USN :

CMR Institute of Technology, Bangalore

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

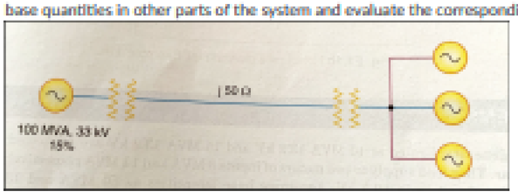
I - INTERNAL ASSESSMENT

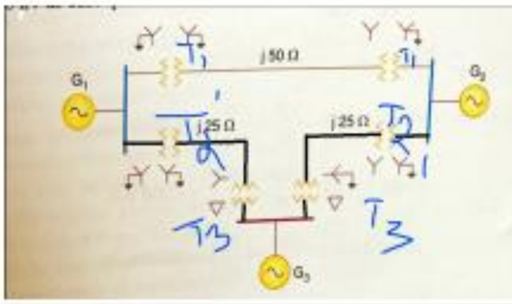
Semester: 6-CBCS 2018	Date: 19 May 2021
Subject: POWER SYSTEM ANALYSIS – 1 (18EE62)	Time: 09:00 AM - 10:30 AM
Faculty: Ms Keka Mukhopadhyaya	Max Marks: 50

Instructions to Students :

Answer any FIVE full Quuestions.
Assume data wherever necessary.

Answer any 5 question(s)

Q.No			Marks	CO	PO	BT/CL
1		Derive the expression of maximum momentary current when a three phase short circuit occurs on a transmission line initially on no load condition. Draw the necessary diagram to model the transmission line and the waveforms of current.	10	CO2	PO1	L2
2		A 100 MVA, 33 kV, 3Ø generator has a subtransient reactance of 15%. The generator is connected to the motors through a transmission line and transformers as shown in figure. The motors have rated inputs of 30 MVA, 20 MVA, and 50 MVA at 30 kV with 25% subtransient reactance. The three phase transformers are rated at 110MVA, 32kV Δ/110kV Y with leakage reactance 8%. The line has a reactance of 50Ω. Selecting the generator rating as the base quantities in the generator circuit, determine the base quantities in other parts of the system and evaluate the corresponding p.u values. Draw the reactance diagram. 	10	CO1	PO1	L3
3	a	Define per unit system. Outline the advantages of working with per unit quantities.	5	CO1	PO1	L2
	b	Two generators are connected in parallel to a 6.6 kV bus. One of the generators has a rating of 20 MVA and a reactance of 15% while the second generator is rated at 15 MVA and has a reactance of 12%. Calculate the pu reactance on a 50 MVA and 6.6 kV base.	5	CO1	PO1	L2
4		A three-phase 20 MVA, 11 kV generator has a reactance of 10% and is connected via a bank of three single-phase transformers to a transmission line whose series reactance is 100 Ω. The transmission line is supplying a load of 10 MVA at 10 kV and 0.8 power factor lagging. The transformer bank at the generator end is connected in delta on the generator side and in star on the transmission line side and the transformer on the load side is star-star connected. Each of the single phase transformers in the bank of transformers is rated at 10 MVA, 11/110 kV with a reactance of 8%. Draw the one line diagram and hence draw the pu circuit diagram for a system base of 10 MVA, 15 kV in the load circuit. Calculate the voltage at the generator terminals.	10	CO1	PO1	L3
5	a	Show that the per unit impedance of a transformer is independent of its primary or secondary side.	5	CO1	PO1	L2
	b	The primary and secondary sides of a single phase 2 MVA , 4kV/2kV transformer have leakage reactance of 2Ω and 4Ω respectively. Find the p.u reactance of the transformer referred to primary and secondary side.	5	CO1	PO1	L3
6		With respect to synchronous machine explain the concept of subtransient, transient and synchronous reactance and explain how to model synchronous macfor a three phase symmetrical fault. Draw the necessary diagram along with current wave form.	10	CO2	PO1	L2

7	A 3-bus system is given in figure. The ratings of the various components are listed below: Generator 1: 50 MVA, 13.8 kV, X"=0.15 pu Generator 2: 40 MVA, 13.2 kV, X"=0.20 pu Generator 3: 30 MVA, 11 kV, X"=0.25 pu Transformer 1: 45 MVA, 11kV Δ/ 110kV Y, x=0.1 pu Transformer 2: 25 MVA, 12.5V Δ/ 115kV Y, x=0.15 pu Transformer 3: 40 MVA, 12.5kV Δ/ 110kV Y, x=0.1 pu The line impedances are shown in figure . Determine the reactance diagram based on 50 MVA and 13.8kV as base quantities in Generator 1. 	10	CO1	PO1	L4

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Transient On A Transmission Line :-

Let us consider short circuit transient on a T.L

Assumption :

(i) The line is fed from a constant voltage source (the case when the line is fed from a realistic synchronous machine will be treated)

(ii) Short circuit takes place when the line is unloaded.

(iii) Line capacitance is negligible and the line can be represented by a lumped RL series circuit.

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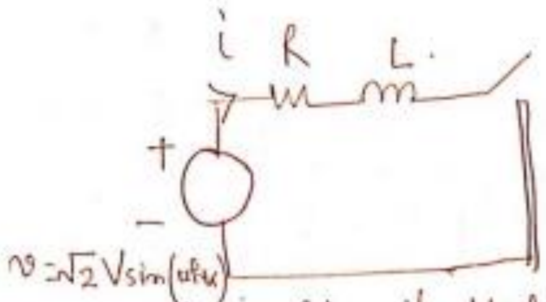
1.



Circuit Model

The short circuit is assumed to take place at $t = 0$.
The parameter α controls the instant on the voltage wave when short circuit occurs.

Current after short circuit composed of two parts!

$i = i_s + i_t$ where i_s = steady state current

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

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

i_t = transient current [it is such that $i(0) = i_s(0) + i_t(0) = 0$.

being an inductive circuit;
it decays corresponding to time constant L/R

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

$\therefore$ short circuit current is

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

Symmetrical short circuit current — DC-offset current

* In power system terminology

- Sinusoidal steady state current is called symmetrical short circuit current.

- unidirectional transient component is called DC off-set current ⇒ causes total short circuit current to be unsymmetrical till the transient decays.

Maximum momentary short circuit current i_{mm} corresponds to first peak.

If the decay of transient current in this short time is neglected

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

Since T.L resistance is small, $\theta \simeq 90°$

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

This has maximum possible value when $\alpha = 0$ i.e. short circuit occurring when the voltage wave is going through zero.

$$\therefore i_{mm}\Big|_{max\ possible} = \frac{2\sqrt{2}V}{|Z|}$$

= twice the maximum of symmetrical short circuit current (doubling effect)

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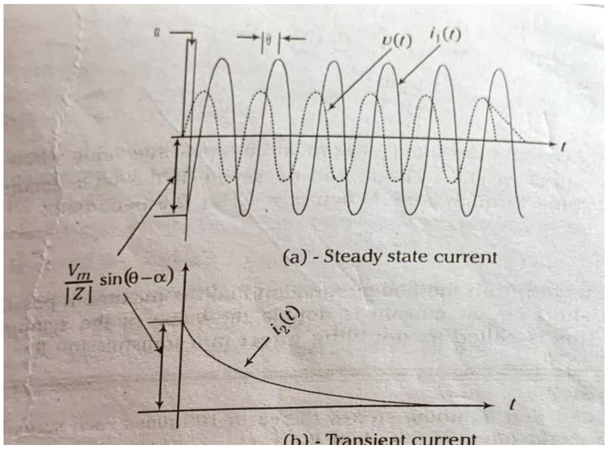
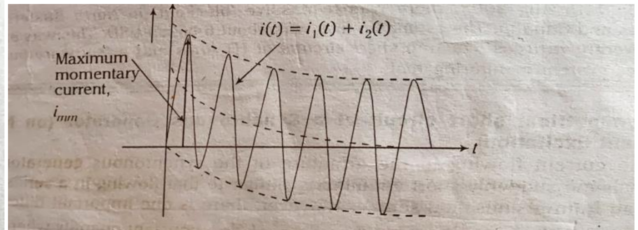


(a) - Steady state current

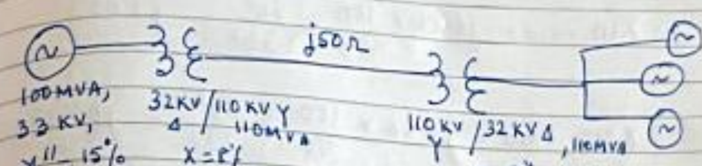
(b) - Transient current



(c) - Total short circuit current

Fig. 2.2

2.



Base power 100 MVA

Base voltage at generator = 33 KV.

∴ Base voltage of transmission line $= 33 \times \frac{110}{32}$

$= 113.44\,KV$

Base voltage of Motors $= 113.44 \times \frac{32}{110} = 33\,KV.$

$X_{g1,new} = X_{g1,old} \times \frac{(MVA)_{B,new}}{(MVA)_{B,old}} \times \frac{(KV_B)^2_{old}}{(KV_B)^2_{new}}$

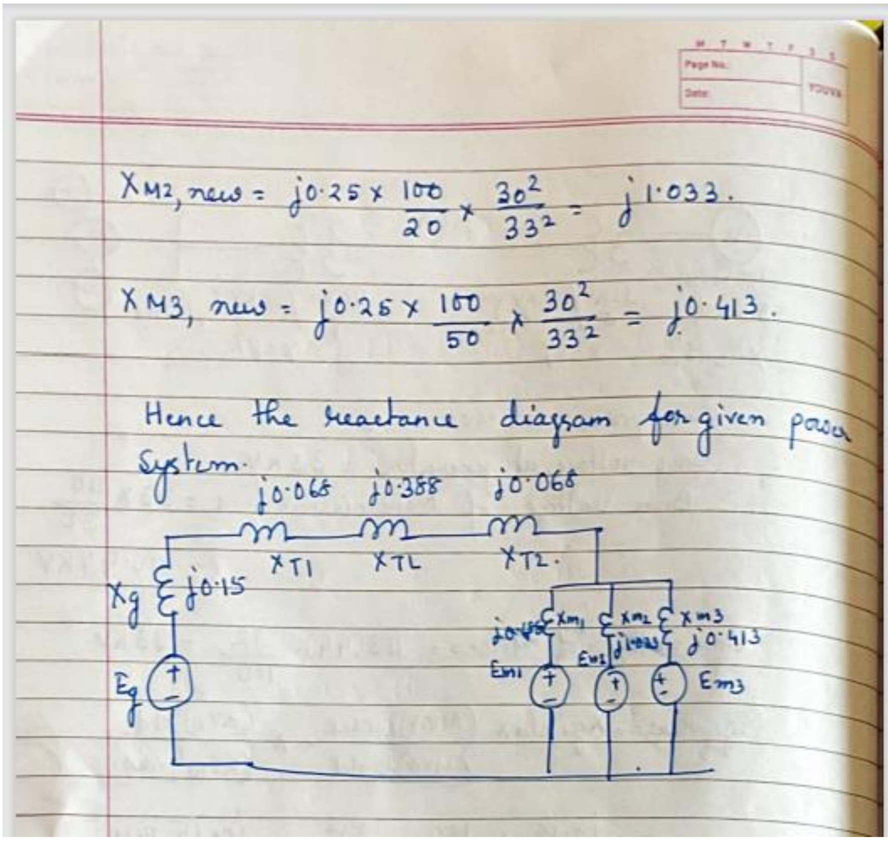
$= j0.15 \times \frac{100}{100} \times \frac{33^2}{33^2} = j0.15$ p.u

$X_{T1,new} = j0.08 \times \frac{100}{110} \times \frac{32^2}{33^2} =$ ~~j0.086 pu~~ $j0.068$ p.u.

$X_{TL} = X(\Omega) \times \frac{(MVA)_B}{(KV_B)^2} = j50 \times \frac{100}{113.44^2} = j0.388$ pu

$X_{T2,new} = j0.08 \times \frac{100}{110} \times \frac{32^2}{33^2} = j0.068$

$X_{M1,new} = j0.25 \times \frac{100}{30} \times \frac{30^2}{33^2} = j0.688$ p.u.



$X_{M2, new} = j0.25 \times \frac{100}{20} \times \frac{30^2}{33^2} = j1.033.$

$X_{M3, new} = j0.25 \times \frac{100}{50} \times \frac{30^2}{33^2} = j0.413.$

Hence the reactance diagram for given power system.

3a. Per unit value of any quantity is defined as the ratio as the actual value of the quantity in any unit to the base or reference value in the same unit. It is dimensionless.

Experiment No.

Page No.:

Advantages of p.u Computations :

•). The greatest advantage of using p.u values is that it considerably simplified the calculations thus making the analysis of the system easier. Other advantages are:

(1) Per unit impedance of transformers is the same ref. to either side of it

(2) The method of connection of transformers (Y-Y, Y-Δ etc) do not effect the p.u. impedance of the transformer.

(3) Manufacturers usually specify the impedance of an apparatus in p.u or percent value on the name plate based on the power rating and voltage rating of the apparatus. Rated impedance can be used directly in any analysis if the base chosen are the same as the name plate ratings of the apparatus.

(4) In case of machines absolute values (ohmic) values of impedance may differ widely based on the constructing materials and the ratings of the machine.
p.u impedance will lie within a narrow range.
Therefore where actual values are not known, good approx value can be used.

Experiment No.

Page No.:

(5) The tools of circuit analysis (ex Kirchoff's Law, Thevenin's theorem) may be directly applied to circuits with components in p.u values.

(6) For simulating the steady state and transient models in computers, the p.u method is very handy.

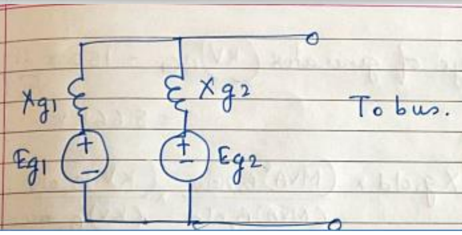
3b.

3b). Base power $(MVA)_B = 50$ MVA.
Base voltage $(KV)_B = 6.6$ kV.
for gen1 and gen2

$$X_{p.u\ new} = X_{p.u\ old} \times \frac{(MVA)_{B,new}}{(MVA)_{B,old}} \times \frac{(KV)^2_{B,old}}{(KV)^2_{B,new}}$$

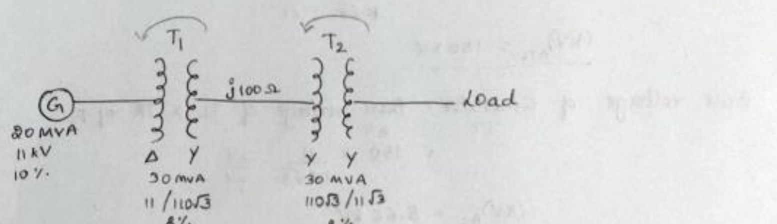
$$X_{g1,new} = j0.15 \times \frac{50}{20} \times \frac{6.6^2}{6.6^2} = j0.375 \text{ p.u}$$

$$X_{g2,new} = j0.12 \times \frac{50}{15} \times \frac{6.6^2}{6.6^2} = j0.4 \text{ p.u.}$$



4.

One line diagram



T_1 and T_2 transformers are three 1-ϕ transformers with 10MVA each.

$\therefore (MVA)_B = 3 \times 10 = 30$ MVA

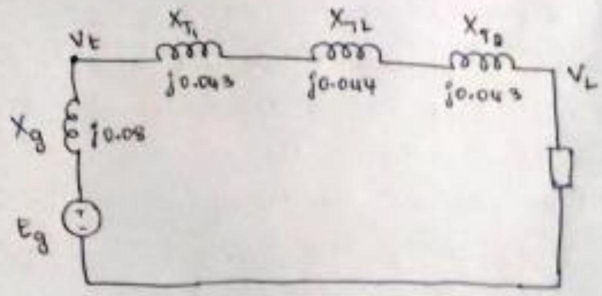
In T_1 primary side is Δ connected, secondary side is star connected. Given 11/110 kV is phase voltage

In Δ $V_L = V_{ph}$ and in Y $V_L = V_{ph}\sqrt{3}$

$\therefore T_1$ voltage rating → $11 / 110\sqrt{3}$ kV (Δ / Y)

T_2 voltage rating → $11\sqrt{3} / 110\sqrt{3}$ kV (Y / Y)

Reactance diagram:



Base power $(MVA)_B = 10\ MVA$

Base voltage $(KV)_B = 15\ KV$ at load

Base voltage of TL (HT) = Base voltage of load (LT) × TR of T_2

$$= 15 \times \frac{110\sqrt{3}}{11\sqrt{3}} \quad \frac{HV}{LV}$$

$$(KV)_{BTL} = 150\ kV$$

Base voltage of Generator (LT) = Base voltage of TL (HT) × TR of T_1

$$= 150 \times \frac{11}{110\sqrt{3}} \quad \frac{LV}{HV}$$

$$(KV)_{BG} = 8.66\ kV$$

Reactances:

(1) Generator

$$X_{g,new} = X_{g,old} \times \frac{(MVA)_{B,new}}{(MVA)_{B,old}} \times \frac{(kV)^2_{B,old}}{(kV)^2_{B,new}}$$

$$= j0.1 \times \frac{10\ (\text{new Base of Load})}{20\ (\text{old - MVA of G})} \times \frac{11^2\ [\text{old - voltage rating of G}]}{8.66^2\ [\text{new - base vlg of G}]}$$

$$\boxed{X_{g,new} = j\,0.08}$$

(ii) Transformer T_1 and T_2

$$X_{T_1} = X_{T_2} = X_{T,old} \times \frac{(MVA)_{B,new}}{(MVA)_{B,old}} \times \frac{(KV)^2_{B,old}}{(KV)^2_{B,new}}$$

$$= j0.08 \times \frac{10 \text{ [new - base of load]}}{30 \text{ [old - MVA of X']}} \times \frac{11^2 \text{ [old - LT side v/g w.r.t } T_1]}{8.66^2 \text{ [new - LT side base v/g w.r.t } T_1]}$$

(or) $\frac{(110\sqrt{3})^2 \text{ [old - HT side v/g]}}{150^2 \text{ [new - HT side base v/g]}}$

(or) $\frac{(11\sqrt{3})^2 \text{ [old - LT side v/g w.r.t } T_2]}{15^2 \text{ [new - LT side base v/g w.r.t } T_2]}$

$$\boxed{X_{T_1} = X_{T_2} = j0.043}$$

(iii) Transmission Line

$$X_{j100\Omega} = \frac{X(\Omega) \times (MVA)_B}{(KV)^2_{BTL}}$$

$$= j100 \times \frac{10}{150^2}$$

$$\boxed{X_{j100\Omega} = 0.044j}$$

Load → 10 MVA, 10 KV, 0.8 pf lag

$pf = -\cos^{-1} 0.8$

$= -36.87°$

Power $= 10\angle -36.87°$

$$\text{pu power of load} = \frac{\text{Actual load MVA}}{\text{Base load MVA}}$$

$$= \frac{10\angle -36.87}{10}$$

pu value power of load $= 1\angle -36.87$ pu

$$\text{pu voltage of load} = \frac{\text{Actual load voltage}}{\text{Base load voltage}} = \frac{10}{15}$$

5a

pu value of load voltage $= 0.66\angle 0°$ pu

Let I be pu value of current

$$I = \frac{\text{pu value of power}}{\text{pu value of voltage}} = \frac{1\angle -36.87°}{0.66\angle 0°}$$

$$I = 1.51\angle -36.87° \text{ pu}$$

Terminal voltage of generator in pu value

$$V_t = V_L + I_L\left[X_{T_1} + X_{T_2} + X_{TL}\right]$$

$$= 0.66 + 1.51\angle -36.87\left[j0.043 + j0.043 + j0.044\right]$$

$$V_{t,pu} = 0.79\angle 11.42°$$

Actual terminal voltage V_t = Base voltage of generator × pu value of V_t

$$= 8.66 \times 0.79\angle 11.42$$

$$\boxed{V_t = 6.84\angle 11.42° \text{ kV}}$$

5.a

Soln Base Values $(MVA)_B$ = rated MVA of the transformer

$(KV_1)_B$ = Base voltage in the primary side.

$(KV_2)_B$ = Base voltage in 2ndary side.

Also, let Zeq1 be the impedance of the transformer ref. to primary side and Zeq2 wrt 2ndary side.

$$(Zeq_1)_{p.u} = Zeq_1(\Omega) \times \frac{(MVA)_B}{(KV_1)_B^2} \quad \text{—(1)}$$

$$(Zeq_2)_{p.u} = Zeq_2(\Omega) \times \frac{(MVA)_B}{(KV_2)_B^2} \quad \text{—(2)}$$

$$Zeq_2(\Omega) = Zeq_1(\Omega) \times \frac{(KV_2)^2_B}{(KV_1)^2_B} \quad \text{—(3)}$$

Substituting (3) in (2),

$$(Zeq_2)_{p.u} = Zeq_1(\Omega) \times \frac{(KV_2)^2_B}{(KV_1)^2_B} \times \frac{(MVA)_B}{(KV_2)^2_B}$$

$$(Zeq_2)_{p.u} = (Zeq_1)_{p.u}$$

5b

5. b) $(MVA)_B = 2$ MVA.

primary side base voltage = 4 KV
2ndary side base voltage = 2 KV.

$X_1 = 2\,\Omega, \quad X_2 = 4\,\Omega.$

Reactance w.r.t primary side.

$X_{eq1} = X_1 + X_2' = 2 + 4 \times \left(\frac{4}{2}\right)^2 = 18\,\Omega.$

$X_{pu} = X_{eq1} \times \frac{(MVA)_B}{(KV_1)^2_B} = 18 \times \frac{2}{4^2} = j2.25$ p.u

Reactance w.r.t 2ndary side.

$X_{eq2} = X_1' + X_2 = 2 \times \left(\frac{2}{4}\right)^2 + 4$

$= 4.5\,\Omega.$

$X_{pu} = 4.5 \times \frac{2}{2^2} = 2.25$ p.u.

6.

Short Circuit of a Synchronous Machine (On No load)

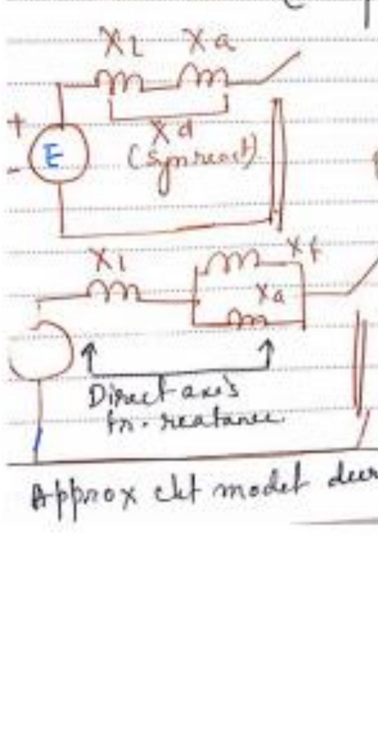
Under steady state short circuit conditions, the armature reaction of a synchronous generator produces a demagnetizing flux.

In terms of a circuit this effect is modelled as a reactance Xa in series with the induced emf.

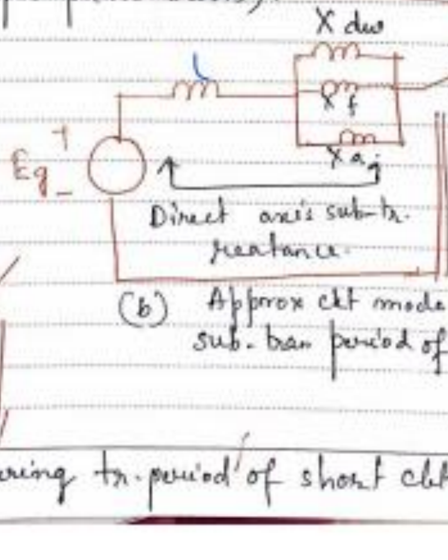
This reactance when combined with leakage reactance X_l of the machine is called synchronous reactance Xd (direct axis syn. reactance for salient pole machine).

Armature resistance being small can be neglected.

The steady state short circuit model of Syn M/C (on per phase basis).



Approx ckt model during tr. period of short ckt.



(b) Approx ckt mode du sub-tran period of shor

Let us consider sudden short circuit (three ... of a synchronous generator, initially operating ... open circuit conditions.

M/c undergoes a transient in all the phase finally ending up in steady state ...

CB must interrupt the current ... before steady conditions are reached.

Immediately, upon short circuit, the off-set currents appear in all the three phases with a different magnitude since the point on the voltage wave at which short circuit occurs ... different for each phase. These D.C offset currents are accounted for separately on an emperical basis and ⇒ therefore concentrate on symmetrical (sinusoidal) short circuit current.

Immediately in the event of a short ... the symmetrical short circuit current is limited ... the leakage reactance of the machine.

Since the air gap flux can not change instantaneously (theorem of constant flux linkage) to counter the demagnetization of the armature short circuit current, currents appear in the field ... as well as in the damper winding in a direct...

to help the main flux. These currents decay in accordance with the winding time constants. The time constant of the damper winding which has low leakage inductance is much less than that of the field winding which has high leakage inductance. Thus during the initial part of the short circuit, the damper and field windings have transformer currents induced in them so that in the circuit model, their reactances —

X_f for field winding X_{dw} — damper winding.

→ appear in parallel with X_a.

As the dw currents are first to die out, X_{dw} effectively becomes open circuited, at a later X_f ⇒ becomes open circuited

The machine reactance thus changes from the parallel combination of X_a, X_f and X_{dw} during the initial period of the short circuit to X_a and X_f in ∥, in the middle period of short circuit and finally X_a in steady state.

The reactance presented by the machine in the initial period of the short circuit

$$X_l + \frac{1}{\left(1/X_a + 1/X_f + 1/X_{dw}\right)} = X_d''$$

X_d'' = sub transient reactance of the machine.

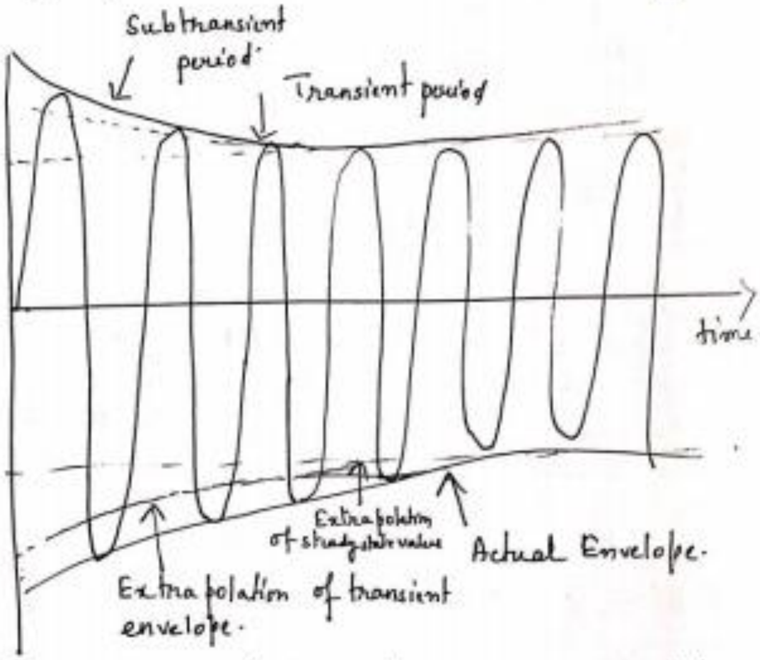
After the damper winding currents have died,

$X'_d = X_l + (X_a \| X'_f) \Rightarrow$ transient reac

The reactance under steady conditions is the synchronous reactance.

$X_d'' < X_d' < X_d$

Machine offers a time varying reactance whi changes from X_d'' to X'_d and finally to X_d



a) Symmetrical short circuit armature current in Synchronous machine.

7.

IAT - 1

(7) G_1 = 50MVA, 13.8KV, X'' = 0.15pu

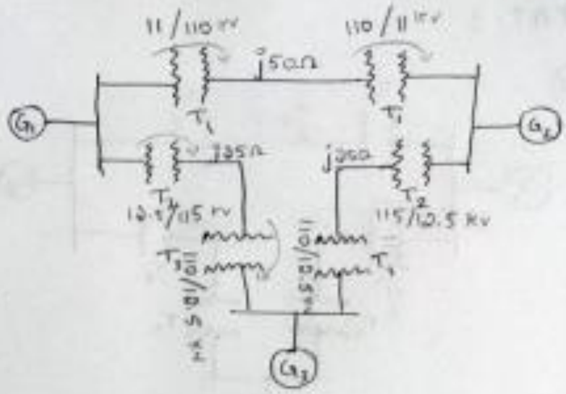
G_2 = 40 MVA, 13.2KV, X'' = 0.2 pu

G_3 = 30 MVA, 11KV, X'' = 0.25pu

T_1 = 45 MVA, 11 kV Δ/110 kV Y, X = 0.1 pu

T_2 = 25 MVA, 12.5 kV Δ/115 kV Y, X = 0.15 pu

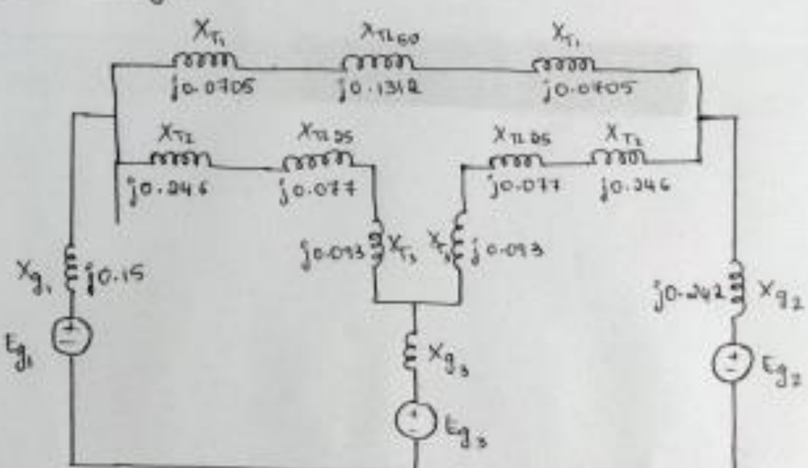
T_3 = 40MVA, 12.5 kV Δ/110 kV Y, X = 0.1pu



Determine reactance diagram based on 50MVA and 13.8KV as base quantities in generator 1.

Sol^n:-

Reactance Diagram



Base values

Base power of G_1 $(MVA)_B$ = 50 MVA

Base voltage $(KV)_B$ = 13.8 KV

Base voltages

(i) $(KV)_B$ for 50Ω TL = Base voltage of G_1 × Transformation Ratio of T_1

HT = $13.8 \times \frac{110}{11} \frac{HV}{LV}$

$(KV)_{B\,50\Omega} = 138\ KV$

(ii) $(KV)_B$ for 25Ω TL (HT) = $(KV)_{BG_1}$ (LT) × TR of T_2

$= 13.8 \times \frac{115}{12.5} \frac{HV}{LV}$

$(KV)_{B\,25\Omega} = 127\ KV$

(iii) $(KV)_B$ for Generator 2 (LT) = $(KV)_{B\,50\Omega}$ (HT) × TR

$= 138 \times \frac{11}{110} \frac{LV}{HV}$

$(KV)_{BG2} = 13.8\ KV$

(iv) $(KV)_B$ for Generator 3 (LT) = $(KV)_{B25\Omega}$ (HT) × TR of T_3

$= 127 \times \frac{12.5}{110} \frac{LV}{HV}$

$(KV)_{BG_3} = 14.43\ KV$

Reactancy:

$$X_{pu,new} = X_{pu,old} \times \frac{(MVA)_{B,new}}{(MVA)_{B,old}} \times \frac{(KV)^2_{B,old}}{(KV)^2_{B,new}}$$

(i) Generator 1

$$X_{g_1,new} = X_{g_1,old} \times \frac{(MVA)_{B,new}}{(MVA)_{B,old}} \times \frac{(KV)^2_{B,old}}{(KV)^2_{B,new}}$$

$$= j0.15 \times \frac{50}{50} \times \frac{13.8^2}{13.8^2}$$

$X_{g_1,new} = j0.15$

(ii) Generator 2

$$X_{g_2,new} = 0.2j \times \frac{50\ [\text{new MVA}]}{40\ [\text{old MVA}]} \times \frac{13.2^2\ [\text{old V/g of G2}]}{13.8^2\ [\text{new base V/g of } G_2]}$$

(base of G1; MVA of G2)

$X_{g_2,new} = j0.2287$

(iii) Generator 3

$X_{g_3,new} = j0.25 \text{ [old]} \times \frac{50 \text{ [new Base MVA of } G_1]}{30 \text{ [old MVA of } G_3]} \times \frac{11^2 \text{ [old vlg - vlg of } G_3]}{14.43^2 \text{ [new vlg - base vlg of } G_3]}$

$\boxed{X_{g_3,new} = j0.242}$

(iv) Transformer 1 T_1

$X_{T_1,new} = j0.1 \text{ (old)} \times \frac{50 \text{ [new-base MVA of } G_1]}{45 \text{ [old-MVA of } T_1]} \times \frac{11^2 \text{ [old-LT side vlg of } T_1]}{13.8^2 \text{ [new-LT side base vlg of } T_1]}$

(or) $\frac{110^2 \text{ (old-HT side vlg of } T_1)}{138^2 \text{ (new HT side base vlg of } T_1)}$

$\boxed{X_{T_1,new} = j0.0705}$

(v) Transformer 2, T_2

$X_{T_2,new} = j0.15 \text{(old)} \times \frac{50 \text{ [new base of MVA } G_1]}{25 \text{ [old. MVA of } T_1]} \times \frac{12.5^2 \text{ [old-LT side vlg of } T_2]}{13.8^2 \text{ [new LT side base vlg of } T_2]}$

(or) $\frac{115^2 \text{ [old HT side of } T_2]}{127^2 \text{ [new-HT side base of } T_2]}$

$\boxed{X_{T_2,new} = j0.246}$

(vi) Transformer 3, T_3

$X_{T_3,new} = j0.1 \times \frac{50 \text{ [base of } G_1]}{40 \text{ [old-MVA of } T_3]} \times \frac{12.5^2 \text{ [old-LT side of } T_3]}{14.43^2 \text{ [new-LT side base vlg of } T_3]}$

(or) $\frac{110^2 \text{ (HT side } T_3)}{127^2 \text{ (HT side base of } T_3)}$

(vii) Transmission Line

$X_{TL} = \frac{X(\Omega) \times (MVA)_B}{KV_B^2}$

$X_{TL}\, j50\Omega = \frac{j50 \times 50}{138^2 \text{ (base vlg of } j50\Omega)}$

$\boxed{X_{TL}\, j50\Omega = j0.1312}$

$X_{TL}\, j25\Omega = \frac{j25 \times 50}{127^2 \text{ (base vlg of } j25\, TL)}$

$\boxed{X_{TL}\, j25\Omega = j0.077}$