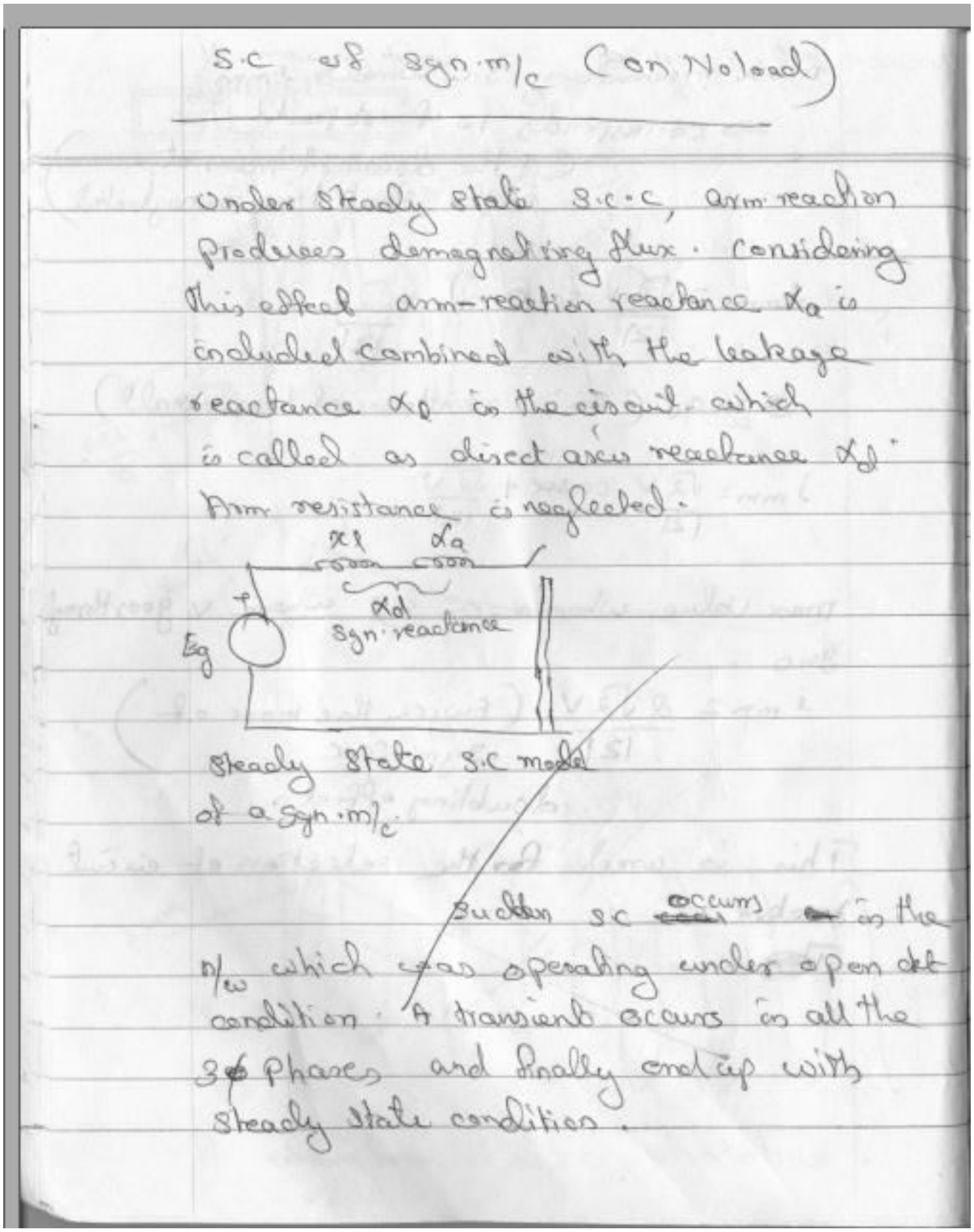
PSA IAT 1 Solution

1 With the help of waveform at the time of three phase symmetrical fault, on synchronous generator define steady state, transient and sub transient reactance. Also prove that Xd” <Xd’<Xd



S.C of syn. m/c (on No load)

Under steady state s.c.c, arm reaction produces demagnetising flux. Considering this effect arm-reaction reactance X_a is included combined with the leakage reactance X_l in the circuit which is called as direct axis reactance X_d.

Arm resistance is neglected.

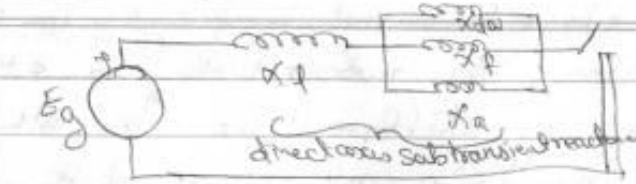
Steady state s.c model of a syn. m/c

Sudden s.c occurs in the n/w which was operating under open ckt condition. A transient occurs in all the 3φ phases and finally end up with steady state condition.

CB must ~~be~~ interrupted the current much before the steady state current is reached. DC off set current appears in all the 3 phases. The magnitude of DC off current is the 3 phases is different from each other b/coz the voltage wave at SCC is different for each wave.

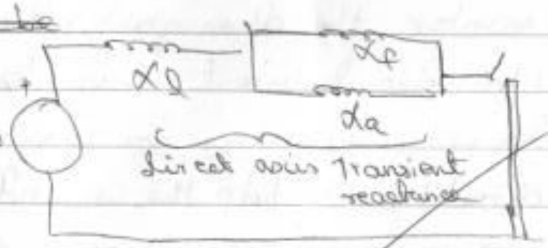
For short circuit studies we concentrate on sym. short circuit current. This current is limited by leakage reactance. Air gap flux doesn't change instantaneously, to counter the demagnetization of arm. short circuit current, currents appear on field wdg as well as in damper wdgs. in a direction to help the main flux. These currents decay in accordance with the winding time constant. Time constant of damper wdg is less than that of time constant of field wdg.

So in the critical part of short circuit X_f, X_{dw}, X_a appear in ||el.



circuit model during subtransient period of S.C.

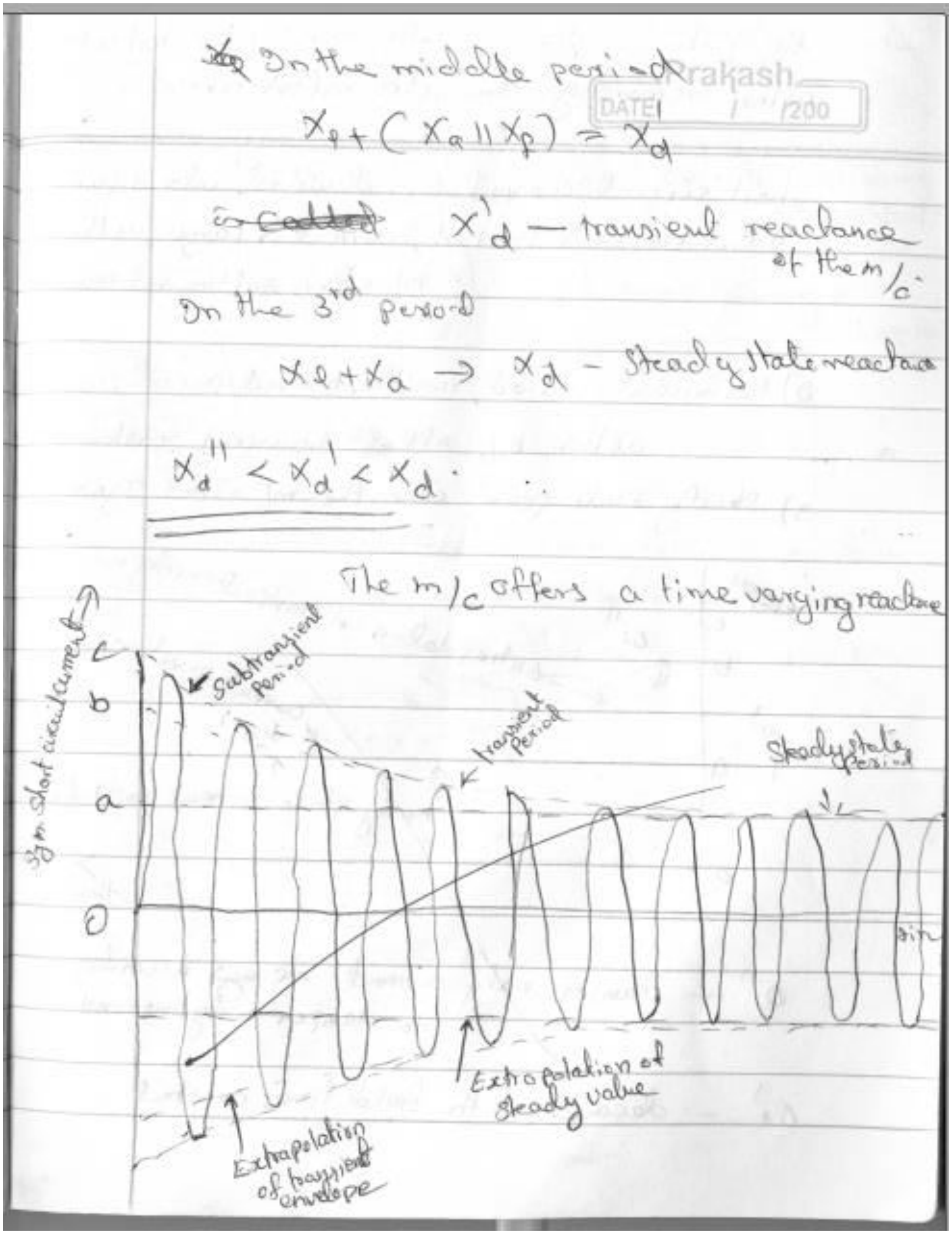
damper wdg currents a first die out and the X_{dw} ~~ckt~~ becoms open circuited Then X_a and X_f becomes ||el. and Then ~~it be~~



~~So~~ finally X_a in steadystate.

So the critical ~~part~~ period the reactance is $X_l + \frac{1}{1/X_a + 1/X_f + 1/X_{dw}} = X_d''$.

X_d'' - Subtransient reactance of the m/c.



~~xx~~ In the middle period

$$X_l + (X_a \,\|\, X_f) = X_d$$

~~is called~~ X'_d — transient reactance of the m/c.

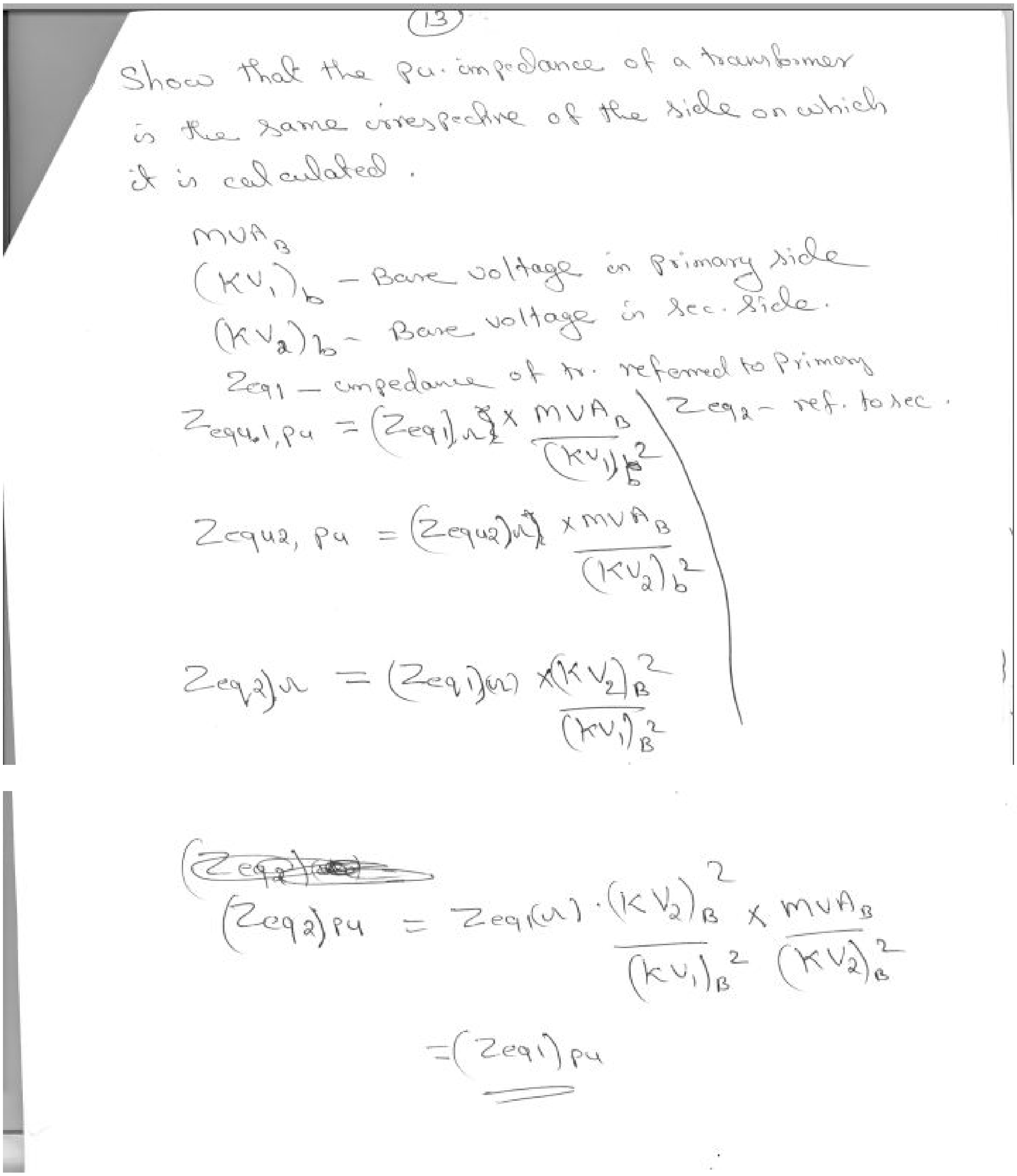
In the 3rd period

$$X_l + X_a \rightarrow X_d$$ - Steady state reactance

$$X''_d < X'_d < X_d .$$

The m/c offers a time varying reactance

2 a Prove that the p.u impedance of a transformer is the same irrespective of the side on which it is calculated.



(13)

Show that the p.u. impedance of a transformer is the same irrespective of the side on which 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 sec.

$$Z_{equ1,pu} = (Z_{eq1})_{\Omega} \times \frac{MVA_B}{(KV_1)_b^2}$$

$$Z_{equ2,pu} = (Z_{equ2})_{\Omega} \times \frac{MVA_B}{(KV_2)_b^2}$$

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

~~(Z_{eq2})~~

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

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

2(b) Mention the advantages of p.u quantities .Derive the expression for the per unit impedance, Zpu for the given set of base values and also write a modified per unit equation Zpu(new) when referred to a new set of base values.

The impedance of a device or component is usually specified in per unit on the base of name plate rating. When a system is formed by interconnecting various devices, it will be convenient for analysis if the impedances are converted to common base. Since all impedance in any one part of a system must be expressed on the common impedance base. It is necessary to have means of converting per-unit impedances from one base to another.

Let, Z = Actual impedance, Ω

Z_b = Base impedance, Ω

$$\text{Per unit impedance of a circuit element} = \frac{Z}{Z_b} = \frac{Z}{\frac{(kV_b)^2}{MVA_b}} = \frac{Z \times MVA_b}{(kV_b)^2} \qquad .....(1.12)$$

The equ(1.12) show that per unit impedance is directly proportional to base megavolt amperes and inversely proportional to the square of the base voltage. Using equ(1.12) we can derive an expression to convert the p.u. impedance expressed in one base value (old base) to another base (new base).

Let $kV_{b,\,old}$ and $MVA_{b,\,old}$ represents old base values and $kV_{b,\,new}$ and $MVA_{b,\,new}$ represents new base value.

Let, $Z_{pu,\,old}$ = p.u. impedance of a circuit element calculated on old base.

$Z_{pu,\,new}$ = p.u. impedance of a circuit element calculated on new base.

If old base values are used to compute the p.u. impedance of a circuit element with impedance Z, then equ(1.12) can be written as,

$$Z_{pu,\,old} = \frac{Z \times MVA_{b,\,old}}{(kV_{b,\,old})^2} \qquad .....(1.13)$$

$$Z = Z_{pu,\,old}\,\frac{(kV_{b,\,old})^2}{MVA_{b,\,old}} \qquad .....(1.14)$$

If the new base values are used to compute the p.u. impedance of a circuit element with impedance Z, then equ(1.12) can be written as

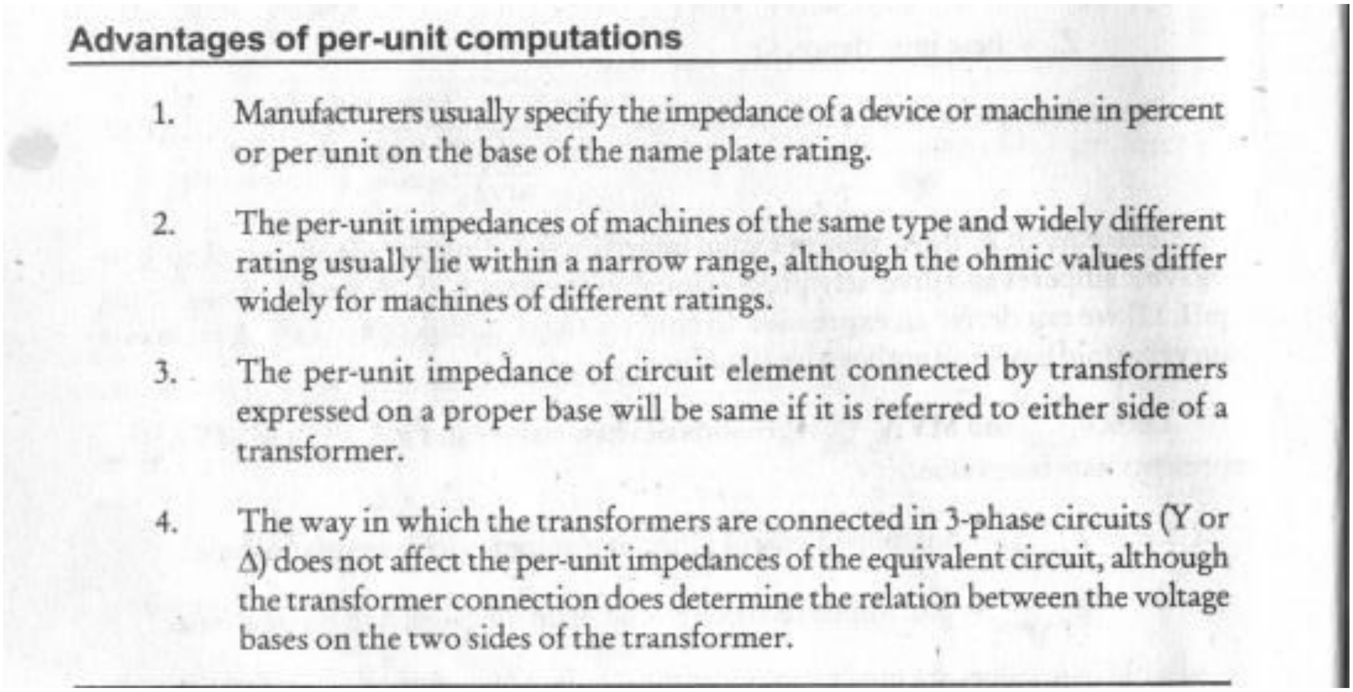
$$Z_{pu,\,new} = \frac{Z \times MVA_{b,\,new}}{(kV_{b,\,new})^2} \qquad .....(1.15)$$

On substituting for Z from equ(1.14) in equ(1.15) we get,

$$Z_{pu,\,new} = Z_{pu,\,old}\,\frac{\left(kV_{b,\,old}\right)^2}{MVA_{b,\,old}} \times \frac{MVA_{b,\,new}}{\left(kV_{b,\,new}\right)^2}$$

$$= Z_{pu,\,old} \times \left(\frac{kV_{b,\,old}}{kV_{b,\,new}}\right)^2 \times \left(\frac{MVA_{b,\,new}}{MVA_{b,\,old}}\right) \qquad .....(1.16)$$

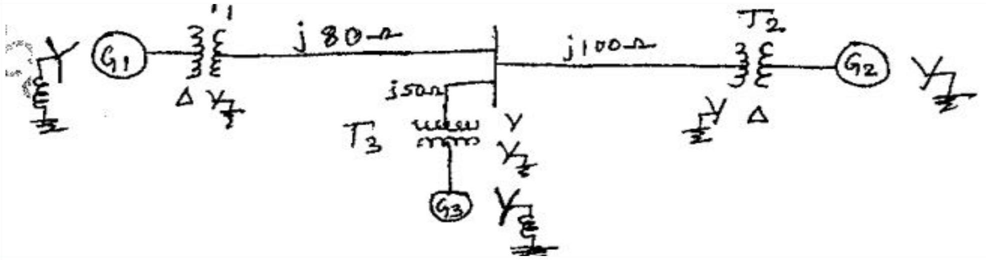
The equ(1.16) can be used to convert the p.u. impedance expressed on one base value to another base.



Advantages of per-unit computations

1. Manufacturers usually specify the impedance of a device or machine in percent or per unit on the base of the name plate rating.
2. The per-unit impedances of machines of the same type and widely different rating usually lie within a narrow range, although the ohmic values differ widely for machines of different ratings.
3. The per-unit impedance of circuit element connected by transformers expressed on a proper base will be same if it is referred to either side of a transformer.
4. The way in which the transformers are connected in 3-phase circuits (Y or Δ) does not affect the per-unit impedances of the equivalent circuit, although the transformer connection does determine the relation between the voltage bases on the two sides of the transformer.

3 The one line diagram of an unloaded power system is shown in fig. Draw the per unit reactance diagram choose a base of 50 MVA, 13.8 KV in the generator G1 circuit.



The generators and transformers are rated as follows.

G1:20MVA , 13.8 KV ,X”=0.2 pu

G2:30MVA , 18 KV ,X”=0.2 pu

G3:30MVA , 20 KV ,X”=0.2 pu

T1:25 MVA ,13.8 KV Δ/220 KV Y , X=10%

T2:Three single phase units each rated 10 MVA,127 KV Y/ 18 KV Δ , X=10 %

T3:35 MVA ,220 KV Y/22 KV Y , X=10 %

Consider 50 MVA, 13.8 kV on generator G1.

$$X_{G_1 pu} = 0.2 \times \left(\frac{50}{20}\right)\left(\frac{13.8}{13.8}\right)^2 = \underline{\underline{0.5 pu}}$$

Transformer T_1

$$kV_b \text{ on HT side } T_1 = 13.8 \times \left(\frac{220}{13.8}\right) = 220 kV$$

$$X_{T_1 pu} = 0.1 \times \left(\frac{50}{25}\right) \times \left(\frac{13.8}{13.8}\right)^2 = \underline{\underline{0.2 pu}}$$

$$Z_{80, pu} = \frac{80}{Z_B} \quad \Bigg| \quad Z_B = \frac{(220)^2}{50} = 968\Omega$$

$$= \frac{80}{968} = \underline{\underline{0.0828 pu}}$$

$$Z_{100, pu} = \frac{100}{968} = \underline{\underline{0.1033 pu}}$$

$$Z_{50, pu} = \frac{50}{968} = \underline{\underline{0.0516 pu}}$$

Transformer T_2 $\quad \sqrt{3} \times 127 / 18 = 220/18$ kV

$$kV_b \text{ on LT side of } T_2 = kV_b \text{ on HT side of } T_2 \times \frac{LT}{HT} \text{ of } T_2$$

$$= 220 \times \frac{18}{220} = \underline{\underline{18 kV}}$$

$$X_{T_2 pu} = 0.1 \times \frac{50}{30} \times \left(\frac{18}{18}\right)^2 = \underline{\underline{0.1667 pu}}$$

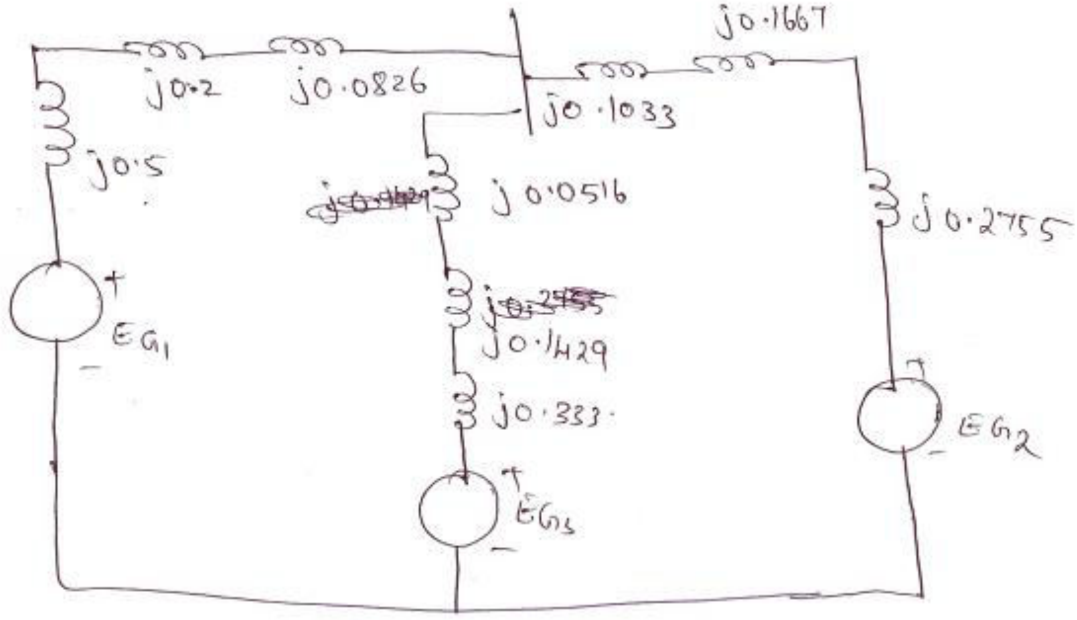
$$X_{G_3 pu} = 0.2 \times \left(\frac{50}{30}\right) \times \left(\frac{18}{18}\right)^2 = \underline{\underline{0.333 pu}}$$

$$kV_b \text{ on LT side of } T_3 = kV_b \text{ on HT side of } T_3 \times \frac{LT}{HT} \text{ of } T_3$$

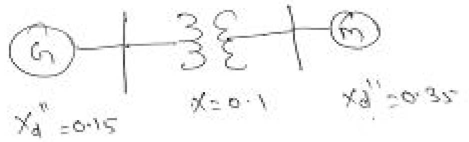
$$= 220 \times \frac{22}{220} = \underline{\underline{22 kV}}$$

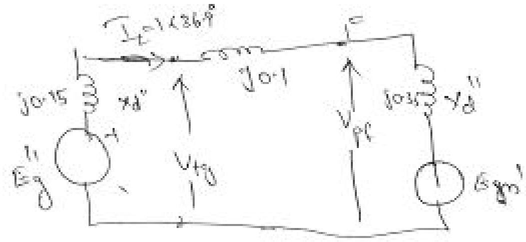
$$X_{G_2 pu} = 0.2 \times \left(\frac{50}{30}\right) \times \left(\frac{20}{22}\right)^2 = \underline{\underline{0.2755 pu}}$$

$$X_{T_3 pu} = 0.1 \times \left(\frac{50}{35}\right) \times \left(\frac{22}{22}\right)^2 = j0.1429$$


j0·1667
j0·2
j0·0826
j0·1033
j0·5
~~j0·1429~~
j0·0516
j0·2755
~~j0·2755~~
j0·1429
j0·333
EG1
EG2
EG3
+
−

A generator is connected through a transformer to a Syn. motor. The subtransient reactances of generator and motor are 0.15 and 0.35 respectively. The leakage reactance of transformer is 0.1 pu. All the reactances are calculated on a common base. A three phase fault occurs at the terminals of the motor when the terminal voltage of the generator is 0.9 pu. The output current of generator is 1 pu and 0.8 pf leading. Find the subtransient current in pu in the fault, generator and motor. Use the terminal voltage of generator as reference vector.





$I_L = 1\angle 36.9°$

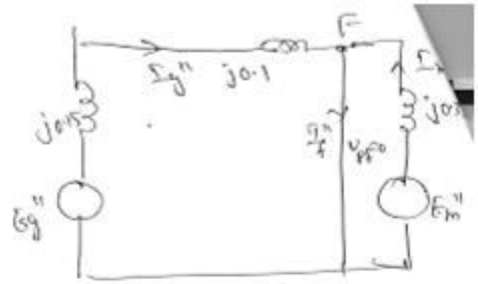
$V_{tg} = 1\angle 0$

$E_g'' = j0.15 \times I_L + V_{tg}$

$E_g = 0.818\angle 8.4°$ pu

$E_m'' = V_{tg} - j0.45 I_L$

$E_m'' = 1.22\angle -17.1°$ pu

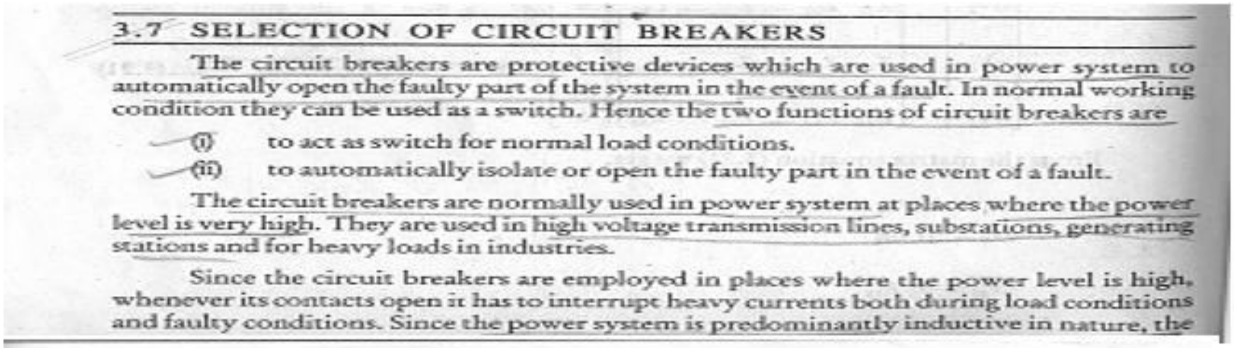


$$I_g'' = \frac{E_g''}{j0.15 + j0.1} = \underline{\underline{3.274\angle -81.6^\circ \text{ pu}}}$$

$$I_m'' = \frac{E_m''}{j0.35} = 3.498\angle -107.1^\circ \text{ pu}.$$

$$I_f'' = I_g'' + I_m'' = \underline{\underline{6.606\angle -94.8^\circ \text{ pu}}}$$

5 (a) Write a short note on circuit breakers.



3.7 SELECTION OF CIRCUIT BREAKERS

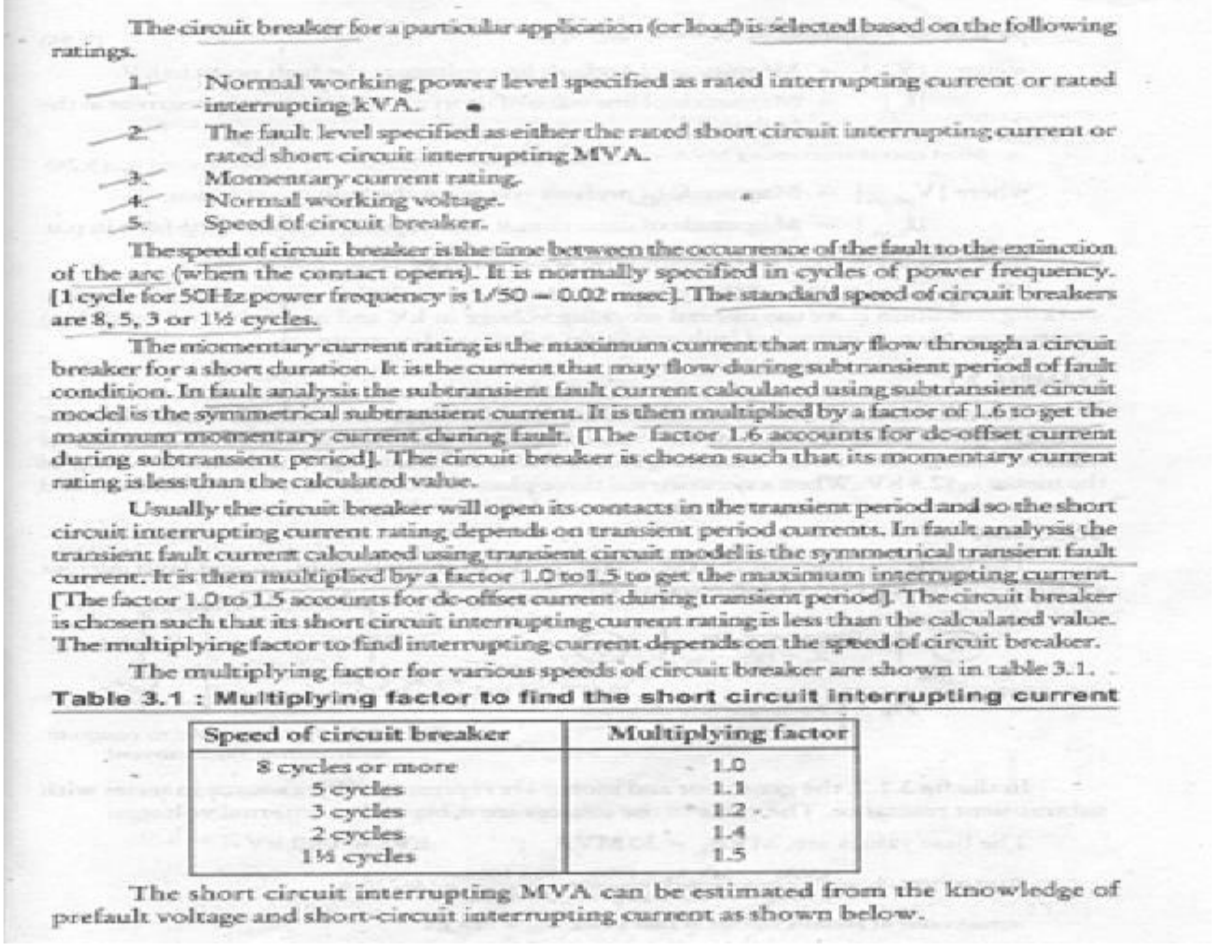
The circuit breakers are protective devices which are used in power system to automatically open the faulty part of the system in the event of a fault. In normal working condition they can be used as a switch. Hence the two functions of circuit breakers are

(i) to act as switch for normal load conditions.

(ii) to automatically isolate or open the faulty part in the event of a fault.

The circuit breakers are normally used in power system at places where the power level is very high. They are used in high voltage transmission lines, substations, generating stations and for heavy loads in industries.

Since the circuit breakers are employed in places where the power level is high, whenever its contacts open it has to interrupt heavy currents both during load conditions and faulty conditions. Since the power system is predominantly inductive in nature, the



The circuit breaker for a particular application (or load) is selected based on the following ratings.

1. Normal working power level specified as rated interrupting current or rated interrupting kVA.
2. The fault level specified as either the rated short circuit interrupting current or rated short circuit interrupting MVA.
3. Momentary current rating.
4. Normal working voltage.
5. Speed of circuit breaker.

The speed of circuit breaker is the time between the occurrence of the fault to the extinction of the arc (when the contact opens). It is normally specified in cycles of power frequency. [1 cycle for 50Hz power frequency is 1/50 = 0.02 msec]. The standard speed of circuit breakers are 8, 5, 3 or 1½ cycles.

The momentary current rating is the maximum current that may flow through a circuit breaker for a short duration. It is the current that may flow during subtransient period of fault condition. In fault analysis the subtransient fault current calculated using subtransient circuit model is the symmetrical subtransient current. It is then multiplied by a factor of 1.6 to get the maximum momentary current during fault. [The factor 1.6 accounts for dc-offset current during subtransient period]. The circuit breaker is chosen such that its momentary current rating is less than the calculated value.

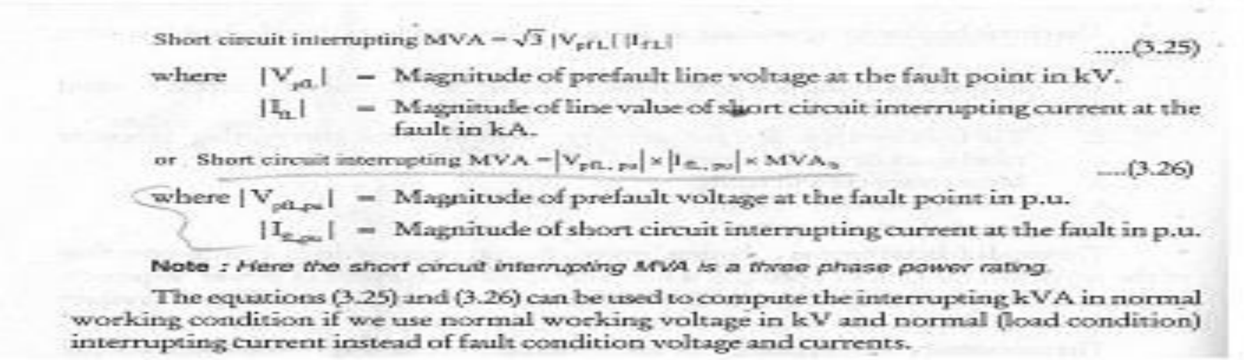
Usually the circuit breaker will open its contacts in the transient period and so the short circuit interrupting current rating depends on transient period currents. In fault analysis the transient fault current calculated using transient circuit model is the symmetrical transient fault current. It is then multiplied by a factor 1.0 to 1.5 to get the maximum interrupting current. [The factor 1.0 to 1.5 accounts for dc-offset current during transient period]. The circuit breaker is chosen such that its short circuit interrupting current rating is less than the calculated value. The multiplying factor to find interrupting current depends on the speed of circuit breaker.

The multiplying factor for various speeds of circuit breaker are shown in table 3.1.

Table 3.1 : Multiplying factor to find the short circuit interrupting current

Speed of circuit breaker	Multiplying factor
8 cycles or more	1.0
5 cycles	1.1
3 cycles	1.2
2 cycles	1.4
1½ cycles	1.5

The short circuit interrupting MVA can be estimated from the knowledge of prefault voltage and short-circuit interrupting current as shown below.



$$\text{Short circuit interrupting MVA} = \sqrt{3}\,|V_{pfL}|\,|I_{fL}| \qquad .....(3.25)$$

where $|V_{pfL}|$ = Magnitude of prefault line voltage at the fault point in kV.

$|I_{fL}|$ = Magnitude of line value of short circuit interrupting current at the fault in kA.

$$\text{or Short circuit interrupting MVA} = |V_{pfL,pu}| \times |I_{sc,pu}| \times MVA_b \qquad ....(3.26)$$

where $|V_{pfL,pu}|$ = Magnitude of prefault voltage at the fault point in p.u.

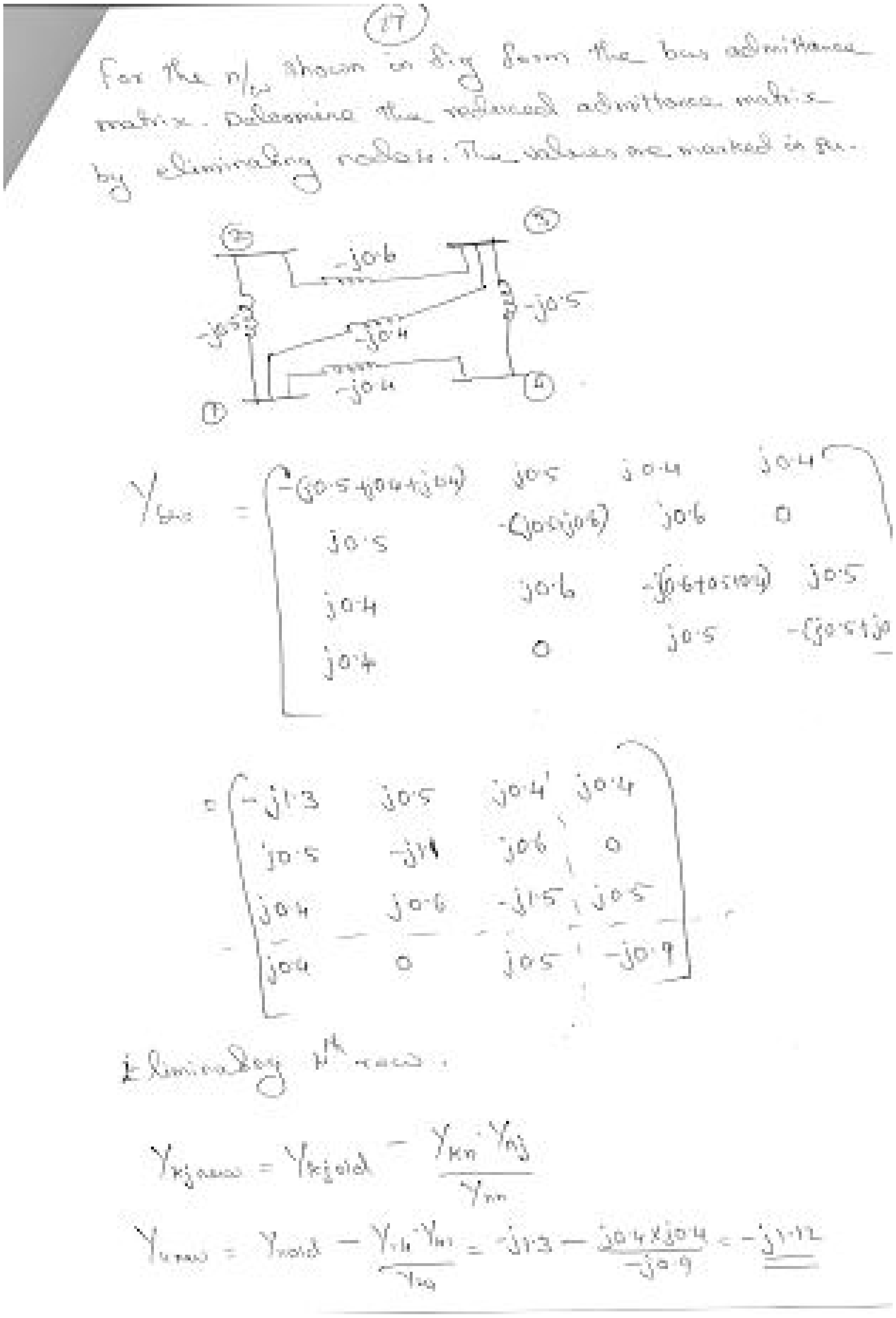
$|I_{sc,pu}|$ = Magnitude of short circuit interrupting current at the fault in p.u.

Note : *Here the short circuit interrupting MVA is a three phase power rating.*

The equations (3.25) and (3.26) can be used to compute the interrupting kVA in normal working condition if we use normal working voltage in kV and normal (load condition) interrupting current instead of fault condition voltage and currents.

5 b

For the network shown in fig form the bus admittance matrix .Determine the reduced admittance matrix by eliminating node 4.The values are marked in pu [5]



(17)

For the n/w shown in fig form the bus admittance matrix. Determine the reduced admittance matrix by eliminating node 4. The values are marked in pu.

$$Y_{bus} = \begin{bmatrix} -(j0.5+j0.4+j0.4) & j0.5 & j0.4 & j0.4 \\ j0.5 & -(j0.5+j0.6) & j0.6 & 0 \\ j0.4 & j0.6 & -(j0.6+j0.5+j0.4) & j0.5 \\ j0.4 & 0 & j0.5 & -(j0.5+j0 \end{bmatrix}$$

$$= \left[\begin{array}{ccc|c} -j1.3 & j0.5 & j0.4 & j0.4 \\ j0.5 & -j1.1 & j0.6 & 0 \\ j0.4 & j0.6 & -j1.5 & j0.5 \\ \hline j0.4 & 0 & j0.5 & -j0.9 \end{array}\right]$$

Eliminating n^{th} row.

$$Y_{kj\,new} = Y_{kj\,old} - \frac{Y_{kn} \cdot Y_{nj}}{Y_{nn}}$$

$$Y_{11\,new} = Y_{11\,old} - \frac{Y_{14} \cdot Y_{41}}{Y_{44}} = -j1.3 - \frac{j0.4 \times j0.4}{-j0.9} = \underline{\underline{-j1.12}}$$

$$Y_{12new} = Y_{12old} - \frac{Y_{14} \cdot Y_{42}}{Y_{44}} = j0.5 - \frac{(j0.4 \times 0)}{-j0.9} = j0.5$$

$$Y_{13} = Y_{13old} - \frac{Y_{14} \cdot Y_{43}}{Y_{44}} = j0.4 - \frac{(j0.4 \times j0.5)}{-j0.9} = j0.622$$

$$Y_{21} = Y_{12} = j0.5$$

$$Y_{22} = Y_{22old} - \frac{Y_{24} Y_{42}}{Y_{44}} = -j1.1 - \frac{0 \times 0}{-j0.9} = -j1.1$$

$$Y_{23} = Y_{23old} - \frac{Y_{24} Y_{43}}{Y_{44}} = j0.6 - \frac{0 \times j0.5}{-j0.9} = j0.6$$

$$Y_{31} = Y_{13} = j0.622$$

$$Y_{32} = Y_{23} = j0.6$$

$$Y_{33} = Y_{33old} - \frac{Y_{34} \cdot Y_{43}}{Y_{44}} = -j1.5 - \frac{j0.5 \times j0.5}{-j0.9} = \underline{\underline{-j1.22}}$$

$$Y_{bus} = \underline{\underline{\begin{bmatrix} -j1.12 & j0.5 & j0.622 \\ j0.5 & -j1.1 & j0.6 \\ j0.622 & j0.6 & -j1.22 \end{bmatrix}}}$$

A generator connected through a five cycle circuit breaker to a transformer is rated at 100 MVA, 18 KV with reactances $X_d'' = 20\%$, $X_d' = 25\%$ and $X_d = 110\%$. It is operated on no load and at rated voltage. When a 3 phase fault occurs between the breaker and the transformer, find

ⓐ Short circuit current in CB

ⓑ The initial symmetrical rms current in CB

ⓒ The max. possible dc component of the short circuit ~~breaker~~ current in the breaker

ⓓ The current to be interrupted by the breaker

ⓔ The interrupting MVA.

Let 100 MVA & 18 KV$_b$ be the base

ⓐ Short ckt current in the breaker

Generator at rated voltage = 1 pu.

$E_g = E_g' = E_g'' = 1$ pu.

Subtransient fault current excluding dc offset current $I_g'' = \frac{E_g''}{jX_d''} = \frac{1\angle 0}{j0.2}$

$= 5\angle -90°$ pu

Transient fault current
excluding dc offset cur

$$I_g' = \frac{E_g'}{jX_d'} = \frac{1\angle 0^\circ}{j0.25}$$

$$= 4\angle -90^\circ$$

Steady state fault current, $I_g = \frac{E_g}{jX_d} = \frac{1\angle 0^\circ}{j1.1}$

$$= \underline{0.909\angle -9}$$

~~maximum momentary short ckt current $= 1.6 \times I_g''$~~
~~dc offset~~

Actual value of sub transient current

$$= I_g'' \times I_b = 16.0375\ kA$$

" of transient current

$$= I_g' \times I_b = 12.83\ kA.$$

" of steady current $= I_g \times I_b = 2.9159\ kA$

maximum momentary short ckt current $= I_g'' \times 1.6 = 5 \times 1.6 = \underline{8\ pu}$

$$= 8 \times I_b = \underline{25.66\ kA}$$

⑤ Initial symmetrical rms current

$$= I_g'' = 5\angle -90^\circ = \underline{16.03\ kA}$$

⑥ maximum possible dc component is the diff b/w max momentary current and initial symm. short ckt current

$$= 25.66 - 16.03 = 9.\underline{6225}\ kA$$

Interrupting current at 5 cycles: $\hookrightarrow$ transient period.

$\Rightarrow$ pu transient current $\times 1.1$

$$= 4 \times 1.1 = \underline{\underline{4.4\,pu}}$$

$$= 4.4 \times \cancel{32}\, I_b = \underline{\underline{14.113\,kA}}$$

(e) Interrupting MVA = $\begin{pmatrix}\text{pu} \\ \text{value of} \\ \text{pre fault} \\ \text{voltage}\end{pmatrix} \times \begin{pmatrix}\text{pu} \\ \text{value of} \\ \text{interrupti-} \\ \text{ng curr}\end{pmatrix} \times MVA_b$

$$= (1.0) \times (4.4) \times 100 = \underline{\underline{440\,MVA}}$$