POWER SYSTEMS NOTES

GATE 2009

JANARDHANARAO

PS-I (19-20)M

SUN.
27/07/2008

→ Power Generation

→ Basic concepts in power Tr. & Tr. line constants.

→ Performance of Tr. line $<$ Short, Medium, Long —(3M)

→ Wave travelling

2M{ → voltage control

→ Concept of corona

→ Over head line Insulators

→ Under ground cables

→ Distribution Systems

8M → PU system, Symmetrical components, fault Analysis.

{ → construction of Z_{BUS}

3M → Power System stability

2M → Economic aspects & economic load dispatch

1M → HVDC Tr.

Power System:

It consists of all most all electrical equipments and they are placed at different locations depends on requirement and all of them working together for the purpose of supplying electrical energy to consumer on economical basis.

It consists of Generation, transmission and Distribution.

Electrical Energy:

↳ To get an artificial illumination in order to see objects very clearly.

↳ To drive the mechanical loads.

Adv.s of Electrical Energy compared to Non-Electrical:

→ Efficiency is more

→ Reliability is high.

→ Economical

→ Easy control

→ No atmospheric pollution

Non-conventional, conventional > Mech. energy → Electrical energy → Mech. Load

Non-conventional	Conventional
* Small capacity power generation for shorter interval of time	* Bulk power Generation for longer interval of time
Eg: Solar, wind, Tidel, Biomass, Geothermal, MHD	Eg: steam (or) Thermal, Hydel, Nuclear, Gas. (Diesel)
* kw	* 5MW – 500MW
220V, 615V, 1.1kV → LV	3.3kV, 6.6 kV, 11 kV, 13.2 kV 18.6 kV and 22 kV (Max). → HV

* 1,30,000 MW

63% Thermal

32% Hydel

5% Nuclear + Gas + Non-conventional

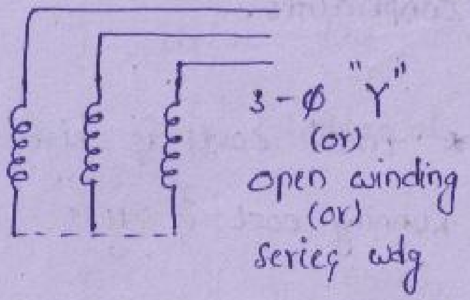
* Reliability is less	* Reliability is more.
* No much installation constraints but there are some operational constraints.	* There are installation constraints but no operational constraints.
* cost → $\underbrace{Rs.x/kw}_{\text{fixed cost}} + \underbrace{Paise\ y/kwh}_{\text{Running cost}}$ fixed cost is less Running cost is high	* fixed cost is high Running cost is less.
* Asynchronous generators are used. (var. speed) Eg: Induction Generators	* Syn. Generators are used (const. speed) Eg: Alternators
* No question of transmission of power because of low power generation. so It is connected to distribution.	* Bulk power is generated at remote places and it has to be carried out to the populated area by using a suitable n/w, known as Transmission and then followed by distribution.

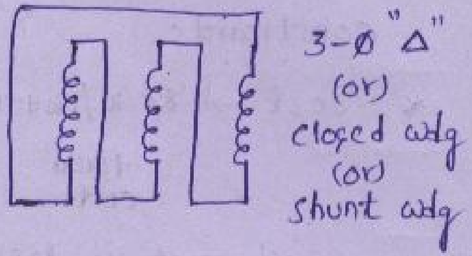
Generation < 1-φ
3-φ → bulk power
↳ Reliability is high
↓
3 Single phase wdgs { (1) Amount of current ($I \propto a$)
(2) at what voltage
(Insulation $\propto V$)

* Leakage current depends on field intensity ($E \propto V$)

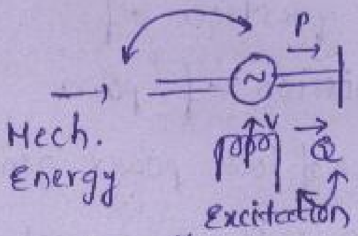
* To prevent leakage current insulation is employed

If the dielectric strength (kv/cm/peak) of the insulation is more than that of field intensity then there are no leakage currents.



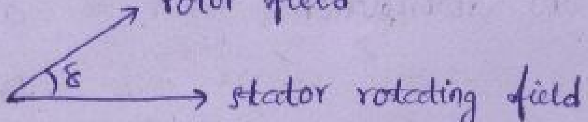


To employ the effective protective system in a phased manner 3-Ø "Y" wdg is preferred. and to provide the closed path for ground faults the neutral of the alternator should be grounded.



Syn. m/c – Stability – Synchronization $\begin{cases} V \\ f \end{cases}$

$E\angle\delta$



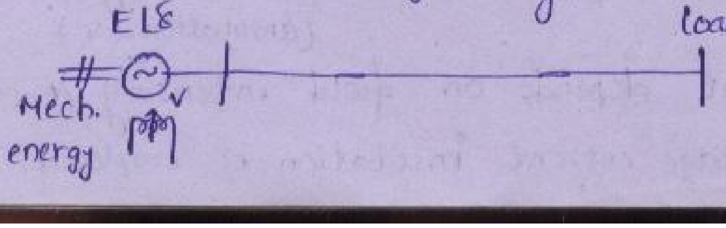
δ – power angle

δ decides "N" → "f".

$\delta \leq 90$ → stable

$\delta > 90$ → unstable operation

To maintain the stability ($\delta \leq 90$) during faults we can prefer resistor neutral grounding, other than inductive neutral grounding.



load $\begin{cases} \text{Asyn. load} \to \text{I/Motor} \to V\angle 0 \\ \text{Syn. load} \to \text{Syn/motor} \end{cases}$

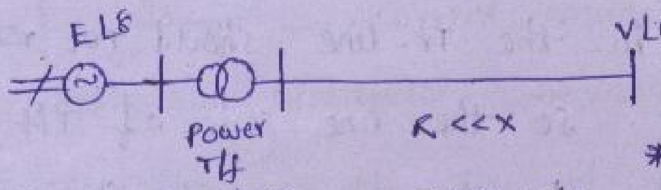
↳ $V\angle\delta$

Upto 33 kV transmission → HV

66 kV, 132 kV, 220 kV → EHV

400 kV → Modern EHV

765 kV and above → UHV.



1MVA & above → power T/f.

≤500 kVA → Distribution T/f

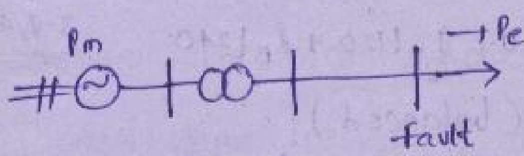
* power transfer, if load is a syn. load,

$$P = \frac{EV}{X} \sin(\delta_s - \delta_r)$$

* Power transfer, if load is Asy load

$$P = \frac{EV}{X_{eq}} . \sin\delta$$

* for getting more stability, δ should be less.



$P = P_m - P_e$

$= P_m \quad (P_e = 0)$

+Ve acceleration

$N > N_s$ ↑ transient stability

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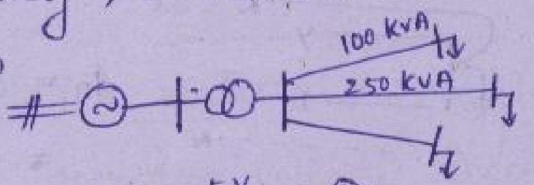
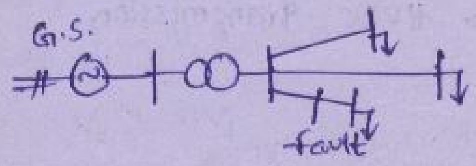


$$P = \frac{EV}{\boxed{X_{eq}}\downarrow} \sin\boxed{\delta}\downarrow$$

steady state stability

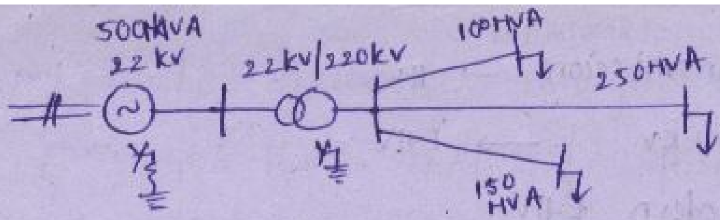
↑ parallel Tr. lines



$P = P_m - P_e\downarrow (\neq 0)$

$= +ve$

In order to maintain SS. stability as well as Tr. stability, it is prefer to run $\parallel^{el}$ tr. lines from the G.S.

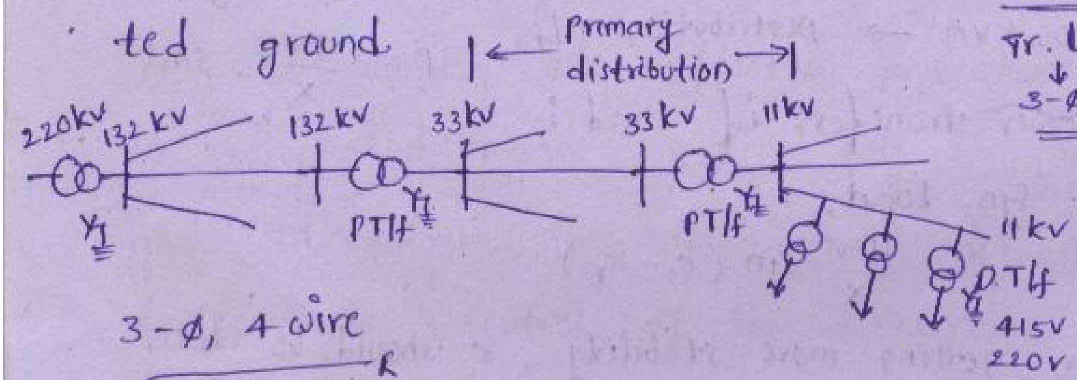


⟹ T/f secondary is Y

So by default, Tr. lines are $\boxed{Y} \Rightarrow V_{ph} = V_L/\sqrt{3}$, $I_{ph} = I_L$

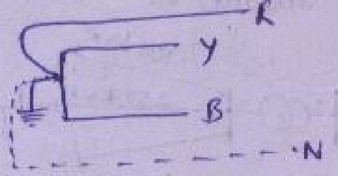
In selecting wdg for the T/f's it should ensure that the faults in the Tr. line should not reflect towards alternator. So the line side of T/f must be grounded and the source side is isolated ground.

Tr. line
↓
3-φ, 3 wire



secondary distribution
↓
3-φ, 4 wire

3-φ, 4 wire



$$I_n = I_R\angle 0 + I_Y\angle 120 + I_B\angle 240$$
$$= 0 \text{ (balanced)}$$

In practical $I_n \neq 0$ (unbalance) → 10 to 15% of full load current. So the relays are designed with 120% of pickup value but not with 100%.

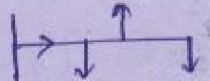
beyond 500 km ⟹ >500 km ⟹ HVDC Transmission.
(To maintain stability)

Max. level of DC in India ± 500 kV.

→ Selection of the size of the conductor for EHV line → Based on current carrying capacity

→ Selection of the insulation of the conductor for EHV line → Based on surge (switching surge)

In Tr. line there are no intermediate consumers hence the mag. of current ~~towards~~ throughout its length is same. → feeders. → constant current density



→ current varies through out its length → Distributor. → variable current density $J = \frac{I}{A}$

→ Selection of the size of the conductor for distribution based on voltage drop.

⇒ for the same power, same material and same length, if the operating volt. is increased by n-times then the area of the cross-section of the conductor is —? $a_2 = \frac{1}{n} a_1$

⇒ for the same power, same material, same length and same loss, if the operating volt. is increased by n-times then the area of the cross-section of the conductor is —? $a_2 = \frac{1}{n^2} a_1$

$$P = V_1 I_1 \cos\phi$$
$$= V_2 I_2 \cos\phi$$
$$V_2 = nV_1$$
$$I_2 = \frac{I_1}{n}$$
$$P = nV_1 \cdot \frac{I_1}{n} \cdot \cos\phi$$
$$= V_1 I_1 \cos\phi$$
$$I \propto a$$
$$I_1 \propto a_1$$
$$I_2 \propto a_2$$
$$I_2 = \frac{I_1}{n} \Rightarrow a_2 = \frac{a_1}{n}$$

$P = VI\cos\phi$ → power

$P = I^2 R$ → loss

$$= I^2 \frac{\rho l}{a}$$
$$\Rightarrow a = \frac{I^2 \rho l}{P}$$
$$= \frac{\left(\frac{P}{V\cos\phi}\right)^2 \rho l}{P}$$
$$= \frac{K}{V^2 \cos^2\phi}.$$
$$\Rightarrow a \propto \frac{1}{V^2 (pf)^2}$$

volume (or) weight of the conductor, $w = a \times l$

$w \propto a$

$a_2 = \frac{a_1}{n}$

$\rightarrow w_2 = \frac{w_1}{n}$

Tr. Line loss → reduced.

$P_1 = I_1^2 R_1$

$P_2 = I_2^2 R_2$

$I_2 = \frac{I_1}{n} \quad \left\{ R = \frac{\rho l}{a} \rightarrow R \propto 1/a \right\}$

$a_2 = \frac{a_1}{n}, \; R_2 = nR_1$

$P_2 = \left(\frac{I_1}{n}\right)^2 (nR_1)$

$= \frac{I_1^2 R_1}{n} = \frac{P_1}{n}$

efficiency $\eta = 1 - \frac{k}{V\cos\phi}$ pu

$\rightarrow \% \eta = \left(1 - \frac{k}{V\cos\phi}\right) 100$

k - constant

If $V \uparrow \Rightarrow \% \eta \uparrow$

$\eta = \frac{o/p}{o/p + \text{losses}}$

$= \frac{P_r}{P_r + I^2 R}$

$= \frac{P_r}{P_r + I^2 \frac{\rho l}{a}} \quad (a = I/J)$

$= \frac{P_r}{P_r + I \rho l J} \quad P = VI\cos\phi \rightarrow I = \frac{P}{V\cos\phi}$

$= \frac{1}{1 + \frac{k}{V\cos\phi}} = \left(1 + \frac{k}{V\cos\phi}\right)^{-1} = 1 - \frac{k}{V\cos\phi}$.

If power factor is constant.

$a \propto \frac{1}{V^2}$

$\frac{a_1}{a_2} = \frac{V_2^2}{V_1^2}$

$V_2 = nV_1$

$\frac{a_1}{a_2} = \frac{(nV_1)^2}{V_1^2}$

$\rightarrow a_2 = \frac{1}{n^2} a_1$

which of the following Tr. line having higher size

(a). 132 kv power handling capacity

(b). 220 kv

✓(c). 400 kv

which of the following Tr. line having higher size for the same power.

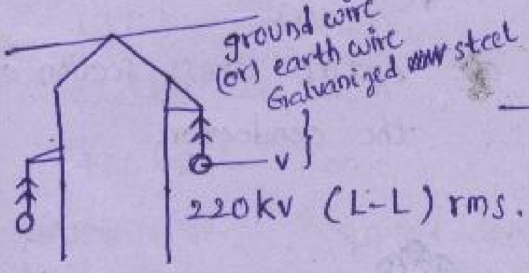
✓(a). 132 kv

(b). 220 kv

(c). 400 kv

The operating volt-s of a 3-ϕ, 3wire tr. line are — ?

ph-ph (rms) (or) L-L (rms).

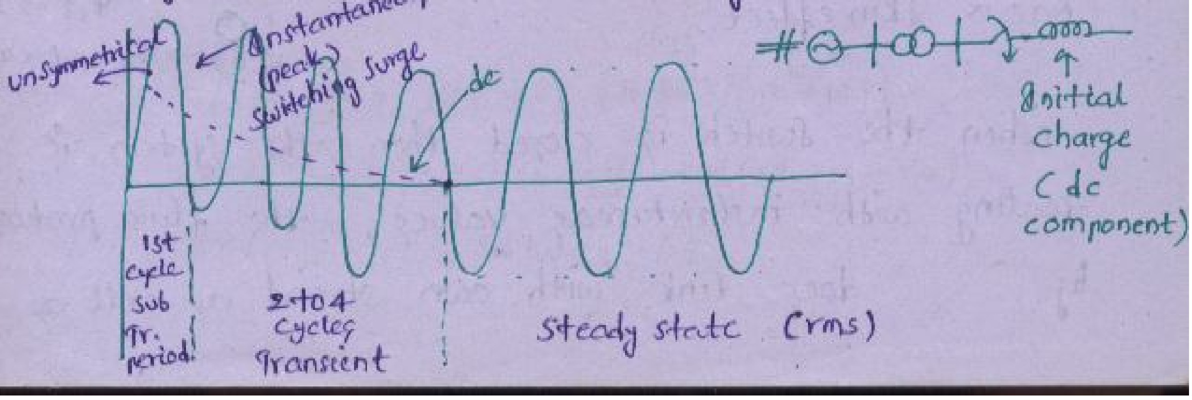


→ Then per ph. voltage is $\frac{220}{\sqrt{3}}$

Over voltages are due to (i). Direct lightning surge
(ii). Switching surge

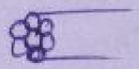
Direct Lightning surges are diverted by using ground wires → Surge diversion.

Running ground wire → Shielding Method



→ Different Types of conductors :-

Solid conductors →


Stranded conductors →

twisted together

Composite stranded conductors → ≤ 220 kv

Bundle conductors → 275 kv and above

Solid	Stranded
1). High skin effect	1) low skin effect

Skin Effect :

In ac system the current distribution is not uniform that means most of current concentrated on the surface (outer). because there are non uniform flux linkages.

$$R_{ac} \text{ (or) } R_{eff} = \frac{\rho l}{a'} \quad ; \quad R_{dc} = \frac{\rho l}{a}$$

(RHS)

a: entire cross-section of the conductor.

a': Area in which current concentration is high. (effective area).

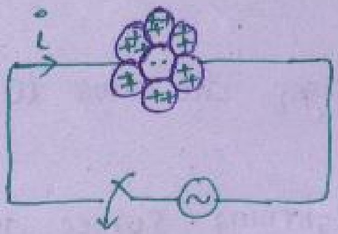
$a' < a$

$\Rightarrow R_{ac} > R_{dc}$

$\Rightarrow R_{ac} = k . R_{dc}$

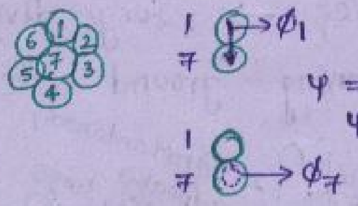
$k = 1.6$

$R_{ac} \propto$ skin effect.



$L_{in} \to$ high

$L_{ex} \to$ low



$\psi = N\phi$

$\psi_7 \uparrow \Rightarrow L_7 \uparrow$

$L \propto \psi$

when the switch is closed then the system is dealing with instantaneous values, the flux produced by does link with own strand as well as inner strand, but not viceversa by the flux produced by the inner strand, so the flux linkages are more in the inner strand than the outer strand.

Then inductance for inner strands is high and for outer strands is low, so most of the current allow to flow through outer strands.

for solid conductors, a' is less when compared to stranded. so R_{ac} is more in the solid so skin effect is more in case of solid compared to stranded.

Span Length : Distance b/w the two towers

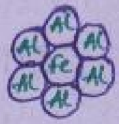
132 kV → 300m

220 kV → 350m

400 kV → 400m

Composite stranded conductor:

→ Inner strand is having high mech. strength and the outers having high conductivity



Eg : ACSR

→ skin effect further reduced compared to stranded.

FRI. 15/08/08

$$7/30 \xrightarrow{37} 132\text{ kV} \quad (\overset{\text{steel}}{(1+6)}/\overset{\text{Al}}{(12+18)})$$

$$7/54 \xrightarrow{61} 220\text{ kV} \quad ((1+6)/(12+18+24))$$

$$1/6 \xrightarrow{7} \leq 33\text{ kV} \quad (1/6)$$

→ selection of size of conductor for Modern EHV line → concept of corona

→ In case of bundle conductors GMR is high b'coz sub condu. spacing is also taking into account. where as no change in GMD.

If self distance increases the field intensity at the surface of each sub condu. is reduced. then ionization of air also reduced.

→ $L/ph = 2\times10^{-7} \ln\left(\frac{GMD}{\text{self GMD}}\right)$ H/m.

$$C/ph = \frac{2\pi\varepsilon_0}{\ln\left(\frac{GMD}{\text{self GMD}}\right)}$$

If self GMD is increased then L/ph reduced and c/ph increased.

→ characteristic impedance $= \sqrt{\frac{L\downarrow}{C\uparrow}}$ → reduced

→ power system stability $P = \frac{EV}{X_{eq}} \cdot \sin\delta$ increased

→ GMR :

$r' = 0.7788r$

where 'r' is the radius of the conductor.

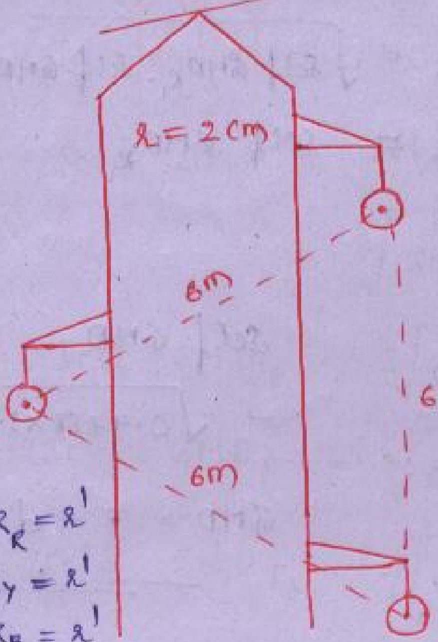
Geometric mean
↓
space quantities

Arithmetic mean
↓
plane quantities

GMR is used for the calculation of inductance but not for capacitance calculations.

b'coz there are inner and outer flux linkages but not inner charge concept,  → inside charge distribution = 0.

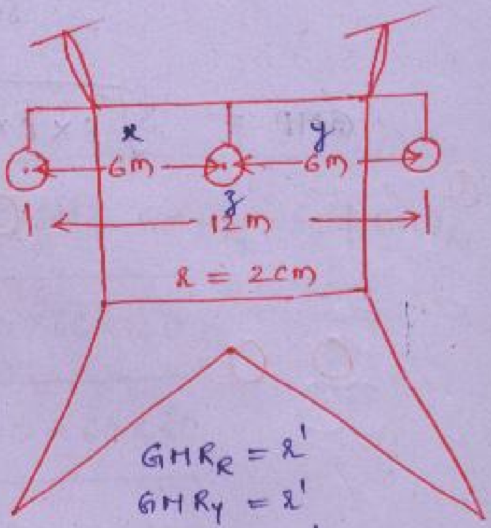
Q.



$GMR_R = r'$

$GMR_y = r'$

$GMR_B = r'$



$GMR_R = r'$

$GMR_y = r'$

$GMR_B = r'$

$$GMR = \sqrt[3]{GMR_R \cdot GMR_y \cdot GMR_B}$$

$$= \sqrt[3]{GMR_R^3} = GMR_R = r'$$

$$= 0.7788 \times 2$$

$GMD_R = \sqrt{6 \times 6} = 6$

$GMD_y = \sqrt{6 \times 6} = 6$

$GMD_B = \sqrt{6 \times 6} = 6$

$$GMD = \sqrt[3]{GMD_R \cdot GMD_y \cdot GMD_B}$$

$$= GMD_R$$

$GMD = d = 6cm$

[equilateral spacing)

$$GMR = GMR_R = r'$$

$$= 0.7788 \times 2$$

$GMD_R = \sqrt{6 \times 12} = 6\sqrt{2}$

$GMD_y = \sqrt{6 \times 6} = 6$

$GMD_B = \sqrt{6 \times 12} = 6\sqrt{2}$

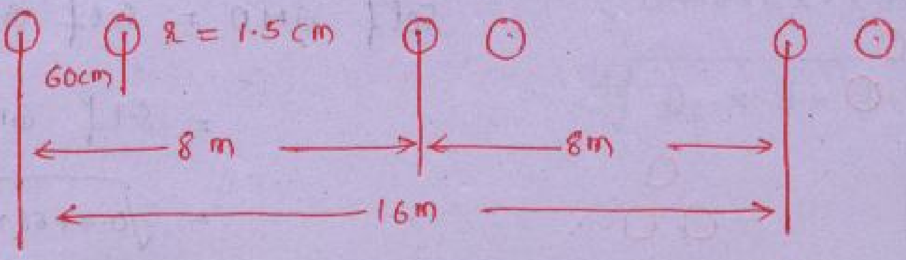
$$GMD = \sqrt[3]{GMD_R \cdot GMD_y \cdot GMD_B}$$

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

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

(un Symmetrical spacing)

Q.



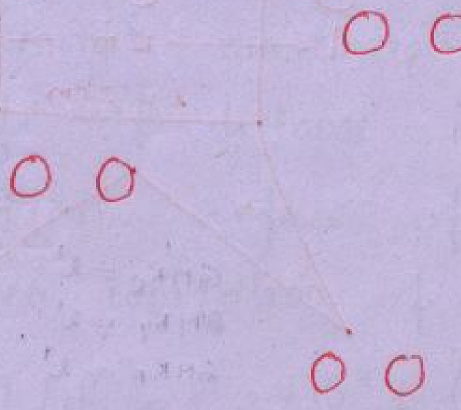
$$\text{Self GMD} = \sqrt{0.7788 \times 1.5 \times 60}$$

$$= \text{Self GMD}_R = \sqrt{\text{Self GMD}_{R_1} \cdot \text{Self GMR}_{R_2}}$$

$$= \text{Self GMD}_{R_1}$$

$$\text{GMD} = \sqrt[3]{8 \times 8 \times 16}$$

Q.



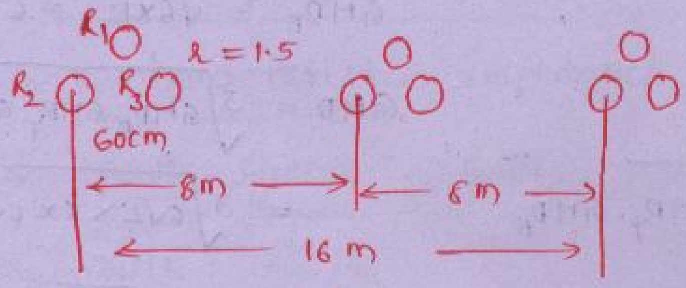
Self GMD

$$= \sqrt{0.7788 \times 1.5 \times 60}$$

$$\text{GMD} = 8 = d \text{ cm}$$

⇒ In case of bundle conductors, consider the sub condu. effect for calc. of self GMD and ignore sub condu. effect for calc. of GMD.

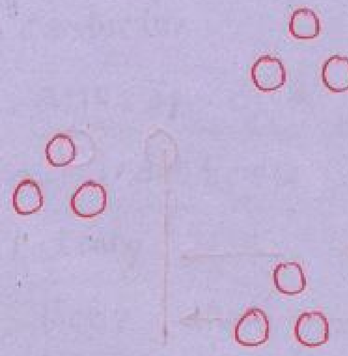
Q.



$$\text{Self GMD} = \text{Self GMD}_R = \text{Self GMD}_{R_1}$$

$$= \sqrt[3]{0.7788 \times 1.5 \times 60 \times 60}$$

Q.

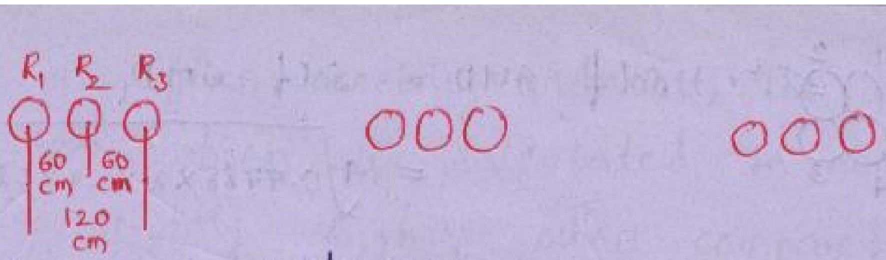


$$\text{Self GMD} = \text{Self GMD}_R$$

$$= \text{Self GMD}_{R_1}$$

$$= \sqrt[3]{0.7788 \times 1.5 \times 60 \times 60}$$

Q.



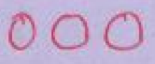
Self GMD = self GMD_R

$= \sqrt[3]{\text{self } GMD_{R_1} \cdot \text{self } GMD_{R_2} \cdot \text{Self } GMD_{R_3}}$

self $GMD_{R_1} = \sqrt[3]{0.7788 \times 1.5 \times 60 \times 120}$

self $GMD_{R_2} = \sqrt[3]{0.7788 \times 1.5 \times 60 \times 60}$

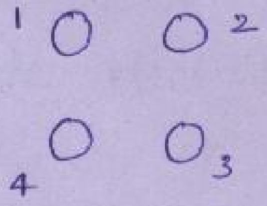
self $GMD_{R_3} = \sqrt[3]{0.7788 \times 1.5 \times 60 \times 120}$



Self GMD = self GMD_R

$= \sqrt[3]{\text{self } GMD_{R_1} \cdot \text{self } GMD_{R_2} \cdot \text{self } GMD_{R_3}}$.

self distance of each sub conductor is 'D_s'. the adjacent distance b/w any two sub. condu.s is 'd'. calc. self GMD.

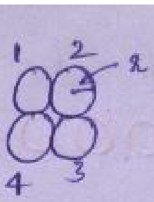


self GMD $= \sqrt[4]{S.G_1 \times S.G_2 \times S.G_3 \times S.G_4}$

= self GMD_1

$= \sqrt[4]{0.7788 \times r \times d \times d \times \sqrt{2}d}$

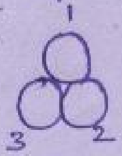
$= \sqrt[4]{D_s \times d \times d \times \sqrt{2}d}$



self GMD = self GMD$_1$

$$= \sqrt[4]{0.7788 \times r \times 2r \times 2r \times 2\sqrt{2}r}$$

There are 3 sub condu. in each ph. touching each other. Radius of each is r. Then self GMD = ?



self GMD = self GMD$_1$

$$= \sqrt[3]{0.7788 \times r \times 2r \times 2r}$$

* for the given receiving end volt, the sending end volt which is calculated in nominal π is slightly high, when compared to nominal-T. so reg in nominal π will be slightly high when compared to nominal-T.

Q. which n/w model of medium Tr. line is more practical ?

(i). N-T [✓ (ii). N-π]

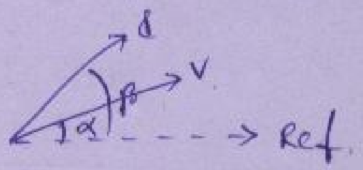
(iii). sending end capacitance

(iv). Receiving (or) load end " .

Ans: Nominal - π.

* In all practical cases, the V_s is fixed where as V_r is variable and the N-π model will provide a better V_r when compared to N-T, b'coz 50% of the capacitance will be placed at the Load point.

* while dealing with AC, it should ensure that the real power is always +ve and Q may be +ve or -ve depends on the load. In order to fulfil the above statement, it is necessary to consider conjugate concept on any one of the electrical quantity.



$$S = VI$$

$$= V\angle\alpha \cdot I\angle\beta$$

$$= VI\angle\alpha+\beta$$

$$S = VI\cos(\alpha+\beta) + J\,VI\sin(\alpha+\beta)$$

If $(\alpha+\beta) > 90^\circ \rightarrow S = -P + JQ$.

If we introduce conjugate concept,

$$S = VI^* = |V| \angle\alpha \cdot |I| \angle -\beta$$

$$= VI \angle \alpha - \beta$$

* If $\alpha > \beta$, the current lags volt. ie inductive load. so P is +ve & Q also +ve.

* If $\alpha < \beta$, the volt lags the current ie capacitive load. so P is +ve & Q is -ve.

Syn. Generator (Alt.) Both (are deliver P↑, Q↑ (Lagging)	Syn. load (Syn. motor) P↓, Q↑ (leading)
Asyn. GEN (Induction GEN) P↑, Q↓ (leading)	Asyn. load (Induction motor) P↓, Q↓ (both are taking) (lagging)

Long Tr. line :-

TUE. 28/10/08

$V_s = \cosh \gamma l \, V_r + Z_c . \sinh \gamma l \, I_r$

$I_s = \frac{1}{Z_c} . \sinh \gamma l \, V_r + \cosh \gamma l . I_r$

$Z_c = Z_s =$ char. impedance $= \sqrt{\frac{B}{C}} = \sqrt{\frac{Z}{Y}}$

$= \sqrt{\frac{\text{imp / km}}{\text{adm / km}}} = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$

for loss-less Tr. line $R = 0$ & $G = 0$.

$\rightarrow Z_c = \sqrt{\frac{L}{C}}$; $\rightarrow$ Z_c is independent of line length as well as freq. of supply.

$\gamma =$ propagation constant

$= \sqrt{ZY} = \sqrt{(R + j\omega L)(G + j\omega C)}$

$\gamma = \alpha + j\beta$

$\rightarrow \alpha =$ attenuation const, Neper/km

$\beta =$ ph. component (or) quadrature component

$=$ rad / km.

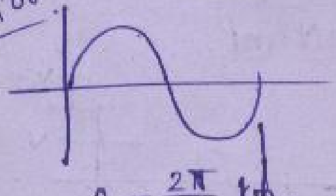
for Loss-less Tr. line,

$\gamma = j\omega\sqrt{LC}$

$= j\beta$ [NO Attenuation]

$\rightarrow \beta = \omega\sqrt{LC}$.

G'08



$\lambda = \frac{2\pi}{\beta}$ km.

The most economical loading on over head T.L is loading > SIL

$\rightarrow Z_L < Z_c$.

The most economical loading on under ground cable is loading < SIL

$\Rightarrow Z_L > Z_c$. in order avoid the failure of insulation due to temp. gradient.

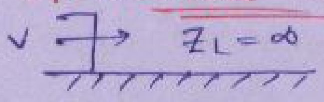
* In order to improve the performance of Tr. line the load volt. has to be improved and to prevent the failure of insulation the load volt. reduced. so it is necessary to have control on load volt.

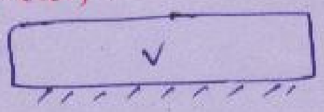
* If loading on the T.L is more than SIL, Syn. capacitor is used for voltage control. It improves the volt. as well as improve the pf of the load. so it will be prefered as pf correction device rather than voltage control device.

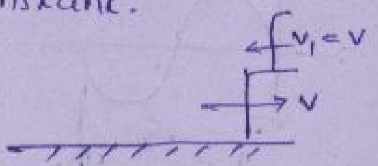
Wave Travelling :-

* The concept of reflection as well as refraction will be predomenent dureng 1st enstant rather than the subsequent instant.

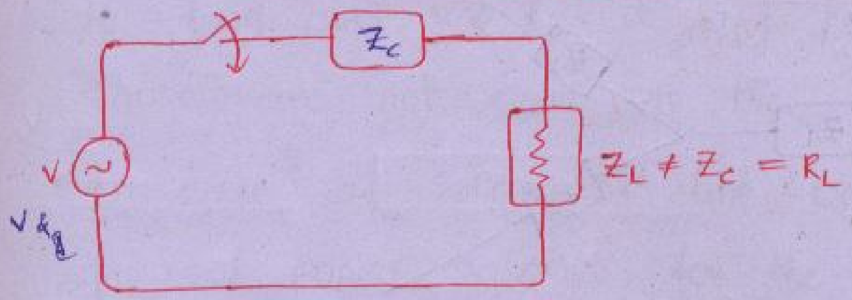
Open circuit condition :-







Line is terminated by a load :-



According to o/c,

$$V_2 = V + V_1$$

According to s/c,

$$I_2 = I + I_1$$

$$\frac{V_2}{Z_L} = \frac{V}{Z_c} - \frac{V_1}{Z_c}$$

To know V_2, replace $V_1 = V_2 - V$

$$\Rightarrow V_2 = 2V \cdot \frac{Z_L}{Z_L + Z_c}$$

$$\frac{V_2}{V} = 2 \cdot \frac{Z_L}{Z_L + Z_c} \rightarrow$$ coe. of refraction for voltage.

$$I_2 = \frac{V_2}{Z_L} = \frac{2V \cdot \frac{Z_L}{Z_L + Z_c}}{Z_L} = 2I \cdot \frac{Z_c}{Z_L + Z_c} \quad [V = I Z_c]$$

$$\Rightarrow \frac{I_2}{I} = \frac{2 Z_c}{Z_L + Z_c} \rightarrow$$ coe. of refraction for current

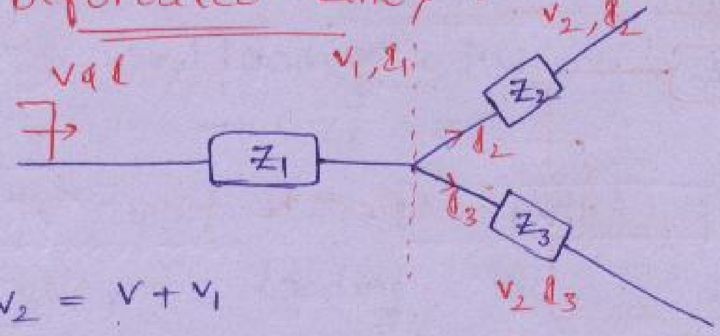
$$V_1 = V \left[\frac{Z_L - Z_c}{Z_L + Z_c} \right]$$

$$\frac{V_1}{V} = \left[\frac{Z_L - Z_c}{Z_L + Z_c} \right] \rightarrow$$ coe. of reflection voltage.

$$I_1 = -\frac{V_1}{Z_c} = \frac{-V \left[\frac{Z_L - Z_c}{Z_L + Z_c} \right]}{Z_c} = -I Z_c \left[\frac{\frac{Z_L - Z_c}{Z_L + Z_c}}{Z_c} \right]$$

$$\rightarrow \frac{I_1}{I} = -\left[\frac{Z_L - Z_c}{Z_L + Z_c} \right] \rightarrow$$ coe. of reflection for current.

Bifurcated Lines :-



$V_2 = V + V_1$

$I_2 + I_3 = I + I_1$

$\frac{V_2}{Z_2} + \frac{V_2}{Z_3} = \frac{V}{Z_1} - \frac{V_1}{Z_1}$

sub. $V_1 = V_2 - V$

$\Rightarrow V_2 = 2V \cdot \frac{Z_2 Z_3}{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1}$

$I_2 = \frac{V_2}{Z_2}$

$I_3 = \frac{V_2}{Z_3}$

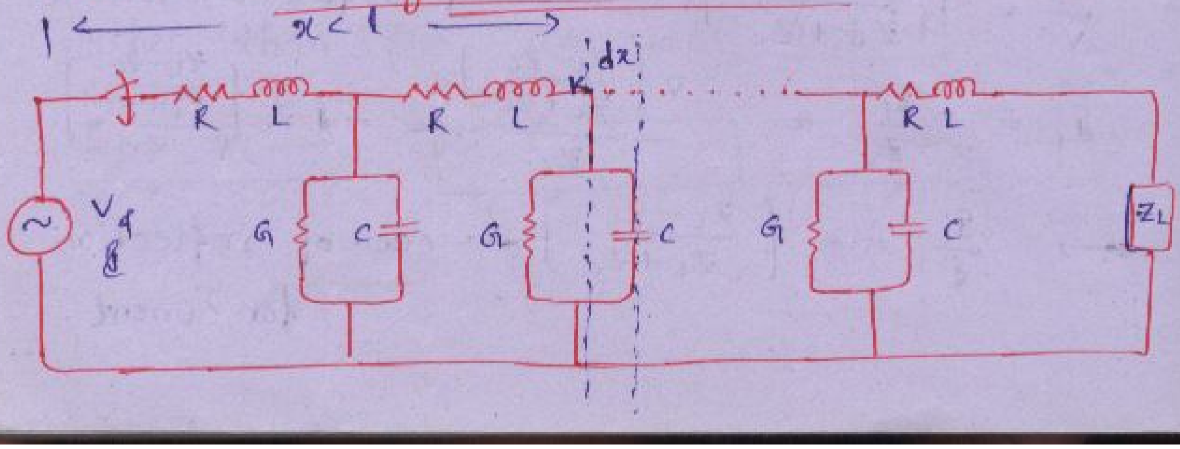
To find V_1, replace $V_2 = V + V_1$

$(V + V_1)\left[\frac{1}{Z_2} + \frac{1}{Z_3}\right] = \frac{V}{Z_1} - \frac{V_1}{Z_1}$

$\Rightarrow V_1 = V\left(\frac{Z_2 Z_3 - Z_1 Z_2 - Z_1 Z_3}{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1}\right)$

$I_1 = -\frac{V_1}{Z_1}$

wave travelling - Attenuated TL. [$R \neq 0$]



Due to resistance of TL, which is necessary to find out V & I at any point. b'coz those are not equal to the switched V & I.

In case of attenuated line, use the concept of real power balance for the purpose of wave travelling

During the wave travelling the pf of TL is assumed as unity b'coz net reactive power is zero.

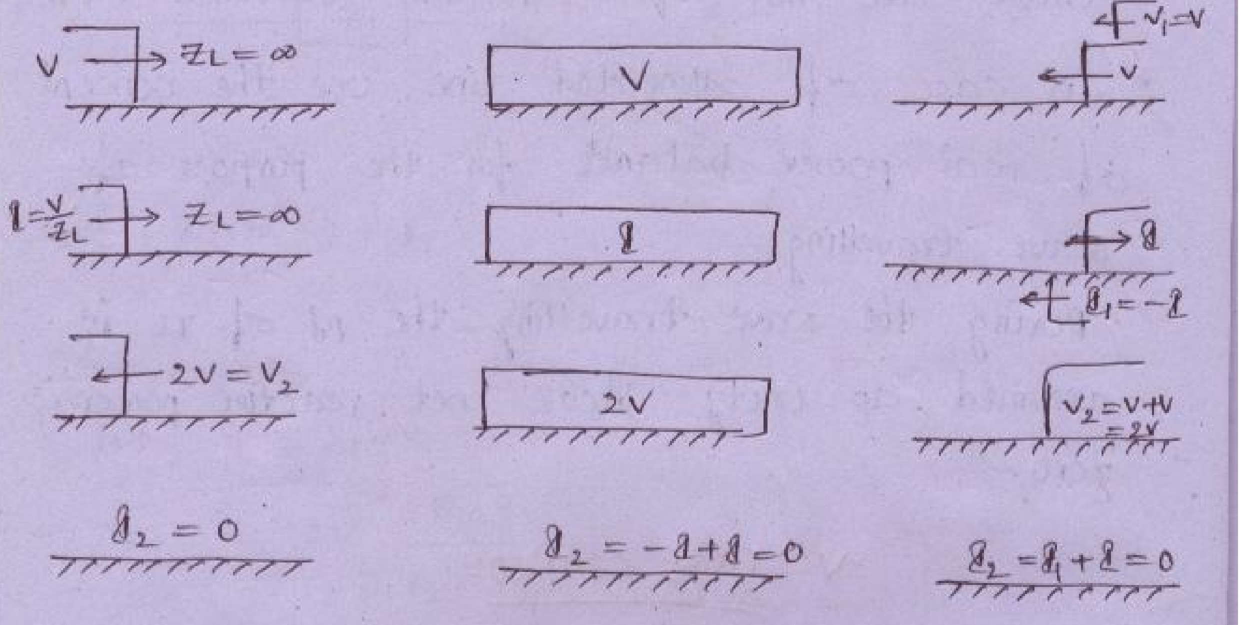
VOLTAGE CONTROL

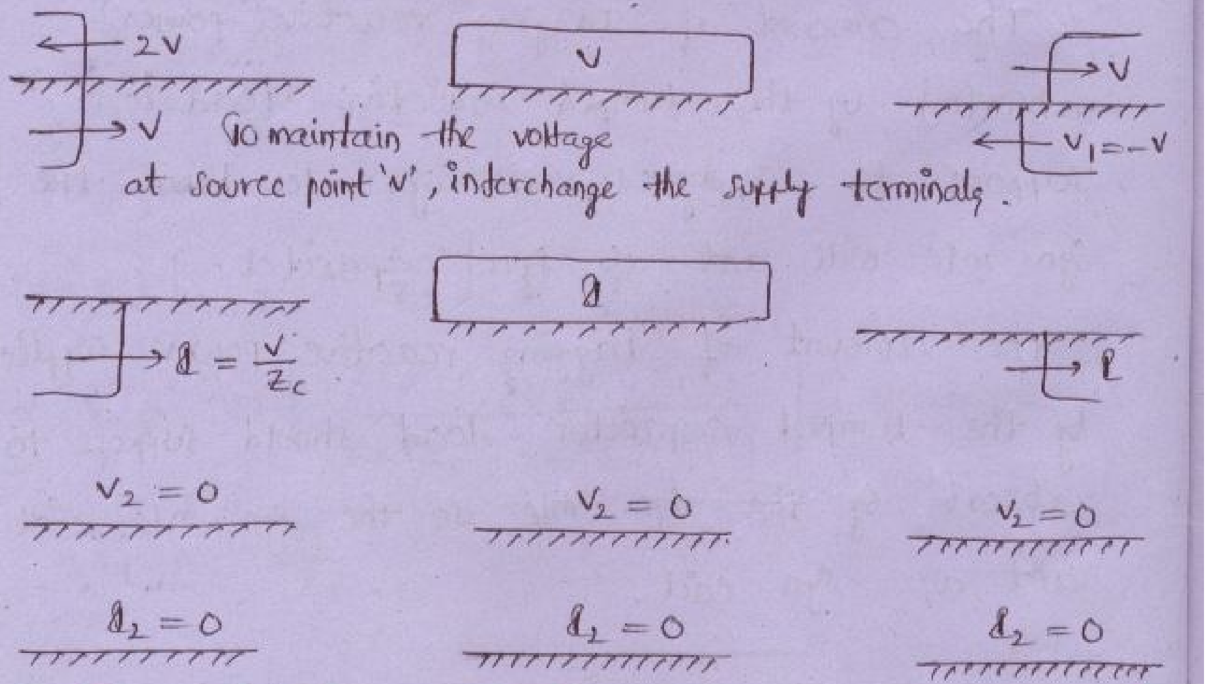
The amount of lagging reactive power absorbed by the lumped inductive load is suppose to supply by the syn. m/c hence the syn m/c will act as syn. capacitor.

The amount of lagging reactive power supplied by the lumped capacitor load should suppose to absorb by the syn. m/c so the syn. m/c will act as syn. coil.

WAVE TRAVELLING

For o/c line [Loss - less line]





To maintain the voltage at source point 'v', interchange the supply terminals.

Sending end side

During TL

Receiving end side

$V_1 = V$

$i_1 = -i$

$V_2 = 2V$

$i_2 = 0$

$\frac{V_1}{V} = 1$

$\frac{i_1}{i} = -1$

$\frac{V_2}{V} = 2$

& $\frac{i_2}{i} = 0$.

$\frac{V_1}{V} = 1$ → coe. of reflection for volt. of o/c line

$\frac{I_1}{I} = -1$ → " " current "

$\frac{V_2}{V} = 2$ → " refeaction for volt. "

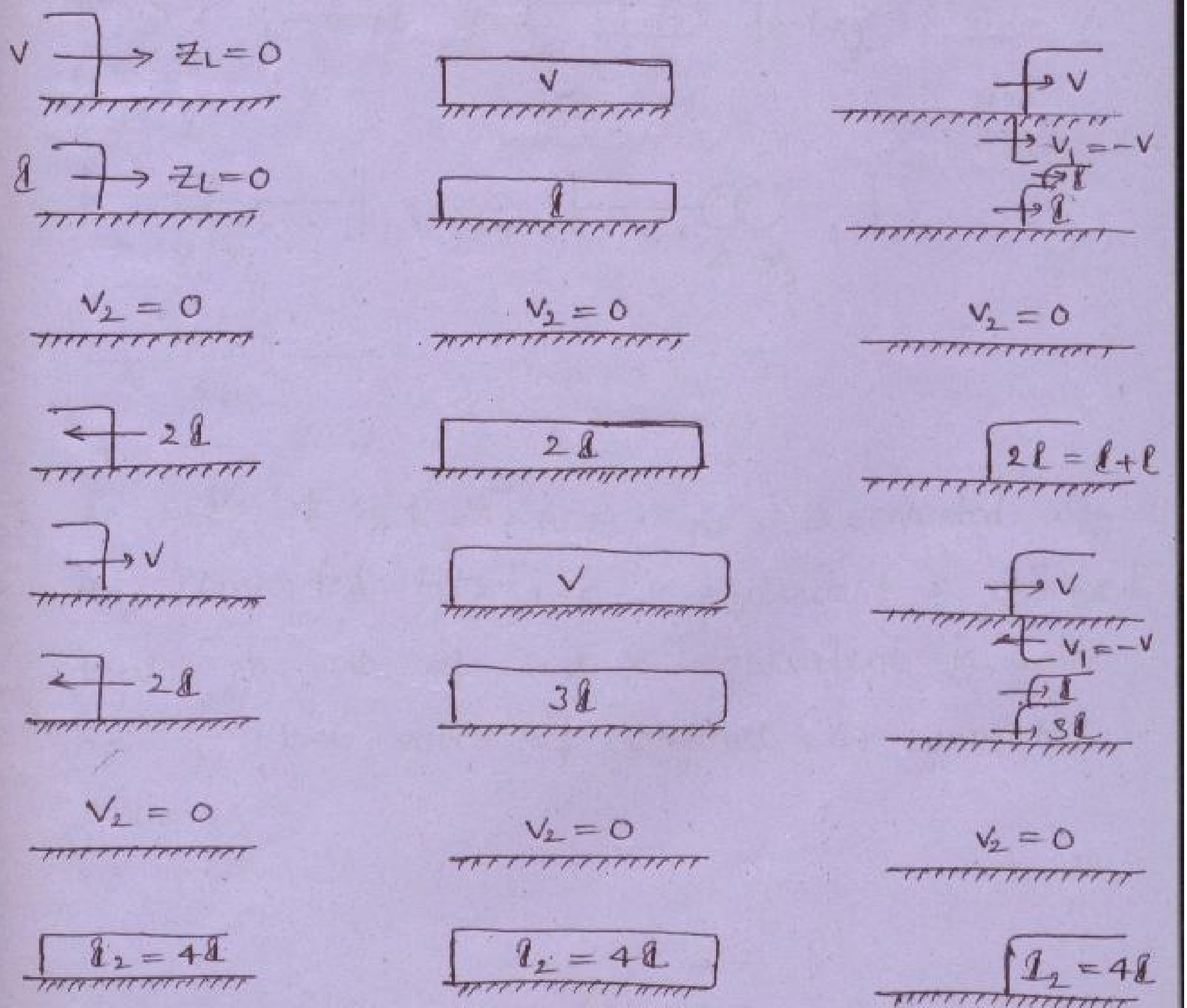
$\frac{I_2}{I} = 0$ → " " for current "

For s/c line [loss-less line] :

sending end side V & I

T.L.

Receiving end side V & I



$v_1 = -V$

$i_1 = i$

$v_2 = 0$

$i_2 = 2i$

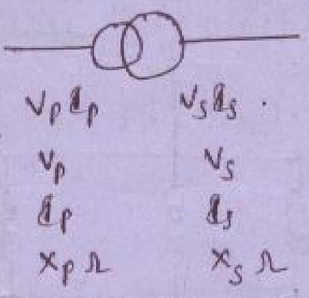
$\frac{v_1}{V} = -1 \longrightarrow$ coe. of reflection for voltage.

$\frac{i_1}{i} = 1 \longrightarrow$ " " " current.

$\frac{v_2}{V} = 0 \longrightarrow$ " refraction " voltage.

$\frac{i_2}{i} = 2 \longrightarrow$ " " " current.

$x_{p\,pu} = x_{s\,pu}$



$$x_{p\,pu} = \frac{x_{p\,\Omega}}{x_b} = \frac{x_{p\,\Omega}}{V_p/I_p}$$

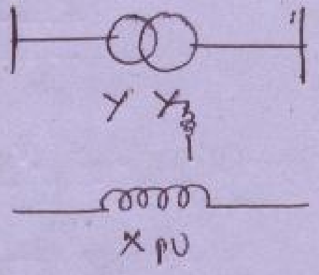
$$= x_{p\,\Omega}\cdot\frac{I_p}{V_p} = \frac{x_{s\,\Omega}}{K^2}\cdot\frac{I_p}{V_p}$$

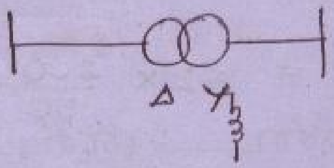
$$= \frac{x_{s\,\Omega}}{\left(\frac{V_s}{V_p}\right)^2}\cdot\frac{I_p}{V_p} = x_{s\,\Omega}\cdot\frac{V_p I_p}{V_s^2}$$

$$= x_{s\,\Omega}\cdot\frac{V_s I_s}{V_s^2}$$

$$= \frac{x_{s\,\Omega}}{V_s/I_s}. \quad = x_{s\,pu}.$$

* In order to get pu reactance of T/F as a equal value on both sides it can be assumed that p. volt. is base value while dealing p. side & s. " " " s. side.





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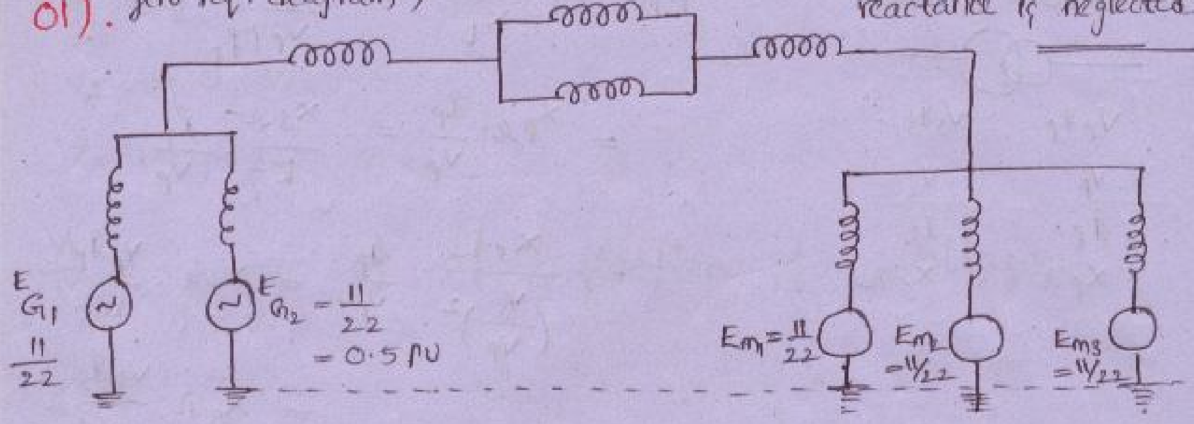
In order to get $x_{p\,pu} = x_{s\,pu}$, Δ connected wdg is converted into 1-ø Y equivalent & assumed that ph. volt. of 1-ø Y-equivalent is same as the L-L volt. of original Δ-connected system.

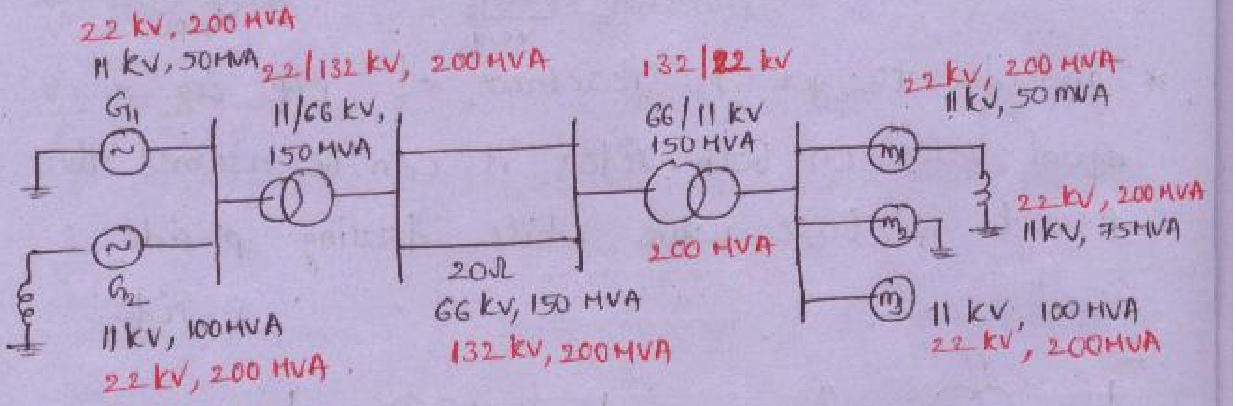
*(Neutral reactance is consider only when ~~sh~~ draw zero seq. diagram)

PU QUANTITIES

* If ground (neutral) is reference then neutral reactance is neglected.

01).





$$X_{G1\,pu\,new} = 1.2 \times \frac{200}{50}\left(\frac{11}{22}\right)^2$$

$$= 1.2 \text{ pu.}$$

$$X_{G2\,pu\,new} = 2.4 \times \frac{200}{100}\left(\frac{11}{22}\right)^2$$

$$= 1.2 \text{ pu}$$

$$X_{T1\,pu\,(new)_p} = 1.0 \times \frac{200}{150} \times \left(\frac{11}{22}\right)^2 = 0.33 \text{ pu}$$

$$X_{T1\,pu(new)_s} = 1.0 \times \frac{200}{150}\left(\frac{66}{132}\right)^2 = 0.33 \text{ pu}$$

$$X_{L1\,pu} = 20 \times \frac{200}{(132)^2} = 0.239$$

$$X_{L2\,pu} = 20 \times \frac{200}{(132)^2} = 0.239.$$

$$X_{T2\,pu\,(new)_p} = 1.0 \times \frac{200}{150}\left(\frac{66}{132}\right)^2 = 0.33$$

$$X_{T2\,pu\,(new)_s} = 1.0 \times \frac{200}{150}\left(\frac{11}{22}\right)^2 = 0.33.$$

X_{m1} pu(new) $= 1.2 \times \frac{200}{50}\left(\frac{11}{22}\right)^2 = 1.2$

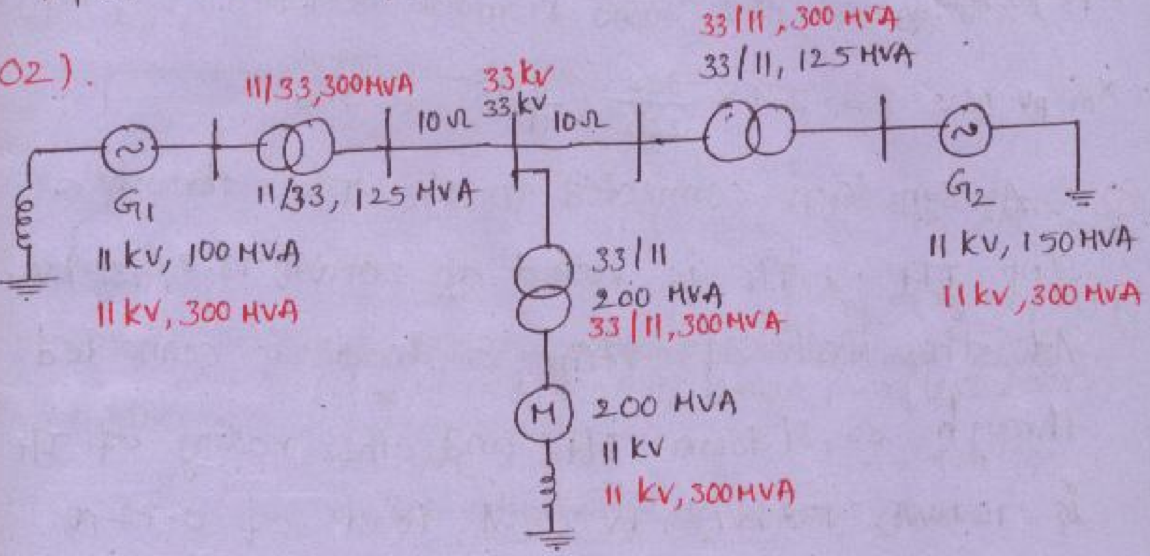
X_{m2} pu (new) $= 1.8 \times \frac{200}{75}\left(\frac{11}{22}\right)^2 = 1.2$

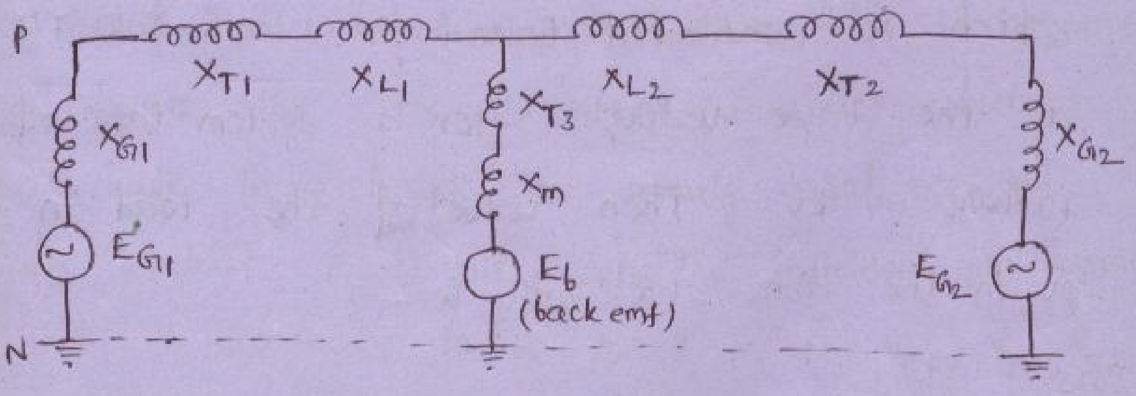
X_{m3} pu (new) $= 2.4 \times \frac{200}{100}\left(\frac{11}{22}\right)^2 = 1.2$

11/66 —×— 33/11

11/66 —✓— 66/6.6

Q2).





X_{G1} pu new $= 1.4 \times \frac{300}{100}\left(\frac{11}{11}\right)^2 = 4.2$

X_{T1} pu new$_{(P)}$ $= 0.8 \times \frac{300}{125}\left(\frac{11}{11}\right)^2 = 1.92$

X_{T1} pu new$_{(S)}$ $= 0.8 \times \frac{300}{125}\left(\frac{33}{33}\right)^2 = 1.92$

X_{L1} pu $= 10 \times \frac{300}{(33)^2} = 2.75$ pu

X_{G2} pu new $= 2.0 \times \frac{300}{150}\left(\frac{11}{11}\right)^2 = 4.0$

$$X_{T2\ pu\ new_{(P)}} = 0.8 \times \frac{300}{125}\left(\frac{11}{11}\right)^2 = 1.92$$

$$X_{T2\ pu\ new_{(S)}} = 0.8 \times \frac{300}{125}\left(\frac{33}{33}\right)^2 = 1.92$$

$$X_{L2\ pu} = 10 \times \frac{300}{(33)^2} = 2.75$$

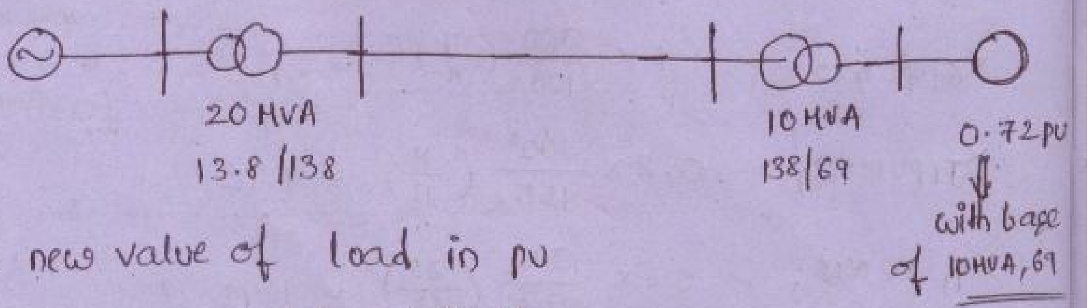
$$X_{T3\ pu\ new_{(P)}} = 1.2 \times \frac{300}{200}\left(\frac{33}{33}\right)^2 = 1.8$$

$$X_{T3\ pu\ new_{(S)}} = 1.2 \times \frac{300}{200}\left(\frac{11}{11}\right)^2 = 1.8$$

$$X_{m\ pu\ new} = 2.4 \times \frac{300}{200}\left(\frac{11}{11}\right)^2 = 3.6$$

Q. A Syn. Gen. connected to the TL through a s/up T/F., T/F is rated as 20MVA, 13.8/138 kV. At the end of T/line a load is connected through a s/down T/F and the rating of T/F is 10 MVA, 138 kV/69 kV. A load of 0.72 pu which is evaluated based on load side T/F as the base values. For a system base of 10 MVA, 69 kV. Then value of the load in pu in the gen. ckt will be —?

Sol:



The new value of load in pu

$$= 0.72 \times \frac{20}{10} \times \left(\frac{69}{13.8}\right)^2$$

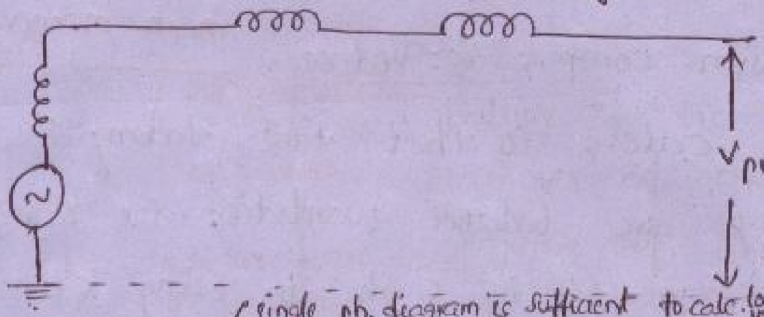
SYMMETRICAL COMPONENTS

The performance of given diagram can be analyse by knowing the load voltage.

Balanced load : $I_R\angle 0 + I_Y\angle 120 + I_B\angle 240 = 0$.

$I_n = 0$.

The load voltage can be calculated by using per ph. reactance deagram along with pu values.



$V_{pu} = E_{pu} - I_{pu} \cdot X_{eq\,pu}$

$X_{eq} = (X_G + X_T + X_L)$ pu

(single ph. diagram is sufficient to calc. load volt for most balance)

unbalance

- Internal ($I_n \leq 10\%$ FL current) → (less severe)
- External ($I_n > 10\%$ " "). → faults
  (Required sym. compo. to calc. load volt). (Severe)

If load is externally unbalance due to occurance of faults then the electrical quantities which are associate in each ph. are severely unbalance and for evaluate load volt consider individual ph. diagram and 3 n/w eq.s to be solved. (for $V_{Rpu}, V_{Ypu}, V_{Bpu}$).

In order to reduce time taking while evaluating unbalanced electrical quantities it is preferred to expressed by a set of 3 balanced electrical quantities namely (Symmetrical quantities. they are ① +ve seq. components (1), ② -ve seq. components (2), ③. zero seq. compo.s (0).

$\therefore V_R = V_{R_0} + V_{R_1} + V_{R_2}$

$V_Y = V_{Y0} + V_{Y1} + V_{Y2}$

$V_B = V_{B0} + V_{B1} + V_{B2}$

Here V_R, V_Y, V_B } unbalanced quantities

$V_{R0}, V_{R1}, V_{R2}, V_{Y0} \dots$ } balanced quantities

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

$I_Y = I_{Y0} + I_{Y1} + I_{Y2}$

$I_B = I_{B0} + I_{B1} + I_{B2}$

But not correct ~~$P_R = P_{R0} + P_{R1} + P_{R2}$~~

power is not calc. in ph. manner.

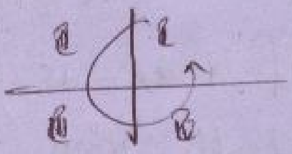
Adv. of sym. comp.s is: reduce the no. of calc.s so that time taking is less.

As sym. comp.s are balance quantities so B & Y comp.s are expressed in R ph. by using k.

k is defined as unity magnitude, ~~anti clock~~ 120° ph. displacement in anti cw. direction.

$k = 1 \angle 120°$

$= -0.5 + j0.867$



$k^2 = 1 \angle 240$

$k^3 = 1$

$k^3 + k^2 + k = 0.$

$\Rightarrow 1 + k' + k^2 = 0.$

$k^4 = k^3 . k = 1 . k = 1 \angle 120.$

$k^5 = k^3 . k^2 = 1 . k^2 = 1 \angle 240°$

FAULTS

- O/C faults (series faults) (less frequent faults)
- S/C faults (shunt faults) (frequent faults)

O/C faults (Series faults) :

(i). Melting of one of the phase fuse or opening of CB.

(ii). Melting of fuse in two ph-s or opening of CB in two ph-s.

⟶ These are unsymmetrical or unbalanced faults.

S/C faults (Shunt faults) :

most common ~~(i).~~ LG

(ii). LL

(iii). LLG

} Unsymmetrical or unbalance

less frequent (iv). LLL ⟶ more severe on T/L.

(v). LLLG ⟶ Symmetrical or balance

} Sources :

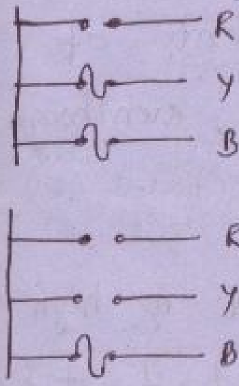
falling of tree branches,

flashover of string of insulators

collapsing of line supports.

In the LG occurs at alternator terminals → most severe.

Most common → LG. both in Alternator & TL.



} Sub transient. (1st cycle when fault occurs).

O/C faults can be characterized as,

(1). increasing ph. voltages

(2). falling of ph-s current

(3). slight improvement in pf

(4). " " of freq of ~~power~~/. supply.

The rise in the volt-s of ph-s will increase the working field intensity which will result as failure of dielectric strength of insulation.

so o/c fault means study of V's of ph's and they are to be expressed in peak value b'coz behaviour of fault is sub-transient.

If a s/c fault takes, then results as

(1). fall in ph.s volt. (volt.s of phases).

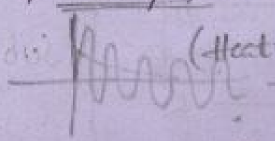
(2). Rise in currents of the phases.

(3). Reduction of pf

(4). Reduction of freq. of supply

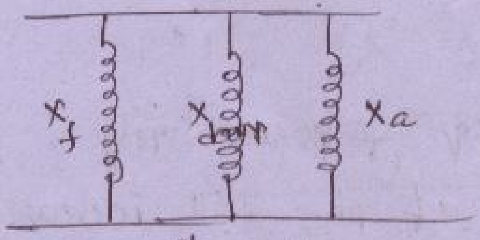
→ Due to rise in the currents of ph.s more temp will be generated in the insulation of ph.s and if operating temp. is more than withstand temp. of insulation then insulation will fail.

so s/c fault is the study of currents of phases and expressed in terms rms, eventhough it is subtransient period



(Heat = I^2Rt)

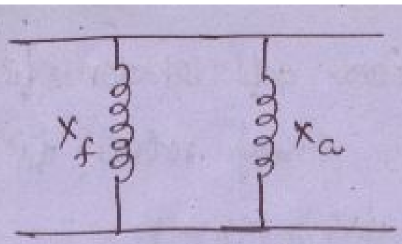
→ The otherway to say fault current is high b'coz sub. transient reactance Affected for the flow of fault i is very less when compared to steady state reactance of the system,



1st cycle.

x_d'' = sub transient

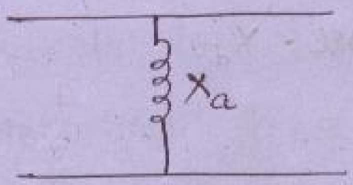
$= x_f \parallel x_{damp} \parallel x_a$



2nd cycle

x_d' = Transient reactance

$= x_f \parallel x_a$.



> 4 cycle.

Steady state reactance

$x_d = x_a$.

* $x_d'' < x_d' < x_d$.

+ve seq. components:

These are having the equal magnitude and 120 ph. displacement and ph. seq. is same as that of orginal ph. seq. of the n/w.

-ve seq. components:

These are the components having equal magnitude and 120 ph. displacement and ph. seq. is opposite to that of orginal ph. seq. of the n/w.

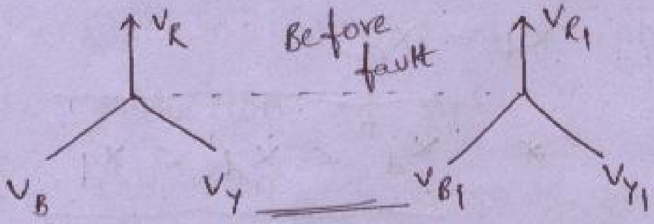
zero seq. components:

These are having equal magnitude without any ph. displacement. If there is no ph. displacement then no phase sequence.

→ Due to rotor airgap flux which is assumed in cw, emf induced in stator wdg, then this will able to deliver current to load, the corr. field produced by i's is assumed in the same dire. as that of field ie cw.

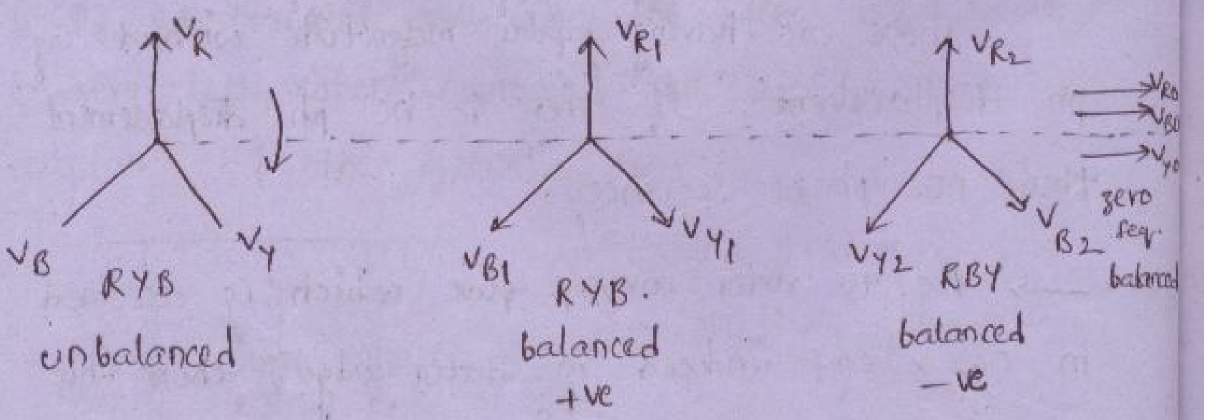
If the dire. of rotation of stator field is same as " " rotor field then such seq. is called +ve seq.

The reactance offered for the flow of i's is steady state reactance 'X_d'.



$V_R = V_{R1}$

Even during the fault, there is no change in airgap flux of rotor, so it will induce an emf in the stator wdg, which results the corr. i is delivered to the point. In the same dire. as that of original dire. but it is offered with sub transient reactance X_d'', so +ve seq. does exists before fault as well as during fault.



Before fault +ve seq. compo. does exists. and also during any type of fault +ve seq comp. also existing and it will helpful in order to set min. pickup value for the relay to operate, so that faulty equipment protected.

for LG fault, the level of fault current is less when compare to LLL and same relay has to look after all faults so relays are given min. pickup value keeping in view of LG fault. During fault, relay can compare the +ve seq. comp. only for its operation b'coz the +ve (ps) seq. subtransient value during fault always more than ps steady state value.

As $X_d'' < X_d \Rightarrow$ ps subtransient current is greater than ps. steady state current.

* SAT. 06/12/08 *

Due to rotor field, the volt. which induced in stator wdg is only +ve seq. voltage.

The mag. of -ve seq volt. at the fault point is always more than the corr. stator wdg. The corr. current flows from the fault point towards source of generator.

→ The field produced by -ve seq. comp-s. is opp. to that of the field produced by +ve seq. in the stator. However w.r.t rotor it is having relative speed of $2N_s$ and it will result as a current is induced in rotor at double the freq. and rotor field wdg over heated. In order to protect rotor field due to over heating -ve. seq. relay is employed in the stator wdg.

→ ZSC will exists provided that,

(a). fault is ground fault

(b). Neutral of the system is grounded.

If the fault is associated with ground & neutral of the system is grounded and fault is flowing to ground and enter into the system through N-grounding. Ground can be provide mag without any ph. displacement.

→ $V_R = V_{R0} + V_{R1} + V_{R2}$

$V_Y = V_{Y0} + V_{Y1} + V_{Y2}$

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

$V_B = V_{B0} + V_{B1} + V_{B2}$

$= V_{R0} + K \cdot V_{R1} + K^2 \cdot V_{R2}$

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

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

$$\begin{bmatrix} \mathcal{E}_{R0} \\ \mathcal{E}_{R1} \\ \mathcal{E}_{R2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & K & K^2 \\ 1 & K^2 & K \end{bmatrix} \begin{bmatrix} \mathcal{E}_R \\ \mathcal{E}_Y \\ \mathcal{E}_B \end{bmatrix}.$$

SYMMETRICAL NETWORKS (OR) SEQUENTIAL NETWORKS :

{ SUB-TRANSIENT REACTANCE N/W's :/ph.

In +ve & -ve seq.s, neutral is reference. and ground is reference for zero seq's.

$\mathcal{E}_n = \mathcal{E}_R + \mathcal{E}_Y + \mathcal{E}_B = 0$, balanced.

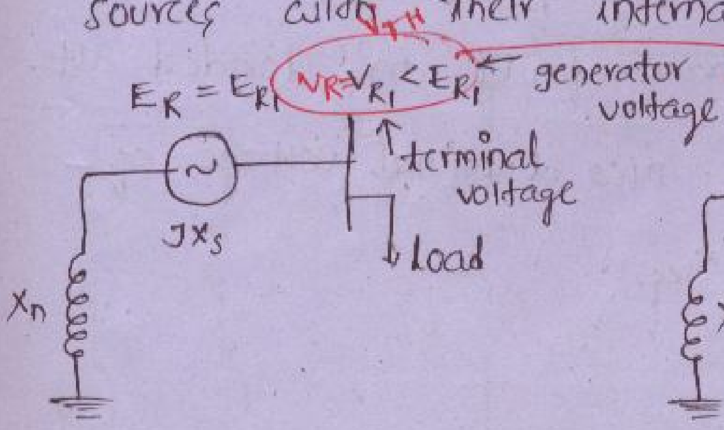
$\mathcal{E}_n = \mathcal{E}_R + \mathcal{E}_Y + \mathcal{E}_B \neq 0$, unbalanced.

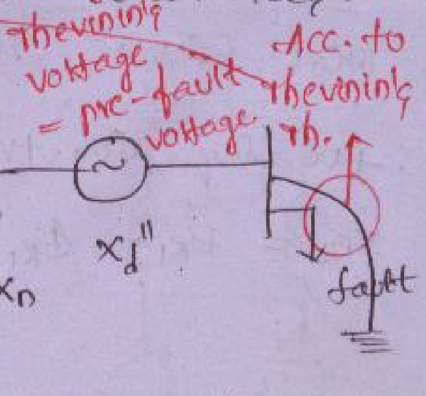
$= \mathcal{E}_{R0} + \mathcal{E}_{R1} + \mathcal{E}_{R2} + \mathcal{E}_{Y0} + \mathcal{E}_{Y1} + \dots$

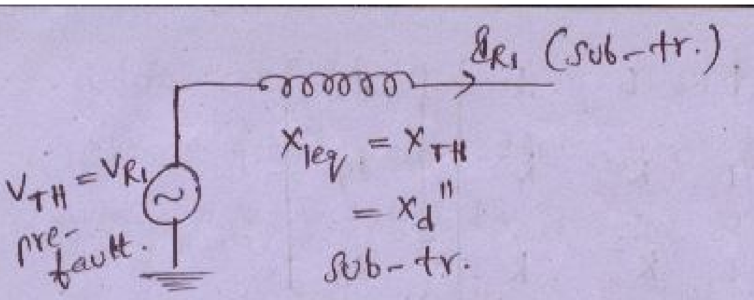
$= 3\mathcal{E}_{R0} + \mathcal{E}_{R1}(1+K^2+K) + \mathcal{E}_{R2}(1+K+K^2)$

$= 3 \cdot \mathcal{E}_{R0}$.

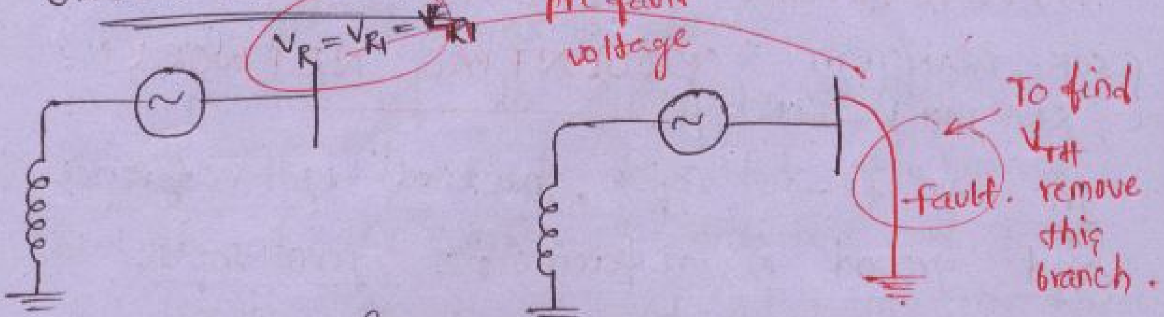
→ Sym. n/w is consists of ~~zer~~ pre-fault volt. at the fault point in series with equi. sub. tr. reactance, which is evaluated w.r.t fault point by replacing all active sources with their internal reactances.

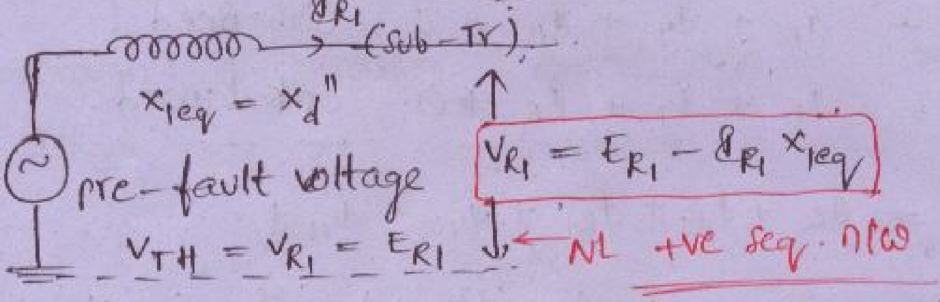






UNDER NO-LOADED:



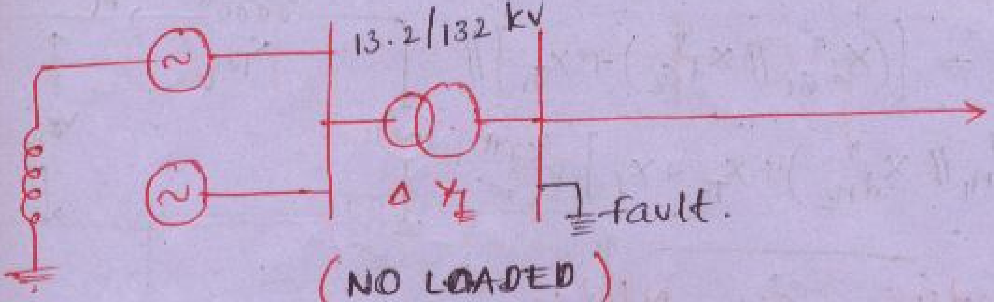


The mag. of sub. tr. current depends on pre-fault voltage. If pre-fault volt. is high then sub-tr. current is high.

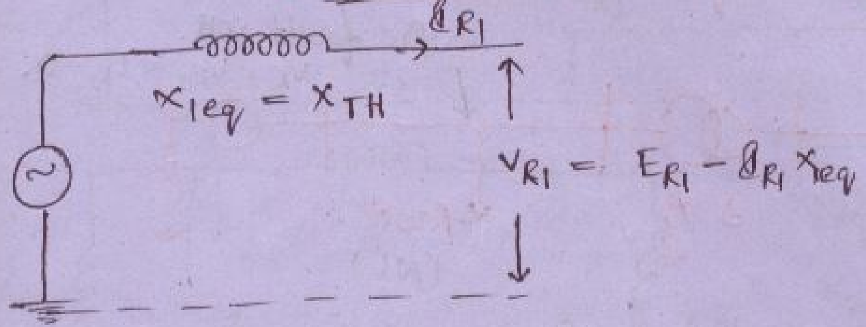
In loaded alt. the pre-fault voltage is < 1 pu. and in NL alt. pre-fault volt = 1pu. If fault is taking place in NL alt. is more severe than fault on loaded alt.

+ve seq. sub tr. n/w terminal voltage eq-

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

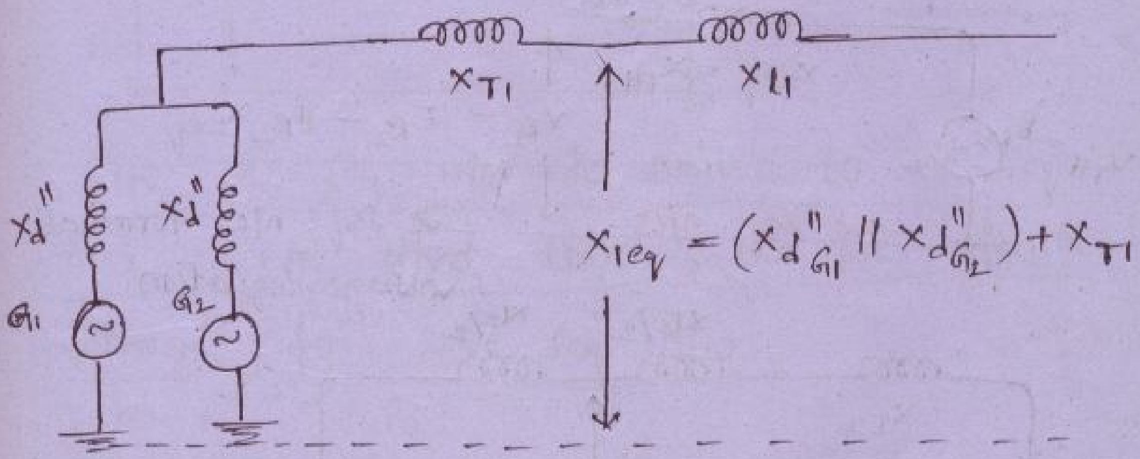


(NO LOADED)

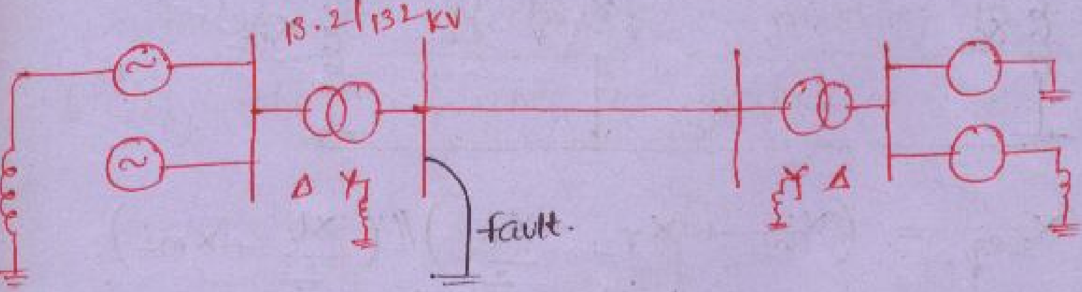


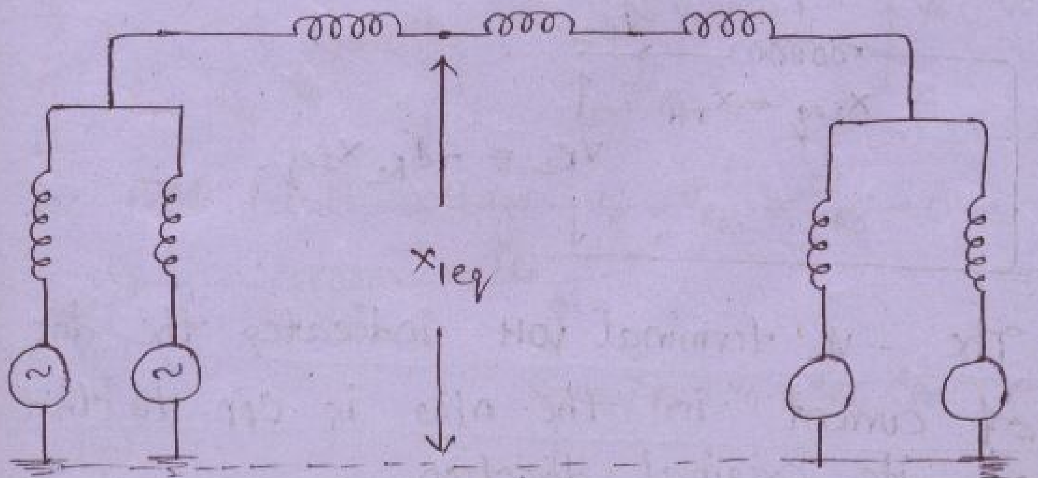
$X_{1eq} = X_{TH}$

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



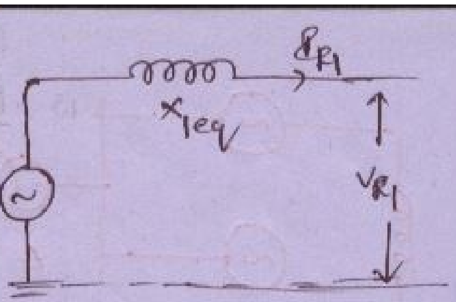
$X_{1eq} = (X_{d_{G1}}'' \parallel X_{d_{G2}}'') + X_{T1}$



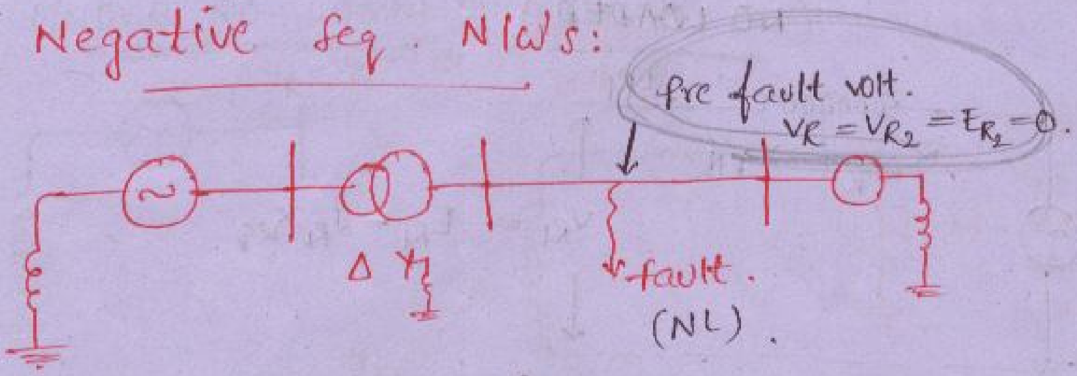


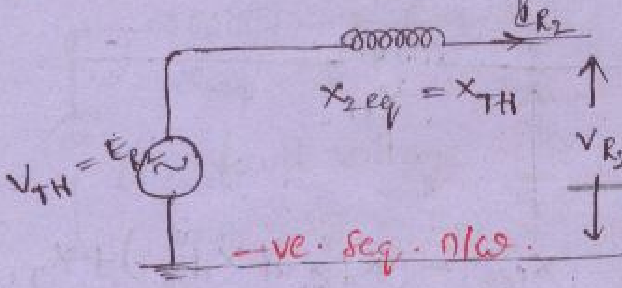
$$X_{1eq} = \left\{\left(X''_{d\,G1} \,\|\, X''_{d\,G2}\right) + X_{T1}\right\} \,\|\, \left\{\left(X''_{d\,M1} \,\|\, X''_{d\,M2}\right) + X_{T2} + X_l\right\}$$

$V_{TH} =$



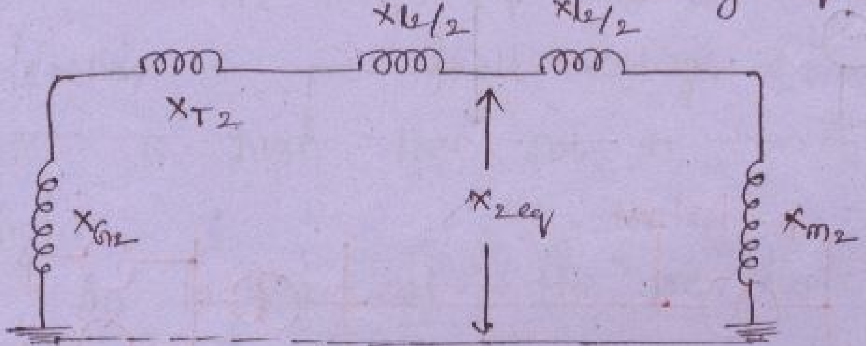
Negative seq. N/w's:



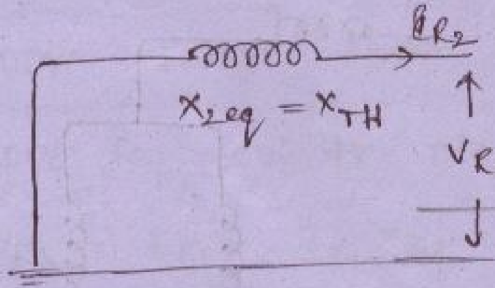


$$V_{R2} = E_{R2} - I_{R2} X_{2eq}$$

-ve seq. n/w terminal voltage equation.

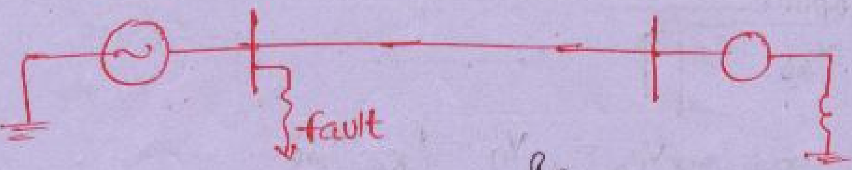


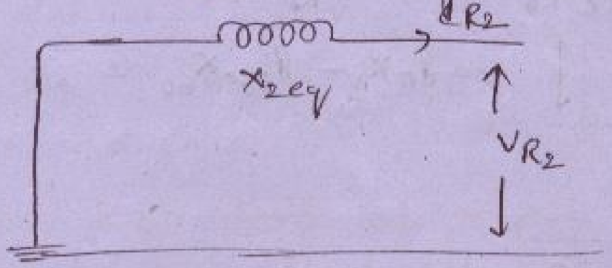
$$X_{2eq} = \left(X_{G2} + X_{T2} + \frac{X_{l2}}{2}\right) \| \left(\frac{X_{l2}}{2} + X_{m2}\right)$$

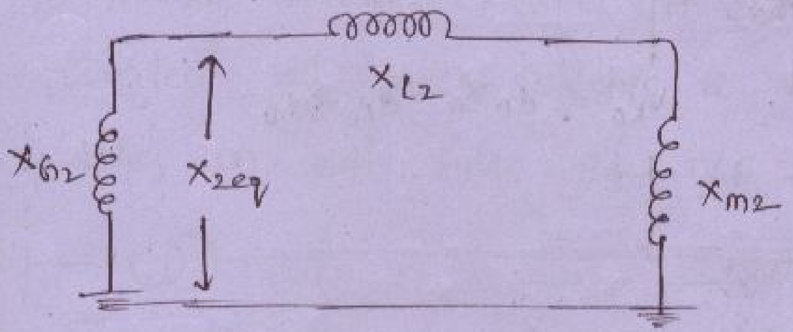


$$V_{R2} = -I_{R2} X_{2eq}.$$

The -ve terminal volt. indicates the dirc of current in the n/w is opp. to that of its original direction.







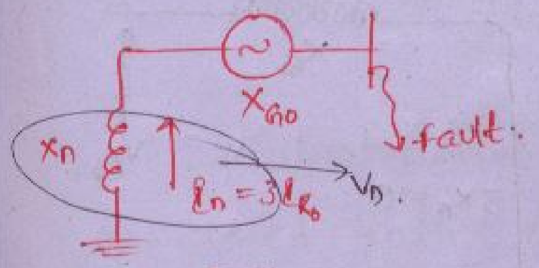
$X_{2eq} =$

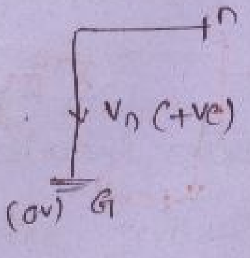
$X_{G2} \parallel (X_{L2} + X_{m2})$

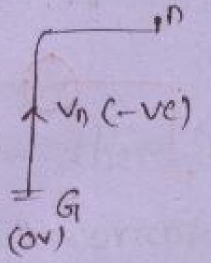
The −ve seq. n/w is similar to +ve seq. n/w except that there is no pre-fault voltage for −ve seq. n/w.

zero seq. n/w's:

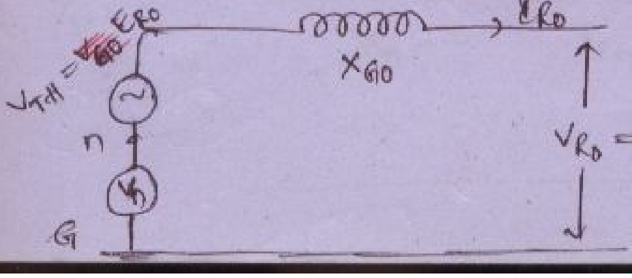
Include the effect of n-grounding in ZSN/w b'coz the reference is ground.



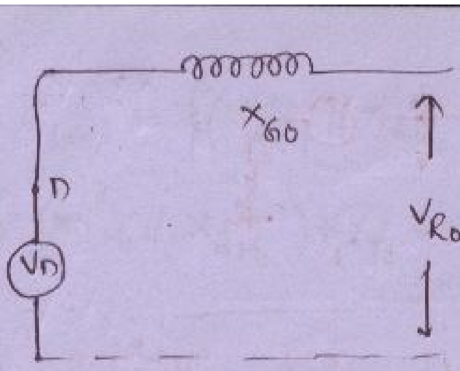




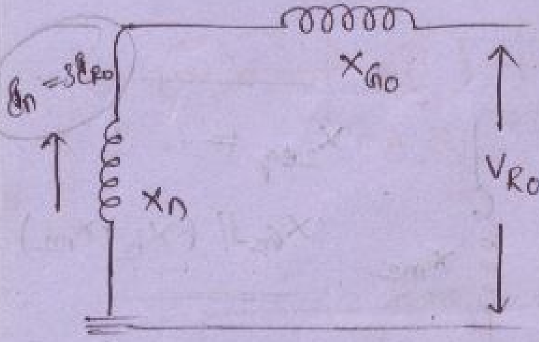
pre-~~fault~~ fault voltage $V_R = V_{R0} = E_{R0} = 0$.



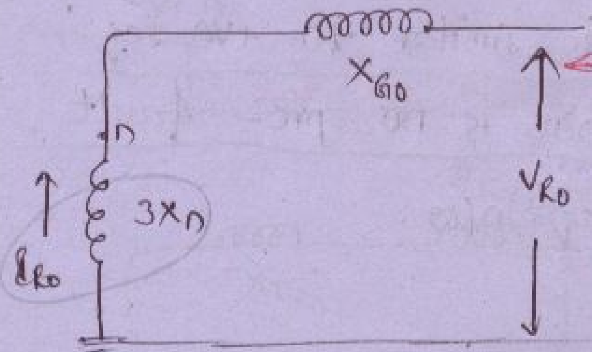
$V_{R0} = E_{R0} + V_n - I_{R0} \cdot X_{G0}$.



$$V_{R0} = V_n - I_{R0} \cdot X_{G0}$$
$$= I_n X_n - I_{R0} \cdot X_{G0}$$



$$V_{R0} = I_n X_n - I_{R0} \cdot X_{G0}$$

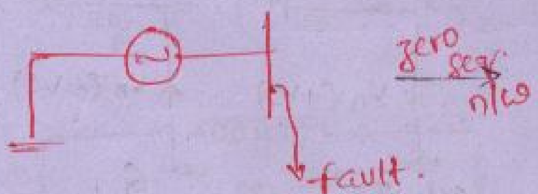


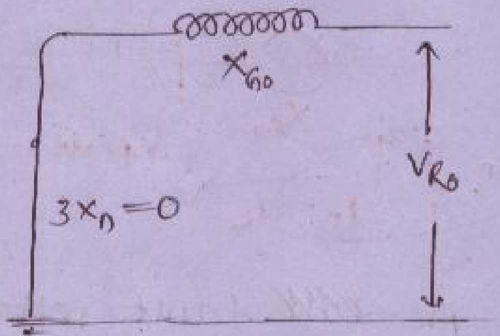
$$V_{R0} = -3I_{R0} \cdot X_n - I_{R0} \cdot X_{G0}$$
$$= -I_{R0}\,[3X_n + X_{G0}]$$
$$= -I_{R0}\,X_{0eq}.$$

→ zero seq. n/w terminal

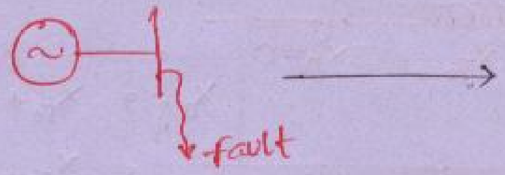
$X_{0eq} = 3X_n + X_{G0}.$

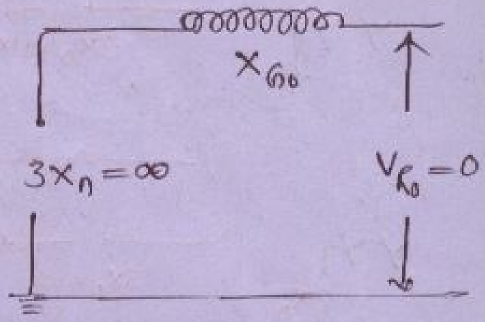
voltage equation.





$$V_{R0} = -I_{R0}\,X_{0eq}$$
$$X_{0eq} = X_{G0}$$
$$(3X_n = 0).$$

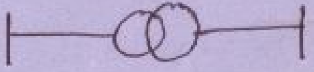


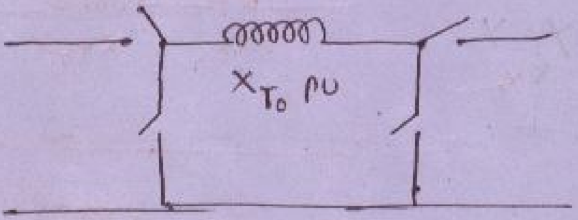


$$X_{0eq} = X_{G0} + \infty$$
$$= \infty.$$

Zero seq. n/w's of T/F:

To include n-effect, the T/F can be made equivalent of mech. switches ie series-parallel switches on both sides of T/F.





Series switch — Y — open wdg

||el switch — Δ — shunt wdg (closed).

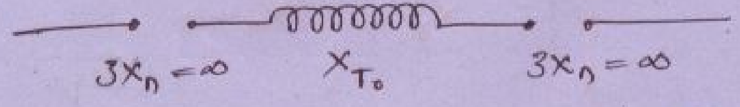
Y — series switch — open $(3X_n = \infty)$.

Y — series switch — close $(3X_n = 0)$

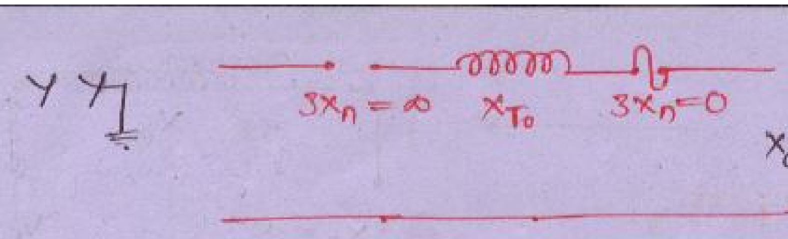
Y — series switch — close $(3X_n)$.

Δ — shunt switch — always close — there is no closed path for the zero-seq. currents.

YY

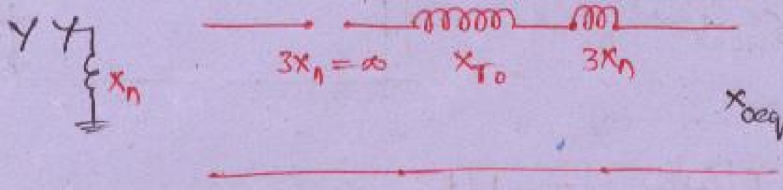


$$X_{0eq} = X_{T_0} + \infty$$
$$= \infty.$$

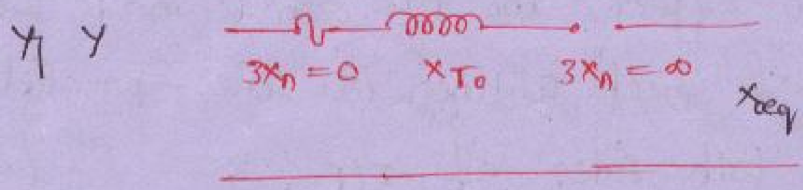


$X_{0eq} = X_{T0} + 0$

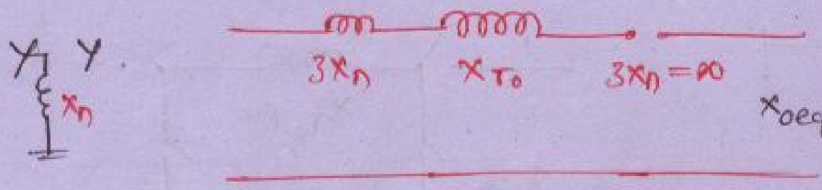
$= X_{T0}$.



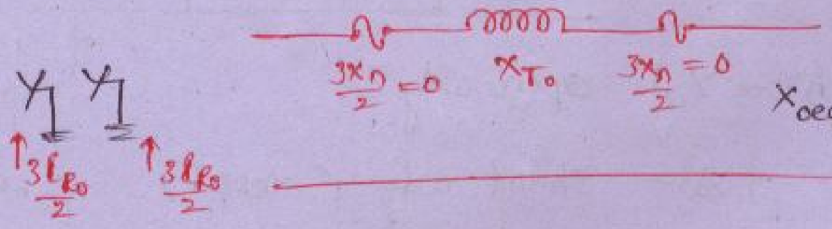
$X_{0eq} = X_{T0} + 3X_n$



$X_{0eq} =$

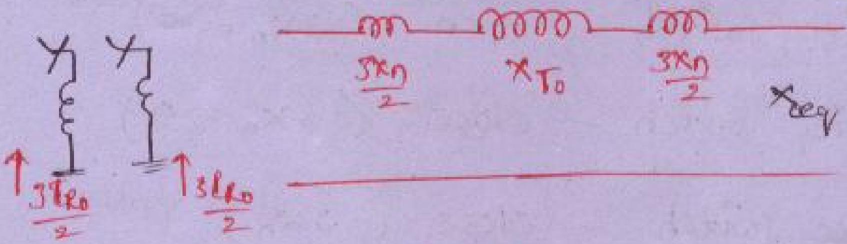


$X_{0eq} =$

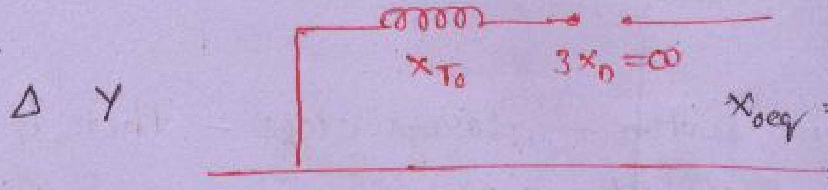


$X_{0eq} = X_{T0} + 0$

$= X_{T0}$.

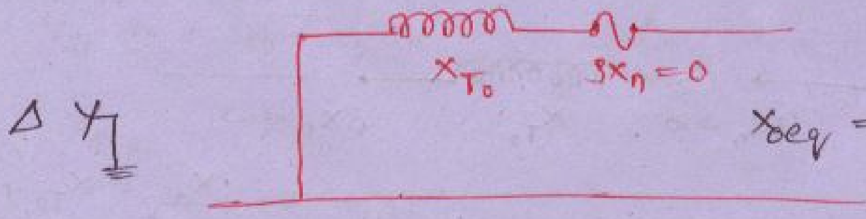


$X_{0eq} = X_{T0} + 3X_n$



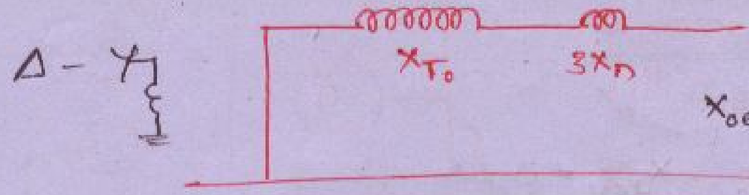
$X_{0eq} = X_{T0} + \infty$

$= \infty$.

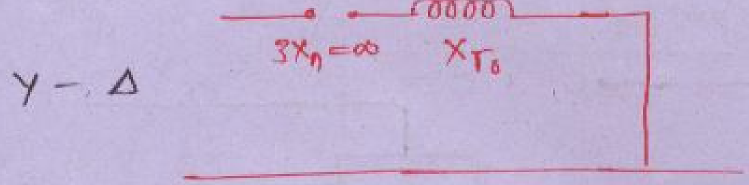


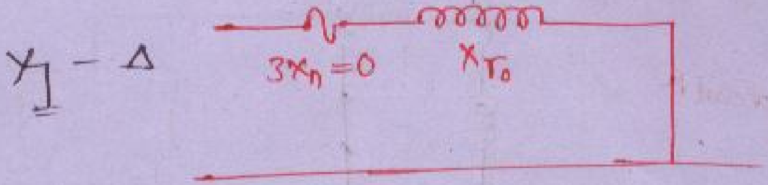
$X_{0eq} = X_{T0} + 0$

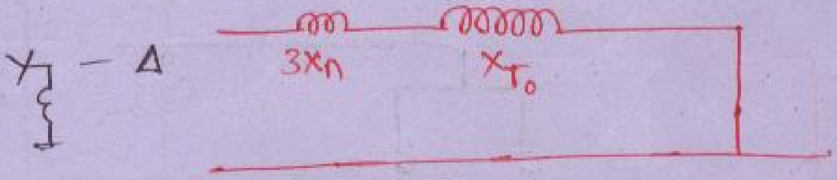
$= X_{T0}$.

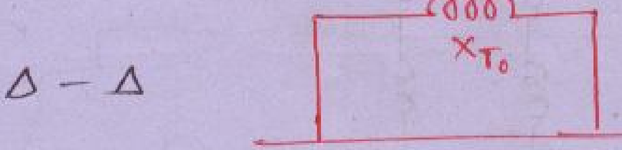


$X_{0eq} = X_{T_0} + 3X_n$.

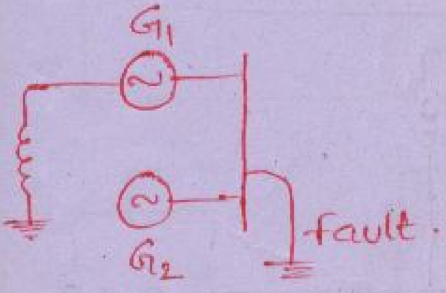




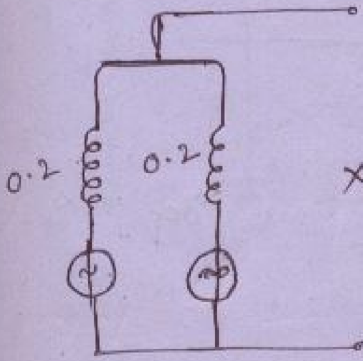




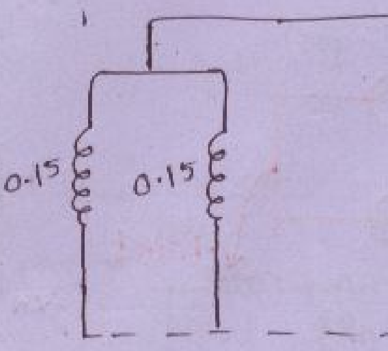
$X_{0eq} = X_{T_0} + \infty$
$= \infty$.



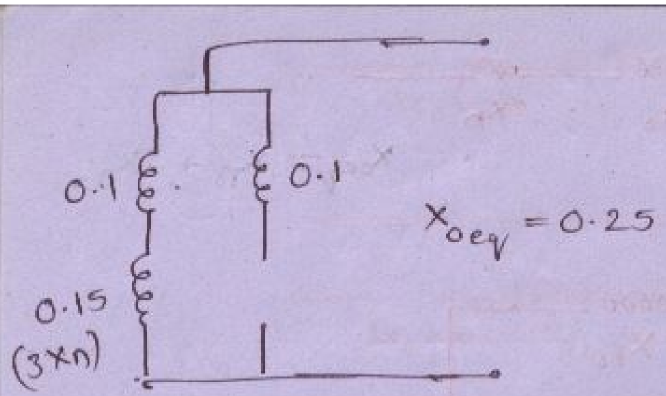
$G_1 = G_2$,
$X_d'' = 0.2$, $X_2 = 0.15$
$X_{G0} = 0.1$, $X_n = 0.05$.

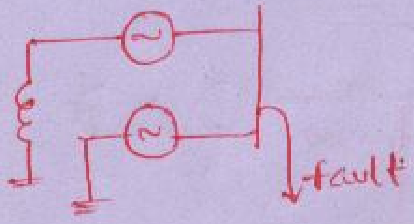


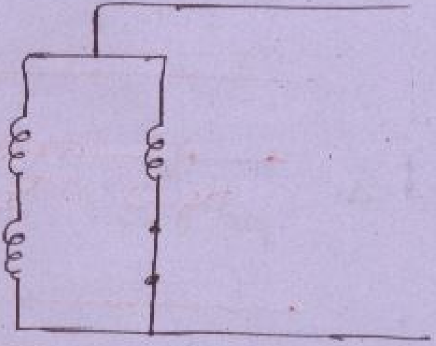
$X_{1eq} = 0.1$

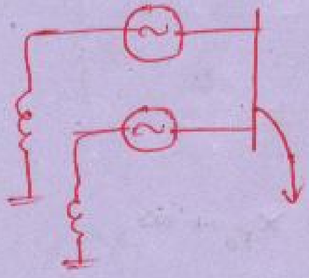


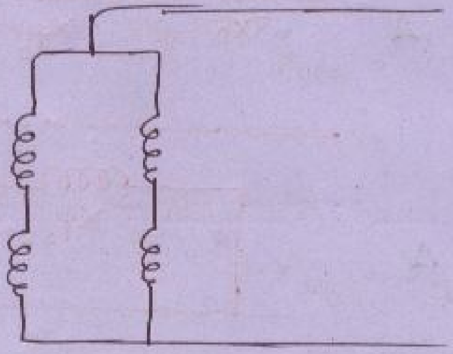
X_{2eq}
$= \frac{0.15}{2}$

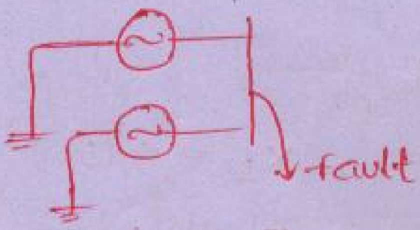

0.1
0.1
0.15
(3xn)
$X_{0eq} = 0.25$

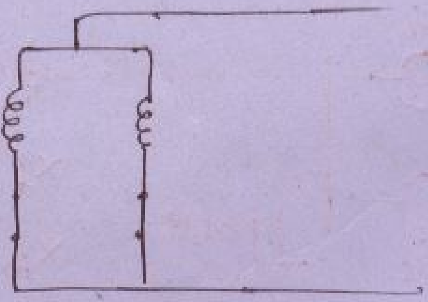

fault

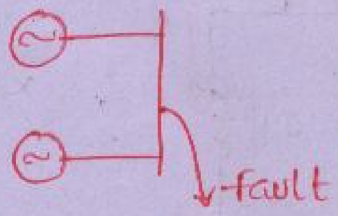


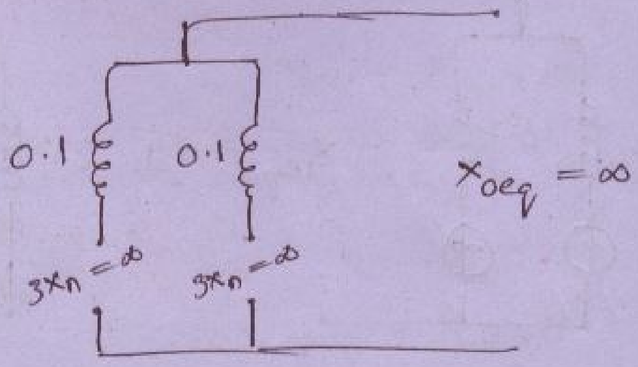


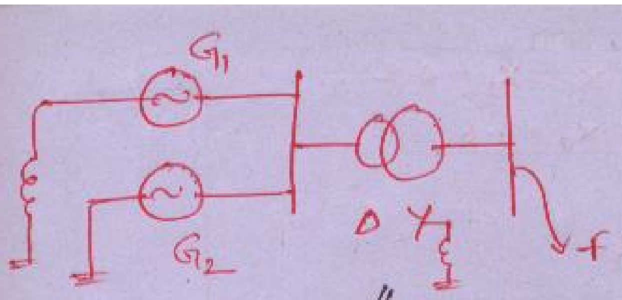



fault




fault


0.1
0.1
3xn = ∞
3xn = ∞
$X_{0eq} = \infty$



$G_2 = G_1$

$x_d'' = 0.2$

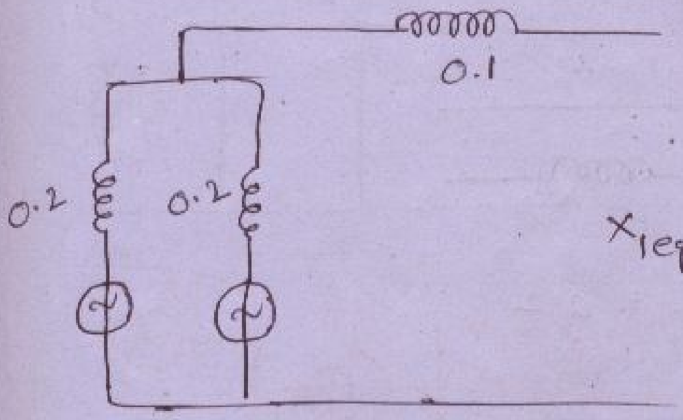
$x_2 = 0.2$

$x_{G0} = 0.1$

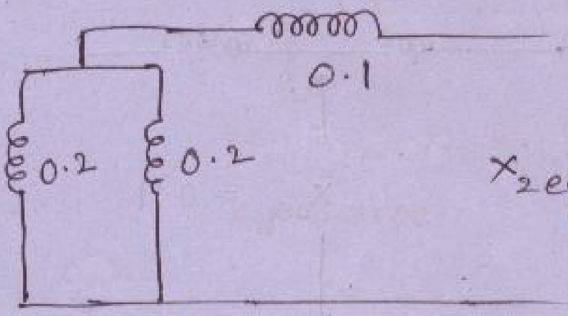
$x_n = 0.05$

$X_{T1} = X_{T2} = X_{T0} = 0.1$

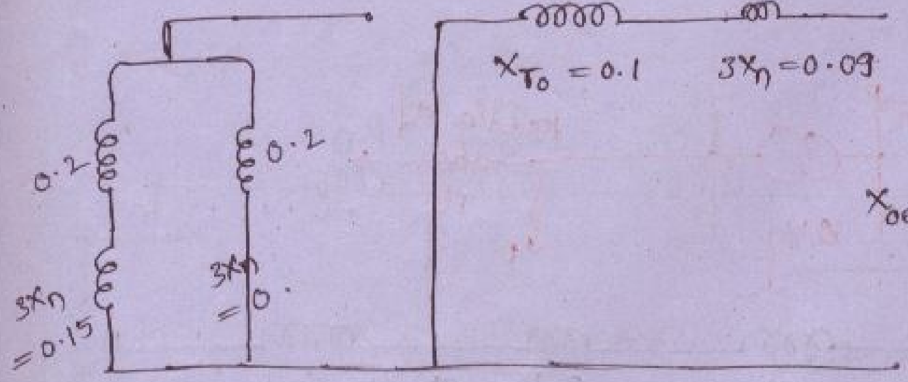
$x_n = 0.03$



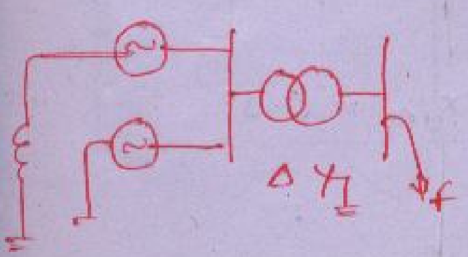
$X_{1eq} = 0.2$

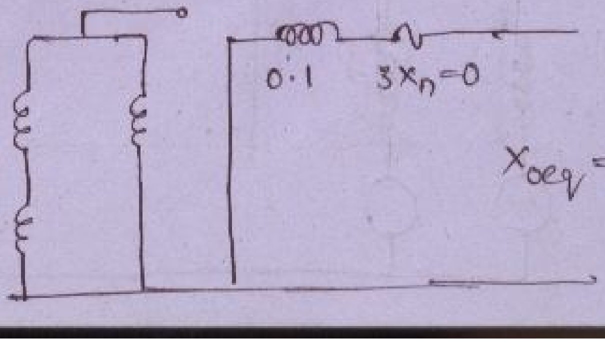


$X_{2eq} = 0.2$

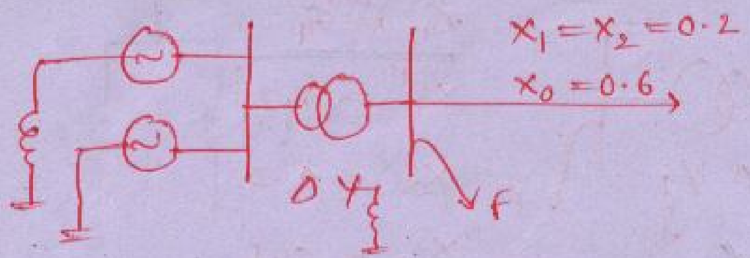


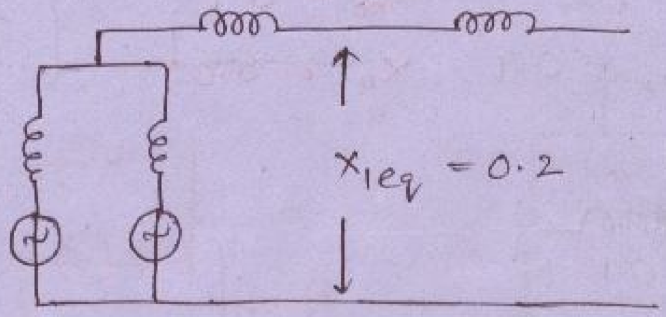
$X_{0eq} = 0.19$

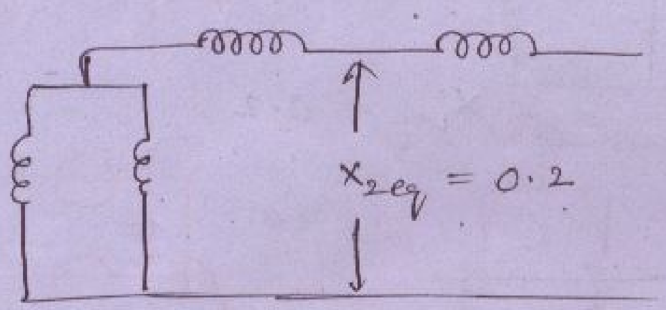


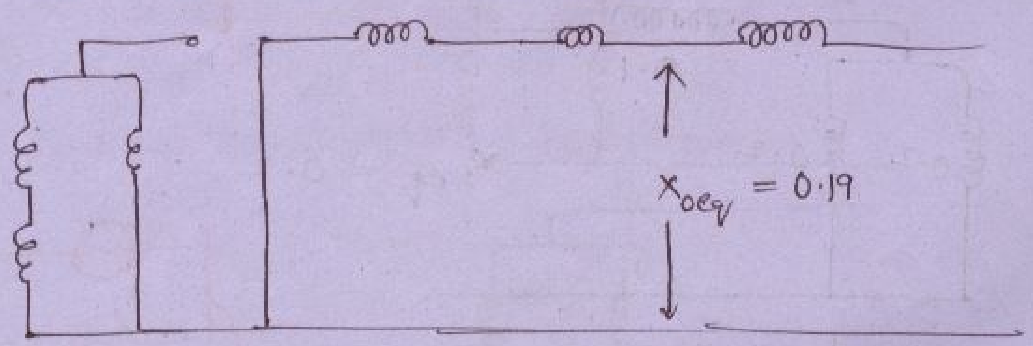


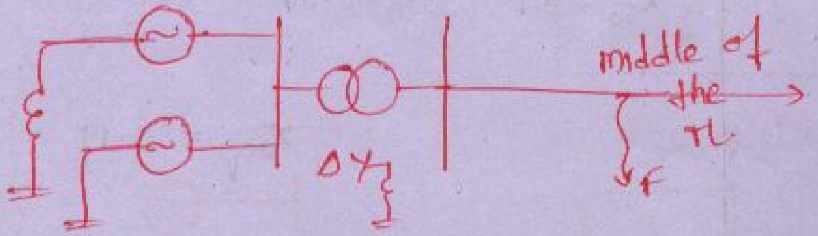
$X_{0eq} = 0.1$

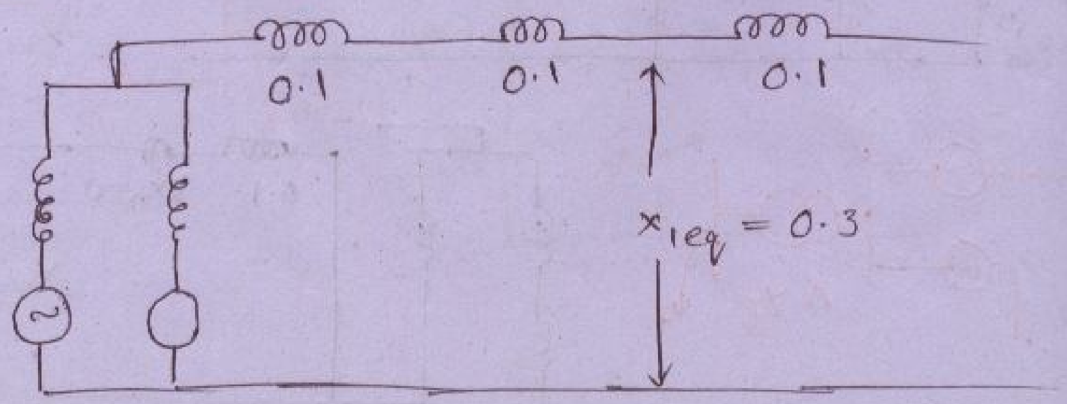

x1 = x2 = 0.2
x0 = 0.6
Δ Y
f

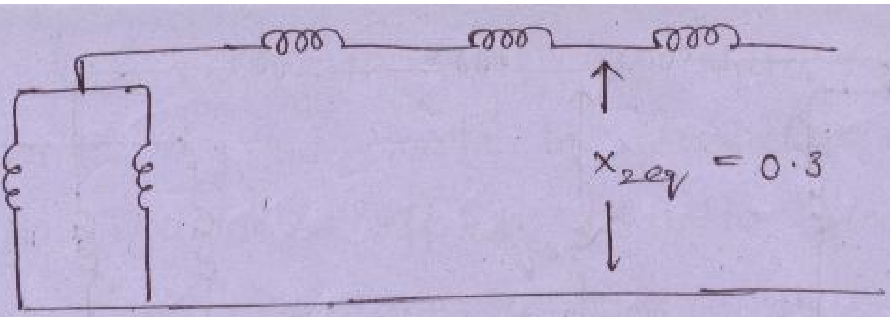

x1eq = 0.2

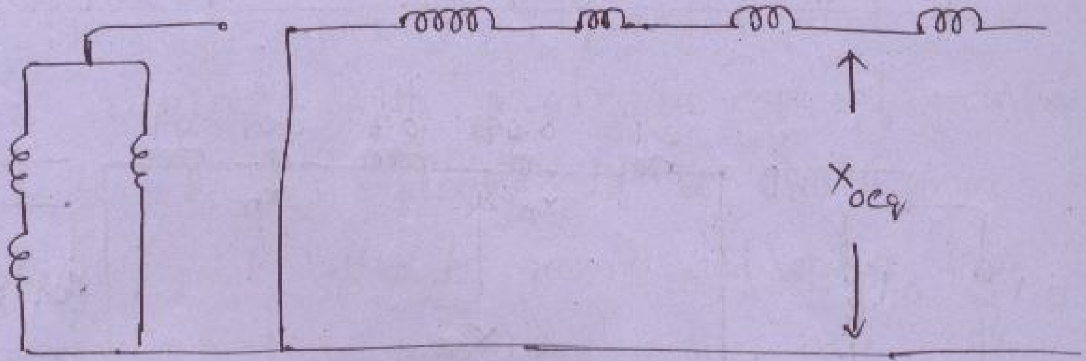

x2eq = 0.2

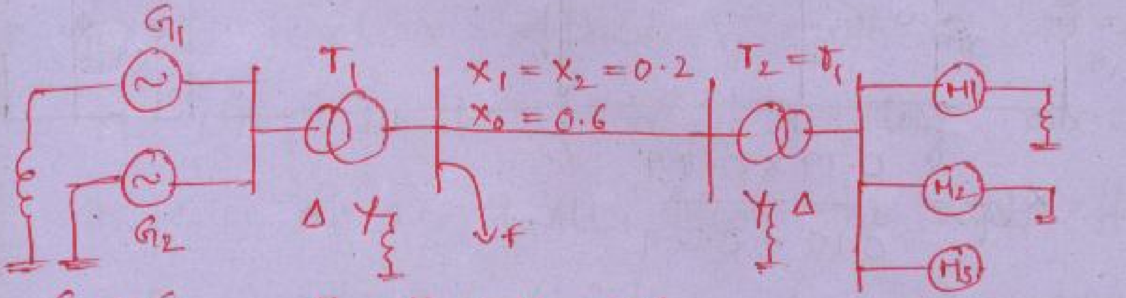

x0eq = 0.19


middle of the TL
Δ Y
f


0.1
0.1
0.1
x1eq = 0.3







$G_2 = G_1$

$x_d'' = 0.2$

$x_2 = 0.2$

$X_{G0} = 0.1$

$x_n = 0.05$

$X_{T1} = X_{T2} = X_{T0} = 0.1$

$X_n = 0.03$ pu

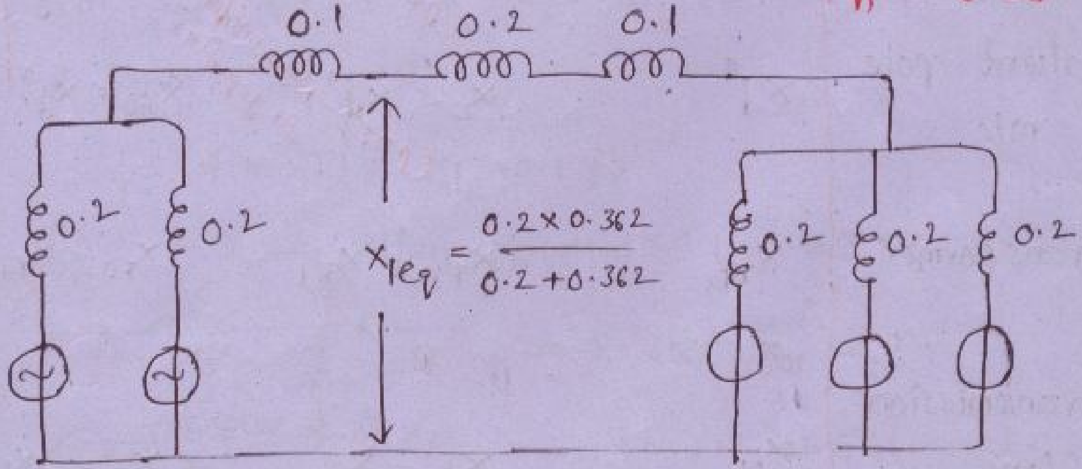
$M_1 = M_2 = M_3$

$x_d'' = 0.2$

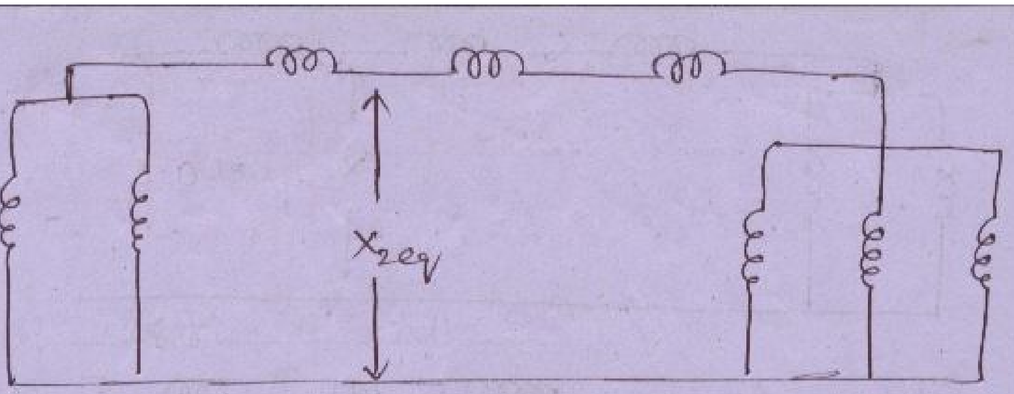
$x_2 = 0.2$

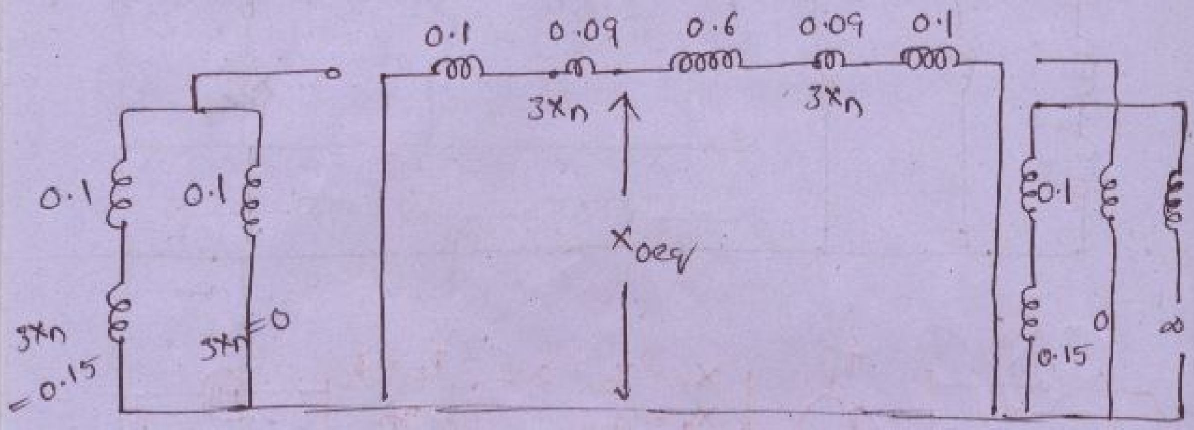
$x_{m0} = 0.1$

$x_n = 0.05$



$$X_{1eq} = \frac{0.2 \times 0.362}{0.2 + 0.362}$$





$$X_{0eq} = \frac{0.19 \times 0.79}{0.19 + 0.79}$$

Relations among seq. reactances :

	+ve	−ve	zero
Turbo m/c	X_d''	$X_2 = X_d''$ uniform air gap flux (p=2)	$X_{G0} < X_d''$
Salient pole m/c	X_d''	$X_2 < X_d''$ non-uniform air gap flux (p>2)	$X_{G0} < X_d''$
Transformer	X_{T1}	$X_{T2} = X_{T1}$	$X_{T0} = X_{T1}$
Transmission line	X_{l}	$X_{l_2} = X_{l_1}$	$X_{l_0} = 3X_{l}$

unsymmetrical wdg (short pitch wdg)

In TL & T/F are the static devices and they are made by bimetallic conductors so reactance offerd for the flow of i in either dirc. will be same.

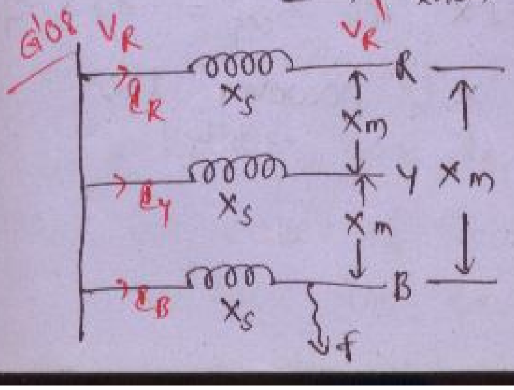
The ZSX does exists provided that fault is associated with ground. In case of grounded fault, I_f is expeccted to be travel from fault point through ground and enters into nearest neutral grounding. while calc. ZSX, include reactance offered by earth in case of TL. b'coz length of TL is too long. whereas in case of T/F & Alt. ignore the earth effect.

The reactance offered by faulty phase condu. is same through out the length but x offered by earth is variable due to dissimilar soil. so net x offered is a variable value which can be varied as $2.5 x_1$ to $3.5 x_1$ with an avg. of $3x_1$.

(short pitch wdg?)

If for TL, $x_{L_1} = 0.1$ pu

$\longrightarrow$ then $X_0 = 3 \times 0.1 = 0.3$ pu.



$\Longrightarrow$ Then $X_{01} = ?$

$X_{02} = ?$

$X_0 = ?$

$V_R \left\langle \begin{matrix} V_{R_1} \\ V_{R_2} \\ V_{R_0} \end{matrix} \right.$ $\quad V_R' \left\langle \begin{matrix} V_{R_1}' \\ V_{R_2}' \\ V_{R_0}' \end{matrix} \right.$ $\quad I_R \left\langle \begin{matrix} I_{R_1} \\ I_{R_2} \\ I_{R_0} \end{matrix} \right.$

$$V_{R_1} = V_{R_1}' + I_{R_1} X_s + I_{Y_1} X_m + I_{B_1} X_m$$

$$= V_{R_1}' + I_{R_1} X_s + k^2 I_{R_1} X_m + k . I_{R_1} X_m$$

$$= V_{R_1}' + I_{R_1} X_s + I_{R_1} X_m (k^2 + k)$$

$$= V_{R_1}' + I_{R_1} X_s - I_{R_1} X_m$$

$$V_{R_1} = V_{R_1}' + I_{R_1} (\underbrace{X_s - X_m}_{X_{1eq}})$$

$$V_{R_2} = V_{R_2}' + I_{R_2} X_s + I_{Y_2} X_m + I_{B_2} X_m$$

$$= V_{R_2}' + I_{R_2} X_s + k . I_{R_2} X_m + k^2 I_{R_2} X_m$$

$$= V_{R_2}' + I_{R_2} X_s + I_{R_2} X_m (k + k^2)$$

$$= V_{R_2}' + I_{R_2} X_s - I_{R_2} X_m$$

$$= V_{R_2}' + I_{R_2} (\underbrace{X_s - X_m}_{X_{2eq}})$$

$$V_{R_0} = V_{R_0}' + I_{R_0} X_s + I_{Y_0} X_m + I_{B_0} X_m$$

$$= V_{R_0}' + I_{R_0} X_s + I_{R_0} X_m + I_{R_0} X_m$$

$$= V_{R_0}' + I_{R_0} [\underbrace{X_s + 2X_m}_{X_{0eq}}]$$

⟹ In T/F, the total ZSX ie X_{0eq} = ZSX of T/F + neutral X, however the ZSX ie $X_{T_0} = X_{T_1}$.

→ In salient pole m/c because of projected poles, induced current in rotor at double the freq due to −ve seq. in the stator wdg will be alternatively max in d-axis as well as in q-axis. and corr. mmf which is produced will also alternatively max. hence −ve seq. reactance offered is the avg. x of the above two axises which is less than +ve seq. reactance.

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

$$\Rightarrow X_2 < X_d''.$$

The reactance offered for leakage flux out of total zero seq. flux which is produced can only consider the reactance offered for the zero seq. currents in stator wdg which is less than positive seq. reactance.

FAULT ANALYSIS:

(1). In any type of S/c fault, the +ve seq. subtransient current can be calculated.

(2). In case of ground fault, the fault current is in terms of zero seq. current so obtain a relation b/w I_{R_1} & I_{R_0}.

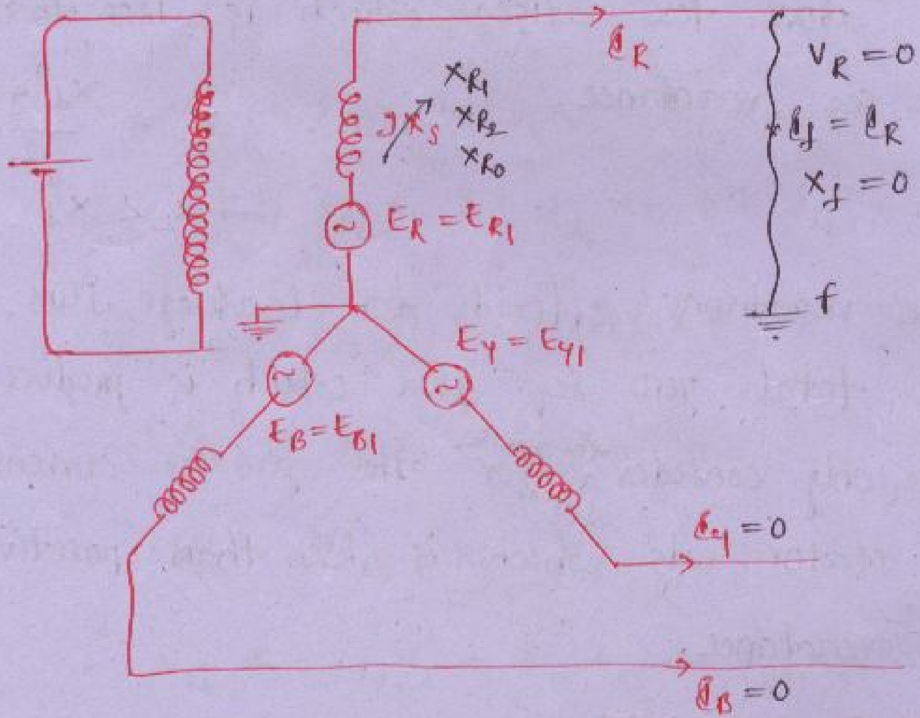
(3). In case of isolated ground fault, but unbalance then the fault current is interms of

–ve seq. current, so obtain a relation b/w I_{R_2} and I_{R_1}.

(4). In case of balanced fault, the fault current is same as +ve seq. sub tr. current.

Line to Ground fault:

Alternator is working at NL at rated voltage solid neutral & solid fault.



During fault,

$I_f = I_R$

$V_R = 0$

$I_Y = I_B = 0$

$$I_{R_0} = \frac{1}{3}\left[I_R + I_Y + I_B\right] = \frac{I_R}{3}.$$

$$I_{R_1} = \frac{1}{3}\left[I_R + k.I_Y + k^2 I_B\right] = \frac{I_R}{3}.$$

$$I_{R_2} = \frac{1}{3}\left[I_R + k^2.I_Y + k.I_B\right] = \frac{I_R}{3}$$

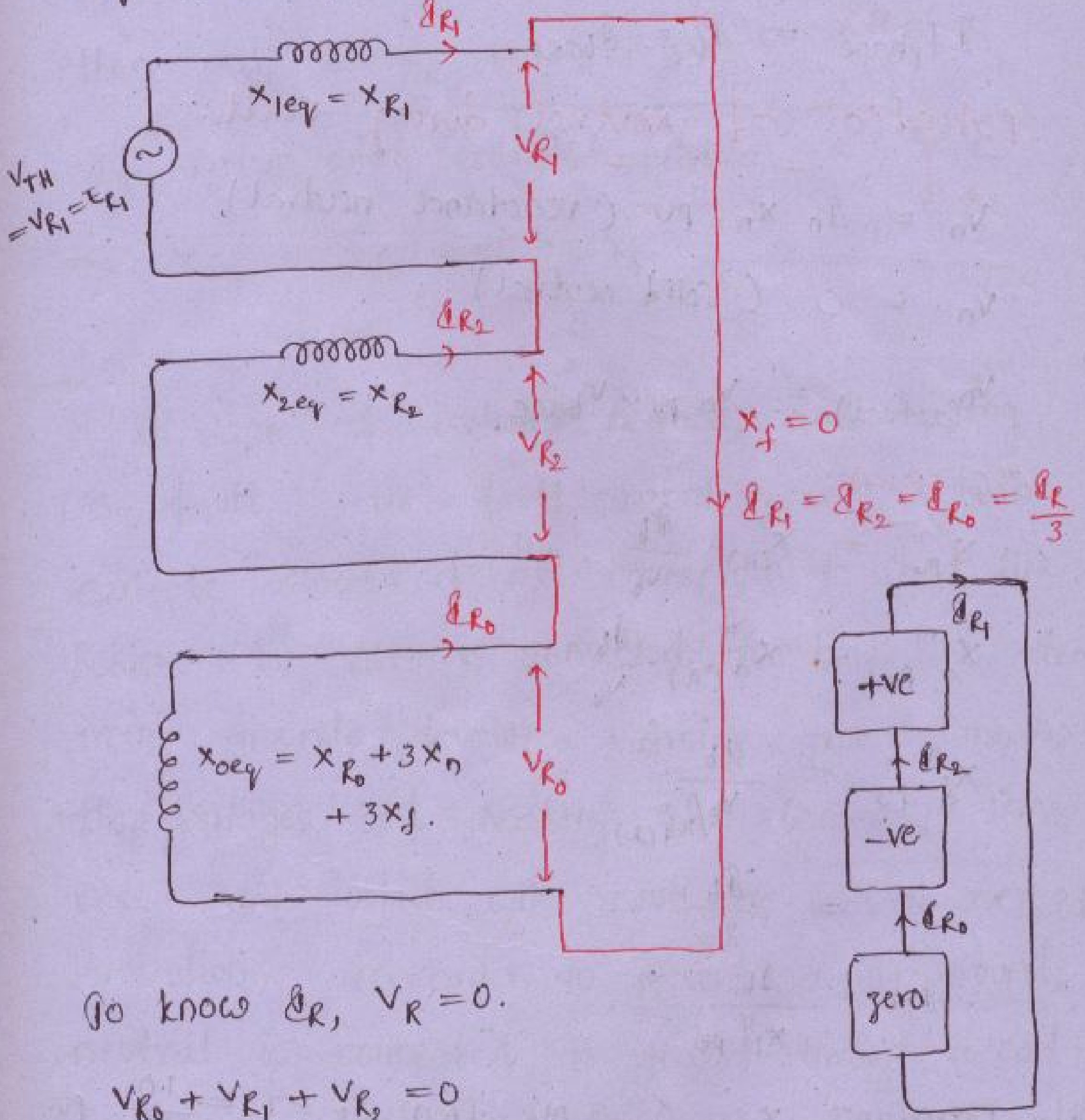
$$I_{R_0} = I_{R_1} = I_{R_2} = \frac{I_R}{3}$$

$I_R = I_f = 3I_{R_0}$ pu

$I_{R_0} = I_{R_1}$

$I_R = I_f = 3.I_{R_1}$ pu

The fault is associated with ground so the 3 seq. comp-s are existing. The associated seq. n/w's are connected in series b'coz seq. currents are same.



So know I_R, $V_R = 0$.

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

$$-I_{R0} \cdot x_{0eq} + E_{R1} - I_{R1} x_{1eq} - I_{R2} x_{2eq} = 0$$

$$\Rightarrow I_{R1} = \frac{E_{R1}}{x_{1eq} + x_{2eq} + x_{0eq}} \text{ pu.}$$

$$I_f = 3 I_{R1} = \frac{3 E_{R1} \angle 0}{x_{1eq} + x_{2eq} + x_{0eq}} \text{ pu}$$

$I_{f\,(actual)} = I_{f\,pu} \cdot I_{base}$ kA or A (rms)

$I_{base} = \frac{S}{\sqrt{3}V}$ $S = \sqrt{3}.V_L.I_L$

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

$I|_{phase} = I_L = I_{base}$

Potential of Neutral during fault:

$V_n = I_n \cdot x_n$ pu (reactance neutral)

$V_n = 0$ (solid neutral)

$V_{n(actual)} = V_{n\,pu} \cdot V_{base}$

S/C MVA:

$X_{pu} = X_{(\Omega)} \cdot \frac{I_b}{V_b}$

$X_d''{}_{pu} = X_d''{}_{(\Omega)} \cdot \frac{I_b}{V_b}$

$X_d''{}_{pu} = \frac{I_b}{V_b / x_d''{}_{(\Omega)}}$

$= \frac{I_b}{I_{sc}}$

$\therefore I_{sc} = \frac{I_b}{X_d''\,pu}$

If, Reactance $x = 0.25$ pu then $I_{sc} = ? = \frac{1.0}{0.25}$ pu.

$X_d'' = \frac{I_b}{I_{sc}} \cdot \frac{3V_b}{3V_b}$

$= \frac{Base\ MVA}{S/C\ MVA}$

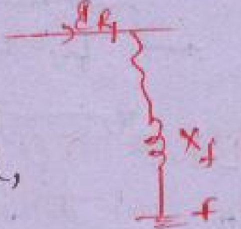
$\rightarrow \boxed{S/C\ MVA = \frac{Base\ MVA}{X_d''\ pu}}$

for L-G :

$$\boxed{S/C\ MVA = \frac{\text{Base MVA}}{X_{1eq} + X_{2eq} + X_{0eq}}}$$

If fault is associated with reactance X_f.

then $X_{0eq} = X_{R_0} + 3X_n + 3X_f$



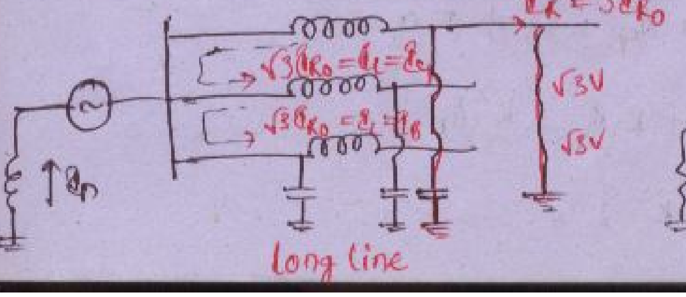
If system with isolated neutral,

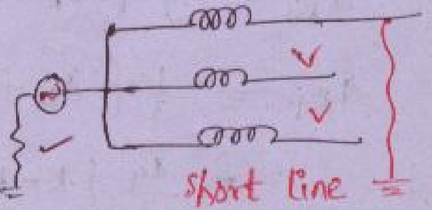
$\Rightarrow X_{0eq} = X_{R_0} + \infty + 3X_f$

$= \infty$.

In case of isolated neutral, and having LG fault, the fault current zero, which can be allowed if alt. connected to short line. however if Alt. is connected to long line, then arcing grounds develop. Arcing ground means the voltages of healthy ph-s become $\sqrt{3}$ times rated volt. which will result as flash over of insulation. In order to prevent arcing ground, neutral is connected to ground through a coil (peterson coil) and type of grounding called as resonant grounding.

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





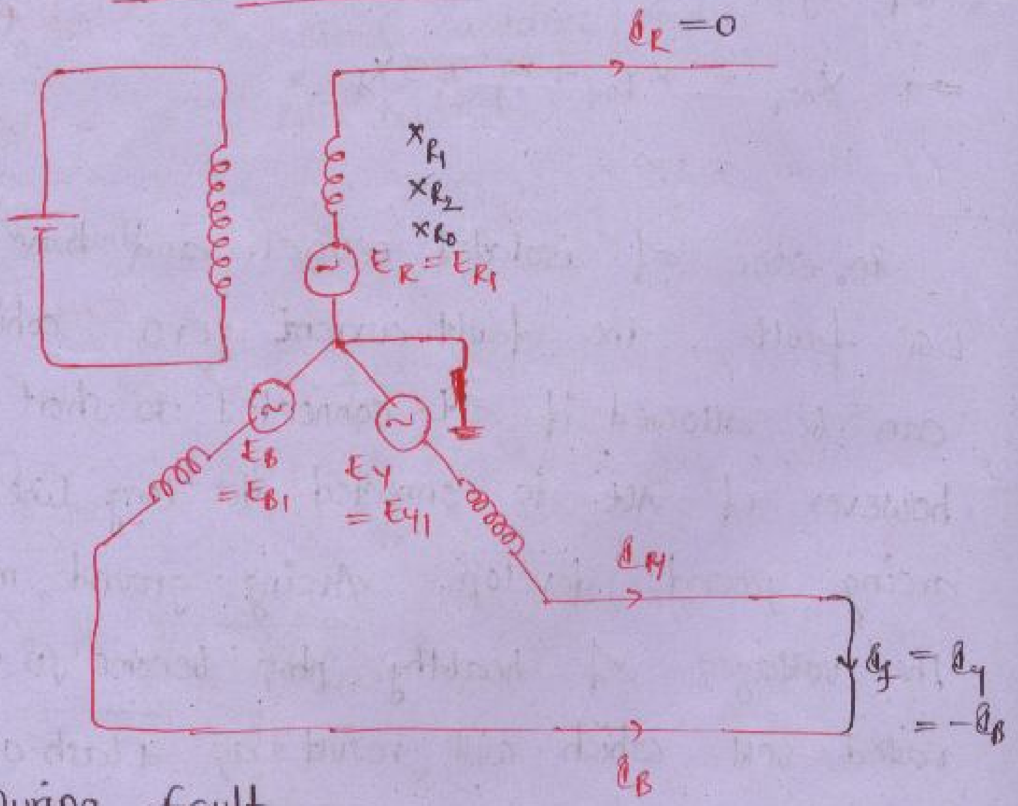
$$I_n = 3 I_{R0}$$

$$\frac{V_{ph}}{X_L} = 3 \times \cdot \frac{V_{phase}}{X_c}$$

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

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

LINE TO LINE FAULT :-



During fault,

fault current $I_f = I_y = -I_B$

$I_R = 0$

$I_y + I_B = 0$

$V_y = V_B$.

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

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

$$= \frac{I_y}{3}\left\{ k - k^2 \right\}$$

$$I_{R_2} = \frac{1}{3}[I_R + k^2 I_Y + k.I_B]$$

$$= \frac{I_Y}{3}[k^2 - k] = -\frac{I_Y}{3}[k - k^2] = -I_{R_1}$$

$I_{R_2} = -I_{R_1}$ ↑ ①

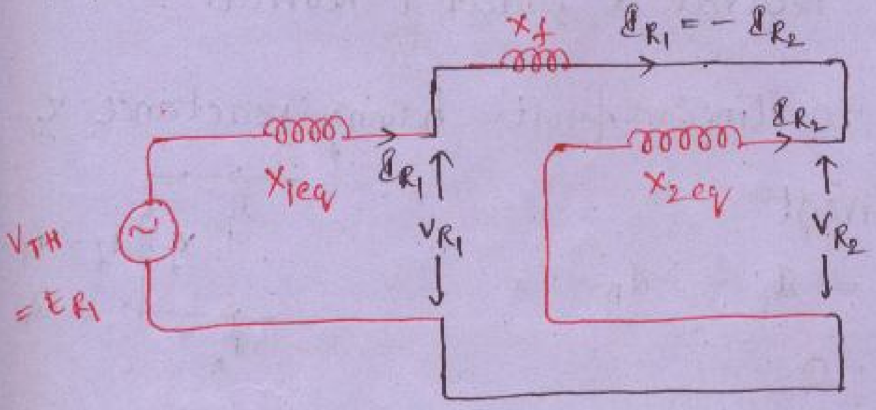
$V_Y = V_B.$

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

$\Rightarrow k^2.V_{R_1} + k.V_{R_2} = k.V_{R_1} + k^2.V_{R_2}$

$\Rightarrow (k^2 - k)V_{R_1} = (k^2 - k)V_{R_2} \rightarrow V_{R_1} = V_{R_2} \longrightarrow ②$

The fault is isolated from ground but unbalanced so there is no zero seq. comp. exists. But it consists of +ve & −ve seq. comp·s. The associated seq. n/ws are connected in anti parallel.



$V_{R_1} = V_{R_2}$

$E_{R_1} - I_{R_1}X_{1eq} = -I_{R_2}.X_{2eq}$

$$\Rightarrow I_{R_1} = \frac{E_{R_1}}{X_{1eq} + X_{2eq}} \text{ pu.}$$

$I_f = I_Y = I_{Y0} + I_{Y1} + I_{Y2}$

$= 0 + k^2 I_{R_1} + k.I_{R_2}$

$= (k^2 - k) I_{R_1}$

$I_f = 1.732\ I_{R_2} \angle 90^\circ = 1.732 \cdot I_{R_1} \angle -90$

$I_f = \sqrt{3} \cdot I_{R_1}$

$$= \frac{\sqrt{3} \cdot E_{R_1}}{X_{1eq} + X_{2eq}} \text{ pu}$$

$I_{f(actual)} = I_{f\,pu} \cdot I_{base}$ KA & A.

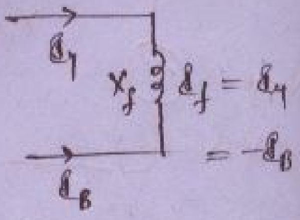
$$S/C \text{ MVA} = \frac{\text{Base MVA}}{X_{1eq} + X_{2eq}}$$

$V_n = I_n \cdot X_n = 0$ (Even in reactance neutral)

The fault current remain same in case of reactance neutral & isolated neutral.

If line to line fault having reactance X_f

fault current



$I_f = I_Y = -I_B$

$I_R = 0.$

$I_Y + I_B = 0.$

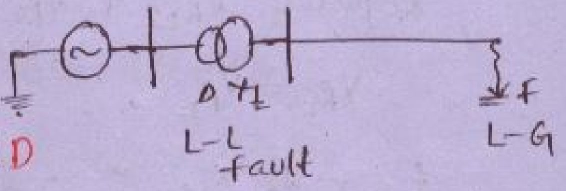
$$I_{R_1} = \frac{E_{R_1}}{X_{1eq} + X_{2eq} + X_f} \text{ pu}$$

$I_f = \sqrt{3} \cdot I_{R_1}$

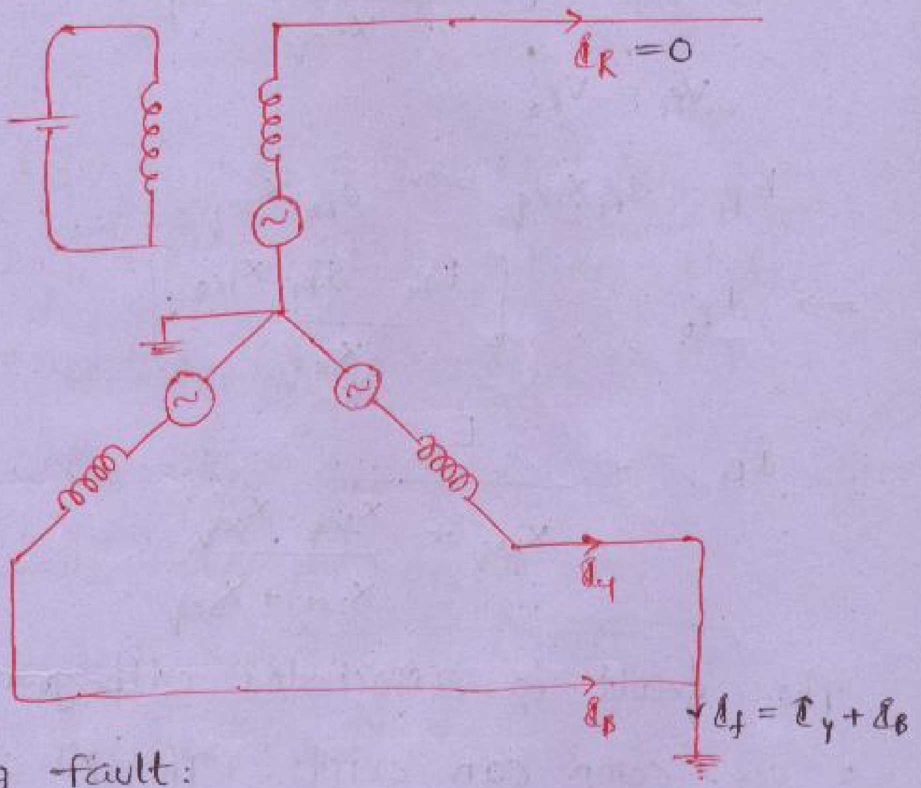
$$= \frac{\sqrt{3} \cdot E_{R_1}}{X_{1eq} + X_{2eq} + X_f} \text{ pu}$$

$$S/C \text{ MVA} = \frac{\text{Base MVA}}{X_{1eq} + X_{2eq} + X_f}$$

If the fault is referred towards the alt. side of T/F then it will be treated as L-L fault.



LINE – LINE – GROUND FAULT :-



During fault:

$I_f = I_Y + I_B$

$I_R = 0$

$V_Y = V_B = 0$

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

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

$V_{R2} = \frac{1}{3}[V_R + k^2V_Y + k.V_B] = \frac{V_R}{3}$.

$V_{R0} = V_{R1} = V_{R2} = \frac{V_R}{3}$

To know I_{R_1}, $I_R = 0$

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

Replace I_{R_2} & I_{R_0} interms of I_{R_1}

$V_{R_1} = V_{R_2}$

$E_{R_1} - I_{R_1} X_{1eq} = -I_{R_2} \cdot X_{2eq}$

$$I_{R_2} = -\left[\frac{E_{R_1} - I_{R_1} X_{1eq}}{X_{2eq}} \right]$$

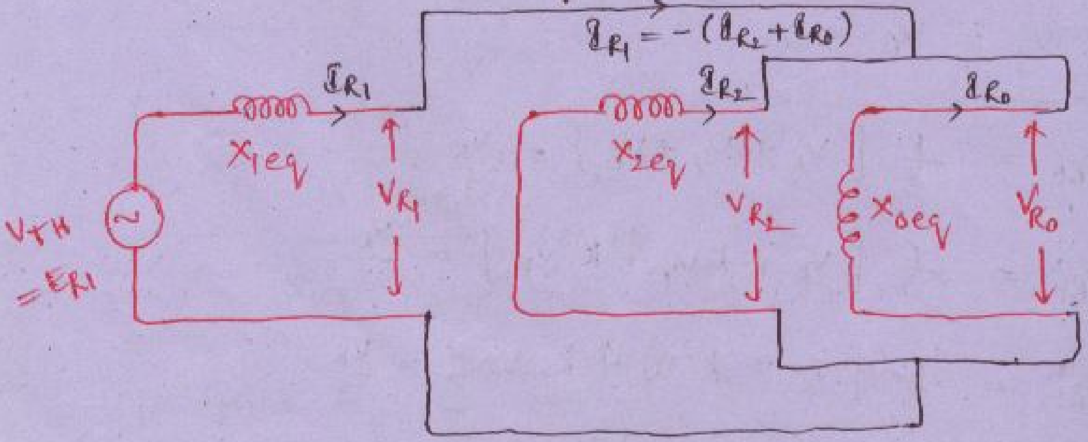
$V_{R_1} = V_{R_0}$

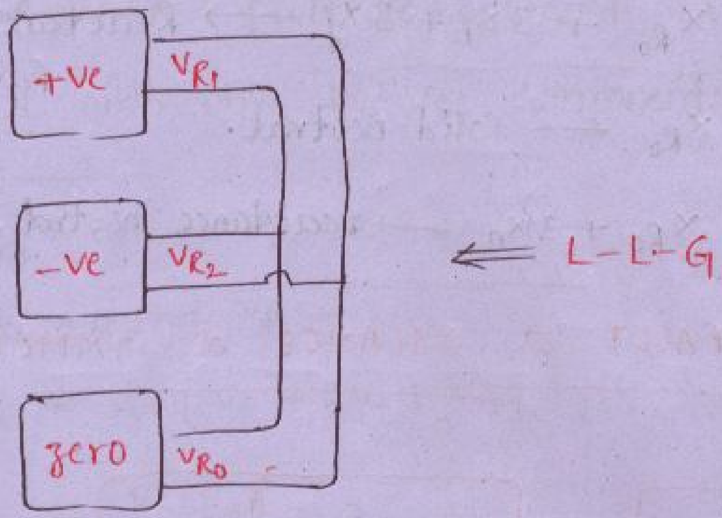
$E_{R_1} - I_{R_1} X_{1eq} = -I_{R_0} \cdot X_{0eq}$

$$\Rightarrow I_{R_0} = -\left[\frac{E_{R_1} - I_{R_1} \cdot X_{1eq}}{X_{0eq}} \right]$$

$$\therefore I_{R_1} = \frac{E_{R_1}}{X_{1eq} + \dfrac{X_{2eq} \cdot X_{0eq}}{X_{2eq} + X_{0eq}}}.$$

The fault is associated with ground so 3 seq. comp. can exists. The $\|^{el}$ combi. of -ve seq. & zero seq. n/w's are connected in series with +ve seq. n/w.





$$I_f = I_Y + I_B$$

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

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

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

$$= 2I_{R0} - I_{R1} - I_{R2}$$

$$I_f = 2I_{R0} + I_{R0} = 3 \cdot I_{R0} \text{ pu}$$

$$I_{R0} = -I_{R1} \cdot \frac{X_{2eq}}{X_{2eq} + X_{0eq}}$$

$$I_{f(actual)} = I_{f\,pu} \cdot I_{base} \text{ kA or A.}$$

$$\text{S/C MVA} = \frac{\text{Base MVA}}{X_{1eq} + (X_{2eq} \parallel X_{0eq})}$$

The potential of neutral,

$V_{n\,pu} = I_n X_n$ (reactance neutral).

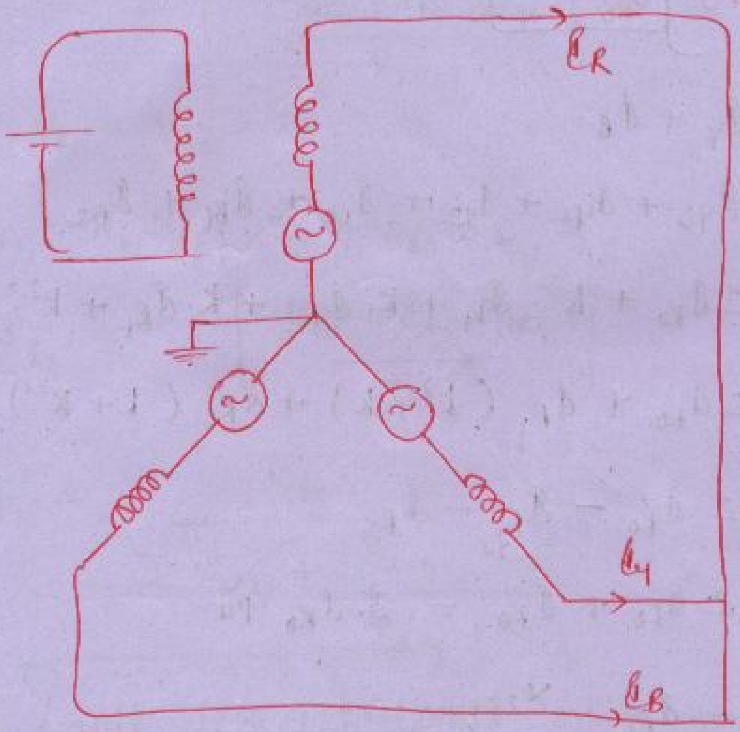
$V_n = 0$ (solid neutral).

$X_{0eq} = X_{R_0} + 3X_n + 3X_f \longrightarrow$ Reactance fault.

$X_{0eq} = X_{R_0} \longleftarrow$ Solid neutral.

$X_{0eq} = X_{R_0} + 3X_n \longleftarrow$ reactance neutral.

L-L-L FAULT or BALANCE or SYMMETRICAL



Alternator working at NL, rated voltage

$X_n = 0$ & $X_f = 0$.

fault current $I_f = I_R = I_Y = I_B$.

$I_R + I_Y + I_B = 0$.

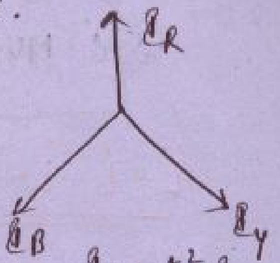
$V_R = V_Y = V_B$

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

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

$I_{R2} = \frac{1}{3}[I_R + k^2.I_Y + k.I_B] = 0$.

As the fault is balanced, it is associated with only +ve seq. components.



$I_Y = K^2 \cdot I_R$

$I_B = K \cdot I_R$

$I_{R_0} = 0 \rightarrow V_{R_0} = 0$

$I_{R_2} = 0 \rightarrow V_{R_2} = 0.$

$V_{R_1} = \frac{1}{3}\left[V_R + KV_Y + K^2 V_B\right]$

$= \frac{V_R}{3}[0] = 0.$

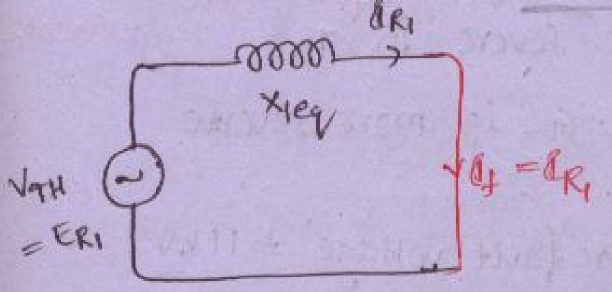
$\Rightarrow \overset{**}{V_{R_1}} = 0$

In a 3-ϕ fault the +ve seq. n/w terminal voltage is zero.

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

$\rightarrow I_{R_1} = \frac{E_{R_1}}{X_{1eq}}$ pu.

$I_f = I_R = I_{R_1} = \frac{E_{R_1}}{X_{1eq}}$. pu



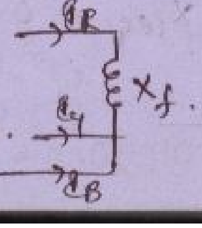
$S/C\ MVA = \frac{B.MVA}{X_{1eq}}$

$V_n = 0$, balanced fault.

for reactance neutral as well as isolated neutral, I_f remain same, b'coz the +ve seq. n/w doesn't depends on neutral grounding

for reactance fault,

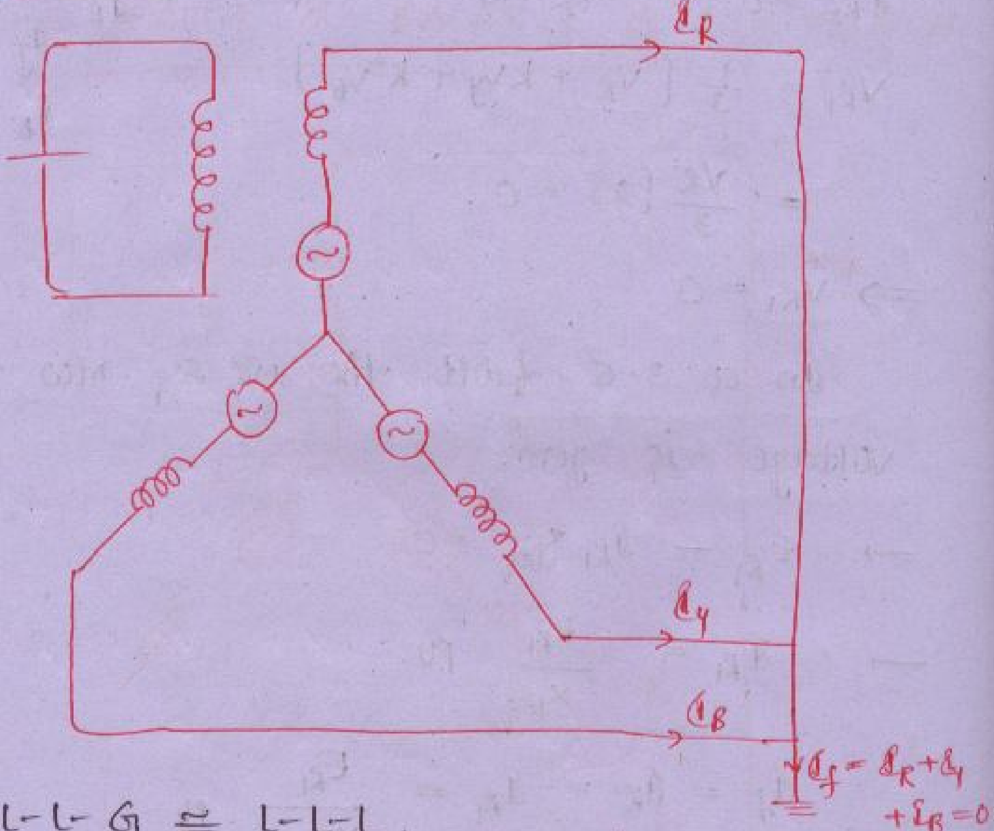
$I_f = I_R = I_{R_1} = \frac{E_{R_1}}{X_{1eq} + X_f}$ pu.



$$I_{f(actual)} = I_f \cdot pu \cdot I_{base}$$

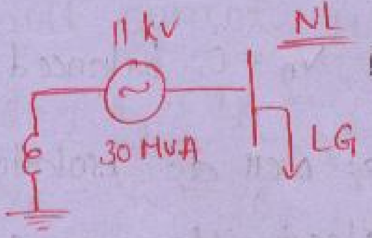
$$S/C \ MVA = \frac{Base \ MVA}{X_{1eq} + X_f} .$$

L-L-L-G :



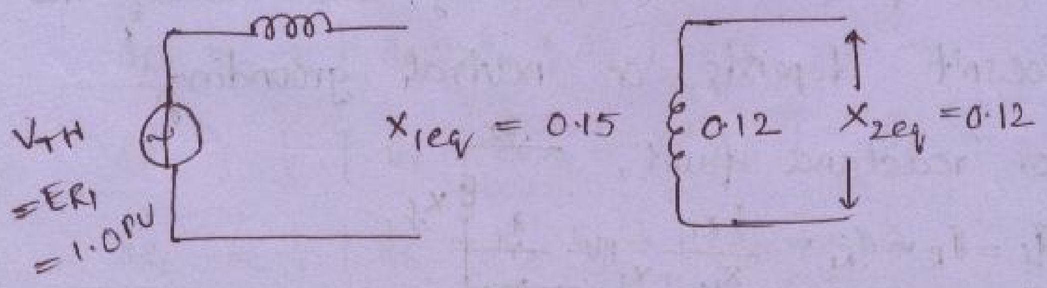
- * L-L-L-G ≅ L-L-L.
- * 3-ϕ fault is more severe in TL. ← b'coz of huge zero seq. currents.
- * In case of alt. L-G is more severe

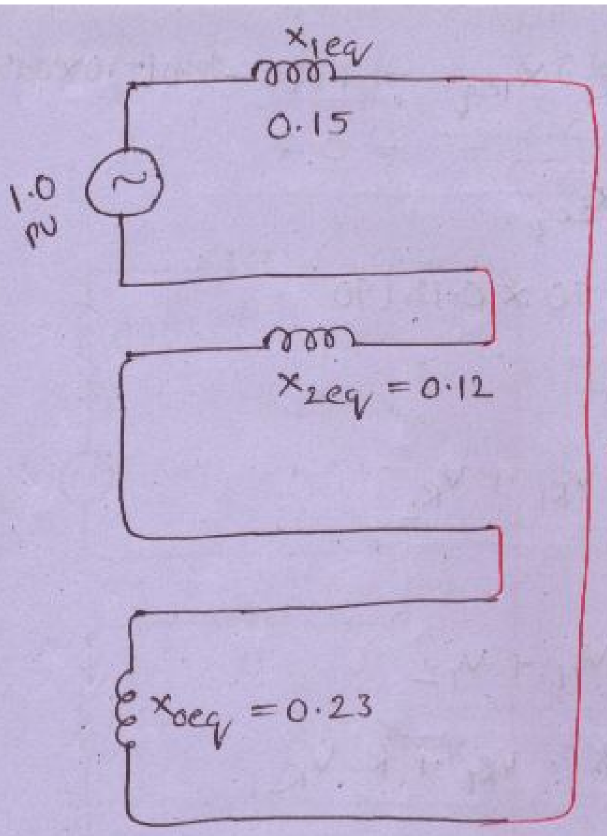
Q1.

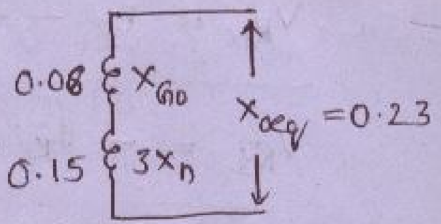


prefault voltage = 11 kV

$= \frac{11}{11} = 1.0 PU$







$$I_f = \frac{3 \times 1.0}{0.15 + 0.12 + 0.23}$$

$$= 6.0 \text{ pu}$$

$$= 6.0 \angle -90 \text{ pu}.$$

To know x_{2eq} & x_{0eq} use simulation diagram of given single line diagram.

$$I_{f(\text{actual})} = I_{f \cdot \text{pu}} \cdot I_{\text{base}}$$

$$= 6.0 \times \frac{30}{\sqrt{3} \times 11} \text{ KA (rms)}$$

$$V_n = I_n \cdot x_n \qquad I_{R_1} = I_{R_2} = I_{R_0}$$

$$= 6.0 \times 0.05 = 0.3 \text{ pu} \qquad = 2.0 \angle -90^\circ.$$

$$V_n = 0.3 \times \frac{11 \times 10^3}{\sqrt{3}} \text{ V}$$

$$\text{SC MVA} = \frac{\text{Base MVA}}{x_{1eq} + x_{2eq} + x_{0eq}}$$

$$= \frac{30}{0.15 + 0.12 + 0.23}$$

$$V_R = V_{R0} + V_{R_1} + V_{R_2}$$

$$V_{R0} = -I_{R0} \cdot x_{0eq} = -2.0\angle -90 \times 0.23\angle 90 = -0.46$$

$V_{R_1} = E_{R_1} - I_{R_1} \cdot X_{1eq} = 1.0\angle 0 - 2.0\angle -90 \times 0.15\angle 90^\circ$

$= 0.7$

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

$= -2.0\angle -90 \times 0.12\angle 90$

$= -0.24$

$\therefore V_R = V_{R_0} + V_{R_1} + V_{R_2}$

$= 0.$

$V_Y = V_{Y_0} + V_{Y_1} + V_{Y_2}$

$= V_{R_0} + K^2 \cdot V_{R_1} + K \cdot V_{R_2}$

$= -0.46 + 0.7\angle 240 - 0.24\angle 120$

$=$

$V_B = V_{B_0} + V_{B_1} + V_{B_2}$

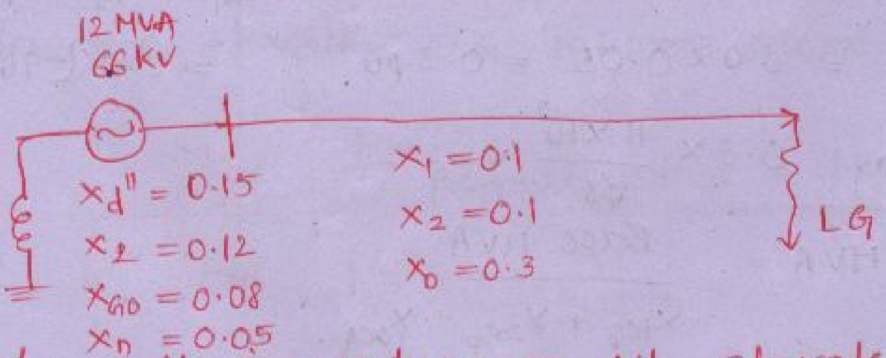
$= V_{R_0} + K \cdot V_{R_1} + K^2 \cdot V_{R_2}$

$=$

$\Rightarrow V_Y = V_B$ & $V_R = 0$.

G'03

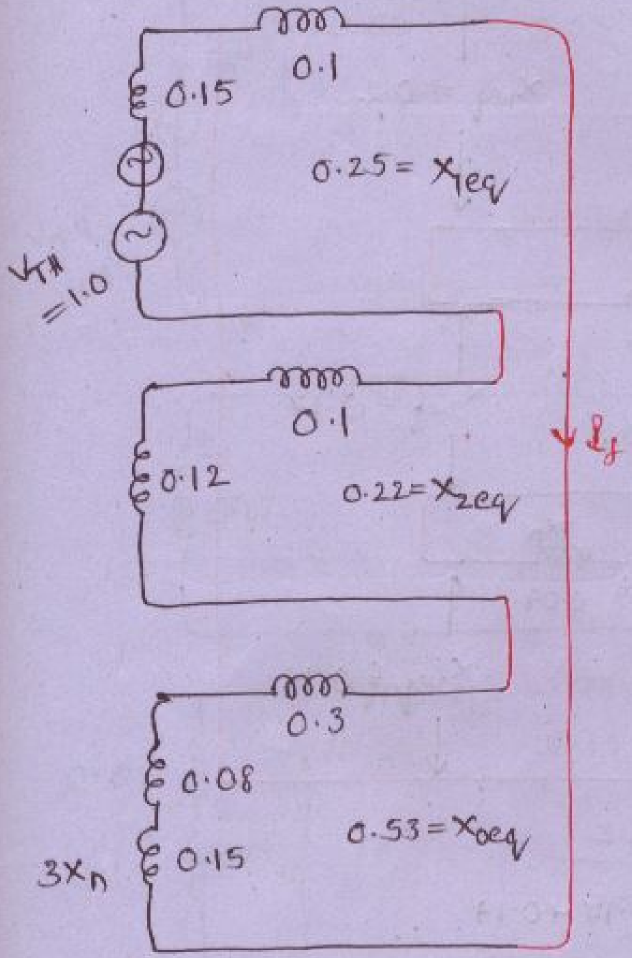
Q. 12 MVA 66 kV



The alt. is working on NL at rated voltage. The potential of N during fault in volts —?

prefault voltage $= 6.6\,kV$

$= \frac{6.6}{6.6} = 1.0\,PU$



$I_f = 3 I_{R0} = 3 I_{R1}$

$= 3 \times \frac{1.0}{0.25 + 0.22 + 0.53}$

$= 3.0\,PU.$

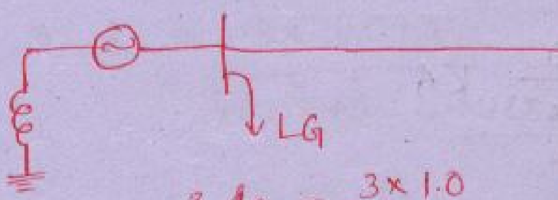
$V_n = I_n X_n$

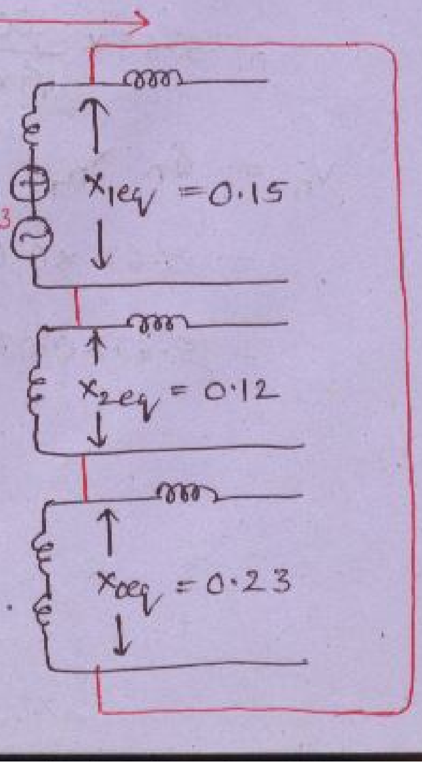
$= I_f \cdot X_n$

$= 3.0 \times 0.05$

$= 0.15\,PU$

$V_n = 0.15 \times \frac{6.6 \times 10^3}{\sqrt{3}}\,V$





$3 \cdot I_{R0} = \frac{3 \times 1.0}{0.15 + 0.12 + 0.23}$

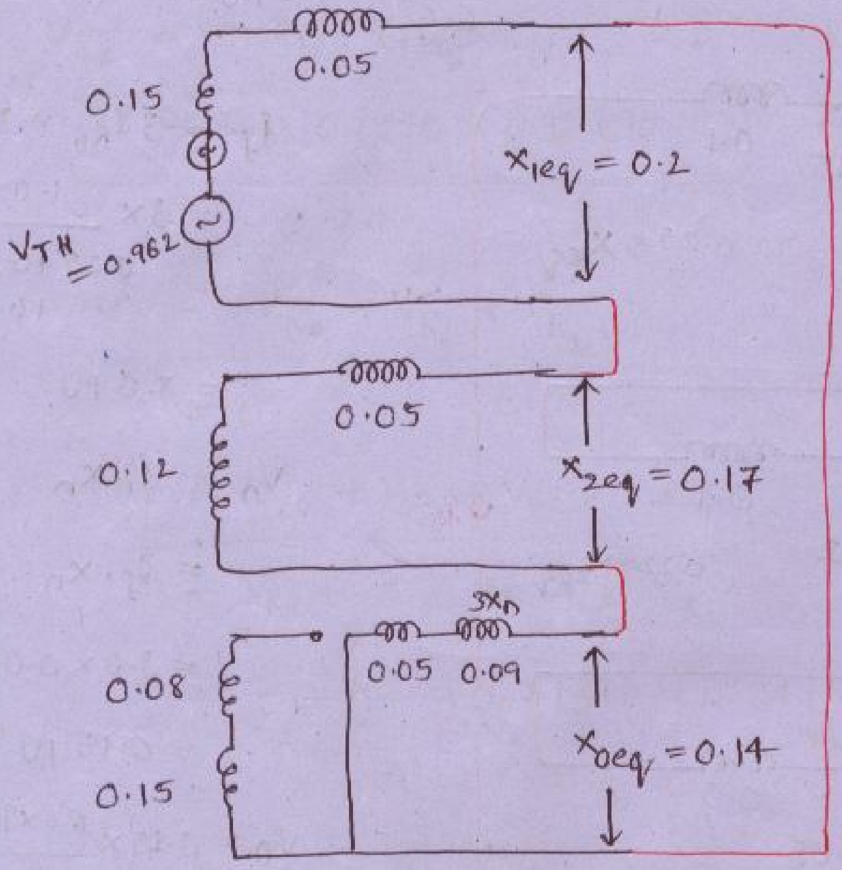
$I_f = 6.0\,PU$

$I_n X_n = I_f X_n$

$V_n = 0.3\,PU = 6.0 \times 0.05$

$V_n = 0.3 \times \frac{6.6 \times 10^3}{\sqrt{3}}\,V$

Q2. prefault voltage $= \frac{31.75}{33} = 0.962$ PU



$$I_f = 3 \times \frac{0.962}{0.2 + 0.17 + 0.14}$$

$= 5.63$ PU

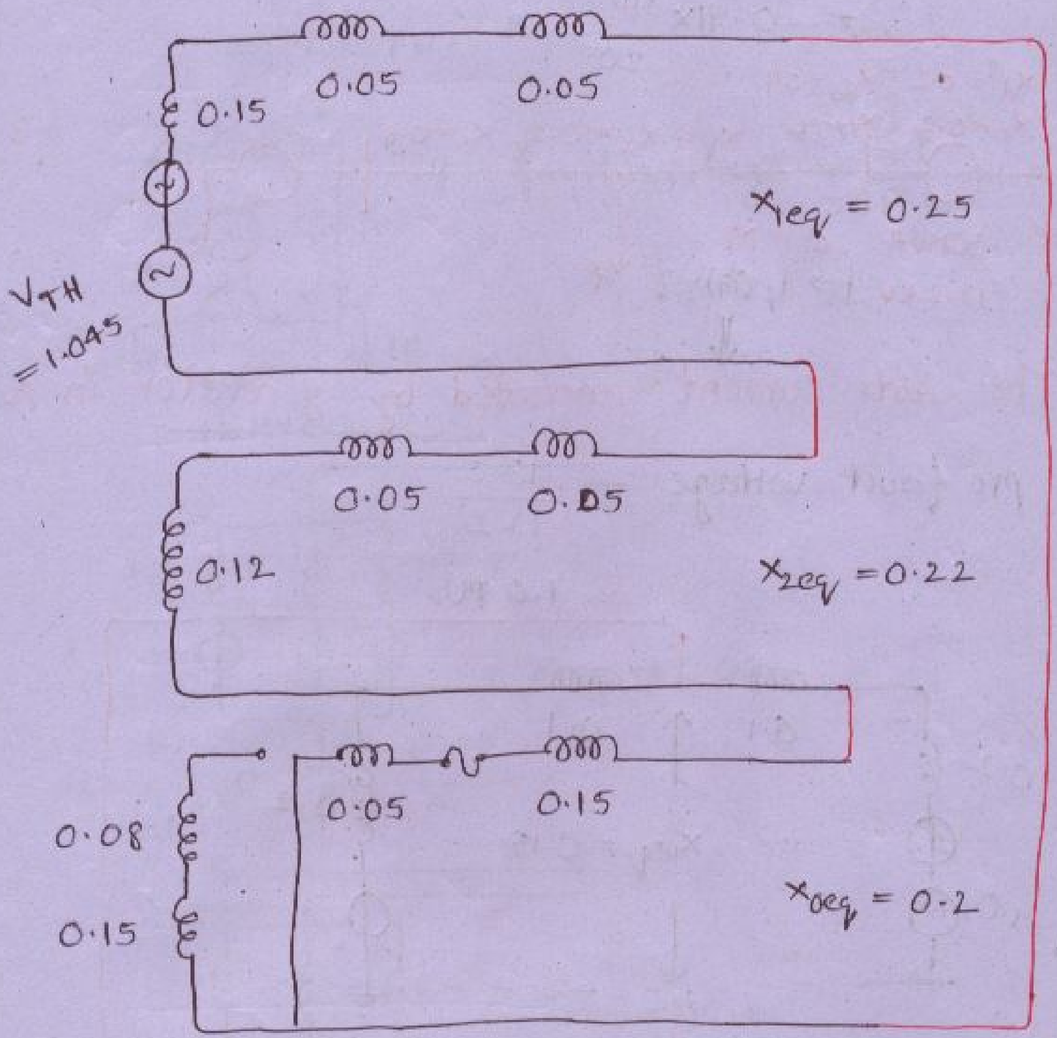
$= 5.63 \times \frac{30}{\sqrt{3} \times 33}$ kA

$V_n = I_n \cdot x_{nT}$.

$= 5.63 \times 0.03$ pu

$= 5.63 \times 0.03 \times \frac{33}{\sqrt{3}} \times 10^3$ V.

03. pre fault voltage $= \frac{34.5}{33} = 1.045$ pu.



$$I_f = \frac{3 \times 1.045}{0.25 + 0.22 + 0.2}$$

$$= 4.67 \text{ pu}$$

$V_n = 0.$

05. I_f = rated current

$\cancel{I_{f(actual)}} = I_{f\,pu} \cdot \cancel{I_{base}}$

$\rightarrow I_{f\,pu} = 1.0$

$$1.0 = \frac{3 E_{R_1}}{x_1 + x_2 + x_{G0} + 3x_n}$$

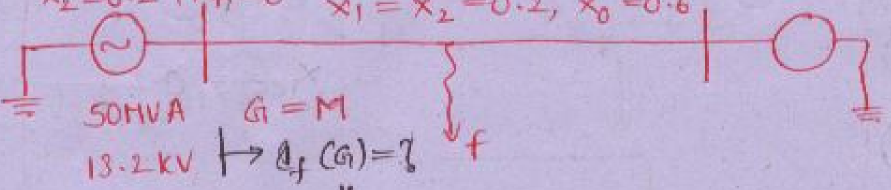
$$x_n = \frac{3.0 - 0.27}{3} = 0.91 \text{ pu}$$

$$= 0.91 \times \frac{(11)^2}{20} \ \Omega.$$

Q. $x_d'' = 0.2$ | $x_{G0} = 0.1$

$x_2 = 0.2$ | $x_n = 0$

$x_1 = x_2 = 0.2, \ x_0 = 0.6$



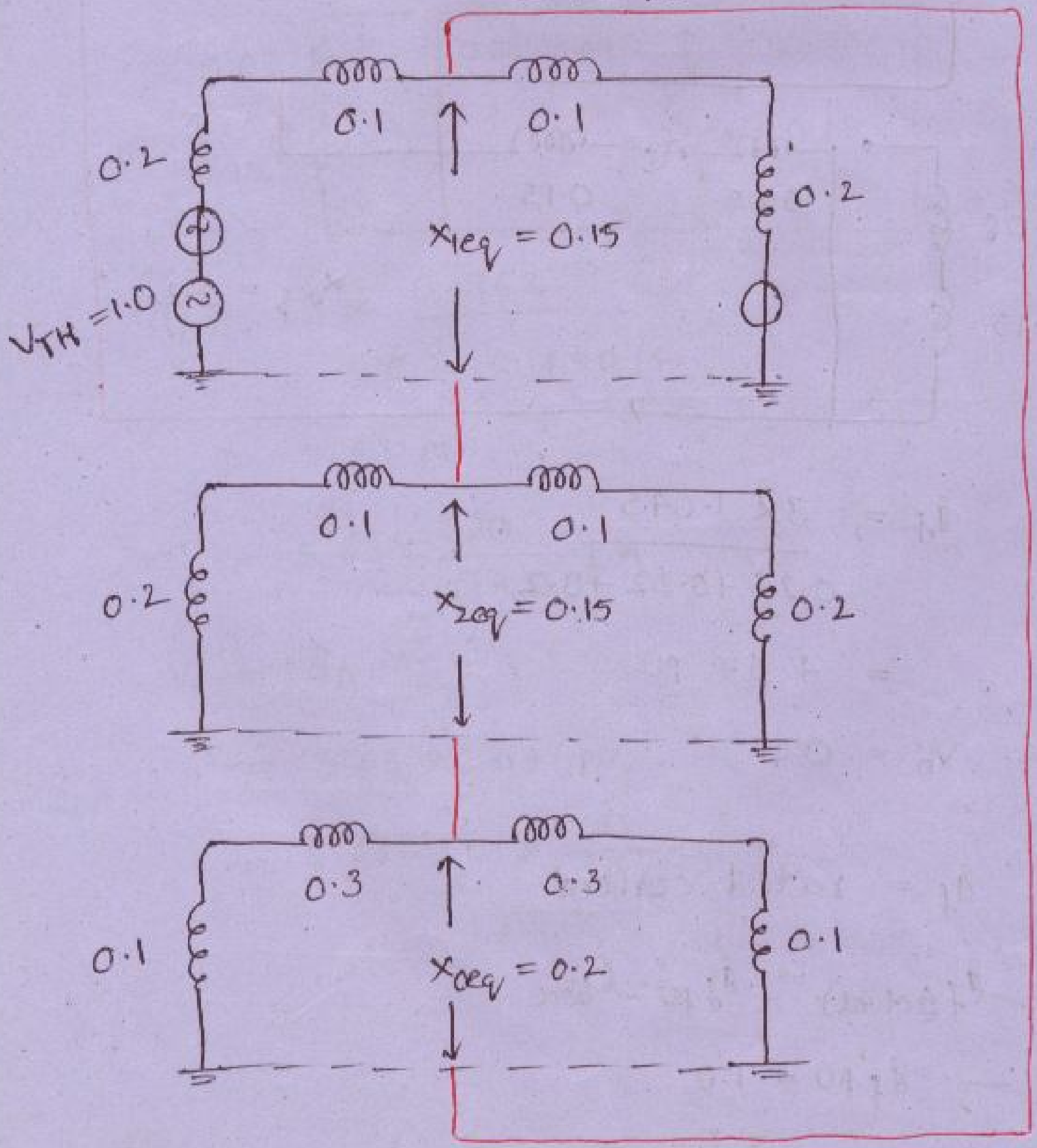
$\mapsto I_f(G) = ?$

⇓

The subtr. current generated by generator in pu ?

$$\text{pre fault voltage} = \frac{13.2}{13.2}$$

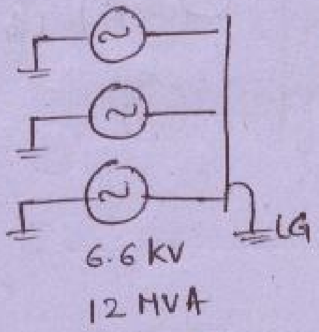
$$= 1.0 \text{ pU}.$$



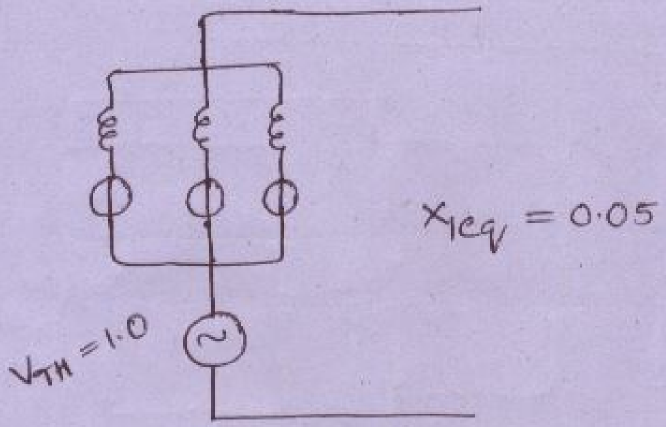
$$I_f = \frac{3\times1.0}{0.15+0.15+0.2}$$

$$= 6.0 \text{ pu.}$$

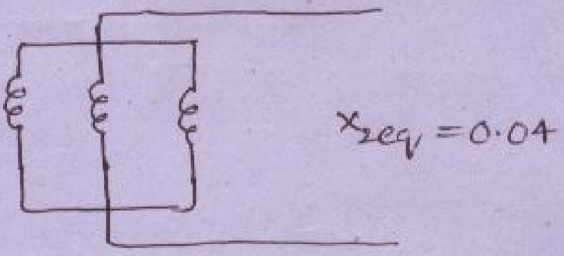
0.6



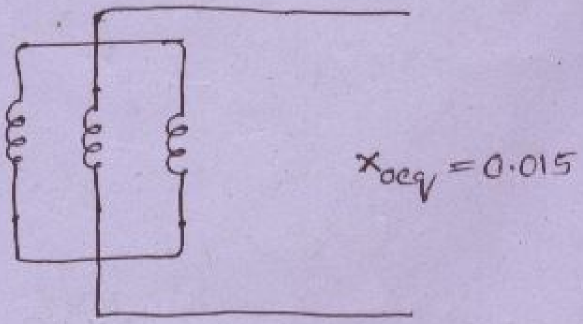
pre fault voltage $= \frac{6.6}{6.6} = 1.0$ PU



$X_{1eq} = 0.05$



$X_{2eq} = 0.04$

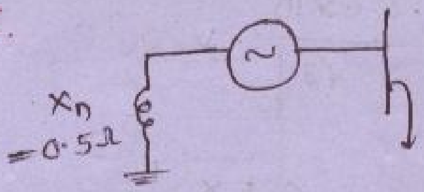


$X_{0eq} = 0.015$

$$I_f = \frac{3\times1.0}{0.05+0.04+0.015} = 28.$$

$$S/C \text{ MVA} = \frac{12}{0.05+0.04+0.015}$$

15.



pre fault voltage $= \frac{16.9}{13.2}$

$= 1.053.$

x_n pu $= 0.5 \times \frac{15}{(13.2)^2}$

$= 0.043.$

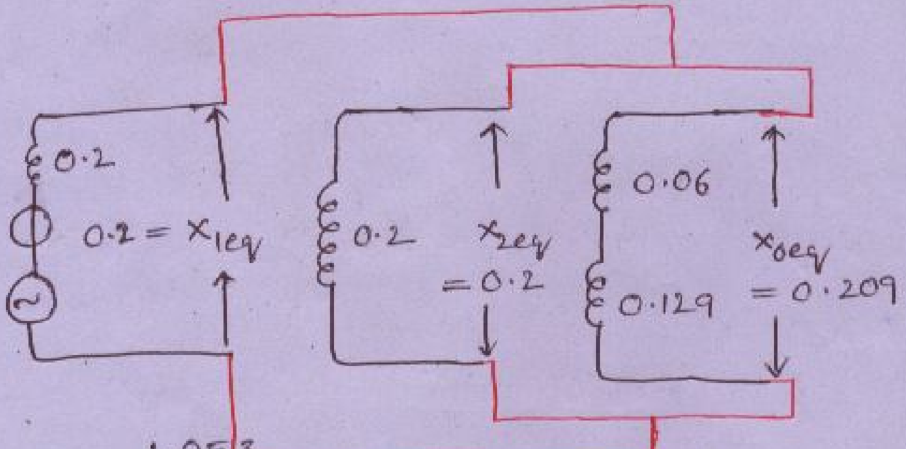
$3x_n = 3 \times 0.043$ pu.

$= 0.129$ pu

$X_{0eq} = X_G + 3X_n$

$= 0.06 + 0.129$

$= 0.209$ pu.



$$I_{G1} = \frac{1.053}{0.2 + \frac{0.2 \times 0.209}{0.2 + 0.209}} = 3.48 \angle -90^\circ$$

$$I_{G0} = 3.46 \angle 90 . \times \frac{0.2}{0.2 + 0.209} = 1.7 \angle 90$$

$$I_{G2} = 1.78 \angle 90$$

$$I_f = I_g = I_n = 3 \times 1.7 \angle 90$$

$$= 5.1 \angle 90 \text{ pu}$$

$$= 5.1 \times \frac{15}{\sqrt{3} \times 13.2} \times 1.6 \text{ kA}$$

$$V_n = I_n X_n = 5.1 \times 0.043 \text{ pu}$$

$$= 5.1 \times 0.043 \times \frac{13.2 \times 10^3}{\sqrt{3}} \text{ V.}$$

$$s/c\ MVA = \frac{15}{0.2 + \frac{0.2 \times 0.209}{0.2 + 0.209}} =$$

$$I_B = I_{B0} + I_{B1} + I_{B2} = I_{a0} + K^2 I_{a1} + K.I_{a2}$$

$$= 1.7\angle 90 + 3.48\angle 240-90 + 1.78\angle 120+90$$

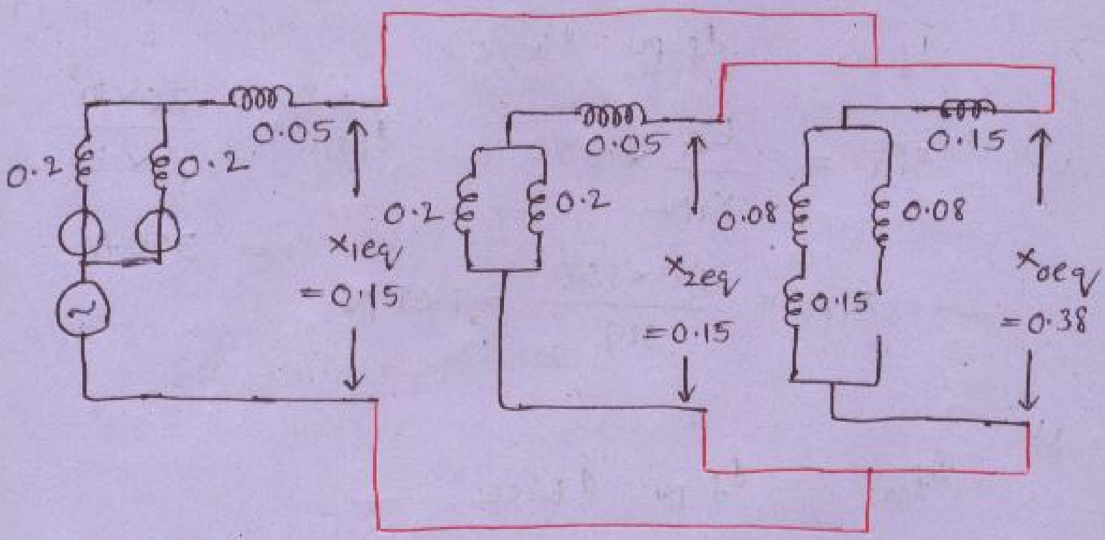
$$I_c = I_0 + I_{c1} + I_{c2} = I_{a0} + K.I_{a1} + K^2.I_{a2}$$

$$= 1.7\angle 90 + 3.48\angle 120-90' + 1.78\angle 240+90$$

Initial symmetrical rms current is same as that of fault or sub tr. current.

Initial current = $I_f \times (1.6)$ KA
(Momentary current)

16. prefault voltage = $\frac{11.25}{11}$ = 1.022 pu



$$I_{R1} = \frac{1.022}{0.15 + (0.15 \parallel 0.38)}$$

$$= 3.96 \text{ pu}$$

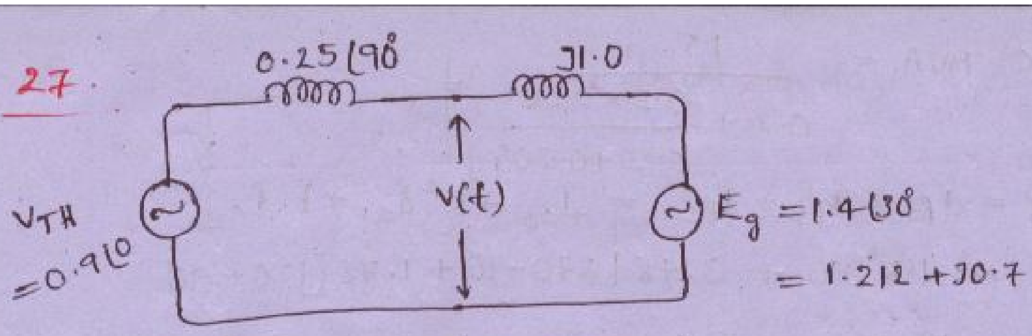
$$I_{R0} = 3.96 \times \frac{0.15}{0.15 + 0.38} = 1.12 \text{ pu}$$

$$I_G = I_f = 3 I_{R0}$$

$$= 3 \times 1.12 = 3.36 \text{ pu}$$

$$\therefore I_f = 3.36 \times \frac{7.5}{\sqrt{3} \times 11} \text{ KA}$$
(rms).

27.



$$I = \frac{1.212 + j0.7 - 0.9\angle 0}{1.25\angle 90°}$$

$$V(t) = 0.9\angle 0 + 0.25\angle 90 \times \frac{0.312 + j0.7}{1.25\angle 90°}$$

$$= \text{ll}$$

25. $I_{f(a)} = I_{f\,pu} \cdot I_{base}$

LLL $319 = \frac{E_{R_1}}{X_{1pu}} \times 350$ $\quad I_{base} = \frac{20\times 10^3}{\sqrt{3}\times 33}$

$= 350A.$

$\rightarrow X_{1pu} = \frac{1.0\times 350}{319} = 1.09\ pu.$

LL

$I_{f(a)} = I_{f\,pu} \cdot I_{base}$

$435 = \frac{\sqrt{3}\cdot E_{R_1}}{X_{1pu} + X_{2pu}} \times 350$

$\rightarrow X_{2pu} =$

LG

$659 = \frac{3\times E_{R_1}}{X_1 + X_2 + X_0} \times 350$

$\Rightarrow$

G'05.

Q. A 220 kV bus bar, s/c MVA for 3-ϕ as well as LG are 4000 & 5000 res.

(1). +ve seq. reactance in Ω.

(2). zero seq. reactance in Ω.

LLL,

$$s/c\ MVA = \frac{Base\ MVA}{X_{1eq}}$$

$$= \frac{Base\ MVA}{(X_1)_\Omega \cdot \frac{Base\ MVA}{(kV)^2}}$$

$$= \frac{(kV)^2}{X_{1\Omega}}$$

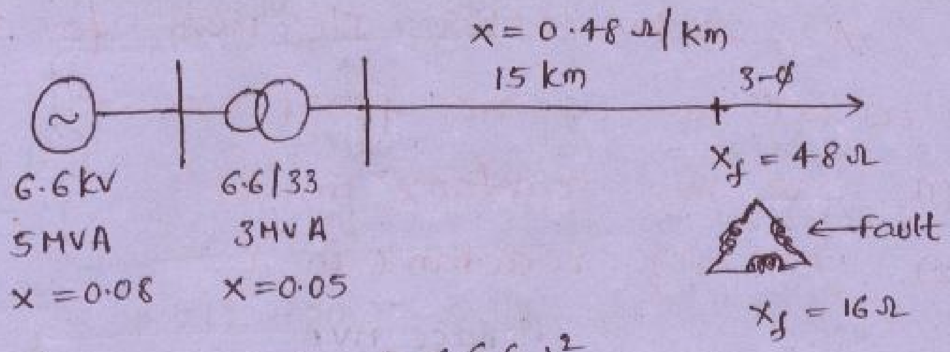
$$\Rightarrow X_{1\Omega} = \frac{220 \times 220}{4000}$$

$$= 12.1\Omega.$$

LG,

$$s/c\ MVA = Base\ '$$

21.



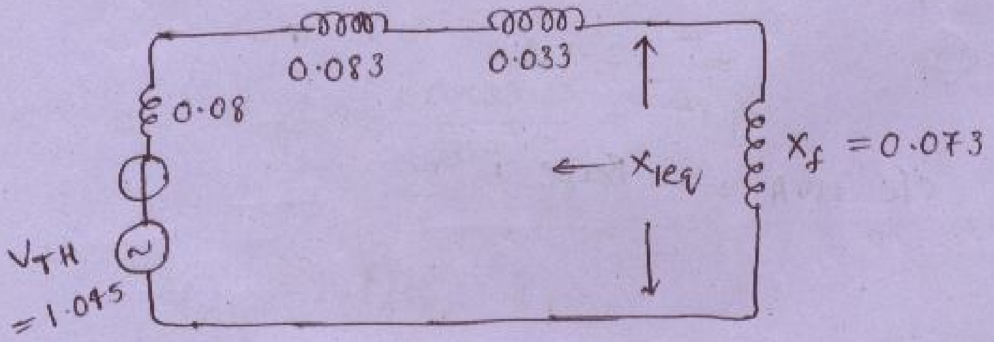
$$X_{T\,new} = 0.05 \times \frac{5}{3}\left(\frac{6.6}{6.6}\right)^2$$

$$= 0.083$$

$$X_{l\,pu} = 0.48 \times 15 \times \frac{5}{(33)^2} = 0.033$$

$$X_{f\,pu} = 16 \times \frac{5}{(33)^2} = 0.073.$$

prefault voltage $= \frac{34.5}{33} = 1.045$



$$I_f = \frac{1.045}{0.08 + 0.083 + 0.033 + 0.073}$$

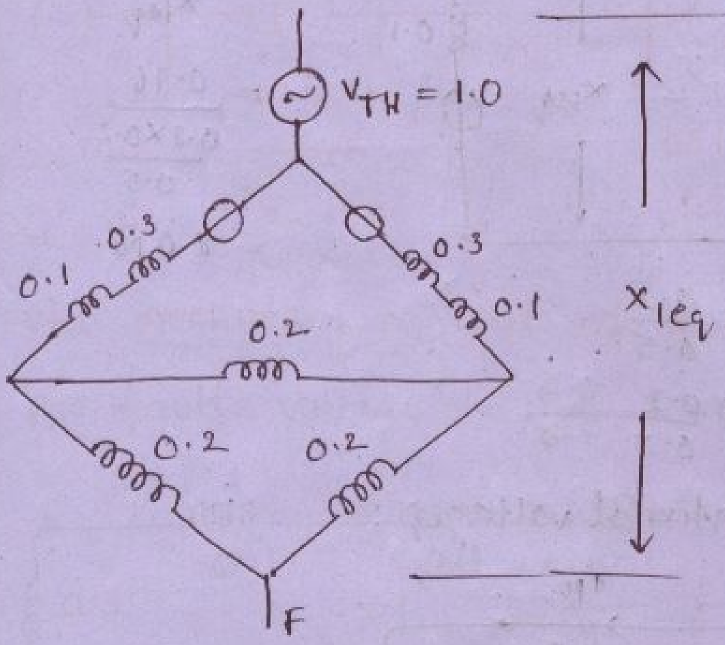
$= 3.88$ pU

$I_{f(G)} = 3.88$ pU

$I_{f(a)} = 3.88 \times \frac{5}{\sqrt{3} \times 33}$ KA

$I_{f(G)} = 3.88 \times \frac{5}{\sqrt{3} \times 6.6}$ KA

22. pre fault voltage $= \frac{66}{66} = 1.0$



$$I_f = \frac{E_{R1}}{X_{1eq}} = \frac{1.0}{X_{1eq}}$$

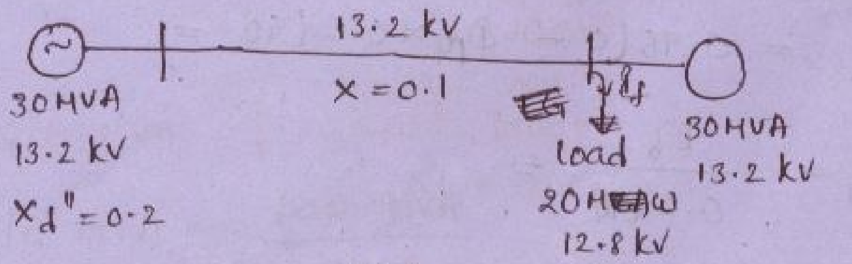
$$= \frac{1.0}{0.3} = 3.33 \text{ pU}$$

$$I_f(f) = 3.33 \times \frac{100}{\sqrt{3}\times 66} \text{ kA}$$

$$I_f(G_1) = I_f(G_2) = \frac{3.33}{2} = 1.66 \text{ pU}$$

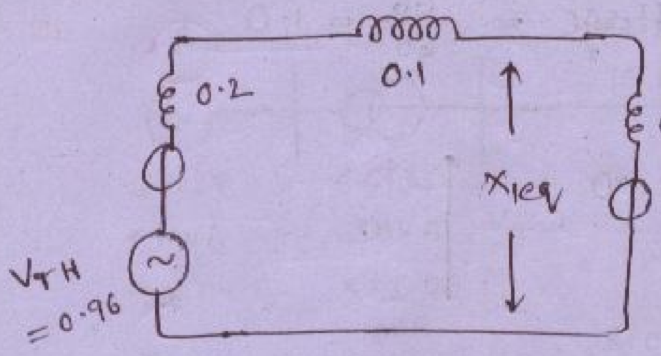
$$I_f(G_1) = I_f(G_2) = 1.66 \times \frac{100}{\sqrt{3}\times 11} \text{ kA.}$$

18.



pre fault voltage $= \frac{12.8}{13.2}$

$= 0.96$

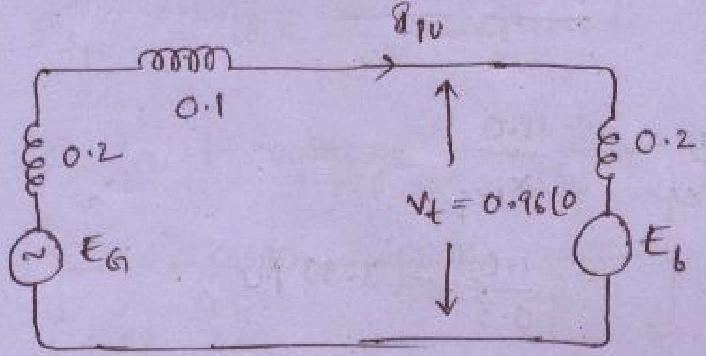


$$I_f = \frac{E_{l1}}{X_{1eq}} = \frac{0.96}{\frac{0.3 \times 0.2}{0.5}} = 8.0 \text{ pu}$$

$$I_f(G) = 8.0 \times \frac{0.2}{0.5}$$

$$I_f(m) = 8.0 \times \frac{0.3}{0.5}$$

Based on Internal voltages :



$$I_{pu} = \frac{I_G}{I_b} = \left[\frac{20 \times 10^6}{\sqrt{3} \times 12.8 \times 10^3 \times 0.8}\right] \Big/ \left(\frac{30 \times 10^6}{\sqrt{3} \times 13.2 \times 10^3}\right)$$

$$= 0.85 \angle 36.86$$

$$I_G = \frac{E_G}{0.3\angle 90} =$$

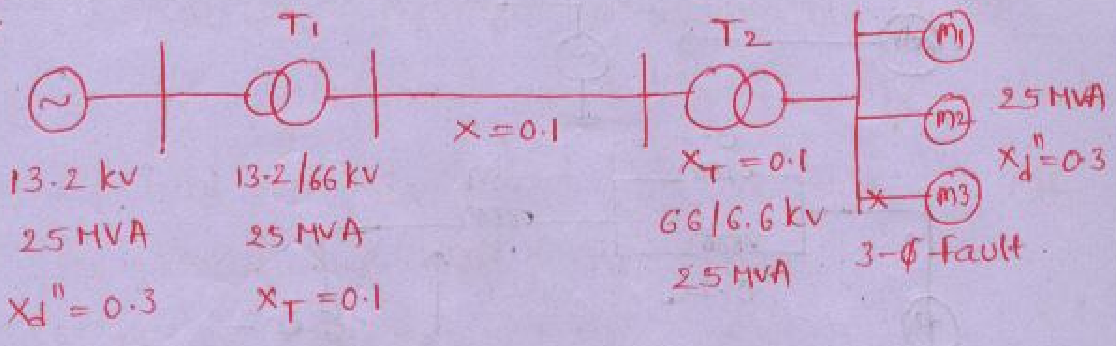
$$E_G = 0.96\angle 0 + I_{pu} \times 0.3\angle 90 =$$

$$E_b = 0.96\angle 0 - I_{pu} \times 0.2\angle 90 =$$

$$I_m = \frac{E_b}{0.2\angle 90} =$$

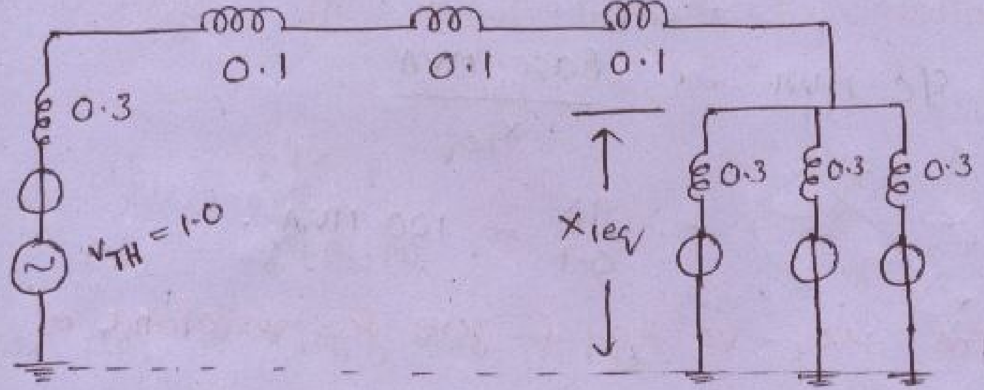
$$I_f = I_G + I_m$$

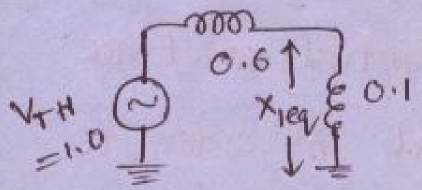
Q.



The ~~momentary~~ current of fault in kA —?

pre fault voltage $= \frac{6.6}{6.6} = 1.0$

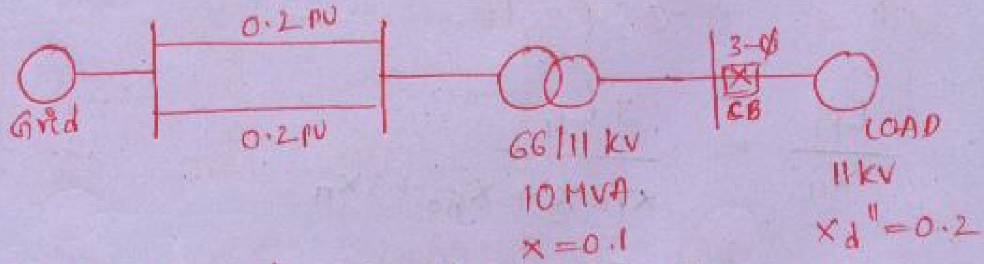




$$I_f = \frac{1.0}{\frac{0.6\times0.1}{0.7}} = 11.66 \text{ PU}$$

$$= 11.66 \times \frac{25}{\sqrt{3}\times6.6} \times 1.6 \text{ kA}.$$

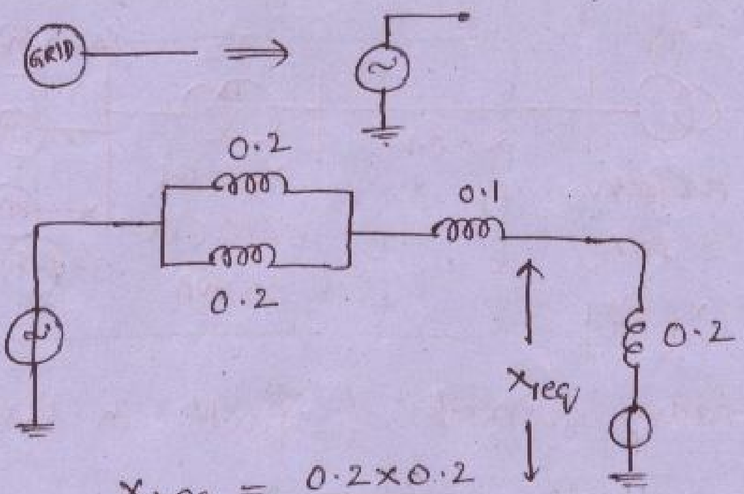
Q.



S/C MVA of circuit breaker is —?

$$S/C \text{ MVA} = \frac{\text{Base MVA}}{X_{1eq}}$$

$$= \frac{10}{X_{1eq}}$$



$$X_1 eq = \frac{0.2 \times 0.2}{0.4}$$

$$= 0.1.$$

$$S/C\ MVA = \frac{Base\ MVA}{X_{1eq}}$$

$$= \frac{10}{0.1} = 100\ MVA.$$

Q. The +ve, −ve seq & zero seq. reactance of alt. are $x_d'' = x_2 = 0.15$, $x_0 = 0.05$ pu. what is the value of neutral reactance to be inserted in neutral in order to have same severity for a LG fault as well as 3-ϕ fault.

$$\frac{E_{R1}}{X_1} = \frac{3 E_{R1}}{X_1 + X_2 + X_{G0} + 3X_n}$$

$$\frac{10}{X_1} = \frac{3 \times 1.0}{X_1 + X_2 + X_{G0} + 3X_n}$$

$$\Rightarrow 0.15 + 0.15 + 0.05 + 3X_n = 3 \times 0.15.$$

$$\Rightarrow X_n = 0.033\ pu.$$

Q. 3 resistors having 1 pu connected as Y to the unbalanced 3-ϕ supply. The neutral of load point is isolated. The +ve seq, -ve seq line volt-s are —

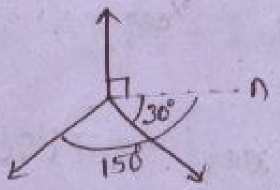
$ab_1 = x \angle \theta_1$ pu

$ab_2 = Y \angle \theta_2$ pu.

The pu calculations are made w.r.t their ratings. The ph. to neutral seq. voltages are —?

$ab_1 = x \angle \theta_1$ pu

$ab_2 = y \angle \theta_2$ pu



(a). $a_{n1} = x \angle \theta_1$, $a_{n2} = y \angle \theta_2$

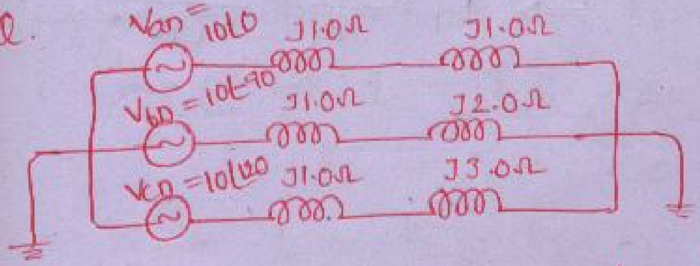
(b). $a_{n1} = x \angle \theta_1 - 30$, $a_{n2} = y \angle \theta_2 + 30^\circ$

✓(c). $a_{n1} = \frac{x}{\sqrt{3}} \angle \theta_1 - 30$, $a_{n2} = \frac{y}{\sqrt{3}} \angle \theta_2 + 30$

(d). $a_{n1} = \frac{x}{\sqrt{3}} \angle \theta_1 - 60$, $a_{n2} = \frac{y}{\sqrt{3}} \angle \theta_2 + 60^\circ$.

G'03

Q.



The +ve seq. component of line 'a' is —?

$I_{a1} = \frac{1}{3}\left[I_a + k I_b + k^2 I_c \right]$

$I_a = \frac{10\angle 0}{2\angle 90} = 5\angle -90$

$I_b = \frac{10\angle -90}{3\angle 90} = 3.33\angle -180$

$I_c = 10\angle 120 / 4\angle 90 = 2.5\angle 30$

$$I_{a1} = \frac{1}{3}\left[5\angle -90 + 3.33\angle -60 + 2.5\angle 270\right]$$

$$=$$

G'05.

Q. The self reactance of TL is — 0.5Ω/km and mutual reactance of TL is 0.2 Ω/km. The +ve, ~~-ve~~ & zero seq are — ?

Ans: 0.3 & 0.9 Ω

$$X_{1eq} = X_s - X_m$$

$$X_{2eq} = X_s - X_m$$

$$X_{0eq} = X_s + 2X_m$$

28.

$$X_{1eq} = 7\angle 90 \qquad I_{a1} = \frac{V_{a1}}{X_{a1}}$$

$$X_{2eq} = 7\angle 90 \qquad I_{a2} = \frac{V_{a2}}{X_{a2}}$$

$$X_{0eq} = 22\angle 90 \qquad I_{a0} = \frac{V_{a0}}{X_{a0}}$$

$$V_{a1} = \frac{1}{3}\left[V_{an} + k\cdot V_{bn} + k^2 V_{cn}\right]$$

$$= \frac{1}{3}\left[100\angle 0 + 60\angle 180 + 60\angle 360\right]$$

$$= 33.33\angle 0 \implies I_{a1} = \frac{V_{a1}}{X_{a1}} = \frac{33.33\angle 0}{7\angle 90}.$$

$$V_{a2} =$$

G'04

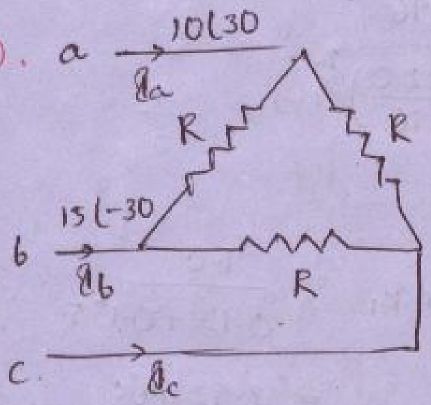
29. $I_{a1} = \frac{1}{3}[I_a + k.I_b + k^2 I_c]$

$I_c = 0,$

$I_{a1} = \frac{1}{3}[10\angle 0 + 10\angle 360]$

$=$

30.



$\longrightarrow I_a + I_b + I_c = 0$

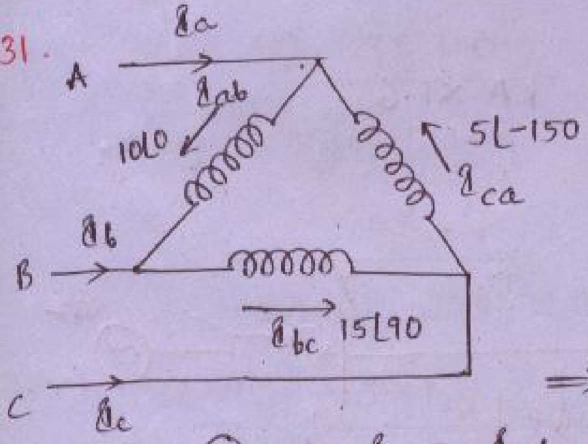
$\Rightarrow I_c = -[I_a + I_b].$

$I_{a1} = \frac{1}{3}[I_a + k I_b + k^2 I_c]$

$= \frac{1}{3}[10\angle 30 + 15\angle$

$=$

31.



$I_{a1} = \frac{1}{3}[I_a + k.I_b + k^2 I_c]$

$I_a + I_{ca} = I_{ab} \longrightarrow ①$

$I_b + I_{ab} = I_{bc} \longrightarrow ②$

$\Rightarrow I_b = I_{bc} - I_{ab}$

$① \Rightarrow I_a = I_{ab} - I_{ca}$

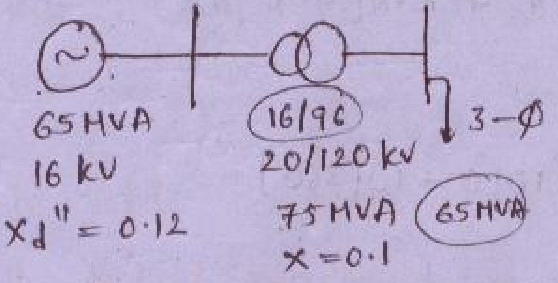
$I_c + I_{bc} = I_{ca} \longrightarrow ③$

$\Rightarrow I_c = I_{ca} - I_{bc}$

The +ve. seq. comp. of Δ connected currents.

$I_{ab_1} = \frac{1}{3}[I_{ab} + k.I_{bc} + k^2 I_{ca}]$

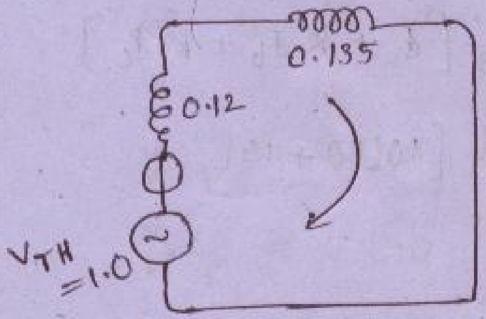
23.



pre fault voltage $= \frac{96}{96} = 1.0$

$X_{Tnew} = 0.1 \times \frac{65}{75}\left(\frac{20}{16}\right)^2$

$= 0.135.$



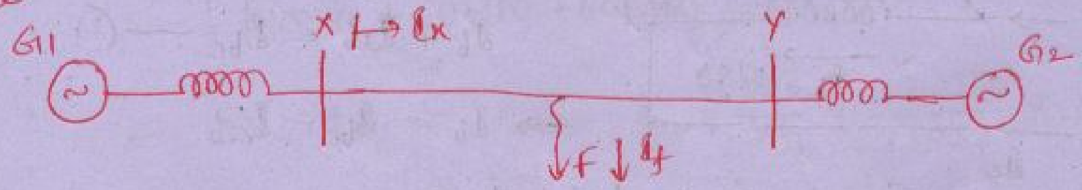
$I_f = I_{K1} = \frac{1.0}{0.12 + 0.135}$

$= 3.92$ pu.

$I_f = 3.92 \times \frac{65}{\sqrt{3} \times 16}$ kA ×1.6

↑ momentary

Q



$Z_{S1} = Z_{S2} = 0.001 + J0.01$ pu

$Z_L = 0.006 + J0.06$ PU

The -ve seq $\overset{Z}{\cancel{X}}$ is same as +ve seq $\overset{Z}{\cancel{X}}$ and zero seq impedance is 3 times +ve seq. Z.

The ckt. capacity is 100 MVA and 400kV line to line.

(1). The initial symmetrical rms fault current of I_x is —? for 3-φ s/c fault.

pre fault voltage = 1.0 pu

$$I_F = \frac{E_{R1}}{Z_{1eq}} \qquad \frac{Z_L}{2} = 0.003 + j0.03$$

$$= \frac{1.0}{(0.004+j0.04) \| (0.004+j0.04)}$$

$$= \frac{10}{\sqrt{(0.002)^2+(0.02)^2}} = 49.75 \text{ pu}$$

$$I_x = \frac{49.75}{2}$$

$$= 24.87 \text{ pu}$$

$$= 24.87 \times \frac{100}{\sqrt{3}\times 400} \text{ kA}.$$

(2). for a 1-ϕ to ground fault the magnitude I_x = ?

$$I_f = \frac{3\times 1.0}{Z_{1eq}+Z_{2eq}+Z_{0eq}}$$

$$= \frac{3\times 1.0}{0.002+j0.02+0.002+j0.02+0.006+j0.06}$$

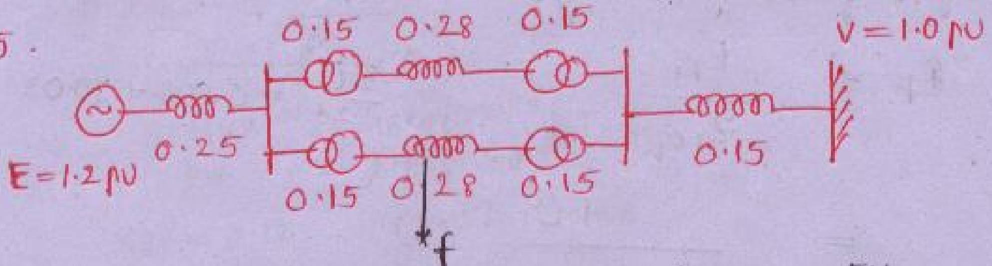
$$= \frac{3\times 1.0}{\sqrt{(0.01)^2+0.1^2}} = 29.85 \text{ pu}$$

$$I_x = \frac{29.85}{2}$$

$$= 14.92 \text{ pu}.$$

P.NO. 67

5.



P_{e1} = power transfer before fault $= \frac{EV}{X_{1eq}} \cdot \sin\delta_0 = P_{m1}\sin\delta$

P_{e2} = " " during fault $= \frac{EV}{X_{2eq}} \cdot \sin\delta = P_{m2}\sin$

P_{e3} = " " after fault $= \frac{EV}{X_{3eq}} \cdot \sin\delta = P_{m3}\sin$

$P_{m1} = \frac{EV}{X_{1eq}}$ = Max. power transfer before fault

X_{1eq} = Transfer reactance before fault.

$P_{m2} = \frac{EV}{X_{2eq}}$ = Max. power transfer during fault

X_{2eq} = Transfer reactance during fault.

$P_{m3} = \frac{EV}{X_{3eq}}$ = Max. power transfer after fault

X_{3eq} = Transfer reactance after fault.

$$P_{m2} = \frac{EV}{X_{2eq}} = \frac{EV}{X_{1eq}} \cdot \frac{X_{1eq}}{X_{2eq}}$$

$$= r_1 P_{m1} \quad \left[r_1 = \frac{X_{1eq}}{X_{2eq}} = \text{real factor} \right]$$

< 1.0

$$P_{m3} = \frac{EV}{X_{3eq}} = \frac{EV}{X_{1eq}} \cdot \frac{X_{1eq}}{X_{3eq}}$$

$$= r_2 \cdot P_{m1} \quad \left[r_2 = \frac{X_{1eq}}{X_{3eq}} = \text{real factor} \right]$$

< 1.0

$(r_2 > r_1)$.

For any line fault:

$P_{m1} > P_{m3} > P_{m2}$

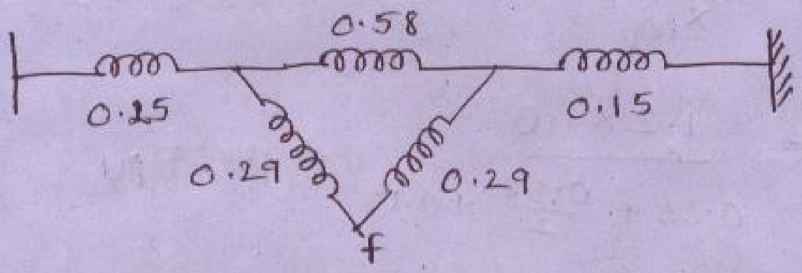
$$P_{m1} = \frac{EV}{X_{1eq}} = \frac{1.2 \times 1.0}{0.25 + \frac{0.58}{2} + 0.15}$$

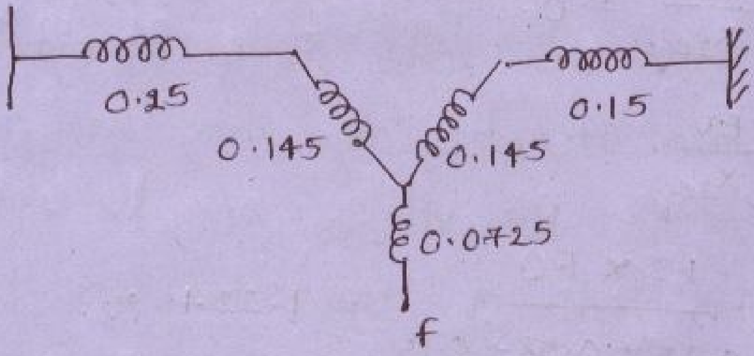
$$= 1.739 \text{ pu.}$$

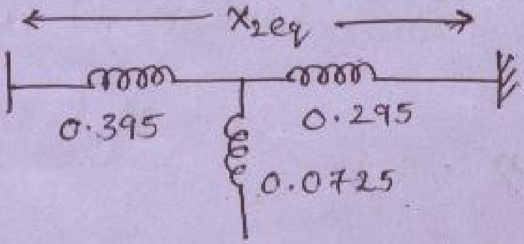
$$P_{m_2} = \frac{EV}{X_{2eq}} = \frac{1.20 \times 1.0}{X_{2eq}}$$

$$P_{m_3} = \frac{EV}{X_{3eq}} = \frac{1.20 \times 1.0}{0.25 + 0.58 + 0.15}$$

$$= 1.224 \text{ pu.}$$



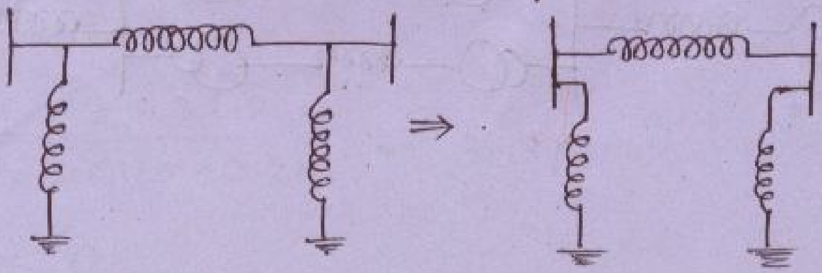




$$X_{2eq} = 0.395 + 0.295 + \frac{0.395 * 0.295}{0.395 + 0.295}$$

$$= 2.29$$

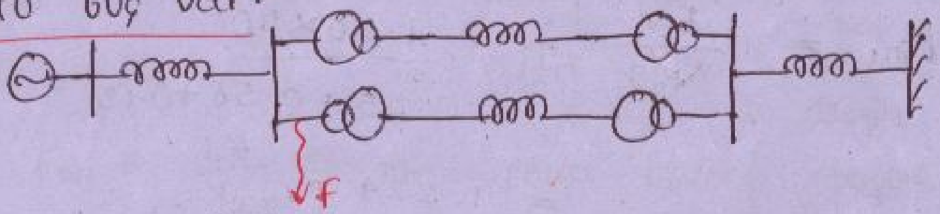
Y → Δ ⟹



$$\therefore P_{m_2} = \frac{EV}{X_{2eq}}$$

$$= \frac{1.2 \times 1.0}{2.29} = 0.52 \text{ pu}$$

Special case : fault occurs on a line near to bus bar:-



$$P_{m_1} = \frac{EV}{X_{1eq}}$$

$$= \frac{1.2 \times 1.0}{0.25 + \frac{0.58}{2} + 0.15} = 1.739 \text{ pu}$$

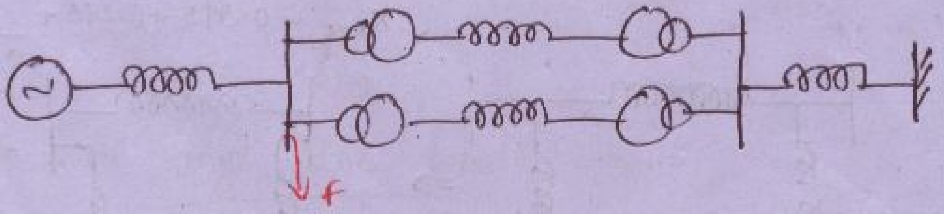
$$P_{m_2} = \frac{EV}{X_{2eq}} = 0.$$

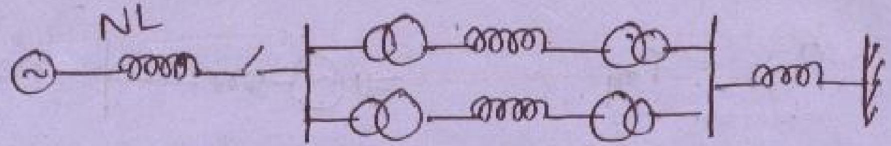
$$P_{m_3} = \frac{EV}{X_{3eq}}$$

$$= \frac{1.2 \times 1.0}{0.25 + 0.58 + 0.15} = 1.224 \text{ pu}.$$

Special case:

fault on bus :-



→ 

$$P_{m1} = \frac{EV}{x_{1eq}}$$

$$= \frac{1.2 \times 1.0}{0.25 + \frac{0.58}{2} + 0.15} = 1.739 \text{ pU}$$

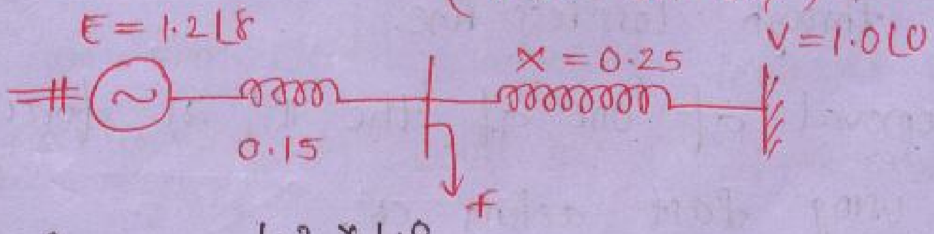
$$P_{m2} = \frac{EV}{x_{2eq}} = 0.$$

$$P_{m3} = \frac{EV}{x_{3eq}} = 0.X$$

$\Longrightarrow P_{m3} = P_{m1}$ [To avoid NL operation of alternator].

If fault on busbar, the alt. isolated from TL, so that alternator working on NL condi. In order to avoid NL operation of Alt., the alt. CB will be closed at a faster rate so that entire n/w will be restored back. Hence $P_{m3} = P_{m1}$.

Special case: (fault on bus)



$$P_{m1} = \frac{1.2 \times 1.0}{0.15 + 0.25} = 3.0 \text{ pU}$$

$$P_{m2} = 0$$

$P_{m3} = P_{m1}$

EQUAL AREA CRITERIA :

→ It is unable to get critical clearing time for given δ_c and also unable to get intermediate position of rotor angle.

APPLICATIONS OF EQUAL AREA CRITERIA:

(1). Sudden increase in mechanical ~~inlet~~ input to Syn. generator.

(2). Sudden increase in mechanical o/p to Syn. motor.

(3). fault occurs at middle of TL in a $\|^{el}$ TL.

(4). fault occurs on a line near to bus bar in a $\|^{el}$ TL.

(5). fault occurs on a busbar in $\|^{el}$ TL.

(6). fault occurs on alt. connected to infinite bus through loss less line.

(7). Removal of one of the $\|^{el}$ TL forcibly by using fast acting CB.

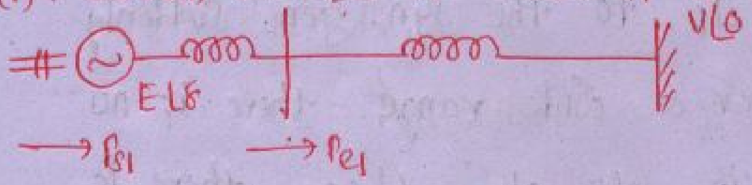
ASSUMPTIONS FOR EQUAL AREA CRITERIA:

(1). $P_a = 0$, & $\omega = \omega_s$, there is no change in rotor angle.

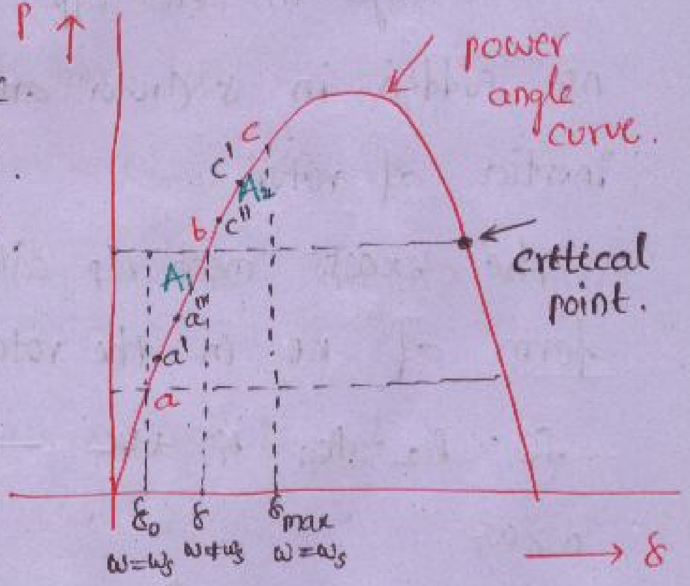
(2). $P_a = 0$ & $\omega \neq \omega_s$ or $P_a \neq 0$ but $\omega = \omega_s$. rotor angle of the system changes.

(3). Momentum of inertia of rotating body also to be taken into account.

(1). Sudden increase in mech. i/p to syn. Generator:



first swing a to c.
second swing a' to c'.
third swing a'' to c''.



Initially alt. supplying with mech. i/p P_{s1} and corr. electrical o/p of P_{e1}. It is represented by point 'a' in P–δ curve.

At 'a'.

$P = P_{s1} - P_{e1}$

$= P_{s1} - P_{m1}\sin\delta_0$

$= 0$

Neither accelerate nor decelerate

$\omega = \omega_s$

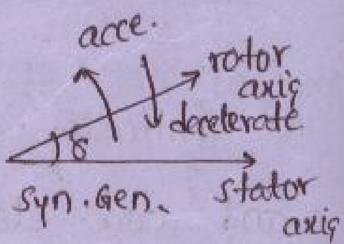
δ doesn't change.

If mech i/p to the syn. gen. suddenly increase over a wide range there is no corr. change in ele. o/p b'coz there is no sudden in δ (rotor angle) due to large inertia of rotor.

The excess mech i/p will be stored in the form of KE in the rotor.

so $P_{s2} - P_{e1}$ is +ve → accelerate

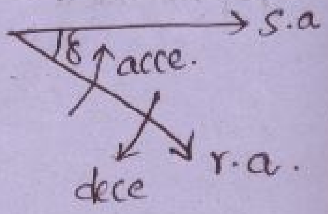
$\omega > \omega_s$.



→ & slowly δ increase

→ Rotor axis is ahead of stator axis.

Syn. motor →



a to b :

$P = P_{S2} - P_{e2}$

$= P_{S2} - P_{m2} \cdot \sin\delta \qquad \left(\begin{matrix} P_{e2} < P_{e1} \\ \delta > \delta_0 \end{matrix} \right).$

$= +ve.$

→ Accelerate

→ $\omega > \omega_s$, δ will increase.

At 'b' :

$P = P_{S2} - P_{e2}$

$= P_{S2} - P_{m2} \cdot \sin\delta_1$

$= 0.$

→ Neither acc. nor dec.

→ $\omega = \omega_{max}$. $\qquad \omega_{max} > \omega_s$

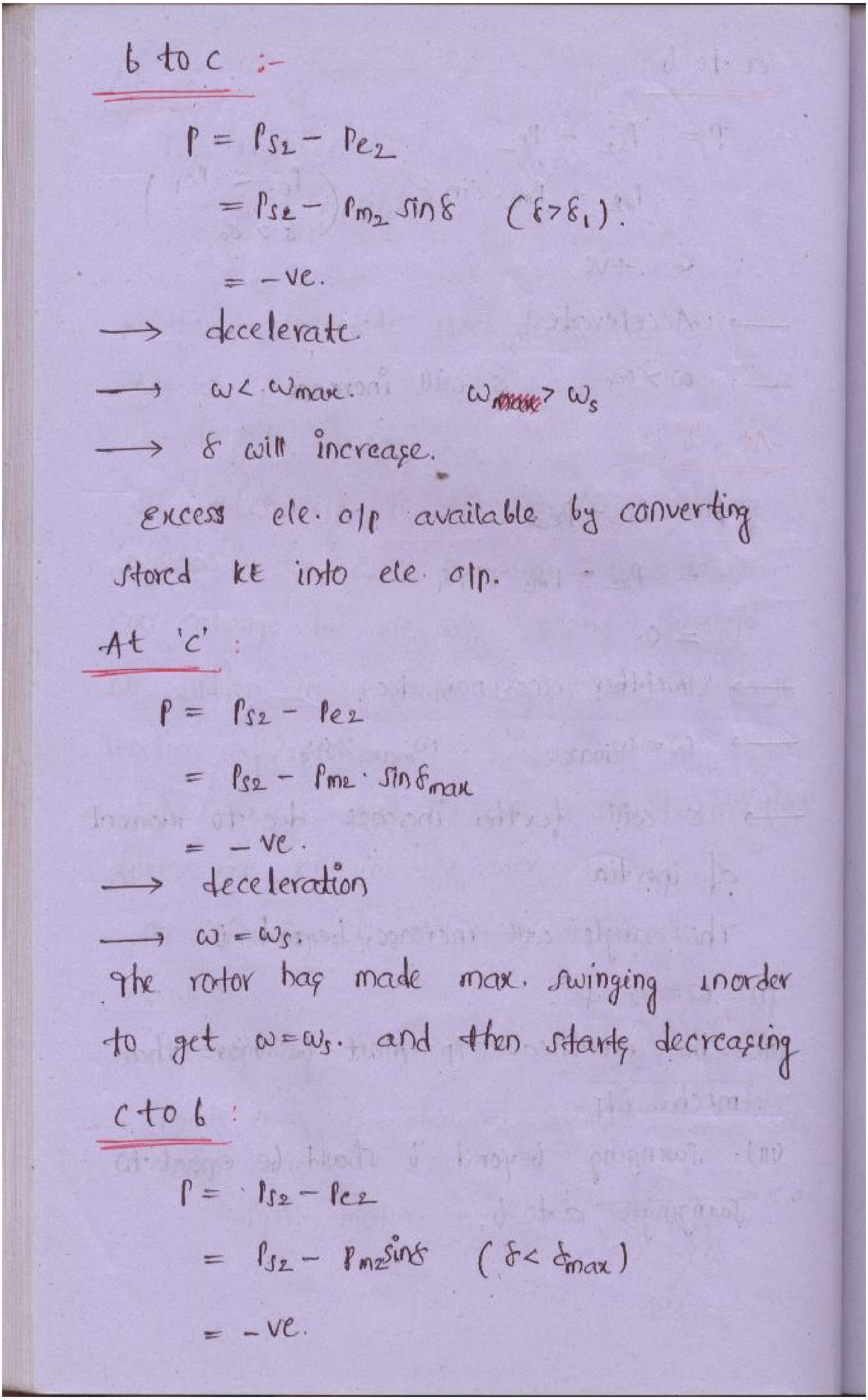
→ δ will further increase due to moment of inertia.

The angle will increase beyond 'b'.

(i) $\omega = \omega_s$ &

(ii). the electrical o/p must be more than mech. i/p.

(iii). Swinging beyond 'b' should be equal to swinging a to b.



b to c :-

$$P = P_{s2} - P_{e2}$$

$$= P_{s2} - P_{m2} \sin\delta \quad (\delta > \delta_1).$$

$$= -ve.$$

→ decelerate

→ $\omega < \omega_{max}$. $\omega_{\cancel{max}} > \omega_s$

→ δ will increase.

excess ele. o/p available by converting stored KE into ele. o/p.

At 'c' :

$$P = P_{s2} - P_{e2}$$

$$= P_{s2} - P_{m2} \cdot \sin\delta_{max}$$

$$= -ve.$$

→ deceleration

→ $\omega = \omega_s$.

The rotor has made max. swinging inorder to get $\omega = \omega_s$. and then starts decreasing

c to b :

$$P = P_{s2} - P_{e2}$$

$$= P_{s2} - P_{m2} \sin\delta \quad (\delta < \delta_{max})$$

$$= -ve.$$

$\longrightarrow$ deceleration

$\longrightarrow$ $\omega < \omega_s$

$\longrightarrow$ δ decreases.

At 'b' :-

$$P = P_{s2} - P_{e2}$$

$$= P_{s2} - P_{m2} \cdot \sin \delta_1$$

$$= 0$$

$\longrightarrow$ Neither acc. nor dec.

$\longrightarrow$ $\omega = \omega_{min} < \omega_s$.

$\longrightarrow$ δ further decreased due to 'M'.

b to a :-

$$P = P_{s2} - P_{e2}$$

$$= P_{s2} - P_{m2} \cdot \sin\delta \quad (\delta < \delta_1)$$

+ve.

$\longrightarrow$ acceleration

$\longrightarrow$ $\omega > \omega_{min}$ but $\omega < \omega_s$.

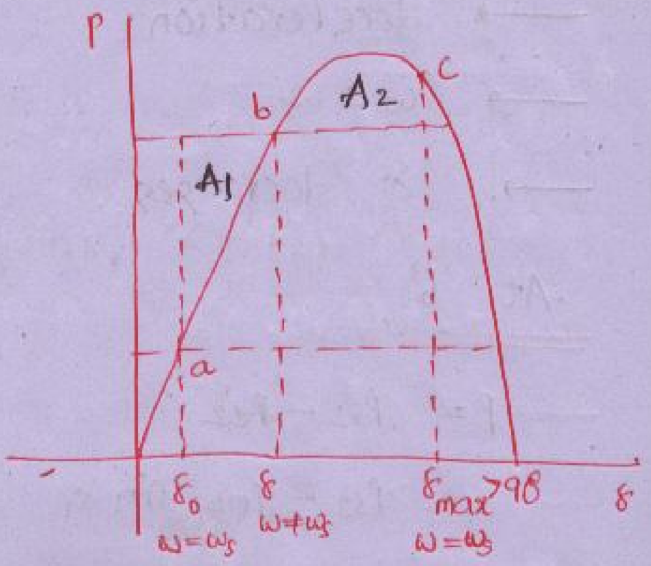
$\longrightarrow$ δ decreases.

NOTE :

* If $\omega = \omega_s$ will be obtained before critical point of curve then EAC is always stable ie $A_1 < A_2$.

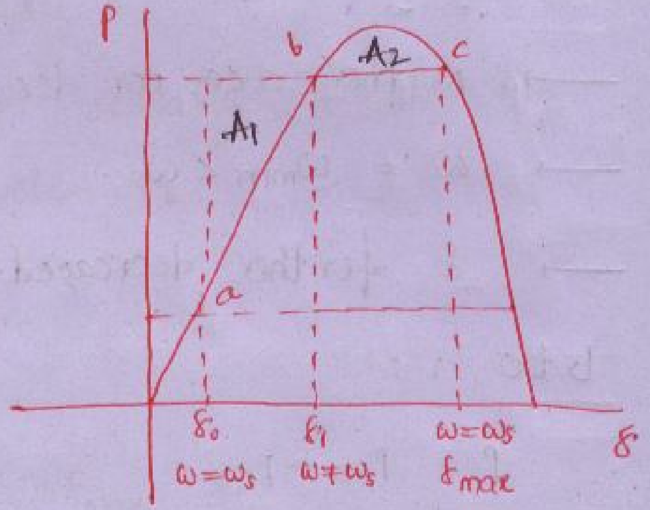
$A_1 < A_2$

→ stable



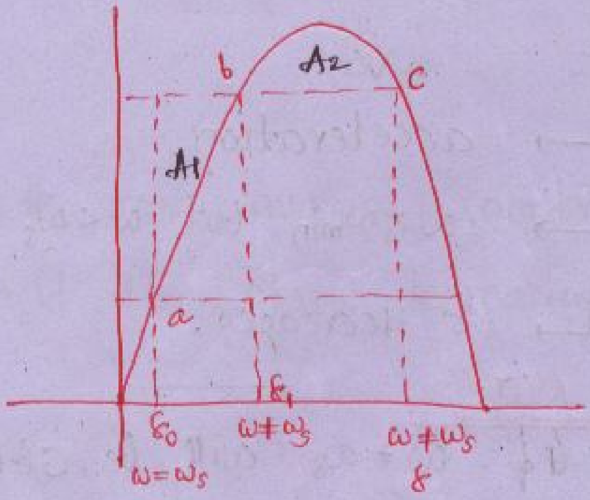
→ $A_1 = A_2$

critically stable.



→ $A_1 > A_2$

∴ unstable.

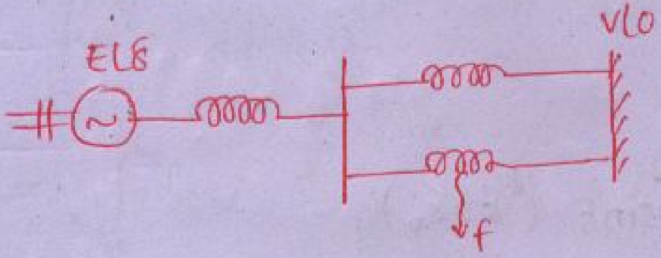


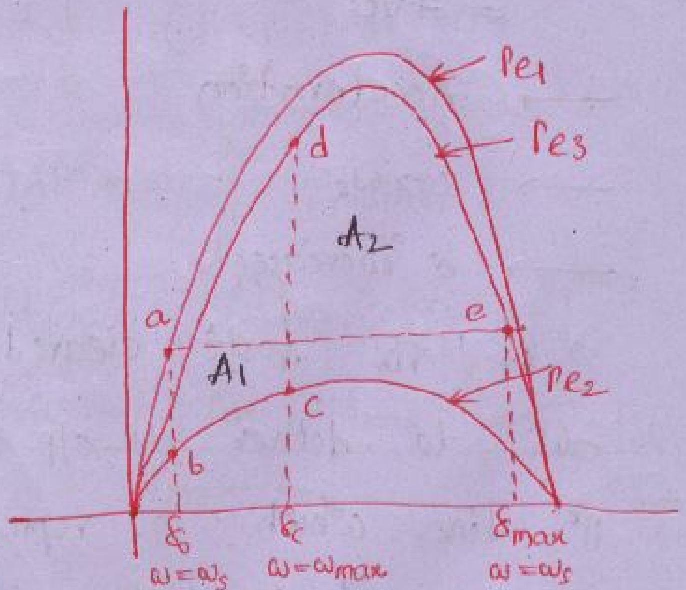
The purpose of EAC, is to calculate critical clearing angle made by rotor at the time of fault.

This can be obtained by considering critically stable condi. of EAC.

(2). Sudden increase in mech. o/p to syn. motor :-

It is mirror image of the first case.





Alt. initially supplying with a mech i/p

If there is 3-ϕ s/c fault on one of TL at the middle of the line which reslult as ele. o/p reduce, where as there is no change in mech i/p which is represented by

It is assumed that fault is cleared by CB at c

b to c:

$$P = P_s - P_{e2}$$

$$= P_s - P_{m2} \sin\delta \quad (\delta > \delta_0)$$

$$= +ve.$$

⟶ Acceleration

⟶ $\omega > \omega_s$

⟶ δ increases

If the fault cleared by breaker, alt. able to deliver ele. o/p with help of another ||el line which is represented by

whereas there is no change in mech due to inertia of rotating body angle will increase further to get $\omega = \omega_s$ in a critical stable manner.

d to e :

$$P = P_s - P_{e3}.$$

$$= P_s - P_{m3} \cdot \sin\delta \quad (\delta > \delta_c)$$

$$= -ve$$

⟶ deceleration

⟶ $\omega < \omega_{max}$ but $\omega > \omega_s$.

⟶ δ increases.

Calculation of critical clearing angle:

$$\int_{\delta_0}^{\delta_{max}} P_a \cdot d\delta = 0$$

$$= \int_{\delta_0}^{\delta_c} P_a \cdot d\delta + \int_{\delta_c}^{\delta_{max}} P_a \cdot d\delta = 0.$$

$$\underbrace{\int_{\delta_0}^{\delta_c} (P_s - P_{e2})\, d\delta}_{A_1} + \underbrace{\int_{\delta_c}^{\delta_{max}} \cdot (P_s - P_{e3}) \cdot d\delta}_{A_2} = 0.$$

$$\int_{\delta_0}^{\delta_c} (P_s - P_{m2} \cdot \sin\delta)\, d\delta = \int_{\delta_c}^{\delta_{max}} P_{m3} \cdot \sin\delta - P_s$$

$$\longrightarrow \quad P_s\delta + P_{m2} \cdot \cos\delta \Big]_{\delta_0}^{\delta_c} = \Big[-P_{m3} \cdot \cos\delta - P_s\delta\Big]_{\delta_c}^{\delta_{max}}$$

$$\Rightarrow \quad \delta_c = \cos^{-1}\left[\frac{P_s \overset{rad.}{(\delta_{max} - \delta_0)} + \overset{deg}{P_{m3} \cdot \cos\delta_{max} - P_{m2}\cos\delta_0}}{P_{m3} - P_{m2}}\right] \text{ele. degree}$$

At 'a' :

$$P_s = P_{e1} = P_{m1} \cdot \sin\delta_0$$

$$\delta_0 = \sin^{-1}\left(\frac{P_s}{P_{m1}}\right) \text{ ele. deg.}$$

$$\delta_0\,(rad) = \delta_0 \times \frac{3.14}{180}$$

At 'e':

$P_s = P_{e3} = P_{m3} \cdot \sin\delta_{max}$

$= P_{m3} \cdot \sin(180 - \delta_{max})$

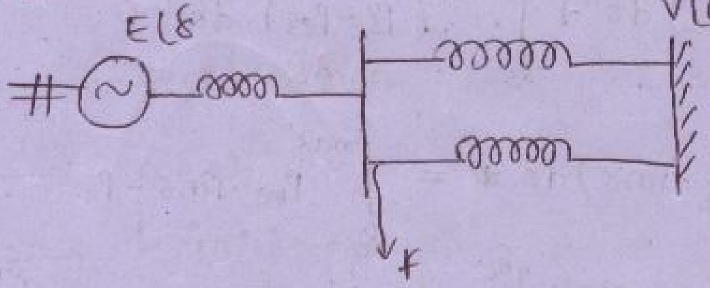
$\sin(180 - \delta_{max}) = \frac{P_s}{P_{m3}}$

$\Rightarrow \delta_{max} = 180 - \sin^{-1}\left(\frac{P_s}{P_{m3}}\right)$ ele. deg

$\delta_{max}\,(rad) = \delta_{max} \times \frac{3.14}{180}$

If actual angle made by breaker during fault is < δ_c, then the system is stable. Other wise system is unstable.

(4). Fault occurs on a line near to busbar:



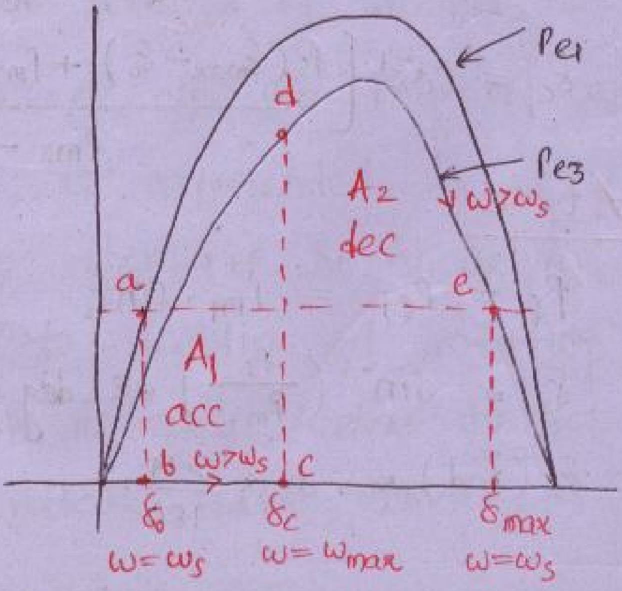
$P_{e2} = 0$

P_{e1}

P_{e3}

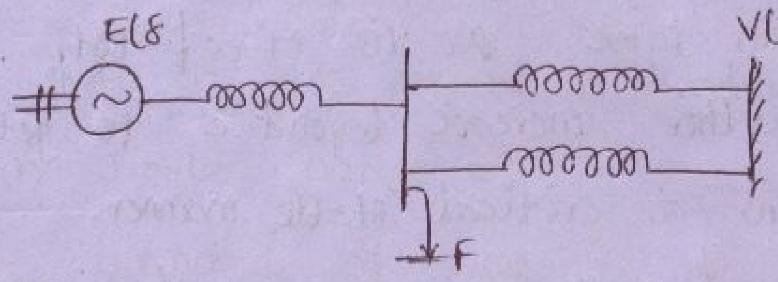
$P_{e1} \neq P_{e3}$

$(P_{m1} > P_{m3})$.

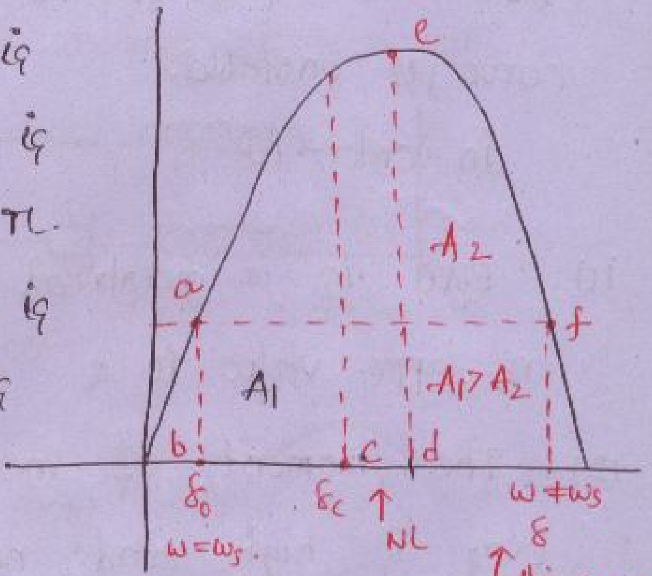


$$\delta_c = \cos^{-1}\left[\frac{P_s(\delta_{max}-\delta_0)+P_{m_3}\cos\delta_{max}}{P_{m3}}\right]. \text{ ele. deg.}$$

(5). fault occurs on a bus bar:



After the fault is cleared by CB, alt. is isolated from $\|^{el}$ TL. so that o/p power is zero and there is no change mech. i/p.



↑ this curve is unstable

where as in two previous cases, alt. delivering
0

To avoid NL operation of alt. it is assumed that CB is closed as ~~many~~ early as possible with minimum cycles

c to d:

$P = P_s - P_{e3}$ → acceleration

$= P_s - 0$ → $\omega > \omega_s$

$= P_s$. → δ increase.

If breaker is closed the entire n/w is restored back so that alt. is able to deliver ele. o/p with the ||el lines and it is represented by 'e'. whereas mech. i/p remain same. Due to 'M' of body angle further increase beyond 'e' to get $\omega = \omega_s$. in a critical stable manner.

But it is unable to get. so that this curve is unstable.

In order to

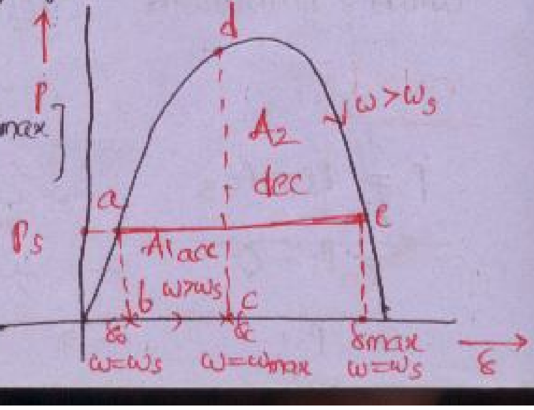
(1). EAC is a graphical soln. and it gives an appr. value to δ_c.

(2). The moment of inertia of rotating body is high and no. of cycles which are lapse after the fault is cleared & before closing breaker are very few.

(3). change in angle & change in speed during that period are negligible.

$P_{m3} = P_{m1}$

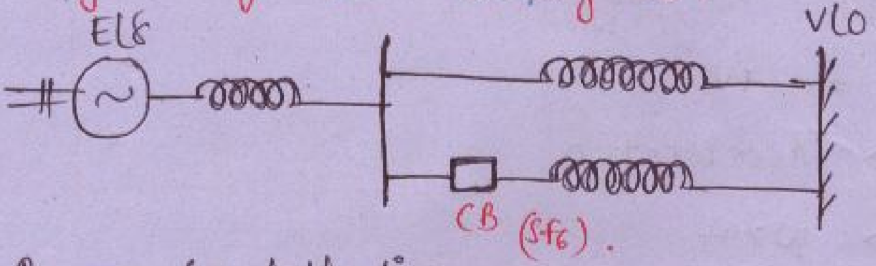
$$\delta_c = \cos^{-1}\left[\frac{P_s(\delta_{max} - \delta_0) + P_{m3} \cdot \cos\delta_{max}}{P_{m3}}\right]$$



(6). fault occurs on alt. connected to infinite bus through loss less line :

EAC of the present application will be of in similar nature of

(7). Removal of one of the ||el τl by using fast acting CB :



P_{e1} — for both lines

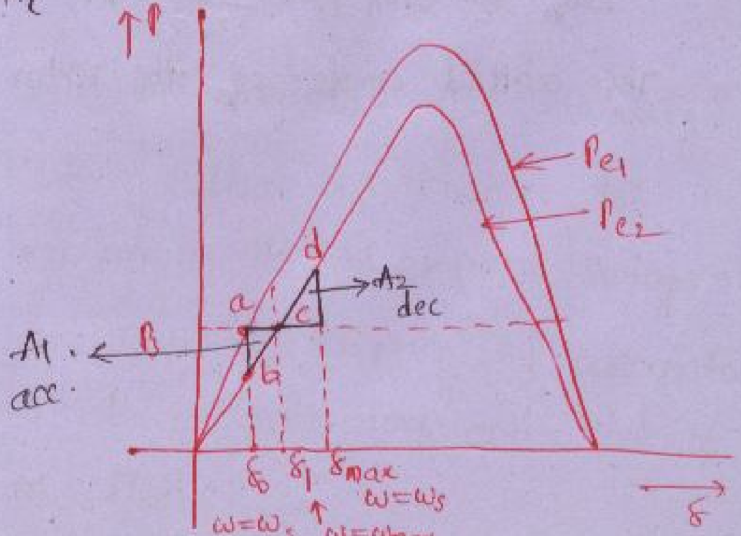
P_{e2} — for one line.

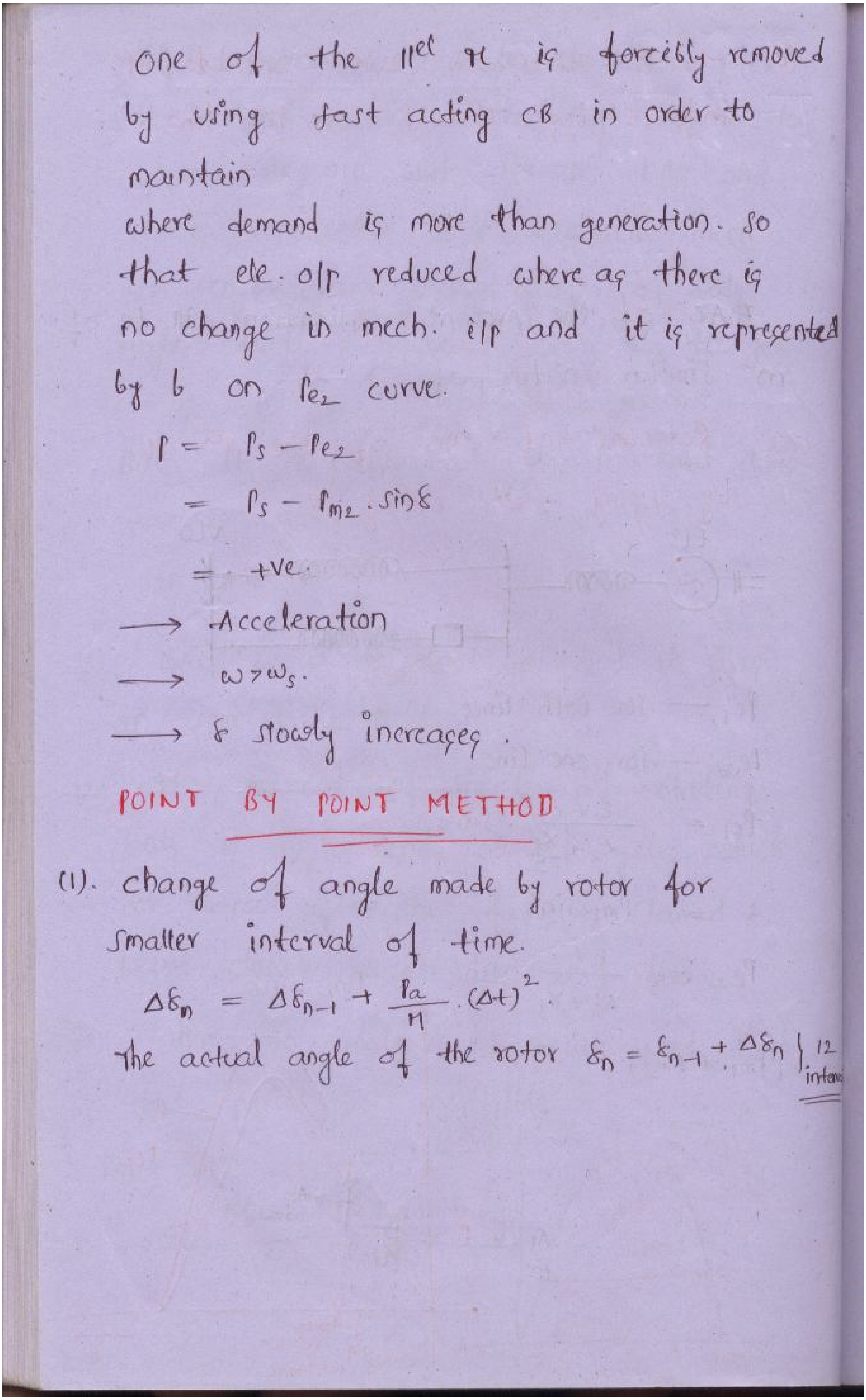
$$P_{e1} = \frac{EV}{X_G + \frac{X_l}{2}} \cdot \sin\delta$$

$$= P_{m1} \cdot \sin\delta$$

$$P_{e2} = \frac{EV}{X_G + X_l} \cdot \sin\delta = P_{m2} \cdot \sin\delta$$

$(P_{m1} \ne P_{m2})$.





One of the $||^{el}$ tl is forcibly removed by using fast acting CB in order to maintain where demand is more than generation. so that ele. o/p reduced where as there is no change in mech. i/p and it is represented by b on P_{e_2} curve.

$$P = P_s - P_{e_2}$$

$$= P_s - P_{m_2} . \sin\delta$$

$$= +ve.$$

$\longrightarrow$ Acceleration

$\longrightarrow$ $\omega > \omega_s$.

$\longrightarrow$ δ slowly increases.

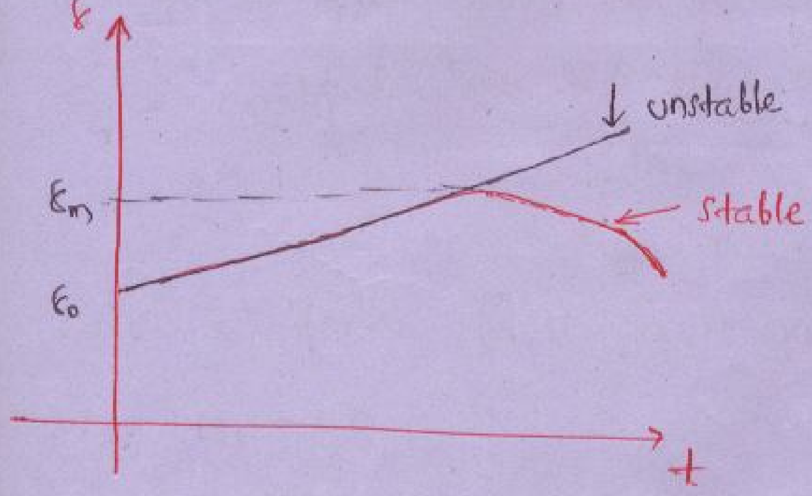
POINT BY POINT METHOD

(1). change of angle made by rotor for smaller interval of time.

$$\Delta\delta_n = \Delta\delta_{n-1} + \frac{P_a}{M} . (\Delta t)^2 .$$

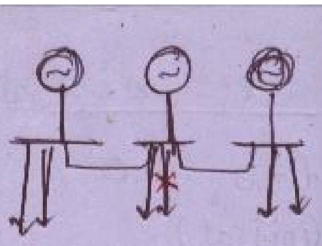
The actual angle of the rotor $\delta_n = \delta_{n-1} + \Delta\delta_n \} \, 12$ interv

t	$\Delta\delta$	δ	
$t=0$ (initial)	0	δ_0	38.5
$t=0.05$	$\Delta\delta_1$	$\delta_1 = \delta_0+\Delta\delta_1$	43.45
$t=0.1$	$\Delta\delta_2$	$\delta_2 = \delta_1+\Delta\delta_2$	49.46
		⋮	56.56
			62.84
			70.14
			80.15
			86.23
			91.13 stable.
			$\boxed{96.55} \rightarrow \delta_{max}$
			95.61



(2). Eventhough a Syn. m/c maintain the stability during the 1st swing there are chances to left the synchronism in the sub-sequent swings. This is called as cascade tripping of alternator.

If there are three generators and there is a fault on G_2 then,



1st swing : G_1 ~~G_2~~ G_3

2nd swing : ~~G_1~~ G_3

3rd swing : ~~G_3~~

are step by step pulled out.

(3). It is a mathematical approach, so δ_c corr. to t_c can be evaluated, further intermediate position of rotor angles can also be evaluated.

06.

$P_s = P_{e1} = 1.0$

$P_{m1} = 1.739$

$P_{m2} = 0.52$

$P_{m3} = 1.224$.

$$\delta_c = \cos^{-1}\left[\frac{P_s(\delta_{max}-\delta_0) + P_{m3}(\cos\delta_{max}) - P_{m2}\cos\delta_0}{P_{m3}-P_{m2}}\right]$$

$$\delta_0 = \sin^{-1}\left(\frac{P_s}{P_{m1}}\right) = 35.1$$

$\delta_{0(rad)} = 0.618$

$$\delta_{max} = 180 - \sin^{-1}\left(\frac{P_s}{P_{m3}}\right) = 125.2$$

$\delta_{max}(rad) = 2.18$.

06 (b). δ_c, for a fault occurs on bus bar

$$\delta_c = \cos^{-1}\left[\frac{P_s(\delta_{max}-\delta_0) + P_{m3}\cdot\cos\delta_{max}}{P_{m3}}\right]$$

calc. δ_c for a fault occurs on bus bar

$P_s = P_{e1} = 1.0$

$P_{m1} = 1.739$

$P_{m2} = 0.$

$P_{m3} = P_{m1} = 1.739.$

$$\delta_c = \cos^{-1}\left[\frac{P_s(\delta_{max}-\delta_0) + P_{m3}\cdot\cos\delta_{max}}{P_{m3}}\right].$$

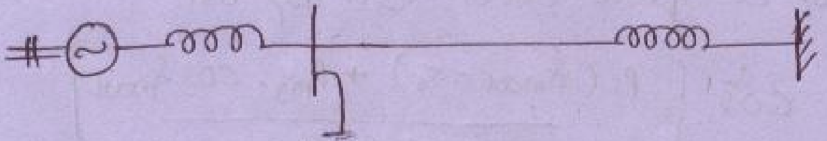
10.

$$P_{m2} = r_1 \cdot P_{m1} = \frac{x_{1eq}}{x_{2eq}} \text{ pu}$$

$$P_{m3} = r_2 \cdot P_{m1} = \frac{x_{1eq}}{x_{3eq}} \text{ pu.}$$

G'03

11.



$P_s = P_{e1} = 1.0$

$P_{m1} = 2.0$

$P_{m2} = 0$

$P_{m3} = P_{m1} = 2.0$

$$\delta_{max} = 110 = 110 \times \frac{3.14}{180} = 1.92 \text{ rad}$$

$$\delta_0 = \sin^{-1}\left(\frac{1.0}{2.0}\right) = 30^\circ$$

$$= 0.521 \text{ rad}$$

$$\delta_c = \cos^{-1}\left[\frac{P_s(\delta_{max} - \delta_0) + P_{m3} \cdot \cos\delta_{max}}{P_{m3}}\right]$$

12. $P_s = P_{e1} = 0.4\ P_{m1}$

$P_{m2} = r_1 P_{m1} = \frac{x_1}{x_2} \cdot P_{m1}$

$= 0.167\ P_{m1}$.

$P_{m3} = 0.8\ P_{m1}$.

$\delta_0 = \sin^{-1}\left(\frac{0.4 P_{m1}}{P_{m1}}\right) = 23.57^\circ$

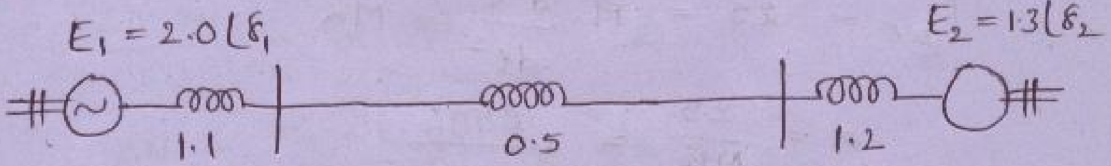
$= 0.411$ rad

$\delta_{max} = 180 - \sin^{-1}\left(\frac{0.4 P_{m1}}{0.8 P_{m1}}\right) = 150^\circ$

$= 2.61$ rad

$$\delta_c = \cos^{-1}\left[\frac{0.4 P_{m1}(2.61-0.411) + 0.8 P_{m1}\cdot\cos 150 - 0.167 P_{m1}\cdot\cos 23.57}{0.8 P_{m1} - 0.167 P_{m1}}\right] \text{ele. deg.}$$

07.



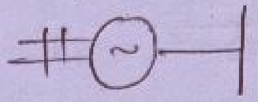
$\longrightarrow P_s = P_e = 0.5$

$0.5 = \frac{E_1 E_2}{X_{eq}} \sin(\delta_1 - \delta_2)$.

$\longrightarrow (\delta_1 - \delta_2) =$

08\.

$P = 400\ MW$



500 MVA

0.8 pf

22 kV

$P_{e1} = 400\ MW$

$P_{s1} = 400\ MW$

$P = 0$

fault,

$P_{s2} = 400\ MW$

$P_{e2} = 0.6 \times 400$

$= 240\ MW$

$P_a = 160 = T_a \omega$

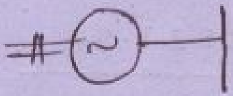
$= T_a \omega_s$.

$$P_a = T_a \cdot \frac{2\pi N_s}{60}$$

$$\Longrightarrow T_a = \frac{160 \times 60}{2\pi \times 1500}$$

$$= 1.01\ MN\text{-}m$$

13\.



$P_{s1} = 50$ $P_{e1} = 50$

$P_{s2} = 75$ $P_{e2} = P_{e1} = 50$

$$P_{acc} = 25 = M \cdot \frac{d^2\delta}{dt^2} = M\alpha$$

$$\alpha = \frac{25}{M} = \frac{25}{\frac{S \cdot H}{180 f}}$$

$$= \frac{25}{\frac{10 \times 100}{180 \times 50}} = 22.5\ deg/sec^2.$$

17).

$$P_{acc} = P_s - P_e$$

$$= 26800 \times 0.735 - 16000$$

26. (b). $\alpha = 337.5$ ele. deg / sec^2

(C). 1 sec $\longrightarrow$ 50 cycles

? $\longrightarrow$ 10 cycles

$$\Longrightarrow \frac{10}{50} = 0.2 \text{ sec.}$$

$$\frac{d^2\delta}{dt^2} = \frac{P_s}{M} = \alpha.$$

before 10 cycles the change of angle as well as change of speed made by alternator are zero.

$$\frac{d\delta}{dt} = \omega = \alpha t.$$

$$t = \Delta t = 0.2 \text{ sec.}$$

$$\Delta\omega = \alpha . \Delta t$$

$$\frac{2\pi \Delta N}{60} = \alpha . \Delta t$$

$$\Delta N = \frac{\alpha . \Delta t . 60}{2\pi}$$

$$= \frac{337.5 \times 0.2 \times 60}{2 \times 180}$$

$$= 11.25 \text{ rpm}$$

$$N = N_s + \Delta N = 1500 + 11.25$$

$$= 1511.25 \text{ rpm.}$$

$$\frac{d\delta}{dt} = \omega = \alpha t$$

on integrating, $\delta = \frac{\alpha t^2}{2} + A.$, $t = \Delta t$

$$\Delta\delta = \alpha \cdot \frac{(\Delta t)^2}{2} + A$$

$\Delta t = 0, \quad \Delta\delta = 0.$

$0 = 0 + A \Rightarrow A = 0.$

$$\Delta\delta = \alpha \cdot \frac{(\Delta t)^2}{2}$$

$$= 337.5 \times \frac{0.2^2}{2}$$

$= 6.75$ ele. deg.

$\delta = \delta_0 + \Delta\delta.$

25.

$H = 9$ kw-sec/kVA

$= 9$ MJ/MVA.

$\Delta\omega = \alpha \cdot \Delta t$

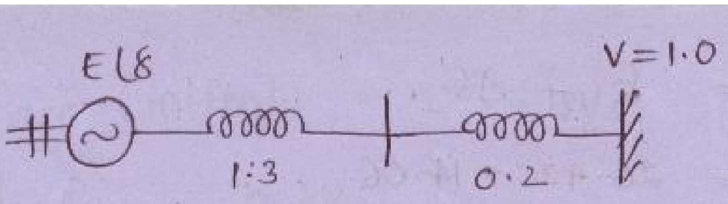
$$= \frac{P_a}{M} \cdot \Delta t$$

$$= \frac{20-16}{\frac{SH}{\pi f}} \times 0.2$$

$$= \frac{4}{\frac{20 \times 9}{3.14 \times 50}} \times 0.2.$$

$= 0.69$ rad/sec.

24.



$P_{max} = 1.2$

$$1.2 = \frac{EV}{x_{eq}}$$

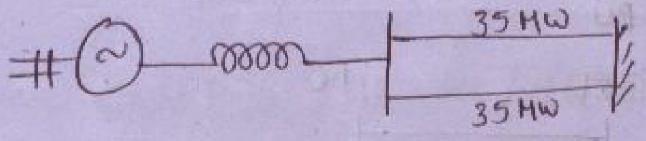
$$\Rightarrow \quad 1.2 = \frac{E \times 1.0}{1.5}$$

$\rightarrow \quad E = 1.8$ pu.

23.

$$M = 0.01 \ MJ \overset{sec}{/} ele.deg$$

$$= 0.01 \ MJ\text{-}sec / ele. degree.$$



$\longrightarrow \quad P_s = P_{e_1} = 25$ MW

$$= P_m . \sin\delta_0$$

$$\delta_0 = \sin^{-1}\left(\frac{25}{70}\right) = 20.92^\circ$$

$3 \times 50 = 150$ msec $= 0.15$ sec

$$\delta = \delta_0 + \Delta\delta$$

$$\Delta\delta = \alpha . \frac{\Delta t^2}{2}$$

$$= \frac{P_a}{M} . \frac{0.15^2}{2}$$

$$= \frac{P_s - P_{e_2}}{M} . \frac{0.15^2}{2}$$

$$= \frac{25 - 35 \sin 20.92}{0.01} \times \frac{0.15^2}{2}$$

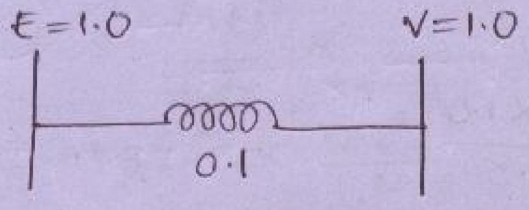
$$= 14.06$$

$$\delta = \delta_0 + \Delta\delta$$

$$= 20.92 + 14.06$$

$$= 35^\circ$$

27.



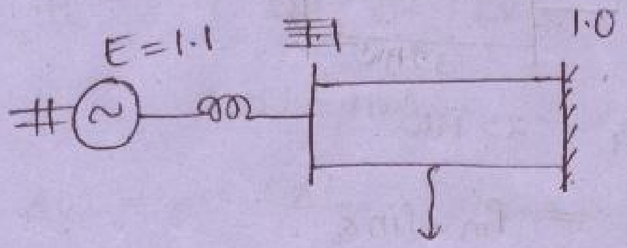
$$P_{max} = \frac{1.0 \times 1.0}{0.1} = 10 \text{ pU}$$

30% margin

$$\text{margin} = 0.3 \times 10 = 3 \text{ pU}.$$

$$P_0 = 7 \text{ pU}$$

28.



$\longrightarrow$ $P_s = P_{e1} = 1.0$ pU

$$\delta_0 = 30^\circ.$$

$$|\longleftarrow Y_{2eq} \longrightarrow|$$

$$X_{2eq} = \frac{1}{0.8} = 1.25.$$

$$P_{acc} \text{ (intial)} = P_s - P_{e2}$$

$$= 1.0 - \frac{EV}{X_{2eq}} \cdot \sin\delta_0$$

$$= 1.0 - \frac{1.1 \times 1.0}{1.25} \cdot \sin 30.$$

P_{acc} (initial) = 0.56 pu

If $P_{acc} = x$ pu

$M\alpha = P_{acc}$

$$\alpha = \frac{P_{acc}}{M}$$

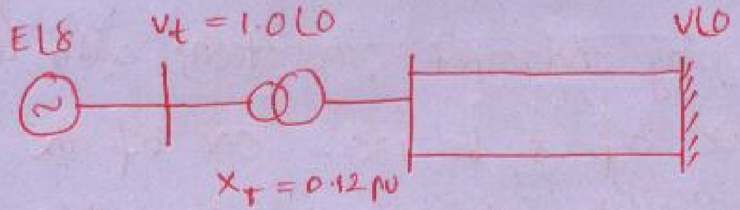
$$= \frac{x \cdot \text{pu}}{\text{pu} \leftarrow \frac{SH}{180f}} = \frac{x}{\frac{1\times5}{180\times50}} = 1800x \text{ deg/sec}^2$$

$$M = \frac{SH}{180f}$$

$$= \frac{100\times5}{180\times50}$$

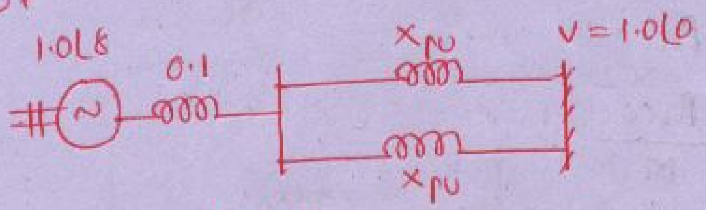
= 0.056 MJ-sec/ele.deg.

G'05.
Q.

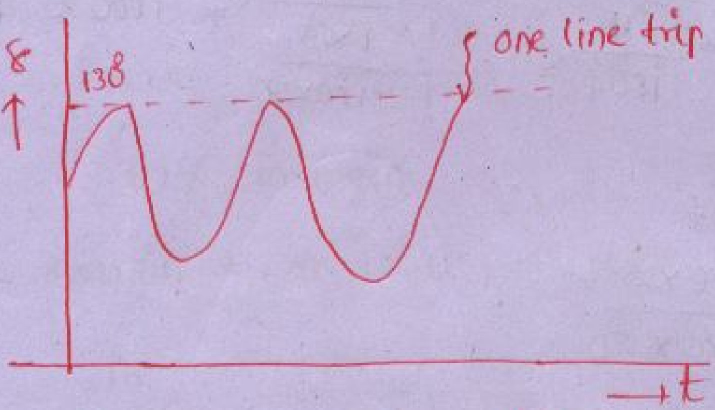


The steady state stability limit is 6.25 if one of the ||el line removed

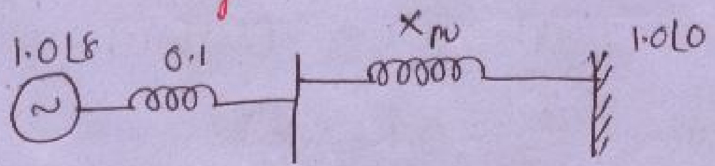
G'07



$\longrightarrow P_s = 1.0$ pu.



Due to some previous disturbance rotor angle δ is under going undamped oscillations with the max value of δ be 138. One of the $\|^{el}$ line trips due to relay maloperation at an instant when $\delta_1 =$ The max. value of the pu line reactance, such that the system doesn't lose synchronism subsequent to this tripping.



$\longrightarrow P_s = 1.0$ pu

$P = 0$

$P_{s_2} = P_{e_2}$.

$$1.0 = \frac{EV}{X_{eq}} \cdot \sin 130^\circ$$

$$X_{eq} = \frac{1.0 \times 1.0 \times \sin 130}{\cancel{}}$$

$$= 0.76 \text{ pu}$$

$X_G + X_L = 0.76.$

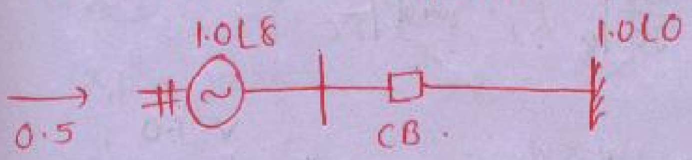
~~$X_G +$~~ $X_l = 0.76 - 0.1 = 0.66$ pu.

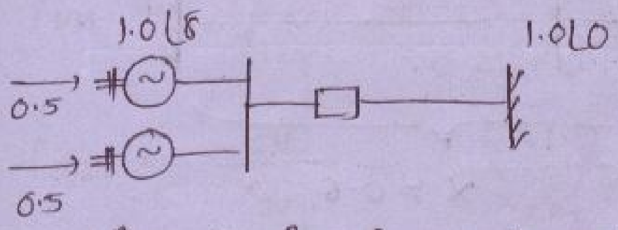
G'08.

In fig. shown below, Syn. gen transfers 1.0 ∠δ to infinite bus. The critical clearing of time of CB is 0.28 sec. If another Syn. gen. is connected in ||el to the existing gen. and each generator is scheduled to supply 0.5 pu. The critical clearing time of CB will be —

(a). reduced to 0.14 (b). reduced but more than 0.14

✓(c). increased beyond 0.28





$P_{acc} = P_s - P_{e2} = P_s$ const.

$$M \cdot \frac{d^2\delta}{dt^2} = P_a \qquad \frac{d^2\delta}{dt^2} = \frac{P_a}{M} = \frac{P_s}{M} \; [P_e = 0].$$

$$\Rightarrow \delta_c = \frac{P_s}{M}\cdot\frac{t_s^2}{2} + A \Rightarrow \delta_0 = A.$$

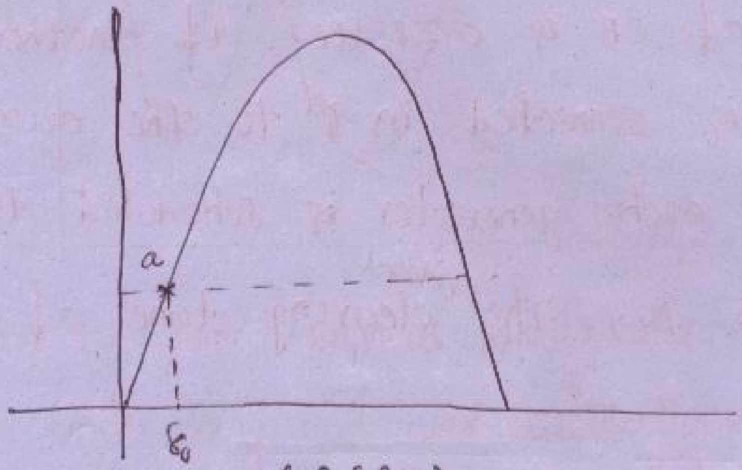
At $P=0$, $\delta_c = \delta_0$

$$\delta_c = \frac{P_s}{M}\cdot\frac{t_c^2}{2} + \delta_0$$

$$\Rightarrow \delta_c - \delta_0 = \frac{P_s}{M}\cdot\frac{t_c^2}{2}$$

$$\Rightarrow t_c = \sqrt{\frac{2M(\delta_c-\delta_0)}{P_s}}$$

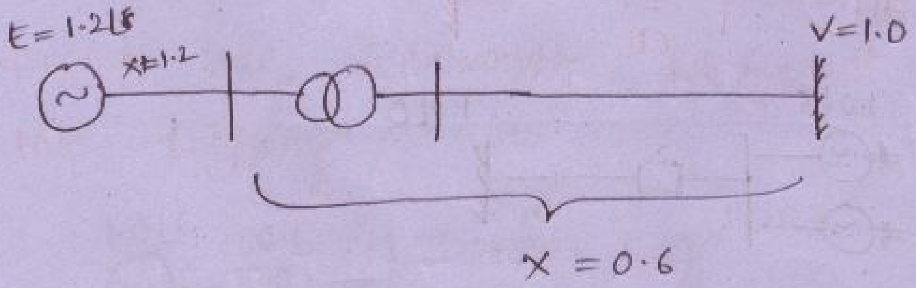
14.



$$= \sin^{-1}\left(\frac{0.8\,P_m}{P_m}\right)$$

$$= 53.13^\circ$$

$$K = \left\{\frac{1}{M}\left(-\frac{\partial P_e}{\partial \delta}\bigg|_{\delta_0}\right)\right\}^{1/2} \text{rad/sec}$$



$H = 4$ MW-sec/MVA

$= 4$ MJ/MVA.

$$\frac{\partial P_e}{\partial \delta}\Big|_{\delta_0} = \frac{EV}{X_{eq}} \cdot \cos\delta$$

$$= \frac{1.2 \times 1.0}{1.8} \cos 53.13$$

$$= \frac{1.2 \times 1.0}{1.8} \times 0.6$$

$$= 0.4 .$$

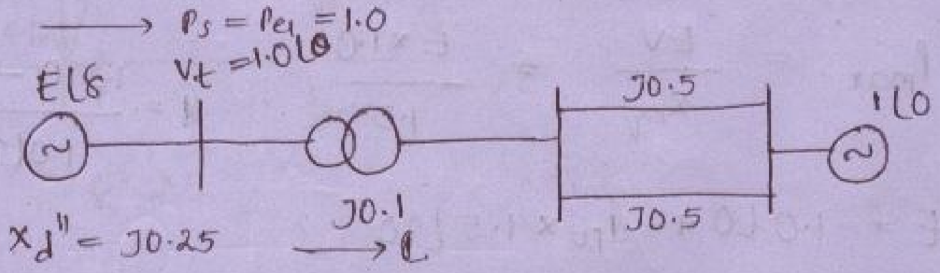
$$k = \left[\frac{1}{\frac{SH}{\pi f}} \times 0.4 \right]^{1/2}$$

$$= \left[\frac{1}{\frac{1.0 \times 4}{3.14 \times 50}} \times 0.4 \right]^{1/2}$$

$$= 3.96 \text{ rad/sec}$$

$$= \frac{3.96}{2\pi} = 0.63 \text{ Hz} .$$

15.



$$P_{m1} = \frac{EV}{X_{1eq}} = \frac{E \times 1.0}{0.25 + 0.1 + \frac{0.5}{2}}$$

$$P_{m2} = \frac{EV}{X_{2eq}} = \frac{E \times 1.0}{X_{2eq}}$$

$$P_{m3} = \frac{EV}{X_{3eq}} = \frac{E \times 1.0}{0.25 + 0.1 + 0.5}$$

$$E = 1.0\angle 0 + I_{pu} \times 0.6\angle 90$$

$$I = \frac{1.0\angle\theta - 1.0\angle 0}{0.35\angle 90}$$

$$E = 1.0\angle 0 + 1.714[1.0\angle\theta - 1.0\angle 0]$$

$$= 1.0\angle 0 + 1.714\angle\theta - 1.714$$

$$= -0.714 + 1.714\cos\theta + j1.714\sin\theta$$

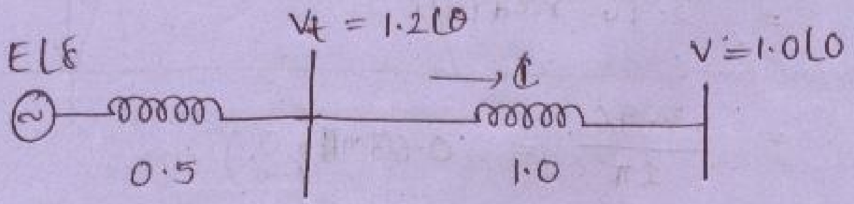
$$1.0 = \frac{V_t V}{x_{eq}} . \sin\theta$$

$$= \frac{1.0\times 1.0}{0.35} . \sin\theta$$

$$\longrightarrow \theta = 20.48$$

$$\Longrightarrow E =$$

16.



$$P_{max} = \frac{EV}{X_{eq}} = \frac{E\times 1.0}{1.5} \; ; \quad I = \frac{1.2\angle\theta - 1.0\angle 0}{1.0\angle 90^\circ}$$

$$E = 1.0\angle 0 + I_{pu}\times 1.5\angle 90$$

$$= 1.0\angle 0 + \frac{1.2\angle\theta - 1.0\angle 0}{1.0\angle 90} \times 1.5\angle 90^\circ$$

$$= 1.0\angle 0 + 1.8\angle\theta - 1.5$$

$$= -0.5 + 1.8\cos\theta + j1.8\sin\theta$$

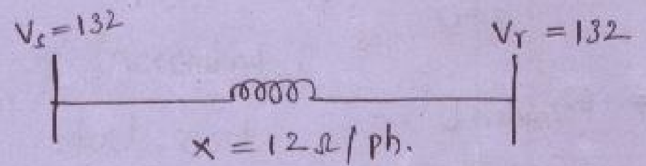
$$\delta = \beta = 90^\circ .$$

for a loss less TL, $\delta = \beta = 98$. in order to deliver max. power. so real part of volt. eq should be equal to zero.

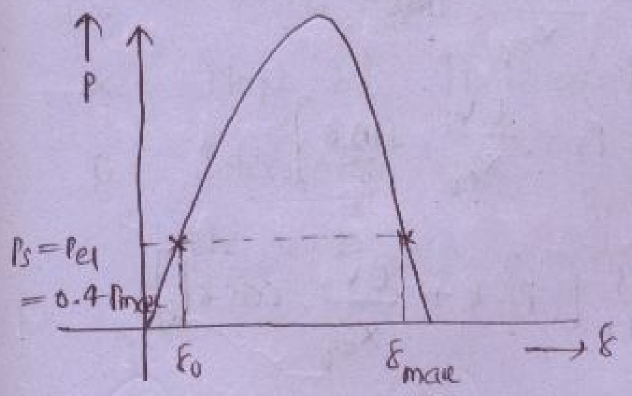
$\Rightarrow \quad -0.5 + 1.8\cos\theta = 0$

$\Rightarrow \quad \theta = 73.87$.

20.



$$P_{max} = \frac{132 \times 132}{12} \text{ MW.}$$



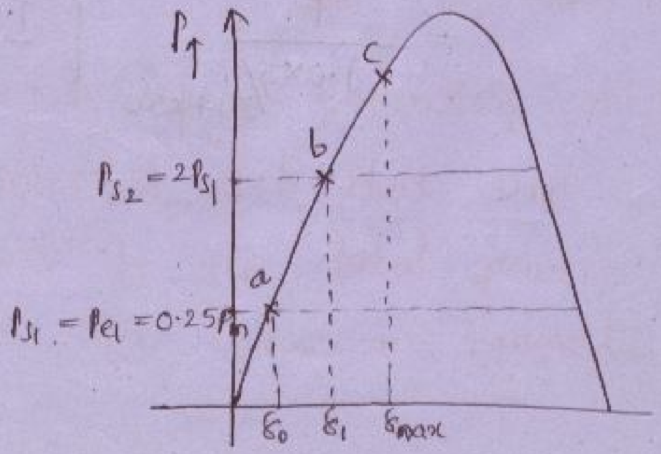
$\delta_0 =$

$\delta_{max} =$

21.

$$\delta_0 = \sin^{-1}\left(\frac{0.25 P_m}{P_m}\right)$$

$= 14.4$

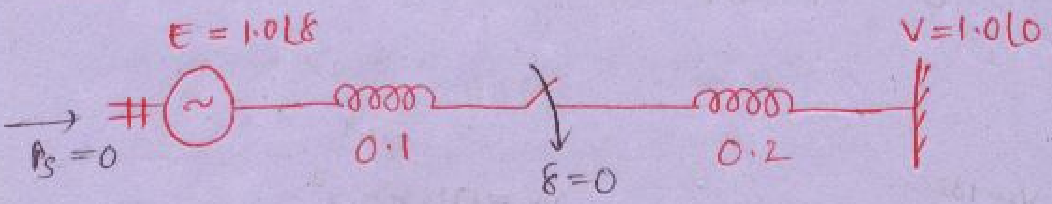


$$P_{s2} = P_{e2} = P_m . \sin\delta_1$$

$$0.5\, P_m = P_m . \sin\delta_1$$

$$\Rightarrow \delta_1 = \sin^{-1}\left(\frac{0.5\, P_m}{P_m}\right) = 30 .$$

22.



$$\omega = \frac{d\delta}{dt} = \omega_{initial}$$

$$M . \frac{d^2\delta}{dt^2} = P_s - P_e$$

$$= P_s - \frac{EV}{x_{eq}} . \sin\delta$$

$$\frac{d^2\delta}{dt^2} = \frac{1}{M}\left[P_s - \frac{EV.}{x_{eq}} . \sin\delta\right]$$

$$\frac{d\delta}{dt} = \omega = \frac{1}{M}\left[P_s . \delta + \frac{EV}{x_{eq}} . \cos\delta\Big|_{\delta_0}\right]$$

$$\omega_{initial} = \frac{1}{SH/\pi f}\left[0\times\delta + \frac{1.0\times1.0}{0.3}\cos 0\right]$$

$$= \frac{1}{1.0\times5/3.14\times50}\left[\frac{1.0\times1.0}{0.3}\right]$$

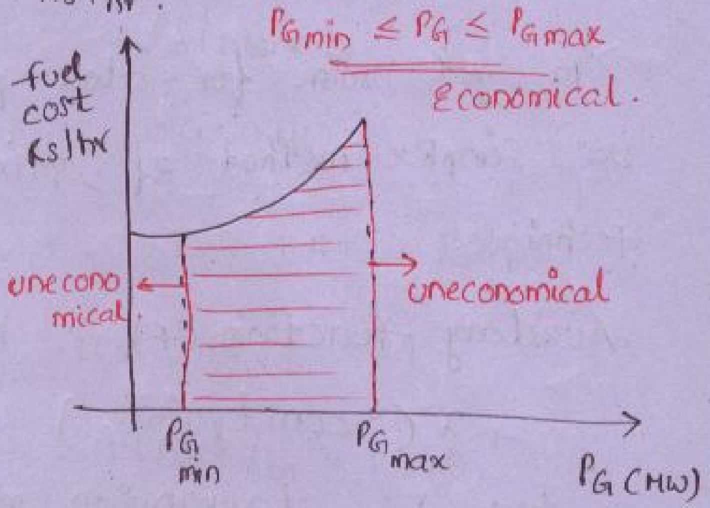
ECONOMIC LOAD DISPATCH

$$f = \frac{1}{2} \alpha P_G^2 + \beta P_G + \gamma \quad Rs/hr$$

α, β, γ are real coe.s. and fuel cost will express in Rs/hr.

To minimize, fuel cost,

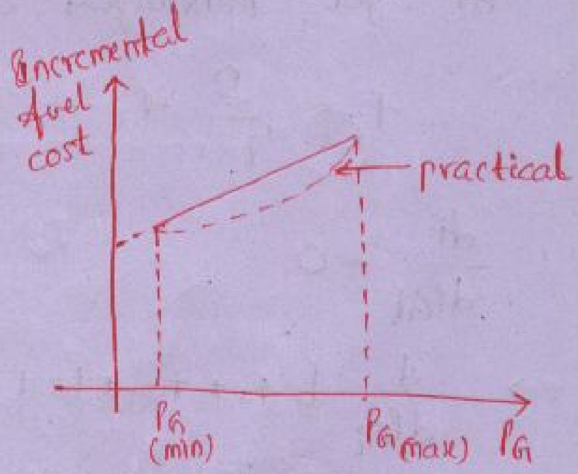
$\frac{df}{dP_G}$ = incremental fuel cost (Rs/MWhr)



$$\frac{df}{dP_G} = \alpha P_G + \beta$$

α = slope of incremental fuel cost curve

β = intersection of the curve.



problem 1:

Minimize fuel cost of n-generators which are optimally selected such that the demand is equal to the total power generation. The line losses are ignored.

Minimize

$$f_T = f_1 + f_2 + \dots + f_n$$

$$\left.\begin{array}{ll} \text{s/to} & P_d = P_{G1} + P_{G2} + \dots + P_{Gn} \\ & P_L = 0 \end{array}\right\} \text{constrained}$$

constrained
equality — Economic load dispatch
inequality — load flow studing

To get soln. for above problem, use simplex method of optimization technique.

Auxilary function (f) = Main function (f_T) + λ (constraints)

where λ – Lagrangian multiplier.

minimize Af w.r.t. generation, so that Mf get minimized along with constraints.

$$f = \sum_{i=1}^{n} f_i + \lambda \left(P_d - \sum_{i=1}^{n} P_{Gi} \right)$$

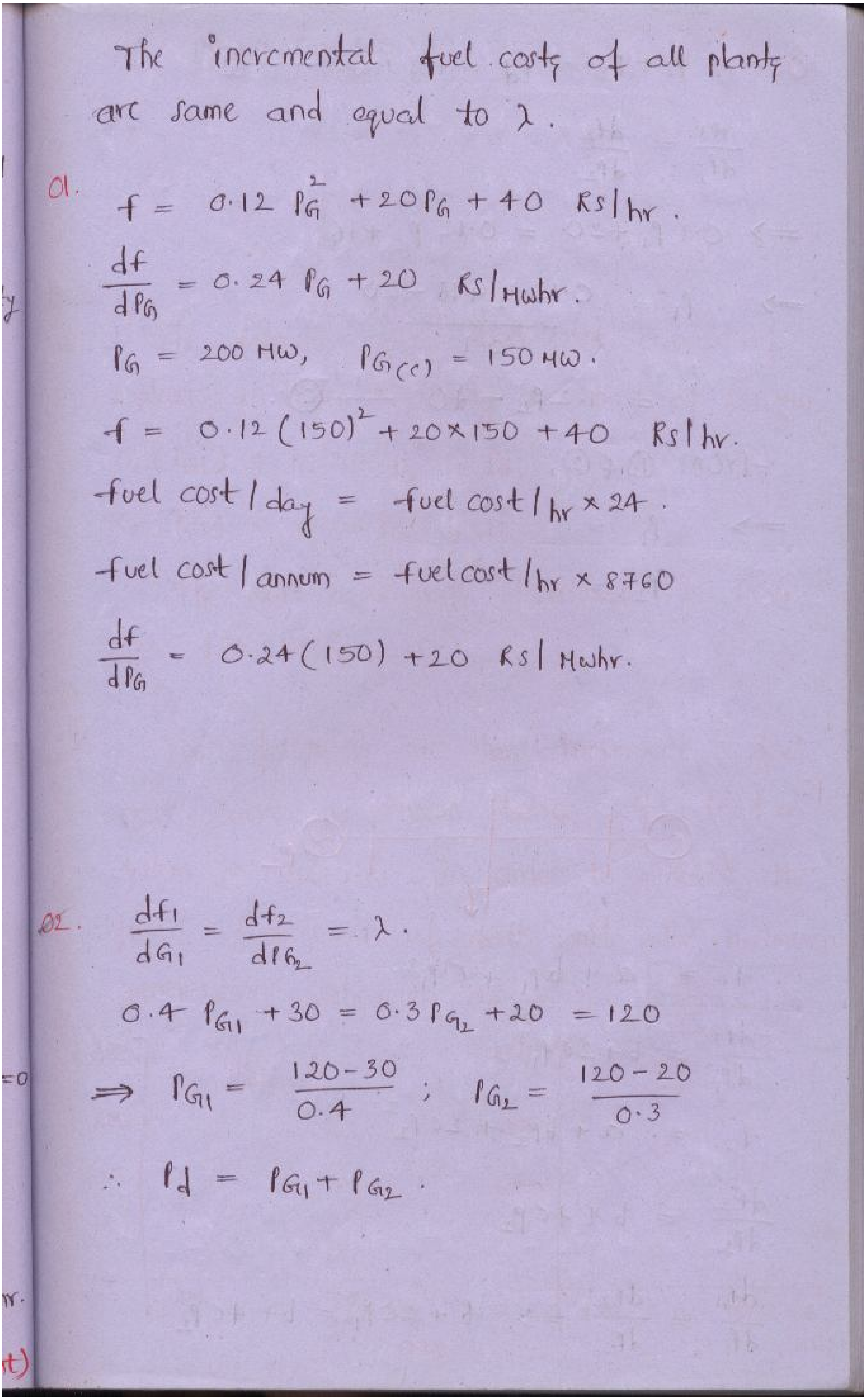
$$\frac{df}{dP_{Gi}} = 0$$

$$\Rightarrow \frac{d}{dP_{Gi}} [f_1 + f_2 + f_3 + \dots + f_n] + \lambda \left[\frac{dP_d}{dP_{Gi}} - \frac{d}{dP_{Gi}} [P_{G1} + P_{G2} + P_{G3} + \dots + P_{Gn}] \right] =$$

$$\Rightarrow \frac{df_i}{dP_{Gi}} = \lambda .$$

$$\rightarrow \frac{df_1}{dP_{G1}} = \frac{df_2}{dP_{G2}} = \frac{df_3}{dP_{G3}} = \dots = \frac{df_n}{dP_{Gn}} = \lambda \quad \text{Rs/MWhr}$$

(cost received for each plant)



The incremental fuel costs of all plants are same and equal to λ.

01. $f = 0.12\, P_G^2 + 20 P_G + 40$ Rs/hr.

$$\frac{df}{dP_G} = 0.24\, P_G + 20 \quad \text{Rs/Mwhr.}$$

$P_G = 200$ MW, $P_{G(c)} = 150$ MW.

$f = 0.12(150)^2 + 20 \times 150 + 40$ Rs/hr.

fuel cost / day = fuel cost / hr × 24.

fuel cost / annum = fuel cost / hr × 8760

$$\frac{df}{dP_G} = 0.24(150) + 20 \quad \text{Rs/Mwhr.}$$

02. $$\frac{df_1}{dG_1} = \frac{df_2}{dP_{G_2}} = \lambda.$$

$0.4\, P_{G_1} + 30 = 0.3\, P_{G_2} + 20 = 120$

$$\Rightarrow P_{G_1} = \frac{120-30}{0.4} \; ; \quad P_{G_2} = \frac{120-20}{0.3}$$

$\therefore P_d = P_{G_1} + P_{G_2}$.

03. $P_1 + P_2 = P_d = 150\ MW.$ —— ①

$$\frac{df_1}{dP_1} = \frac{df_2}{dP_2}$$

$$\Rightarrow 0.1\,P_1 + 20 = 0.12\,P_2 + 16$$

$$\Rightarrow P_1 = \frac{0.12\,P_2 + 16 - 20}{0.1}$$

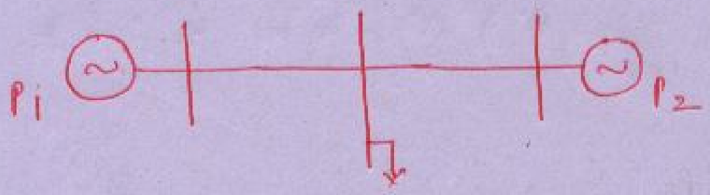
$$= 1.2P_2 - 40 \text{ —— ② .}$$

from ① & ②,

$$\Rightarrow P_1 =$$

$$P_2 =$$

12.



$$f_1 = a + bP_1 + CP_1^2$$

$$\frac{df_1}{dP_1} = b + 2CP_1$$

$$f_2 = a + bP_2 + 2CP_2^2$$

$$\frac{df_2}{dP_2} = b + 4CP_2$$

$$\frac{df_1}{dP_1} = \frac{df_2}{dP_2} \Rightarrow b + 2CP_1 = b + 4CP_2$$

& $P_1 + P_2 = 300$ MW

$\Longrightarrow$

G'08

Q. The following are fuel cost curves of 2 plants in order to supply a load of 250 MW.

$C_1(P_{G_1}) = 0.055 P_{G_1}^2 + P_{G_1}$

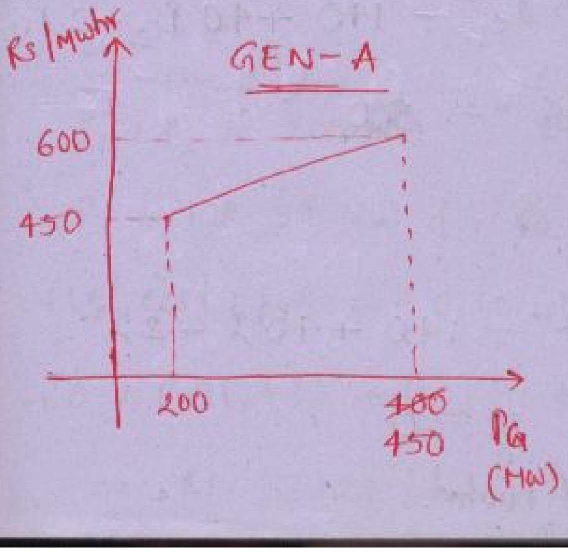
$C_2(P_{G_2}) = 0.03 P_{G_2}^2 + 3P_{G_2}$

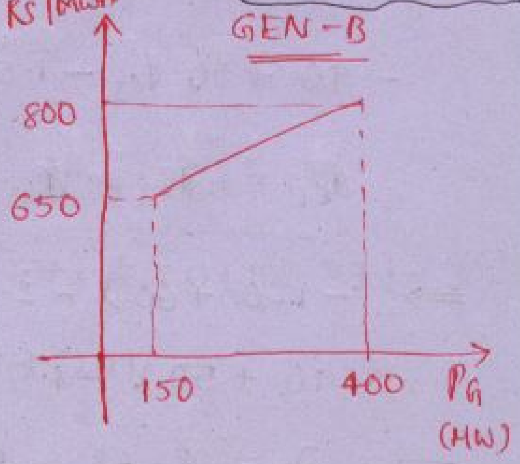
The most economical divisional of load b/w two loads — ?

G'07.

Q. The following are the incremental fuel cost curve as shown below, the load on system is 700 MW. In order to minimize the total fuel cost of both units the optimum generation schedules are — ?

Ans:-
Gen A = 450
Gen B = 250





Q. The fuel cost of 3 plants are –

$f_1 = 0.1 P_1^2 + 12P_1 + 16$ Rs/hr

$f_2 = 0.2 P_2^2 + 8P_2 + 12$ Rs/hr.

$f_3 = 0.15 P_3^2 + 10P_2 + 14$ Rs/hr

The most economical division of load of 800 MW among 3 units are – ?

$$P_1 + P_2 + P_3 = 800$$

$$\frac{df_1}{dP_1} = \frac{df_2}{dP_2} = \frac{df_3}{dP_3}$$

G'03
~~09~~. $I_{C1} = I_{C2} \mp I_{C3}$ (b'oz I_{C3} is const.)

$P_G \min = 50$ & $P_G \max = 300$

$\Longrightarrow P_{G3} = 300$ MW

& $P_1 + P_2 = 400$ MW.

~~07~~. $\frac{df}{dP} = IC = \alpha P + \beta$.

$P_1 + P_2 + P_3 = 500$ MW.

$-120 + 60 I_{C1} - 2.5 I_{C1}^2 - 140 + 40 I_{C2} - 2 I_{C2}^2$

$-90 + 50 I_{C3} - 1.5 I_{C3}^2 = 500$

$I_{C1} = I_{C2} = I_{C3} = \lambda$.

$\Longrightarrow -120 + 60\lambda - 2.5\lambda^2 - 140 + 40\lambda - 2\lambda^2$

$-90 + 50\lambda - 1.5\lambda^2 = 500$

$\Longrightarrow \lambda = 8.68$ Rs/MWhr.

$\Rightarrow P_1 =$

$P_2 =$

$P_3 =$

04.

$$P_1 + P_2 = 100 \text{ — ①}$$

$$\frac{df_1}{dP_1} = \frac{df_2}{dP_2}$$

$$0.3P_1 + 20 = 0.4P_2 + 16$$

$$\Rightarrow P_2 = 0.75P_1 + 10 \text{ — ②}$$

from ① & ②,

$P_1 = 51.42$ MW

$P_2 = 48.58$ MW

$$P_1 + P_2 = 200 \text{ — ③}$$

$$\frac{df_1}{dP_1} = \frac{df_2}{dP_2}$$

$$0.3P_1 + 20 = 0.4P_2 + 16$$

$$P_2 = 0.75P_1 + 10 \text{ — ④}$$

from ③ & ④,

$P_1 = 108.57$ MW

$P_2 = 91.43$ MW.

$$\text{Total fuel cost}/_{\text{day}} = [0.15(51.42)^2$$
$$+20[51.42] + 30 + 0.2(48.58)^2 + 16(48.58)$$
$$+12] \times 12 \quad + [0.15(108.57)^2 + 20(108.57)$$
$$+30 + 0.2(91.43)^2 + 16(91.43) + (20)] \times 12$$
$$=$$

05.

$P_1 + P_2 = 200$ MW.

$P_1 = 108.57$ MW & $P_2 = 91.43$ MW.

$$\text{fuel cost}/\text{hr} = 0.15(108.57)^2 + 20(108.57) + 30$$
$$+0.2(91.43)^2 + 16(91.43) + (20)$$
$$= \text{Rs. } 7124/\text{hr}.$$

Equal load sharing : $\longrightarrow$ (uneconomical)

$P_1 = P_2 = 100$ MW.

fuel cost / hr $= 0.15(100)^2 + 20(100) + 30$

$+ 0.2(100)^2 + 16(100) + 20$

$=$ Rs. 7150 / hr.

Saving / hr $=$ uneconomical $-$ economical

$= 7150 - 7124$

$=$ Rs. 26/ hr.

Saving / day $= 26 \times 24$

06. $P_1 + P_2 = 300$ MW.

$$\frac{df_1}{dP_1} = \frac{df_2}{dP_2}$$

$\Rightarrow 0.1 P_1 + 20 = 0.12 P_2 + 15$

$\Rightarrow P_1 =$

$P_2 =$

fuel cost / hr $= f_1 + f_2$

$= 0.1 \frac{P_1^2}{2} + 20 P_1 + r_1 + 0.12 \frac{P_2^2}{2}$

$+ 15 P_2 + r_2$

$=$

for equal load sharing,

$P_1 = P_2 = 150$ MW.

fuel cost / hr =

Saving / hr = uneconomical − economical dispatch

Saving / annum = Saving / hr × 8760