CBCS SCHEME

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21EE53

Fifth Semester B.E. Degree Examination, Dec.2023/Jan.2024
Power System Analysis – I

Time: 3 hrs. Max. Marks: 100

Note: Answer any FIVE full questions, choosing ONE full question from each module.

Module-1

1 a. Define per unit quantity. Show that the per unit impedance of a transformer is same irrespective of the side on which it is calculated. **(08 Marks)**

b. Fig.Q1(b) shows the schematic diagram of a radial transmission system. The ratings and reactances of various components are also shown. A load of 60 MW at 0.9 p.f. lagging is tapped from the 66 KV substation which is to be maintained at 60 KV. Calculate the terminal voltage of the machine. Represent the transmission line and transformer by series reactances only.

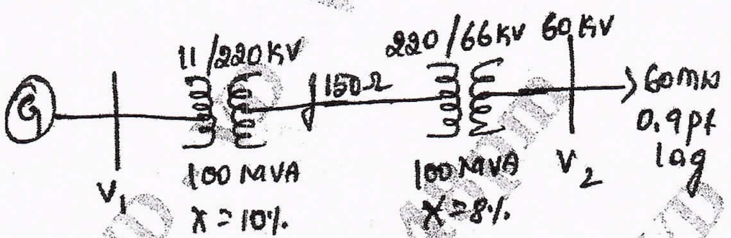

Fig.Q1(b) **(12 Marks)**

OR

2 a. Define impedance and reactance diagrams. Explain with the help of typical electrical power system. **(08 Marks)**

b. Draw the reactance diagram of the system shown in Fig.Q2(b). The ratings of the components are:

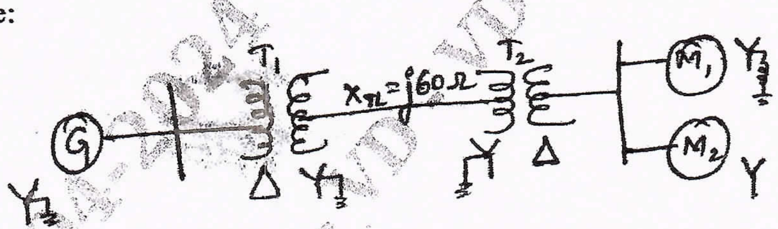

Fig.Q2(b)

G : 15 MVA, 6.6 KV, $X'' = 12\%$ T_1 : 20MVA, 6.6/66 KV, X = 8%
T_2 : 20 MVA, 66/6.6 KV, X = 8% M_1 and M_2 : 5 MVA, 6.6 KV, $X'' = 20\%$ **(12 Marks)**

Module-2

3 a. Explain clearly the variation of current and impedance of an alternator when is 3ϕ sudden short circuit occurs at its terminals. **(08 Marks)**

b. A synchronous generator and motor are rated for 30,000 KVA, 13.2 KV and both have subtransient reactance of 20%. The line connecting them has a reactance of 10% on the base of machine ratings. The motor is drawing 20,000 KW at 0.8 p.f. leading. The terminal voltage of the motor is 12.8 KV. When a symmetrical 3ϕ fault occurs at motor terminals, find the subtransient current in generator, motor and at the fault point. Solve using Kirchoff's laws. **(12 Marks)**

OR

4 a. Write a short note on selection of circuit breakers. **(08 Marks)**

b. A 25 MVA, 13.8 KV generator with $X''_d = 15\%$ is connected through a transformer to a bus that supplies four identical motors as shown in Fig.Q4(b). Each motor has $X''_d = 20\%$ and $X'_d = 30\%$ on a base of 5 MVA, 6.9 KV. The three phase rating of the transformer is 25 MVA, 13.8 – 6.9 KV, with a leakage reactance of 10%. The bus voltage at the motors is 6.9 KV when a three phase fault occurs at point P. For the fault specified, determine:

(i) Subtransient current in the fault
(ii) Subtransient current in the breaker A
(iii) Momentary current in breaker A
(iv) Current to be in interrupted by breaker in 5 cycles.

Assume $X''_{dc_1} = j0.15$.

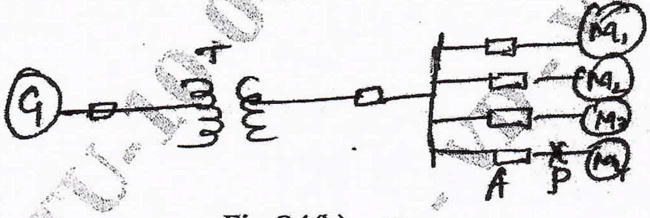

Fig.Q4(b) **(12 Marks)**

Module-3

5 a. Prove that a balanced set of 3ϕ voltages will have positive sequence components of voltages only. **(08 Marks)**

b. A delta connected balanced resistive load is connected across an unbalanced three phase supply as shown in Fig.Q5(b), find the symmetrical components of line current and delta current.

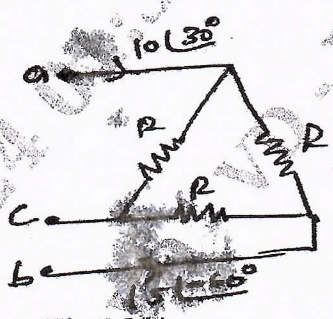

Fig.Q5(b) **(12 Marks)**

OR

6 a. Obtain the relation sequence components of phase and line voltages in star connected systems. **(10 Marks)**

b. A 250 MVA, 11 KV, 3ϕ generator is connected to a large system through a transformer and a line as shown in Fig.Q6(b).

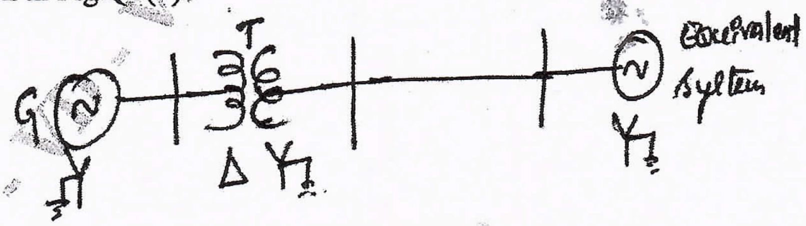

Fig.Q6(b)

The parameters on 250 MVA base are:
G : $X_1 = X_2 = 0.15$ pu, $X_0 = 0.1$ pu
Transformer : $X_1 = X_2 = X_0 = 0.12$ pu
Line : $X_1 = X_2 = 0.25$ pu, $X_0 = 0.75$ pu
Equivalent system : $X_1 = X_2 = X_0 = 0.15$ pu
Draw the sequence network diagrams for the system and indicate all per unit values. **(10 Marks)**

Module-4

7 a. For a double line to ground fault on an unloaded generator, derive the equation for fault current and draw the interconnected sequence network. **(10 Marks)**

b. A three phase, 50 MVA, 11 KV, star connected neutral solidly grounded generator operating on an no load at rated voltage gave the following sustained fault current for the faults specified.
Three phase fault – 2000 A
Line to line fault – 1800 A
Line to ground fault – 2200 A
Determine the three sequence reactances in ohms and pu. **(10 Marks)**

OR

8 a. Explain the series types of faults in a power system. **(06 Marks)**

b. A three phase generator with an open circuit voltage of 400 V is subjected to an LG fault through a fault impedance of j2Ω. Determine the fault current in $Z_1 = j4\Omega$, $Z_2 = j2\Omega$ and $Z_0 = j1\Omega$. Solve the problem for LL and LLG fault. **(14 Marks)**

Module-5

9 a. Derive power system stability and differentiate between steady stability and transient stability. **(10 Marks)**

b. Derive the swing equation with usual notation. Also the graph of swing curve. **(10 Marks)**

OR

10 a. Explain equal area criterion when a power system is subjected to sudden change in mechanical input. **(10 Marks)**

b. Write a note on multi machine system stability. **(10 Marks)**

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Solution of VTU Question Paper
Dec 2023 | Jan 2024

Power System Analysis - 1 [21EE53]

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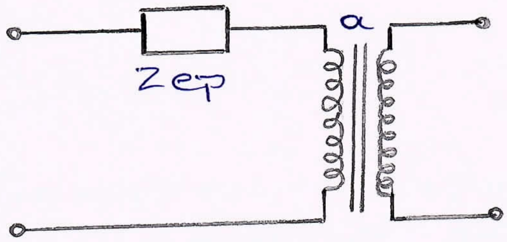
Module - 01

01.a. Define per unit quantity. Show that the per unit impedance of a transformer is same irrespective of the side on which it is calculated. [08 Marks]

Per unit quantity is a ratio of actual value to the base value.

$$\text{Per unit value} = \frac{\text{actual value in any unit}}{\text{base value in same unit}}$$

Consider a 1-ϕ equivalent of a 3-ϕ transformer as shown below.



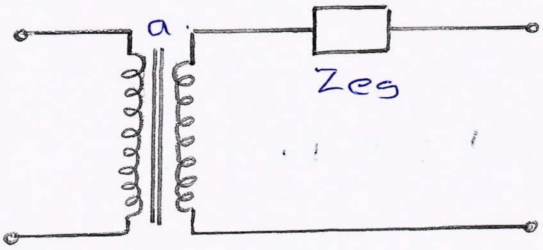
Where Zep is the impedance of the transformer refered to primary side and 'a' is the transformation ratio.

Let $(MVA_B)_P$ and $(kV_B)_P$ be the base volt ampere and base voltage on primary side.

Then PU impedance

$$Z_{ep(pu)} = \frac{Z_{ep}}{(kV_B)_P^2} * (MVA_B)_P \longrightarrow (1)$$

The single phase equivalent with transformer impedance on secondary side is as shown below.



where Zes is impedance refered to secondary side of the transformer.
Let $(MVA_B)_s$ and $(kV_B)_s$ be the base voltampere and base voltage on secondary side.

Then P.U impedance

$$Zes(pu) = \frac{Zes}{(kV_B)_s^2} * (MVA_B)_s \longrightarrow (2)$$

But we know that

$$Zes = Zep / a^2$$

$$(MVA_B)_P = (MVA_B)_s$$

$$(kV_B)_s = (kV_B)_P / a$$

equation (2) becomes.

$$Zes(pu) = \frac{Zep / a^2}{(kV_B)_P^2 / a^2} * (MVA_B)_P$$

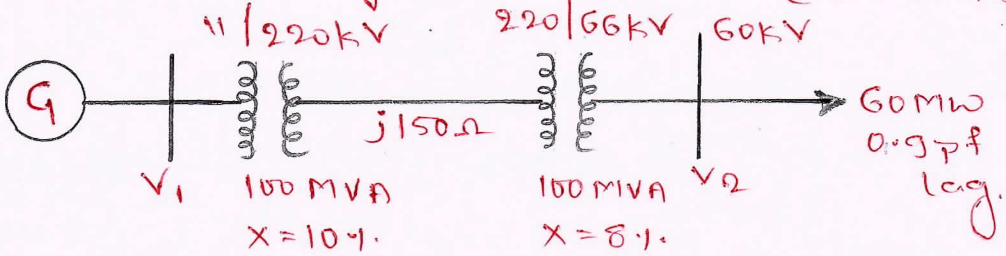
$$= \frac{Zep}{(kV_B)_P^2} * (MVA_B)_P$$

$$Zes(pu) = Zep(pu)$$

Thus it shows that PU impedance refered to primary and secondary of the transformer are same, provided base voltampere on both side of transformer are same, and the base voltages on both side are on ratio of transformation.

01.b. Fig. below shows the schematic diagram of a radial transmission system. The ratings and reactances of various components are also shown. A load of 60 MW at 0.9 pf lagging is tapped from the 66 kV substation which is to be maintained at 60 kV. Calculate the terminal voltage of the machine. Represent the transmission line and transformer by series reactance only.

[12 Marks]



* Choose a common base MVA as 100 MVA
* Base voltages
  - at generator circuit = 11 kV
  - at transmission line = 220 kV.
  - at load side = 66 kV.
* PU impedance

of transformer 1 $= Z_{pu(old)} \times \dfrac{MVA(new)}{MVA(old)} \cdot \dfrac{kV^2_{(old)}}{kV^2_{(new)}}$

$$= 0.1 \times \frac{100}{100} \times \frac{11^2}{11^2} = j0.1\ pu$$

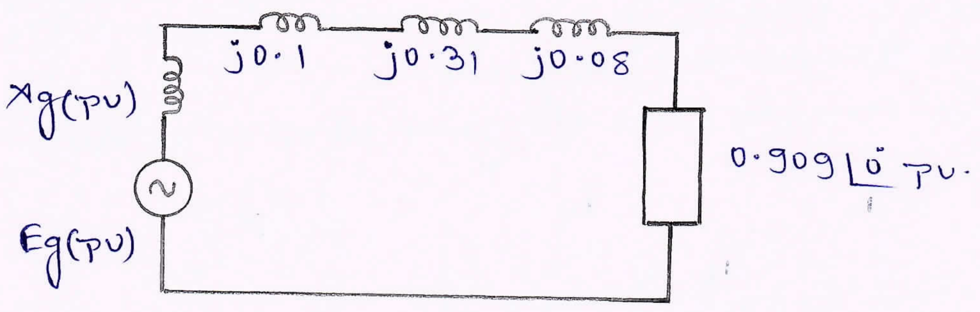
of transmission line = actual / base impedance

$$= \text{actual} / (kV_B^2 / MVA_B)$$

$$= j150 \times \frac{100}{220^2} = j0.31\ pu.$$

of transformer 2 $= 0.08 \times \dfrac{100}{100} \times \dfrac{220^2}{220^2} = j0.08\ pu.$

* PU circuit



PU voltage across load $V_{pu} = 60kV / \text{base voltage}$

$$V_{pu} = \frac{60}{66} = 0.909\angle 0^\circ\ pu.$$

Load current $= P/\sqrt{3} V \cos\phi = 60\times10^6/\sqrt{3}\times60\times10^3\times0.9$

$= 641.5 \angle \cos^{-1}0.9$

$= 641.5 \angle -25.84^\circ$ A.

Base current in load current

$$I_B = \frac{MVA}{\sqrt{3}\,KV}\times1000 = \frac{100\times1000}{\sqrt{3}\times66} = 874.7A$$

$$I_{L(pu)} = \frac{641.5}{874.7} = 0.73 \angle -25.84^\circ \text{ pu.}$$

Terminal voltage of generator.

$$E_{t(pu)} = 0.909 \angle 0^\circ + [(j0.1 + j0.31 + j0.08)(0.73 \angle -25.84)]$$

$$= 1.113 \angle 16.87 \text{ pu.}$$

terminal voltage E_t = PU voltage x base voltage

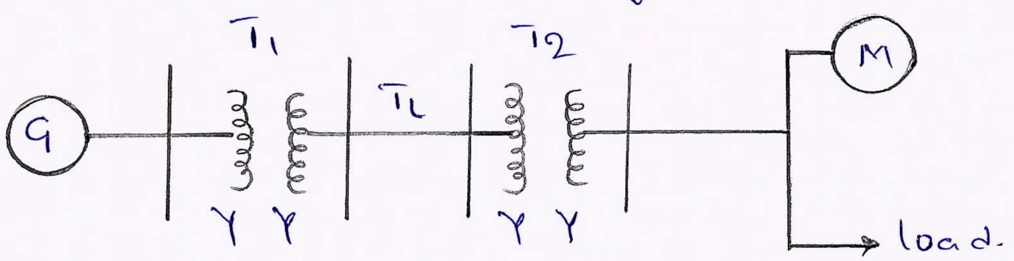
$= 1.113 \times 11$ KV

$|E_t| = 12.2$ KV

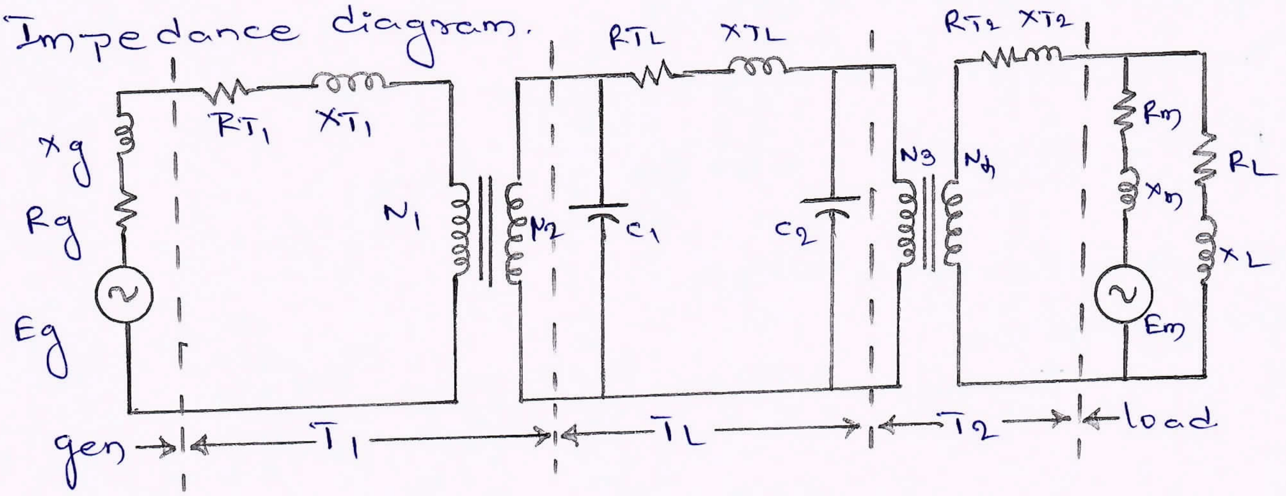
Q2.a. Define impedance and reactance diagrams. Explain with the help of typical electrical power system. [08 Marks]

The impedance diagram is obtained by replacing each component of the power system by its single phase equivalent circuit. The simplied diagram got after omitting all resistances, the magnetising circuit of the transformer and the capacitance of the transmission line in the impedance diagram is called as the reactance diagram.

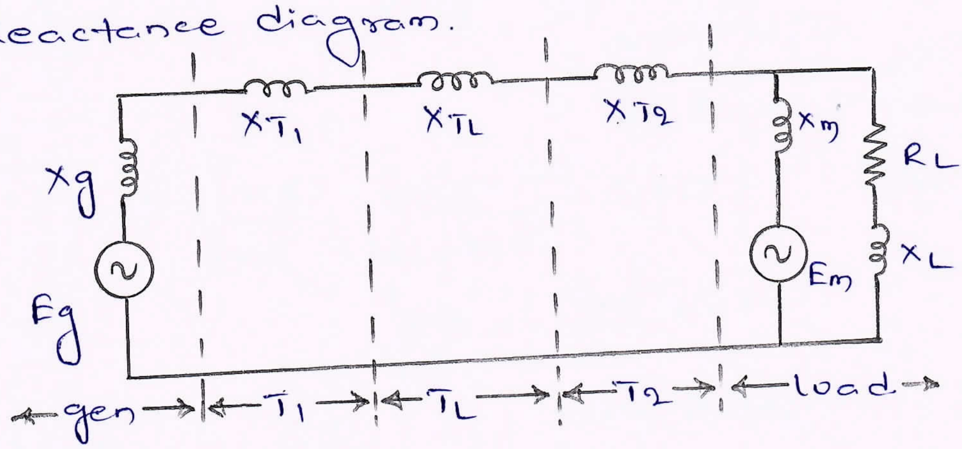
Consider a single line diagram shown below.



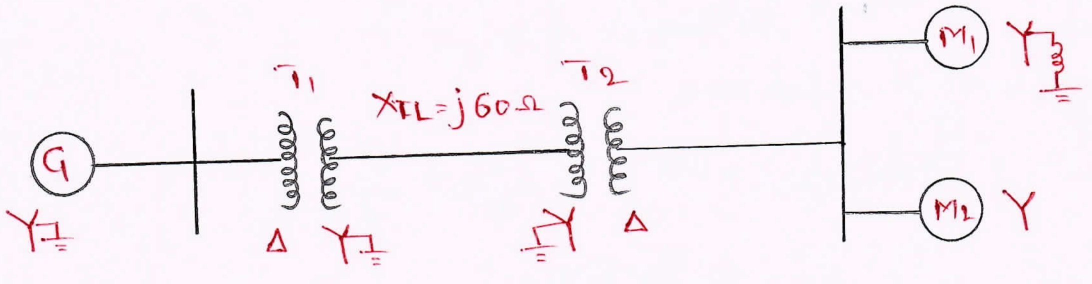
Impedance diagram.



Reactance diagram.



Q2.b Draw the reactance diagram of the system shown below. The ratings of the components are.



G : 15 MVA, 6.6 KV, $x'' = 12\%$. T_1 : 20 MVA, 6.6/66 KV, $X = 8\%$.

T_2 : 20 MVA, 66/6.6 KV, $X = 8\%$.

M_1 and M_2 : 5 MVA, 6.6 KV, $X'' = 20\%$.

[12 Marks]

* Base values.

let choose a common base voltampere as

$(MVA)_B = 15$ MVA

Base voltage in

Generator circuit = 6.6 kV

Transmission line = $6.6 \times \frac{66}{6.6} = 66$ kV.

Motor circuit = $66 \times \frac{6.6}{66} = 6.6$ kV.

* Reactance calculation

→ Generator.

$$X_{g\,new} = X_{g\,old} \times \frac{MVA_{B\,new}}{MVA_{B\,old}} \cdot \frac{KV^2_{B\,old}}{KV^2_{B\,new}}$$

$$= j0.12 \times \frac{15}{15} \times \frac{6.6^2}{6.6^2}$$

$$= j0.12 \text{ pu.}$$

→ Transformer T_1 and T_2

$$X_{T\,new} = X_{T\,old} \times \frac{MVA_{B\,new}}{MVA_{B\,old}} \cdot \frac{KV^2_{B\,old}}{KV^2_{B\,new}}$$

$$= j0.08 \times \frac{15}{20} \times \frac{6.6^2}{6.6^2}$$

$$= j0.06 \text{ pu.}$$

→ Transmission line

$$X_{TL_{pu}} = X_{TL} \cdot \frac{MVA_B}{KV_B^2} = j60 \times \frac{15}{66^2}$$

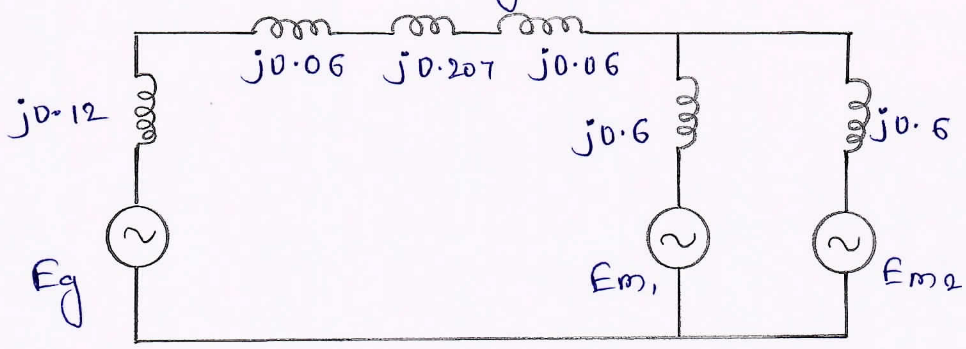
$$X_{TL} = j0.2066 \text{ pu.}$$

→ Motors M_1 and M_2

$$X_{M\,new} = 0.2 \times \frac{15}{5} \times \frac{6.6^2}{6.6^2}$$

$$= j0.6 \text{ pu.}$$

* PU. reactance diagram

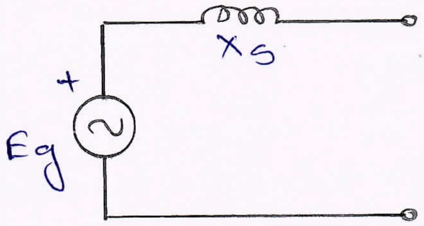


All values in pu.

Module - 02

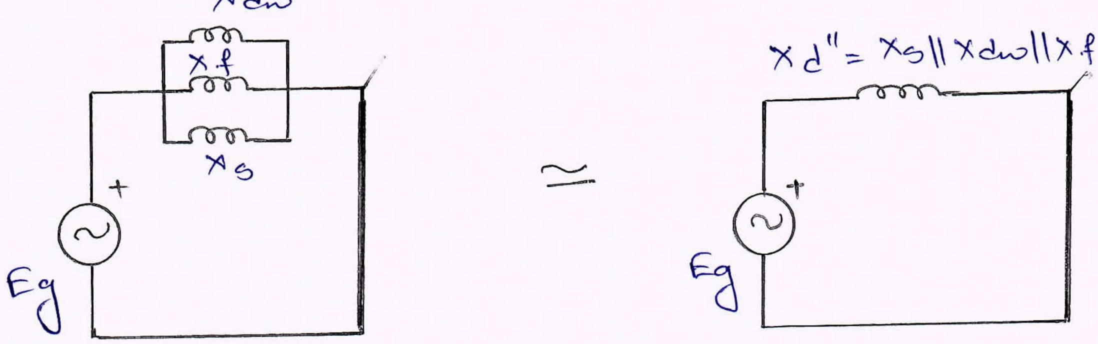
03.a. Explain clearly the variation of current and impedance of an alternator when is 3ϕ sudden short circuit occurs at its terminals. [08 Marks]

Consider a synchronous generator operating at no-load. The current in the stator winding is zero. So there is only main flux in the air gap. The circuit model is shown below.



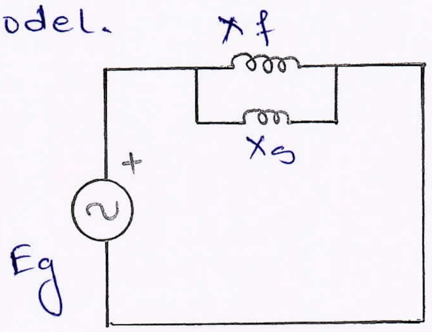
Where X_s = Synchronous reactance.

Now sudden 3-ϕ fault occurs at the terminals of synchronous generator. Suddenly very high current flows through stator winding. This current will produce stator flux which demagnetises the rotor flux and resultant flux in the air gap reduces. But according to theory of constant flux linkage, change in flux in infadecimally small time is not permitted. Because of this, current is induced in damper and field winding in a direction to help the main flux. So to take this effect the reactance of damper and field winding refered to stator winding is included in parallel with synchronous reactance as shown below.



Where X_d'' = Subtransient reactance.

Currents in the damper winding and field winding decay in accordance with the winding time constant. The time constant of the damper winding which has low leakage reactance is much less than that of field winding. So current induced becomes zero after some instant of time. So its reactance is not needed to be included. So we get reduced circuit model.



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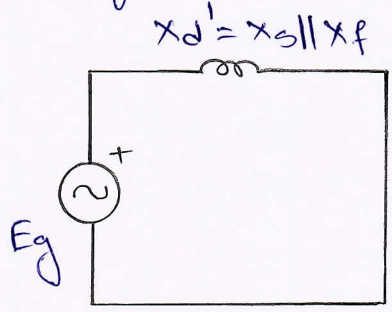
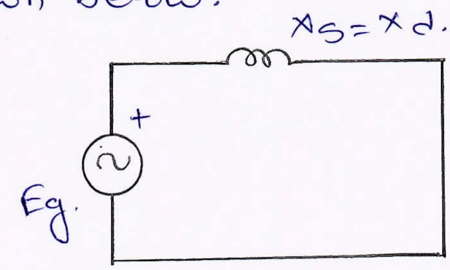


X_d' = transient reactance.

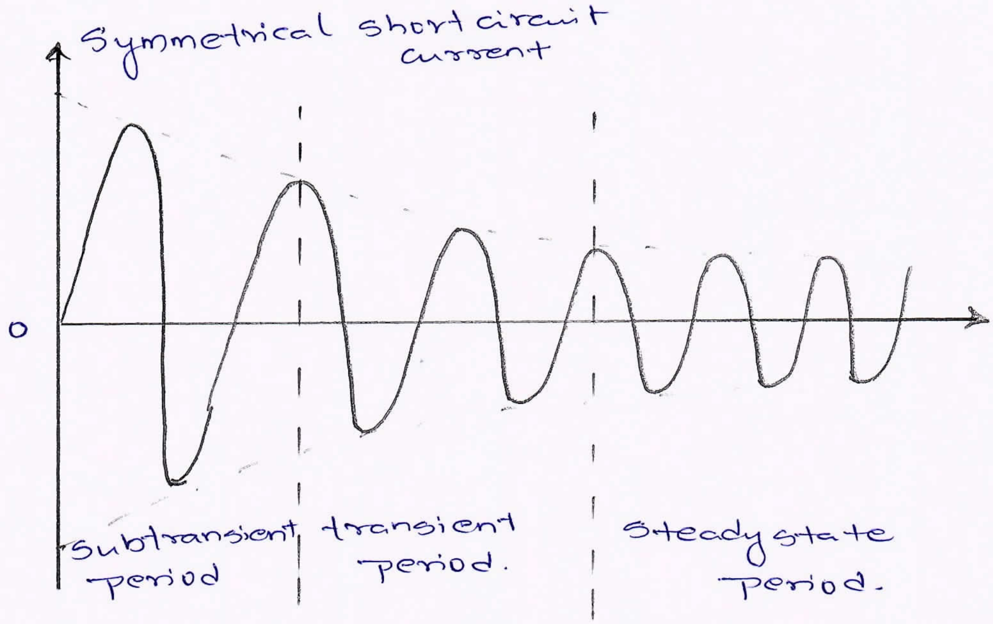
After some instant current in field winding also becomes zero. So its reactance is also removed from the circuit model. The reduced circuit model is as shown below.



X_d = direct axis reactance.

So we can conclude that $X_d'' < X_d' < X_d$.

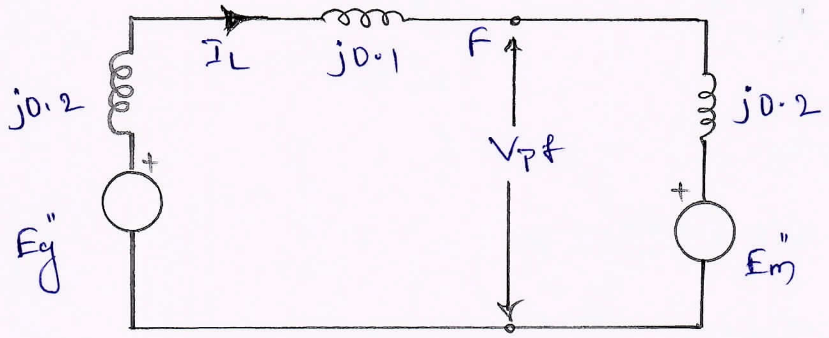
The current waveforms of stator current is as shown below.



Q3.b. A synchronous generator and motor are rated for 30,000 KVA, 13.2 KV and both have subtransient reactance of 20%. The line connecting them has a reactance of 10% on the base of machine ratings. The motor is drawing 20,000 KW at 0.8 pf leading. The terminal voltage of the motor is 12.8 KV. When a symmetrical 3-ϕ fault occurs at motor terminals find the subtransient current in generator, motor, and at the fault point. Solve using Kirchoff's law.

[12 Marks]

Equivalent circuit before fault.



let base MVA = 30 MVA

base KV = 13.2 kV.

Prefault voltage at fault point $V_{pf} = 12.8\,kV$.

$$V_{pf\,pu} = \frac{12.8}{13.2} = 0.97\angle 0^\circ\ pu.$$

$$\text{Base current } I_B = \frac{MVA_B}{\sqrt{3}\,KV_B} = \frac{30\times10^6}{\sqrt{3}\times13.2\times10^3} = 1312\,A.$$

$$\text{load current } I_L = \frac{20000\times10^3}{\sqrt{3}\times12.8\times10^3\times0.8}\ \angle\cos^{-1}0.8$$

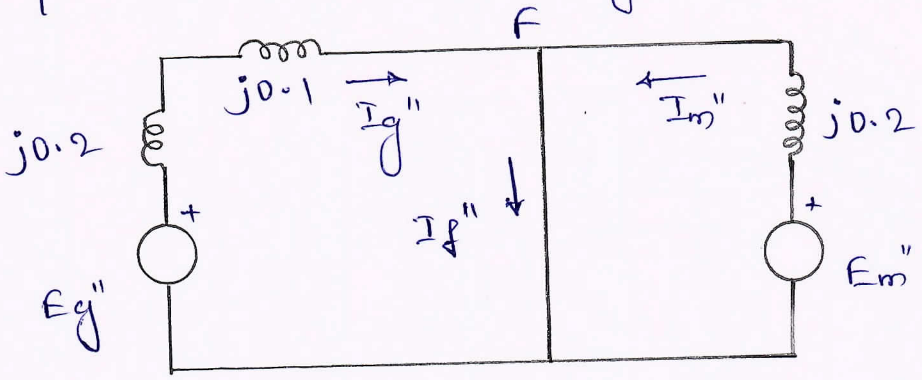
$$= 1128\angle 36.86^\circ\ A$$

$$I_{L\,pu} = \frac{1128}{1312} = 0.8597\angle 36.86^\circ\ pu.$$

$$E_g'' = (j0.2 + j0.1) I_L + V_{pf}$$
$$= 0.84 \angle 14.2^\circ \text{ pu.}$$

$$E_m'' = V_{pf} - j0.2 I_L$$
$$= 1.0819 \angle -7.3^\circ \text{ pu.}$$

Equivalent circuit during fault.



$$I_g'' = E_g''/j0.3 = 2.8 \angle -75.8^\circ \text{ pu.}$$

$$I_m'' = E_m''/j0.2 = 5.409 \angle -97.3^\circ \text{ pu.}$$

fault current $I_f'' = I_g'' + I_m'' = 8.065 \angle -90^\circ$ pu.

04.a. Write a short note on selection of circuit breakers. [08 Marks]

The choice of a circuit breaker for particular application depends on the following ratings of the circuit breaker.

i. Normal working power level specified as rated interrupting current or rated interrupting MVA.
ii. The fault level specified as either rated short circuit interrupting current or rated short circuit interrupting MVA.
iii. Momentary current rating.
iv. Normal working voltage.
v. Speed of circuit breaker.

Q4.b. A 25 MVA, 13.8 kV generator with $X_d'' = 15\%$ is connected through a transformer to a bus that supplies four identical motors as shown below. Each motor has $X_d'' = 20\%$ and $X_d' = 30\%$ on a base of 5 MVA, 6.9 kV. The three phase rating of the transformer is 25 MVA, 13.8/6.9 kV, with a leakage reactance of 10%. The bus voltage at the motors is 6.9 kV, when a three phase fault occurs at point P. For the specified, determine

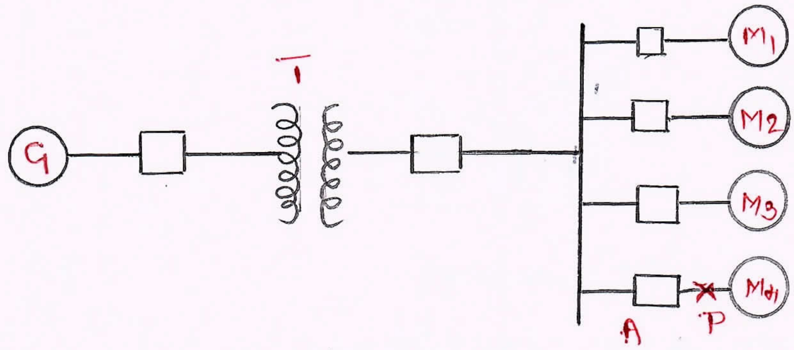
(i) Subtransient current in the fault.

(ii) Subtransient current in the breaker A.

(iii) Momentary current in breaker A

(iv) current to be interrupted by breaker in 5 cycles.

Assume $X''_{dc_1} = j0.15$



[12 Marks]

* Assume base MVA and base kV in generator as.

$(MVA)_B = 25$ MVA

$(kV)_B$ in generator $= 13.8$ kV.

$(kV)_B$ in motors $= 13.8 \times \dfrac{6.9}{13.8} = 6.9$ kV.

* Reactance of generator.

$X_{dg}'' = j0.15$ pu

$X_{dg}' = j0.15$ pu.

transformer.

$X_T = j0.1$ pu.

motors

$$X''_{dM} = j0.2 \times \frac{25}{5} \times \frac{6.9^2}{6.9^2} = j1 \text{ pu}$$

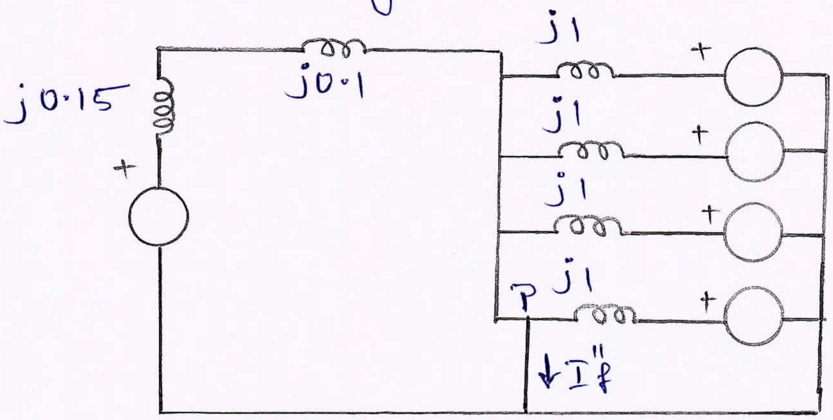
$$X'_{dm} = j0.3 \times \frac{25}{5} \times \frac{6.9^2}{6.9^2} = j1.5 \text{ pu.}$$

Prefault voltage at point P $= 6.9 \text{kV} = \frac{6.9}{6.9} = 1 \text{pu}.$

Base current in motors circuit.

$$I_B = \frac{25 \times 10^6}{\sqrt{3} \times 6.9 \times 10^3} = 2091.8 \text{ A.}$$

Reactance diagram with subtransient values.



(i) Subtransient fault current

$$I''_f = 4 \times \frac{1}{j1} + \frac{1}{j0.25} = -j8 \text{ pu.}$$

$$= -j8 \times 2091.8 = -j16734.4 \text{ A}$$

(ii) Subtransient current in breaker A.

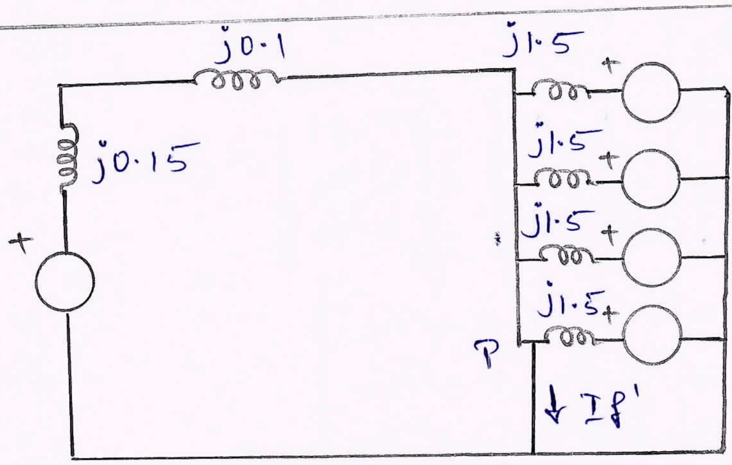
$$I'' = 3 \times \frac{1}{j1} + \frac{1}{j0.25} = -j7 \text{ pu.}$$

$$= -j7 \times 2091.8 = -j14642.6 \text{ A.}$$

(iii) Momentary current through breaker A $= 1.6 \times 14642.6$

$= 23428.16$ A.

Reactance diagram with transient values.



(iii) Momentory current in breaker A $= 3 \times \frac{1}{j1.5} + \frac{1}{j0.25}$

$= -j6 \text{ pu}.$

$= -j6 \times 2091.8 = -j12550.8 \text{ A}$

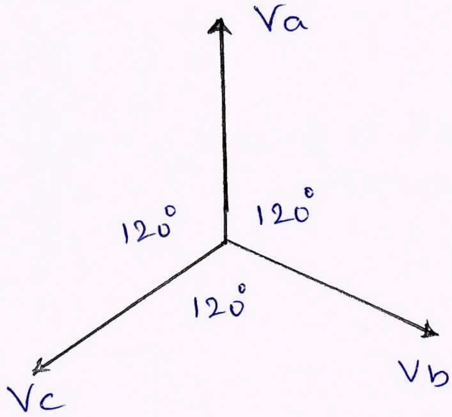
(iv) Current to be interrupted by breaker in 5 cycles.

$= 1.1 \times 6 \times 2091.8 = 13805.88 \text{ A}.$

Module-03

05.a Prove that a balanced set of 3-ϕ voltages will have positive sequence components of voltages only. (08 Marks)

Consider a balanced 3-ϕ system of voltages shown below.



So we have

$$\left.\begin{aligned} V_a &= V_a. \\ V_b &= a^2 V_a. \\ V_c &= a V_a. \end{aligned}\right\} \rightarrow (1).$$

we also have.

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

Using equation (1)

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

$$= 1/3 \begin{bmatrix} V_a + a^2 V_a + a V_a \\ V_a + a^3 V_a + a^3 V_a \\ V_a + a^4 V_a + a^2 V_a \end{bmatrix}$$

but $a^3 = 1$, and $a^4 = a$.

$$= \frac{1}{3} \begin{bmatrix} V_a + a^2 V_a + a V_a \\ V_a + V_a + V_a \\ V_a + a V_a + a^2 V_a \end{bmatrix}$$

$$= \frac{1}{3} \begin{bmatrix} V_a(1+a+a^2) \\ 3V_a \\ V_a(1+a+a^2) \end{bmatrix}$$

$1 + a + a^2 = 0$

So

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 0 \\ 3V_a \\ 0 \end{bmatrix}$$

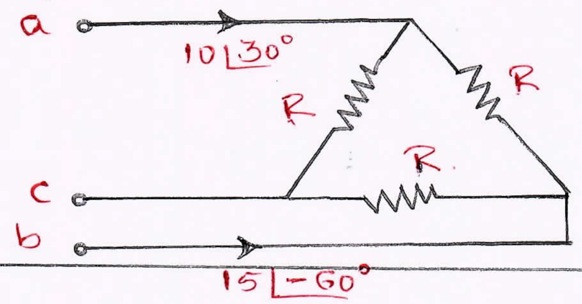
$V_{a0} = 0$

$V_{a1} = V_a$.

$V_{a2} = 0$.

It shows that a balanced set of 3-ϕ voltages will have only positive sequence component.

05.b. A delta connected balanced resistive load is connected across an unbalanced three phase supply as shown below, find the symmetrical components of line current and delta current. [12 Marks]



We have $I_a + I_b + I_c = 0$

or $I_c = -(I_a + I_b)$

$= -(10\angle 30^\circ + 15\angle -60^\circ]$

$= -16.16 + j8$

$I_c = 18\angle 154^\circ$ A

Symmetrical components of line currents are.

$I_{a1} = \frac{1}{3}(I_a + aI_b + a^2 I_c]$

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

$= 13.94\angle 41.86^\circ$ A

$I_{a2} = \frac{1}{3}(I_a + a^2 I_b + aI_c]$

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

$= 4.65\angle -111.57^\circ$ A.

$I_{a0} = \frac{1}{3}(I_a + I_b + I_c]$

$= 0$ A

Sequence components of delta currents are

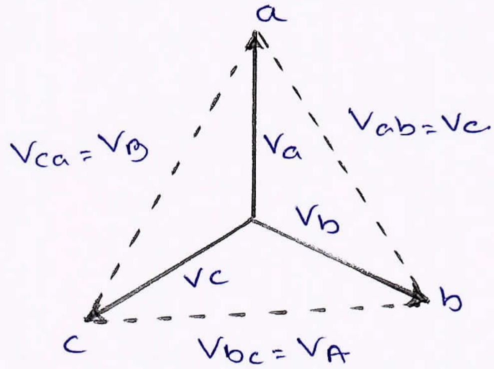
$I_{A1} = \frac{I_{a1}}{j\sqrt{3}} = 8.05\angle -48.14^\circ$ A

$I_{A2} = \frac{I_{a2}}{j\sqrt{3}} = 2.68\angle -21.57^\circ$ A

$I_{A0} = 0$ A.

06.a. Obtain the relation sequence components of phase and line voltages in star connected System. (10 Marks)

Let V_a, V_b and V_c be the phase voltages having a phase sequence abc as shown below



The three line voltages of the system are V_{bc}, V_{ca}, and V_{ab}. From elementary vector algebra.

$$V_{bc} = V_c - V_b$$
$$V_{ca} = V_a - V_c$$
$$V_{ab} = V_b - V_a.$$

Let $V_{bc} = V_A$

$V_{ca} = V_B$

$V_{ab} = V_c.$

So we get $V_A = V_{bc} = V_c - V_b.$

$V_B = V_{ca} = V_a - V_c.$

$V_C = V_{ab} = V_b - V_a.$

The positive sequence component of line voltage is given as.

$$V_{A1} = \frac{1}{3}\left[V_A + aV_B + a^2 V_C\right]$$
$$= \frac{1}{3}\left[(V_c - V_b) + a(V_a - V_c) + a^2(V_b - V_a)\right]$$
$$= \frac{1}{3}\left[a(V_a + aV_b + a^2V_c) - a^2(V_a + aV_b + a^2V_c)\right]$$
$$= \frac{1}{3}(a - a^2)(V_a + aV_b + a^2V_c)$$

but $(V_a + aV_b + a^2V_c) = 3 \cdot V_{a1}$ and $(a - a^2) = j\sqrt{3}.$

$$\therefore V_{A1} = \frac{1}{3}(j\sqrt{3})\, 3(V_{a1})$$

$$V_{A1} = j\sqrt{3} \cdot V_{a1}$$

The negative sequence component of line voltage is.

$$V_{A2} = \frac{1}{3}\left[V_A + a^2 V_B + aV_C\right]$$
$$= \frac{1}{3}\left[(V_c + V_b) + a^2(V_a - V_c) + a(V_b - V_c)\right]$$
$$= \frac{1}{3}\left[a^2(V_a + a^2V_b + aV_c) - a(V_a + a^2V_b + aV_c)\right]$$
$$= \frac{1}{3}(a^2 - a)(V_a + a^2V_b + aV_c)$$

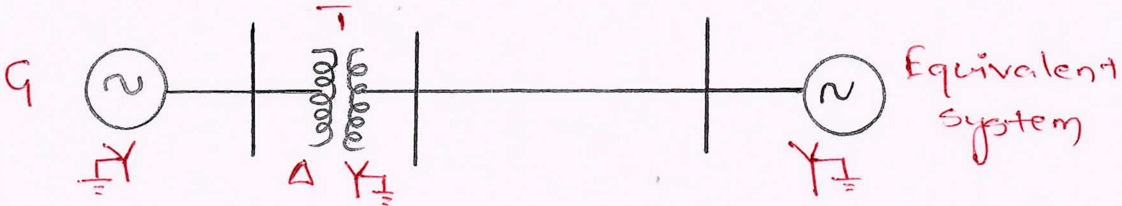
$= \frac{1}{3}(-j\sqrt{3})\, 3 V_{a2}$ $\left[\because V_a + a^2 V_b + a V_c = 3 \cdot V_{a2}\right.$ and $\left. a^2 - a = -j\sqrt{3}.\right]$

So $V_{A2} = -j\sqrt{3}\, V_{a2}$.

The zero sequence component of line voltage is

$$V_{A0} = \frac{1}{3}(V_A + V_B + V_C) = 0.$$

06.b. A 250MVA, 11kV. 3 ϕ generator is connected to a large system through a transformer and a line as shown below.



The parameters on 250 MVA base are

G : $X_1 = X_2 = 0.15$ pu, $X_0 = 0.1$ pu

Transformer : $X_1 = X_2 = X_0 = 0.12$ pu.

Line : $X_1 = X_2 = 0.25$ pu, $X_0 = 0.75$ pu.

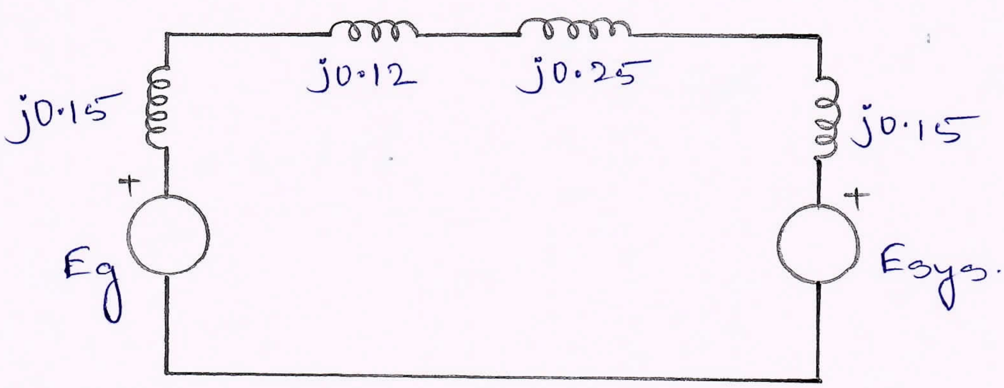
Equivalent system : $X_1 = X_2 = X_0 = 0.15$ pu.

Draw the sequence network diagrams for the system and indicate all per unit values.

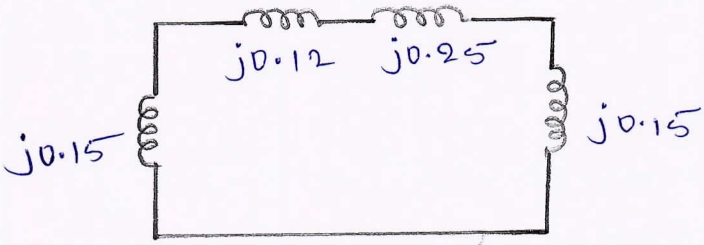
(10 Marks)

All reactances are on a common base, so there is no need to go for change of base

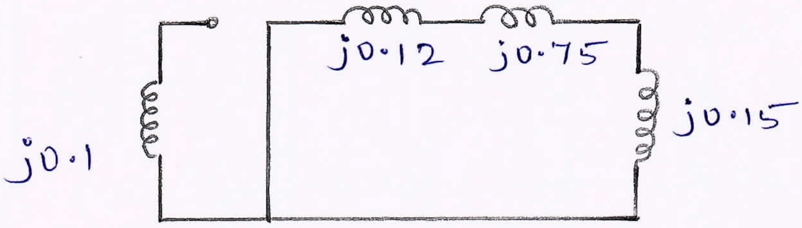
*Positive sequence network.



* Negative sequence network.



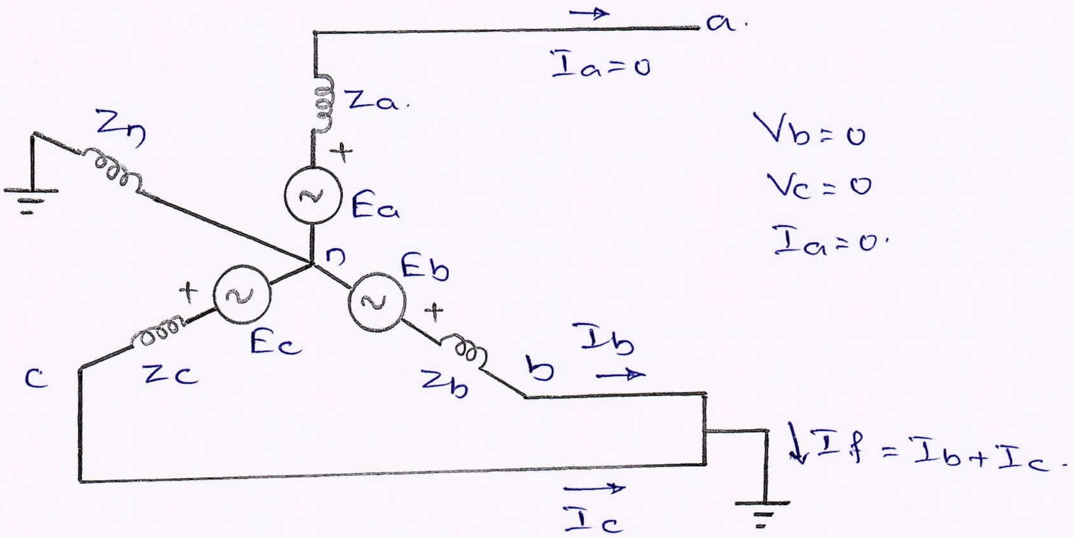
* Zero sequence network.



Module - 04.

07.a. For a double line to ground fault on an unloaded generator, derive the equation for fault current and draw the interconnected sequence network. [10 Marks]

Consider a star connected generator whose neutral is grounded through reactor. Assume that the fault takes place in phase b and c.



Symmetrical component of voltage given by

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_a \\ V_b = 0 \\ V_c = 0 \end{bmatrix}$$

$V_{a0} = \frac{1}{3} V_a.$

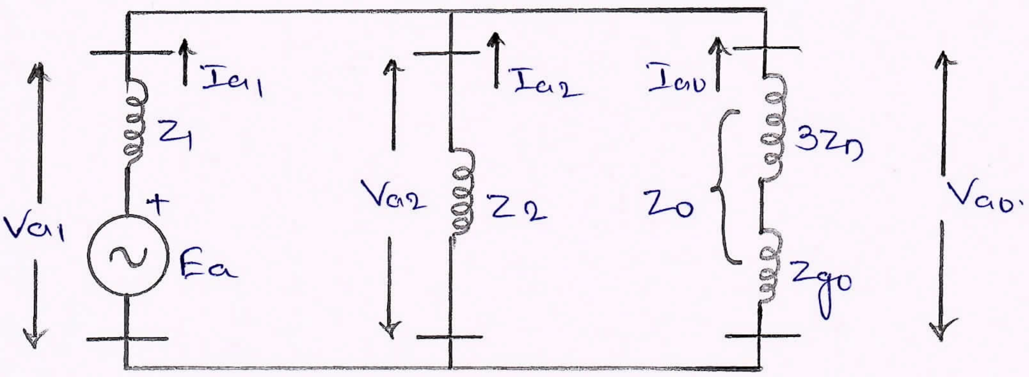
$V_{a1} = 1/3\, V_a.$

$V_{a2} = \frac{1}{3} V_a.$

So $V_{a0} = V_{a1} = V_{a2} = \frac{1}{3} V_a.$

also $I_a = 0 \Rightarrow I_{a0} + I_{a1} + I_{a2} = 0$

Equations indicates that sequence networks are connected in parallel.



So $V_{a1} = V_{a2} = V_{a0} = E_a - I_{a1} Z_1.$

$$I_{a1} = E_a / [Z_1 + (Z_2 \| Z_0)]$$

$$= E_a \Big/ Z_1 + \left(\frac{Z_2 Z_0}{Z_2 + Z_0}\right)$$

$I_{a2} = -(I_{a1} + I_{a0})$

$E_a - I_{a1} Z_1 = -Z_2 I_{a2}.$

$E_a - I_{a1} Z_1 = Z_2 (I_{a1} + I_{a0})$

$E_a - I_{a1} Z_1 = Z_2 I_{a1} + Z_2 I_{a0}.$

$E_a - I_{a1}(Z_1 + Z_2) = Z_2 I_{a0}.$

$$I_{a0} = \frac{E_a - I_{a1}(Z_1+Z_2)}{Z_2}.$$

$$I_{a2} = -(I_{a1} + I_{a0})$$

Fault current

$$I_f = I_b + I_c.$$

$$= \left[I_{a0} + a^2 I_{a1} + a I_{a2}\right] + \left(I_{a0} + a I_{a1} + a^2 I_{a2}\right]$$

$$= 2 I_{a0} + (a+a^2) I_{a1} + (a+a^2) I_{a2}.$$

$$= 2 I_{a0} - I_{a1} - I_{a2} \qquad (\because a+a^2 = -1)$$

$$= 2 I_{a0} - (-I_{a0}) \qquad (\because I_{a1} + I_{a2} = -I_{a0}]$$

$$I_f = 3 I_{a0}$$

$$\therefore I_f = 3\left[-I_{a1}Z_2 / Z_2+Z_0\right]$$

if neutral is ungrounded then $Z_0 = \infty$ and $I_f = 0$

07.b. A three phase, 50 MVA, 11kV, star connected neutral solidly grounded generator operating on noload at rated voltage gave the following sustained fault current for the faults specified.

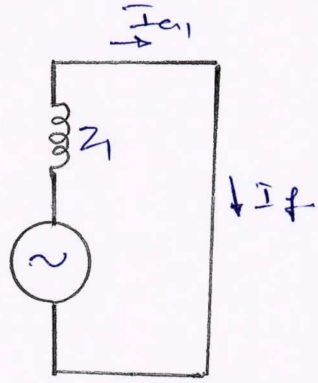
Three phase fault - 2000 A.

Line to line fault - 1800 A

Line to ground fault - 2200 A

Determine the three sequence reactances in ohms and PU. [10 Marks]

* Three phase fault



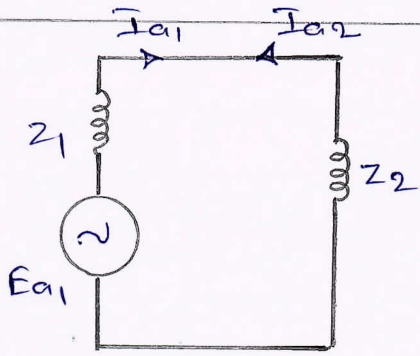
$$I_{a1} = \frac{E_{a1}}{Z_1} = \frac{11\times10^3/\sqrt{3}}{Z_1} = 2000\,A$$

$$Z_1 = 3.175\,\Omega.$$

$$Z_{base} = \frac{KV_B^2}{MVA_B} = \frac{11^2}{50} = 2.42\,\Omega$$

$$Z_{1pu} = \frac{3.175}{2.42} = 1.31\text{ pu}.$$

* Line to line fault



$$I_{a_1} = \frac{E_a}{Z_1 + Z_2}$$

and $I_f = \sqrt{3}\, I_{a_1}$

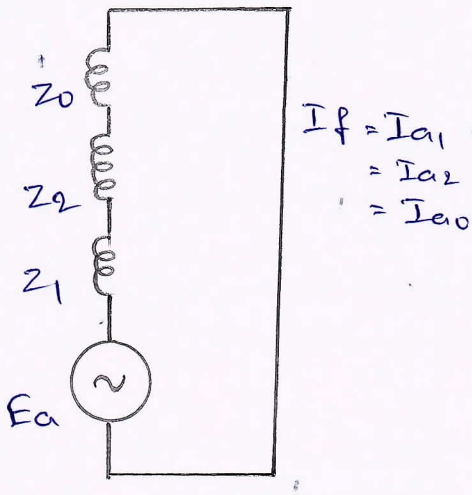
$$\therefore I_{a_1} = \frac{I_f}{\sqrt{3}} = \frac{1800}{\sqrt{3}} = 1039.23\ A$$

$$\therefore 1039.23 = \frac{11 \times 10^3 / \sqrt{3}}{3.175 + Z_2}$$

$$Z_2 = 2.935\ \Omega$$

$$Z_{2pu} = \frac{2.935}{2.42} = 1.21\ pu.$$

* Line to ground fault



$$I_{a_0} = I_{a_1} = I_{a_2} = E_a / Z_1 + Z_2 + Z_0.$$

and $I_f = 3\, I_{a_0}$.

$$\therefore I_{a_0} = \frac{I_f}{3} = \frac{2200}{3} = 733.33\ A$$

$$\therefore 733.33 = \frac{11 \times 10^3 / \sqrt{3}}{3.175 + 2.935 + Z_0}$$

$$\therefore Z_0 = 2.55\ \Omega$$

$$Z_{0pu} = \frac{2.55}{2.42} = 1.05\ pu.$$

So

$Z_1 = 3.175\ \Omega$ or $1.31\ pu$

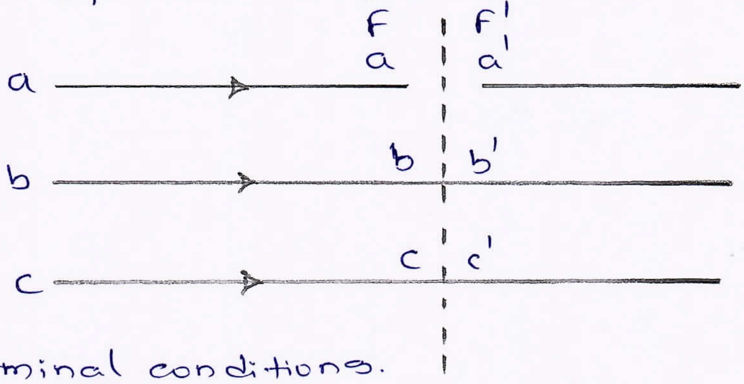
$Z_2 = 2.935\ \Omega$ or $1.21\ pu$

$Z_0 = 2.55\ \Omega$ or $1.05\ pu$.

08.a. Explain the series types of faults in a power system. [06 Marks]

01. One conductor open fault.

Assume that the conductor 'a' of a system gets opened as shown below.



Terminal conditions.

$I_a = 0, \quad V_{bb'} = 0, \quad V_{cc'} = 0.$

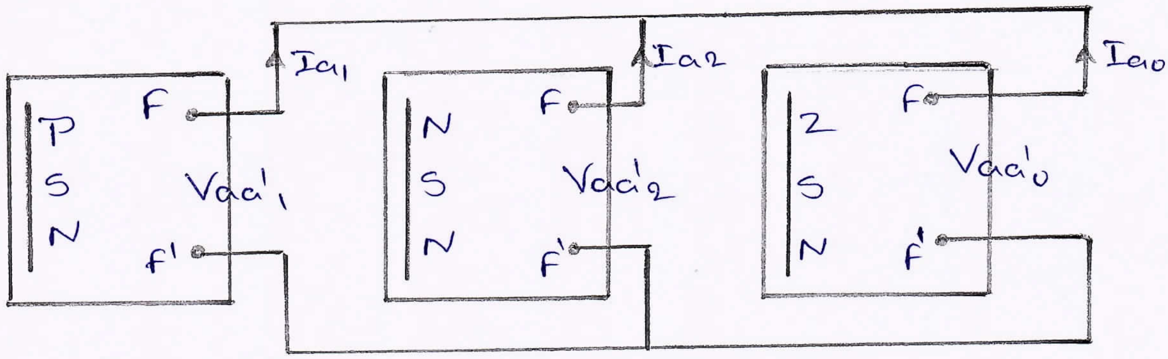
Symmetrical component of voltages are given by.

$$\begin{bmatrix} V_{aa'0} \\ V_{aa'1} \\ V_{aa'2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_{aa'} \\ V_{bb'}=0 \\ V_{cc'}=0 \end{bmatrix}$$

$\therefore V_{aa'0} = V_{aa'1} = V_{aa'2} = 1/3\, V_{aa'}$

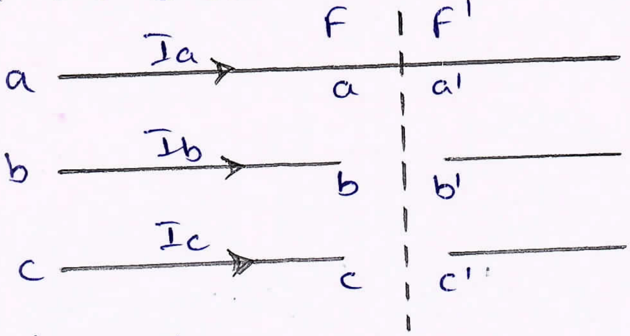
and $I_a = I_{a0} + I_{a1} + I_{a2} = 0.$

Equations suggest that the three sequence networks are connected in parallel.



02. Two conductor open fault.

Assume that two conductors b and c get opened as shown below.



Terminal condition.

$I_b = 0, \quad I_c = 0, \quad V_{aa'} = 0.$

symmetrical component of current are given by.

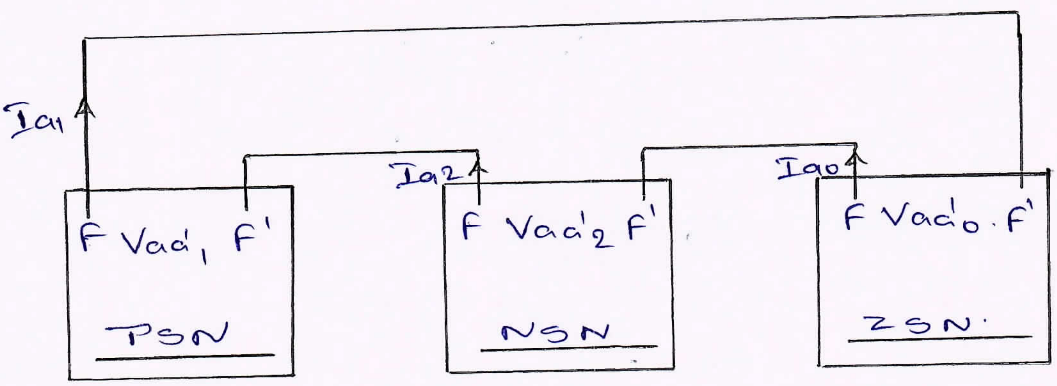
$$\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ I_b = 0 \\ I_c = 0 \end{bmatrix}$$

So $I_{a0} = I_{a1} = I_{a2} = \frac{1}{3} I_a.$

also $V_{aa'} = 0$

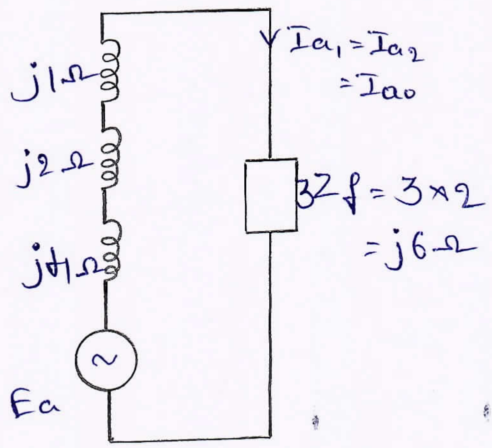
i.e $(V_{aa'})_1 + (V_{aa'})_2 + (V_{aa'})_0 = 0.$

Equations suggest that sequence networks are connected in series as shown below



08.b. A three phase generator with an open circuit voltage of 400V is subjected to an LG fault through a fault impedance of $j2\Omega$. Determine the fault current if $Z_1 = j4\Omega$, $Z_2 = j2\Omega$ and $Z_0 = j1\Omega$. Solve the problem for LL and LLG fault. [14 Marks]

* LG fault



$$I_{a0} = E_a / Z_1 + Z_2 + Z_3 + 3Z_f$$

$$= \frac{400/\sqrt{3}}{j4 + j2 + j1 + j6}$$

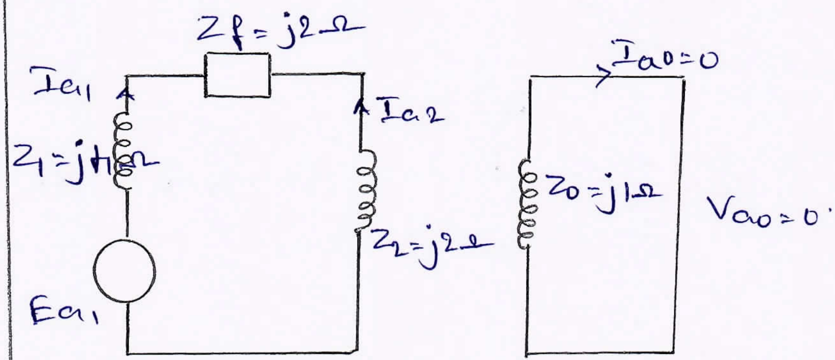
$$= -j17.765\ A$$

fault current $I_f = 3|I_{a0}|$

$$= 3 \times 17.765$$

$$= 53.295\ A$$

* LL fault.



$$I_{a1} = E_a / Z_1 + Z_2 + Z_f = \frac{400/\sqrt{3}}{j4 + j2 + j2}$$

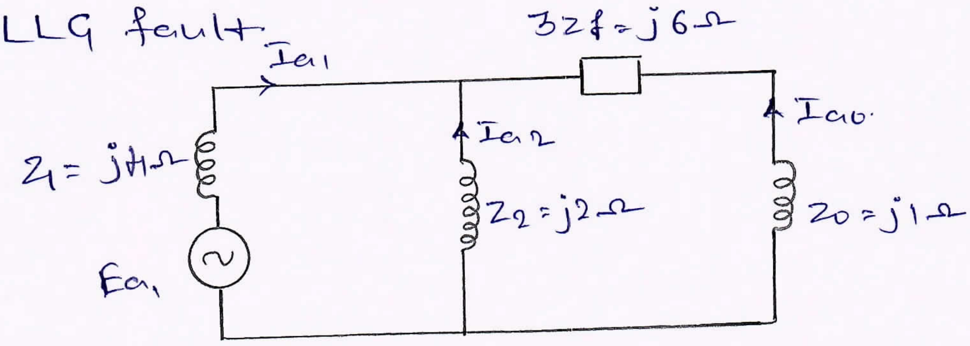
$$= -j\,28.87\ A$$

fault current $I_f = \sqrt{3}|I_{a1}|$

$$= \sqrt{3} \times 28.87$$

$$= 50\ A$$

* LLG fault



$$I_{a1} = E_a \Big/ Z_1 + \frac{Z_2(Z_0+3Z_f)}{Z_2+Z_0+3Z_f} = \frac{400/\sqrt{3}}{j\left[4+\frac{2(1+6)}{2+1+6}\right]}$$

$$= -j41.57\ A$$

Using current division equation.

$$I_{a0} = -I_{a1}\left[\frac{Z_2}{Z_2+Z_0+3Z_f}\right]$$

$$= j41.57\left[\frac{2}{2+1+6}\right]$$

$$= j9.24\ A$$

fault current $I_f = 3|I_{a0}| = 3 \times 9.24$

$$= 27.72\ A.$$

Module-05

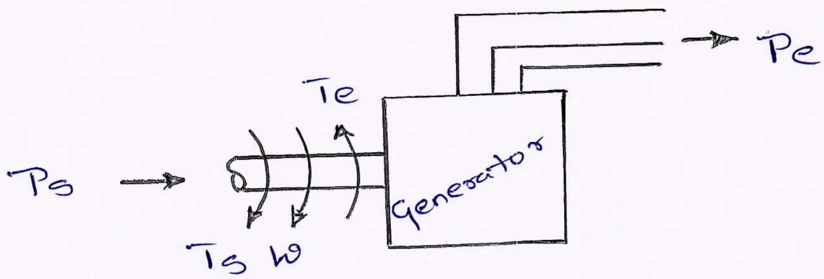
09.a. Define power system stability and differentiate between steady state stability and transient stability. (10 Marks)

Power system stability is the ability of an electrical power system, for a given initial operating condition to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded, so that practically the entire system remains intact.

Parameter.	Steady state stability.	Transient Stability.
Defination	Ability of a power system to maintain synchronism when subjected to small disturbances, like gradual load changes.	Ability of a power system to maintain synchronism when subjected to significant disturbances, such as short circuits, loss of generation etc.,
Duration.	long term behavior over extended period	few seconds after the disturbance
Disturbance type	Small, gradual change.	Large, sudden change.
Analysis.	Involves linearized models.	Involves nonlinear models.
Objective	Ensure system can operate under normal conditions without losing synchronism.	Ensure system can return to a stable condition after a major disturbance

Q9.b. Derive the swing equation with usual notation. Also the graph of swing curve [10 Marks]

Consider a generator shown below. It receives mechanical power P_s at torque T_s and rotor speed W. via shaft from prime mover. It delivers electrical power P_e to the power system network via a busbar. The generator developes electromechanical torque T_e in opposition to T_s.



Assuming that winding and frictional losses to be negligible, the accelerating torque on the rotor is given by.

$$T_a = T_s - T_e$$

multiplying by 'ω' on both sides.

$$\omega T_a = \omega T_s - \omega T_e.$$

but $\omega T_a = P_a$ = accelerating power.

$\omega T_s = P_s$ = mechanical power input.

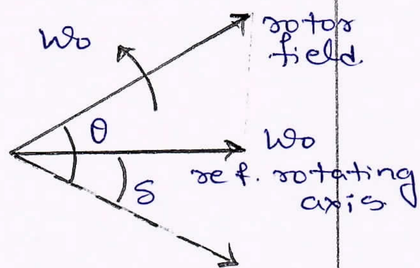
$\omega T_e = P_e$ = electrical power output.

$\therefore P_a = P_s - P_e.$

Under steady state condition $P_s = P_e$ so, $P_a = 0$.
When the balance between P_s and P_e is disturbed the machine dynamics is governed by.

$$P_a = T_a\omega = I\alpha\omega = M\frac{d^2\theta}{dt^2}$$

where $\alpha = \frac{d^2\theta}{dt^2}$ = angular acceleration of the rotor.



$$\delta = \theta - \omega_0 t.$$

taking time derivatives

$$\frac{d\delta}{dt} = \frac{d\theta}{dt} - \omega_0.$$

and $\frac{d^2\delta}{dt^2} = \frac{d^2\theta}{dt^2}.$

We have $P_a = P_s - P_e = M\frac{d^2\delta}{dt^2}$

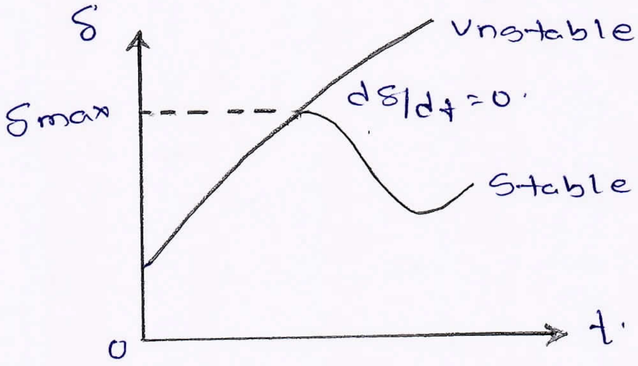
and $M = GH/180f$.

$$\therefore \frac{GH}{180f}\frac{d^2\delta}{dt^2} = P_a = P_s - P_e$$

G is in MVA rating. divide by G will give P in per unit

$$\frac{H}{180f}\frac{d^2\delta}{dt^2} = P_a = P_s - P_e \quad \text{PU.}$$

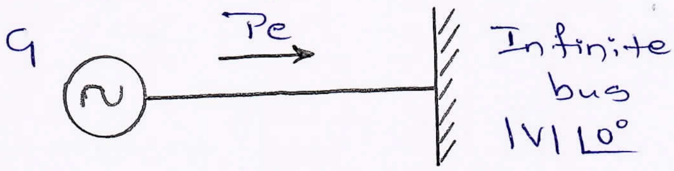
It is called swing equation.



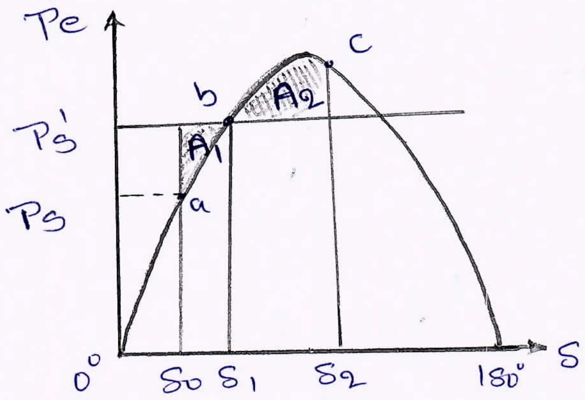
Swing curve.

10. a. Explain equal area criteria when a power system is subjected to sudden change in mechanical input. [10 Marks]

Fig below shows the single line diagram of a synchronous generator connected to an infinite bus.



consider sudden increase in mechanical input. Fig below shows the plot of $(P_e - \delta)$, the power angle curve with the system operating at point 'a' corresponding to input P_s. Let the mechanical input be suddenly increased to P_s' as shown.



The accelerating power $P_a = P_s' - P_e$ causes the rotor to accelerate. Hence the rotor angle δ increases, the electrical power transfer increases reducing P_a. till a point 'b' at which $P_a = 0$. The rotor angle δ, however, continues to increase because of the inertia of the rotor and P_a becomes negative causing the rotor to decelerate. At some point 'c' where area A_1 = area A_2 the rotor velocity becomes zero. and then starts to become negative owing to continued negative P_a.. the rotor angle thus reaches the maximum value δ_2 and then starts to decrease.

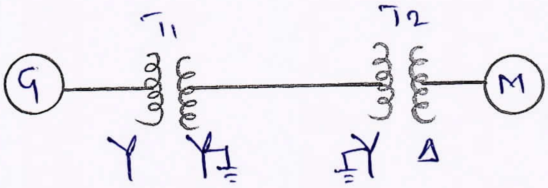
$$A_1 = \int_{\delta_0}^{\delta_1} (P_s' - P_e)\, d\delta$$

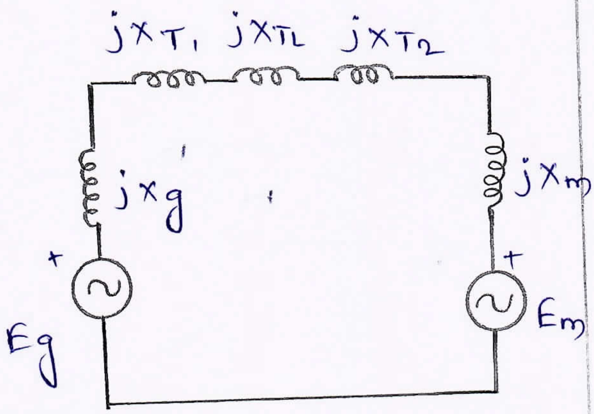
$$A_2 = \int_{\delta_1}^{\delta_2} (P_e - P_s')\, d\delta.$$

For system to be stable, find angle δ_2 such that $A_1 = A_2$.

10.b. Write a note on multi machine system stability. [10 Marks]

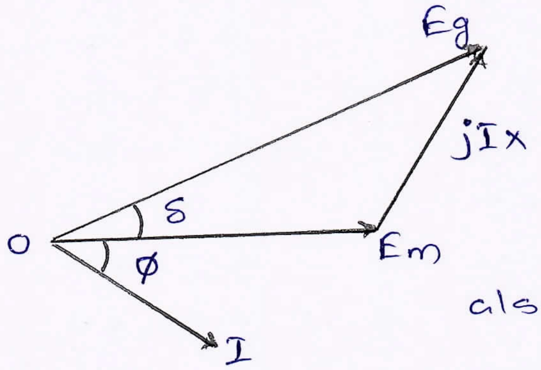
Consider a two machine system consisting of a generator and a motor interconnected through transformer and transmission lines as shown.





total reactance $X = X_g + X_{T_1} + X_{TL} + X_{T_2} + X_m$

The phasor diagram of the system is shown below.



$E_g = E_m + jIX$

or $I = \dfrac{E_g - E_m}{jX}$

also $P_g = P_{motor}$ (no losses)

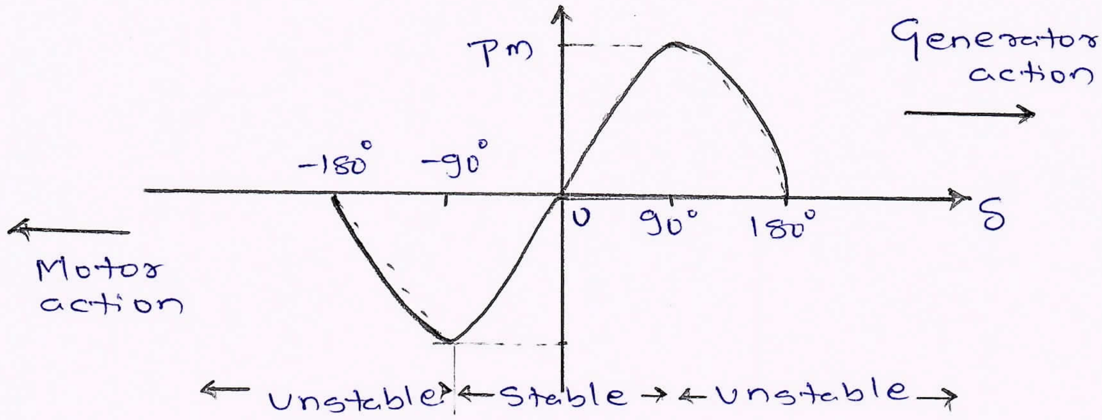
$$P_g = \text{real}\left(E_g I^*\right)$$

$$= \text{real}\left[|E_g|\angle\delta \left[\frac{|E_g|\angle\delta - |E_m|\angle 0^\circ}{|X|\angle 90^\circ}\right]^*\right]$$

$$= \frac{|E_g|^2}{|X|}\cos 90^\circ - \frac{|E_g||E_m|}{|X|}\cos(90+\delta)$$

$$= -\frac{|E_g||E_m|}{|X|}(-\sin\delta)$$

$$\therefore P_g = \frac{|E_g||E_m|}{|X|}\sin\delta$$



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