Representation of Power System Components.

→ Three major components :- (1) Generation System. (2) Tx Sys (3) Dist Sys.

→ 3-ϕ generation or supply as well as 3-ϕ Tx and networks are balanced and therefore. So far as the calculation are concerned the analysis. they can be treated as a single phase system for

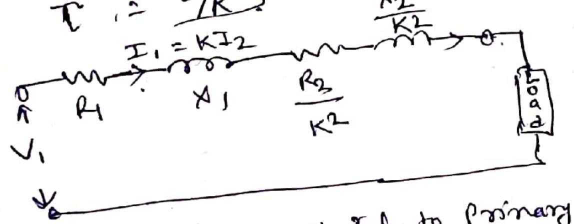
→ In addition to the unbalanced supply or excitation, the 3-ϕ n/w is also unbalanced, their ~~ϕ~~ transformation into component quantities will not serve the purpose bcz even after transformed ion, the phasor quantities remain coupled. But such situation are not very common.

→ For the development of fairly accurate models of the P.S network, It is necessary that model reflects correctly the terminal behaviour of each component of the network for the purpose of study for which the model has been developed.

→ Representation of synchronous generator for the purpose of ~~ϕ~~ transient stability studies is a constant voltage source behind proper reactance. The voltage source may be subtransient transient or steady state voltages.

→ The current flowing in the syn gen just after occurrence of the three phase short ckt at its terminals is similar to ~~the three phase short ckt at its terminal~~ current that flows in an RL ckt upon which sudden ac voltage is applied. Hence the current will have both ~~ac~~ dc as well as ~~dc~~ ac (i-e transient) (i-e steady state) component as well as component which decays exponentially with time constant

$T := L/R$

→ 

eq ckt of T/F reffered to primary.

→ The 3-ϕ n/w consisting of transmission system and also the distribution systems are assumed to be symmetrical or balanced.

→ The performance of T/x line is governed by its four parameters - Series R & L and shunt C & G

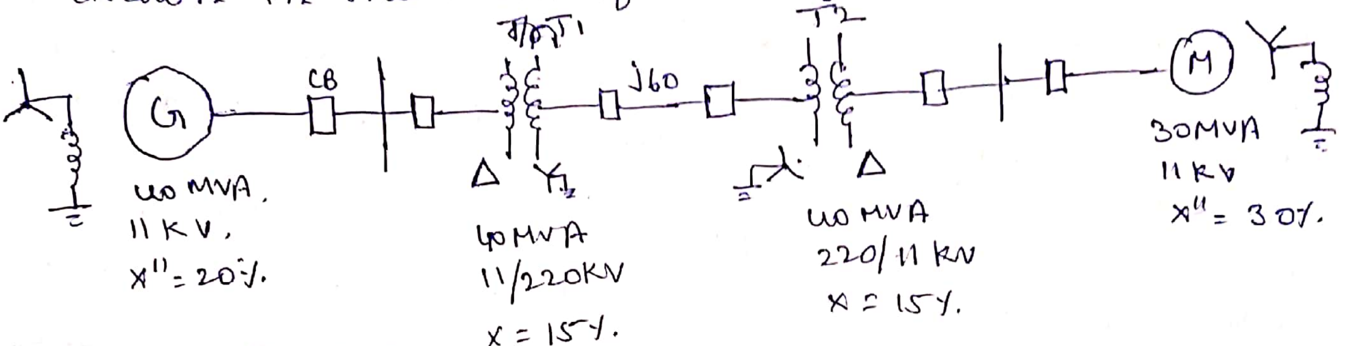
→ R → every conductor offers opposition to the flow of current

L → the current carrying condr is surrounded by the magnetic lines of force.

C → . Condr carrying current forms a capacitor with earth.
G → due to flow of leakage currents over the surface of insulators especially during bad weather.
However, the conductance is normally neglected in the case of tx line calculation since leakage at normal freq are negligible.

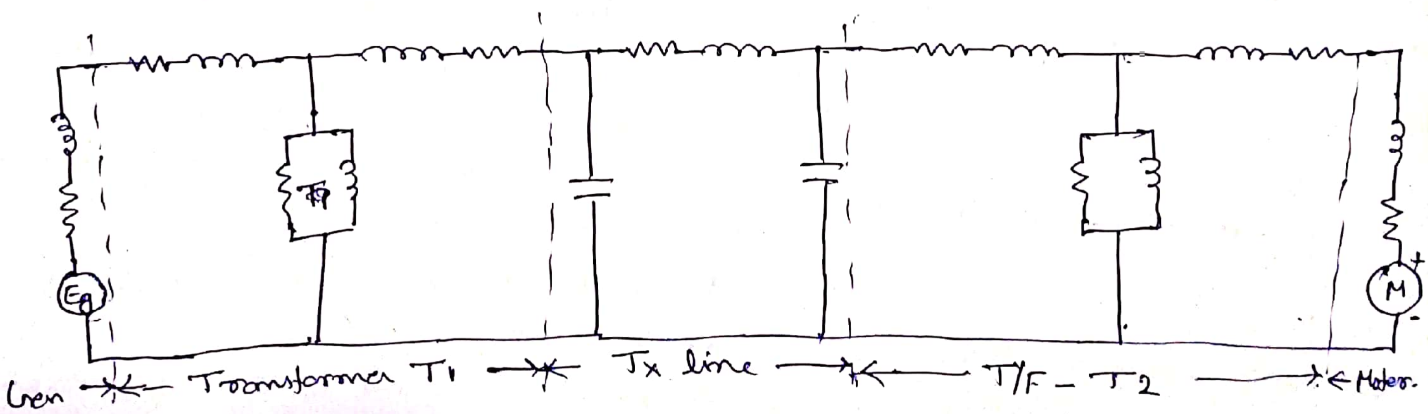
→ Representation of Power System.

→ Single line diagram :- main connections and arrangements of the system components along with their data. (such as output rating, voltage, resistance and reactance etc).
In single line diagram, the system components are usually drawn in the form of their symbols.



→ Any 3-ϕ n/w consisting of gen, T/F, Tx line etc, can be solved as a single phase n/w composed of one of the three phases and a neutral return. if it is a balanced under normal operation. Many times, the components of the system are shown in a single line diagram omitting the neutral also.

→ Impedance diagram Representation of a power system.
In impedance diagram each components is represented by its equivalent ckt. (Tx line by nominal π ckt).



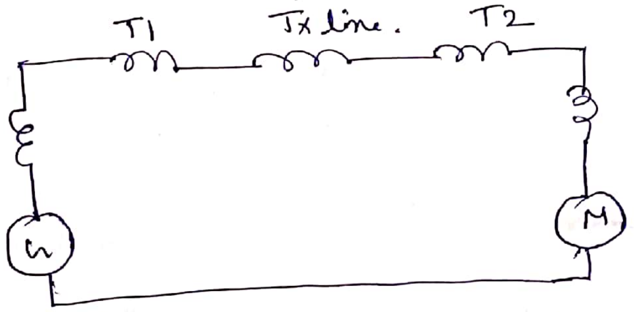
→ Neutral earthing impedance do not appear in the diagram as balanced conditions are assumed.

ve impedance diagram known as positive sequence diagram since it is drawn for a balanced 3-ϕ system.

* three seperate (+ve, -ve, & zero sequence) impedance diagrams are used in short ckt studies of unsymmetrical faults.

→ Reactance diagram Representation of a P.S.

Certain assumption i.e neglecting effective resistance.



→ quite accurate results for many P.S studies such as short ckt studies etc. bcz. resistance << reactance.

→ If the $R < \frac{1}{3} X$ and Res neglected. then error introduced will not be more than 5%.

if $R \leq \frac{1}{2} X$ then error 12% may be introduces.

By errors it is meant that calculation will result in values higher than is actually the case being obtained and in some cases, lead to purchase of protective gear with a higher rating than required.

→ Percentage Resistance and Reactance and Base KVA and kV.

$$\% X = \frac{IX}{V} \times 100.$$

$$\% R = \frac{IR}{V} \times 100 ;$$

I → full load current

V → Rated voltage

R → in Ω.

→ Base KVA. → If number of equipments such as gen. T/F. Tx line etc connected: it is difficult to compare %R & %X until and unless they are all and their combined effect referred to a common kVA. This common kVA which is arbitrary one is known as base kVA.

A base KVA may be chosen in the following manner.

1. Equal to the kVA rating of the largest unit connected in the n/w.
2. Equal to the sum of the KVA ratings of all the units connected in the n/w.
3. Any arbitrary value.

→ For the calculation of short ckt current base MVA is to be taken into consideration.

→ <u>Per unit method of Representation</u>

$$\text{Pu value} = \frac{\text{The actual value of the quantity in any unit}}{\text{the base or ref value in the same unit.}}$$

→ Calculation are simplified.

→ By choosing suitable base KV's for the ckts the per unit reactance remains the same, reffered to either sides of T/F.

→ Provides a method of comparision.

→ Base current $I_B = \frac{KVA_B}{KV_B}$; $Z_B = \frac{V_B}{I_B} = \frac{V_B \times V_B}{I_B \times V_B}$

$$= \frac{V_B^2 / 1000 \times 1000}{V_B I_B / 1000 \times 1000}$$

$$= \frac{(KV_B)^2 \times 1000}{KVA}$$

$$= \frac{(KV_B)^2}{MVA_B}$$

$$\Rightarrow Z_B = \frac{(KV_B)^2}{MVA_B}$$

→ If in the n/w there is no T/F present, the same base voltage is used throughout, but if the T/F are present, the rule is to change the base voltage in the proportion to the Transformation ratio of the T/F. when T/F is reached.

$$I_{pu} = \frac{\text{Actual current}}{\text{Base Current}} = I \cdot \frac{(KV)_B}{(KVA)_B}$$

$$Z_{pu} = Z \times \frac{MVA_B}{(KV_B)^2}$$

→ <u>3-φ system.</u>

$$(Y) \rightarrow I_B = \frac{KVA_B}{\sqrt{3}\, KV_B} \; ; \; Z_B = \frac{(KV_B)^2}{MVA_B} = \frac{\left(\frac{KV_B}{\sqrt{3}}\right)^2}{\frac{MVA}{\sqrt{3}}}$$

$Z_B \rightarrow$ same exp for 1-φ & 3-φ system.

$$Z_{pu\,new} = Z_{pu\,old} \times \frac{KVA_{new}}{KVA_{old}} \times \frac{(KV_{old})^2}{(KV_{new})^2}$$

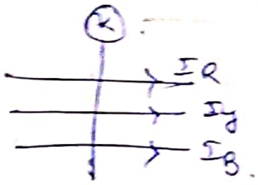
① S-L-G. ② L-L fault ③ L-L-G fault ①

UNSYMMETRICAL FAULT ANALYSIS

Condition before fault is $I_R = I_y = I_B = 0$. → unloaded cond^n

Step - I

At faulted bus K;



$$\begin{bmatrix} I_{R_0} \\ I_{R_1} \\ I_{R_2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} I_R \\ I_y \\ I_B \end{bmatrix}$$

1st find I_{R_0}, I_{R_1}, I_{R_2}.

Step - 2

For the known seq currents I_{R_1}, I_{R_2}, I_{R_0}, the 3-ϕ currents at bus K

$$\begin{bmatrix} I_R \\ I_y \\ I_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix}\begin{bmatrix} I_{R_0} \\ I_{R_1} \\ I_{R_2} \end{bmatrix}$$

Step - 3

The Seq Voltages = ?

$V_{R_1} = E - I_{R_1} Z_1$

$V_{R_2} = - I_{R_2} Z_2$

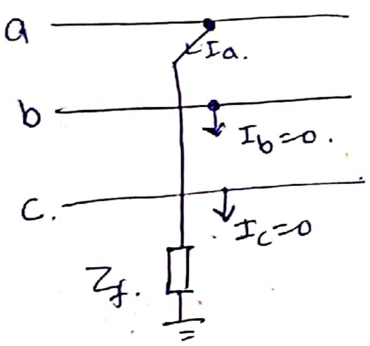
$V_{R_0} = - I_{R_0} Z_0$.

Step - 4

Finally determine the 3-ϕ voltages.

$$\begin{bmatrix} V_R \\ V_y \\ V_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix}\begin{bmatrix} V_{R_0} \\ V_{R_1} \\ V_{R_2} \end{bmatrix}$$

→ **S-L-G fault**



$I_a = I_{f,LG}$.

$I_b = I_c = 0$.

$V_a = I_a Z_f$.

$$\begin{bmatrix} I_{a_0} \\ I_{a_1} \\ I_{a_2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix}\begin{bmatrix} I_a \\ 0 \\ 0 \end{bmatrix};$$

Step-1

$I_{a_1} = I_{a_2} = I_{a_0} = \frac{1}{3} I_a = \frac{1}{3} I_{f,LG}$.

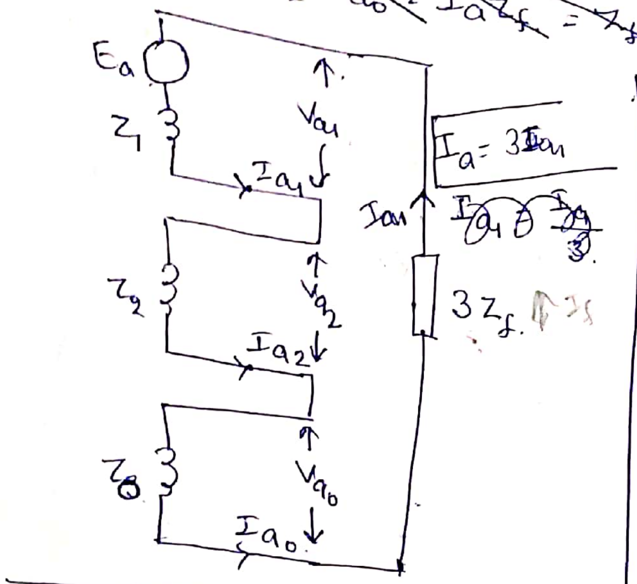
↳ all 3 seq N/W are in series.

$I_{a_1} = \frac{3 E_a}{\ldots}$

Step-2 $\boxed{I_a = 3 I_{a_1} = I_{f,LG} = \frac{3 E_a}{(Z_1+Z_2+Z_3)+3Z_f} \quad I_b = I_c = 0.}$

$\therefore \cancel{V_a = I_a Z_f}$

$\cancel{V_{a1} + V_{a2} + V_{a0} = I_a Z_f = Z_f \, I_{fLL} = 3 Z_f I_{a1}}$



$I_a = 3 I_{a1}$

$I_{a1} = \frac{I_a}{3}$

Step-3

$V_{a1} = E_a - Z_1 I_{a1}$

$V_{a2} = -Z_2 I_{a2}$

$V_{a0} = -Z_3 I_{a0}$

Step - 4

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix}$$

$V_a = V_{a0} + V_{a1} + V_{a2}$. $\Rightarrow V_a = I_{a1} \cdot 3Z_f = I_a Z_f$.

$V_a = I_a Z_f$

$\Rightarrow V_{a0} + V_{a1} + V_{a2} = I_a Z_f$

$\Rightarrow I_a Z_f = E_a - Z_1 I_{a1} - Z_2 I_{a2} - Z_3 I_{a0} = E_a - (Z_1 + Z_2 + Z_0) \frac{I_a}{3}$

$\because I_{a1} = I_{a2} = I_{a0} = \frac{I_a}{3} = \frac{I_{fLL}}{3}$

$\Rightarrow I_a Z_f + (Z_1 + Z_2 + Z_0) \frac{I_{a1}}{3} = E_a \Rightarrow \frac{E_a}{(Z_1 + Z_2 + Z_3) + 3Z_f}$

$\Rightarrow I_a = \frac{3E_a}{Z_1 + Z_2 + Z_0 + 3Z_f}$

$V_a = I_a Z_f = \frac{3 E_a \cdot Z_f}{Z_1 + Z_2 + Z_0 + 3Z_f}$

$= \frac{E_a \cdot 3Z_f}{(Z_1 + Z_2 + Z_3) + 3Z_f}$

$V_a = E_a - (Z_1 + Z_2 + Z_3) \cdot \frac{I_{fLL}}{3}$

$= E_a - (Z_1 + Z_2 + Z_3) \cdot \frac{E_a}{(Z_1 + Z_2 + Z_3) + 3Z_f}$

$= \frac{E_a (\cancel{Z_1} + \cancel{Z_2} + \cancel{Z_3} + 3Z_f - \cancel{Z_1} - \cancel{Z_2} - \cancel{Z_3})}{(Z_1 + Z_2 + Z_3) + 3Z_f}$

$$\Rightarrow \boxed{V_a = \frac{E_a \cdot 3Z_f}{(Z_1 + Z_2 + Z_3) + 3Z_f}}$$

$V_b = V_{a0} + \alpha^2 V_{a1} + \alpha V_{a2} = \alpha^2 (E_a - Z_1 \frac{I_a}{3}) + \alpha (-Z_2 \frac{I_a}{3}) + (-Z_0 \frac{I_a}{3})$

$\alpha^2 V_{a1} + \alpha V_{a2} + V_{a0}$.

$= \alpha^2 E_a - \frac{I_a}{3} [\alpha^2 Z_1 + \alpha Z_2 + Z_0]$

$\because I_a = 3 I_{a1} = \frac{3 E_a}{(Z_1 + Z_2 + Z_0) + 3Z_f}$.

$= \alpha^2 E_a - \frac{E_a (\alpha^2 Z_1 + \alpha Z_2 + Z_0)}{Z_1 + Z_2 + Z_0 + 3Z_f}$

$= \frac{E_a [\alpha^2 (\cancel{Z_1} + Z_2 + Z_0 + 3Z_f) - \alpha^2 \cancel{Z_1} - \alpha Z_2 - Z_0]}{(Z_1 + Z_2 + Z_0) + 3Z_f}$

$$V_b = \frac{E_a [Z_2 (\alpha^2 - \alpha) + Z_0 (\alpha^2 - 1) + 3\alpha^2 Z_f]}{(Z_1 + Z_2 + Z_0) + 3Z_f}$$

$$V_c = V_{a0} + \alpha V_{a1} + \alpha^2 V_{a2}$$

$$= \alpha V_{a1} + \alpha^2 V_{a2} + V_{a0}$$

$$= \alpha \left[E_a - Z_1 \frac{I_a}{3}\right] + \alpha^2\left(-Z_2 \frac{I_a}{3}\right) + \left(-Z_0 \frac{I_{a0}}{3}\right)$$

$$= \alpha E_a - \frac{I_a}{3}\left[\alpha Z_1 + \alpha^2 Z_2 + Z_0\right]$$

$$= \alpha E_a - \frac{E_a(\alpha Z_1 + \alpha^2 Z_2 + Z_0)}{Z_1 + Z_2 + Z_0 + 3Z_f}$$

$$= \frac{E_a\left[\alpha(Z_1 + Z_2 + Z_0 + 3Z_f) - \alpha Z_1 - \alpha^2 Z_2 - Z_0\right]}{Z_1 + Z_2 + Z_0 + 3Z_f}$$

$$V_c = \frac{E_a\left[Z_2(\alpha - \alpha^2) + Z_0(\alpha - 1) + 3\alpha Z_f\right]}{Z_1 + Z_2 + Z_0 + 3Z_f}$$

⇒ for. S-L-G fault.

$$\boxed{I_{a1} = I_{a2} = I_{a0} = \frac{I_a}{3} = \frac{1}{3} I_{f,LG}}$$ → Sequence currents.

$$I_a = 3I_{a1} = I_{f,LG} = \frac{3E_a}{Z_1 + Z_2 + Z_3 + 3Z_f}$$

$$I_b = I_c = 0$$

→ Phase current.

$$V_{a1} = E_a - Z_1 I_{a1}$$

$$V_{a2} = -Z_2 I_{a2}$$

$$V_{a0} = -Z_3 I_{a0}$$

→ Sequence voltages.

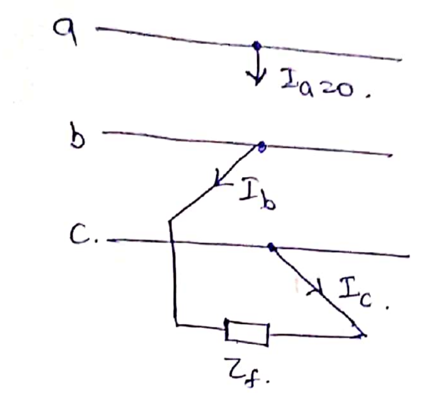
$$V_a = \frac{E_a \cdot 3Z_f}{(Z_1 + Z_2 + Z_3) + 3Z_f}$$

$$V_b = \frac{E_a\left[Z_2(\alpha^2 - \alpha) + Z_0(\alpha^2 - 1) + 3\alpha^2 Z_f\right]}{Z_1 + Z_2 + Z_0 + 3Z_f}$$

$$V_c = \frac{E_a\left[Z_2(\alpha - \alpha^2) + Z_0(\alpha - 1) + 3\alpha Z_f\right]}{Z_1 + Z_2 + Z_0 + 3Z_f}$$

→ Phase voltages.

L-L Fault :-



$I_a = 0$. $I_b = I_c = I_{f,LL}$.

$V_b - V_c = I_b Z_f \Rightarrow V_c = V_b - I_b Z_f$.

$$\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix}\cancel{\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}}\begin{bmatrix} 0 \\ I_b \\ -I_b \end{bmatrix}$$

$I_{a0} = \frac{1}{3}[I_b - I_b] = 0$.

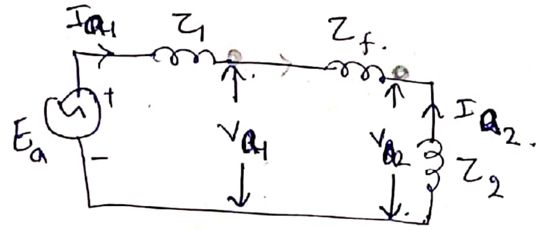
$I_{a1} = \frac{1}{3}[0 + \alpha I_b - \alpha^2 I_b] = \frac{1}{3} I_b(\alpha - \alpha^2)$.

$I_{a2} = \frac{1}{3}[0 + \alpha^2 I_b - \alpha I_b] = \frac{1}{3} I_b(\alpha^2 - \alpha) = -I_{a1}$

$\alpha^2 - \alpha$
$= \alpha(\alpha - 1)$.
$= (-0.5 + j0.88) \times (-0.5 + j0.88 - 1)$
$= (-0.5 + j0.88) \times (-1.5 + j0.88)$.
$= 0.000044 + j1.732$
$= -j\sqrt{3}$.

Step-I $\Rightarrow$ $\boxed{I_{a0} = 0 \quad I_{a2} = -I_{a1} = \frac{1}{3} I_b(\alpha^2 - \alpha)} = \frac{1}{3} I_{f,LL} \cdot (-j\sqrt{3})$. Seq. currents.

Step-2 $\Rightarrow$ $\boxed{I_a = 0;\ I_b = I_c.}$ $\rightarrow$ Phase currents.



$I_{a2} = -I_{a1} = \frac{1}{\cancel{3}} I_{fLL}(-j\cancel{\sqrt{3}})$ $\frac{}{\sqrt{3}}$ $= -\frac{I_{fLL}}{j\sqrt{3}}$

$= -\frac{E_a}{Z_1 + Z_2 + Z_f}$.

$\because I_{a0} = 0$ so zero seq n/w is unconnected.

$\Rightarrow I_{fLL} = j\sqrt{3}\, I_{a2} = -j\sqrt{3}\, I_{a1} = \frac{-j\sqrt{3}\, E_a}{Z_1 + Z_2 + Z_f}$.

$|I_{f,LL}| = \frac{\sqrt{3}\, E_a}{Z_1 + Z_2 + Z_f}$.

$\Rightarrow \boxed{\frac{I_{fLL}}{j\sqrt{3}} = \frac{-E_a}{Z_1 + Z_2 + Z_f} = I_{a2} = -I_{a1}}$.

Step-3

from ckt.

$V_{a1} = E_a - I_{a1} Z_1$

$V_{a2} = -I_{a2} Z_2$.

$V_{a1} - V_{a2} = I_{a1} Z_f$.

or.
$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

$V_c \rightarrow V_b - I_b Z_f$.

$V_{a_0} = \frac{1}{3}[V_a + V_b + V_b - I_b Z_f] = \frac{1}{3}[V_a + 2V_b - I_b Z_f]$

$V_{a_1} = \frac{1}{3}[V_a + \alpha V_b + \alpha^2 (V_b - Z_f I_b)]$.

$= \frac{1}{3}[V_a + V_b(\alpha + \alpha^2) - \alpha^2 Z_f I_b]$

$\Rightarrow 3V_{a_1} = V_a + V_b(\alpha + \alpha^2) - \alpha^2 Z_f I_b$. —— (1)

Similarly. $3V_{a_2} = V_a + V_b(\alpha + \alpha^2) \cancel{V_b} - \alpha Z_f I_b$. —(2).

from (1) - (2).

$3V_{a_1} - 3V_{a_2} = Z_f I_b(\alpha - \alpha^2) = +j\sqrt{3} Z_f I_b$.

$\Rightarrow V_{a_1} - V_{a_2} = -\frac{Z_f I_b}{j\sqrt{3}}$

$\because$ $\cancel{I_b = (\alpha^2 - \alpha)}$ $I_{a_1} = -\frac{1}{3} I_b(\alpha^2 - \alpha) = -\frac{1}{3}(-j\sqrt{3}) I_b = \frac{I_b}{-j\sqrt{3}}$

$\Rightarrow$ $\Rightarrow I_b = -j\sqrt{3} I_{a_1}$

Now. $V_{a_1} - V_{a_2} = -\frac{Z_f I_b}{j\sqrt{3}} = -\frac{Z_f}{j\cancel{\sqrt{3}}} \times -j\cancel{\sqrt{3}} I_{a_1} = Z_f I_{a_1}$

$\Rightarrow \boxed{V_{a_1} - V_{a_2} = Z_f I_{a_1}}$ $\Rightarrow$

Now from seq currents & seq voltage eqn. +ve & -ve seq. are in parallel connecn and. $\because$ $I_{a0} = 0$ So zero seq n/w is unconnected.

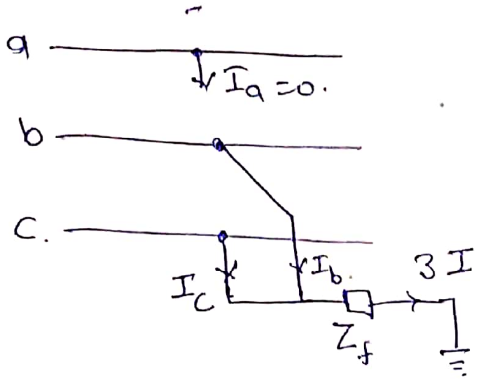
$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix}$$

$V_{a2} = V_{a1} - Z_f I_{a1}$.

$V_a = V_{a0} + V_{a1} + V_{a2} = V_{a0} + V_{a1} + V_{a1} - Z_f I_{a1} = V_{a0} + 2V_{a1} - Z_f I_{a1}$.

L-L fault (4)

L-L-G Fault



$I_a = 0.$

$V_b = V_c = Z_f(I_b + I_c) = 3Z_f I_{F.LLG}.$

$I_{f.LLG} = \frac{I_b + I_c}{3}$

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

$V_{a0} = \frac{1}{3}[V_a + V_b + V_c] = \frac{1}{3}(V_a + 2V_b).$ — 1

$V_{a1} = \frac{1}{3}[V_a + \alpha V_b + \alpha^2 V_c] = \frac{1}{3}[V_a + (\alpha + \alpha^2)V_b].$

$V_{a2} = \frac{1}{3}[V_a + \alpha^2 V_b + \alpha V_c] = \frac{1}{3}[V_a + (\alpha + \alpha^2)V_b]$

$\Rightarrow V_{a1} = V_{a2} = \frac{1}{3}[V_a + V_b(\alpha + \alpha^2)].$ — 2.

↳ means +ve & -ve seq. n/w are in parallel.

Now.

$V_{a0} - V_{a1} = \frac{1}{3}(V_a + 2V_b) - \frac{1}{3}[V_a + V_b(\alpha + \alpha^2)]$

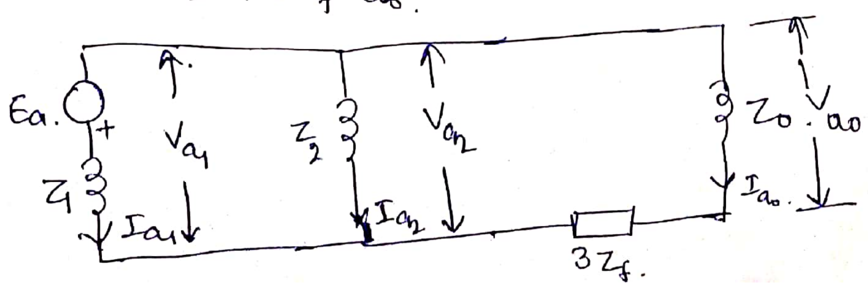
$= \frac{1}{3}[\cancel{V_a} + 2V_b - \cancel{V_a} - V_b(\alpha + \alpha^2)]$

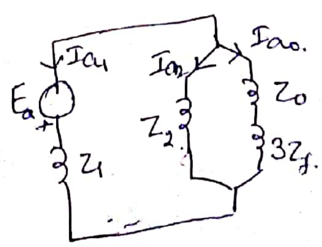
$= \frac{1}{3}V_b(2 - \alpha - \alpha^2) = V_b = 3Z_f I_{a0}.$

$2 - \alpha - \alpha^2 - 1 + 1$
$= 2 - (\alpha + \alpha^2 + 1) + 1$
$= 3 - (1 + \alpha + \alpha^2)$
$= 3 - 0 = 3.$

$\Rightarrow V_{a0} = V_{a1} + 3Z_f I_{a0}.$

$= V_{a2} + 3Z_f I_{a0}.$





$$I_{a_1} = \frac{E_a}{Z_1 + Z_2 \parallel (Z_0 + 3Z_f)} = \frac{E_a}{Z_1 + Z_2(Z_0+3Z_f)/(Z_2+Z_0+3Z_f)}$$

$$= \frac{E_a.(Z_2+Z_0+3Z_f)}{Z_1(Z_2+Z_0+3Z_f)+Z_2(Z_0+3Z_f)}$$

$$= \frac{\cancel{E_a(Z_2+Z_0+3Z_f)}}{}$$

$$I_{a_2} = -I_{a_1} \cdot \frac{Z_0+3Z_f}{Z_2+Z_0+3Z_f}$$

$$I_{a_0} = -I_{a_1} \cdot \frac{Z_2}{Z_2+Z_0+3Z_f}$$

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} I_{a_0} \\ I_{a_1} \\ I_{a_2} \end{bmatrix}$$

$$I_a = I_{a_0} + I_{a_1} + I_{a_2} = -I_{a_1}\frac{Z_2}{Z_2+Z_0+3Z_f} - I_{a_1}\frac{Z_0+3Z_f}{Z_2+Z_0+3Z_f} + I_{a_2}$$

$$= \frac{-I_{a_1}}{\cancel{Z_2+Z_0+3Z_f}}\cancel{(Z_2+Z_0+3Z_f)} + I_{a_2} = I_{a_2} - I_{a_1}.$$

$$I_b = I_{a_0} + \alpha^2 I_{a_1} + \alpha I_{a_2}$$

$$I_c = I_{a_0} + \alpha I_{a_1} + \alpha^2 I_{a_2}.$$

PER UNIT SYSTEM

→ A per unit method uses per unit values.
→ A per unit value is a unit less quantities.
→ $$\text{P.U Value} = \frac{\text{Actual value in some unit}}{\text{Base or ref value in some units}}$$
→ P.U value × 100 = % Value.

Advantages of P.U method.

→ It simplifies power system calculations.
→ It avoids the discontinuities problem posed by the presence of T/F.

Selection of Base Values.

→ We only select base values from power, voltage, current and impedance.

→ Base Power = KVA_b / MVA_b ; Base current (I_b in Amp) = $\frac{KVA_b}{KV_b}$ / $\frac{MVA \times 1000}{KV_b}$

Base voltage = KV_b ; Base impedance (Z_b Ω) = $\frac{KV_b^2}{MVA_b}$ or $\frac{KV_b^2}{KVA_b/1000}$

→ The bas power and base voltage always selected and other two (I_b & Z_b) is derived.

→ Dimension of actual and base value must be match.

3-ϕ System

Base quantities are 3-ϕ quantities i.e. 3-ϕ power and line voltages.

Base Power = $KVA_{b,3\phi}$, $MVA_{b,3\phi}$.

Base voltage = KV_b.line.

→ 3-ϕ system always work on single phase basic bcz phases are symmetri[c] after that ans is converted to 3-ϕ quantities.

→ We assume many thing eg. 3ϕ system is balanced and star connected. Short Tx line is in star connected, anticlockwise dirn is +ve. ratings are in 11 KV, 33 KV, 132 KV -- there is no reason only conversion. $3 \cdot V_p I_p \cos\phi = 3 \cdot \frac{V_L}{\sqrt{3}} I_L \cos\phi$

→ $P_{3\text{-}\phi} = \sqrt{3}\, V_L I_L \cos\phi$

$$I_b = \frac{MVA_{b,3\phi}/3}{\frac{KV_{b,line}}{\sqrt{3}} \times 1000} \text{ Amp} = \frac{KVA_{b,3\phi}}{\sqrt{3} \cdot KV_{b\,line}}$$

$$Z_b(\Omega) = \frac{(KV_{b,line})^2}{MVA_{b,3\phi}} = \frac{(KV_{b,l}/\sqrt{3})^2}{\frac{MVA_{b,3\phi}}{3}} = \frac{KV_b^2}{MVA_b} = Z_{b,1\phi}$$

$$\Rightarrow Z_{b,3\phi} = Z_{b,1\phi}.$$

→ The base values selected in 3-ϕ system is pure 3-ϕ quantities.

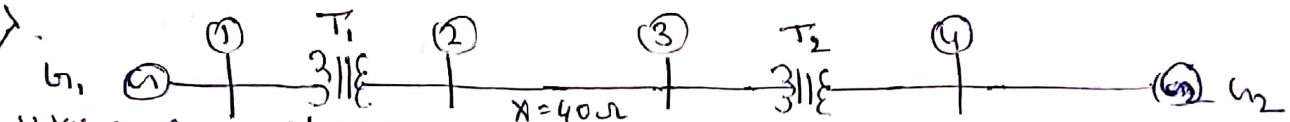
→ A single line diagram representation of P.S indicates that the P.S is 3-ϕ, ~~work~~ balanced condn. So. ~~1-ϕ~~ Analysis is for 1-ϕ basis for 3-ϕ system.

→ A P.S n/w. containing per unit impedances represents 1-ϕ n/w.

→ $$Z_{pu,new} = Z_{pu.old} \left(\frac{KV_{b,old}}{KV_{b,new}}\right)^2 \times \frac{MVA_{b,new}}{MVA_{b,old}}$$

→ When T/F is present in the n/w.
↳ two sets of base values must be selected per either side of T/F. & their ratio must be equal to Transformation ratio of actual T/F.
or a common base value for entire n/w.

Q).



G_1: 11 KV, 8 MVA. $X_{G_1} = j0.4\Omega$.

T_1: 11/400 KV, 10 MVA. $X_{T_1,LV} = j0.1\Omega$.

T_2: 400/6.6 KV, 5 MVA. $X_{T_2,HV} = j0.2$ pu.

G_2: 6.6 KV. 5 MVA. $X_{G_2} = j0.1$ pu

$MVA_b = 15$ MVA. $KV_b = 11$ KV. ⟷ 400 KV   400 KV ⟷ 6.6 KV   6.6 KV.

Soln: – G_1 $V_{G_1} = \frac{11 KV}{11 KV} = 1$ pu.

$$X_{G_1 b} = \frac{(11 KV)^2}{15} = 8.06.$$

$$X_{G_1}(pu) = \frac{j0.4}{8.06} = j0.049 \text{ pu}.$$

G_2 $V_{G_2} = \frac{6.6 KV}{6.6 KV} = 1$ Pu.

$$X_{G_2 b} = \frac{(6.6)^2}{15} = 2.904$$

$X_{G_2}(pu) = j0.1$ pu on base of 6.6 KV & 5 MVA.

$$= X_{G_2} \cdot \frac{5}{(6.6)^2} \Rightarrow X_{G_2} = ?$$

$$X_{G_2} = j0.1 \times \frac{(6.6)^2}{5} = j0.871$$

$$X_{G_2(Pu\,new)} = \frac{j0.871}{2.904} = j0.3 \text{ pu}.$$

or,

$$X_{G_2 new}(pu) = j0.1 \times \left(\frac{6.6}{6.6}\right)^2 \times \frac{15}{5}$$

$$= j0.3 \text{ pu}.$$

(T1) $X_{T_1,LV} = j0.1\Omega$

$X_{T_1,HV} = j0.1\Omega \times \left(\frac{400}{11}\right)^2$

$= j132.2\,\Omega$.

$X_{T_1}(pu) \Rightarrow \frac{j0.1}{8.06} = j0.012$ pu. (Primary)

$\frac{j132.2}{10666.6\Omega} = j0.12$ pu (Secondary)

$Z_b = \frac{(kV)^2}{MVA} = \frac{400^2}{15} = 10666.67$

$\frac{I_2}{I_1} = \frac{V_1}{V_2} = a \Rightarrow Z_1 = \frac{V_1}{I_1} = \frac{aV_2}{I_2/a} = a^2 \cdot \frac{V_2}{I_2} = a^2 Z_2$

$\Rightarrow V_1 =$

$\Rightarrow Z_2 = \frac{1}{a^2} Z_1$

pu values of T/F whether it is on LV & HV side is same.

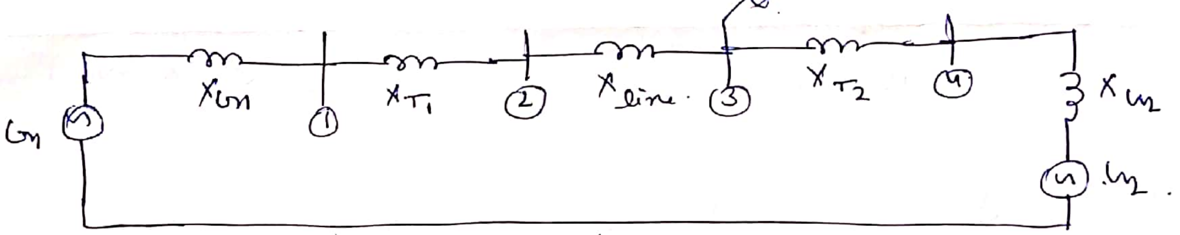
(T2) $X_{T_2,HV} = j0.2$ pu.

$X_{T_2,HV(new)} = j0.2 \times \left(\frac{kV_{old}}{kV_{New}}\right)^2 \times \left(\frac{MVA_{new}}{MVA_{old}}\right) = j0.2 \times \left(\frac{400}{400}\right)^2 \times \frac{15}{5} = j0.6$ pu

$= j0.2 \times \left(\frac{6.6}{6.6}\right)^2 \times \frac{15}{5} = j0.6$ pu.

Tx line. (on HV side of T_1/T_2).

$X_{line}(pu) = \frac{j40}{10666.6} = j0.00375$ pu.



ZPB.

Per unit equivalent reactance diagram.

→ A base KVA may be chosen in the following manner.

1. Equal to the KVA rating of the largest unit connected in the n/w.
2. Equal to the sum of the KVA ratings of all the units connected in the n/w.
3. Any arbitrary value.

→ Three major components in P.S representation – Generation, Tx & distribution system.

→ 3-ϕ supply & Tx are balanced, so study on the basis of 1-ϕ.

→ In case of unbalanced sys, study on the basis of component.

→ Syn gen for transient study represented by const v source with series reactance, V source may be subtransient or steady state.

→ The current flowing in the syn gen just after occurrence of the three phase short ckt at its terminal is similar to current that flows in an RL ckt upon which sudden ac voltage is applied. Hence current will have both both dc (steady state) component as well as ac (transient component) which decay exponentially with time const L/R.

→ Single line diagram — System components along with their data. (such as o/p rating, voltage, resistance & reactance etc)

→ Impedance diagram → Components is represented by its equivalent ckt. (Tx line by nominal π n/w

→ Neutral earthing impedance do not appear in the diagram as balanced cond.ⁿ are assumed.

→ Reactance diagram — assumption R << X so 5–12%. ~~error~~ in calculation. will result in values higher than its ~~actually the~~ actual and in some cases lead to purchase of protective gear with a higher rating than required

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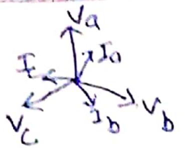
Symmetrical components

→ Balanced system → 

three phases (V & I), each have equal magnitude and displaced by 120° by each other.

→ Knowledge of V & I in one phase is sufficient to completely determine voltages and currents in the other two phases.

→ Real and Reactive powers are simply three times the corresponding per phase values.

→ Unbalanced system is the result of balanced system due ~~ta~~ to unsymmetrical fault.

→ Symmetrical component Analysis :- The impedances presented by various power system elements (Syn gen, T/F, Tx line etc) to symmetrical components are decoupled from each other resulting in independent system n/ws for each components (balanced set).

→ 3 ϕ (3L) fault — 5 %
L-L-G — 10 %
LL — 15 %
L-G — 70 %

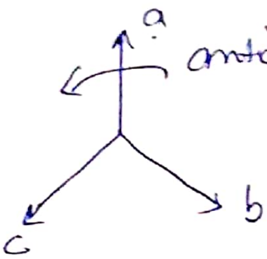
→ 3-ϕ symmetrical fault analysis is carried out by symmetric component theory. which has only mathematical meaning. not electrical meaning (bcz only in +ve seq component we take source but for zero and -ve seq component we shou no voltage source, so this is passive n/w. but we show that a -ve & zero seq current flowing.

→ . Symmetrical components.

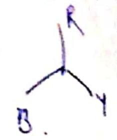
$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} I_{a0} \\ I_{b0} \\ I_{c0} \end{bmatrix} + \begin{bmatrix} I_{a1} \\ I_{b1} \\ I_{c1} \end{bmatrix} + \begin{bmatrix} I_{a2} \\ I_{b2} \\ I_{c2} \end{bmatrix}$$

↓ Unbalanced condn | ↑ zero seq | ↑ +ve seq | -ve seq.

3. sets of balanced condn:-



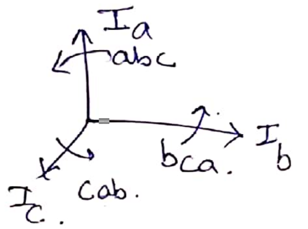
or



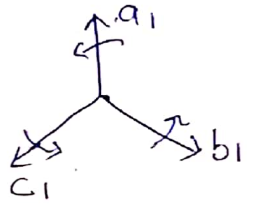
R → Red
Y → Yellow
B → Blue.
Black. for neutral.

→ . Positive sequence components.

These balanced components vectors has a same sequence as original unbalanced vectors.



anticlockwise dirn. Unbalanced original vector.



+ve seq. anticlockwise dirn. Same as actual unbalanced vector.

'a' operator.

$a = 1\angle 120° = -0.5 + j0.866$

$a^2 = 1\angle 240° = -0.5 - j0.866$

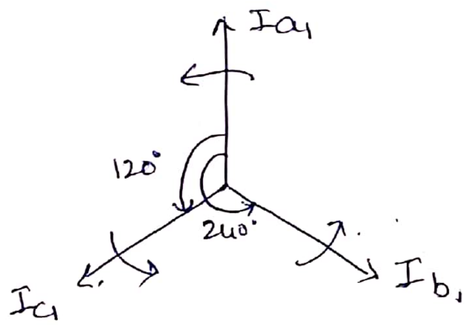
$a^3 = 1\angle 360° = 1$

$1 + a + a^2 = 0$.

$a^* = a^2$ | $1 + a^2 =$

$(a^2)^* = a$

$1 - a^2 = \sqrt{3}\angle 30°$.



$I_{a1} = I_{a1}\angle 0°$

$I_{b1} = I_{a1}\angle 240° = a^2 I_{a1}$

$I_{c1} = I_{a1}\angle 120° = a\, I_{a1}$

Matrix form

$$\equiv \begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix} I_{a1}$$

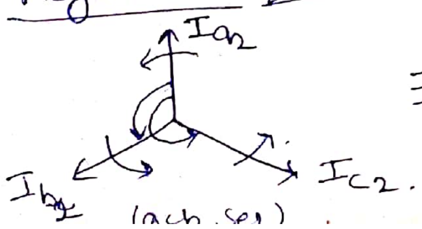
↳. $I_{b1} = I_{a1}\angle 240°$ → . I_{b1} lead 240° by I_{a1}

I_{a1} move 240° in dirn of original by $\angle 240°$ to reach I_{b1}.

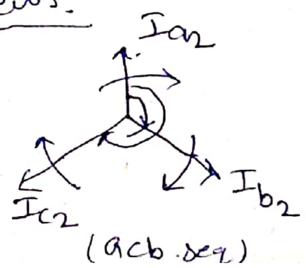
↳ We can avoid of b and c phase component and operating only on a phase by operator 'a'.

↳. The operator a transform the b and c phase components into a phase components. such that we can work on single phase basis.

→ Negative seq components.



≡



$I_{a2} = I_{a2}\angle 0°$

$I_{b2} = I_{a2}\angle 120° = a\, I_{a2}$

$I_{c2} = I_{a2}\angle 240° = a^2 I_{a2}$

$$= \begin{bmatrix} 1 \\ a \\ a^2 \end{bmatrix} I_{a2}.$$

zero seq. components :-

$\uparrow \quad \uparrow \quad \uparrow$

$I_{a0} \quad I_{y0} \quad I_{B0}$

$I_{R0} = I_{y0} = I_{B0} \equiv \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} I_{R0}$

No phase diff. $\rightarrow$ operator 'a' is not required. bcz no phase difference.

→. +ve seq.

$I_a = I_{a0} + I_{a1} + I_{a2}$

$I_b = I_{b0} + \underbrace{I_{b1}}_{\to a^2 I_{a1}} + \underbrace{I_{b2}}_{\to a I_{a2}}$

$I_c = I_{c0} + \underbrace{I_{c1}}_{\to a I_{a1}} + \underbrace{I_{c2}}_{\to a^2 I_{a2}}$

$$\Rightarrow \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix}$$

$[A]^{-1} = \frac{Adj[A]}{|A|}$

$\Rightarrow [I]_{abc} = [A][I]_{012}$

Adj $[A]$ = Co-factor matrix.

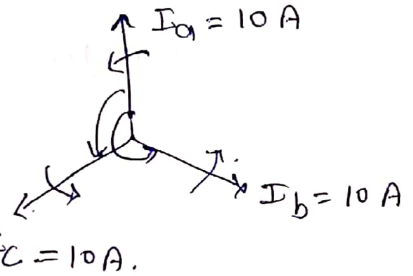
$\Rightarrow [I]_{012} = [A]^{-1}[I]_{abc}$.

$$\begin{bmatrix} + & - & + \\ - & + & - \\ + & - & + \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix}_{012} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

Observation :-

(1). In a balanced 3-ϕ system only +ve seq components are present.



$I_a = 10\angle 0' = 10$

$I_b = 10\angle 240' = a^2 \cdot 10$

$I_c = 10\angle 120' = a \cdot 10$.

$I_{a1} = \frac{1}{3}\left[I_a + a I_b + a^2 I_c\right] = \frac{1}{3}\left[10 + a \cdot a^2 \cdot 10 + a^2 \cdot a \cdot 10\right]$

$= \frac{1}{3}\left[10(1 + a^3 + a^3)\right] = 10. \quad (\because a^3 = 1$

$I_{a2} = \frac{1}{3}\left[I_a + a^2 I_b + a I_c\right] = \frac{1}{3}\left[10 + a^2 \cdot a^2 \cdot 10 + a \cdot a \cdot 10\right]$

$= \frac{1}{3}\left[10 + 10 \cdot a + a^2 \cdot 10\right]$

$= \frac{1}{3} \times 10\left[1 + a + a^2\right] = 0.$

$I_{a0} = \frac{1}{3}\left[I_a + I_b + I_c\right] = \frac{1}{3}\left[10 + a^2 \cdot 10 + a \cdot 10\right]$

$= \frac{1}{3} \times 10\left[1 + a + a^2\right] = 0.$

(2). In an unbalanced 3-ϕ system. all seq components may present.

(3). +ve and -ve seq current can't flow through neutral, only zero sequence current can appear in neutral wire.

$$I_n = I_{n_0} + I_{n_1} + I_{n_2}.$$

$$I_{n_0} = (I_{a_0} + I_{b_0} + I_{c_0}) = I_{a_0} + I_{a_0} + I_{a_0} = 3 I_{a_0}.$$

$$I_{n_1} = (I_{a_1} + I_{b_1} + I_{c_1}) = I_{a_1} + a^2 I_{a_1} + a I_{a_1} = I_{a_1}(1+a^2+a) = 0.$$

$$I_{n_2} = (I_{a_2} + I_{b_2} + I_{c_2}) = I_{a_2}(1+a+a^2) = 0.$$

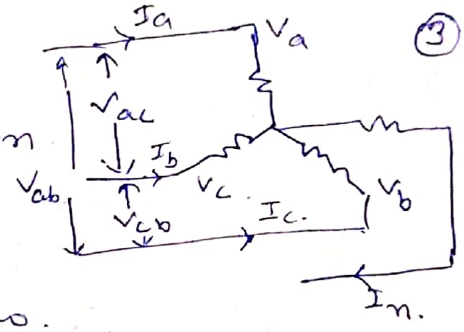
(4). For the flow of +ve and -ve seq current the return path through ground is not compulsory or the condn of neutral has got no effect for the flow of +ve/-ve seq current.

(5). For the flow of zero seq current return path through ground is compulsory or the condn of neutral. (ungrounded, solidly grounded, reactance grounded.) has got effect for the flow of zero seq currents.

(6). The original 3-ϕ system [a.b.c] is mutually joined n/w but the three seq n/ws (+ve & -ve, & zero) are mutually disjoined n/ws.

Observation :-

three phase system with neutral return



(3)

(7) The sum of three line voltages will always be zero. Therefor the zero sequence component of line voltages is always zero i.e.

$V_{ab0} = \frac{1}{3}(V_{ab} + V_{bc} + V_{ca}) = 0$. | $V_{ab} + V_{bc} + V_{ca}$ $= V_a - V_b + V_b - V_c + V_c - V_a = 0$

On the other hand sum of phase voltages (line to neutral) may not be zero so that there zero seq comp V_{a0} may exist

$\because I_n = I_a + I_b + I_c \Rightarrow I_{a0} = \frac{1}{3}(I_a + I_b + I_c) = \frac{1}{3} I_n$

→ Power Invarience

(8). Means sum of powers of the three symmetrical components equal the three phase power.

$S = V_p^T I_p^* = [V]_{abc}[I]^*_{abc}$ | $I^* \to$ complex conjugate. I^* b'cz we need phase diff b/w Voltage phase & current phase. S = complex power.

$~~= V_a I_a^* + V_b~~$

$= V_a I_a^* + V_b I_b^* + V_c I_c^*$

or, $[V]^T_{abc} = ([A][V]_{012})^T$ or. $[I]^*_{abc} = [[A][I]_{012}]^*$ $= [A]^* [I]^*_{012}$

$\Rightarrow S = [A]^T [V]^T_{012} [A]^* [I]^*_{012}$.

$= A^T A^* [V]^T_{012} [I]^*_{012}$

$A^T \to$ whose rows are colume of original

$A^T = A'$; $A = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix}$

$A^T A^* = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}$

$A^T = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix}$

$= 3 \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} = 3U$.

$A^* \to$ conjugate of a matrix is by taking conjugate of each element of A.

$\Rightarrow S = 3 [V]^T_{012} U . [I]^*_{012}$

$A^* = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}$ | $a^* = a^2$ $(a^2)^* = a$.

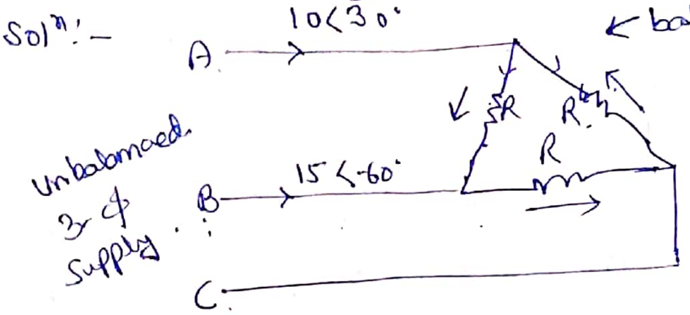
$= 3 . [V_{a0} I_{a0}^* + V_{a1} I_{a1}^* + V_{a2} I_{a2}^*]$

= Sum of Symmetrical comp power

Q). A delta connected balanced resistive load is connected across fault ① unbalanced three phase supply as shown in fig. with current in lines A and B specified. find the symmetrical components of line currents. [Also find the symmetrical components of delta currents]. ~~Do you~~

↓ mean currents in leg of Δ   leg → Δ

Soln :-



← balanced Resistive load.

∵ load is balanced — ①.

$$\boxed{I_A + I_B + I_C = 0}$$

$\Rightarrow 10\angle 30^\circ + 15\angle -60^\circ + I_C = 0$

$\Rightarrow I_C = -16.2 + j8 = 18\angle 154^\circ$ A.

$$\begin{bmatrix} I_{A0} \\ I_{A1} \\ I_{A2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix}$$

unbalanced currents — ②.

$I_{A0} = \frac{1}{3}(I_A + I_B + I_C) = \frac{1}{3} \times 0 = 0.$

$\Rightarrow I_{A1} = \frac{1}{3}[I_A + a \cdot I_B + a^2 I_C]$

$= \frac{1}{3}\{I_A$

$I_{A1} = \frac{1}{3}[10\angle 30^\circ + 15\angle(-60+120^\circ) + 18\angle(154+240^\circ)]$

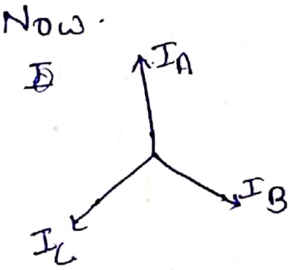
$= 10.35 + j9.3 = 14\angle 42^\circ$ A.

$I_{A2} = \frac{1}{2}[I_A + a^2 I_B + a I_C] = \frac{1}{3}[10\angle 30^\circ + 15\angle(-60+240^\circ) + 18\angle(154+120^\circ)]$

$= -1.7 - j4.3 = 4.65\angle 248^\circ$ A.

I_{A1} +ve. I_{A2} I_{C1} I_{B1} I_{B2} I_{C2} -ve.

Now.



$I_A = I_A\angle 0^\circ$

$I_B = I_A\angle 240^\circ$

$I_C = I_A\angle 120^\circ$.

$I_{A0} = 0$.

$I_{A1} = 14\angle 42^\circ$

$I_{A2} = 4.65\angle 248^\circ$

$I_{B0} = 0$.

$I_{B1} = 14\angle(42+240)$
$= 14\angle 282^\circ$.

$I_{B2} = 4.65\angle(248+120^\circ)$
$= 4.65\angle 368$
$= 4.65\angle 8^\circ$.

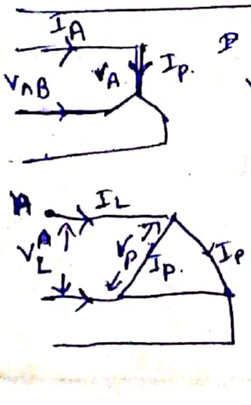
$I_{C0} = 0$.

$I_{C1} = I_A\angle 120^\circ = 14\angle 42+120 = 14\angle 162^\circ$

$I_{C2} = I_A\angle 240^\circ = ~~14\angle 42~~\ 4.62\angle(248+240).$

$= 4.62\angle 488 = 4.62\angle 128^\circ$ A.

$488 - 360 = 128$



$I_L = I_p$.
$V_p = \frac{V_{AB}}{\sqrt{3}}$

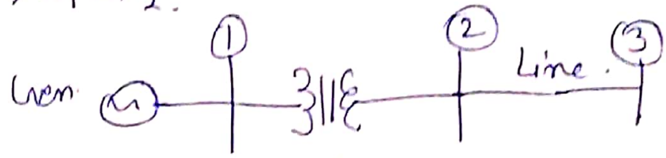
I_L
$V_L = V_p$.
$I_L =$
$I_p = \frac{I_L}{\sqrt{3}}$

Sequence impedance :

Generator → $X_{G0} < X_{G2} < X_{G1}$

T/F & Tx line → $X_0 >> X_1 = X_2$.

Sequence Networks :-



3-φ sym

① Generator representation : 

→ . N/w have 3-φ symmetry bcz of which current of particular seq passed . voltage drop of same seq appear i.e the elements posses only self impedances to seq currents. so seq n/ws are decoupled represented.

① Generator representation :  | Syn imp of gen (Z_s) = Z_1 of gen. = Z'' (normally)

→ Syn m/c is designed with symmetrical wdgs.

→ If Armature resistance (very low value) is assumed negligible, the positive seq impedance Z_1 is | m/c equivalently offers a direct axis reactance. Whose values ↓ as below

$Z_1 = jX_d''$ (if 1 cycle subtransient considered) .

$= jX_d'$ (if 3-4 " " ")

$= jX_d$ (if steady state condn) .

typical value ~~.08~~ to Z_1 ~~8~~ to 12 to 14%

Z_{g0} → 5 to 7%

$*Z_1$, $R_a + X_l$

→ . If the m/c short ckt takes place from unloaded. condn the terminal voltage constitute the +ve seq voltage

→ If sckt occurs from loaded condn, the voltage behind appropriate reactance (X'', X', X_s) constitute the +ve seq voltage .

→ The ref bus (ZPB) or neutral for +ve seq n/w is at ground potential. bcz no current flows from ground to neutral .

→ -ve seq ~~$Z_{at} = E$~~ field rotates in the opposite dirn to that of the +ve seq field and therefore at double synchronous speed w.r.t rotor . currents at double the stator frequency are therefore induced. in rotor field and damper wdg . The -ve seq mmf ~~The~~ is alternately presented with reluctance of direct and quadrature axes . The -ve seq imp (considering dampers wdg & field wdg) $Z_2 = j\frac{X_d'' + X_q''}{2} \approx X_d''$, $|Z_2| < |Z_1|$

$X_d \geq X_q$

-ve seq imp found to oscillate betn X_d'' & X_q'' so X_2 = avg value $= \frac{X_d'' + X_q''}{2}$

Z_2 ↓ X_{2P} $R_a || X_l || X_{dw}$

$N_r = N_s$ → for synchronous

$S = N_s - (-N_s)$ $= 2N_s$.

→ The flow of zero seq currents creates three mmfs, which are in time phase but are distributed in space phase by 120°. The resultant air gap field caused by zero seq currents is therefore zero. Hence only rotor wdg leakage reactance caused to flow of zero seq currents.

3-φ ... $I_{g0} = I_a + I_b + I_c \simeq 0$ very less value

Z_{0g}
↓
$X_{l\,rotor}$

$$\boxed{Z_{0g} < Z_2 < Z_1}$$

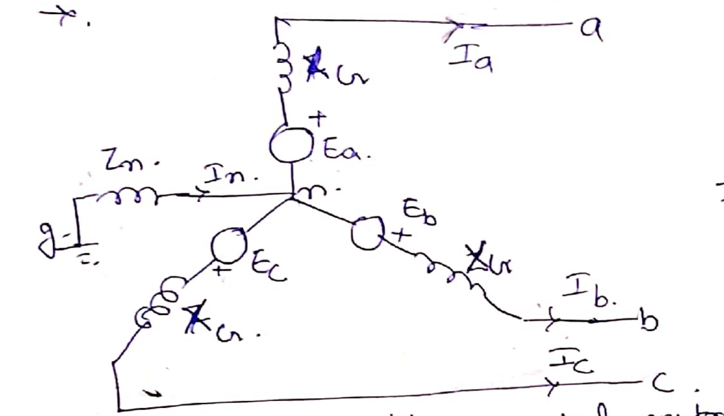
X_{L2} is slightly less than X_{L1}

$$V_{a0} = -3Z_n I_{a0} - Z_{0g} I_{a0} = -(3Z_n + Z_{0g}) I_{a0}$$

$$\Rightarrow \boxed{Z_0 = 3Z_n + Z_{0g}}$$

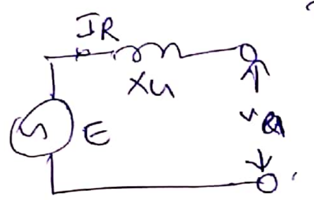
values for 5 MVA 6.6kV, 3000 rpm rated gen.

→



3-φ gen with grounded neutral.

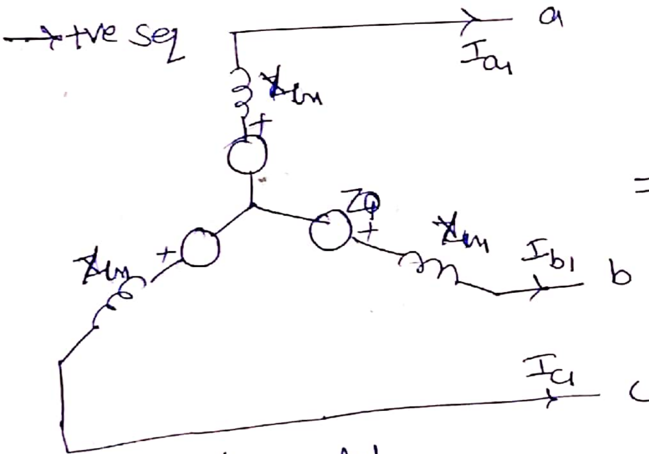
⇒



original n/w without grounded neutral. (anticlockwise).

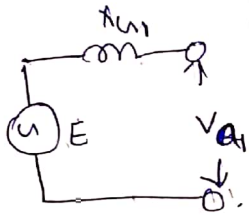
gen rotates in anticlockwise dir^n so generates voltage. So voltage is represented.

→ +ve seq



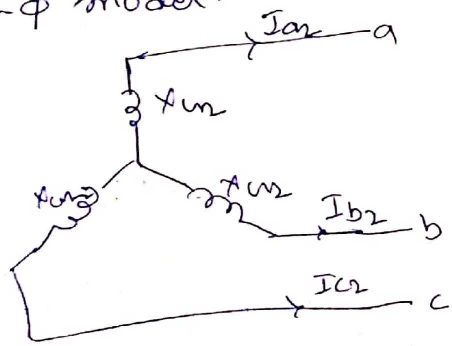
3-φ model.

⇒

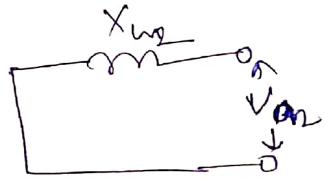


+ve seq n/w anticlock wise.

$V_{a1} = E - I_{a1} X_{L1}$

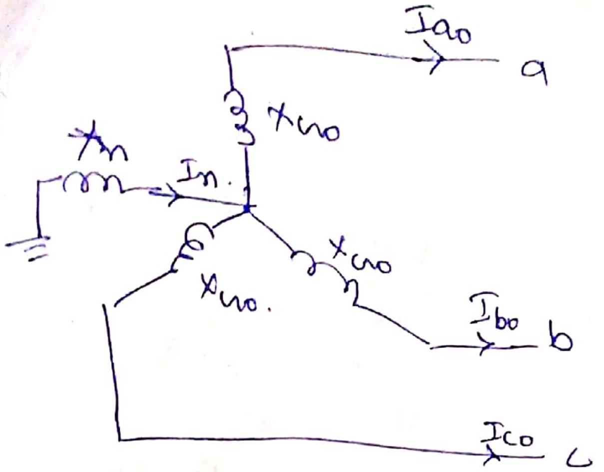


⇒

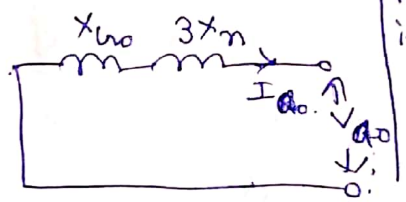


$V_{a2} = I_{a2} X_{L2}$

rotor must rotate in clockwise dir^n but actually rotates in anticlockwise dir^n so this is not possible at same time so voltage is zero.



$\Rightarrow$



gen have no phase seq i.e it is in stand still so $E=0$.

$$V_{a0} = -(3X_n + X_{g0})\, I_{a0}.$$

$$X_0 = 3X_n + X_{g0}.$$

$$\Rightarrow V_{a0} = -X_0 I_{a0}.$$

→. The rotor rotates in anticlockwise dirn and produced voltage in RYB phase. for +ve seq voltage we must rotate rotor in anticlockwise dirn i.e in RYB phase so it generates voltage.

→. For -ve sequence voltage rotor must rotate in clockwise dirn but rotor already rotates in anticlockwise dirn so this is not possible at same time so -ve seq voltage is zero.

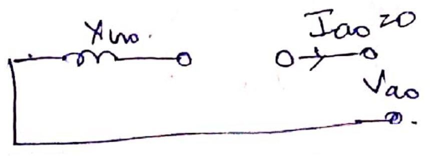
→. For zero seq voltage generator must have no phase seq i.e it is in stand.still so in this case $E=0$.

→. The generator wdg in always in Y bcz in Δ connection circulating currents flows. which heats the gen wdg so problem of insulation.

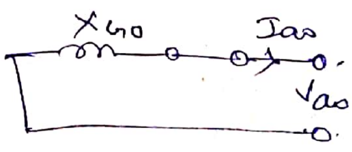
→. In zero seq n/w → if neutral is ungrounded than it is represented by open ckt.

Solidly grounded. → short ckt

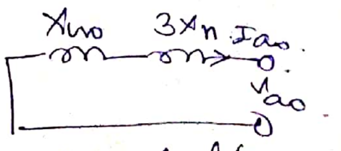
grounded by some reactance (X_n) → $3X_n$ in series with X_{g0}



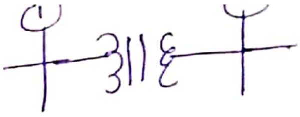
ungrounded.



Solidly grounded.

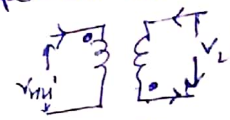


grounded by X_n.

② Transformer Representation  ①

→ Phase shift in Star-delta T/F.

→ +ve & -ve seq voltages and currents undergo a phase shift in passing through a star-Δ transformer which depends on the labelling of terminals.

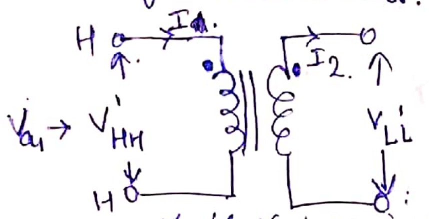


$V_{HH'}$ & $V_{LL'}$ are out of phase. i-e 180° phase diff.

→ Polarity of $V_{HH'} = V_{LL'}$.

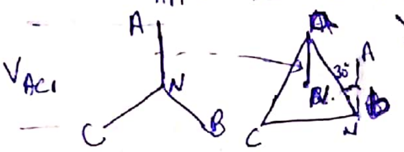
→ magnetizing current neglected.

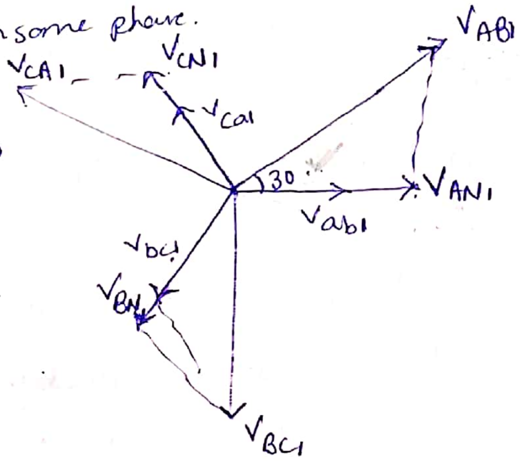
→ T/F excited with V_{a1} so I_{a1} flows.



Sceme of wdg in HV & LV side is opposite so $V_{HH'}$ & $V_{LL'}$ are out of phase to remove this dot convension adopted.

$V_{HH'}$ & $V_{LL'}$ are in same phase.





$V_{AB1} = \cancel{x\, V_{ab}}$

$V_{AB1} = \cancel{x\, V_{AB1}}$

$V_{AN1} = \dfrac{V_{AB1}}{\sqrt{3}} \angle 30°$

$$V_{AN1} = \frac{V_{AC1}}{\sqrt{3}} = \frac{V_{AB1}}{\sqrt{3}}$$

V_{AC1}

(Y) $V_{AB} = x\, V_{AB} \angle 30°$,

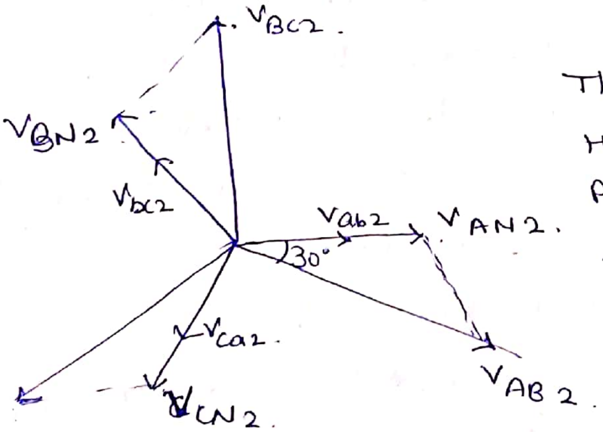
x = Phase transformation ratio.

→ The positive sequence line voltages on star side the corresponding voltages on the delta side by 30° (The same result for phase voltages.) and same result for current also.

⇒ when T/F excited by -ve seq voltages. (Y-Δ T/F.

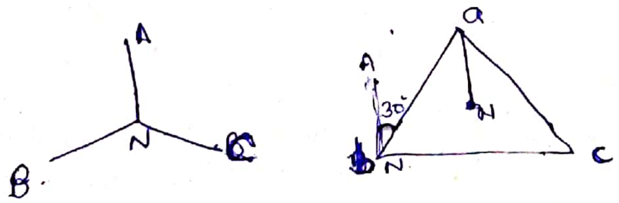
Y → HV side.

Δ → low voltage side.



The positive seq quantities on the HV side lead their corresponding positive seq quantities on the LV side by 30°. The reverse in case of -ve seq quantities wherein HV quantities lag the correspondg LV quantities by 30°.

ie.



star lead 30° by Δ

32

Sequence impedances and Networks of transformers. ⑥

$\boxed{Z_0 >> \,|\, Z_1 = Z_2 = Z_{leakage}}$

| $Z_0 \rightarrow$ rated phase impedance. Usually the value corresponding to I_N measurement is carried out with $3 \times I_N \rightarrow$ always not true.

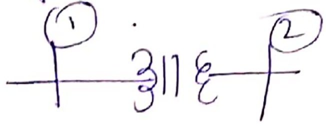
Since T/T is a static device, the leakage impedance does not change with alteration of phase seq of balanced applied voltages.

→ Z_0 slightly differ from Z_1 & Z_2 $I_{NL} = 4\text{-}5\%\, I_{fL}$.

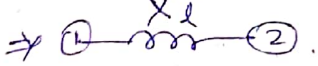
→. Zero seq magnetizing current (No-load current → total current in primary when secondary open ckt.) is higher in core than shell type.

~~Zero seq N/w of T/F~~

~~imp observation~~



→ X_l → for X_1 & X_2



ZPB.

+ve / -ve / zero seq N/w

→ All seq n/w of T/F is represented by series reactance.

→ The type of wdg and condn of neutral have got no effect on representing the T/F seq n/w. (+ve & -ve).

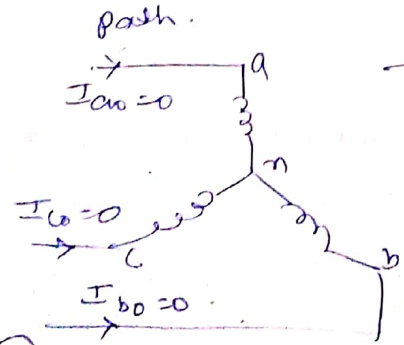
→. The type of wdg and condn of neutral have got effect in representing zero seq n/w.

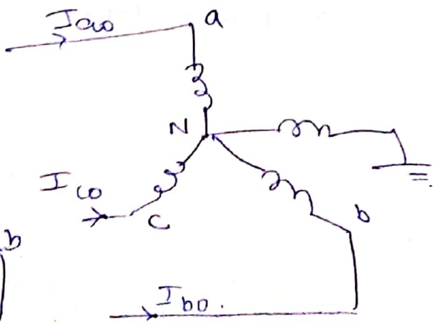
Zero Seq N/ws of T/Fs.

three imp observation.

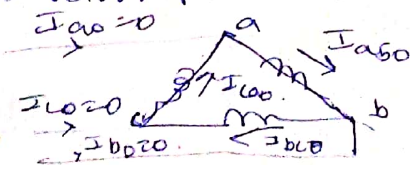
(I). When magnetizing current is neglected, Transformer primary would carry current only if there is current flow on the secondary side.

(II) Zero seq currents can flow in ~~star~~ leg of star only if star pt is grounded. i.e. ~~so~~ which provide return path.

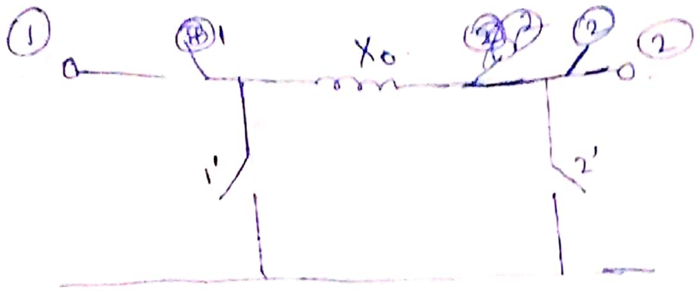




(III). In Δ connection No return path so in the leg of Δ of no zero seq current.



Switch Diagram : Used to represent T/F in zero seq n/w



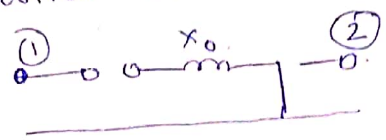
$11' \rightarrow$ Primary switches.
$22' \rightarrow$ Secondary switches.
$12 \rightarrow$ Series switch
$1'2' \rightarrow$ Shunt switch.

ZPB.

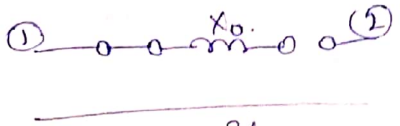
→ A Series switch is closed when the T/F is star connected with neutral grounded.

→ A shunt switch is closed when the T/F is Δ connected.

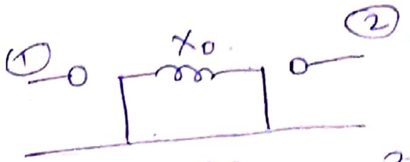
(1) Y Δ →



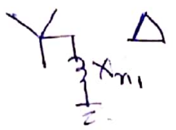
(2) Y Y



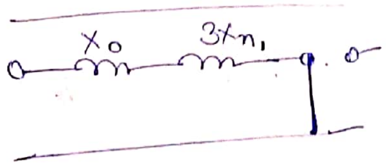
(3) Δ Δ



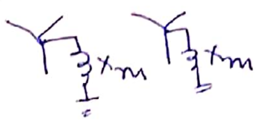
(4)

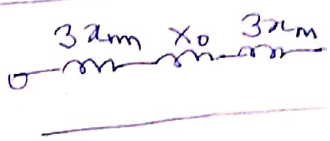


Δ

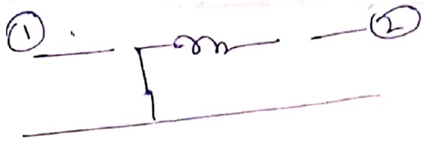


(5)

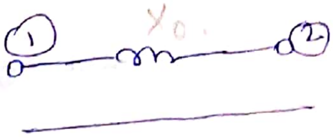




(6) Δ Y

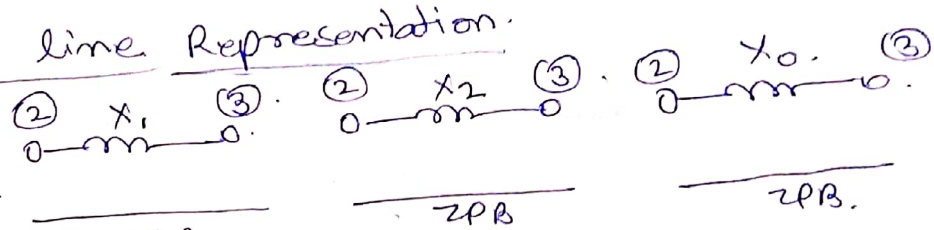


(7)



Transmission line Representation.

→

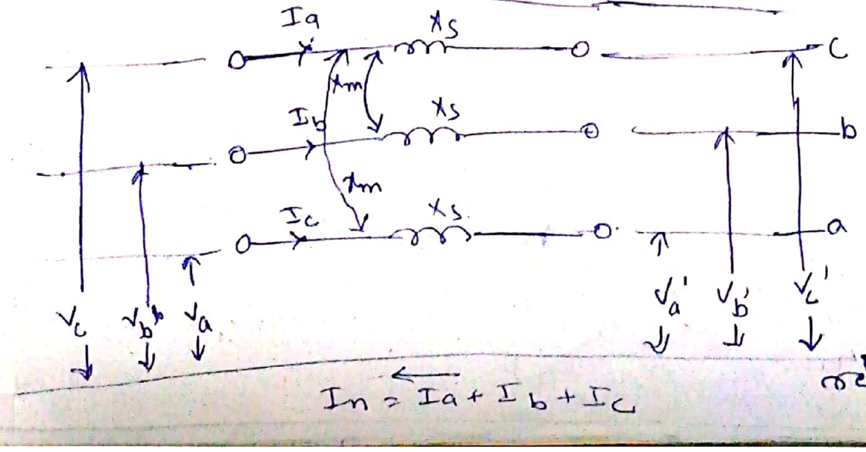


ZPB
+ve seq.

ZPB
−ve seq.

ZPB.

Sequence impedances and Networks of ~~Synchronous~~ ~~[illegible]~~ Transmission lines.



fully transposed lines.
Carrying unbalanced currents.
return path is sufficiently away to ignored the mutual effect

$I_n = I_a + I_b + I_c$

returned path (ZPB).

$$V_a - V_a' = jI_aX_s + jI_bX_m + jI_cX_m.$$

$$V_b - V_b' = jI_bX_s + jI_aX_m + jI_cX_m$$

$$V_c - V_c' = jI_cX_s + jX_aX_m + jI_bX_m.$$

$$\Rightarrow \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} - \begin{bmatrix} V_a' \\ V_b' \\ V_c' \end{bmatrix} = j\begin{bmatrix} X_s & X_m & X_m \\ X_m & X_s & X_m \\ X_m & X_m & X_s \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

$$\Rightarrow [V_p] - [V_p'] = Z[I_p]$$

$$\Rightarrow A[V_s - V_s'] = Z.A\,I_s$$

$$\Rightarrow (V_s - V_s') = A^{-1}ZAI_s.$$

Symmetrical component.

$$\Rightarrow A^{-1}ZA = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} jX_s & jX_m & jX_m \\ jX_m & jX_s & jX_m \\ jX_m & jX_m & jX_s \end{bmatrix}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix}$$

$$= j\begin{bmatrix} X_s+2X_m & 0 & 0 \\ 0 & X_s-X_m & 0 \\ 0 & 0 & X_s-X_m \end{bmatrix}$$

$[V]_{RYB} = [X]_{RYB}[I]_{RYB}.$

$[A][V]_{012} = [X]_{RYB}[A][I]_{012}$

$[V]_{012} = \underbrace{[A]^{-1}[X]_{RYB}[A]}_{[X]_{012}}[I]_{012}$

$[V]_{012} = [X]_{012}[I]_{012}$

$[X]_{012} = [A]^{-1}[X]_{RYB}[A]$

$$= \begin{bmatrix} X_s+2X_m & 0 & 0 \\ 0 & X_s-X_m & 0 \\ 0 & 0 & X_s-X_m \end{bmatrix}$$

off diagonal element of seq matrix is zero i.e seq n/w is disjoined n/w.

$$\Rightarrow (V_s - V_s') = \underline{A^{-1}ZAI_s}.$$

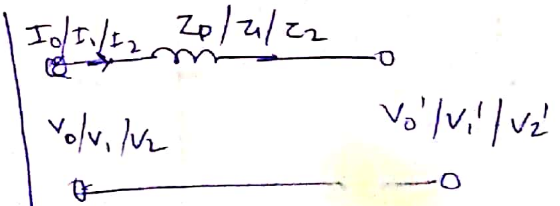
$$\Rightarrow \begin{bmatrix} V_0 \\ V_1 \\ V_2 \end{bmatrix} - \begin{bmatrix} V_0' \\ V_1' \\ V_2' \end{bmatrix} = j\begin{bmatrix} X_s+2X_m & 0 & 0 \\ 0 & X_s-X_m & 0 \\ 0 & 0 & X_s-X_m \end{bmatrix}\begin{bmatrix} I_0 \\ I_1 \\ I_2 \end{bmatrix}$$

$$= \begin{bmatrix} Z_0 & 0 & 0 \\ 0 & Z_1 & 0 \\ 0 & 0 & Z_2 \end{bmatrix}\begin{bmatrix} I_0 \\ I_1 \\ I_2 \end{bmatrix}$$

$$\Rightarrow Z_0 = X_s + 2X_m.$$

$$Z_1 = X_s - X_m = Z_2$$

$$\Rightarrow \boxed{Z_0 >> Z_1 = Z_2}$$



$I_0, V_0, Z_0 \rightarrow$ zero seq.

$I_1, V_1, Z_1, \rightarrow$ +ve seq

$I_2, V_2, Z_2 \rightarrow$ -ve seq.

+ve, -ve, & zero seq n/w of T/F, Tx lines syn m/c. all are decoupled n/w.

→ Active Power (P) watt or Real P, actual P, true Power, wattfull P, usefull P)

↳ which is really ~~transferred~~ to load; 1W = 1V × 1A.

$P(\text{DC ckt}) = VI$

$P(\text{AC ckt}) = VI\cos\theta$ (1-ϕ AC ckt).

$P(3\phi) = \sqrt{3}V_L I_L \cos\theta$ (3-ϕ AC ckt)

$= 3V_{ph} I_{ph} \cos\theta$.

$P = \sqrt{S^2 - Q^2} = \sqrt{VA^2 - VAR^2}$

S → apparent P.

Q → reactive P.

Reactive Power Q.

useless Power, wattless Power

↳ Power that continuously bounce back and forth b/w Source and load.

↳ may be absorbed or returned in load

↳ energy first stored & then release in the form of mag field or electrostatic field in case of inductor and capacitor resp.

$Q = VI\sin\theta$; +ve for inductive load.

L Voltampere; −ve for Capacitive load.

1 VAR = 1V × 1A.

θ → phase angle.

→ Reactive P

$Q = VI\sin\theta$.

$VAR = \sqrt{VA^2 - P^2} = \sqrt{S^2 - P^2} = \sqrt{VA^2 - Watt^2}$

$V_a = V_{a1} + V_{a2} + V_{a0}$

$V_b = \alpha^2 V_{a1} + \alpha V_{a2} + V_{a0}$.

$V_c = \alpha V_{a1} + \alpha^2 V_{a2} + V_{a0}$.

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ & \alpha & \alpha \\ & & \end{bmatrix} \begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix}$$

→ Apparent Power (S)

$S = VI$ (θ → ignored)

↳ rms value.

1 VA = 1V × 1A

Pure resistive ckt → S = P.

reactive ckt → S > P

$|S| = \sqrt{P^2 + Q^2}$ ~~≠ P + Q~~

length of complex Power is apparent P.

Complex Power (S).

$S = P + jQ$.

↳ KVAR.

↳ Volt ampere reactive.

$S = VI^*$

I^* = Conjugate of Complex current.

$S = VI\angle\theta$

$= VI\cos\theta + jVI\sin\theta$.

Complex Power in Capacitive loads.

$Z = R - jX_C$.

$I = I_P + jI_Q$.

$\cos\theta = R/|Z|$ (leading).

$I^* = I_P - jI_Q$.

$S = P - jQ$.

Capacitive load provide leading ~~load~~ vars i.e. eliminates VARS i.e. jI_Q.

Complex Power in inductive loads.

$Z = R + jX_L$.

$I = I_P - jI_Q$.

$\cos\theta = R/|Z|$ (lagging).

$I^* = I_P + jI_Q$.

$S = P + jQ$.

inductive loads, Provide lagging VARs i.e. added vars & lies the overall power factor.

SYMMETRICAL FAULT ANALYSIS

→ Symmetrical short ckt (3-ϕ fault, may be a solid 3-ϕ short ckt or may involve arc impedance)

→ Caused in the system accidentally through insulation failure of equipment or flashover of lines initiated by a lightning stroke or through accidental faulty operation.

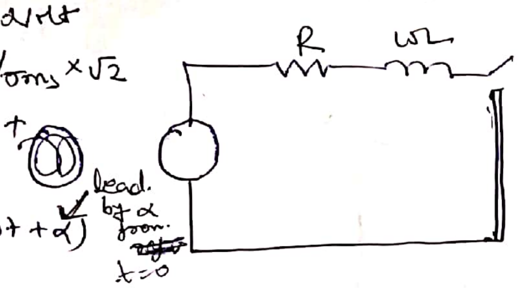
→ Operating conditions at the time of fault are important the loads can be neglected during fault, as voltages dip very low so that currents drawn by loads can be neglected in comparison to fault currents.

→ In the event of a short circuit, the flux per pole undergoes dynamic change with associated transients in damper and field windings.

Transient on a Transmission line. ⇒ assumption $R \neq 0$

Assumption :- V_s = const, short ckt when line is unloaded.
C → negligible and represented by lumped series RL ckt

rms = V avrg
maxm = $V_{rms} \times \sqrt{2}$



SC is assumed to take place at $t = 0$.

current after short ckt

$$i = i_s + i_t$$

$I_s \rightarrow$ Steady state
$I_t \rightarrow$ transient

$$i_s = \frac{\sqrt{2}\,V}{|Z|} \sin(\omega t + \alpha - \theta)$$

lagging phase (shifted left) leading phase +θ (represent it appears earlier than ref wave)

$|Z| = (R^2 + \omega^2 L^2)^{\frac{1}{2}} \angle \left(\theta = \tan^{-1} \frac{\omega L}{R}\right)$

$V_s = V_{ref} \sin(\omega t + \alpha)$
V_{ref} lag by V_s by α

i_t such that $i(0) = i_s(0) + i_t(0) = 0$.

$$i_t = -i_s(0)\, e^{-(R/L)t} = -\frac{\sqrt{2}\,V}{|Z|} \sin(\alpha - \theta)\, e^{-(\frac{R}{L})t}$$

→ -ve time const i.e. current decay.

(at t=0, ωt=0.)

bcz it vanishes after some time

RL ckt, θ

$$\boxed{i = \frac{V}{R} e^{-t/T}}$$

$T = \frac{L}{R}$

$= \frac{V}{R} e^{-\frac{R}{L}t}$

Short ckt current $i = i_s + i_t$.

$$i = \frac{\sqrt{2}\,V}{|Z|} \sin(\omega t + \alpha - \theta) + \frac{\sqrt{2}\,V}{|Z|} \sin(\theta - \alpha)\, e^{-\frac{R}{L}t}$$

→ Symmetrical SC current
(steady state current called)
imp. terminology.

DC off-set current.
(Unidirectional transient comp is called DC off-set current)

i_{mm} max^m momentary short ckt current, ~~correspond to 1st peak~~ ~~transient comp neglect~~

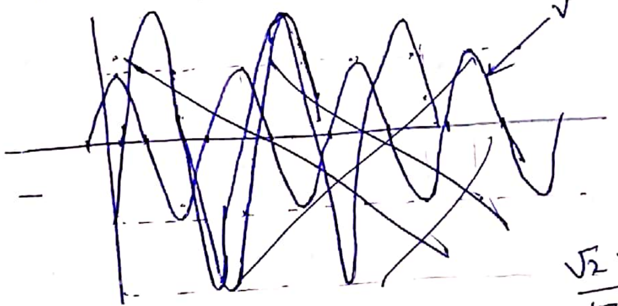
$\sin(A-B) = \sin A \cos B - \cos A \sin B$

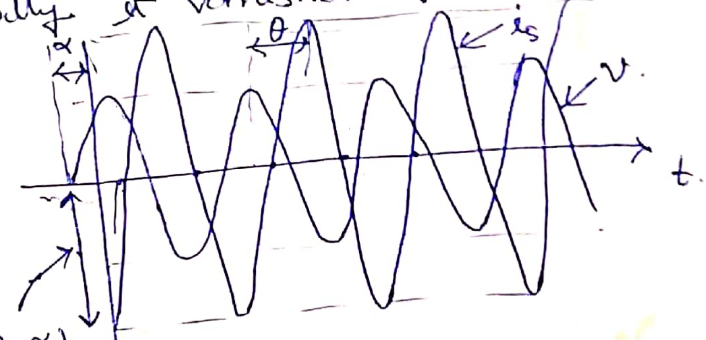
$$i_{mm} = \frac{\sqrt{2}V}{Z}\sin(\omega t + \alpha - \theta)$$

$$= \frac{\sqrt{2}V}{Z}\sin[\omega t - (\theta - \alpha)]$$

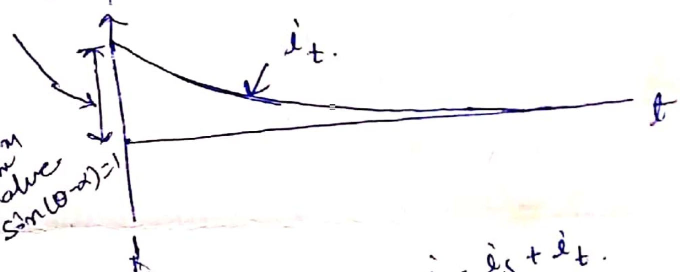
$$= \frac{\sqrt{2}V}{Z}\sin\omega t \cos(\theta - \alpha)$$

The 2nd term is a transient which vanishes theoretically after infinite time. But practically it vanishes after 2 or 3 cycles





$\frac{\sqrt{2}V}{|Z|}\sin(\theta-\alpha)$



Imm = max^m momentary current

if decay of i_t in short time is neglected, correspond to the 1st peak. then.

max^m value $\sin(\theta-\alpha)=1$

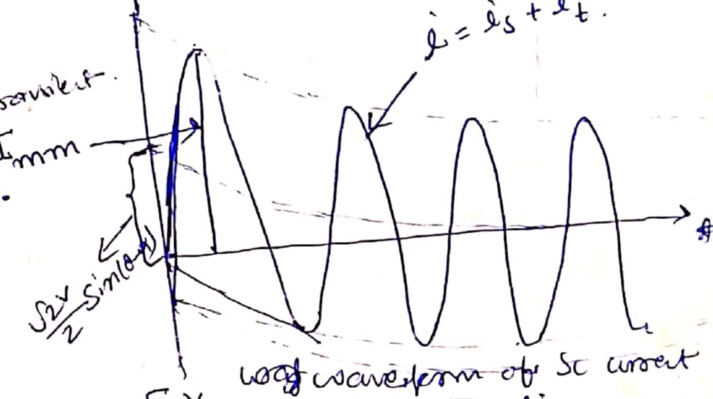
at $\omega t = 0$.

$$i_{mm} = \frac{\sqrt{2}V}{|Z|}\sin(\theta-\alpha) + \frac{\sqrt{2}V}{|Z|} \rightarrow \text{transient}$$

~~transient~~ steady state

∵ Tx line R is small so $\theta \simeq 90°$

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



~~wave~~ waveform of SC current in Tx line.

$$(i_{mm})_{max^m\ possible\ (\alpha=0)} = \frac{\sqrt{2}V}{|Z|} + \frac{\sqrt{2}V}{|Z|} = 2\cdot\frac{\sqrt{2}V}{|Z|}$$

= twice the max^m symmetrical short ckt current (doubling effect).

→. Initial dc component decay over time, eventually reaching zero.

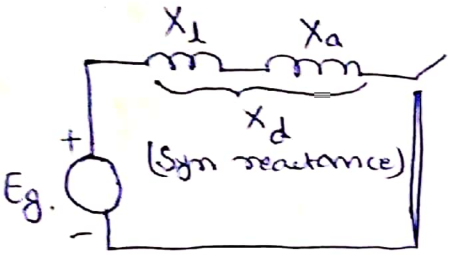
DC comp + symmetrical SC current = Asymmetrical short ckt current

Short circuit of a synchronous machine (on No load).

under steady state short ckt condⁿ, the armature reaction of synchronous generator produces demagnetizing flux.

$X_d \rightarrow$ direct axis syn reactance (salient pole m/c).

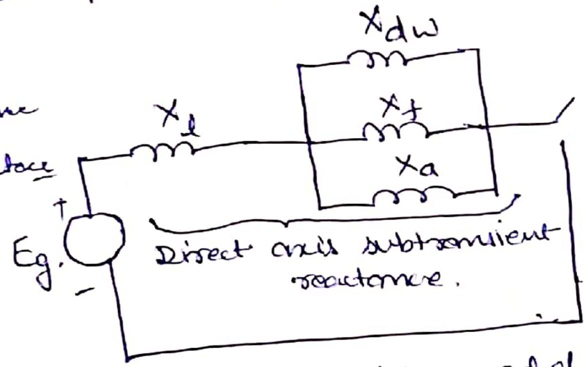
$R_a \rightarrow$ small (neglected).



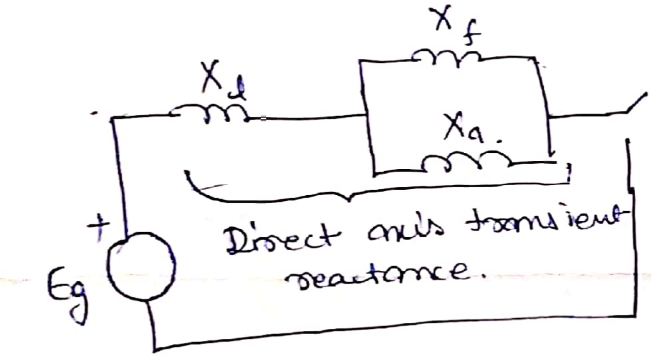
$x_l \rightarrow$ leakage reactance

$x_a \rightarrow$ armature reactance

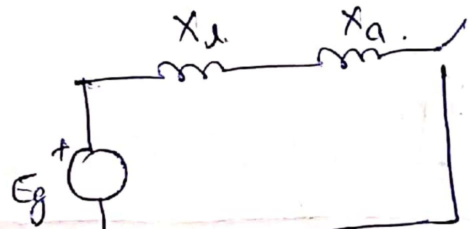
(a) steady state short ckt model of a syn m/c.



(b) approximate ckt model during subtransient period of short ckt.



© Approximate ckt model during transient period.



finally same as steady state model.

→ Sudden short ckt (3-ϕ) of syn gen initially operated under open circuit condition. (no load condⁿ).

→ The DC-off-set currents appear in all the three phases each with a different magnitude since the point on the voltage wave at which short ckt occurs is different for each phase. These DC off-set currents are accounted for seperately on an empirical basis. (→ unidirectional transient comp.)

based on observation or experience

So for short ckt studies contentrate only on symmetrical (sinusoidal) short ckt currents only.

↳ sinusoidal steady state current.

→ In the event of a short ckt the ~~ag~~ I_s is limited by only X_d. Since the air gap flux can't change instantaneously (theorem of constant flux linkages), to counter the demagnetization of the armature short ckt currents, currents appear in the field wdg as well as damper

damper wdg$_r$ during initial period of short ckt in a dir^n to help the main flux. these current decay in accordance with the wdg constants.

Time const of Damper wdg (x_l low) $X_{d}''w$. << T field wdg. (X_f)

→ The reactance in initial period of short ckt X_d''

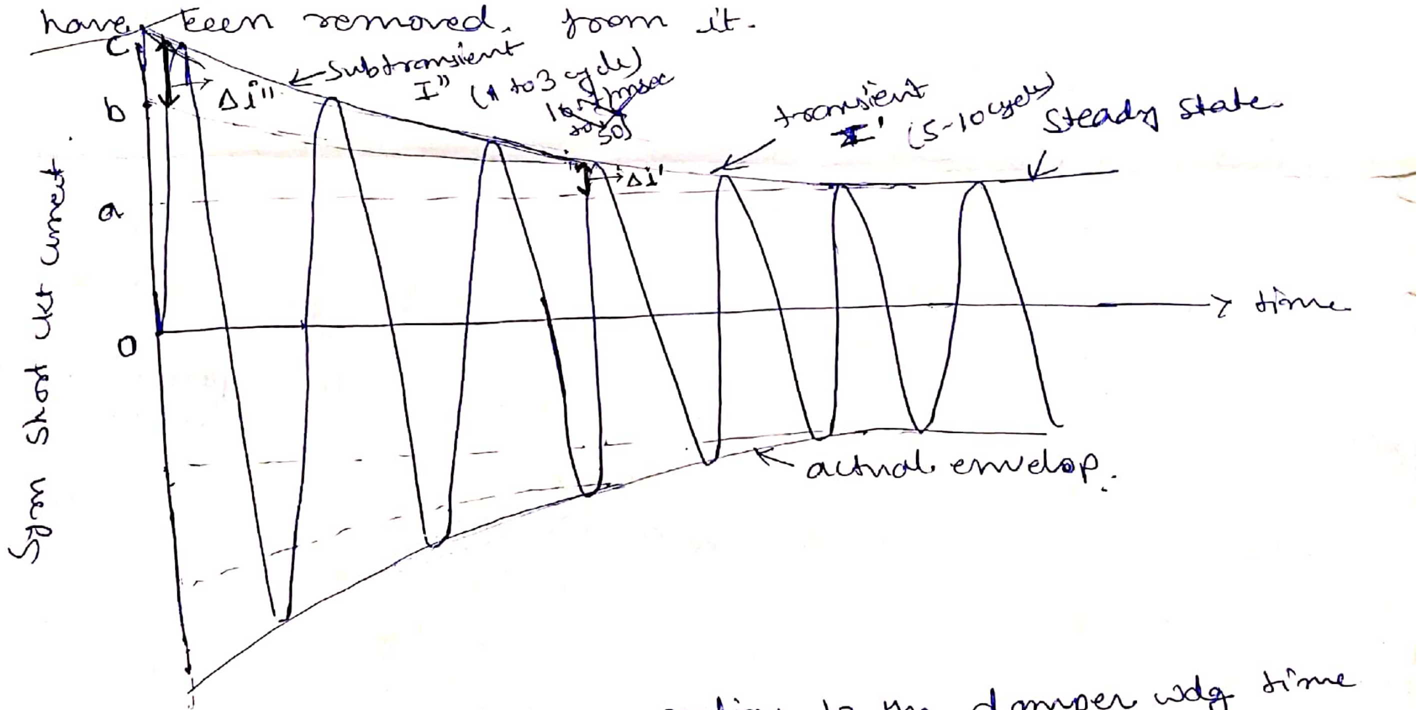
$$X_d'' = X_l + \frac{1}{\frac{1}{X_a} + \frac{1}{X_f} + \frac{1}{X_{dw}}}$$ (Subtransient reactance)

$$X_d' = X_l + (X_a \| X_f) = X_l + \frac{1}{\frac{1}{X_a} + \frac{1}{X_f}}$$ (transient reactance)

X_d → synchronous reactance (Steady cond^n).

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

→ Short circuit current of syn m/c after the DC-off set current have been removed from it.



→. Δi'' (X_{dw}) decays fast according to the damper wdg time const.

→ Δi' decays in accordance with field time const.

→ $|I| = \frac{0a}{\sqrt{2}} = \frac{|E_g|}{X_d}$; $|I'| = \frac{0b}{\sqrt{2}} = \frac{|E_g|}{X_d'}$; $|I''| = \frac{0c}{\sqrt{2}} = \frac{|E_g|}{X_d''}$

$|I|$ ⇒ steady state current (rms).

$|I'|$ = Transient current (rms) excluding DC component.

$|I''|$ = Subtransient current (rms) excluding DC component.

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X_d = direct axis synchronous reactance.

X_d' = direct axis transient reactance.

X_d'' = direct axis subtransient reactance.

$|E_g|$ = per phase no load voltage (rms).

~~oa, ob, oc~~ :

Both $\Delta i''$ & $\Delta i'$ decay exponentially. as.

$$\Delta i'' = \Delta i''_0 \exp(-t/\tau_{dw}) = \Delta i''_0 \, e^{-t/\tau_{dw}}$$

$$\Delta i' = \Delta i'_0 \, e^{-t/T_f}$$

$$\tau_{dw} << T_f$$

→ Normally both generator and motor subtransient reactances are used to determine the momentary current flowing on occurrence of short ckt.

→ To decide interrupting capacity of CB. except those which open instantaneously.

Subtransient reactance is used for generator.

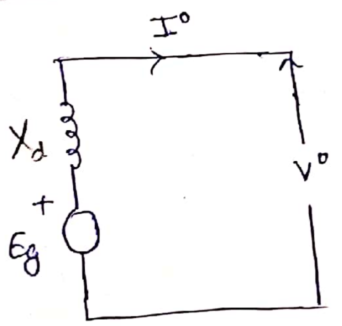
transient reactance is used for motor. // Numerical ① & ②.

Short ckt of a loaded synchronous machine.

E_g → induced emf,

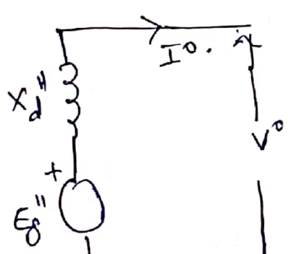
V^0 → terminal voltage.

I^0, V^0 → prefault voltage & Prefault current



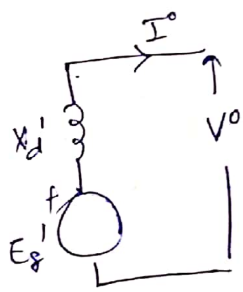
ckt model of loaded m/c. (steady state condn).

→ when short ckt occurs at the terminal of this m/c.



ⓐ ckt model for computing subtransient current.

$$E_g'' = V^0 + jI^0 X_d''$$



ⓑ ckt model for computing transient current.

$$E_g' = V^0 + jI^0 X_d'$$

if I^0 is zero (no load case), $E_g'' = E_g' = E_g$. the no load voltage ckt model as in previous case.(no load case)

For motor : E_g replaced by E_m and dir^n of I^o reversed.

$$E_m'' = V^o - jI^o X_d''$$

$$E_m' = V^o - jI^o X_d'$$

→ Whenever we are dealing with short ckt of an interconnected system, the synchronous machines (gen and motors) are replaced by their corresponding ckt models.

~~Q.① For the radial network shown in fig~~ :

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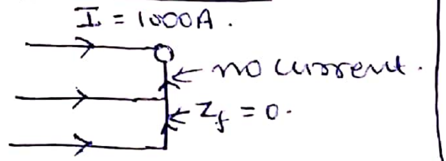
→ 3-φ fault. i.e



$Z_f = 0$ bcz no current flowing through this

In this fault, a high balanced current is flowing through phases but not through connecting object of 3-φ line, bcz it is in balanced cond^n.

Here $Z_f = 0$ so called dead short ckt.

The impedance upto fault location limit the fault current not Z_f.

→ If Z_f has finite value then called as a short ckt.

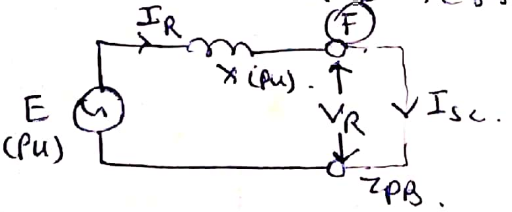
Procedure.

→ ZPB → The neutral of a balanced system.
↳ zero power bus.

① Convert the given line diagram P.S n/w into per unit equivalent reactance diagram.

② Look for the faulted bus terminal F & ZPB. (Zero Power Bus).

③ Reduced the P.S n/w into thevenin's equivalent ckt across F and ZPB terminal.



V_R = Voltage across the faulted bus terminal

E = Thevenin's equivalent prefault voltage.

X = Thevenin's equivalent reactance.

on single phase basis, for R-phase

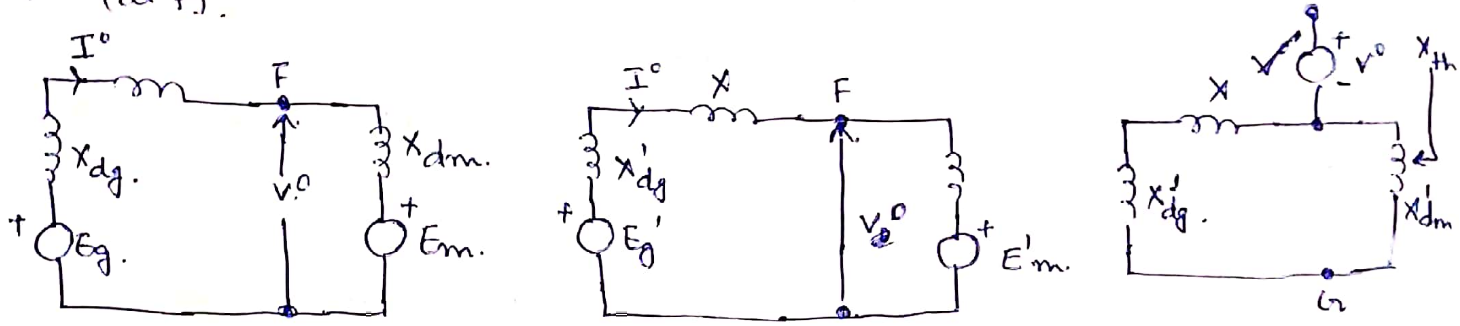
$$I_{sc} = I_R = I_{f,3\phi} = \frac{E}{X} = I_Y = I_B$$

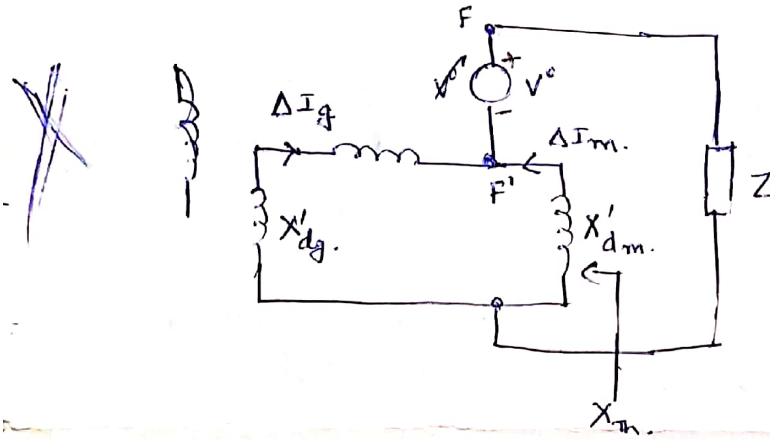
$$V_R = V_Y = V_B = 0.$$ (Voltage across short ckt = 0)

→ Bcz of majority of time generator represented by 1pu voltage so thevenin's equivalent is 1pu. so $\boxed{E_g = 1\,pu = E_{th}}$

$\boxed{I_{f3\text{-}\phi} = \frac{E}{X} = \frac{1}{X}\,pu}$; $P_{f,3\text{-}\phi\,(pu)} = E \cdot I_{sc} = 1 \cdot \frac{1}{X}$; or $P_{f3.\phi\,(pu)} = \frac{P_{f,3\phi}}{P_{Base}}$.

In m/c are represented by their transient reactances (or subtransient reactances if subtransient currents are of interest) in series with voltages behind transient reactances. This change does not disturb the prefault current I^0 and prefault voltage V^0 (at F).





$X_{Th} \rightarrow$ thevenin equivalent.

$V^0 \rightarrow$ Prefault voltage.

$I^0 \rightarrow$ Prefault current

$I_f \rightarrow$ fault current

$X'_{dg} \rightarrow$ gen transient reactance.

$X'_{dm} \rightarrow$ motor transient reactance.

Fault at F through an impedance Z^f.

I^0 does not appear in the passive thevenin imp n/w.

$$I^f = \frac{V^0}{jX_{Th} + Z^f}$$

$$\Delta I_g = \frac{X'_{dm}}{X'_{dg} + X + X'_{dm})} I^f \quad ; \quad \Delta I_m = \frac{X'_{dg} + X}{X'_{dm} + X + X'_{dg}} I^f.$$

$I_g^f = I^0 + \Delta I_g$.
Postfault

$I_m^f = -I_0 + \Delta I_m$.
Postfault.

→ In case of loaded load in MW, kVA

$$I_0 = \frac{MW}{V^0 \times P.f}$$

kV

Post fault voltage $V^f = V^0 + (-jX_{Th} I_g^f) = V^0 + \Delta V$

→ Assumption (1). All prefault voltage magnitudes are 1 pu.

(2) All prefault currents are zero. (no load cond^n).

→ changes in current caused by short ckt are quite large, of the order of 10-20 pu and are purely reactive; whereas the prefault load currents are almost purely real.

Hence the total postfault current can be largest comp magnitude (caused by fault). This satisfy assumption (2).

→ Due to ~~severe~~ demagnetization effect during fault V is zero. So we need prefault voltage or thevenin's voltage.

→ Short ckt KVA or fault level $= V_{rated} \times I_{sc}$.

→ The main $appl^n$ of conducting short ckt and fault analysis is to design the breaking capacity of CB.

→ A short ckt is a high current, low voltage, highly lagging, low p.f phenomenon.

→ Since P.S is not starting for operation before protecting devices are installed and CB breaking capacity is found by short ckt study so short ckt study is performed first now system is on steady state so after SC study load flow study is performed, after that P.S goes to dynamic $cond^n$ so stability after that system is in steady state so again load flow analysis.

→ To limit the value of Isc

(a) Series Resistance is not considered due to continuous P loss.

(b) Series Capacitance is not considered due to breakdown of $insl^n$. during the time of short circuit.

(c) Series reactors are widely used for limiting short ckt current. (to avoid saturation no core or air core reactor.

→ Resistance is a linear element until temp maintained const.

$L = \frac{N\phi}{I}$ I↑ then B↑ for high current saturation occurs so after saturation L↓.

* So inductor is a linear element until saturation takes place and capacitor is a linear element until V attains its final value.

Q.) A 100 KVA equipment has 5% impedance to limit the short ckt KVA to 250. the percentage reactance required for series reactor is?

$SC\ KVA = V_{rated} \times I_{sc}$, $I_{sc} = \frac{SC\ KVA}{V_{rated}}$

$(KVA)_{pu} = \frac{250}{100} = 2.5$

$I_{sc}(pu) = \frac{250}{100} = 2.5\,pu \rightarrow \frac{(KVA)_{pu}}{V_0(pu)}$

at the time of fault V = 1 pu

KVA (pu) $= \frac{250}{100} = 2.5$

$\frac{(250/100)}{1} = 2.5\,pu$

$\frac{V(pu)}{X_{se} + \% X} = 2.5 \Rightarrow \frac{1}{X_{se} + 0.05} = 2.5 \Rightarrow X_{se} + 0.05 = \frac{1}{2.5} = 0.4$

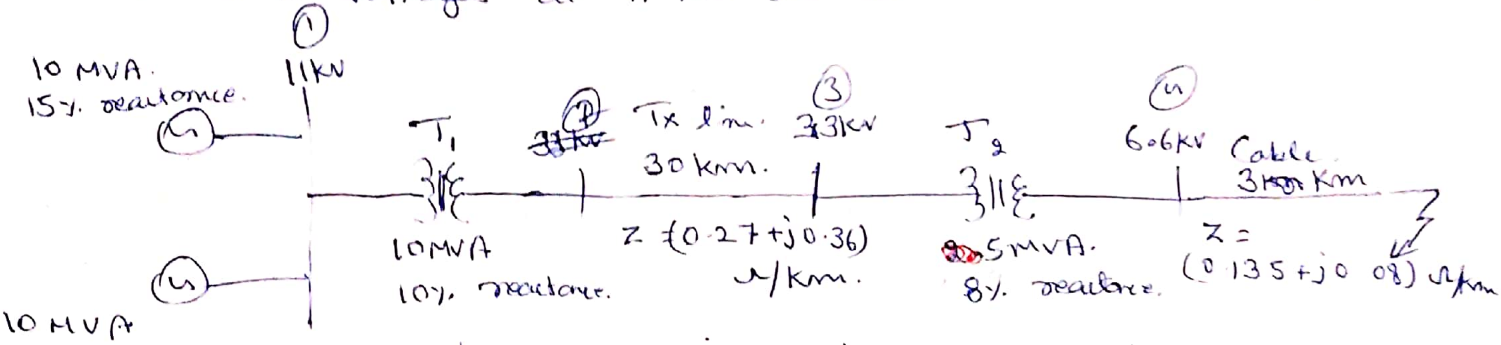
$\Rightarrow X_{se} = 0.4 - 0.05$

$= 0.35$.

$\% X_{se} = 35\%$

5

For the radial n/w shown in fig, a three-phase fault occurs at F. Determine the fault current and the line voltage at 11 kV bus under fault conditions.



Sol^n:— Base MVA = 100 MVA.

$X_b = \frac{(KV)^2}{MVA}$, $X_{pu} = \frac{X_\Omega \; MVA}{KV^2}$

$$X_{G_1} = j0.15 \times \left(\frac{KV_{old}}{KV_{New}}\right)^2 \times \left(\frac{MVA_{New}}{MVA_{old}}\right) = j0.15 \times \left(\frac{11}{11}\right)^2 \times \frac{100}{10} = j1.5 \text{ pu.}$$

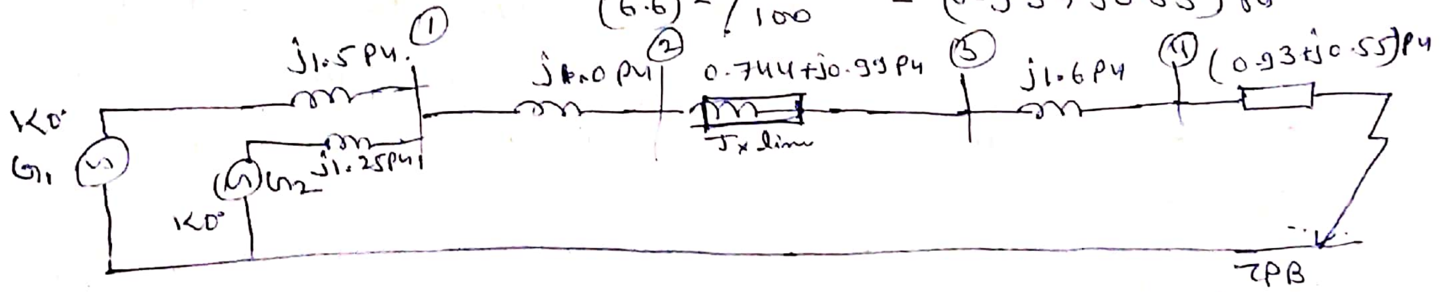
$$X_{G_2} = j0.125 \times \frac{100}{10} = j1.25 \text{ pu}$$

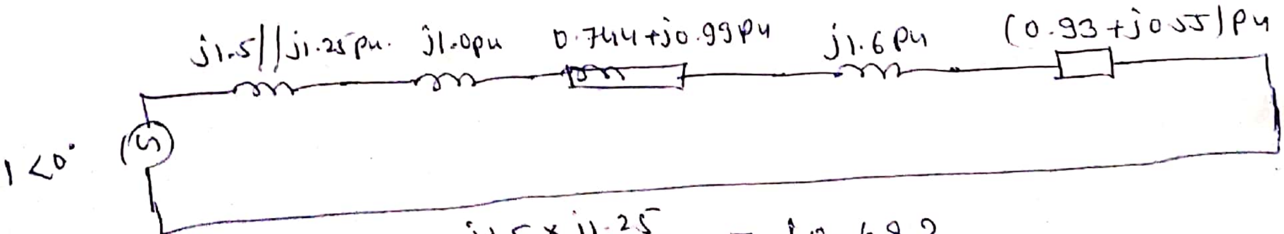
$$X_{T_1} = j0.01 \times \frac{100}{10} = j1.0 \text{ pu.}$$

$$X_{T_2} = j0.08 \times \frac{100}{5} = j1.6 \text{ pu.}$$

$$X_{Tx} = \frac{Z(\Omega)}{KV^2/MVA} = \frac{30 \times (0.27 + j0.36)}{33^2/100} = 0.744 + j0.99 \text{ pu}$$

$$X_{Cable} = \frac{3 \times (0.135 + j0.08)}{(6.6)^2/100} = (0.93 + j0.55) \text{ pu}$$





$$j1.5 \,||\, j1.25 \text{ pu} = \frac{j1.5 \times j1.25}{j2.75} = j0.682.$$

Total impedance $= (j0.682 + j1.0 + j0.99 + j1.6 + j0.55) + (0.744 + 0.93)$

$= 1.674 + j4.82 = 5.1\angle 70.8° \text{ pu.}$

$$I_{sc} = \frac{1\angle 0}{5.1\angle 70.8°} = 0.196\angle -70.8° \text{ pu.}$$

$$I_{Base} = \frac{100 \times 10^3}{\sqrt{3}\,\cancel{3} \times \frac{6.6}{\sqrt{3}}} = \frac{100 \times 10^3}{\sqrt{3} \times 6.6} = 8748$$

$$I_{sc} = 0.196 \angle \cancel{-70.83}\ pu \times 8748 = 1714.61\ A.$$
$$\simeq 1715\ A.$$

total impedance b/w F and 11 kV bus.

$$= \cancel{0.93 + j\,0.55}\ \cancel{j0}\ j1.0 + (0.744 + j0.99 + j1.6 + 0.93 + j0.55$$

$$= 1.674 + j4.14 = 4.43 \angle 76.8°\ pu.$$

Voltage at 11 kV bus $= 4.43 \angle 67.8° \times 0.196 \angle -70.8°$

$$= 0.88 \angle -3°\ pu\ \cancel{= 0.88 \times 11}$$

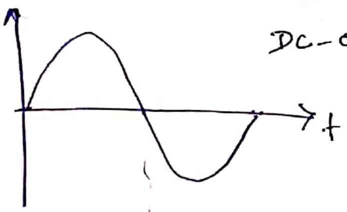
$$= 0.88 \times 11 = 9.68\ kV.$$

... is connected

→ X_l (leakage reactance in alternator) → In an ac m/c any flux setup by load current which does not contribute to the useful flux of the m/c is called a leakage flux. the effect of this leakage flux is to setup self induced emf in the armature wdg. which taken into account by introduction of leakage reactance drops. ~~current~~ voltage induce in the phases by leakage flux are the leakage reactance drops and lead the currents producing them by 90° degree.

↳ This leakage flux makes the armature wdg inductive in nature. So wdg posses a leakage reactance in addition to the resistance. Called synchronous reactance. $X_s = X_l + X_a$.

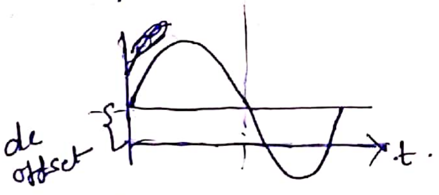
→ DC-offset in fault currents.



DC-offset = 0. ↳ dc-offset is how many volts ~~(amount)~~ above and below the ground.

→ when fault occurs at when current sine wave is not at zero then this is cause dc-offset.

its decays based on $\frac{X}{R}$ ratio. of the ckt.



$I_{DC\ offset} + I_{Sym} = I_{Asym}$.

↳ The initial value of the dc component is dependent on the exact time within a cycle at which the fault takes place and the value of current at that time.

↳ At the initiation of a fault, the current in any system can't instantly change (~~inductance opposes instant change~~) from its value of fault inception to that of its steady state value. To compensate for this, a dc comp is introduced. The dc component is equal to the value of the instantaneous ac current at fault inception and of opposite polarity.

→ mag of the dc component is dependent on where in the cycle the fault inception takes place.

in worse case, the initial dc-offset will be $\sqrt{2}$ times the Symmetrical short ckt value. (RMS).

$$I_{dc \cdot offset} = \sqrt{2}\, I_K e^{-t/T}$$ → Completely decay after few cycle.

I_K → Sym SC current.

T → decay time Const = $\frac{1}{2\pi f}\left(\frac{X}{R}\right)$.

t → time since fault inception (s).

→ For most distribution CB., a system time Const of dc decay of 45 ms. (X/R of 17 at 60Hz) is assumed.

→ $\frac{X}{R}\uparrow$, ~~time~~ $T\uparrow$ so decay slower.

→ gen ckt typically larger $\frac{X}{R}$ ratio so CB manufactured for this type of application would typically be designed for a system time Const of 133 ms ($\frac{X}{R} = 50$ at 60Hz).

Assignment – I (8th sem).
Power System Design

Due Date: 9/04/2020

Q. (1) Write down the steps for Symmetrical fault Calculations.

Q (2). A 3-phase, 20 MVA, 100 KV alternator has internal reactance of 5% and negligible resistance. Find the external reactance per phase to be connected in series with the alternator so that steady current on short-ckt does not exceed 8 times the full load current.

Assignment – II. (PSD). 8th sem

Due Date. 10/04/2020.

Q. (1) List the types of faults occurs in P.S.

Q. (2) A 3-phase, 11 kV, 25 MVA generator with $X_0 = 0.05$ pu, $X_1 = 0.2$ pu, and $X_2 = 0.2$ pu is grounded through a reactance of $0.3\,\Omega$. Calculate the fault current for a single line to ground fault.

Q (3) Write short notes on
(i) Positive sequence n/w.
(ii) Negative sequence n/w.