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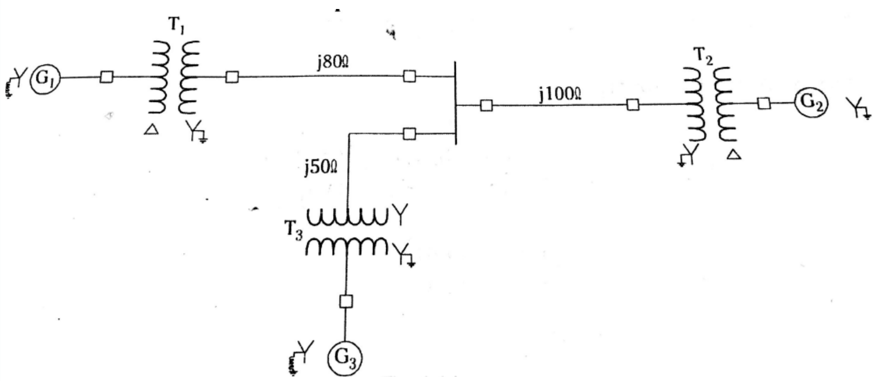
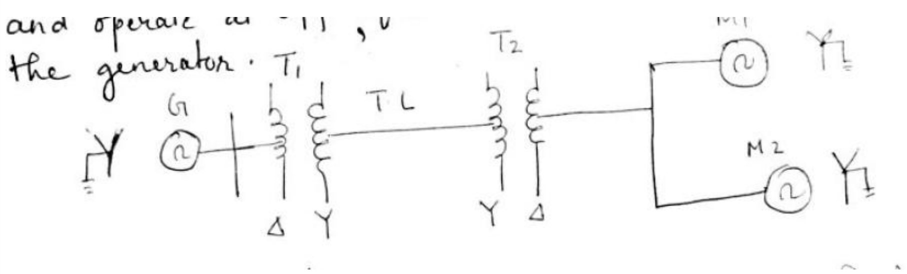
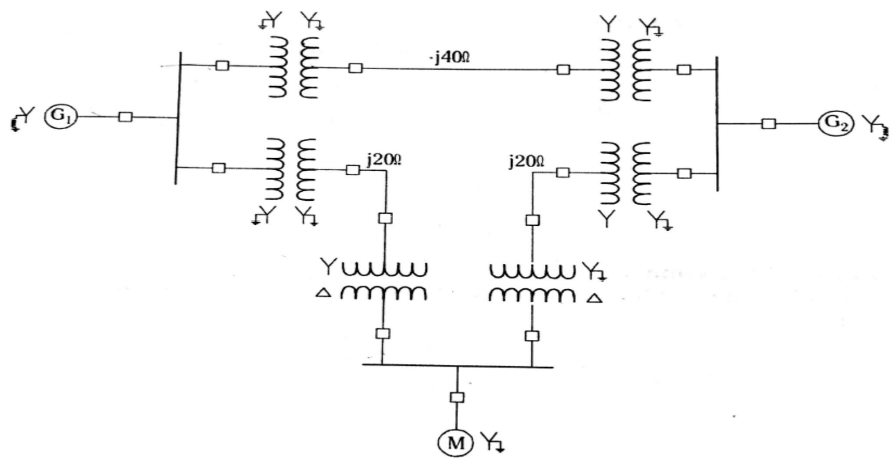
Internal Test1 –March 2019

Sub:	Power System Analysis-1							Code:	15EE62/10EE61
Date:	05/03 /2019	Duration:	90 mins	Max Marks:	50	Sem:	VI	Branch:	EEE
Note: Answer any FIVE full questions with neat diagram wherever necessary.									

		Marks	OBE CO	OBE RBT
1a.	Show that the per unit impedance of a transformer is the same whether computed from primary or secondary side so long as the voltage bases on the two sides are in the ratio of transformation.	[5]	CO1	L1
1b.	A three phase Δ/Y transformer with rating 100kVA,11kV/400Vhas its primary and secondary leakage reactance as 12-Ω/phase and 0.05Ω/phase respectively. Calculate p.u reactance of transformer.	[5]	CO1	L3
2.	The one line diagram of an unloaded generator is shown in figure. Draw the p.u. impedance diagram. Choose a base of 50 MVA, 13.8kkV in the circuit of generator G1. The generators and transformers are rated as follows: G1: 20MVA, 13.8kV, X”=0.2 p.u. G2: 30MVA, 18kV, X”=0.2 p.u. G3: 30MVA, 20kV, X”=0.2 p.u. T1: 25 MVA, Y 220kV/13.8kVΔ, X=10% T2: Three single phase units each rated 10MVA, 127/18kV, X=10% T3: 35 MVA,220kV Y/22kV Y, X=10% 	[10]	CO1	L3
3.a	A generator is rated 500MVA, 22kV. Its Y-connected windings have a reactance of 1.1p.u. Find the ohmic value of the reactance of the windings. Find the reactance in p.u for a base of 100MVA, 20kV.	[5]	CO1	L2
3.b	Write down the advantages of per unit system in power system analysis.	[5]	CO1	L1
6.	With the help of oscillogram of short circuit current of a synchronous generator, operating on no load, distinguish between subtransient, transient and steady state periods. Also write the corresponding equivalent circuits, which are used in computing Xd”, Xd’ and Xd. .	[10]	CO2	L1

5.	A 300 MVA, 20kV, 3ϕ generator has a reactance of 20%. The generator supplies two motors M1 and M2 over a transmission line of 64km as shown in figure. The ratings of components are as follows: T1: 350MVA, 230kV Y/20kV Δ, X=10%; TL: Length =64km, reactance 0.5Ω/km; T2: composed of three 1ϕ transformer each rated 127/13.2 kV,100MVA with leakage reactance of 10%.; M1: 200MVA,13.2kV, X"=20%; M2: 100MVA,13.2 kV, X"=20%. Select the generator ratings as base and draw the reactance diagram with all reactance marked in p.u. If the motors M1 and M2 have inputs of 120MW and 60MW at 13.2 kV and operate aat upf, find the voltage at the terminals of the generator. 	CO1	L3
6.	Obtain the impedance diagram of the electrical power system shown in figure. Mark all the impedance values in per unit on a base of 50MVA, 138kV in the 40Ω line. The machine ratings are :G1: 20 MVA, 13.2 kV, X"=15%;G2: 20 MVA, 13.2 kV, X"=15%; M; 30 MVA, 6.9kV, X"=20%; Three phase Y-Y transformers: 20 MVA, 13.8/138kV, X=10%; Three phase Y-Δ transformers: 15 MVA, 6.9/138kV, X=10%	CO1	L3



1a

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 w.r.t 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),

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

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

1b

Solution: Case (i)

The high voltage winding (primary) ratings are chosen as base values.

∴ Base Kilovolts, $KV_B = 11\,KV$.

Base $KVA_B = 100\,KVA$

Base $MVA_B = 100/1000 = 0.1\,MVA$

Base impedance / per phase $Z_B = \dfrac{(KV_B)^2}{MVA_B} = \dfrac{11^2}{100/1000}$

$= 1210\,\Omega$.

Transformer line voltage ratio

$$K = \frac{400}{11{,}000} = 0.0364.$$

Total leakage reactance ref. to primary $X_{01} = X_1 + X_2'$

$$= X_1 + \frac{X_2}{K^2} = 12 + \frac{0.05}{0.0364^2}$$

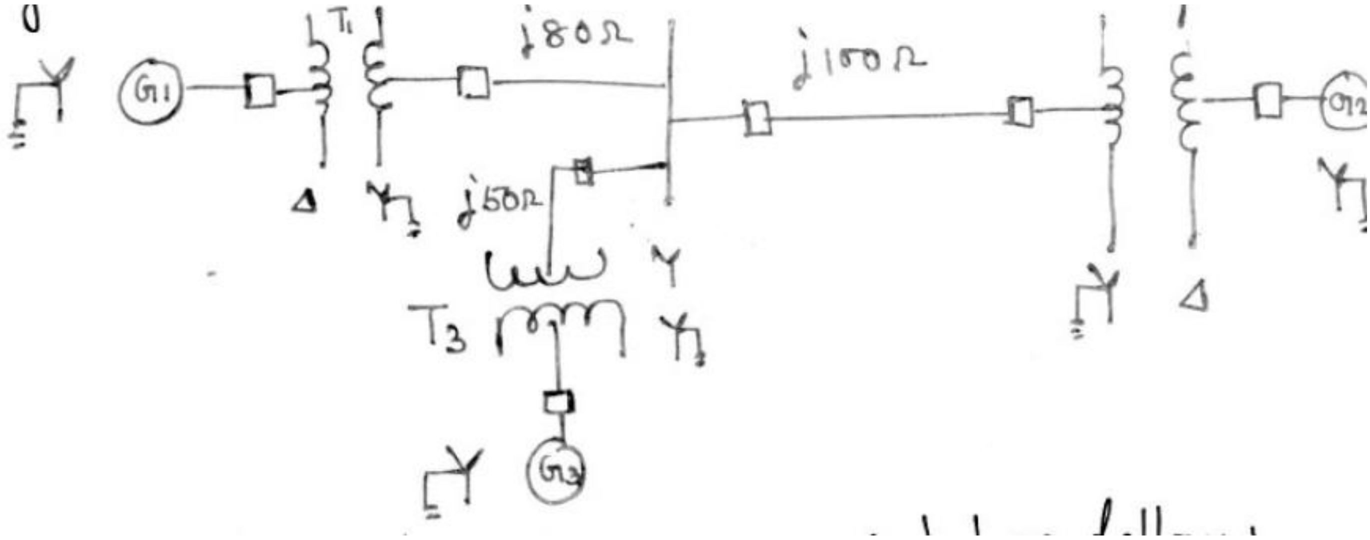
$$= 49.737\,\Omega/\text{phase}.$$

p.u reactance per phase $X_{pu} = \dfrac{\text{Total leakage reactance}}{\text{Base impedance}}$

$$= \frac{X_{01}}{Z_B} = \frac{49.737}{1210}$$

$$= 0.0411\text{ p.u.}$$

2.



Solution Base values

Base Power $(MVA)_B = 50$ MVA

Base voltage on the generator $G_1 = 13.8$ KV

Base voltage on the j80Ω T.L $= 13.8 \times \frac{220}{13.8} = 2$

" " " j50Ω TL = 220 KV

" " " j100Ω TL = 220 KV.

Base voltage on the generator $G_3 = 220 \times \frac{22}{220} = 2$

The transformer T_2 is a three phase bank formed using three single phase transformers with voltage rating of 127/18 KV. In this, the H.T side is star connected & L.T side is Δ connected.

∴ Voltage ratio of 3φ line voltage of 3 φ transformer bank $= \frac{\sqrt{3} \times 127}{18} = \frac{220\text{ KV}}{18\text{ KV}}$

∴ Base voltage of generator $G_2 = 220 \times \frac{18}{220} = 18$

Reactance of generator G_1

$$X_{G1,new} = X_{G1,old} \times \frac{(MVA)_{B\,new}}{(MVA)_{B\,old}} \times \frac{(KV)^2_{B,old}}{(KV)^2_{B,new}}$$

$$= j0.2 \times \frac{50}{20} \times \frac{13.8^2}{13.8^2} = j0.5 \text{ p.u}$$

Reactance of transformer T_1

$$X_{T1,new} = X_{T1,old} \times \frac{(MVA)_{B\,new}}{(MVA)_{B\,old}} \times \frac{(KV)^2_{old}}{(KV)^2_{new}}$$

$$= j0.1 \times \frac{50}{25} \times \frac{13.8^2}{13.8^2} = j0.2 \text{ p.u}$$

Reactance of T.Ls.

j80Ω line, $X_{TL1} = X_{TL1}(\Omega) \times \frac{(MVA)_B}{KV_B^2}$

$= j80 \times \frac{50}{220^2} = j0.083$ p.u

j100Ω line $X_{TL2} = X_{TL2}(\Omega) \times \frac{(MVA)_B}{KV_B^2}$

$= j100 \times \frac{50}{220^2} = j0.1033$ p.u.

j50Ω line $X_{TL3} = X_{TL3}(\Omega) \times \frac{50}{220^2} = j0.0516$ p.u

Reactance of tranformer T2

This is a bank of 3 1φ tranformer, $(MVA)_{B,old} = 3 \times 10 = 30$

$\therefore X_{T2,new} = X_{T2,old} \times \frac{50}{30} \times \frac{220^2}{220^2} = j0.1667$ p.u.

Reactance of Generator G2

This is connected to LT side of T2

$\therefore X_{G2,new} = X_{G2,old} \times \frac{50}{30} \times \frac{18^2}{18^2} =$

$= j0.2 \times \frac{50}{30} \times \frac{18^2}{18^2} = j0.333$ p.u.

Reactance of tranformer T3

$X_{T3,new} = X_{T3,old} \times \frac{(MVA)_{B\,new}}{(MVA)_{B\,old}} \times \frac{(KV)^2_{B,old}}{(KV)^2_{B,new}}$

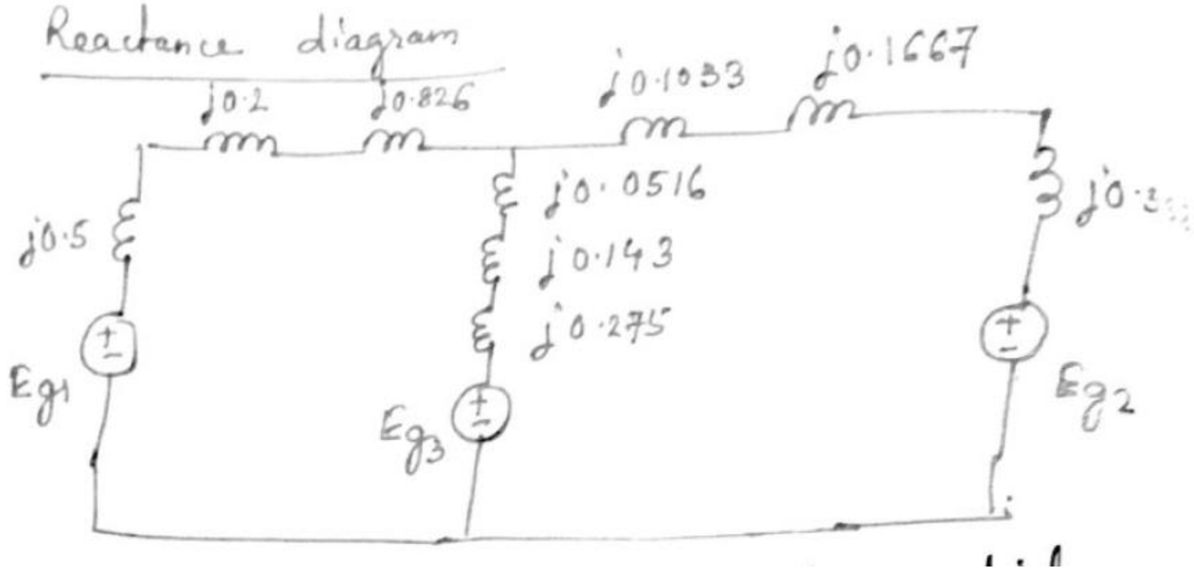
$= j0.1 \times \frac{50}{35} \times \frac{22^2}{22^2} = j0.143$ p.u

Reactance of generator G3

$X_{G3,new} = X_{G3,old} \times \frac{(MVA)_{B,new}}{(MVA)_{B,old}} \times \frac{(KV)^2_{B,old}}{(KV)^2_{B,new}}$

$= j0.2 \times \frac{50}{30} \times \frac{20^2}{22^2} = j0.275$ p.u.

Reactance diagram



3a

3a). p.u value = actual value $\times \frac{MVA}{KV^2}$

1.1 ⟶

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

$$= 1.1 \times \frac{100}{500} \times \frac{22^2}{20^2} = 0.2662\ p.u$$

3b

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.

(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 computer, the p.u method is very handy.

4.

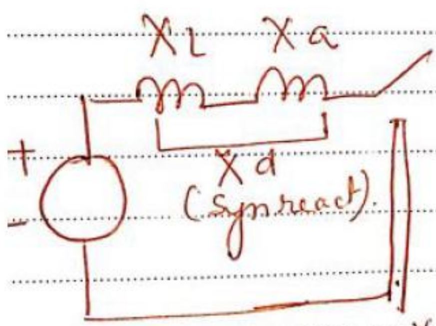
Short Circuit of a Synchronous Machine (On No load).

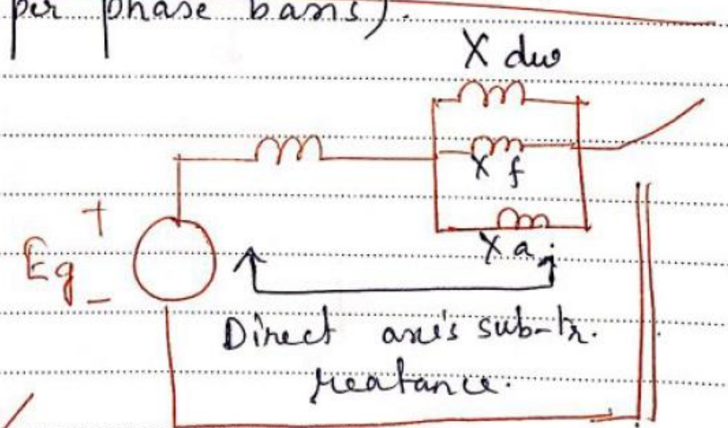
Under steady state short circuit conditions, the armature reaction of a synchronous generator produces a demagnetizing flux. In terms of a circuit this effect is modelled as a reactance X_a in series with the induced emf.

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

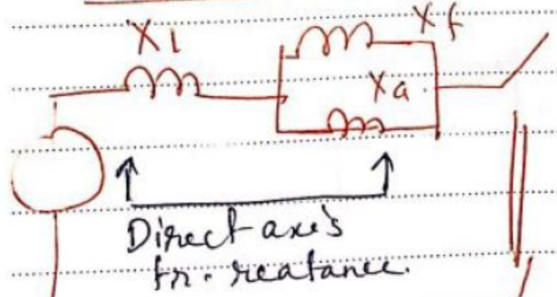
Armature resistance being small can be neglected.

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





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



Approx ckt model during tr. period of short ckt.

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

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

CB must interrupt the current around 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 is different for each phase. These D.C offset currents are accounted for separately on an empirical basis and ⇒ therefore concentrate on symmetrical (sinusoidal) short circuit current.

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

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

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

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

X_d'' = sub transient reactance of the machine.

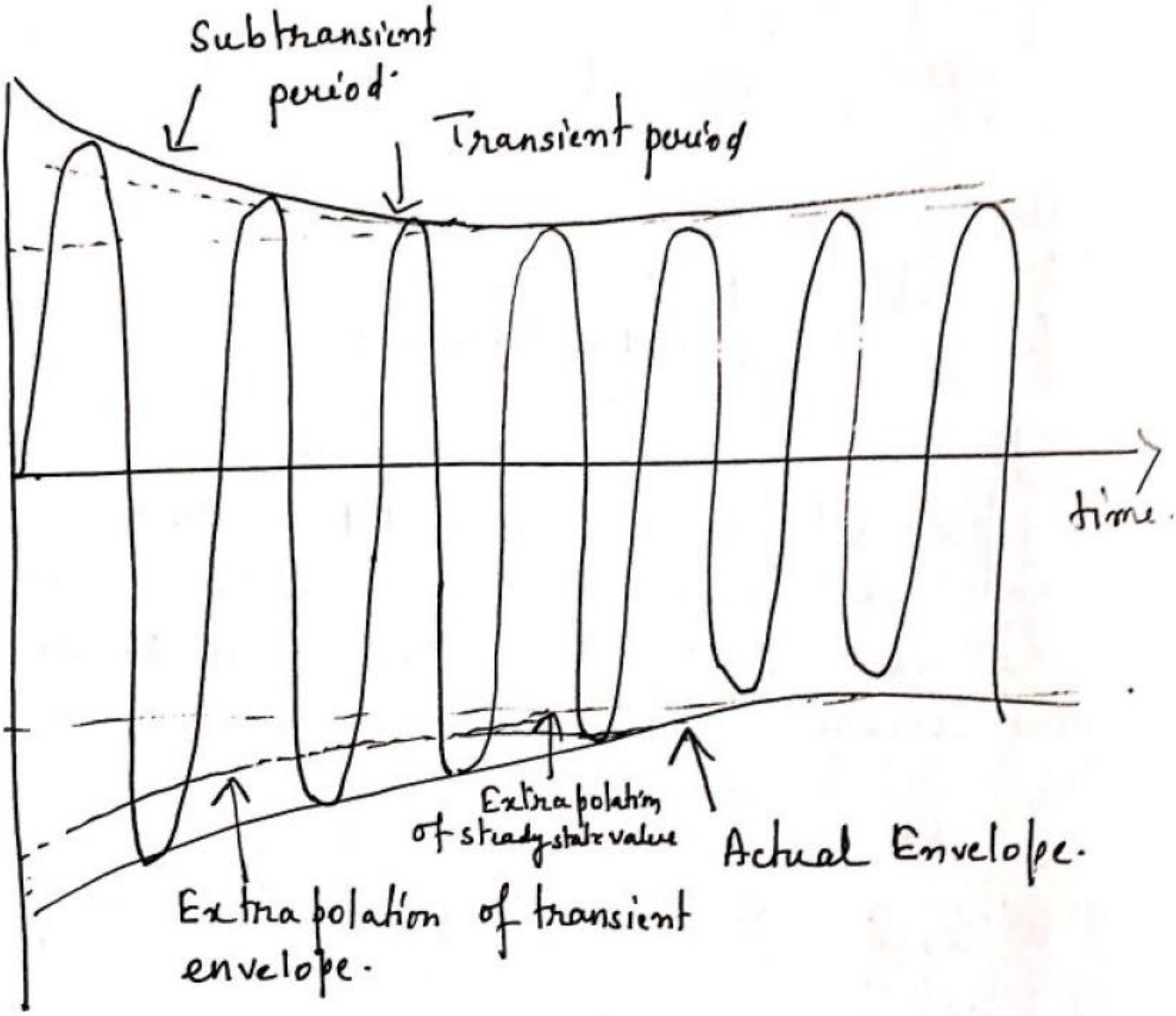
After the damper winding currents have died,

$$X'_d = X_l + (X_a \parallel X_f) \Rightarrow \text{transient reac.}$$

The reactance under steady conditions is the <u>synchronous reactance</u>.

$$X_d'' < X_d' < X_d$$

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



a) Symmetrical short circuit armature current in Synchronous machine.

If we examine the oscillogram of the short current of a synchronous machine after the DC off-set currents have been removed from it, current wave form is as given in fig(1), envelope of current wave shape is fig(2).

The short circuit current can be divided into three periods — initial subtransient period, when the current is large as the machine offers subtransient reactance

⇒ the middle transient period where the machine offers transient reactance

⇒ steady state period when the machine offers synchronous reactance.

☆ If transient envelope is extrapolated backwards in time, the difference between the transient and subtransient envelopes is the current $\Delta i''$ corresponding to damper winding ⇒ which decays first acc. to damper winding time constant.

☆ Uly the difference $\Delta i'$ between the steady state and transient envelopes decays in accordance with the field time constant.

$$|I| = \frac{|E_g|}{X_d} \quad \text{— i)} \qquad I'' = \frac{|E_g|}{X_d''} \quad \text{— iii)}$$

$$|I'| = \frac{|E_g|}{X_d'} \quad \text{→ ii)}$$

where $|I| \Rightarrow$ steady state current (r.m.s)

$|I'| \Rightarrow$ transient current (r.m.s) excluding DC component.

$|I''| \Rightarrow$ subtransient current (rms) excluding DC component.

$X_d \Rightarrow$ direct axis synchronous reactance.

$X_d' \Rightarrow$ " " transient "

$X_d'' \Rightarrow$ " " subtransient "

$|E_g| \Rightarrow$ per phase no load voltage (r.m.s)

⇒ Though machine reactance depends upon magnetic saturation corresponding to excitation, the values normally lie within certain predictable limits for different types of machines.

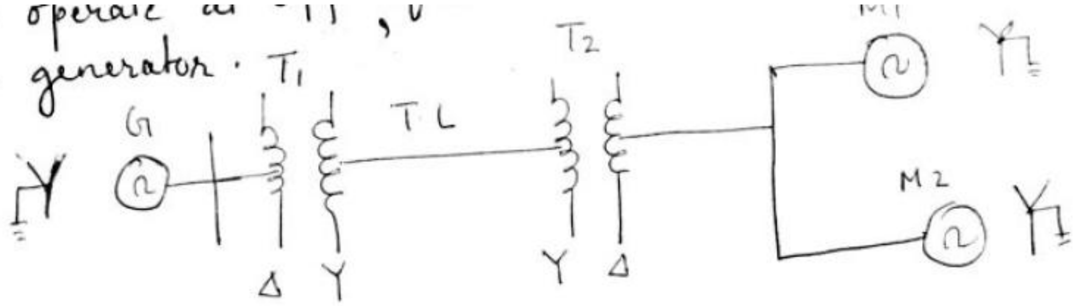
⇒ For both generator and motor X_d'' are used to determine momentary current flowing on occurance of a short circuit.

⇒ To decide interrupting capacity of circuit breaker except those which open instantaneously, X_d'' for gen and $X_d' \Rightarrow$ for motors.

$X_d \Rightarrow$ for stability studies.

5.

and operate at [illegible], [illegible]
the generator.



Solution Base values.

Component	$(MVA)_{B,old}$	$(MVA)_{B,new}$	$(KV)_{B,old}$	$(KV)_{B,new}$
Generator G	300	300	20	20
Transformer T_1	350	300	230 (HT)	$20 \times \frac{230}{20} = 230$
TL	–	300	–	$20 \times \frac{230}{20} = 230$
T_2	$100 \times 3 = 300$	300	$127\sqrt{3}$ (HT)	230
M_1	200	300	13.2	$230 \times \frac{13.2}{127\sqrt{3}} = 13.8$
M_2	100	300	13.2	13.8

Reactance of generator G

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

$$= j0.2 \times \frac{(300)}{(300)} \times \frac{(20)^2}{(20)^2} = j0.2 \text{ p.u}$$

Reactance of transformer T_1

$$X_{T1,new} = X_{T1,old} \times \frac{(MVA)_{B,new}}{(MVA)_{B,old}} \times \frac{(kV)^2_{B,old}}{(kV)^2_{B,new}}$$

$$= j0.1 \times \frac{(300)}{(350)} \times \frac{230^2}{230^2} = j0.085 \text{ p.u}$$

Reactance of TL

$$X_{TL,new} = X_{TL,old} \times \frac{(MVA)_B}{(kV)^2_B}$$

$$= j0.5 \times 60 \times \frac{300}{230^2} = j0.181 \text{ p.u}$$

Reactance of Transformer, T_2

$$X_{T2,new} = X_{T2,old} \times \frac{(MVA)_{B,new}}{(MVA)_{B,old}} \times \frac{(kV)^2_{B,old}}{(kV)^2_{B,new}}$$

$$= j0.1 \times \frac{300}{300} \times \frac{(127\sqrt{3})^2}{230^2} = j0.09[illegible]$$

Reactance of motor M_1

$$X_{M1, new} = X_{M1, old} \times \frac{(MVA)_{B, new}}{(MVA)_{B, old}} \times \frac{(kV)^2_{B, old}}{(kV)^2_{B, new}}$$

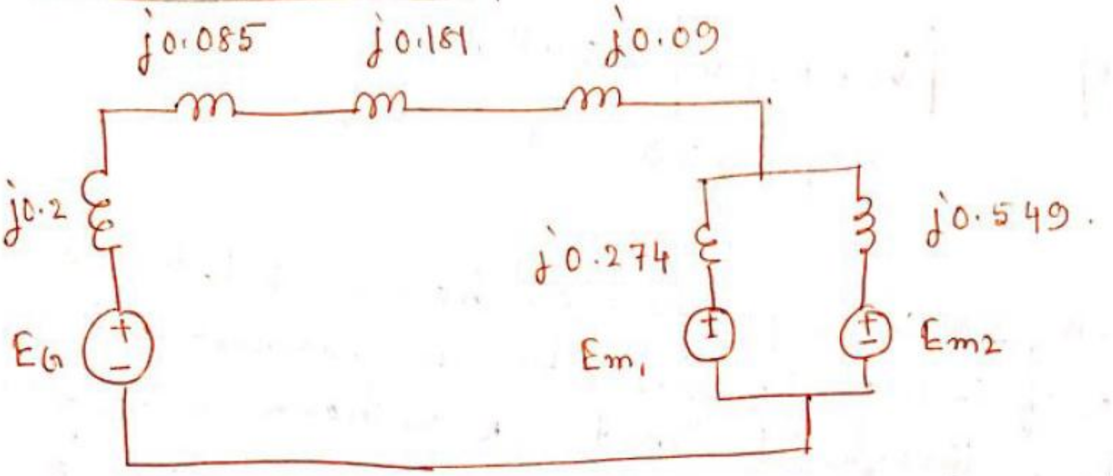
$$= j0.2 \times \frac{300}{200} \times \frac{13.2^2}{13.8^2} = j0.274 \text{ p.u}$$

Reactance of motor M_2

$$X_{M2,new} = X_{M2,old} \times \frac{(MVA)_{B,new}}{(MVA)_{B,old}} \times \frac{(KV)^2_{B,old}}{(KV)^2_{B,new}}$$

$$= j0.2 \times \frac{300}{100} \times \frac{13.2^2}{13.8^2} = j0.549 \text{ p.u.}$$

Reactance diagram



Let V_{Mt} = terminal voltage at the motor ends

V_{Gt} = terminal voltage of the generator

The total electric power flows in the motors is

$P = 120 + 60 = 180$ MW at upf.

∴ The current drawn by motors $I_m = \frac{180 \times 10^6}{\sqrt{3} \times 13.2 \times 10^3 \times 1}$

$= 7873$ A.

It is required to express the current in p.u

Base current $I_B = \frac{300 \times 10^6}{\sqrt{3} \times 13.8 \times 10^3} = 12551$ A.

∴ I_m in p.u $= \frac{I_m}{I_B} = \frac{7873}{12551} = 0.627 \angle 0°$ p.u

V_{Mt} in p.u $\frac{13.2 \angle 0°}{13.8} = 0.96 \angle 0°$ p.u.

$$\therefore V_{Gt} = V_{Mt} + j I_m (X_{T1} + X_{T2} + X_{T2}).$$

$$= 0.96\angle 0^\circ + j0.627(0.085 + 0.181 + 0.09)$$

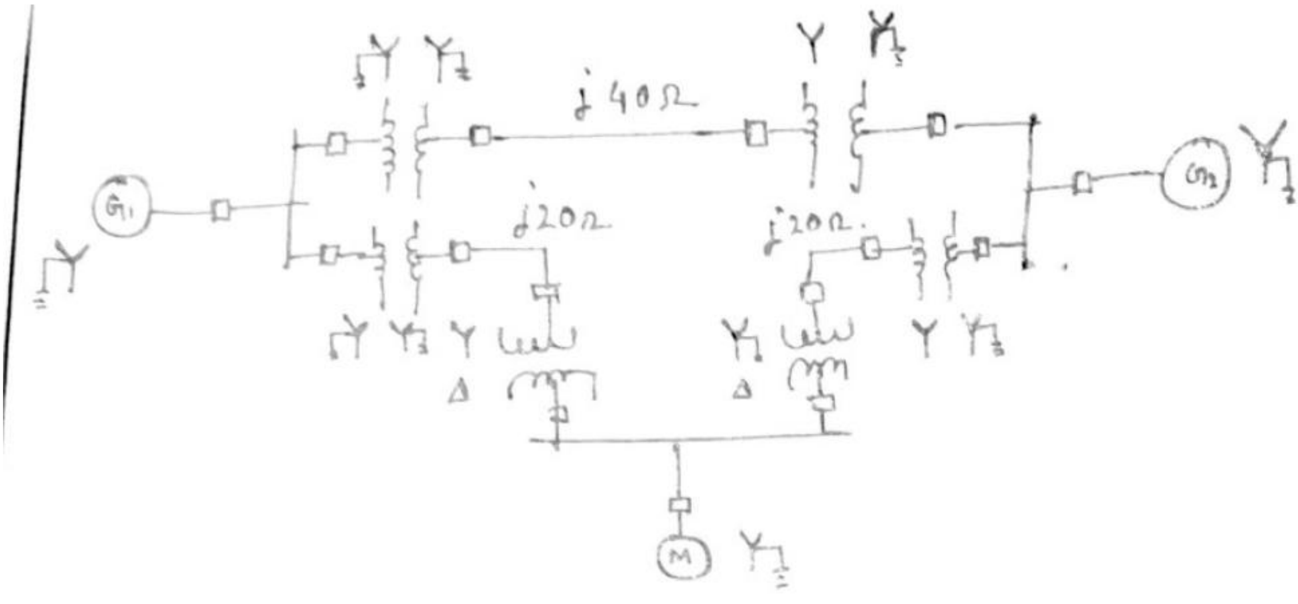
$$= 0.96\angle 0^\circ + j0.223$$

$$= 0.986\angle 13.07^\circ \text{ p.u}$$

$$\therefore |V_{Gt}| = |V_{Gt} \text{ in p.u}| \times 20 KV.$$

$$= 0.986 \times 20 = 19.72 KV.$$

6.



Solution

Base values

Base power, $(MVA)_B = 50$ MVA

Base voltage on the j40 Ω ~~transf~~ T.L = 138 KV

Base voltage on generator $G_1 = 138 \times \frac{13.8}{138} = 13.8$ KV

" " " " $G_2 = 138 \times \frac{13.8}{138} = 13.8$ KV.

Base voltage of j20Ω T.Ls $= 138 \times \frac{138}{138} = 138$ KV

" " on motor M $= 138 \times \frac{6.9}{138} = 6.9$ KV.

Reactance of j40Ω T.L.

$$X_{TL1} = X(\Omega) \times \frac{(MVA)_B}{KV_B^2} = j40 \times \frac{50}{138^2} = j0.105 \text{ p.u}$$

Reactance of generator G_1 and G_2

Generators G_1 and G_2 are identical. Hence their p.u reactances are same.

$$X_{G1,new} = X_{G2,new} = X_{G1\,old} \times \frac{(MVA)_{B,new}}{(MVA)_{B,old}} \times \frac{(KV)^2_{B,old}}{(KV)^2_{B,new}}$$

$$= j0.15 \times \frac{50}{20} \times \frac{13.2^2}{13.8^2} = j0.343 \text{ pu}$$

Reactance of Y-Y connected transformer

Y-Y connected trs are all identical. Hence their p.u reactance are same

$$X_{TR1,new} = X_{TR1,old} \times \frac{(MVA)_{B\,new}}{(MVA)_{B\,old}} \times \frac{(KV)^2_{B\,old}}{(KV)^2_{B\,new}}$$

$$= j0.1 \times \frac{50}{20} \times \frac{13.8^2}{13.8^2} = j0.25\ p.u$$

Reactance of j20 Ω T.L

Both the sections of j20Ω lines have same values of reactances and same bases. Hence their p.u reactance will be same.

$$X_{TL2,new} = X_{TL2}(\Omega) \times \frac{(MVA)_B}{(KV)^2_B}$$

$$= j20 \times \frac{50}{138^2} = j0.052\ p.u$$

Reactance of Y-Δ connected transformers

Since both the Y-Δ transformers are identical, [illegible]

$$X_{TR2,new} = X_{TR_2,old} \times \frac{(MVA)_{B\,new}}{(MVA)_{B\,old}} \times \frac{(kV)^2_{B\,old}}{(kV)^2_{B\,new}}$$

$$= j0.1 \times \frac{50}{15} \times \frac{138^2}{138^2} = j0.33\ p.u$$

Reactance of the motor M

This is connected onto LV side of Y-Δ transformer

$$X_{M,new} = X_{M1,old} \times \frac{(MVA)_{B\,new}}{(MVA)_{B\,old}} \times \frac{(KV)^2_{B\,old}}{(KV)^2_{B\,new}}$$

$$= j0.2 \times \frac{50}{30} \times \frac{6.9^2}{6.9^2} = j0.33\ p.u$$

Impedance (reactance) diagram of the system :-