CMR
INSTITUTE OF
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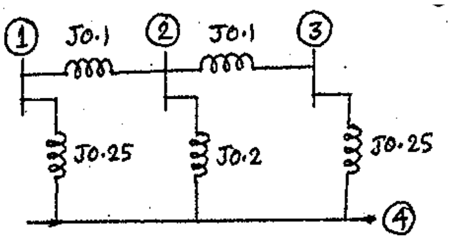
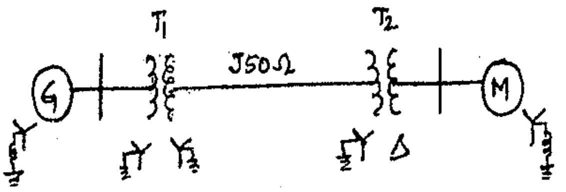
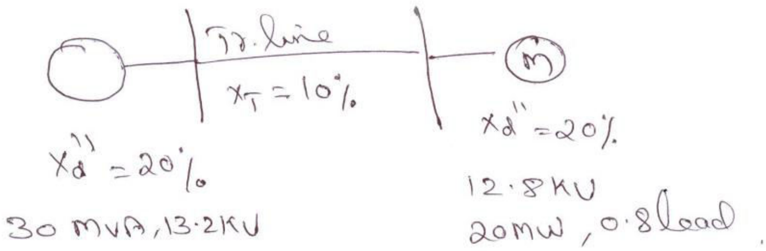
Internal Assesment Test - I

Sub:	Power System Analysis							Code:	15EE62
Date:	12/03/2018	Duration:	90 mins	Max Marks:	50	Sem:	6	Branch:	EEE
Answer Any FIVE FULL Questions									

		Marks	OBE	
			CO	RBT
1a	For a four bus system shown in Fig 1 ,determine the bus admittance matrix.The pu line reactances are indicated on the diagram.Treat bus 4 as reference bus /ground.  	[5]	CO1	L3
1b	Show that per unit impedance of a two winding transformer on either of its side is equal	[5]	CO1	L2
2	A single line diagram of a power system is shown in fig 2.Draw its impedance diagram .Choose a base of 100 MVA ,220 kV in 50 Ω line.The ratings of generator ,motor and transformer are given below.  Generator : 40 MVA, 25 kV, X″ = 20% Sync. Motor : 50 MVA, 11 kV, X″ = 30% Y-Y Transformer : 40 MVA, 33/220 kV, X = 15% Y-Δ Transformer : 30 MVA, 11/220 kV(Δ/Y), X = 15%	[10]	CO1	L3
3	With the help of waveform at the time of three phase symmetrical fault, on synchronous generator define steady state ,transient and subtransient reactances.	[10]	CO2	L2
4a	Mention the advantages of pu system	[5]	CO1	L1
4b	Derive an expression for the pu impedance for the given set of base values and also write a modified pu equation Zpu(new) when referred to new set of base values.	[5]	CO1	L2

5	A synchronous generator and motor are rated for 30 MVA,13.2 kV and both have sub transient reactance of 20 %.The line connecting them has a reactance of 10 % on the base of machine ratings. The motor is drawing 20 MW at 0.8 pf leading .The terminal voltage of the motor is 12.8 kV.When a symmetrical three phase fault occurs at motor terminals, find the sub transient current in generator, motor and at the fault point.	[10]	CO2	L3



A 300 MVA ,20 KV, 3 phase generator has sub transient reactance 20 %.The generator supplies 2 syn motors through a 64 Km transmission line having transformers at both ends as shown in fig 3.In this T1 is a 3 phase transformer and T2 is made of 3 single phase transformer of rating 100 MVA,127/13.2 kV,10% reactance. Series reactance of the transmission line is 0.5 Ω /Km. Draw the reactance diagram with all the reactances marked in pu. Select the generator rating as base values.

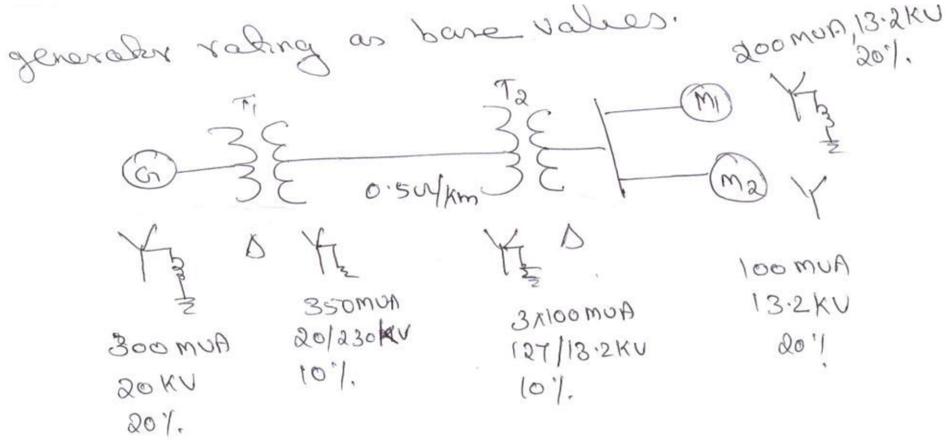


Fig 3.

Course Outcomes		PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1:	Relate the power system network to network topology.	2	-	-	-	-	-	-	-	-	1	-	-
CO2:	Recognize the network and form the matrix.	3	-	-	-	-	-	-	-	-	1	-	-
CO3:	Use the algorithms to calculate the load flow in the power system.	3	-	1	-	-	-	-	-	-	1	-	-
CO4:	Analyse the different algorithms for the load flow in the power system.	3	-	-	-	-	-	-	-	-	1	-	-
CO5:	Apply the economic scheduling algorithm for the load dispatch in power system.	3	-	-	-	-	-	-	-	-	1	-	-
CO6:	Apply different mathematical methods to solve the swing equation.	3	-	-	-	-	-	-	-	-	1	-	-

Cognitive level	KEYWORDS
L1	List, define, tell, describe, identify, show, label, collect, examine, tabulate, quote, name, who, when, where, etc.
L2	summarize, describe, interpret, contrast, predict, associate, distinguish, estimate, differentiate, discuss, extend
L3	Apply, demonstrate, calculate, complete, illustrate, show, solve, examine, modify, relate, change, classify, experiment, discover.
L4	Analyze, separate, order, explain, connect, classify, arrange, divide, compare, select, explain, infer.
L5	Assess, decide, rank, grade, test, measure, recommend, convince, select, judge, explain, discriminate, support, conclude, compare, summarize.

PO1 - *Engineering knowledge*; PO2 - *Problem analysis*; PO3 - *Design/development of solutions*; PO4 - *Conduct investigations of complex problems*; PO5 - *Modern tool usage*; PO6 - *The Engineer and society*; PO7- *Environment and sustainability*; PO8 – *Ethics*; PO9 - *Individual and team work*; PO10 - *Communication*; PO11 - *Project management and finance*; PO12 - *Life-long learning*

Solution

1a

$$\begin{bmatrix} -j14 & +j10 & 0 \\ j10 & -j25 & j10 \\ 0 & j10 & -j14 \end{bmatrix}$$

1b

how that the p.u. impedance of a transformer is the same irrespective of the side on whic[h] it is calculated.

MVA_B

$(KV_1)_b$ – Base voltage in primary side

$(KV_2)_b$ – Base voltage in sec. side.

Z_{eq1} – impedance of tr. referred to Primary

Z_{eq2} – ref. to se[c]

$$Z_{eq1,pu} = (Z_{eq1})_{\Omega} \times \frac{MVA_B}{(KV_1)_B^2}$$

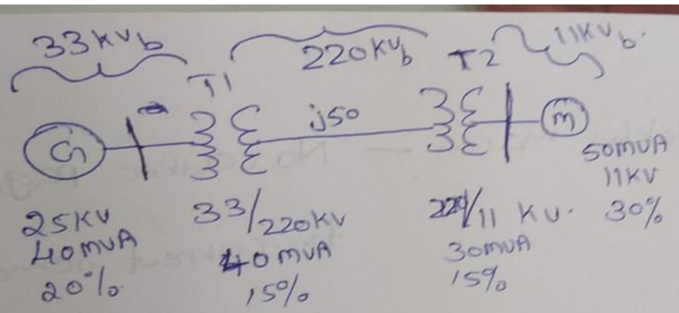
$$Z_{eq2,pu} = (Z_{eq2})_{\Omega} \times \frac{MVA_B}{(KV_2)_b^2}$$

$$(Z_{eq2})_{\Omega} = (Z_{eq1})_{(\Omega)} \times \frac{(KV_2)_B^2}{(KV_1)_B^2}$$

$$(Z_{eq2})_{pu} = Z_{eq1}(\Omega) \cdot \frac{(KV_2)_B^2}{(KV_1)_B^2} \times \frac{MVA_B}{(KV_2)_B^2}$$

$$= (Z_{eq1})_{pu}$$

2



$MVA_b = 100\ MVA$

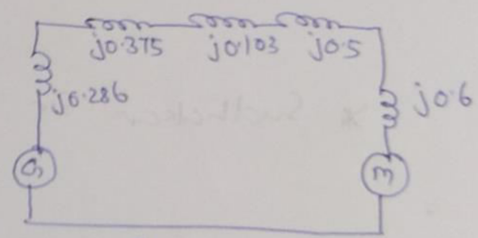
$x_g(pu) = 0.2 \times \frac{100}{40} \times \left(\frac{25}{33}\right)^2 = 0.286$

$x_{T_1}\ pu = 0.15 \times \frac{100}{40} \times \left(\frac{33}{33}\right)^2 = 0.375$

$x_{TL}\ pu = \frac{50}{(220)^2} \times 100 = 0.103$

$x_{T_2}\ pu = 0.15 \times \frac{100}{30} \times \left(\frac{220}{220}\right)^2 = 0.5$

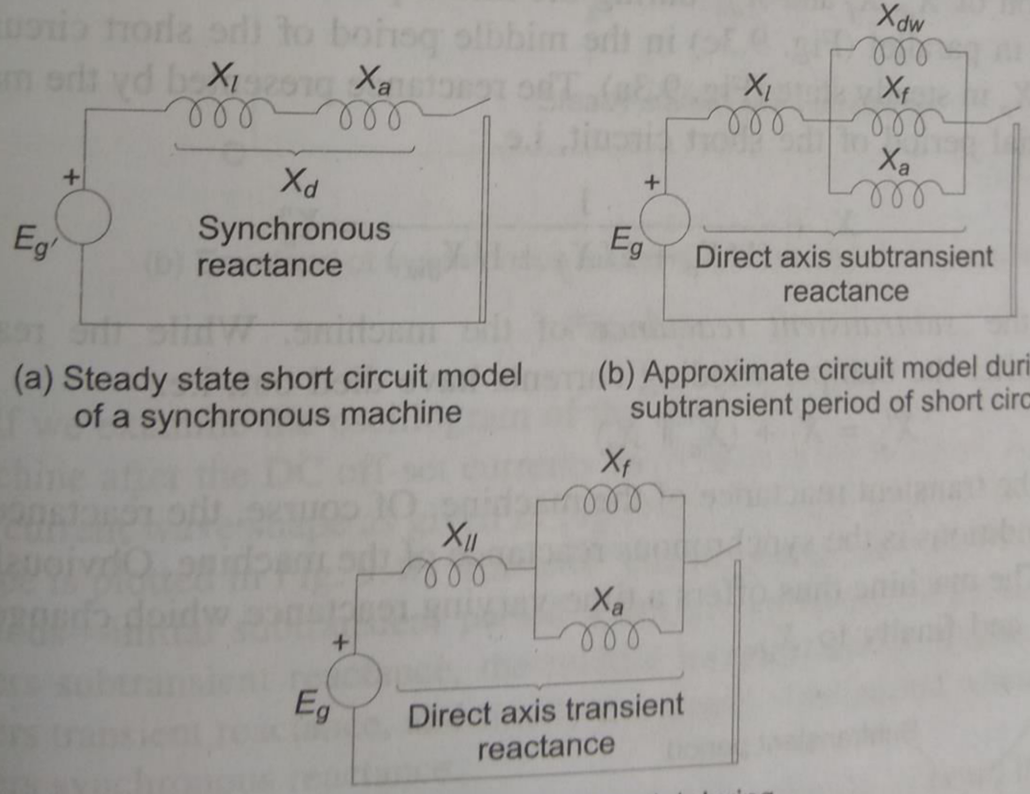
$x_m\ pu = 0.3 \times \frac{100}{50} \times \left(\frac{11}{11}\right)^2 = 0.6$



Reactance diagram.

3

effect is modelled as a reactance X_a in series with the induced emf. This reactance when combined with the leakage reactance X_l of the machine is called *synchronous reactance* X_d (direct axis synchronous reactance in the case of salient pole machines). Armature resistance being small can be neglected. The steady state short circuit model of a synchronous machine is shown in Fig. 9.3a on per phase basis.



(a) Steady state short circuit model of a synchronous machine

(b) Approximate circuit model during subtransient period of short circuit

(c) Approximate circuit model during transient period of short circuit

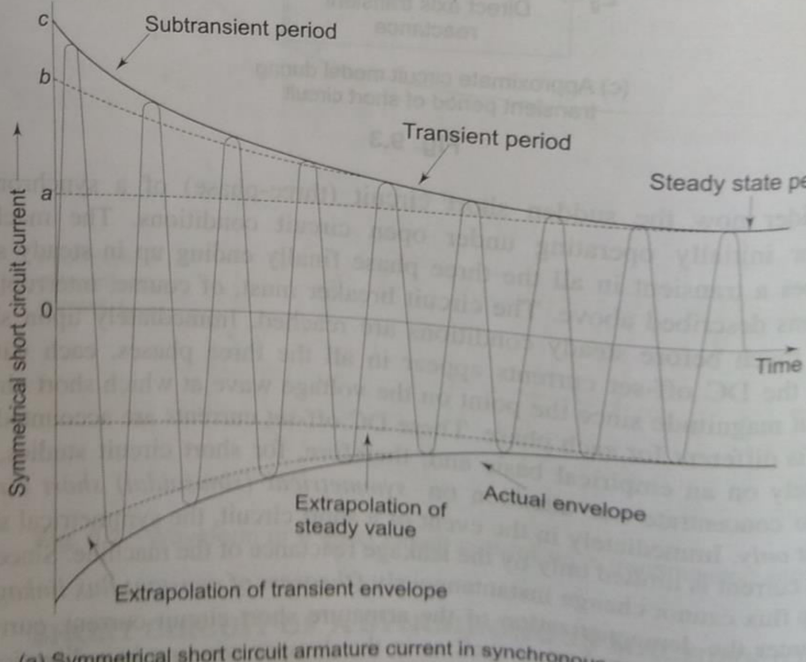
Consider now the sudden short circuit (three-phase) of a synchronous generator initially operating under open circuit conditions. The machine undergoes a transient in all the three phase finally ending up in steady state conditions described above. The circuit breaker must, of course, interrupt the current much before steady conditions are reached. Immediately upon short circuit, the DC off-set currents appear in all the three phases, each with a different magnitude since the point on the voltage wave at which short circuit occurs is different for each phase. These DC off-set currents are accounted for separately on an empirical basis and, therefore, for short circuit studies, we need to concentrate our attention on *symmetrical (sinusoidal) short circuit current only*. Immediately in the event of a short circuit, the symmetrical short circuit current is limited only by the leakage reactance of the machine. Since the air gap flux cannot 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 of field winding and X_{dw} of damper winding—appear in parallel* with X_a as shown in Fig. 9.3b. As the damper winding currents are first to die out, X_{dw} effectively becomes open circuited and at a later stage 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 parallel (Fig. 9.3c) in the middle period of the short circuit, and finally to X_a in steady state (Fig. 9.3a). The reactance presented by the machine in the initial period of the short circuit, i.e.

$$X_l + \frac{1}{(1/X_a + 1/X_f + 1/X_{dw})} = X_d'' \tag{9.5}$$

is called the *subtransient reactance* of the machine. While the reactance effective after the damper winding currents have died out, i.e.

$$X'_d = X_l + (X_a \parallel X_f) \tag{9.6}$$

is called the transient reactance of the machine. Of course, the reactance under steady conditions is the synchronous reactance of the machine. Obviously $X_d'' < X_d' < X_d$. The machine thus 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

Fig. 9.4 (Contd.)

4a

Advantages of p.u computations

1) Manufactures usually specify the impedance in percent or p.u. on the base of nameplate rating.
2) p.u impedance of m/c of same type and different rating usually lie within a narrow range although the ohmic value differ materially. This will help you to select from tabulated average value if the impedance is not known definitely.

3) ~~The method of connection of trs do not~~ ~~The Tr. connections in 3ϕ ckts does not affect the p.u impedance of the equivalent ckt.~~ effect the p.u impedance of the transformer.

4. when impedance in ohms is specified in an equivalent circuit, each impedance must be referred to the same circuit by multiplying it by the square of the ratio of the rated voltage of two sides of the transformer connecting the reference ckt and the circuit containing the impedance. P.u impedance, once it is expressed on the proper base, is the same referred to either side of any tr.

P.u impedance of transformers is the same referred to either side of it.

Complex power

5) P.u values makes the calculation relatively easier.

\4b

Per unit (pu) system

p.u value of any quantity

$$= \frac{\text{actual value in any unit}}{\text{Base or reference value in same unit}}$$

Base volt amperes $= (VA)_B$ VA

Base voltage $= V_B$ V

Then Base current $I_B = \frac{(VA)_B}{V_B}$ A

Base impedance $Z_B = \frac{V_B}{I_B} = \frac{(V_B)^2}{(VA)_B}$ Ω

If the actual impedance is Z, its p.u value is

$$\frac{Z}{Z_B} = Z_{(p.u)}$$

$$= Z \times \frac{(VA)_B}{(V_B)^2}$$

Base megavoltamperes $= MVA_B$
or
Base kilo volt amperes $= KVA_B$

Base kilovolts $= KV_B$

Base current $I_B = \frac{1000 \times MVA_B}{KV_B} = \frac{KVA_B}{KV_B}$ A

Base impedance $Z_B = \frac{1000 \times KV_B}{I_B}$ Ω

$100 \times MVA$ / Z_B / V_B

$$= \frac{KV_B^2}{MVA_B} = \frac{1000 \times KV_B^2}{KVA_B}$$

P.u impedance $Z_{pu} = \frac{Z \times MVA_B}{KV_B^2}$

$$= \frac{Z \times KVA_B}{KV_B^2 \times 1000}$$

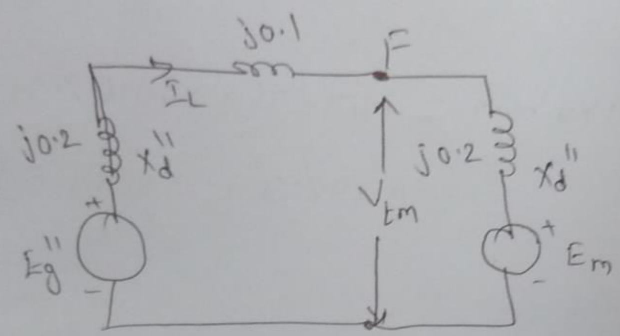
If the MVA base is change to new value

$$Z_{pu\,new} = Z_{pu.\,old} \times \frac{MVA_{new}}{MVA_{old}} \times \frac{KV^2_{B\,old}}{KV^2_{B\,new}}$$

$$(KV)_{B \text{ on HT section}} = KV_{B \text{ on LT section}} \times \frac{\text{HT voltage rating}}{\text{LT voltage rating}}$$

$MVA_b = 30\ MVA$, $KV_b = 13.2\ KV$.

$$I_b = \frac{MVA_b \times 1000}{\sqrt{3}\, KV_b} = \frac{30 \times 1000}{\sqrt{3} \times 13.2} = 1312.16A$$



Pre fault voltage at fault pt, $V_{tm} = 12.8KV$

(i) $\frac{12.8}{13.2} = 0.9697$ pu

$S = VI$

20mw 0.8pf = 25 MVA

$\frac{25}{30} = \frac{12.8}{13.2} \times I$

$I = 0.8594\angle 36.9°$

Real power of load = 20mw ~~0.8pf = 20/0.8 = 25MVA~~

~~(i) 20/30 = 0.6666pu~~

$P = VI\cos\phi$ (i) $20/30 = 0.66$ pu

Load current, pu $= \frac{P}{V\cos\phi} = \frac{0.6667}{0.9697 \times 0.8} = 0.8594$

$V_{tm} = 0.9697\angle 0°$ pu

$I_L = 0.8594\angle 36.9°$ pu

Prefault condition

Apply KVL to the ckt.

$E_g'' = (j0.2 + j0.1)I_L + V_{tm}$

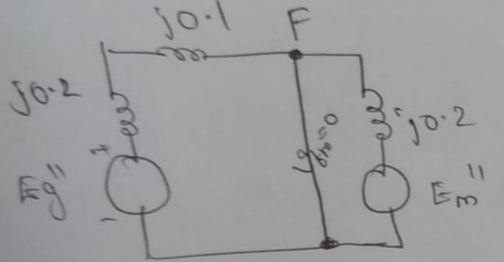
(i) $E_g'' = (j0.3) \times 0.8594\angle 36.9° + 0.9697\angle 0° = 0.8406\angle 14.2°$

$E_m'' \mp j0.2 I_L = V_{tm}$

$E_m'' = V_{tm} - j0.2 I_L = 0.9697\angle 0^\circ - j0.2 (0.8594 \angle 36.9^\circ)$

$= 1.0817 \angle -7.3^\circ$ pu

Fault condition



During fault $V_{tm} = 0$.

(a) $E_g'' = I_g''(j0.2 + j0.1) = j0.3 \times I_g''$

∴ Subtransient fault current in generator, $I_g'' = \frac{E_g''}{j0.3} = \frac{0.8406 \angle 14.2^\circ}{j0.3}$

$= 2.802 \angle -75.8^\circ$ pu

Subtransient current in motor, $I_m'' = \frac{E_m''}{j0.2} = \frac{1.0817 \angle -7.3^\circ}{j0.2}$

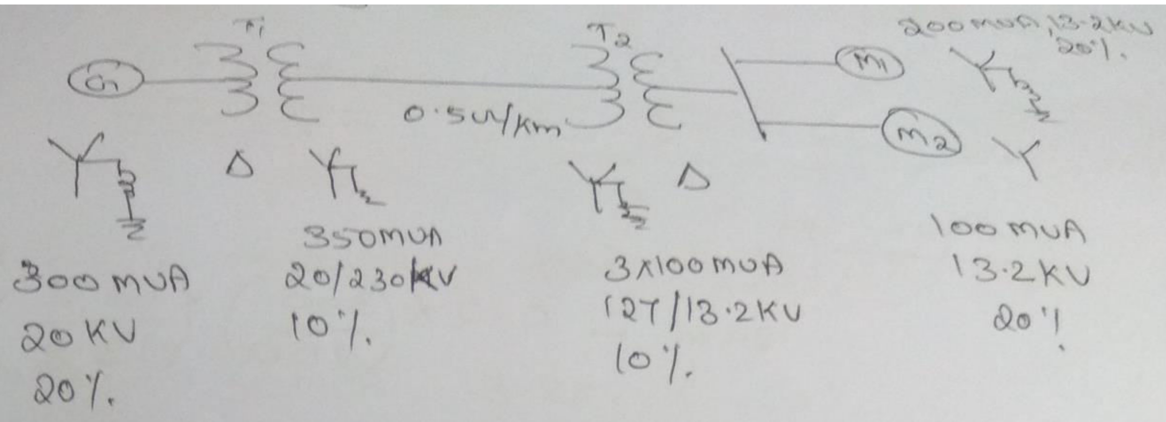
$= 5.4085 \angle -97.3^\circ$ pu

$I_f = I_m'' + I_g'' = 2.802 \angle -75.8^\circ + 5.4085 \angle -97.3^\circ$ pu

$= 8.081 \angle -90^\circ$ pu

$I_f = 8.081 \angle -90^\circ \times 1312.16 = 10603.56 \angle -90^\circ$ A

$= 10.60$ kA



$MVA_b = 300\,MVA$

$KV_b = 20\,KV$.

~~Base~~ KV_b HT side of T_1 = KV_b on LT side × $\frac{\text{HT rating}}{\text{LT rating}}$

$= 20 \times \frac{230}{20} = \underline{\underline{230\,KV}}$

~~KV_b on LT side of T_2~~ Generator reactance p.u = $\underline{\underline{0.2\,pu}}$

Transformer T_1

$X_{T_1,pu} = 0.1 \times \frac{300}{350} \times \left(\frac{20}{20}\right)^2 = 0.0857\,pu$

Tr. line (10)

total reactance $= 0.5 \times 64 = 32\Omega$

$$Pu = \frac{32 \times 300}{(230)^2} = \frac{32}{176.33\Omega} = 0.1815\,pu$$

Transformer T_2:

Base voltage on LT side of T_2 = KV_b of HT side × LT rating / HT rating

Voltage rating of T_2 = $\frac{\sqrt{3} \times 127}{13.2} = \frac{220\,kV}{13.2}$

$$= \frac{230 \times 13.2}{220} = 13.8\,kV$$

$$X_{pu.T_2} = 0.1 \times \left(\frac{300}{300}\right) \times \left(\frac{13.2}{13.8}\right)^2$$

$$= 0.0915\,pu$$

motor M_1

$$X_{pu\,m_1} = 0.2 \times \left(\frac{300}{200}\right) \times \left(\frac{13.2}{13.8}\right)^2 = 0.2745\,pu$$

motor M_2

$$X_{pu\,m_2} = 0.2 \times \left(\frac{300}{200}\right) \times \left(\frac{13.2}{13.8}\right)^2 = 0.549\,pu$$