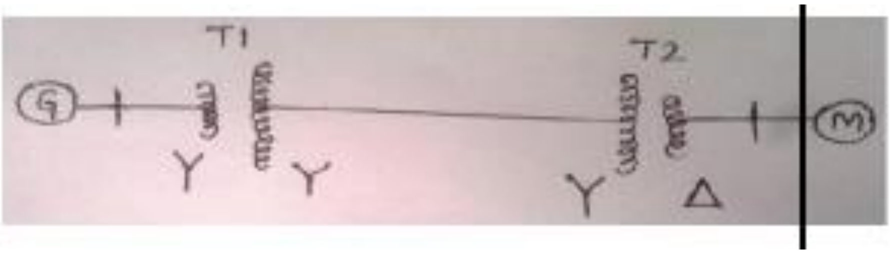
CMR
INSTITUTE OF
TECHNOLOGY

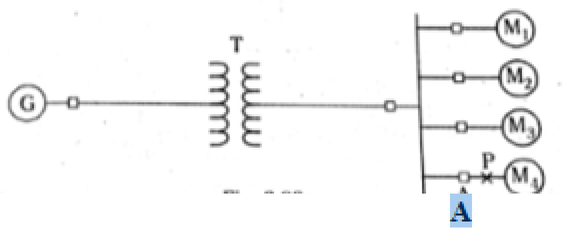
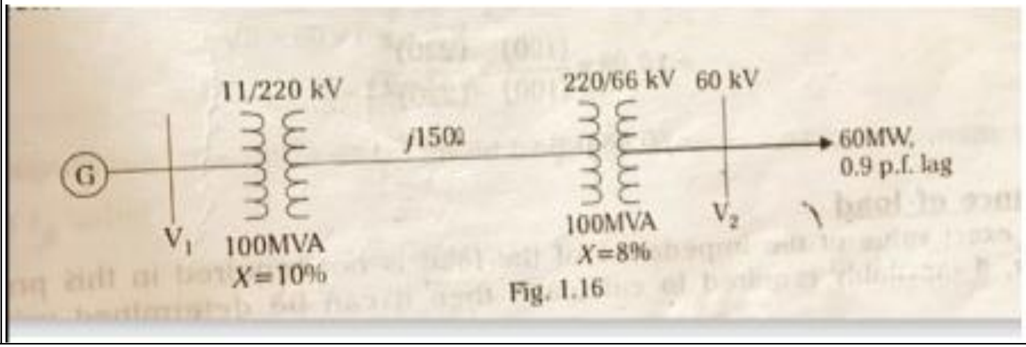
USN

Internal Assessment Test - I

Sub:	**Power System Analysis-1**							Code:	18EE62
Date:	06/05/2022	Duration:	90 mins	Max Marks:	50	Sem:	6th	Branch:	EEE
Answer Any FIVE FULL Questions. Assume missing Data									

		Marks	OBE	
			CO	RBT
1A	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	L2
1B	Two generators are connected in parallel to a 6.6 kV bus. One of the generators has a ratinng 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	L2
2	Draw the per unit impedance diagram for the system shown in Fig by taking a base of 100MVA, 11kV in the generator circuit. The various component ratings are: T1- 3 phase unit 90MVA, 11/110kV, X=10%, T2- made up of 3 single phase units each rated 33.33MVA, 69/6.6kV, X=10%, synchronous generator: 80MVA, 10kV, X=10%, Motor: 95MVA, 6.3 MVA, X=15% and the line reactance is 20Ω. 	10	CO1	L4
3	Explain the advantages of defining per unit impedance. Derive the equation for Z base in terms of a chosen, MVA base and kV base.	5+5	CO1	L1
4	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 on loaded condition.	10	CO2	L2

P.T.O

5	A 25 MVA, 13.8kV generator with Xd”=15% is connected through a transformer with a leakage reactance 10% to a bus that supplies four identical motors as shown in figure. Each motor has Xd”=20% and Xd’=30% on a base of 5 MVA, 6.9kV. A three phase fault occurred at at the point P. For the fault specified determine: a)The sub transient current in the fault. b)The sub transient current in the breaker A. c)The momentary current in breaker A. d) The current to be interrupted by breaker A in 5 cycles.  	10	CO2	L2
6	Fig. shows the schematic diagram of a radial transmission system. The ratings and reactance of the various components are shown in the figure. A load of 60 MW and 0.9 pf lagging is tapped from the 66kV substation which is to be maintained at 60kV. Calculate the terminal voltage of the machine..  Fig. 1.16	10	CO1	L3

CCI **HOD**

1 A.

$(MVA)_B = 2\,MVA.$

$(KV_1)_B = 4\,KV$

$(KV_2)_B = 2\,KV$

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

$X_{01} = X_1 + X_2'$

$X_2' = 4 + \frac{4^2}{2^2} = 16\Omega.$

$X_{01} = 2 + 16 = 18\Omega.$

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

$= 18 \times \frac{2}{4^2} = j2{\cdot}25 \text{ p.u}$

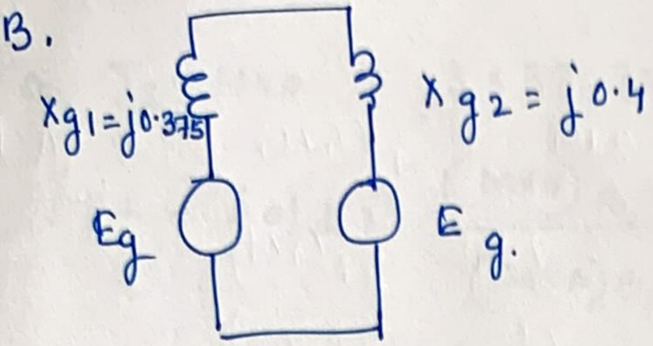
$X_{02} = X_2 + X_1'$

$X_1' = 2 \times \frac{2^2}{4^2} =$ ~~0.0~~ $0{\cdot}5$

$X_{02} = 4 + 0{\cdot}5 = 4{\cdot}5\,\Omega.$

$X_{2pu} = 4{\cdot}5 \times \frac{2}{2^2} = j2{\cdot}25 \text{ p.u.}$

1B.



Base power = 50 MVA

Base voltage = 6.6 KV.

G_1 = 20 MVA, $X_{g\,old}$ = 15%.

$G_2 \Rightarrow$ 15MVA, $X_{g\,old}$ = 12%.

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

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

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

2. Base power = 100 MVA

Base voltage of generator = 11 KV

T_1 = 3 φ unit, 90 MVA, 11/110KV, X = 10%.

T_2 = made up of 3 single phase units each rated 33.33 MVA, 69/6.6 KV, X = 10%.

G = 80 MVA, 10 KV, X = 10%.

M = 95 MVA, 6.3KV, X = 15%.

line reactance = 20 Ω.

Base voltage of transmission line = Base voltage of gen × transformation ratio of T_1

$$= 11 \times \frac{110}{11} = 110 \text{ KV.}$$

Base voltage of motor = B.V of j20 T.L × T.R of T_2

$$= 110 \times \frac{6.6}{69\sqrt{3}} = 6.07 \text{ KV}$$

For T_2 MVA $= 3 \times 33.33 = 99.99$, $69\sqrt{3} / 6.6$ kV.

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

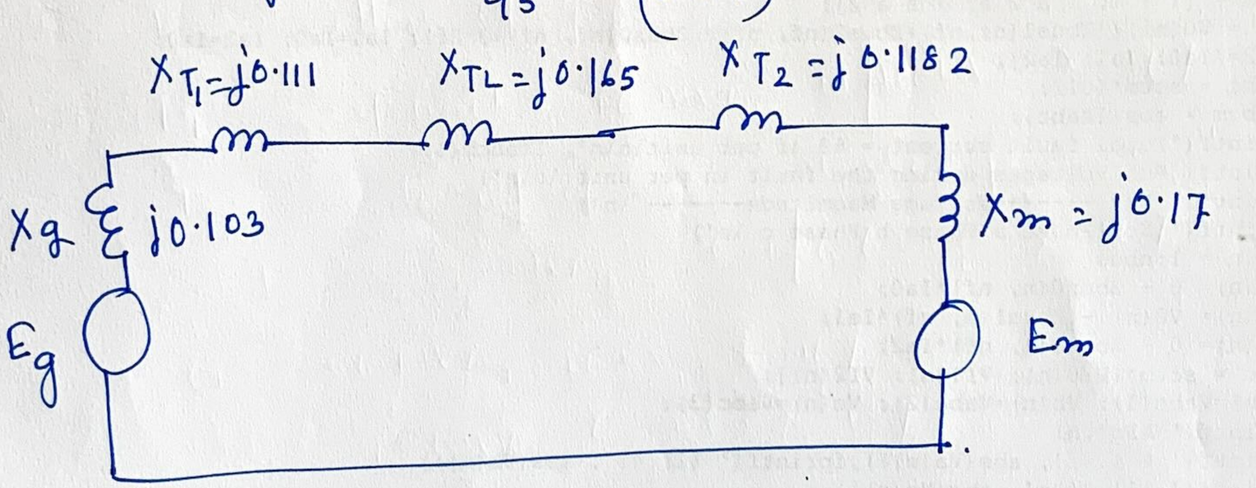
$$X_g = j0.1 \times \frac{100}{80} \times \frac{10^2}{11^2} = j0.1033$$

$$X_{T1} = j0.1 \times \frac{100}{90} \times \frac{11^2}{11^2} = j0.111 \text{ pu}$$

$$X_{T2} = j0.1 \times \frac{100}{99.99} \times \frac{6.6^2}{(6.07)^2}.$$

$$= j0.1182 \text{ p.u}$$

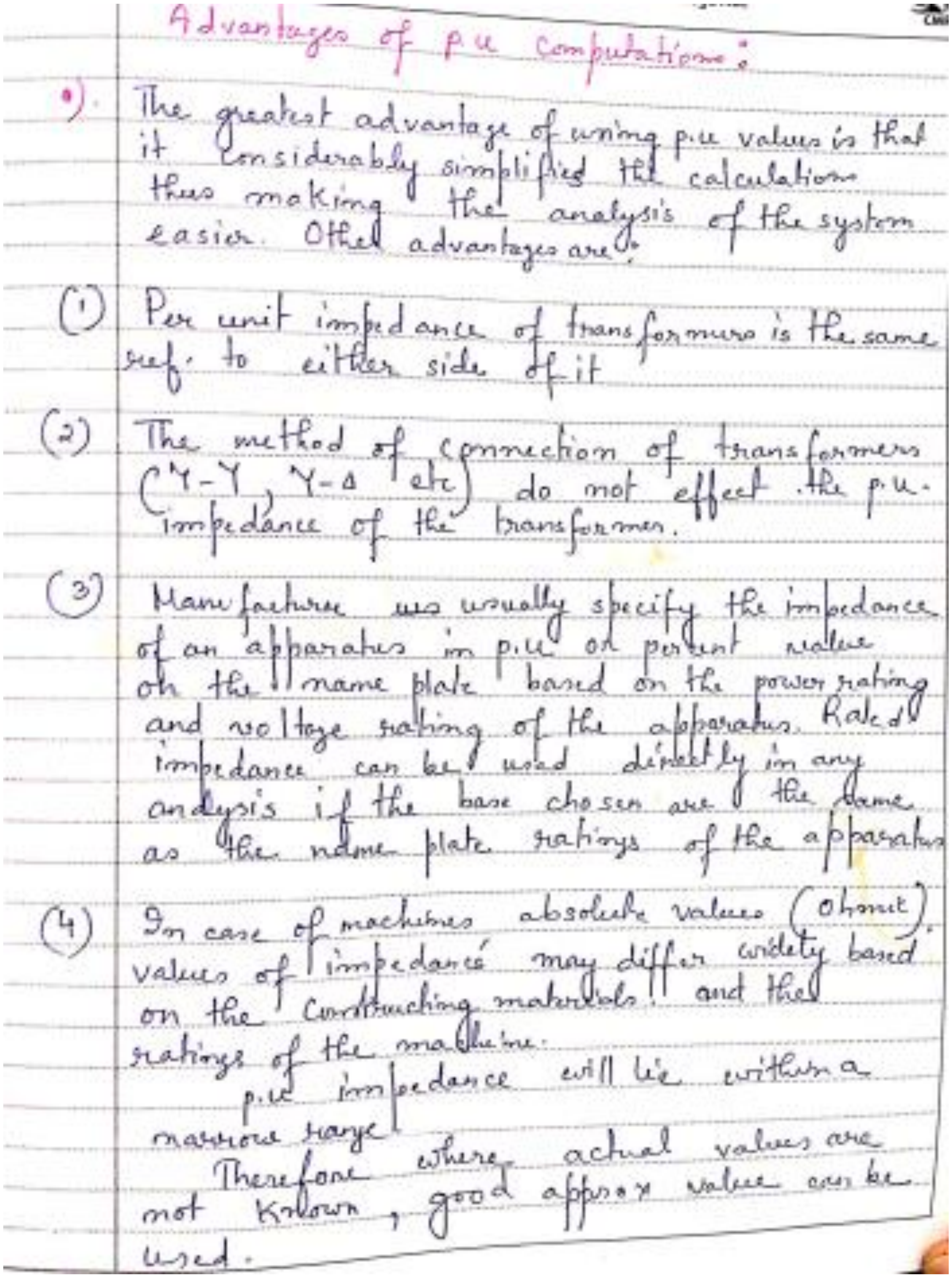
$$X_M = j0.15 \times \frac{100}{95} \times \frac{6.3^2}{(6.07)^2} = j0.1700 \text{ p.u.}$$



$$X_{TL} = 20 \times \frac{100}{110^2} = \qquad X_{pu} = X(\Omega) \times \frac{(MVA)_B}{(KV_B)^2}$$

$$= j0.165$$

3.



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.

Drawbacks.

Per unit system extended to three phase circuits.

Let the three phase base power be $(MVA)_B$ and line to line base voltage (KV_B).

Assume Y connection (if circuit is not star, equivalent star can always found for three phase circuits).

$$\text{Base current } I_B = \frac{1000 \times (MVA)_B}{\sqrt{3}\,(KV)_B}$$

$$\text{Base impedance } Z_B = \frac{1000 \times (KV)_B}{\sqrt{3}\, I_B}$$

$$= \frac{\cancel{1000} \times \cancel{(MVA)_B}\,(KV)_B}{\cancel{\sqrt{3}} \times \frac{\cancel{1000}}{\cancel{\sqrt{3}}}\,\frac{(MVA)_B}{(KV)_B}} = \frac{(KV_B)^2}{(MVA)_B}.$$

If the actual impedance is $Z\,\Omega$, then its p.u impedance can be computed as

$$Z_{p.u} = \frac{Z(\Omega)}{Z_B} = \frac{Z(\Omega)}{(KV_B)^2}$$

Short Circuit of a Synchronous Machine (On No load)

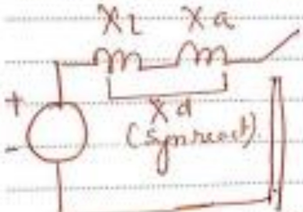
Under steady state short circuit conditions, the armature reaction of a synchronous generator produces a demagnetizing flux.

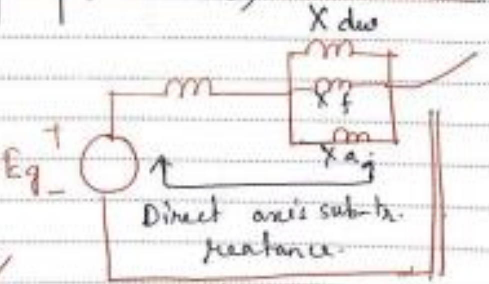
In terms of a circuit this effect is modelled as a reactance Xa in series with the induced emf.

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

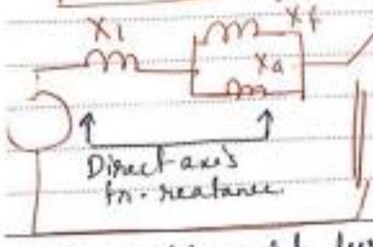
Armature resistance being small can be neglected.

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





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



Approx ckt model during tr. period of short ckt.

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

M/c undergoes a transient in all th
phase finally ending up in steady state co

CB must interrupt the current an
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 o
the voltage wave at which short circuit occurs
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 cir
the symmetrical short circuit current is limited b
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 sh
circuit current, currents appear in the field win
as well as in the damper winding in a direc

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 $X_f \Rightarrow$ 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 $\parallel$, 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.

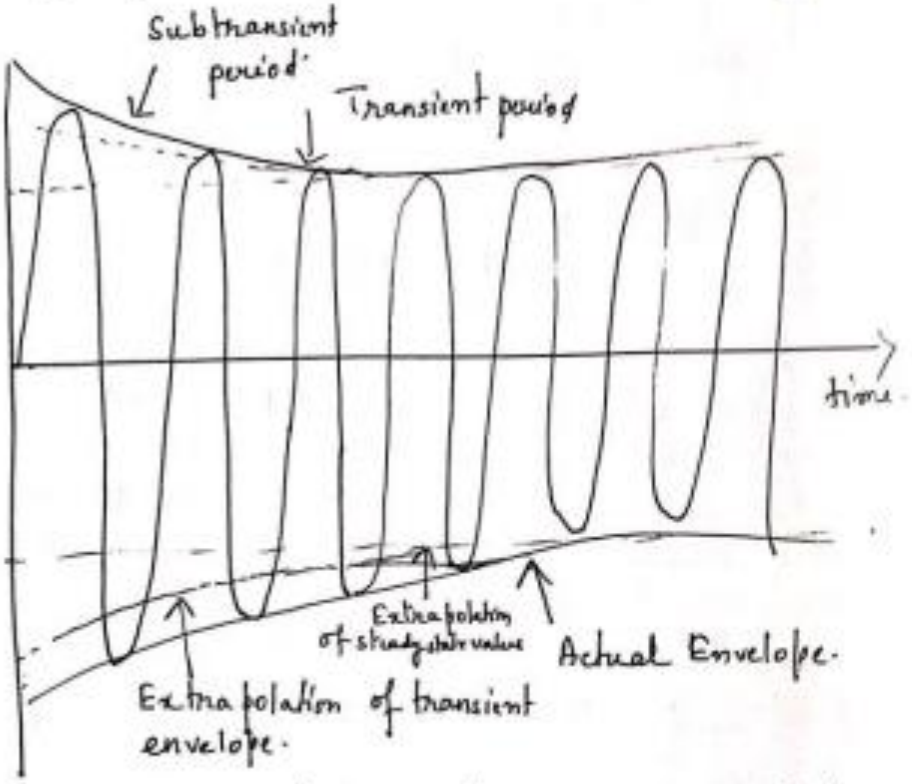
After the damper winding currents have died,

$X'_d = X_l + (X_a \parallel X'_f) \Rightarrow$ 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 whi 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 fig①, envelope of current wave shape is fig②.

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 machin 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.

$|I| = \frac{|E_g|}{X_d}$ — i) $I'' = \frac{|E_g|}{X_d''}$ — iii).

$|I'| = \frac{|E_g|}{X_d'}$ → ii)

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

$|I'| \Rightarrow$ transient current (r.m.s) excludi
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

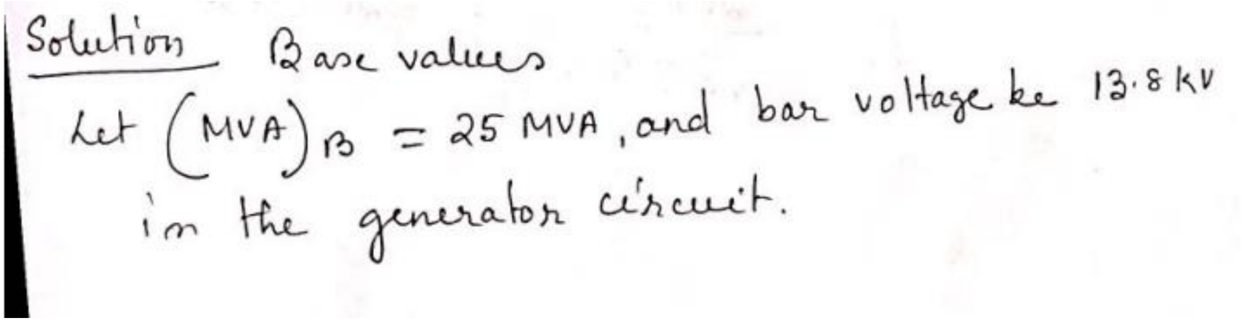
$\Rightarrow$ Though machine reactance depends upon mag saturation corresponding to excitation, the values normally lie within certain predictable limits for different types of machines.

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

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

$X_d \Rightarrow$ for stability studies.

5.



<u>Solution</u> Base values

Let $(MVA)_B = 25$ MVA, and bar voltage be 13.8 kV in the generator circuit.

Base voltage on the motor side $= 13.8 \times \frac{6.9}{13.8}$

$= 6.9$ kV.

Reactance of generator G:

$X_{dG}'' = j0.15$

$X_{dG}' = j0.15$ (as it is not specified).

Reactance of transformer T:

$X_T = j0.1$

Reactances of motors

$$X_{dM}'' = j0.2 \times \frac{25}{5} \times \frac{(6.9)^2}{(6.9)^2}$$

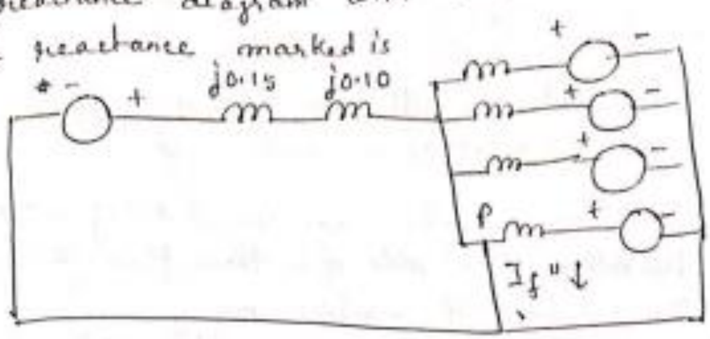
$$= j1.0 \text{ p.u}$$

$$X_{dM}' = j0.3 \times \frac{25}{5} \times \frac{(6.9)^2}{(6.9)^2} = j1.5 \text{ p.u}$$

The prefault voltage at the point P is 6.9 kV $= \frac{6.9}{6.9} \times = 1$ p.u and base current in the 6.9 kV circuit is

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

The reactance diagram with subtransient values of the reactance marked is



a) Subtransient fault current

$$I_f'' = 4 \times \frac{1}{j1.0} + \frac{1}{j0.25} = -j8 \text{ pu}$$

absolute value of current is $I_f'' = -j8 \times 2091.8$

$= -j16734.4$ A.

b) sub transient breaker A, $I'' = 3 \times \frac{1}{j1.0} + \frac{1}{j0.25} = -j7$ p.

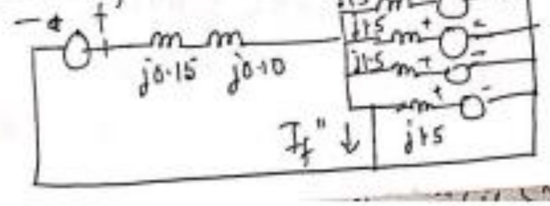
Absolute value of current is $I'' = -j7 \times 2091.8$

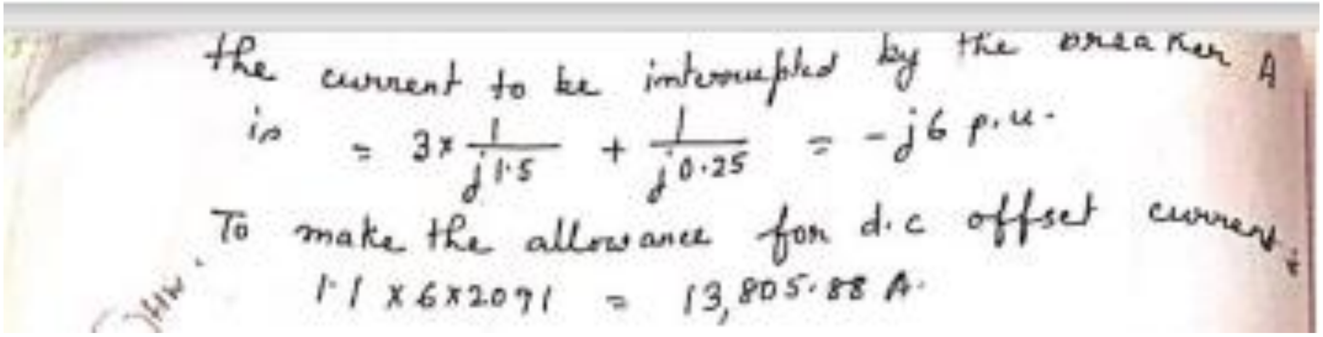
$= -j14642.6$ A.

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

$= 23428.16$ A.

d) to compute the current to be interrupted by the breaker: transient reactance model is





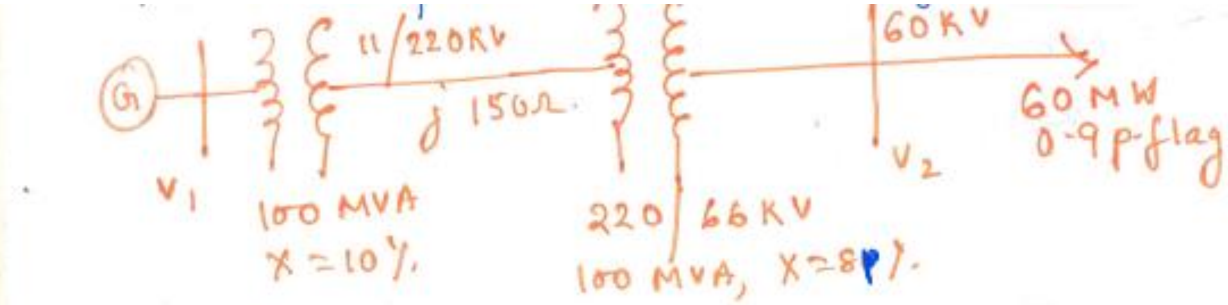
the current to be interrupted by the breaker A

is $= 3 \times \frac{1}{j1.5} + \frac{1}{j0.25} = -j6$ p.u.

To make the allowance for d.c offset current:

$1.1 \times 6 \times 2071 = 13{,}805.88$ A.

6.



Solution **Base values**

Let Base $(MVA)_B = 100$ MVA

Base voltage in T.L $= 220$ KV

Base voltage on the load $= 220 \times \frac{66}{220} = 66$ KV

" " on generator side $= 220 \times \frac{11}{220} = 11$ KV

Reactance of 11/220KV tranformer

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

$$= j0.1 \times \frac{100}{100} \times \frac{220^2}{220^2} = j0.1\ p.u.$$

Reactance of j150Ω T.L.

$$X_{TL} = X_{TL}(\Omega) \times \frac{(MVA)_B}{(KV^2)_B} = j150 \times \frac{100}{220^2} = j0.31\,p.u.$$

Reactance of 220/66KV TR.

$$X_{T2,new} = j0.08 \times \frac{100}{100} \times \frac{220^2}{220^2} = j0.08\ p.u$$

Impedance of load

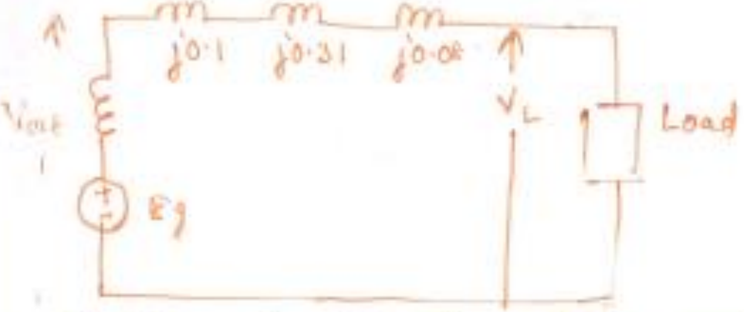
$$Z = \frac{|V_L|^2}{P - jQ}$$

V_L = voltage at the terminals of load

P = active component of power at the load

Q = Reactive " " , " " ,

Terminal voltage of the machine & Reactance dia



Let V_{mt} = terminal voltage of the machine

V_L = load voltage

I_L = load current, $V_L = 60\,KV = \frac{60}{66} = 0.909\,p.u$

$$I_L = \frac{P}{\sqrt{3} V_L \cos\phi} \angle -\cos^{-1}\phi$$

$$= \frac{60 \times 10^6}{\sqrt{3} \times 60 \times 10^3 \times 0.9} \angle -\cos^{-1} 0.9$$

$$= 641.5 \angle -25.84^\circ \text{ A}$$

Base current $I_B = \frac{\cancel{\sqrt{3}} (MVA)_B \times 1000}{\sqrt{3} \times (KV)_B} = \frac{1000 \times 100}{\sqrt{3} \times 66}$

$$= 874.77 \text{ A}$$

$\therefore I_L$ in p.u $= \frac{I_L}{I_B} = \frac{641.5 \angle -25.84^\circ}{874.77} = 0.733 \angle -25.84^\circ$ p.u

from the reactance diagram

$$(V_{Gt})_{p.u} = (V_L)_{p.u} + I_L (X_{T1} + X_{T2} + X_{TL})$$

$$= 0.909 + 0.733 \angle -25.84^\circ (j0.1 + j0.08 + j0.31)$$

$$= 0.909 + 0.359 \angle 64.16^\circ$$

$$= 0.909 + 0.156 + j0.323$$

$$= 1.065 + j0.323$$

$$= 1.112 \angle 16.87^\circ \text{ p.u}$$

V_{GT} in KV $= (V_{GT})_{p.u} \times$ base voltage on the gen

$$= 1.112 \times 11 =$$

$$\therefore |V_{GT}| = 12.232 \text{ KV}$$