon_r > 1$

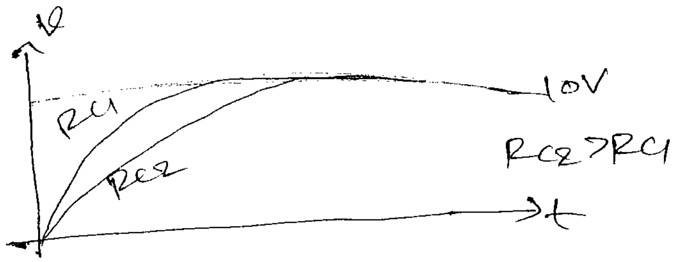
$V(\text{cable}) < V(\text{OH line})$

steepness ⟶ rate of rise in waveform

Time constant $(\tau) = RC$

$\tau(\text{cable}) > \tau(\text{OH line})$

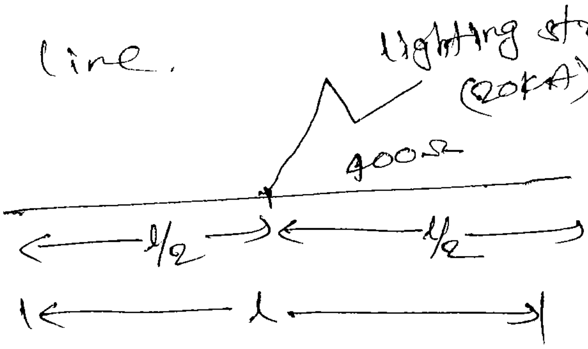




→ The steepness will be reduced in the cable due to more time compared to overhead line

→ A surge of 20kAmp is attacked on a TL which is having a surge impedance of 400 Ω. what is the voltage experienced by line, when the surge is attacking at middle of TL and $\frac{1}{3}$ length of line.

1) at middle of the line

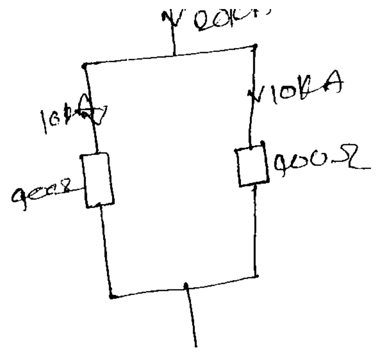


surge impedance of line = 400 Ω

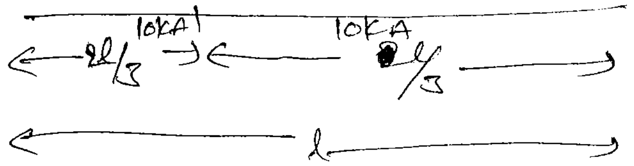
Independent of length of line

Voltage experience by line

$V_{line} = I Z_c = 10 * 400 = 4000\ kV$

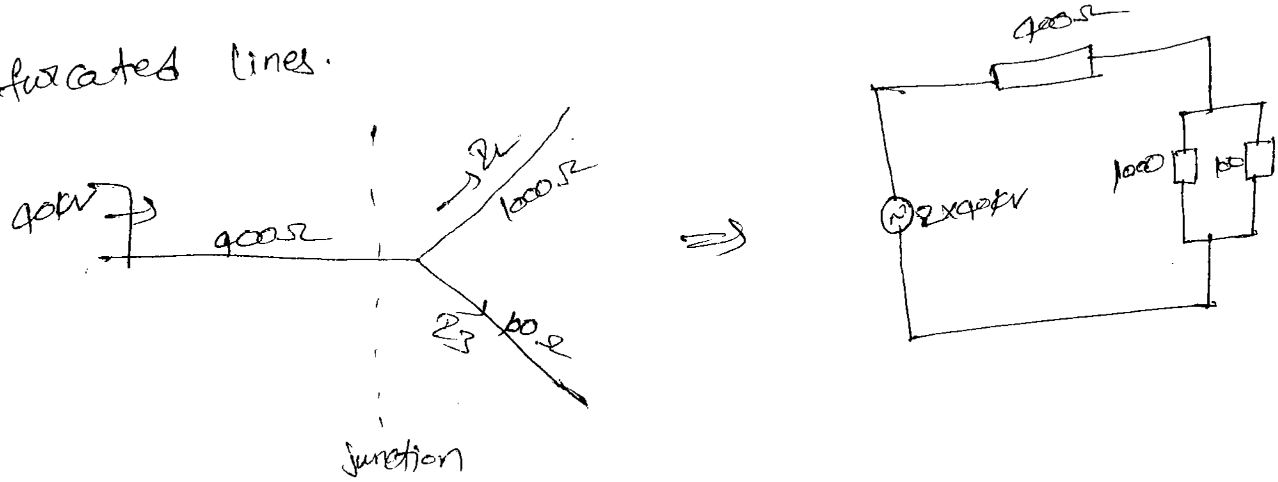


ii) At $1/3^{rd}$ of length of line :-



$V_{line} = 10k \times 400 = 4000\ kV$

→ what is the junction voltages & currents of the following bifurcated lines.



refracted (or) junction voltage is

$$V_2 = 2 * 40k * \frac{Z_{eq}}{Z_{eq}+400}$$

$$Z_{eq} = \frac{1000 \times 100}{1000+100} = 90.91\ \Omega$$

$$V_2 = 80k * \frac{90.91}{90.91+400} \Rightarrow 14.81\ kV$$

$$\text{refracted current } (I_2) = \frac{V_2}{1000} = \frac{14.81}{1000} = 14.81\ \text{Amps}$$

$$I_3 = \frac{V_2}{100} = \frac{14.81}{100} = 148.1\ \text{Amps}$$

reflected voltage $(V_1) = V_2 - V$

$V_1 = 14.81 - 40\ kV$

$V_1 = -25.19\ kV$

refected current $(I_1) = \underbrace{I_2 + I_3}_{\text{Total refracted}} - \underset{\text{Incident}}{I}$

$= 14.81 + 148.1 - I$

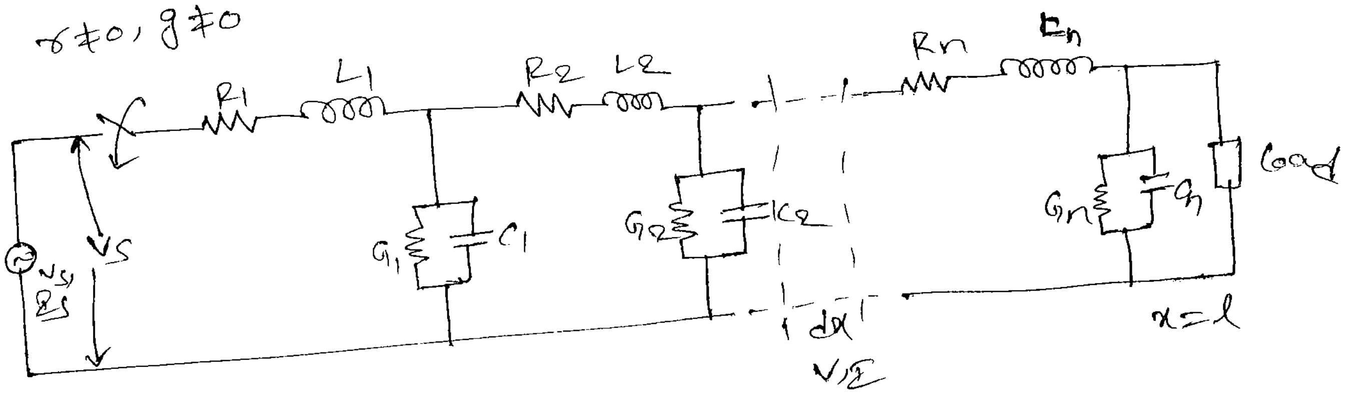
Incident current $(I) = \frac{40k}{400} = 100$ Amp

$I_1 = (14.81 + 148.1) - 100$

$I_1 = 62.9$ A

wave travelling in attenuated line :- (long line)

$r \neq 0, g \neq 0$



wave travelling distance $x = 0$

R → resistance / km

G → shunt conductance / km

dx → small section

wave travelling in attenuation line will be done based on power loss in TL.

Power loss in 'dx' section $dP = I^2 R\,dx + V^2 G\,dx$

Z_c → Characteristic impedance of line

$V = I Z_c$ (during propagation)

$dP = I^2 R\,dx + (I Z_c)^2 G\,dx$

$$\boxed{dP = I^2 R\,dx + I^2 Z_c^2 G\,dx} \rightarrow ①$$

Power at 'dx' section

$\boxed{dP = I^2 R\,dx + I^2 Z_c^2 G\,dx} \rightarrow ①$

Power at 'dx' section

$P = VI\cos\phi$ (ϕ = angle b/n V & I)

→ Assume that the reactive power taken by TL and supplied by TL are same upto 'dx' section.

$Q_{net} = 0$

Power factor of transmission line is unity

$\therefore P = VI$ ($\cos\phi = 1$)

$P = (I \cdot Z_c) \cdot I \Rightarrow I^2 Z_c$

differentiate w.r.to 'I'

$$\frac{dP}{dI} = 2 I Z_c$$

P_1 ——— P_2

$P_1 > P_2$

$dP = P_2 - P_1$

$dP = -ve$

$$\boxed{dP = -2 I Z_c \, dI} \rightarrow (2)$$

-ve sign indicates power loss in TL (in the direction)

equate (1) & (2)

$$I^2 R\,dx + I^2 Z_c^2 G\,dx = -2 I Z_c \, dI$$

$$\underbrace{\left(\frac{R + Z_c^2 G}{-2 Z_c}\right)}_{a} dx = \frac{dI}{I}$$

$$-a\,dx = \frac{dI}{I}$$

Integration on both sides

$$-ax + \underset{\text{constant}}{A} = \ln(I)$$

at $x = 0$, $V = V_s$, $I = I_s$

$0 + A = \ln(I_s)$

$A = \ln(I_s)$

$\therefore \ln(I) = -ax + \ln(I_s)$

$\ln(I) - \ln(I_s) = -ax$

$\ln(I/I_s) = -ax$

$\frac{I}{I_s} = e^{-ax} \Rightarrow \boxed{I = I_s \cdot e^{-ax}}$

|||'ly $\boxed{V_o = V_s \cdot e^{-ax}}$

$a = \frac{R + Z_c^2 G}{2Z_c}$ → constant

$G \approx 0$

$a = \frac{R}{2Z_c}$, R → resisiptance /km

Voltage control:-

during over voltage and under voltage conditions

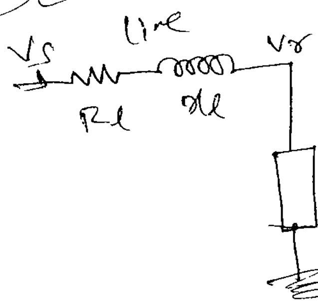
→ "steady state voltage control"

over voltage → due to ferranti effect (no-load, light load, loading Pf loading conditions)

under voltage → due to over load in the system.

More practical case

Disadvantages due to low voltage (or) under voltages



→ ~~I~~

→ If $V_r \downarrow$, current in transmission line is more

→ Ploss $= I^2 R_l$ = Ploss is more

reactive power at source $Q_{source} = Q_{load} + Q_{line}$

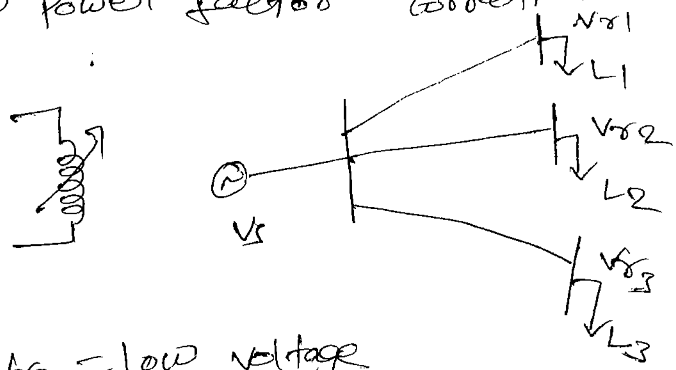
$= (I^2 X_L)$

→ reactive power requirement is more in the system

→ Powerfactor will be reduced.

→ voltage control is also known as reactive power ...

(or) power factor correction.



* by changing the excitation of the generator V_s is changes.

V_{r3} = low voltage

V_{r1}, V_{r2} = with in the limits ($V \pm 5\%$)

voltage control methods:-

i) internal method:-

In this method the excitation of the alternator will be changed in order to control voltage at the specified buses. The remaining buses in the system may — (or) under voltages according to change in excitation.

ii) external method:-

A seperate voltage control device is used.

a) synchronous generator:-

source of Q — over excitation (...) condition

$Q_L = I^2 X_L$
$= I^2 \cdot 2\pi f L$
$Q_L \propto I^2 L$

→ source pf means effect, reactive power ∝ magnetic energy (or) field energy

→ operates at lagging power factor

sink of Q — under excitation condition

→ operates at leading power factor

b) Induction generator:

under excited machine excitation = 0.

sink of Q — operates at leading pf

c) transformer:

Always sink of reactive power.

d) Transmission line:

loading > SIL → sink of Q

loading < SIL → source of Q (reactive power)

loading = SIL → neither sink nor source.

e) Induction motor:

excitation = 0.

sink of 'Q' — operates at lagging pf

f) synchronous motor:

under excitation — sink of 'Q' — pf is lagging

over excitation — source of 'Q' — pf is leading

types of voltage control devices:

i) shunt capacitor
ii) shunt inductor (or) reactor
iii) series capacitor

} static voltage control devices

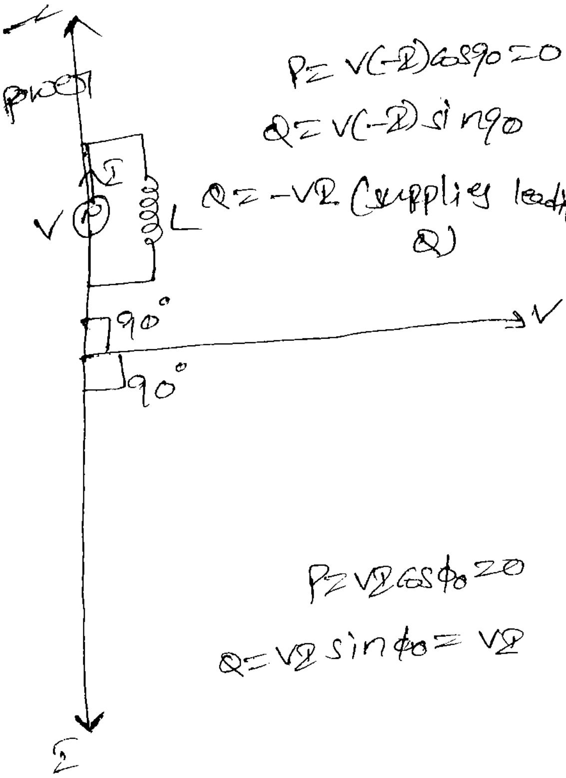
iv) synchronous condenser
v) synchronous coil (or) inductor
vi) synchronous phase modifier (or) advancer

} dynamic voltage control devices.

Inductor:-

→ Inductor is absorbs lagging reactive power

$$\boxed{\begin{array}{l} Q_L \propto I^2 L \\ \quad \propto \text{magnetic energy} \end{array}}$$



$P = V(-I)\cos 90 = 0$

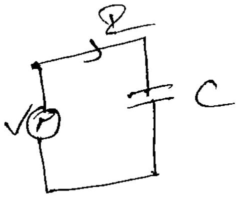
$Q = V(-I)\sin 90$

$Q = -VI$ (supplies leading Q)

$P = VI\cos\phi_0 = 0$

$Q = VI\sin\phi_0 = VI$

capacitor:-



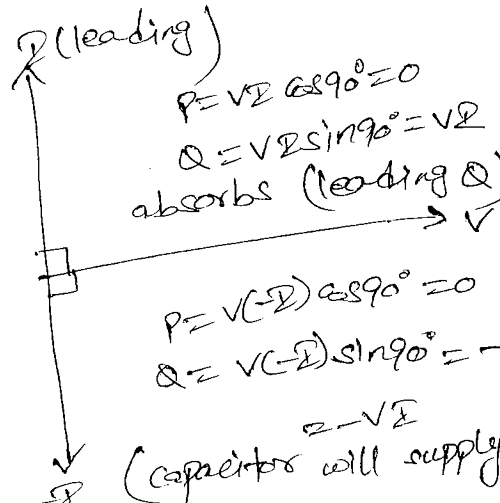
→ capacitor will absorbs the leading reactive power.

$$Qc = \frac{V^2}{x_c} = V^2 \omega c$$

$$Qc \propto V^2 c$$

$\propto$ electrostatic energy

∴ reactive power $\propto$ field energy



$P = VI\cos 90° = 0$

$Q = VI\sin 90° = VI$

absorbs (leading Q)

$P = V(-I)\cos 90° = 0$

$Q = V(-I)\sin 90° = -VI$

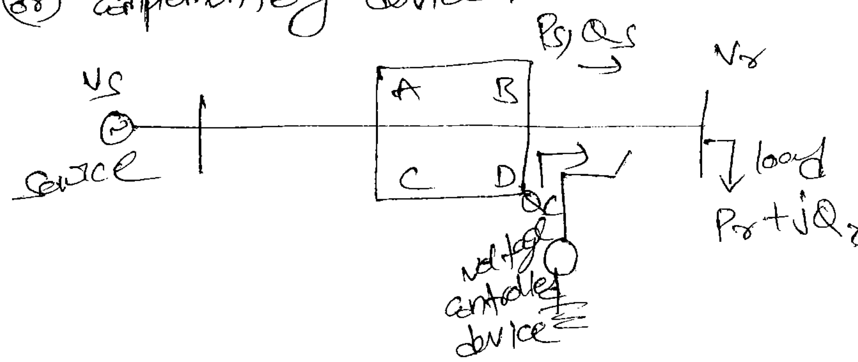
$= -VI$

(capacitor will supply the lagging reactive power)

→ voltage control → purely related to reactive power in system.

→ real power taken by voltage control device is approximately zero.

→ voltage control device is also called as compensating device (or) complementary device.



* reactive power supplied by voltage controlled device is 'Qc'.

→ without compensating device $Q_s = Q_r$

with compensating device $Q_s = Q_r - Q_c$

reactive power supplied by source will be reduced.

no-change in real power supply $\boxed{P_s = P_r}$ → always

MVA supplied by source $S = \sqrt{P_s^2 + Q_s^2}$

with compensating device Q_s is less

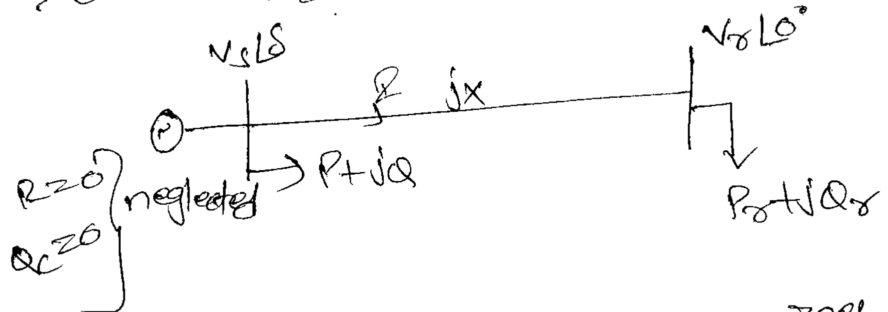
→ MVA supplied by source is less

→ current in TL line reduces

→ voltage drop reduces

→ voltage at terminal will be improve (V_r)

relation b/n reactive power & terminal voltage (V_r) :-



P+jQ is power supplied by sources

$|V_r| \angle 0° = |V_s| \angle \delta - jIX$

change in reactive power (or) voltage is very very less w.r.to changes in δ.

$|V_s| \angle \delta \simeq |V_s|$

$|V_r| = |V_s| - jIX$ —— ①

$V_s I^* = P + jQ$ → complex power supplied by source.

$I^* = \frac{P + jQ}{V_s}$

$I = \frac{P - jQ}{}$

$V_s^* \simeq |V_s|$ (neglecting effect of δ on voltage)

$$I = \frac{P - jQ}{|V_s|} \rightarrow (2)$$

sub (2) in (1)

$$|V_r| = |V_s| - j\left(\frac{P - jQ}{|V_s|}\right) \cdot X$$

$$= |V_s| - \frac{jXP}{|V_s|} - \frac{QX}{|V_s|}$$

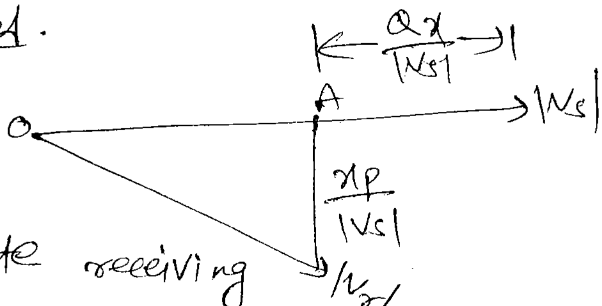
$$\boxed{\tan^{-1}\left[\frac{XP/|V_s|}{|V_s| - XQ/|V_s|}\right]}$$

$|V_s| = 1$ PU, $P = 0.8$ PU, $X = 0.3$ PU, $Q = 0.6$ PU; angle $= 16^\circ$

vector sum is very very less compared to arithmatic sum (or) angle b/n $|V_s|$, $|V_r|$ is neglected.

$$\therefore \boxed{|V_r| = |V_s| - \frac{X}{|V_s|} \cdot Q}$$

→ approximate receiving end voltage



$|V_r|$ is variable w.r.to $|V_s|$, Q, X.

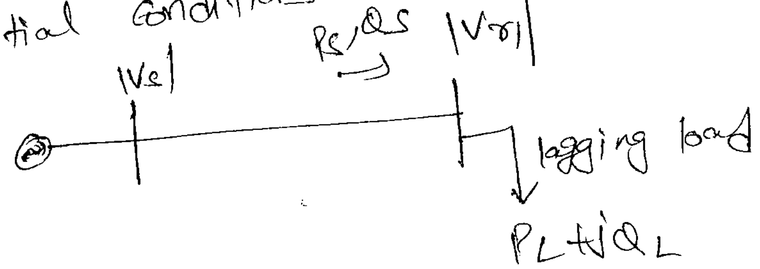
$|V_s|$ → Internal, Q → external, X → external

If $Q \downarrow$, keeping $|V_s|$ = constant → $|V_r| \uparrow$

If $X \downarrow$, $|V_r| \uparrow$ ⇒ series capacitor

shunt capacitor:-

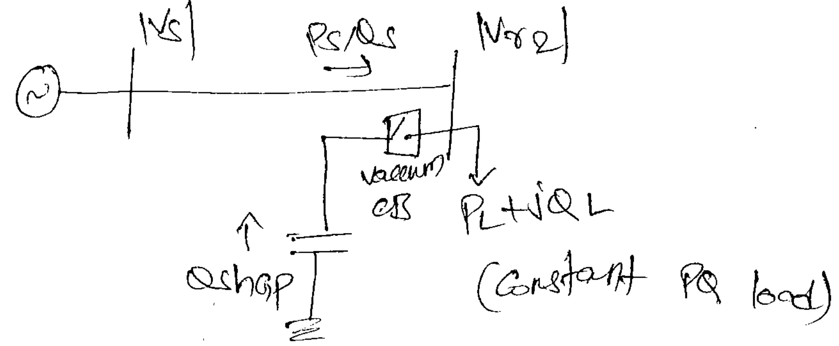
initial conditions



$P_s = P_L$, $Q_s = Q_L$

$$|V_{r1}| = |V_s| - \frac{X}{|V_s|} \cdot Q_s$$

final condition



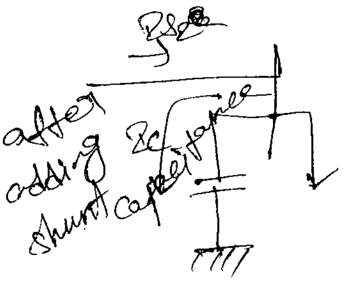
$P_s = P_L + j0$

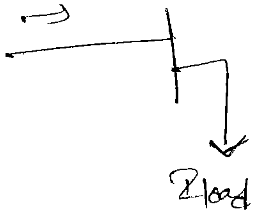
$Q_s = Q_s - Q_{shgp}$

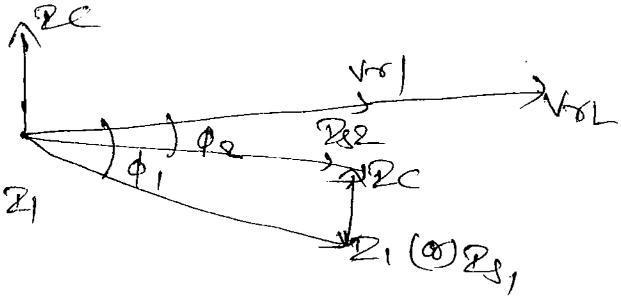
$|V_{r2}| = |V_s| - \frac{x}{|V_s|}(Q_s - Q_{shgp})$

$|V_{r1}| > |V_{r2}|$

$P_{s2} \rightarrow$ (before adding shunt capacitance)







load → lagging with a pf $\cos\phi$

$P_{s2} = Z_1 + Q_C$

$|P_{s2}| < |P_{s1}|$

$|V_{r2}| > |V_{r1}|$

$\phi_1 > \phi_2$ $\boxed{\cos\phi_2 > \cos\phi_1}$

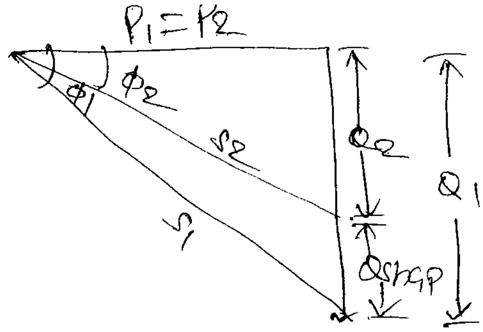
power factor of system will be improved.

→ Power factor correction is more important. so, shunt capacitor is called as power factor correction device.

→ without shunt capacitor P_1, Q_1
→ with shunt capacitor P_2, Q_2
} supplied by source.

$P_2 = P_1$, $Q_2 = Q_1 - Q_{shgp}$

Power triangle



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

$$S_2 = \sqrt{P_2^2 + Q_2^2}$$

$$\tan\phi_1 = \frac{Q_1}{P_1} \Rightarrow Q_1 = P_1 \tan\phi_1$$

$$\tan\phi_2 = \frac{Q_2}{P_2} \Rightarrow Q_2 = P_2 \tan\phi_2$$

$$Q_{shGP} = Q_1 - Q_2$$

$$= P_1 \tan\phi_1 - P_2 \tan\phi_2$$

$$Q_{shGP} = P_1 [\tan\phi_1 - \tan\phi_2] \quad (\because P_1 = P_2)$$

$$Q_{shGP(3-\phi)} = \underbrace{P_{1(3-\phi)}}_{\to 3-\phi \text{ real power}} [\tan\phi_1 - \tan\phi_2]$$

$$Q_{shGP}/Ph = \frac{P_1}{3} [\tan\phi_1 - \tan\phi_2]$$

$V \to$ voltage at capacitor

$X_C \to$ capacitive reactance / phase

$$Q_{shGP}/Ph = \frac{V_{Ph}^2}{X_C/Ph} = V_{Ph}^2 \omega C/Ph$$

$$Q_{shGP(3-\phi)} = \frac{V_L^2}{X_C/Ph} = V_L^2 \omega C/Ph$$

after designing shunt capacitor (value of capacitor in pf is very less)

$$\boxed{Q_{shGP} \propto V^2 f}$$

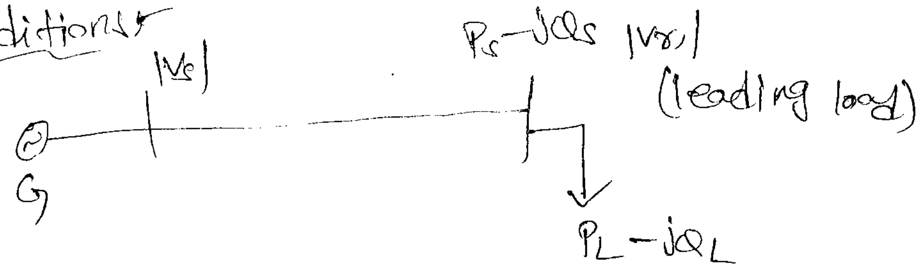
Shunt inductor

voltage will be reduced at recieved places.

→ This will be used during ferranti effect conditions.

→ steady state over voltages

Initial conditions:



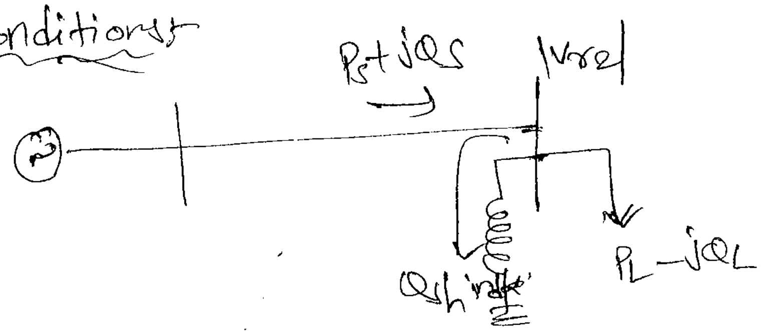
$|V_{r1}| > |V_s|$ $\quad Q_s = Q_L$

$$|V_{r1}| = |V_s| - \frac{X}{|V_s|}(-Q_s)$$

$$= |V_s| + \frac{X}{|V_s|} Q_s$$

after adding shunt inductor.

final conditions:



$Q_s = Q_{sh \cdot ind} - Q_L$

$$|V_{r2}| = |V_s| - \frac{X}{|V_s|} Q_s$$

$$|V_{r2}| = |V_s| - \frac{X}{|V_s|}(Q_{sh \cdot ind} - Q_L)$$

$$|V_{r2}| = |V_s| + \frac{X}{|V_s|}(Q_L - Q_{sh \cdot ind})$$

$|V_{r2}| < |V_{r1}| \rightarrow$ voltage got reduced.

$|V_{r2}| = |V_s| \rightarrow$ is not economical

$\therefore |V_{r2}| > |V_s| \rightarrow$ reducing the overvoltage less.

$\rightarrow$ without shunt inductor P_1, Q_1 $\Big\}$ supplied by source
$\rightarrow$ with shunt inductor P_2, Q_2

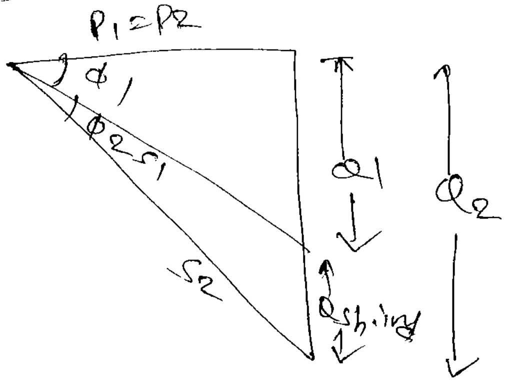
$$P_1 = P_2$$

$Q_1 = Q_L$

$Q_2 = Q_L + Q_{sh.ind}$ } $Q_{sh.ind} = Q_2 - Q_1$

$Q_2 = P_2 \tan\phi_2$ } (from power triangle)

$Q_1 = P_1 \tan\phi_1$



$Q_{sh.ind} = P_2 \tan\phi_2 - P_1 \tan\phi_1$

$Q_{sh.ind} = P_1[\tan\phi_2 - \tan\phi_1]$

* for lagging load

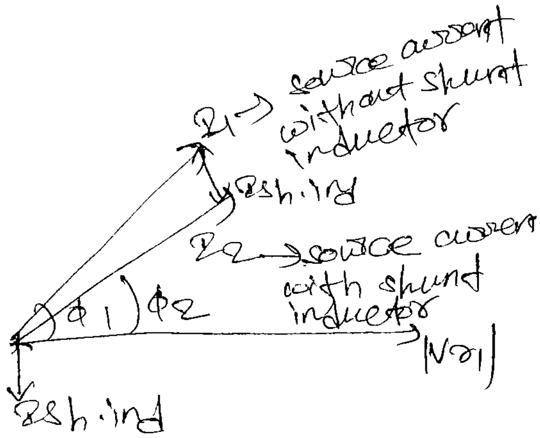
$\phi_2 > \phi_1$

$\boxed{\cos\phi_1 > \cos\phi_2}$ → for lagging load

* for leading load

$\phi_1 > \phi_2$

$\boxed{\cos\phi_2 > \cos\phi_1}$ → for leading load



inductive reactance → X_L

operating voltage → V

$$Q_{sh.ind}/Ph = \frac{V_{Ph}^2}{X_L/Ph} = \frac{V_{Ph}^2}{\omega L/Ph}$$

$$Q_{sh.ind}(3-\phi) = \frac{V_L^2}{X_L/Ph} = \frac{V_L^2}{\omega L/Ph}$$

after designing inductor

$\boxed{Q_{sh.ind} \propto \frac{V^2}{f}}$ → high amount of impedance.

→ The impedance of shunt connected devices will be high and impedance of series connected devices will be low for the voltage control.

4/9/12

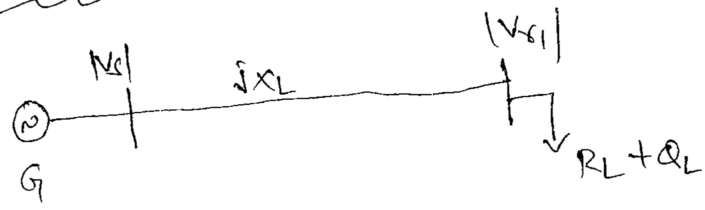
Series capacitor

Effective resistance of the transmission line will be changed (reduced)

(Z of line)↓ ⇒ (Voltage drop)↓ ⇒ Voltage will be improved.

→ series capacitor increases voltage and series reactor reduces voltage in system.

Initial conditions:-



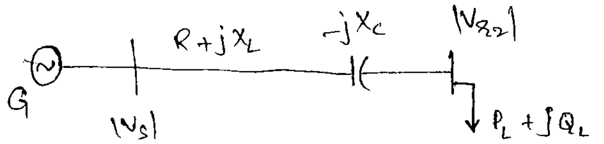
$|V_{r1}| < |V_s|$

$$\underbrace{|V_{r1}| = |V_s|}_{\Delta V_i} - \frac{X_L}{|V_s|} \cdot Q_s$$

Let consider 'R' of the line also, then $Z_L = R_L + jX_L$.

with 'R' of line voltage drop ⇒ $|V_s| - |V_r| = I_1 R \cos\phi_r + I_1 X_L \sin\phi_r$

After compensation



The load impedance Z_{Load} very high than line impedance, So there may not any change in current due to 'X_c'.

$Z_{Load} >> Z_{Line}$, So the current value will not change with respect to changes in transmission line 'Z'

$$\underbrace{|V_s| - |V_{r2}|}_{\Delta V_2} = I_1 R \cos\phi_r + I_1 (X_L - X_c) \sin\phi_r$$

voltage improve after adding series,

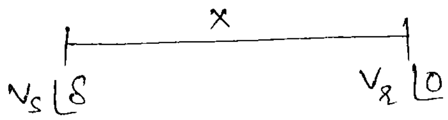
$$\boxed{\Delta V_c = \Delta V_1 - \Delta V_2 = I_1 X_c \sin\phi_R}$$

Reactive power supplied by series capacitor,

$$\boxed{Q_{series\ 'c'} = I^2 X_c = \frac{I_1^2}{\omega C}}$$

$$\boxed{Q_{s.c} \propto \frac{I^2}{f}}$$

* with respect to load changes series capacitor reactive power is more effected compared to shunt capacitor and shunt inductor



⇒ Power transfer in transmission line is $\frac{V_s \cdot V_R}{X} \sin\delta$

$P_{max1} = \frac{V_s \cdot V_R}{X_L}$ (without X_c)

$X_c \rightarrow$ Series Capacitor Reactance

$P_{max2} = \frac{V_s \cdot V_R}{X_L - X_c}$ (with X_c)

$P_{max2} > P_{max1}$

we have 3 - Stabilities.

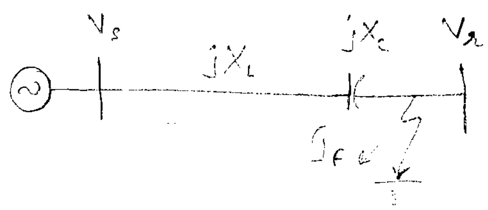
1) Power Angle Stability
2) Voltage Stability
3) Frequency stability

⇒ After adding series capacitor 'δ' will be reduced and stability of the system will be increased.

⇒ Power angle stability is more important than voltage stability.

⇒ So series capacitor is treated as "Stability improvement device."

* Fault current Analysis:—



$|I_{F1}| = \frac{|V_s|}{X_L}$ (without X_c)

$|I_{F2}| = \frac{|V_s|}{(X_L - X_c)}$ (with X_c)

$|I_{F2}| > |I_{F1}|$

Due to Series Capacitor fault level (MVA Capacity of S.C)

is increases.

→ Due to Voltage across Capacitor

$$V_{C1} = -j I X_c \sin\phi_r \text{ (without fault)}$$

rise in voltage.

$$V_{C2} = -j I_F X_c \sin\phi_r \text{ (with fault)}$$

$\Delta V_c = I_F X_L$ (I_F is very high

$(\because \Delta V_c = I_F X_c \cancel{\sin\phi_r}^{1} \Rightarrow (\sin 90°)$

the $\phi_r = 90°$

since $R = 0$

$\tan\phi_r = \frac{X}{R} \Rightarrow$

$\phi_r = 90$

$I_f \uparrow \Rightarrow \Delta V_c \uparrow$

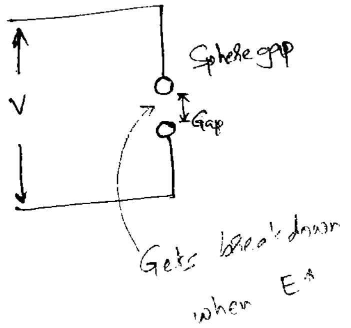
Series capacitor is designed for low voltage, high current rating.

Then during fault condition due to high ΔV_c the capacitor gets damaged (Due to low voltage rating).

→ C.B is only for current protection.

→ Surge Arresters used for voltage protection.

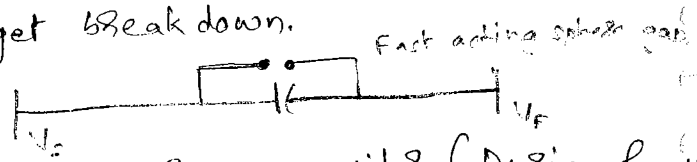
→ The series capacitor is protected from over voltages. by fast acting Spark acting gap or Sphere gap will be used.



Works on Electric field intensity principle

(On the surface of sphere)

If electric field intensity ↑, the gap will get break down.

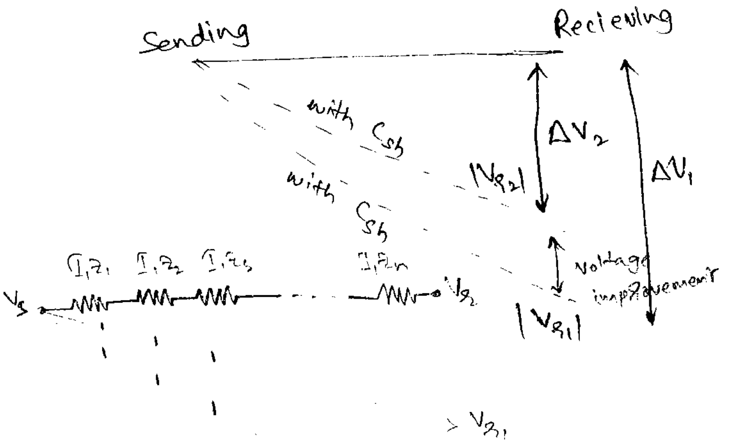


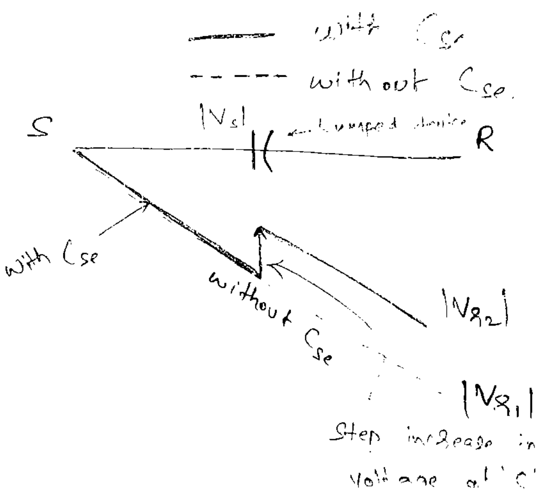
Sphere gap is connected across the series capacitor (During fault it bypass the capacitor).

Sphere Gap → Hallow sphere, Large size

* Differences between Shunt and Series Capacitor.

Shunt Capacitor	Series Capacitor
1. Current in t/m line is reduced	1. Impedence of T/m line is reduced
2. Voltage improvement is uniform	2. Voltage improvement is not uniform



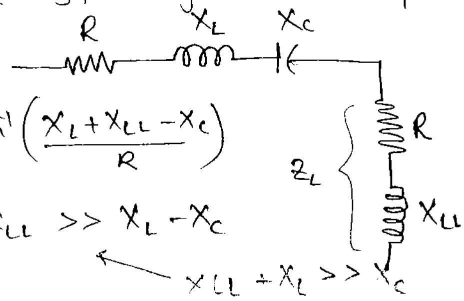


3. $P_{max}\uparrow = \frac{V_s V_R \updownarrow}{X}$ → This increase in P_{max} is not in appreciable value. Therefore stability improvement is very less

3. $P_{max}\uparrow = \left(\frac{V_s \cdot V_R}{X\downarrow}\right)\uparrow$. There is appreciable increase in P_{max}. Therefore stability will be improved

4. Power factor of system will be improved.

4.



$\phi = \tan^{-1}\left(\frac{X_L + X_{LL} - X_c}{R}\right)$

But $X_{LL} >> X_L - X_c$

$X_{LL} + X_L >> X_c$

So there is not appreciable change in ϕ

There is not improvement in the P.F of the system because

$X_c << X_L + X_{LL}$

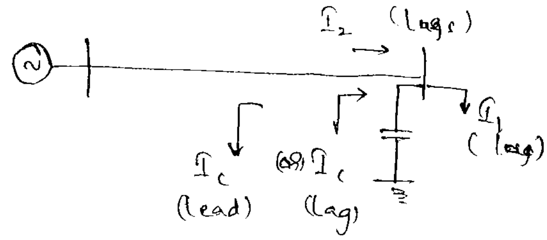
5. There is no increment in fault level.

5. Fault level will be increased.

* For same voltage improvement

Before shunt capacitance, $I_2 = I_1$

voltage drop $\Delta V_1 = I_1 X$



After adding shunt capacitor $I_2 = I_1 - I_c$

$$\Delta V_2 = (I_1 - I_c)\, X$$

Voltage improved by $C_{sh} \Rightarrow \Delta V_c = \Delta V_1 - \Delta V_2$

$$\Delta V_c = I_c X$$

$$Q_{sh} = \frac{V^2}{X_c} = V \cdot \frac{V}{X_c} \Rightarrow V \cdot I_c \Rightarrow I_c = \frac{Q_{sh}}{V}$$

$$\boxed{\therefore \Delta V_c = I_c X = \frac{Q_{sh}}{V} \cdot X} \rightarrow (1)$$

Voltage Improvement with respect to C_{sh}

For series capacitor voltage improvement

$$\Delta V_c = I X_c \cdot \sin\phi_r = \frac{I^2 X_c \sin\phi_r}{I} \Rightarrow -jI^2 X_c$$

(delivering Q to system) ($\because -jX_c$)

$$\boxed{\Delta V_c = \frac{Q_{se} \sin\phi_r}{I}} \rightarrow (2)$$

For same voltage improvement eq (1) = eq (2).

$$\frac{Q_{sh}}{V} \cdot X = \frac{Q_{se}}{I} \cdot \sin\phi_r$$

$$\frac{Q_{se.cap}}{Q_{sh.cap}} = \frac{IX}{V}\left(\frac{1}{\sin\phi_r}\right) \Rightarrow \frac{IX}{V}\left(\frac{1}{\sin\phi_r}\right)$$

$$\frac{Q_{se.cap}}{Q_{sh.cap}} = \frac{IX/V}{\sin\phi_r} \simeq \text{P.U } V_{reg}.$$

Typical P.F = 0.8

$\cos\phi_r = 0.8$

$\Rightarrow \sin\phi_r = 0.6$

$$\frac{Q_{se.cap}}{Q_{sh.cap}} = \frac{0.2}{0.6} = \frac{1}{3}$$

Typical value of V_{reg} is 10 to 20% of T/M line.

$$\boxed{Q_{se.cap} < Q_{sh.cap}}$$

$Q_{sh\,cap} > Q_{se\,cap} \Rightarrow Q_{sh\,cap}$ capacity of C_{sh}

$\therefore$ Cost of C_{sh} is more.

$$\boxed{\frac{Q_{se\,cap}}{Q_{sh\,cap}} < 1}$$

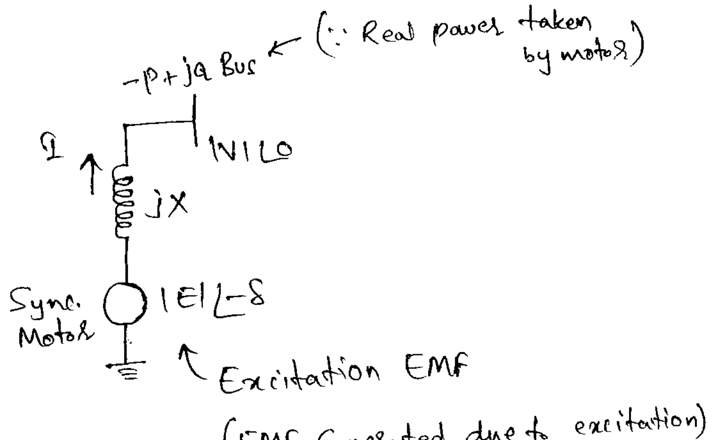
* For the same voltage improvement the rating of C_{se} is less than C_{sh}. ∴ Cost of C_{sh} is more.

→ Due to series capacitor there is a sub synchronous resonance in power system, the shaft of Alternator will get broken during sub synchronous resonance (Shaft fatigue).

* Synchronous Condencer:—

These voltage control devices are synchronous Motor with variable excitation.

* Synchronous Condencer/capacitor → Dynamic Capacitor.
* Synchronous coil / Inductor → Dynamic Inductor.
* No load, underexcited synchronous motor → Synchronous Coil.
* No load, Overexcited synchronous motor → Synchronous Condenser



Complex power at bus,

$$S = VI^*$$

$$I = \frac{|E|\angle -\delta - |V|\angle 0^\circ}{jX}$$

$$\Rightarrow I = \frac{|E|\angle -\delta - |V|\angle 0}{X\angle 90^\circ}$$

$$S = |V|\angle 0\left[\frac{|E|}{X}\angle -\delta-90^\circ - \frac{|V|}{X}\angle -90^\circ\right]^*$$

$$= |V|\angle 0\left[\frac{|E|}{X}\angle 90+\delta - \frac{|V|}{X}\angle 90\right]$$

$$= \frac{|E||V|}{X}\angle \delta+90 - \frac{|V|^2}{X}\angle 90$$

$$P = \frac{|E||V|}{X} \angle \delta + 90^\circ - \frac{|V|^2}{X} \angle 90^\circ$$

$$P = \frac{|E||V|}{X} \cos(\delta + 90^\circ) - \frac{|V|^2}{X} \cancel{\cos 90^\circ} \rightarrow 0$$

$$P = \frac{-|E||V|}{X} \cdot \sin\delta$$ (Taken by bus, i.e., Supplied by motor

$-P \rightarrow$ Taken by motor supplied by bus

$$Q = \frac{|E||V|}{X} \sin(\delta + 90) - \frac{|V|^2}{X} \cancel{\sin 90^\circ} \rightarrow 1$$

$$Q = \frac{|E||V|}{X} \cos\delta - \frac{|V|^2}{X}$$ (supplied by Motor)

No load $\delta = 0$ $\leftarrow$ ($\because$ No load $P = 0 \Rightarrow \frac{EV}{X} \cancel{\sin\delta} \rightarrow \delta = 0$

$\Rightarrow \delta = 0$

Reactive power supplied by Sync. Motor under no-load conditions.

$$Q = \frac{|E||V|}{X} \cdot \cos(0) - \frac{V^2}{X} \Rightarrow \frac{|E||V|}{X} - \frac{|V^2|}{X}$$

$$Q = \frac{|V|}{X}\left[|E| - |V|\right]$$

$P = 0$ (Under Ideal Case)

* During $|E| > |V|$ over excitation $\Rightarrow$ Sync. Condensor.

$$Q = \frac{|V|}{X}\left[|E| - |V|\right] \Rightarrow +ve$$ $\Rightarrow$ Supplying reactive power

$\Rightarrow$ Synchronous ~~Supplying~~ Condensor.

→ voltage will be increases,

P.F of system will be improved.

* During $|E| < |V|$ under excitation $\Rightarrow$ Synchronous. coil.

$$Q = \frac{|V|}{X}\left[|E| - |V|\right] \Rightarrow -ve$$ $\Rightarrow$ Absorbing reactive power.

→ voltage at the terminal will be reduced where the Sync. Motor connected.

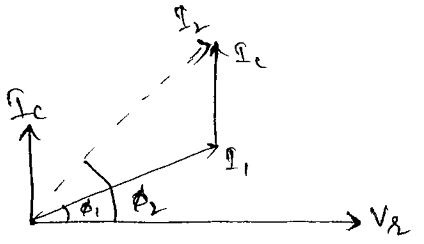
→ P.F of system will be Improved (or) Increased for leading

Mag of P.F

* Synchronous Capacitor or Synchronous Condensor:—

Leading loads → P.F reduces
Lagging Loads → P.F increases

} System P.F Magnitude



Leading

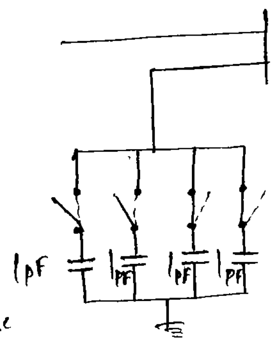
$\phi_2 > \phi_1$

$\cos\phi_2 < \cos\phi_1 \Rightarrow$ P.F reduces

* Differences between Shunt Capacitor and Synchronous Condenser.

Shunt Capacitor.

1)



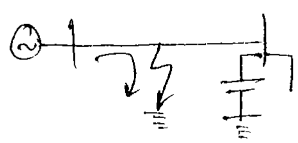
Voltage increment is in step nature (i.e, 200kV, 210 kV, 220kV etc...)

Each cap can increase 10KV

2. No stability problem for shunt capacitor

3. Di-electric loss in shunt capacitor is very low
(Real power) $P_{input} = 0$

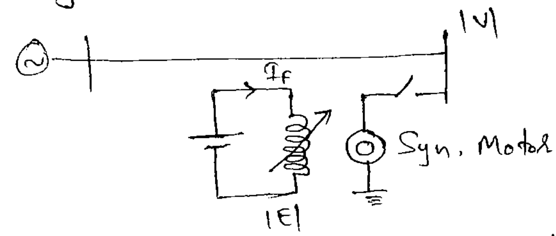
4. There is not increment in fault level after adding C_{sh}



5. No concept of Self starting.

Synchronous Condenser

1.



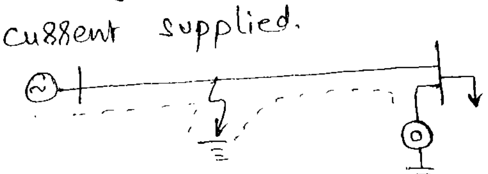
Voltage improvement (or) Control is smoth in Sync. Condensor.

2. There is a stability problem in synchronous motor presence.

3. Due to no-load power in Sync. Motor input power is not zer

$P_{input} \neq 0$

4. With sync. motor for some time fault current supplied.

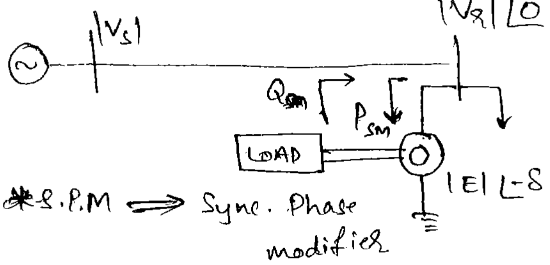


Due to K.E stored in the rotor some fault will be circulated from Sync. Motor to fault point. The K.E will be reduced wi respect to time. After some time the K.E in the rotor will become zero & there is no fault current suppli by Sync.motor. Fault current or level increases.

5. Sync. Motor is not self starting Motor.

* Synchronous phase modifier (or) phase advancer :—

It is a sync. motor operating with over excitation at loaded condition



*S.P.M ⟹ Sync. Phase modifier (S.P.M)

→ Real power taken by S.P.M

$$P = \frac{|E|\,|V_R|}{X} \cdot \sin\delta$$

→ Reactive power supplied by S.P.M

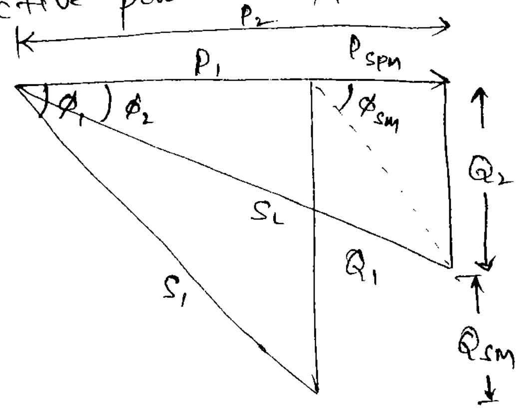
$$Q = \frac{|V_R|}{X}\left[|E|\cos\delta - |V_R|\right] \Rightarrow +ve \text{ when } |E|\cos\delta > |V_R| \quad \& \ \delta \neq 0 \ (\because \text{loaded})$$

→ S.P.M will supply reactive power if $|E|\cos\delta > |V_R|$

→ The excitation required for Sync. Phase Modifier is more compared to Sync. Condenser for same voltage improvement (both the m/c's are identical) [Due to factor $\cos\delta$ which is less than 1].

→ without SPM source supplying P_1, Q_1 $P_1 = P_L$, $Q_1 = Q_L$ with sync. phase modifier real power supplied by source is $P_2 = P_1 + P_{sm}$, P_{sm} → Real power taken by SPM. Reactive power supplied by source is $Q_2 = Q_L - Q_{sm}$, Q_{sm} → Reactive power supplied by SPM.

→ Reactive power supplied by SPM.



$Q_{sm} = Q_1 - Q_2$

$\phi_2 < \phi_1$

$\cos\phi_2 > \cos\phi_1$

⇒ P.F. improved.

→ P.F of S.P.M

$$\phi_{sm} = \tan^{-1}\left(\frac{Q_{sm}}{P_{sm}}\right)$$

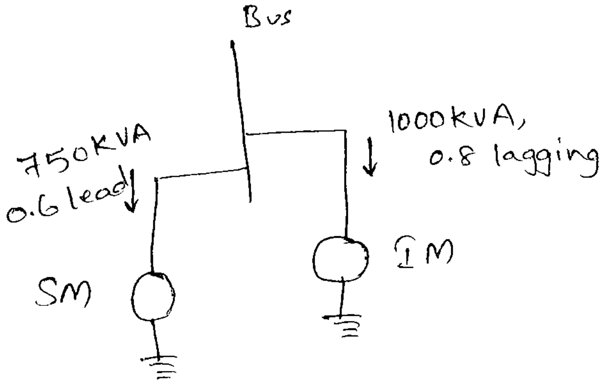
P.F of S.P.M $= \cos\phi_{sm}$

→ $Q_1 = P_1\tan\phi_1$, $Q_2 = P_2\tan\phi_2$

$$\boxed{Q_{sm} = Q_1 - Q_2 = P_1\tan\phi_1 - P_2\tan\phi_2}$$

$P_2 > P_1$

5/9 ✱ A 3-φ IM taking [illegible] lagging, A sync. M/C is connected in parallel to IM which will take an additional 750 KVA power at 0.6 leading. What is the p.f of the total load supplied by mains.



For Induction Motor

$P_{IM} = S \cdot \cos\phi$

$= 1000 \times 0.8$ KW

$= 800$ KW

$Q_{IM} = S \cdot \sin\phi$

$= 1000 \times 0.6$

$= 600$ KVAR (lagging)

For Synchronous Motor

$P_{SM} = S \cdot \cos\phi$

$= 750 \times 0.6$

$= 450$ KW

$Q_{SM} = S \cdot \sin\phi$

$= 750 \times 0.8$

$= 600$ KVAR (leading)

Net reactive power supplied by source

$Q_{Net} = Q_{IM} - Q_{SM}$

$= 600 - 600$

$= 0$ KVAR

$P_{Net} = P_{IM} + P_{SM}$

$= 800 + 450$

$= 1250$ KW

Resultant power factor

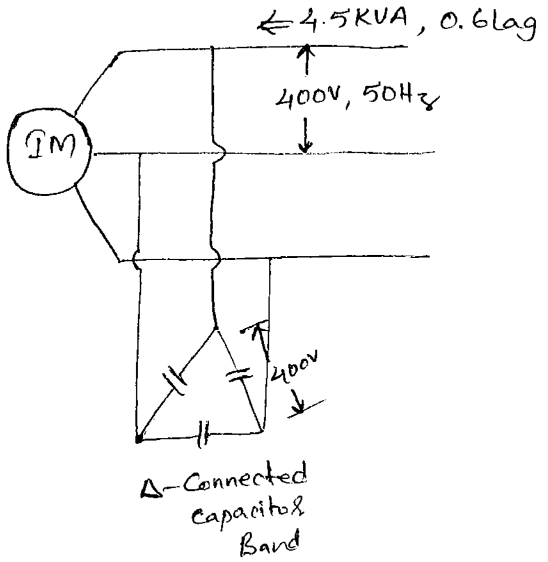
$$\cos\phi = \frac{P_{net}}{\sqrt{P_{net}^2 + Q_{net}^2}}$$

$$= \frac{1250}{\sqrt{(1250)^2 + 0}}$$

$= 1.$

$\boxed{\cos\phi = 1}$

*. A 3-ϕ Induction Motor is rated for 400V, 50Hz connected to a pump which is running at a p.f of 0.6 and the input to the motor is 4.5KVA. To improve the p.f by a value 0.8 lagging what should be the rating of Δ-connected capacitor band and capacitance per phase.



Sol:-

$\cos\phi_1 = 0.6$ lag

$\cos\phi_2 = 0.8$ lag

Real power taken by IM,

$P_1 = S \times \cos\phi = 4.5 \times 0.6$

$= 2.7$ KW

After adding C-Band,

$P_2 = P_1 = 2.7$ KW

$Q_{sh.\,cap\,(3\text{-}\phi)} = P_1(\tan\phi_1 - \tan\phi_2)$

$= 2.7\left(\frac{0.8}{0.6} - \frac{0.6}{0.8}\right)$

$= 1.56$ KVAR

$Q_{sh.\,cap}(3\text{-}\phi) = 3 \times \frac{V_{ph}^2}{X_c/ph}$

$V_{ph} \rightarrow$ Phase voltage of capacitor bank

$1.56 \times 10^3 = 3 \times \frac{400^2}{X_c/ph}$

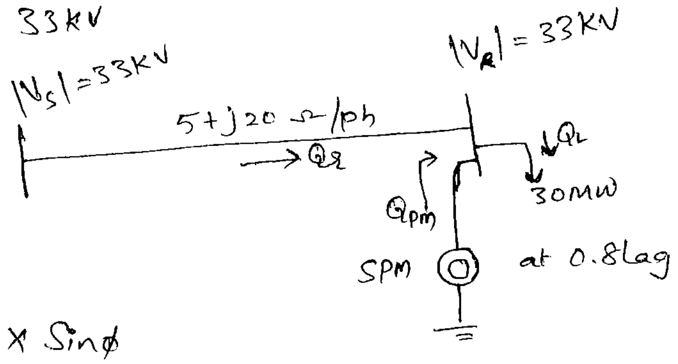
$\Rightarrow X_c/ph = \frac{3 \times 400^2}{1.56 \times 10^3} = 307.6\,\Omega$

$\frac{1}{\omega C/ph} = 307.6$

$C/ph = \frac{1}{2\pi \times 50 \times 307.6}$

$= 10.4\,\mu F$

* A 3-ϕ line having an impedance of $(5+j20)\,\Omega/ph$ delivers a load of 30MW at 0.8 PF lagging, 33-KV. Determine the capacity of phase modifier required to be installed at the recieving end. At the voltage at sending end maintained at 33KV



SPM- Synchronous Phase Modifier

Load Reactive Power Q_L = Apparant Power × $\sin\phi$

$$= \frac{30M}{0.8} \times 0.6$$

$$= 22.5\,MVAR$$

$$Q_R + Q_{PM} = Q_L$$

$$Q_{PM} = Q_L - Q_R$$

Recieving end reactive power

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

ABCD parameters of that line

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 5+j20 \\ 0 & 1 \end{bmatrix} \quad \left[\because \begin{bmatrix} 1 & z \\ 0 & 1 \end{bmatrix}\right]$$

$$= \begin{bmatrix} 1 & 20.6\angle 75.9 \\ 0 & 1 \end{bmatrix}$$

Recieving end real power

$P_R = 30MW$

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

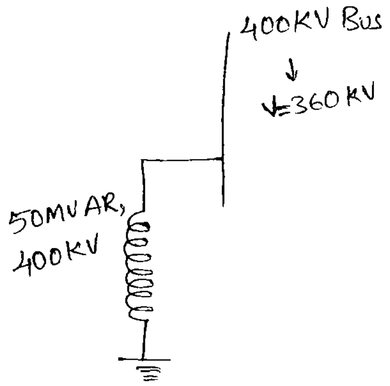
$$30MW = \frac{33K \cdot 33K}{20.6} \cos(\beta-\delta) - \frac{1}{20.6} (33K)^2 \cos(75.9$$

$\beta - \delta =$

$Q_R =$

$Q_{PM} = Q_L - Q_R$

* In a 400KV Network 360KV is recorded at a Bus. A shunt reactor of 50MVAR, 400KV is connected to the bus. What is the reactive power absorbed by shunt reactor?



$$Q_{sh.\,Inductor} \propto V^2$$

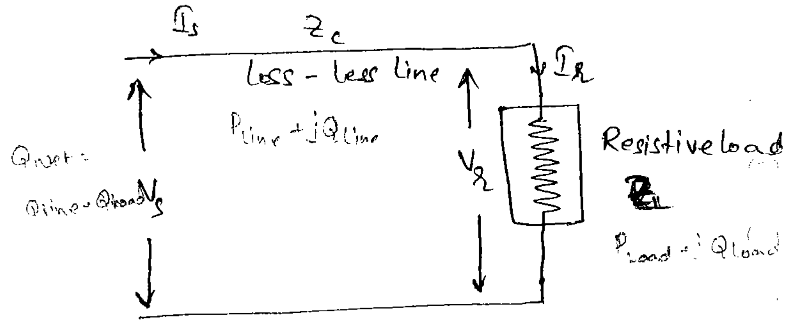
$$\frac{Q_{sh.\,Ind2}}{Q_{sh.\,Ind1}} = \frac{V_2^2}{V_1^2}$$

$$\underset{(360KV)}{Q_{sh.\,Ind2}} = \underset{(400KV)}{Q_{sh.\,Ind}} \times \frac{(360)^2}{(400)^2}$$

$$= 50 \times \left(\frac{360}{400}\right)^2 \text{ MVAR}$$

$$= 40.5 \text{ MVAR.}$$

* Surge Impedance Loading:-



If load (Impedance) on transmission line is equals to surge impedance of T.L then the line at Surge Impedance Loading condition

SIL → Natural Loading (or) Characteristic Impedance Loading (or) Ideal loading.

at SIL condition → $Z_L = Z_c$

Variable ← Loading = Surge Impedence Loading (SIL) → constant

$$SIL = \frac{V_s \cdot V_R}{Z_c}$$

$$Loading = \frac{V_R^2}{Z_L}$$

1. At Loading = SIL :—

$$\frac{V_s \cdot V_R}{Z_c} = \frac{V_R^2}{Z_L}$$

$$Z_L = Z_c \Rightarrow |V_s| = |V_R|$$

$$\Rightarrow |I_s| = |I_R|$$

This is the flat voltage profile

There is no reflections at the end of line

i.e., Infinite line (or) flat line (or) Matched line.

Net reactive power supplied by a source,

$$\boxed{Q_{Net} = Q_{Line} + Q_{load}}$$

$Q_{load} = 0$ ($\because$ load is pure resistive)

$$Q_{Net} = Q_{Line}$$

$$= Q_L - Q_c$$

$$= \frac{1}{2} L I^2 - \frac{1}{2} C V^2$$

During this condition, (Loading = SIL)

$$\frac{1}{2} L I^2 = \frac{1}{2} C V^2$$

$\boxed{Q_{Net} = 0}$ Power factor of load and source is Unity.

2. If loading < SIL :-

$$Z_L > Z_c$$

$$SIL = \frac{V_S \cdot V_R}{Z_c}$$

$$\text{loading} = \frac{V_R^2}{Z_L}$$

Current will be reduced

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

$\frac{1}{2} C V^2 \rightarrow$ More

$$\frac{1}{2} L I^2 < \frac{1}{2} C V^2$$

$$Q_{net} = \frac{1}{2} L I^2 - \frac{1}{2} C V^2$$

$$= -ve.$$

powerfactor of source is leading.

But load P.F is unity.

$$|V_R| > |V_S|$$

(due to the Ferranti effect)

Voltage regulation is -ve.

3. If loading > SIL :-

$$Z_L < Z_c$$

Current in Transmission Line is more

$$\frac{1}{2} L I^2 > \frac{1}{2} C V^2$$

$$Q_{net} = \frac{1}{2} L I^2 - \frac{1}{2} C V^2$$

$$= +ve$$

powerfactor of source is lagging

But P.F of the load is unity.

$$|V_R| < |V_S|$$

Voltage regulation is +ve.

Conclusions :-

Loading = SIL → Good with respect to Electrical parameters, not economical, Impractical.

Loading < SIL → Practical, Economical for Underground Cable (Z_c is low).

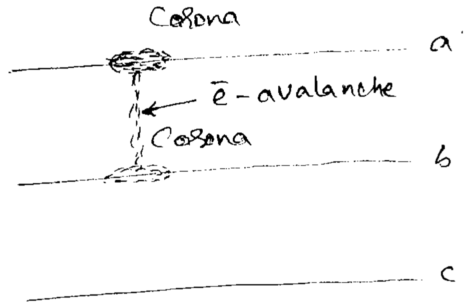
loading > SIL → Practical and Economical for Over Head lines.

* Concept of Corona:-

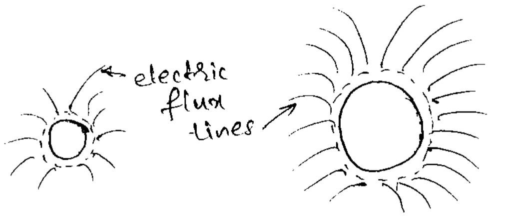
If electric field intensity on surface of conductor is more compared to di-electric strength of air then there is an Ionisation on surface of conductor is called as Corona in OH-T.Lines.

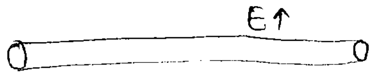
Corona will be limited to only surface of conductor

Corona → Breakdown of air.



If the corona is ~~sirious~~ Severe between the two conductors then there is a formation of ē-avalanche between the conductors. which will lead to L-L fault





Initiating ē - for breakdown of air will be provided by radio activity (or) Cosmic Rays

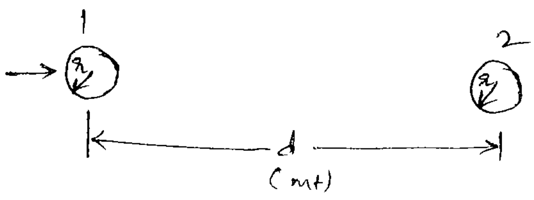
* Methods to observe Corona in Transmission line:

1. Releasing of Ozone Gas from the conductor
2. Hissing noise produced by conductor.
3. White Bluish Glow on surface of conductor.

For 1-ϕ, 2-wire System:-

d - Distance between two lines in Mts

V - Applied Voltage (or) Excitation Voltage.



'E' on Surface of the conductor.

$$E = \frac{V}{r \cdot \ln(d/r)}$$

* if $E >$ Di-electric Strength of Air ($30\,kV/cm$ peak) then Ionisation (or) Corona will happen.

* If $V_{operating} > V_d$ then corona will happen.

V_d ↓ Critical Disruptive Voltage

Critical Disruptive Voltage is the operating voltage of conductor above which the corona will happen.

$$g = \frac{V_d}{r \cdot \ln(d/r)} \quad kV/cm$$

Critical Disruptive voltage $(V_d) = g \cdot r \cdot \ln(d/r)$

where g = Di-electric strength of air

$= 30\,kV/cm$ (peak)

$= 21.1\,kV/cm$ (rms)

g - depends on atmospheric conditions

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

where δ = air density factor

which is a function of pressure & Temp.

$$\delta = \frac{3.92h}{273+t}$$

h - is the pressure in terms of 'cm of Hg'

t - Temp. in terms of '°C'

at NTP, $h = 76\,cm$, $t = 25°C$.

$V_d = g \cdot r \cdot \ln(d/r)$ → at NTP [Normal Temperature and Pressure].

$V_d = g \cdot \delta \cdot r \cdot \ln(d/r)$ → at any temperature and pressure.

If the conductor surface is not uniform, then corona will happen for less amount of Disruptive voltages.

$V_d = g \cdot \delta \cdot m \cdot r \cdot \ln(d/r)$ → for any conductor for any temp & pressure (t & h).

m → Surface irregularity conductor.

$m = 1$ for solid and hollow conductors.

$m = 0.93 - 0.97$ for stranded conductors.

(Valid for more than 7-strands in conductor).

As no. of layers increases in stranded conductor, the m-value will be increases.

For 7-strand conductor $m = 0.83 - 0.87$.

For 3-ϕ system,

$V_d = g \cdot \delta \cdot m \cdot r \cdot \ln\left(\frac{GMD}{r}\right)$ → Single conductor system

$V_d = g \cdot \delta \cdot m \cdot (\text{self GMD}) \cdot \ln\left(\frac{GMD}{\text{Self GMD}}\right)$ → Sub conductor system.

$\text{Self GMD} = \sqrt{r_1 \times S}$ → Two subconductor system.

Visual distouptive voltage (V_v):-

if $V_{ph} > V_v$ then visual corona will happen on surface of conductor. Always $V_v > V_d$ (critical distouptive voltage)

$$V_v = g \cdot \delta \cdot r \cdot m \cdot K \cdot \ln(d/r)$$

↳ factor of multiplication ($K > 1$)

$$K = 1 + \frac{0.3}{\sqrt{r\delta}}$$

$$V_v = g \cdot \delta \cdot m \left(1 + \frac{0.3}{\sqrt{r\delta}}\right) r \ln(d/r) \rightarrow 1-\phi, 2\text{-wire system}$$

Formula for corona loss:-

$$\boxed{P_{loss} = (241 \times 10^{-5}) \left(\frac{f+25}{\delta}\right) \sqrt{\frac{r}{d}} \, (V_{ph} - V_d)^2}$$ for frequency supply.

units = kW/Phase/km

→ $f = 50\,Hz$, $h = 71\,cm$ of Hg, $t = 25°C$, $r = 1\,cm$, $d = 1.5\,m$, $V_{ph} = 100\,kV$, $V_d = 110\,kV$, find corona loss.

if $\boxed{V_{ph} < V_d}$ ($100 < 110\,kV$) ⇒ corona loss (or) $P_{loss} = 0$

if $V_{ph} > V_d$ ⇒ $P_{loss} \neq 0$

factors effecting corona:-

1) electrical factors
2) Atmospheric conditions
3) factors related to conductor

1) electrical factors:-

1) supply frequency:- As $f \uparrow$, $P_{loss} \uparrow$

$$\boxed{P_{loss} \propto (f + 25)}$$

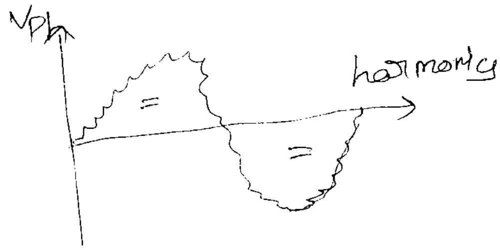
→ At $f = 50$ Hz, $P_{loss} = 1.2$ kW / phase / km, at $f = 60$ Hz, $P_{loss} = ?$

$$P_{loss}(60\text{ Hz}) = P_{loss}(50\text{ Hz}) \times \frac{60+25}{50+25}$$

$$= 1.2 \times \frac{85}{75} \Rightarrow 1.36 \text{ kW/ph/km}$$

corona loss $\neq 0$ in HVDC conductor. But corona loss in HVDC lines is less compared to P_{loss} in HVAC lines.

ii) nature of supply waveform:



1 3 5 7 9 - - -

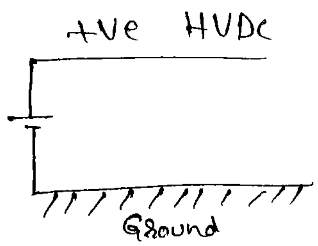
odd harmonics → fundamental

3rd harmonic is dominant

$P_{Loss} \propto (f + 3f + 25)$ as harmonic component is more in the 'V_{ph}', Corona loss ↑

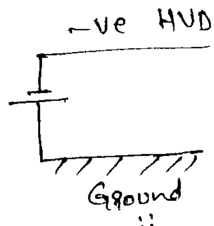
iii) Polarity of supply to Conductor:-

It is with respect to HVDC conductor



(i)

Availability of free electrons is more



ii)

availability of free electrons is less.

(i) → Mobility of $\bar{e}$

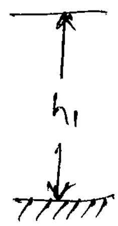
$$P_{Loss}\begin{pmatrix}-\text{ve HVDC} \\ \text{conductor}\end{pmatrix} < P_{Loss}\begin{pmatrix}+\text{ve HVDC} \\ \text{conductor}\end{pmatrix}$$

⇒ In monopolar system always -ve HVDC conductor is preferable.

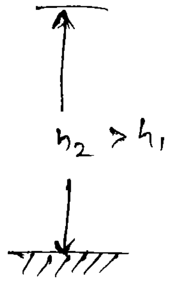
⇒ In homo polar system, both the conductors will be operated with -ve supply.

iv) Height of Conductor :-

$V_d \propto \ln\left(\frac{h}{r}\right)$,



(i) Good voltage profile



(ii) Voltage profile is not good.

as $h \uparrow$, $V_d \uparrow$

$P_{loss} \downarrow \propto (V_{ph} - V_d \uparrow)^2 \downarrow$

height of conductor increases, tower height increases

$\Rightarrow$ Cost $\uparrow$, The 'l' is more and the 'c' is less in case-ii,

$\Rightarrow$ the $l \downarrow$, $c \uparrow$ in case-i,

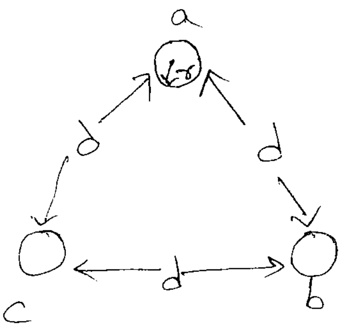
v) Distance between conductors :-

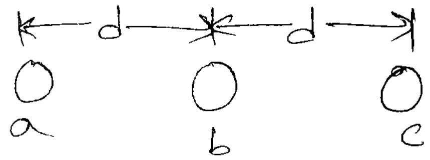
as $d \uparrow$, $V_d \propto \ln\left(\frac{d}{r}\right)$

$\Rightarrow d \uparrow, V_d \uparrow$

as $V_d \uparrow$, $P_{loss} \downarrow$ $\quad P_{loss} \propto (V_{ph} - V_d)^2$

vi) Configuration of conductors :-





$V_d \downarrow P_{loss} \uparrow$

GMDs are equal to V_d is same for each conductor.

GMD's are different V_d is difficults for conductors

→ Middle conductor in horizontal spacing will have more corona loss compared to conductors with in the system.

→ The total corona loss in unsymmetrical configuration is less compared to total corona loss in equivalent symmetrical configuration.

2) Atmospheric factors:-

i) Temperature and pressure:-

As $t\uparrow$, $\delta = \dfrac{3.92\,h}{t+273} = \delta\downarrow$

$V_d \downarrow \propto \delta \downarrow$

$\uparrow P_{loss} \propto (V_{ph} - V_d\downarrow)^2 \uparrow$

As $h\downarrow, \delta\downarrow, V_d \downarrow \propto \delta \downarrow$

$= P_{loss}\uparrow$

t, h	$t\downarrow, h\downarrow$
P_{loss} is less	P_{loss} is more
sea level	hilly area (or) above sea level

all density factor, $\delta = \dfrac{3.92\,h\downarrow}{\downarrow t+273}$

decrement in 'h' is more compared to decrement is $(t+273)$

$\delta\downarrow, V_d\downarrow, P_{loss}\uparrow$

ii) Deposition of foreign particles on surface of conductor:-

Dust, snow, ice, fog

Bad weather condition → D.S of air $\downarrow$, $V_d\downarrow$, $P_{loss}\uparrow$

surface irregularity is more

factor $m\downarrow$, $V_d\downarrow \propto \downarrow m \Rightarrow P_{loss}\uparrow$

During Bad weather (or) foul conditions

$V_d = 0.8 \times V_d$ at good weather (or) at NTP condition

Due to Ice loading on conductor

sag ↑, clearence for conductor ↓.

V_d ↓, P_{loss} ↑

factors related to conductor :-

i) radius or diameter of the conductor :-

as r ↑, $V_d \propto r \uparrow \ln\left(\frac{d}{r}\right) \downarrow$

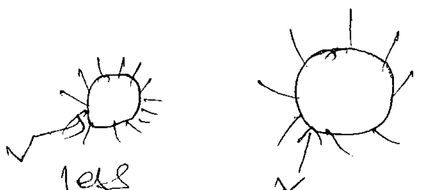
↳ decrement is less

increment is more

V_d ↑, P_{loss} ↓

$P_{loss} \downarrow \propto \sqrt{\frac{r}{d}} \uparrow (V_{ph} - V_d)^2$

loss more



ii) Type of material used for conductor :-

for same resistance :-

$\rho_{Al} > \rho_{cu}$

$R = \frac{\uparrow \rho l}{\uparrow a}$ ⇒ $a_{Al} > a_{cu}$

constant $r_{Al} > r_{cu}$

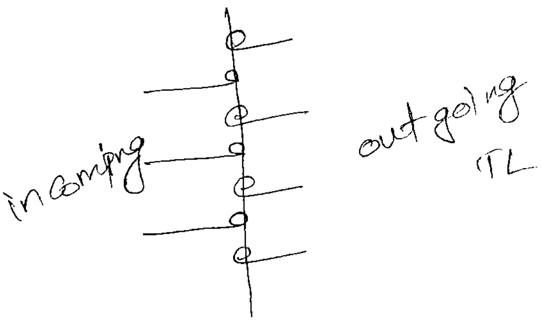
for same current carrying capacity (or) same resistance, the cor a loss in 'Al' conductor, is less compared to 'cu' conductor.

iii) surface of conductor :-

conductor - circular configuration.

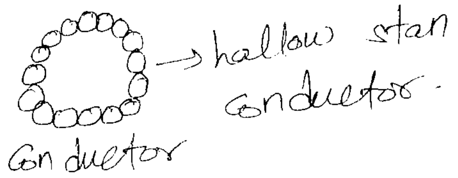
$m = 1$ for solid & hallow conductor.

→ for same current carrying capacity the size of hallow conductor is more than size of solid conductors. so corona loss is less in hallow conductor compared to solid conductor.



Hallow conductor

Bus-bar application



mcl for standard and

Disadvantages of corona loss:-

i) power loss is more in the system η is less

ii) Radio interference (or) influence / T.V. interference is more in communication system.

methods to reduce the corona:-

i) By using hallow (or) an conductors

ii) By using Bundle conductors (or) sub conductor configuratio

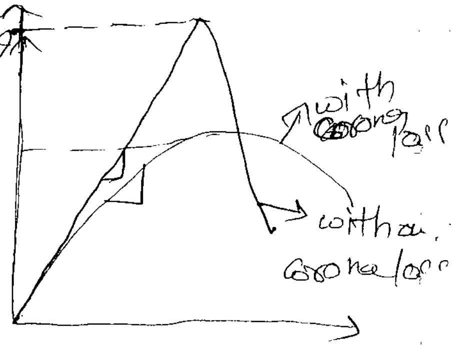
self GMD ↑, d ↑, V_d ↑, P_{loss} ↓

Advantages of corona:-

i) effective diameter of conductor is more and 'c' of system ↑

ii) some part of lightning energy will be dissipated in the form of corona loss. Lightning over voltage experience by the line is less. Due to introduction of damping in transmission system, the steepness of lightning over voltage reduces.

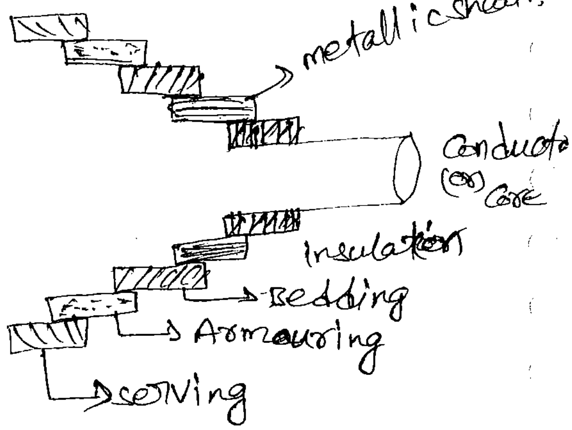
→ To reduce corona loss in HV power apparatus, corona (Al) ring will be provided at outcoming terminale.



non-linear resitance:-

under ground cables:-

~~Insulator~~
Insulation will be placed on surface of conductor (or) core.



Purpose:- To reduce leakage currents flowing through earth.

Properties of insulating material:-

1) High Dielectric strength
2) High insulation resistance
3) non-Hydroscopic (Corrosion should be less)
4) Insulator should be free from impurities (moisture, voids at designing stage)
5) chemically and electrically inactive

→ for cable insulations materials,

→ Vulcanized India Rubber (VIR) — dielectric strengths in 10 kV/mm to 20 kV/mm

→ Impregnated paper (17 kV/mm)

→ Poly vinyl chloride (PVC) (20 kV/mm)

→ XLPE — corona linked polythene (20 kV/mm)

metallic sheath:-

To avoid the entry of moisture from earth surface to insulations material.

ex: Al (or) lead

Bedding :- To width stand for electro static stress produced by conductor, it is a low grade insulator.

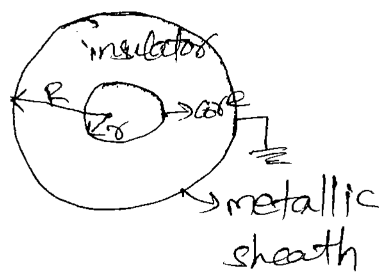
Armouring :- To protect insulating material and conductor from mechanical damage. ex:- galvanised steel.

Serving :- To avoid corrosion on surface of after armouring
fibrous material

Cross-sectional view of 1-core cable :-

$r \to$ radius of core, $R \to$ radius of cable

Thickness of insulation, $t = R - r$



→ Loading < SIL for cable

→ characteristic impedance of cable. $Z_c = 40-80\Omega$

→ verify of wave travelling

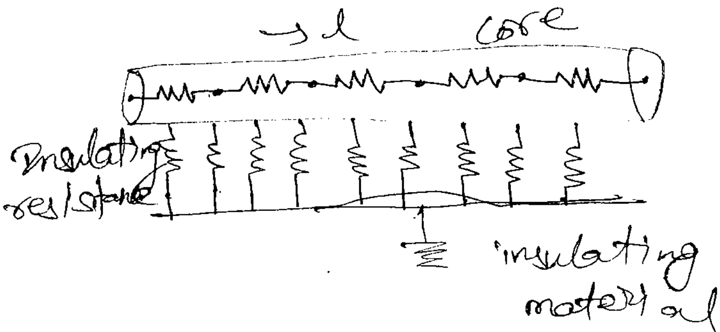
$$V = \frac{1}{\sqrt{LC}} = \frac{3\times10^5}{\sqrt{\epsilon_r}} \text{ km/s}$$

→ cable is also called as surge absorber.

Calculation of insulation resistance :-

core resistance

$$R_{core} = \frac{\rho_{core} \cdot l}{a}$$



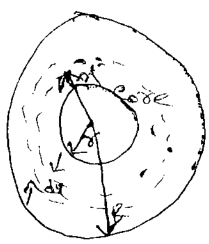
↳ length of cable

$$\boxed{R_{core} \uparrow \propto l \uparrow}$$

$R_{ins} \propto \frac{1}{l}$

dx - width of cylinder

x - radius of cylinder



calculation of Rins of cable :-

dx = width of cylinder

x = radius of cylinder

surface area of cylinder $= 2\pi x l$

resistance of cylinder position, $d\,R_{ins} = \frac{R_{ins}}{2\pi x l} \cdot dx$

$$\int d \cdot R_{in} = \int_{x=r}^{R} \frac{\rho_{ins}}{2\pi x l}\, dx \Rightarrow R_{ins} = \frac{\rho_{ins}}{2\pi l}\left[\ln(x)\right]_r^R$$

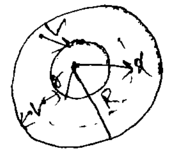
$$R_{ins} = \frac{\rho_{ins}}{2\pi l}\, \ln R - \ln r \Rightarrow \boxed{R_{ins} = \frac{\rho_{ins}}{2\pi l} \ln\left(\frac{R}{r}\right)}$$

$$\boxed{R_{ins} \propto 1/l}$$

As temp ↑, Rcore ↑, Rins ↓ (∵ insulation will have -ve temperature coefficient of resistance)

electro static stress distribution in cable :-

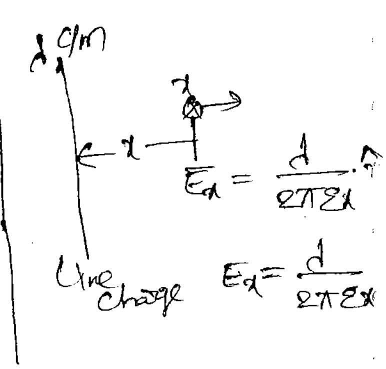
↳ electric field intensity

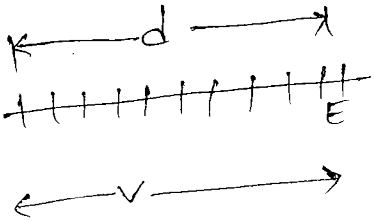


Assume core has a line charge (d)

Electric field intensity of a point 'x' from centre of cable.

$$E_x = \frac{d}{2\pi \varepsilon x}$$





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

electric field intensity inside core (or) conductor is zero

$$V = \int_{x=r}^{R} \frac{d}{2\pi\varepsilon x}\, dx \Rightarrow V = \frac{d}{2\pi\varepsilon}\left[\ln x\right]_r^R$$

$$V = \frac{d}{2\pi\varepsilon} \cdot \ln(R/r) \Rightarrow d = \frac{V \cdot 2\pi\varepsilon}{\ln(R/r)}$$

Put 'd' in $E_x \Rightarrow E_x = \frac{V \cdot 2\pi\varepsilon}{\ln(R/r)} \cdot \frac{1}{2\pi\varepsilon x} \Rightarrow \boxed{E_x = \frac{V}{x \cdot \ln(R/r)}}$

electric field intensity on surface of core $\rightarrow E_r = \frac{V}{r\ln(R/r)}$

ully " " " " " cable $\rightarrow E_R = \frac{V}{R\ln(R/r)}$

$$E_{max} = \frac{V}{r\ln(R/r)} \rightarrow \text{on surface of core}$$

$\downarrow$

Due to this the insulation near to core will be damaged.

To find most economical radius (or) minimise electric field intensity on surface of core.

min E_{max}

max $f(r) = r \cdot \ln\left(\frac{R}{r}\right)$ R = radius of cable (constant)

$$\frac{df}{dr} = 0 \rightarrow \ln\left(\frac{R}{r}\right) + r \cdot \frac{1}{(R/r)} \times \left(\frac{-R}{r^2}\right) = 0$$

$$\ln(R/r) + \frac{r^2}{R}\left(\frac{-R}{r^2}\right) = 0$$

$$\ln(R/r) = 1 \Rightarrow \boxed{R/r = e}$$

min. maximum 'E' on core

$$(E_{max})_{min} = \frac{V}{r\ln(e)} \Big|_{\frac{R}{r}=e}$$

$$= \frac{V}{r} = \frac{2V}{d} \quad \text{(d-diameter of core)}$$

'E' on surface of cable, $E_R = \frac{V}{R}\Big|_{\frac{R}{r}=e} = \frac{2V}{D}$

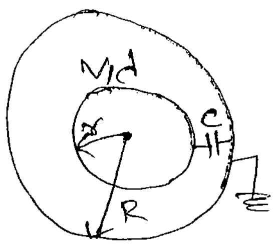
D → diameter of cable

for stability reason $\boxed{\frac{R}{r} > e,\ \frac{r}{R} < \frac{1}{e}}$

$\boxed{e = 2.718}$

capacitance of single core cable:-

$$C = \frac{q}{V} = \frac{\text{Charge}}{\text{Voltage}} = \frac{V \cdot 2\pi\epsilon}{\ln(R/r)}$$



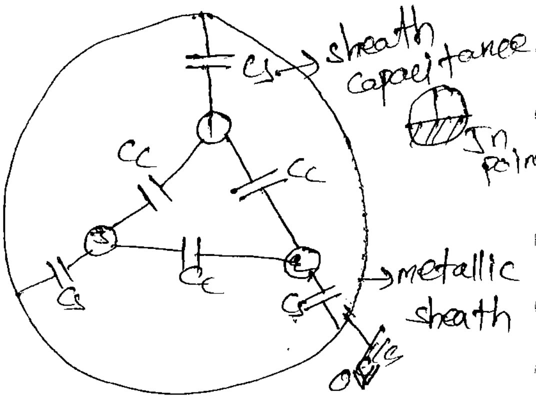
$$\boxed{C = \frac{V \cdot 2\pi\epsilon}{\ln(R/r)} \cdot \frac{1}{V}}$$

$$\boxed{C = \frac{2\pi\epsilon}{\ln(R/r)} \ \text{F/m}}$$

$\epsilon = \epsilon_0 \epsilon_r$

$\epsilon_r \rightarrow$ relative permitivity of cable insulation

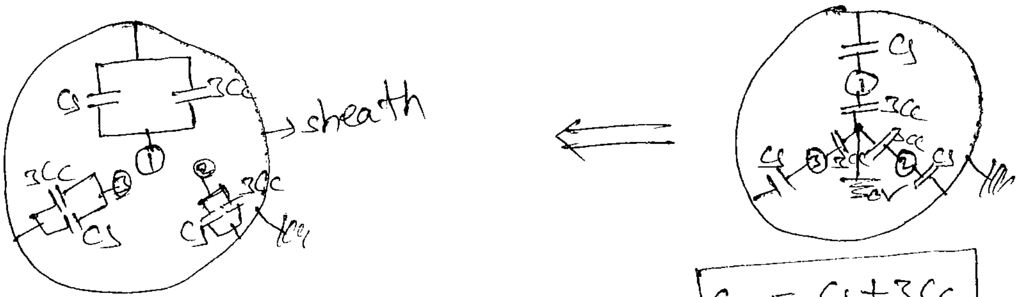
capacitance of three core cable:-



$C_c \rightarrow$ capacitance b/n any two cores

$C_s \rightarrow$ " " core to sheath

convert Δ-connected C_c's in 'Y'.



capacitance/nutral (or) per phase $\boxed{C_N = C_s + 3C_c}$

charging current taken by cable per phase $I_{c/ph}$ (or) $I_{c/N} = \frac{V_{ph}}{X_{c/ph}}$

$$\boxed{I_{c/ph} = V_{ph} \cdot \omega C_{/ph}}$$

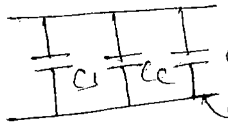
methods to calculate C_s, C_N & C_c:-

1) Any of two cores will be connected to sheath & capacitance will be measured b/n remaining conductor to sheath

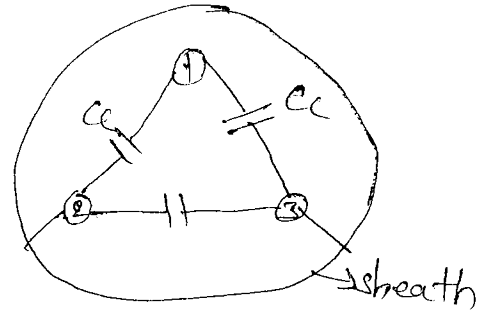
but 2,3 cores → connected to sheath

capacitance measured b/n ① & sheath → C_1 (known)

$25\% \rightarrow$



$\Rightarrow C_{eq} = C_s + 2C_c$

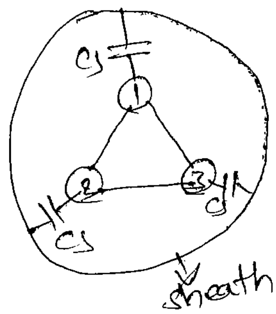


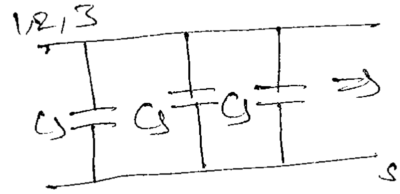
$\therefore \boxed{C_1 = C_s + 2C_c} \rightarrow (1)$

2) connect all cores together (short ckt)

measure c b/n any core to sheath

Practical capacitance C_2 (known value)





$\Rightarrow C_{eq} = 3C_s$

$\boxed{C_2 = 3C_s} \rightarrow (2)$

$\therefore \boxed{C_s = \frac{C_2}{3}}$

from (1) $C_1 = \frac{C_2}{3} + 2C_c$

$C_c = \frac{1}{2}\left[C_1 - \frac{C_2}{3}\right] = \frac{C_1}{2} - \frac{C_2}{6}$

capacitance to nutral $C_N = C_s + 3C_c$

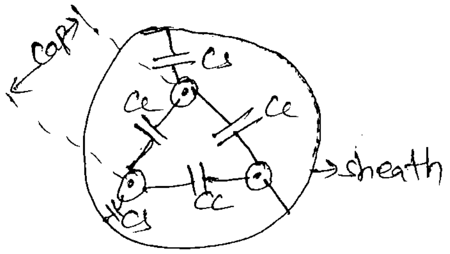
$= \frac{C_2}{3} + 3\left[\frac{C_1}{2} - \frac{C_2}{6}\right]$

$C_N = \frac{3C_1}{2} + \frac{C_2}{3} - \frac{C_2}{6}$

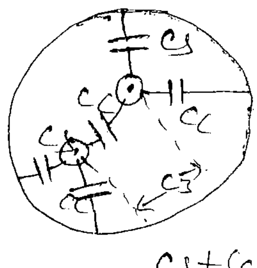
$\therefore \boxed{C_N = \frac{3C_1}{2} - \frac{C_2}{6}}$

3) connect any one core to sheath & find 'c' b/n remaining two cores

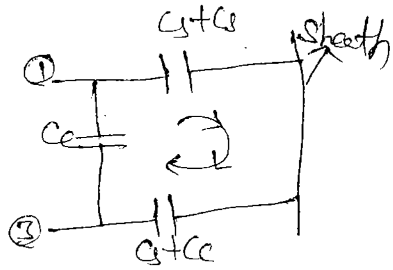
Practical capacitance $= C_3$ (known value)

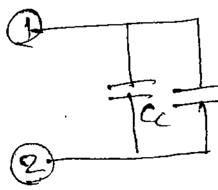


$\Rightarrow$



$\Rightarrow$





$\Rightarrow C_3 = C_c + \frac{C_s + C_c}{2} \Rightarrow \frac{3C_c + C_s}{2}$

$C_3 = \frac{C_N}{2}$

$\therefore$ capacitance per nutral $\boxed{C_N = 2C_3}$

Losses in cables/heating in cables:-

1) core (or) conductor loss
2) dielectric loss
3) sheath loss & armouring loss

core (or) conductor loss:-

$I_{core}^2 \cdot R_{core}$ loss in core

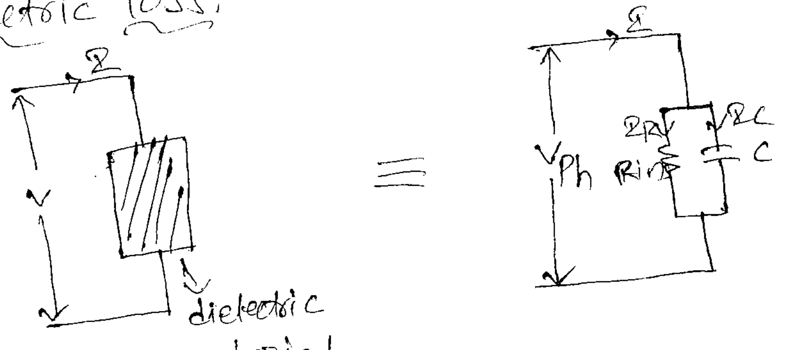
hot resistance of core $R_h = R_a + \alpha[1 + (t - 15.6)]$

α = the temp coeff of core material

15.6°c → t_a, ambient temperature

R_a will be calculated from standard tables.

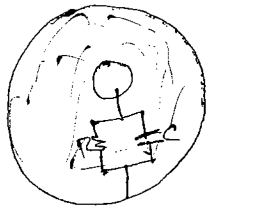
Dielectric loss:-



$\bar{I} = \bar{I}_R + \bar{I}_C$

Dielectric loss = $I_R^2 \cdot R_{ins} = \dfrac{V_{ph}^2}{R_{ins}}$ (1-core cable)

Dielectric loss = $3 I_R^2 R_{ins} = 3 \cdot \dfrac{V_{ph}^2}{R_{ins}}$ (3-core cable)

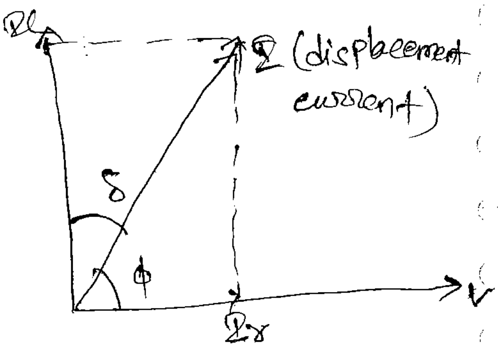


Dielectric loss is due to dielectric hysterisis (reversal of polarisation)

→ If l ↑, R_{ins} ↓, dielectric loss ↑

ϕ → P.f angle of dielectric material

Dielectric loss = real power taken by dielectric
= $VI \cos\phi$



$\tan\delta = \frac{I_R}{I_C} \Rightarrow I_R = I_C \tan\delta$

$\therefore$ dielectric loss $= V.I\cos\phi = V.I_R = V.I_C \tan\delta$

$I_C = \frac{V}{X_C} = V.\omega C$

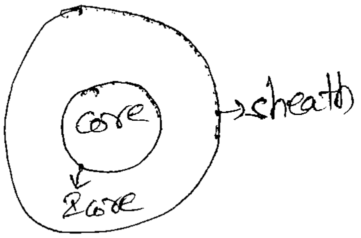
Dielectric loss $= V^2 \omega C \tan\delta$

$\tan\delta$ = loss Tangent $\simeq \delta$ (radians) for small values of 'δ'

$\therefore \boxed{\text{dielectric loss} = V^2 \omega C . \delta}$

P.f, $\cos\phi = \cos(90-\delta) = \sin\delta \simeq \delta$ (loss angle)

sheath loss & armouring loss :-



$I_{core} \Rightarrow$ alternating flux (ϕ)

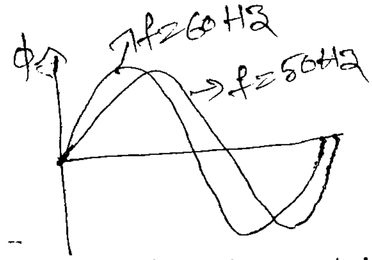
w.r.to $\phi \Rightarrow$ induced emf in sheath & armouring

$\Rightarrow$ circulating current will be produced (isheath).

sheath loss $= i^2_{sheath} \cdot R_{sheath}$

As length of the cable $\uparrow$, sheath loss $\uparrow$

If core current got $\uparrow$ed $\Rightarrow \phi_{core} \uparrow, e_{sheath} \uparrow, i_{sheath} \uparrow$



$\Rightarrow$ sheath loss $\uparrow$

As $f\uparrow$, $\frac{d\phi}{dt}\uparrow$,

$e\uparrow$, $i_{sheath}\uparrow \Rightarrow$ sheath loss $\uparrow$.

As f $\uparrow$es, dielectric loss $\uparrow$es.

→ A single core cable has 10 MΩ insulation resistance & 0.1Ω core resistance for a length of 50 kms. what is insulator resistance & core resistances for a length of 100 kms.

$\boxed{R_{ins} \propto \frac{1}{l}} \Rightarrow R_{ins(100km)} = R_{ins(50km)} \times \frac{50}{100} = 10M\Omega \times \frac{50}{100}$

$R_{ins} = 5M\Omega$

$R_{core} \propto l \Rightarrow R_{core(100)} = R_{core(50)} \times \frac{100}{50} \Rightarrow 0.2\Omega$

→ A 6.6 kV, 50Hz, single core cable has a core diameter of 1.5 cms & overall diameter as 3 cms with a length of 4 kms. The resistivity of the insulation is 1.3×10^{12} Ω-m, $\epsilon_r = 3.5$. Calculate insulation resistance, capacitance of the cable & maximum electrostatic stress on the surface of core

$d = 1.5\,cm$ $\quad D = 3\,cm$ $\quad l = 4\,km$ $\quad \epsilon_r = 3.5$

$r = 0.75$ $\quad R = 1.5\,cm$ $\quad R_{ins} = 1.3\times10^{12}\,\Omega\text{-m}$

i) $R_{ins} = ?$ $\quad$ ii) $C = ?$ $\quad$ iii) $E_{max} = ?$

i) $R_{ins} = \frac{\rho_{ins}}{2\pi l}\ln(R/r) = \frac{1.3\times10^{12}}{2\times\pi\times4000}\ln\left(\frac{1.5}{0.75}\right) = 35.85\,M\Omega$

$R_{ins}/km = 35.85\times4 =$ $\quad$ $\boxed{R_{ins} \propto \frac{1}{l}}$

ii) $C = \frac{2\pi\epsilon_0\epsilon_r}{\ln(R/r)}$ F/m

$= \frac{2\pi\times8.85\times10^{-12}\times3.5}{\ln(1.5/0.75)} = 0.28\,\mu F/km$

$C_{total} = 0.28\,\mu F\times4 \Rightarrow 1.12\,\mu F$

iii) $E_{max} = \frac{V_{max}}{r\ln(R/r)} = \frac{6.6\times\sqrt{2}}{0.75\ln\left(\frac{1.5}{0.75}\right)}$ kV/cm

$=$

$V_{max} = V\times\sqrt{2} \Rightarrow$ 1 core cable
↳ rated voltage of rms value.

$V_{max} = \frac{V}{\sqrt{3}}\times\sqrt{2} \Rightarrow$ 3 core cable

V = rated voltage (L-L rms)

→ The capacitance of a 3 core cable b/n any two conductors with other conductor connected to sheath is 2 μf. what is the capacitance/nutral $(C_N) = ?$

$C_3 = 2\,\mu f$, $\quad C_3 = \frac{C_N}{2} \Rightarrow C_N = 2C_3 \Rightarrow 2(2) \Rightarrow 4\,\mu f$

→ A 40 kms long cable has a capacitance of 0.15 μf b/n any two conductors when the other conductor is connected to sheath, the operating voltage of cable is 33 kV with 50 Hz frequency. what is the charging current/phase is ?

$l = 40\,km$, $C_3 = 0.15\,\mu F/km$ (MH-3)

$C_N = 2C_3 = 0.3\,\mu f/km$

$C_{total}/Ph = 0.3\,\mu f \times 40 = 12\,\mu f$

$I_c/Ph = \frac{V_{Ph}}{X_c/Ph} = V_{Ph} \cdot \omega c/Ph = \frac{33k}{\sqrt{3}} \times 2\pi \times 50 \times 12\,\mu f$

$= 71.82\,A$

→ A 110 kV single core cable operating at 50 Hz has a capacitance of 125 nf/km, the dielectric loss tangent is 2×10^{-4}, what is the dielectric power loss in the cable in terms of watts/km.

Dielectric loss $= V^2 \omega C \tan\delta = (110k)^2 \cdot 2 \times \pi \times 50 \times 125 \times 10^{-9} \times 2 \times 10^{-4}$

$= 95.03\,w/km.$

Over head Line Insulators:-

OH Line insulator is provided b/n towers (cross arm) & power conductor (T/L). OH line insulation designed based on switching over voltages (or) internal over voltage.

Purpose:- To reduce leakage currents flowing through the earth

OH line Insulator should have high mechanical strength.

example for insulating material:-

Porcelain, glass, epoxy resin (synthetic polymers)

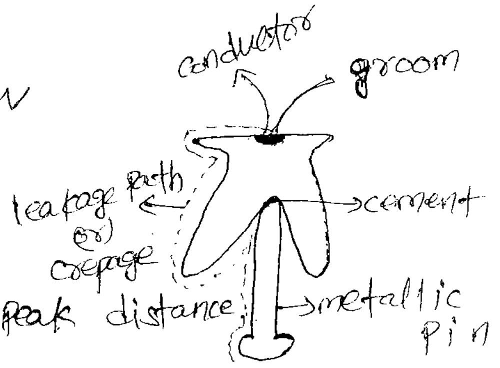
Types of OH line insulators:-

1) Pin type
2) shackle type
3) suspension type string insulator
4) strain type string insulator

} string insulators

5) stay insulator (or) guy insulator (or) egg type insulator
6) post insulator.

Pin type insulator:-



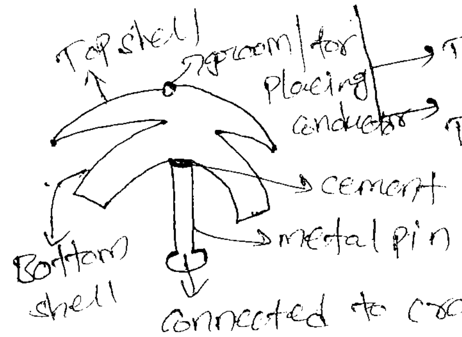
Used in distribution systems up to 33KV

Leakage current $\propto \dfrac{1}{\text{length of leakage path}}$

dielectric strength of Porcelain = 60 KV/cm peak

single shell pin type (11 KV)

multishell insulator (33 KV)

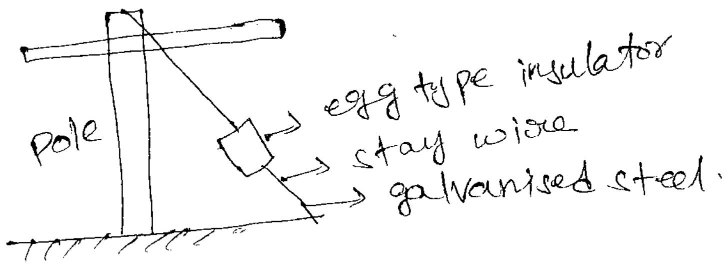


→ To avoid (or) reduce the effect of atmospheric condition on dielectric strength of insulator

→ To increase leakage path distance.

stay insulator:-

only used in distributive system

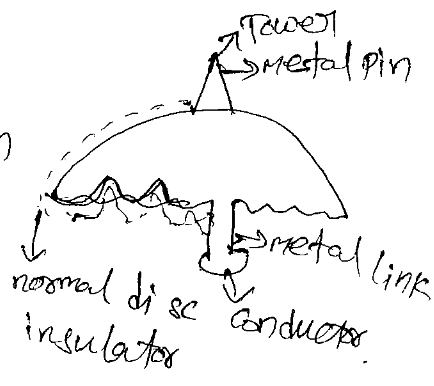


string insulators:-

↳ By connecting no. of insulator disc in cascade

each disc is rated for 11 KV

wavy shape is to ↑ leakage path at bottom

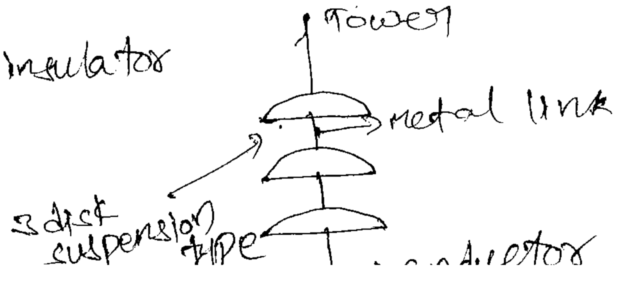


→ Aerofoil & Antifog disc insulator

↳ In deserts we use this

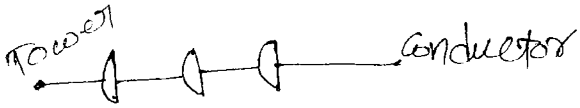
suspension type:-

no. of disc ↑ vertically mounted insulator

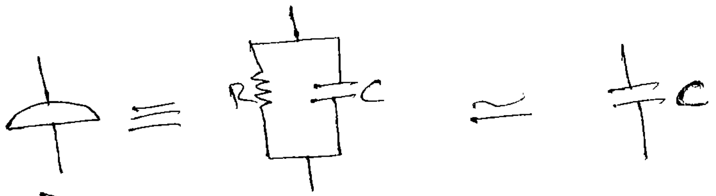


Strain type :-

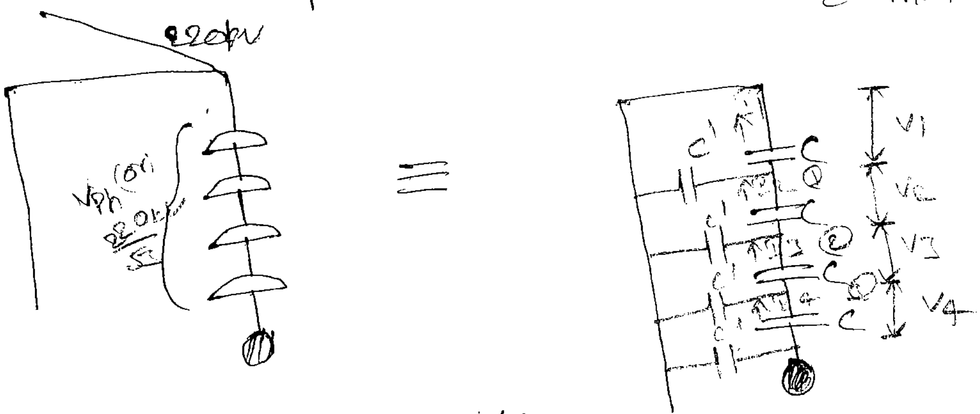
It is horizontally mounted



Purpose is to reduce strain on T/L at railway crossings, road crossings and curvatures.



C – self capacitance of disc
C' – mutual " " "



$V_1 + V_2 + V_3 + V_4 = V_{ph}$

Voltage distribution across string :-

KCL at node ① $I_2 = I_1 + I_1'$

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

$$V_2 = V_1 + V_1 \frac{C'}{C}$$

Assume that, $K = \frac{\text{mutual capacitance}}{\text{self capacitance}} = \frac{C'}{C}$

$$V_2 = V_1 + V_1 K \Rightarrow V_1(1+K)$$ KCl & always K = +ve

$$\boxed{V_2 > V_1}$$

Apply KCL at node ② $I_3 = I_2 + I_2'$

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

$$V_3 = V_2 + (V_2 + V_1)\frac{C'}{C}$$

$$V_3 = V_2 + V_2 K + V_1 K$$

$$V_3 = V_2(1+K) + K V_1$$

$$V_3 = V_1 (1+K)^2 + KV_1$$

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

$$\boxed{V_3 > V_2 > V_1}$$

Apply KCL at node ③ $I_4 = I_3 + I_3'$

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

$$V_4 = (\quad) V_1$$

$$\boxed{V_4 > V_3 > V_2 > V_1}$$

→ The voltage stress on disc near to the power conductor is high & the stress will be low on the disc near to tower.

→ chances for failure of DISC near to conductor is more

→ To represent non-uniformity in voltage distribution across string

(or) utilisation factor of string insulator.

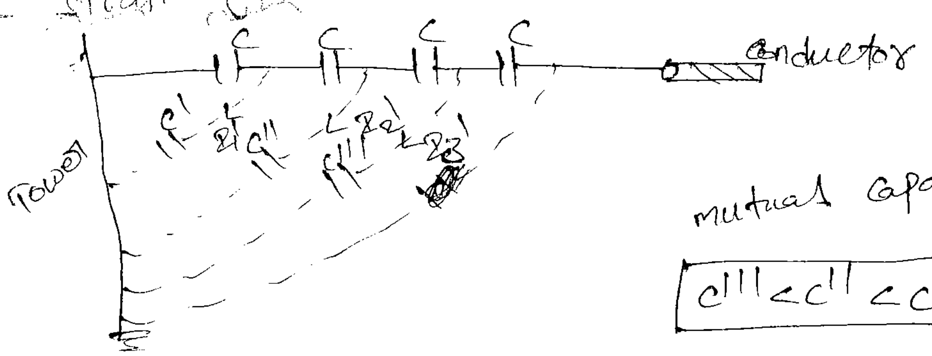
$$\text{string efficiency} = \frac{\text{Voltage across total string}}{\text{no. of disc in the string insulator} \times \text{voltage across the disc near to conductor}}$$

for 4 disc insulator ⇒ $\eta_{string} = \frac{\overbrace{V_1 + V_2 + V_3 + V_4}^{\text{operating}}}{4 V_4}$ voltage of conductor

for a suspension type $\eta_{string} < 100\%$

due to charging currents taken by mutual capacitances.

4 - disc strain type :-



mutual capacitances

$$\boxed{C''' < C'' < C'}$$

The strain type insulators will have more string efficiency compared to suspension type due to low current of charging currents drawn by mutual capacitances.

$\boxed{\eta_{string} > 70\%}$

For HVDC string Insulators:-

charging currents taken by mutual capacitances is zero but there is a finite amount of current taken by insulator due to finite amount of insulation resistance. current carries by disc is same ⇒ voltage across each disc is same, i.e.)

$\boxed{\eta_{string} = 100\%}$ for both suspension & strain type

methods to improve string efficiency in AC system:-

1) selection of 'K' value
2) Grading the insulators (or) capacitances grading
3) guard wire (or) grading ring provision for insulator.

1) selection of 'K' value :-

'K' value should be low

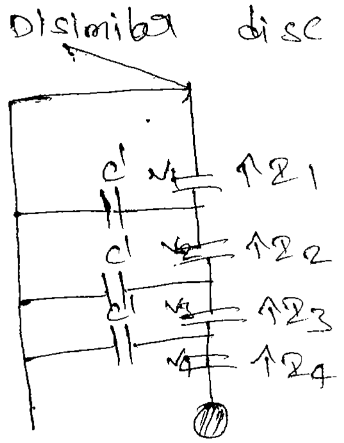
$K\downarrow = \frac{c'}{c}\downarrow$ → By increasing distance b/n insulator string & tower

Disadvantages:-

* cost is more
* $Wph \uparrow$, $Clph \downarrow$
* It is not practical. Generally $K = \frac{1}{10}$ to $\frac{1}{6}$

2) Grading of insulators (or) capacitance grading:-

Dissimilar disc will be used each disc is different (C is different)



To make $\eta_{string} = 100\%$

$V_1 = V_2 = V_3 = V_4$

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

$I_4 > I_3 > I_2 > I_1$

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

$$\frac{1}{\omega C_4} < \frac{1}{\omega C_3} < \frac{1}{\omega C_2} < \frac{1}{\omega C_1}$$

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

Assume that C_1 & C' are known $K = \frac{C'}{C_1} \Rightarrow C' = KC_1$

KCL at node ①

$$I_2 = I_1 + I_1'$$

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

$$V_1 = V_2 = V_3 = V_4 = V \text{ (say)}$$

$$C_2 = C_1 + C'$$

$$\boxed{C_2 = (1+K) C_1} \qquad C' = KC_1$$

Apply KCL at node ②

$$I_3 = I_2 + I_2'$$

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

$$C_3 = C_2 + 2C'$$

$$= C_1 (1+K) + 2KC_1$$

$$\boxed{C_3 = (1+3K) C_1}$$

Apply KCL at node ③

$$I_4 = I_3 + I_3'$$

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

$$C_4 = C_3 + 3C' \Rightarrow (1+3K) C_1 + 3(KC_1)$$

$$\boxed{C_4 = (1+6K) C_1}$$

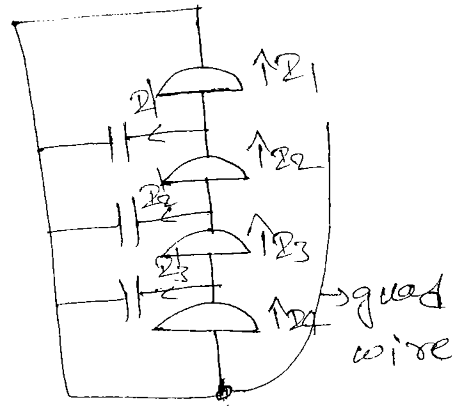
$$C_1 : C_2 : C_3 : C_4 = 1 : (1+K) : (1+3K) : (1+6K)$$

→ There is a flexibility in changing the voltage rating of string insulator which is not possible with pin type insulator.

→ The designing of string insulator is difficult by capacitance grading. This is not practical method to

Guard wire (or guarding ring)

→ Mutual capacitor's are compensated (or) cancelled. ∃ each disc has to carry same amount of current.

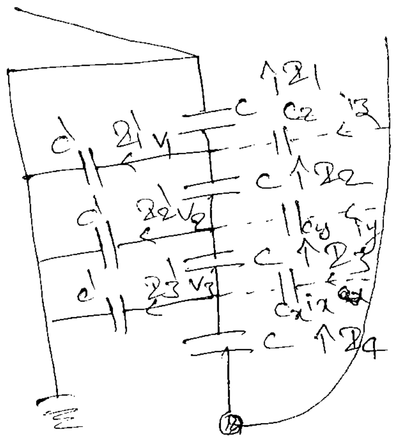


$$I_1 = I_2 = I_3 = I_4$$

$$V_1 = V_2 = V_3 = V_4$$

→ Identical discs has to be used

C_x, C_y, C_z → static capacitances b/n guard wire & metal link



at metal link ①

$$i_z = I_1'$$

$$(V_2 + V_3 + V_4)\,\omega . C_z = V_1 . \omega c'$$

$$3V\omega C_z = V\omega c' \qquad (c' = kc)$$

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

$$\therefore \boxed{C_z = \frac{kc}{3}}$$

at metal link ②

$$i_y = I_2'$$

$$2V\omega C_y = 2V\omega c'$$

$$C_y = c'$$

$$\boxed{C_y = kc}$$

at metal link ③

$$i_x = I_3'$$

$$V\omega C_x = 3V.\omega c'$$

$$C_x = 3c' \rightarrow \boxed{C_x = 3kc}$$

$$\frac{3 \times kc}{4 \cdot 3}$$

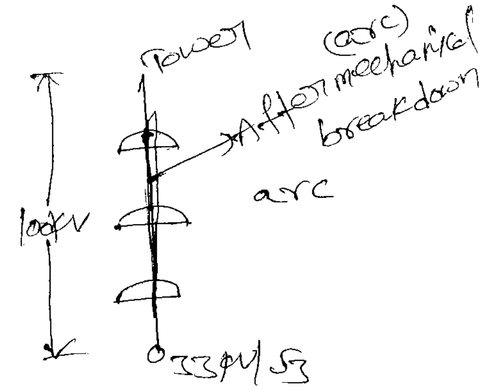
for n-disc insulator, pth metal link & guard wire

$$\boxed{C_p = \frac{P \times K_c}{n-P}}$$

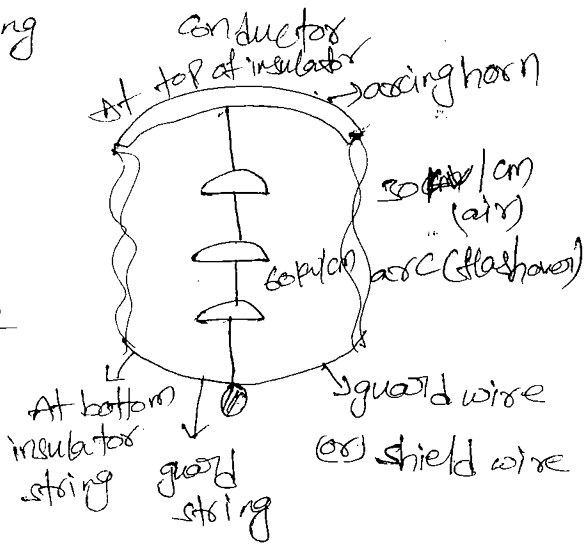
→ Practical method to improve η string.

Arcing Horn:-

→ Due to electrical break down (or) arc for motion through the insulator then it's life will be reduced



→ arc will be more away from insulating string by using guard wire & arcing horn combination. so lie of insulator will more(ie.,(50kV - 75 kV), because there is no electrical breakdown in the insulator.



PSP (SGP)

POWER SYSTEM PROTECTION

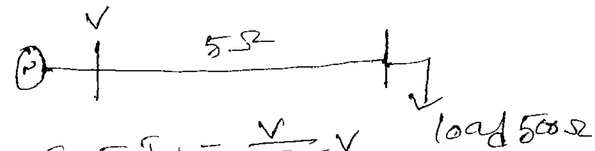
→ circuit breakers
→ Protective relays

→ The main aim of fault analysis is to design protective switchgear for the system.

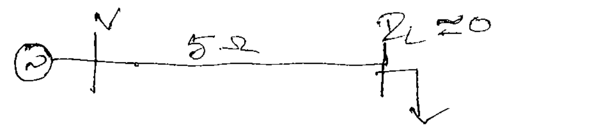
Faults are, open conductor fault (consequence is over voltages in system)
short circuit fault (over currents in the system)

→ over voltage protection connected in ‖el to system
→ over current protection connected in series with the system

consequences of over current
→ Power apparatus damage
→ Reliability of system is less
Reliability - continuous supply to load i.e., $I_L = 0$ in case(ii)

i) 

$I_L = I_1 = \frac{V}{505}$ V

ii) 

$(0.1\,\Omega) \| (500\,\Omega) \simeq 0.1\,\Omega$

$I_f = \frac{V}{5+0.1}$ A

$I_f >> I_1$, $I_L \simeq 0$

Basic relays :-
→ over current relays
→ Distance relays

→ Remove fault element as early as possible from system, power apparatus damage avoided and reliability gets improved.
→ Disconnect the faulted section only power apparatus damage avoided but reliability is less.
→ Two types of faults according to time period of fault existence
1) Transient fault → Time period is less (fault cleared by fault element only)
2) Sustain fault → fault time period is more (fault cleared by operated)

→ Protective system will be design to operate only for sustain faults.

option (2) is achieved by providing series switch – Protective switch.

Types of protective switches:-

1) fuse

2) Load interrupter

3) Line insulator

4) circuit breaker + relay.

Fuse:- operated based on heat energy concept

If heat energy generated by fuse > Thermal limit

Then fuse will melt down, faulted section will be isolated.

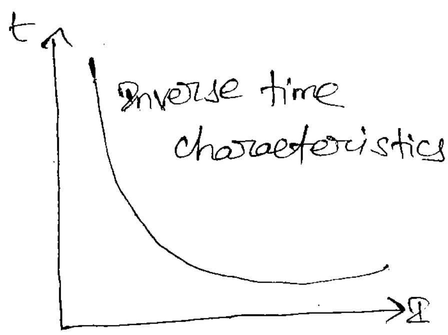
→ fuse is a primary protective device for distribution systems and domestic applications.

→ fuse is used as a backup protective device in substation and transmission system.

heat develop $= I^2Rt \rightarrow$ melting-time of fuse

Load interrupter:-

operated only under full load (or) normal operating conditions. for load shedding (or) load curtailment load interrupter used energy management.



1-∅ ch. of fuse.

→ over load $I\uparrow$, $T_{em} \alpha\ \phi I_a \Rightarrow T_{em}\uparrow$

speed of rotor $\omega\downarrow = \dfrac{T_{pm} - T_{em}\uparrow}{B} \Rightarrow \omega\downarrow, N\downarrow \Rightarrow f\downarrow$

$\uparrow\phi = \dfrac{V}{f\downarrow} \Rightarrow \phi\uparrow \Rightarrow I_\mu\uparrow \Rightarrow$ m/c draws more amount of reactive

Power, P.f of the system reduces, ... of

load is poor..

→ To avoid this some load are removed by load interrupter, this is called load shedding or load curtailment.

→ To avoid over load on the system, the load interrupter removes the full load apparatus

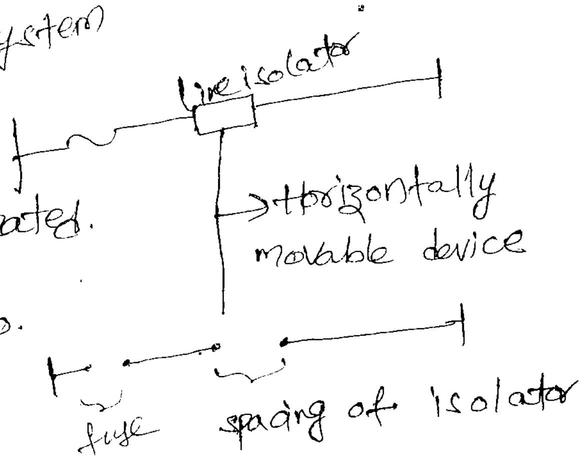
Line isolator:-

operated only under no-load condition

→ To provide more clearance for the system

→ After the operation of over current device the line isolator will be operated.

→ Breaking capacity of isolator is zero.



circuit breaker:-

operated under all conditions (no-load, full load & abnormal)

→ circuit breaker will not be operated as line isolator

→ CB acts as load interruptor for full load

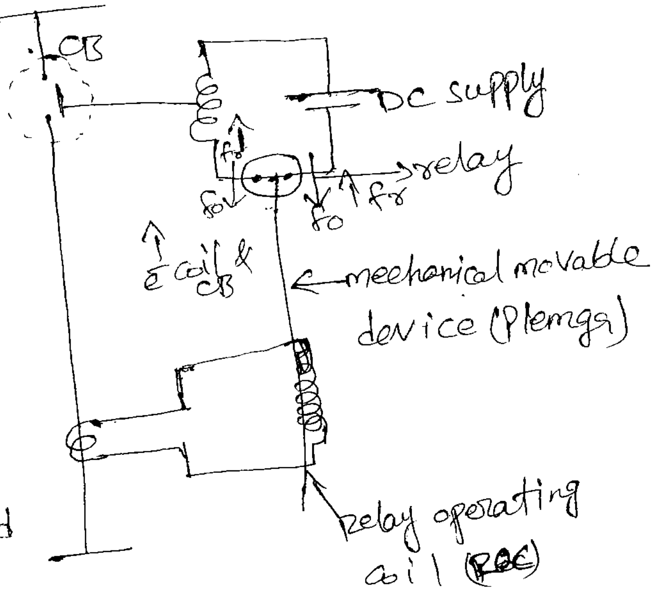
→ CB operation is same as fuse under abnormal conditions.

→ CB is a protective device which will make the circuit and break the circuit during normal and abnormal operating conditions respectively.

Basic Protection scheme:-

CT → To stepdown the current to protective system operation level (or) To provide electrical isolation b/n power system & Protective system.

→ To restrict the operation of protective system under normal conditions a restraining force will be produced such that the relay contacts should not be closed under normal condition

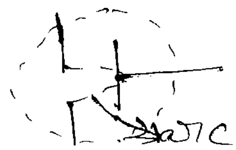


→ The restraining force (f_r) provided by spring

→ The resultant force $f_{res} = F_o - f_r$, if $f_{res} > 0$ the relay will operate.

→ During CB opening, arc will strike b/n contacts

Arc – column of ionised gases



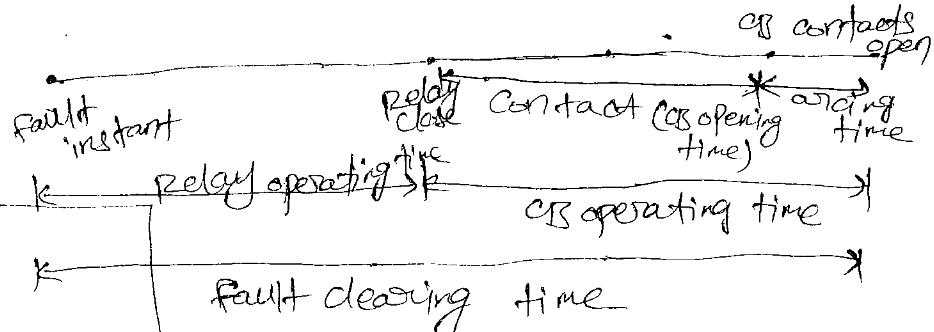
Two types of contacts

→ fixed contacts (2)

→ movable contacts (1)

Fault clearing time:–

Time b/n fault interruption instant to arc extinction in CB.

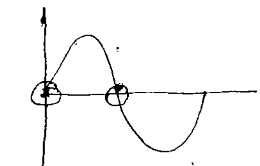


fault clearing time = Relay operating time + CB opening time + Arcing time electromechanical, numerical, static relays.

→ relay operating time | CB opening | arcing time

electromechanical → 1 to 5 cycles | 1 to 3 cycles | Depends on Interruption instant (1 to 2 half cycle)

→ operating time of protective system is 0.25 sec, relay operating time is 0.15 sec, find the CB opening time & Arcing time



two zero points for one cycle.

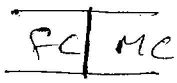
a) 0.055, 0.055 ✓b) 0.085, 0.025

c) 0.025, 0.085 d) none

Always
CB opening time > Arcing time

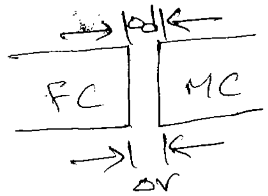
Arcing initiation:-

→ At closed position (or) contacts are about to seperate ($t = 0^+$) → contact resistance is zero.



contacts resistance

→ At $t = 1ns$ → contact spacing = Δd, very less (nm (or) μm). Carbon is used for contacts electric field is zero.



contact resistance ≠ (very less value)

small voltage ΔV appears across contacts (b/n contacts)

$$E = \frac{\Delta V}{\Delta d}$$

Let $\Delta d = 1\mu m$, $\Delta V = 20V$

$$E = \frac{\Delta V}{\Delta d} = \frac{20}{1\mu} V/m = 20\ mV/\mu = 200\ kV/cm > \text{Air dielectric}$$

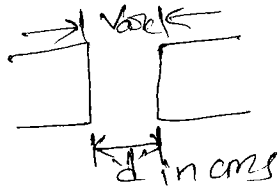
arc

→ The 'E' in the space of contact is very high at the instant of contact seperator, so the arc will be initiated due to high field gradient (or) field emission process.

Arc maintainance :-

After contacts fully seperated, spacing be 'd'

Ave voltage = 3% of rated voltage



For 132 kV, d = 1 cm

$V_{arc} = 3\%$ of $\frac{132}{\sqrt{3}} = 2.280$ kV/cm < dielectric strength

Low field gradient because 'E' < dielectric strength of air

→ The arc will be maintained due to high heat energy developed by arc which is called as thermal ionisation process.

* Arc Initiation:-

Cause for arc emission is field emmission process (or) high field gradient.

→ Arc is maintained due to thermal insulation (or) high heat energy developed in the space of C.B. Contacts.

→ So conductance of arc $\propto$ no. of elements generated/cm^3 during ionization

$\propto$ volume of arc (or) $(\text{diameter})^3$

$$\propto \frac{1}{\text{length of arc } (l)}$$

→ Resistance of the arc $R_{arc} \propto \frac{1}{\underset{\downarrow\ d^3}{\text{volume of arc}}} \propto \frac{1}{a}$, * $R_{arc} \propto$ length of the arc

→ Heat energy developed by the arc $= I_{arc}^2 R_{arc} t$.

$I_{arc} \propto a$, $R_{arc} \propto \frac{1}{a}$

Heat energy $\propto a^2 \cdot \frac{1}{a}$

$\boxed{\text{Heat energy} \propto a}$ area of cross-section.

HRC ... (or) extintion

i) High resistance method → Arc lengthing ($R_{arc} \propto l$) ; reducing area of crosssection of arc ($R \propto \frac{1}{a}$) ; cooling the arc

ii) current zero interruption of arc

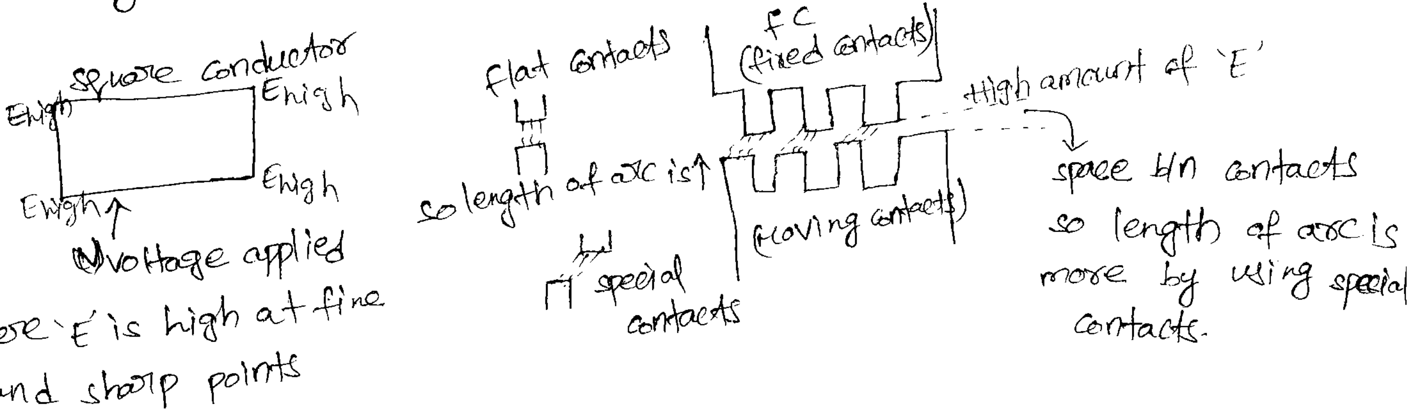
i) High resistance method:-

a) Arc lengthening:-

At the designing state of circuit breaker the contact spacing should be maintained as more

→ Due to this size and cost of CB is more, so we can't go for it.

→ so by using special contacts we are going to design CB.

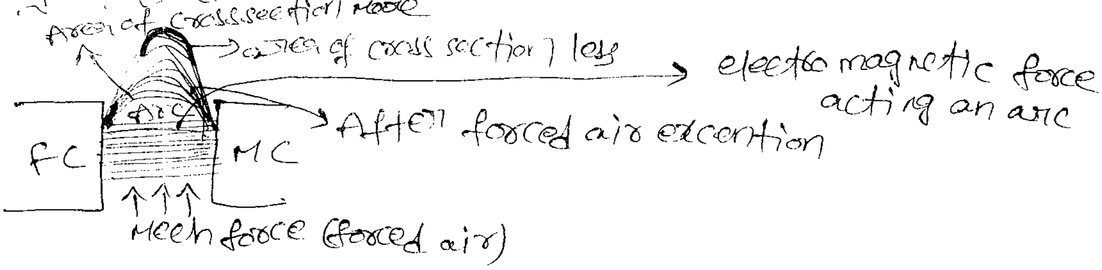


Always arc formation is b/n high electric field intensity points.

→ length of the arc is more compared to length of arc in flat contacts

→ manufacturing of contacts is difficult so we are not going to special contacts

b) reducing area of crosssection of arc:-



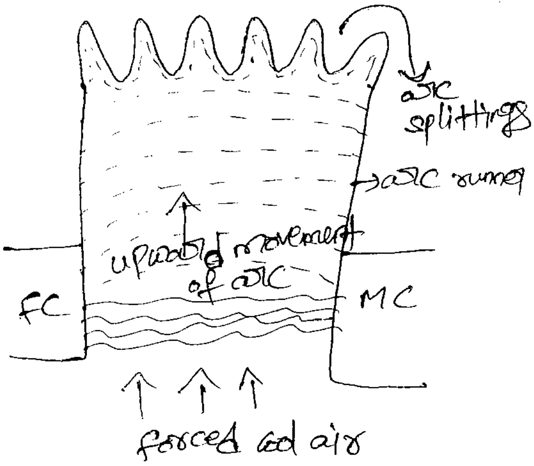
→ so overall crosssection of arc is less and the length of the arc is more.

$R_{arc}\uparrow$, heat energy ↓

c) Cooling the arc:-

Coolant (or) oil air will be sent into the arcing chamber

$R_{arc}\uparrow$ due to -ve temperature coefficient of resistance for arc



→ Combinding these three methods

m/c used II^{nd} m/d + III^{rd} m/d

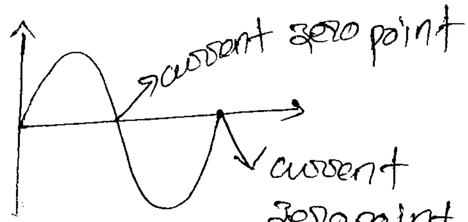
→ And the combination of three high resistance m/d's and it is used in air blast circuit breaker

→ Arc splittings will increase length of the arc further.

ii) current zero arc interruption method:-

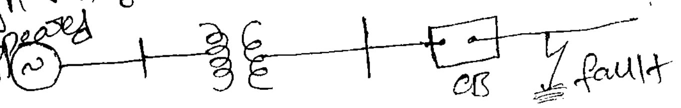
At $I=0$, their no arc b/n the contacts that means the electro magnetic force is zero but the molecules in the space are having more heat (or) ionized, At current zero point

→ At $I=0$, cool air (or) coolent will be sent into the space of contacts inorder to deionize spacing molecules b/n the contacts such that the current should not raise further. (i.e., after $I=0$)

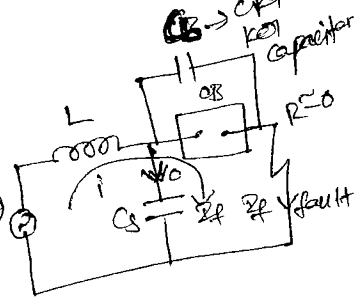


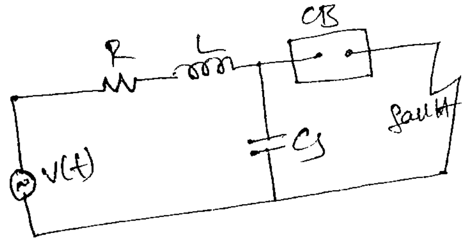
→ If we interrupt the arc at $I \neq 0$ point then arc interruption medium required more and a high voltage will be appeared across contacts so the arc may get restricted.

why high voltage is appeared



+ve sequence diagram





R → equivalent resistance upto CB $(R_g + R_T)$

L → equivalent inductance upto CB location $(L_g + L_T)$

Cs → stray capacitance at CB terminal

Cs is very very low. so $\frac{1}{\omega C_s}$ = high

so current flowing through CB

At $I \neq 0$ arc interruption the electro magnetic energy stored in inductor $\left[\frac{1}{2}L i^2\right]$ will be transferred to capacitor in electro static form

$$\frac{1}{2}Li^2 = \frac{1}{2}(C_s + C_b) \cdot v^2$$

↳ CB capacitance

$$\frac{1}{2}Li^2 = \frac{1}{2}Cv^2$$

energy transfer

$$\frac{v^2}{i^2} = \frac{L}{C} \Rightarrow \boxed{v = i\sqrt{L/C}}$$ → high voltage across contacts

This voltage is called as prospective voltage

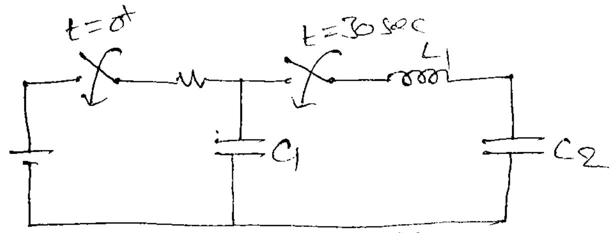
This is across CB contacts

At i=0 point v=0. so no voltage.

so we can interrupt the arc at i=0 point.

equivalent circuit

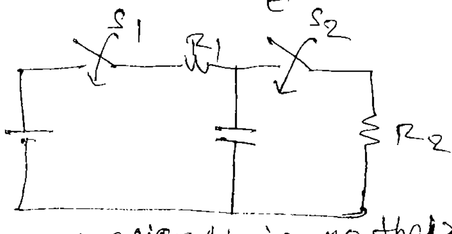
Arbitrary n/w for dis



RC1 = 1msec

Transient core there after switch S2 is closed.

≈



Transients is no there after switch S2 is closed.

→ At i=0 arc interruption there are only transient voltages across contacts w.r.to source. At i≠0 arc interruption voltage across breaker contacts is transient voltage w.r.to source + prospective voltage

→ so the possibility of arc ~~restriking~~ restriking is more for non current zero arc interruption.

Arc interruption theories:-

↳ It is to say wheather the arc is interrupted (or) not

1) energy balance theory (or) cassier's theory

2) Recovery rate theory (or) slepain's theory

→ According to energy balance theory the arc will be interrupted when heat dissipation is more than heat generation in the space of CB contacts.

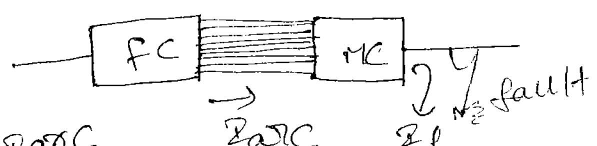
→ According to recovery rate theory if the recovery of dielectric strength b/n contacts is more than ~~heat~~ generation rate of raise of restriking voltage then the arc will be interrupted.

if recovery of DS > rate of rise of restriking voltage

→ recovery rate theory is inconsistant w.r.to units because dielectric strength is having the units as kV/cm and rate of rise of ~~restt~~ rest voltage → kV/ms. so generally we follow energy balance theory to say arc is interrupted (or) not.

Terms regarding arc phenomina:-

i) Arc voltage:- R_{arc} → resistance of arc

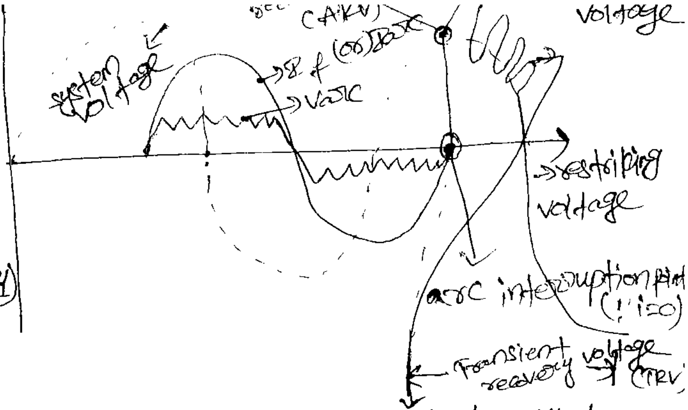


then $R_f = R_{arc}$ $\quad I_{arc} = I_f$

lags system voltage by 90°, fault pf $\cos 90° = 0$ lagging

Arc voltage is defined as the voltage across breaker contacts during arcing time.

so, $V_{arc} = I_{arc} \times R_{arc}$ (inductance L & C of arc are neglected)



Transient oscillations and 'c' it goes to steady state and the voltage across it is 'V_c'

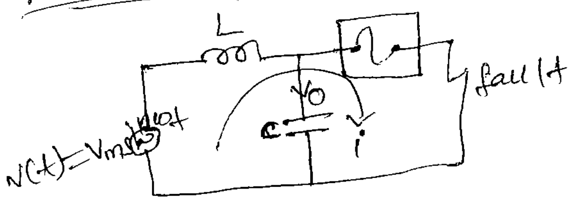
→ phase relation b/n V_{arc} & I_{arc} is "V_{arc} and I_{arc} in phase" and arc power fault is unity

→ so, arc will be modeled as non-linear resistor (as corona) as $I_{arc}\uparrow$, Temp$\uparrow$, $R_{arc}\downarrow$ (because it is having -ve temp coeff)

so $V_{arc} = I_{arc} \times R_{arc}$ → and it is almost constant after some value of I_{arc}.

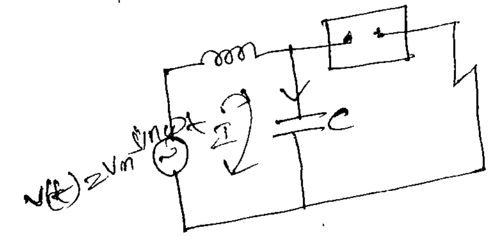
→ V_{arc} ⟹ 3% of rated voltage.

equivalent circuit :-

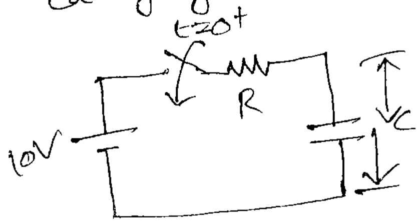


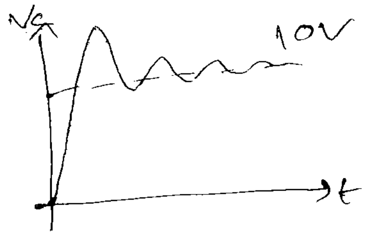
At i=0 point the arc is going to be interrupted and the current is going to be circulated through LC circuit

After interruption



After arc interruption the capacitor starts carrying current and it is explained below.





i) Transient recovery voltage (TRV) :-

It is the voltage across contacts after arc interruption both transient + steady state part.

iii) Restriking voltage :-

voltage across CB contacts at the instant of arc interruption

iv) Recovery voltage :-

It is the power frequency rms voltage appearing across breaker across breaker contacts after find extigution of arc.

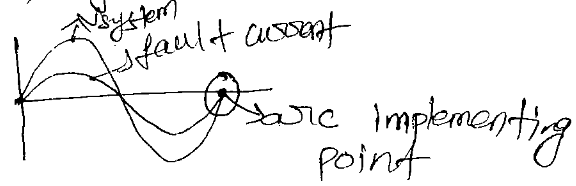
1) Active recovery voltage:-

It is the instantaneous value of recovery voltage at the instant of arc interruption (ARV).

Expression for active recovery voltage:-

a) fault power factor

Case-(i) $\cos\phi = 1$ (Hypothetical case), $\phi = 0^\circ$ i.e., system voltage and fault current both are in phase

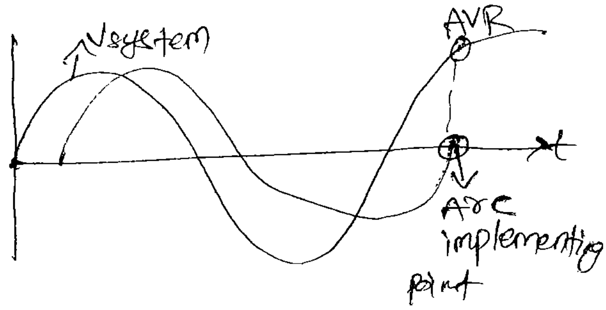


then ARV = 0

Case-(ii) $\cos\phi = 0.8$ lagging, $\phi = 36.86^\circ$ lag

ARV > 0 but ARV < Vmax

so $0 < ARV < V_{max}$



Case-(iii)

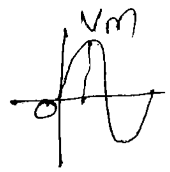
$\cos\phi = 0$ lagging, $\phi = 90^\circ$ lag

ARV = Vmax

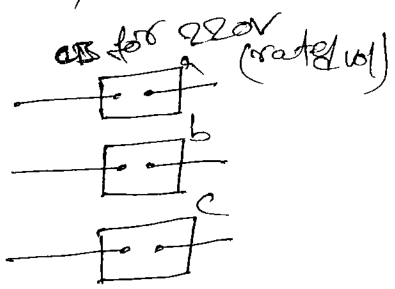
Based on these three we have to get relation b/n fault point and phase angle.

$\therefore$ so $\boxed{ARV \propto \sin[\text{P.f angle }(\phi)]}$

ARV $\propto \sin\phi$
if $\phi = 0$ ARV = 0
$\phi = 90^\circ$ ARV = Vm



$\boxed{ARV = K_1 K_2 K_3 V_{max} \sin\phi}$

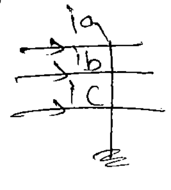


$V_{max} = \frac{V_{LL}}{\sqrt{3}} \times \sqrt{2}$ (Peak value)
(per phase)

K_1 → represents demagnetising action of armature reaction $\boxed{K_1 < 1}$

K_1 = recovery voltage of the system rated voltage

LG
LL
LLG
LLL



K_2 → 1st pole to clear factor

$K_2 = 1.0$ for grounded faults (LG, LLG)

$K_2 = 1.5$ for ungrounded faults (LL, LLL, LLLG) $\boxed{LLLG = LLL}$

$K_3 = 1$ (or) $\sqrt{3}$ → To calculate ARV (L–L)

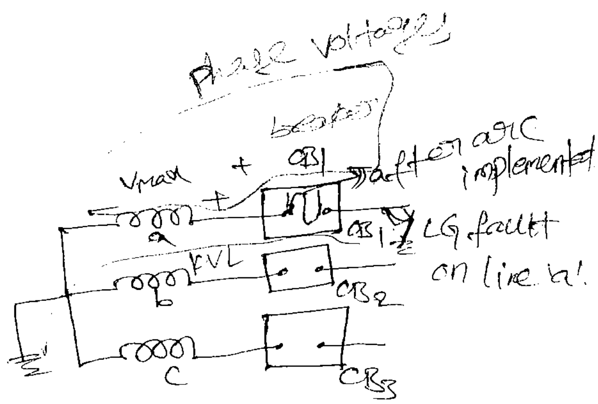
↓

To calculate ~~ARV~~ phase

1st pole to clear factor (K_2):–

for grounded faults

circuit breaker contacts are going to be opened with a displacement of 120°



Time displacement → CB1 → t = 0 sec

$\frac{120}{360} \times 0.02\,sec$ ⟶ CB2 → t = 0.0066 sec

$\frac{240}{360} \times 0.02\,sec$ ⟶ CB3 → t = 0.0125 sec

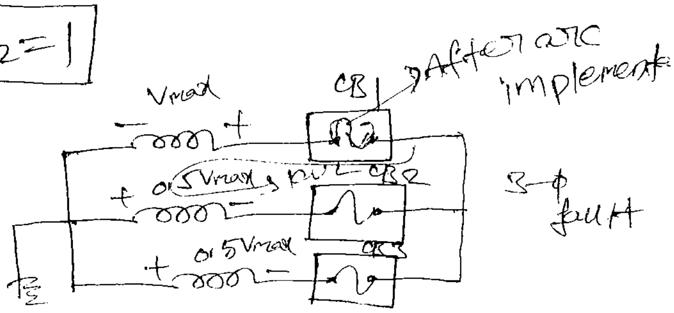
Illy arc interruption will be done with a displacement of 120°.

KVL for loop

$V_{max} - V_{breaker} = 0$

$V_{breaker} = V_{max} \Rightarrow \boxed{K_2 = 1}$

for unground faults:–



KVL for loop

$V_{max} - V_{breaker} + 0.5\,V_{max} = 0$

$V_{breaker} = 1.5\,V_{max}$

$\boxed{K_2 = 1.5}$

at $\omega t = 90°$

$V_a = V_{max}$

$V_b = -0.5\,V_{max}$

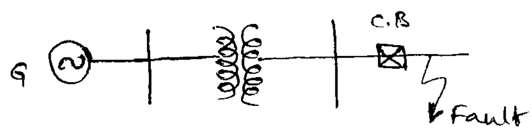
$V_c = -0.5\,V_{max}$

$V_a = V_{max} \sin \omega t$

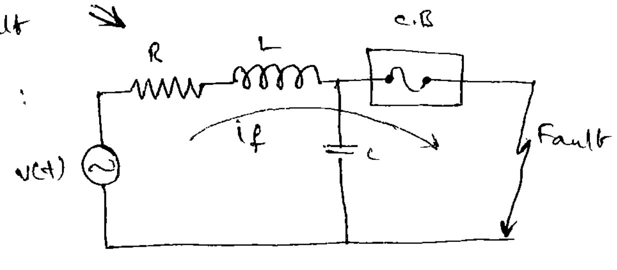
$V_b = V_{max} \sin(\omega t - 12$

$V_c = V_{max} \sin(\omega t + 1$

* Expression for restriking voltage:–



Electrical Equivalent Circuit :

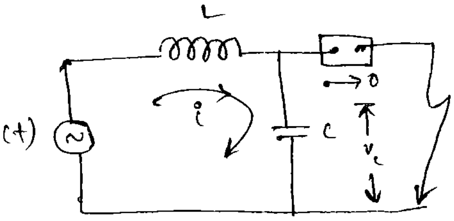


$C = C_s + C_b$

Restriking voltage (V_r) = Voltage across breaker contacts at the instant of arc extinction.

V_r = Voltage across Capacitor (V_c) at the instant of arc extinction

At the instant of arc extinction,



$$v(t) = L \cdot \frac{di}{dt} + V_c$$

Current through capacitor, $i = C \cdot \frac{dV_c}{dt}$

$$\therefore v(t) = L \cdot \frac{d}{dt}\left[C \cdot \frac{dV_c}{dt}\right] + V_c$$

$$= LC \frac{d^2 V_c}{dt^2} + V_c$$

$$\Rightarrow \frac{d^2 V_c}{dt^2} + \frac{V_c}{LC} = \frac{v(t)}{LC}$$

$$\left(D^2 + \frac{1}{LC}\right) V_c = \frac{v(t)}{LC} \longrightarrow (1)$$

→ If $v(t) = V_m \sin wt$ then solution of eq (1) will give transient recovery voltage

→ If $v(t) = V_m$ then solution of eq (1) will give restriking voltage

Characteristic equation of the eq (1),

$$D^2 + \frac{1}{LC} = 0 \qquad \therefore \text{Roots are} \quad D = \pm j \frac{1}{\sqrt{LC}}$$

Natural Frequency of Oscillation.

$$W_n = \frac{1}{\sqrt{LC}} \text{ rad/sec}$$

$$f_n = \frac{1}{2\pi\sqrt{LC}} \text{ Hz (or) } 1/s.$$

To find restriking voltage,

$$\left(D^2 + \frac{1}{LC}\right)\cdot V_c = \frac{V_m}{LC}$$

After solving the differential equation $V_c = V_m\left(1 - \cos\frac{t}{\sqrt{LC}}\right)$

Restriking voltage, $\boxed{V_r = V_m\left[1 - \cos\frac{t}{\sqrt{LC}}\right]}$

Max value of Restriking voltage is, $V_{r\,max} = 2 \times ARV$

$(V_m = ARV)$

Time at which max. restriking voltage occurs

$$\cos\frac{t}{\sqrt{LC}} = -1 \Rightarrow \frac{t}{\sqrt{LC}} = \pi \Rightarrow \boxed{t = \pi\sqrt{LC}}$$

* Rate of Rise of Restriking Voltage [RRRV]:-

$$RRRV = \frac{dV_r}{dt}$$

$$= \frac{d}{dt}\left[ARV\left(1 - \cos\frac{t}{\sqrt{LC}}\right)\right]$$

$$= ARV\left(0 + \sin\frac{t}{\sqrt{LC}}\right)\frac{1}{\sqrt{LC}}$$

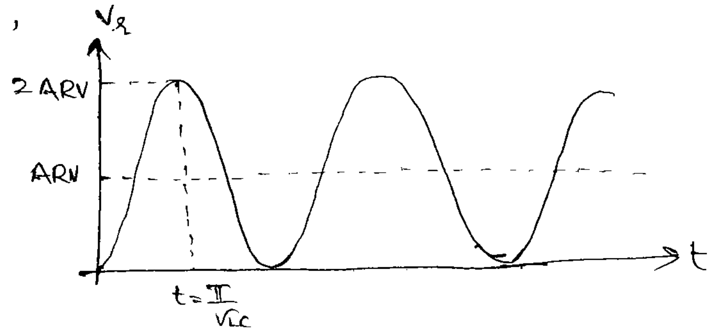
$$\boxed{RRRV = \frac{ARV}{\sqrt{LC}}\cdot\sin\frac{t}{\sqrt{LC}}}$$ units $kV/\mu s$

$$\text{Max. } RRRV = \frac{ARV}{\sqrt{LC}} \; kV/\mu s$$

Time at which max. RRRV occurs

$$\frac{t}{\sqrt{LC}} = \frac{\pi}{2} \Rightarrow \boxed{t = \frac{\pi\sqrt{LC}}{2}}$$

⇒ Restriking Voltage Waveform,



Average Restriking Voltage = ARV (V_m)

Avg. RRRV upto First peek $= \dfrac{2\,ARV - 0}{\pi\sqrt{LC} - 0}$

$$= \frac{2 \times ARV}{\pi\sqrt{LC}}$$

$$= \frac{\text{max Restriking voltage}}{\text{Time at which } V_{rmax} \text{ occurs}}$$

$$\text{Avg. RRRV} = \frac{ARV}{\pi\sqrt{LC}/2} = \frac{2 \times ARV}{\pi\sqrt{LC}}$$

Q. A 132 KV C.B having Avg. RRRV as 10 KV/μs at fault powerfactor of 0.8. what is avg RRRV at a powerfactor of 0.66 by keeping all other conditions as same.

Sol:- 132 KV, C.B. Avg RRRV = 10 KV/μs at $\cos\phi = 0.8$

Avg RRRV $\propto$ ARV

ARV = $K_1 K_2 K_3 \, V_{max} \sin\phi$

Avg RRRV $\propto \sin\phi$

$$\frac{\text{avg RRRV}_{0.8}}{\text{avg RRRV}_{0.66}} = \frac{\sin(\cos^{-1} 0.8)}{\sin(\cos^{-1} 0.66)}$$

$$\text{avg. RRRV}_{0.66} = 10 \times \frac{\sin(\cos^{-1} 0.66)}{\sin(\cos^{-1} 0.8)} \text{ KV/μs}$$

$$= 12.5 \text{ KV/μs.}$$

Q. Reactance of a 132 KV, 50 Hz rated system is 3 Ω and equavalent capacitance up to C.B location is 0.012 μF. C.B got opened during fault what is the natural frequency of oscillations experienced by restriking voltage during arc interuption process

Sol: $X = 3\Omega$, $F_n = \frac{1}{2\pi\sqrt{LC}}$ Hz

$$L = \frac{X}{\omega} = \frac{3}{2\pi \times 50} = 9.549\,mH$$

$$f_n = \frac{1}{2\pi\sqrt{9.549\times10^{-3} \times 0.012\mu}}$$

$$= 14.87\,KHz.$$

* If $R \neq 0$, Frequency of oscillations made by restriking voltage

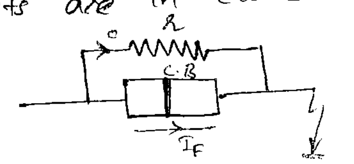
$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \left(\frac{R}{2L}\right)^2}$$

Due to high frequency voltage appears across C.B contacts during ARC interruption the C.B contacts will get damaged (because we design the C.B contacts for fixed frequency 50Hz.)

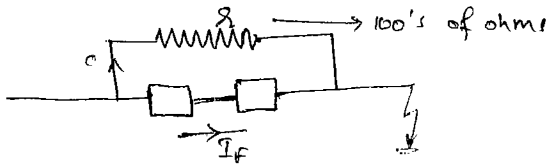
* Resistance Switching:-

The purpose is, to reduce frequency of oscillations made by Restriking voltage and by using resistance switching active recovery voltage, max restriking voltage, RRRV and Avg. RRRV values will be reduced

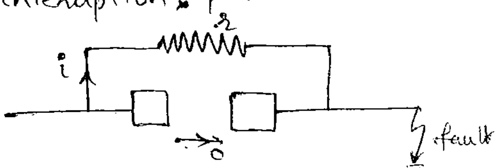
1. CB contacts are in closed position:



2. CB contacts are in open position:

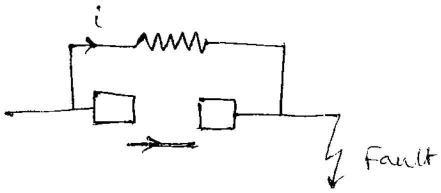


3. Arc interruption instant position:



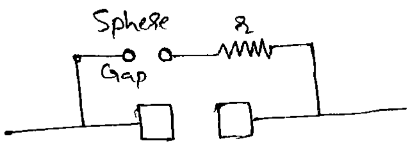
Frequency of oscillations ↓ across the C.B contacts.

4. After final extinction of ARC:



Fault current (I_F) will be circulated

To avoid the disadvantage due to permanent resistor connection the resistance switching is done such that 'r' has to be connected only during ARC interuption and it has to be disconnected after final extinction of ARC



⇒ At the instant of arc interuption, restriking voltage appears across sphere gap. ⇒ Gap will be ionised

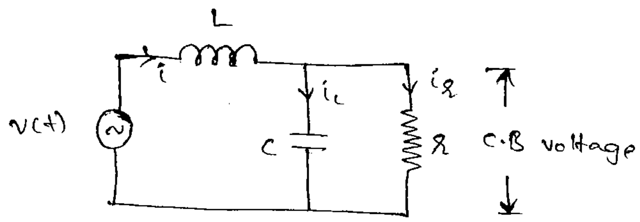
⇒ 'r' will connected into circuit.

⇒ After arc interuption, voltage across the sphere gap is normal voltage.

⇒ Gap will be deionised

⇒ 'r' will be disconnected from circuit.

⇒ During ARC Interuption,



frequency of oscillations made by voltage across C.B

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \left(\frac{1}{2rC}\right)^2}$$

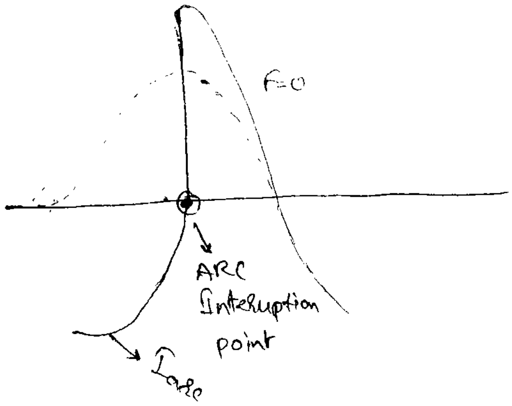
* To make frequency of oscillations across C.B as zero is called critical voltage.

To make $f = 0$,

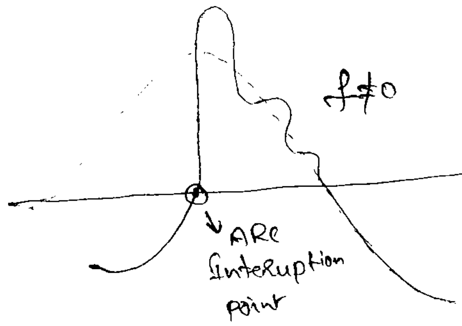
$$\frac{1}{LC} - \left(\frac{1}{2rC}\right)^2 = 0$$

critical

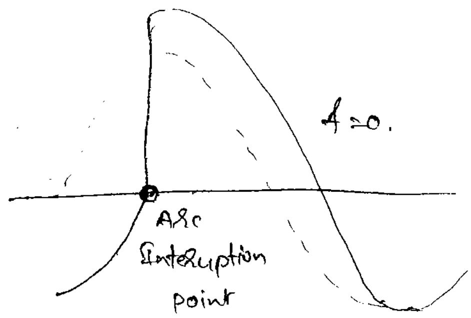
⇒ if $r = \frac{1}{2}\sqrt{\frac{L}{C}}$, circuit will behave as critically damped circuit.



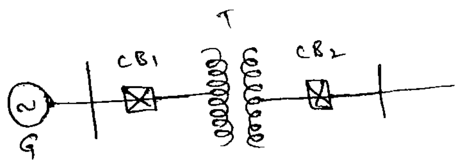
⇒ if $r > \frac{1}{2}\sqrt{\frac{L}{C}}$, circuit will behaves as under damped circuit.



⇒ if $r < \frac{1}{2}\sqrt{\frac{L}{C}}$, circuit will behaves as over damped circuit.



* Current Chopping:—



current chopping phenomina while interupting low magnetising currents. ↝ It is Noload Current (or) Magnetising current of Transformer.

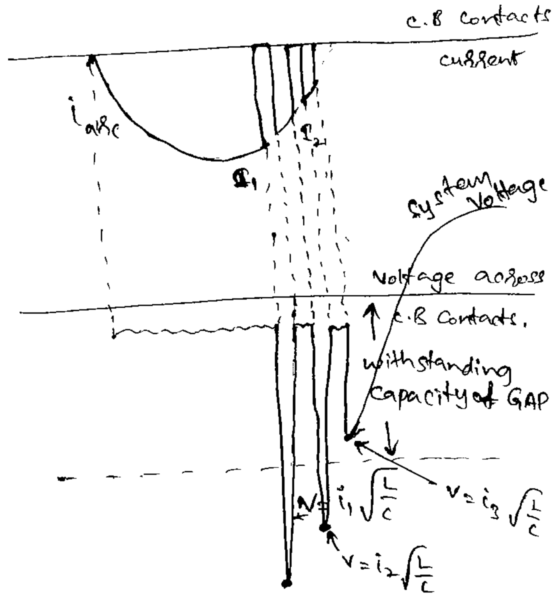
Current chopping phenomina is severe in Air Blast C.B

CB_2 operate at Full load condition

CB_1 operated to interupt No load current of Transformer,

CB_1 and CB_2 are air blast circuit breakers

Current carried by arc between C.B, contacts is less



Arc interruption medium strength is independent on arc strength (magnitude of i_{arc}) in Air blast C.B.

- Current chopping happens during non-current zero arc interruptions.

~~The~~ During $I \neq 0$ arc interruption electro-magnetic energy stored in 'L' will converted in to electrostatic energy across 'C'.

$$\frac{1}{2}CV^2 = \frac{1}{2}Li^2$$

$$V^2 = \frac{L}{C}i^2$$

$$\boxed{V = i\sqrt{\frac{L}{C}}}$$ → Prospective voltage across C.B contacts.

If prospective voltage > with standing capacity of gap then the arc will ~~resistive~~. restrike.

Arc will be interupted again after restriking because the arc interuption medium strength is appriciable quantity ~~in~~ the space of contacts.

Current chopping phenomina will be reduced by using Resistance switching.