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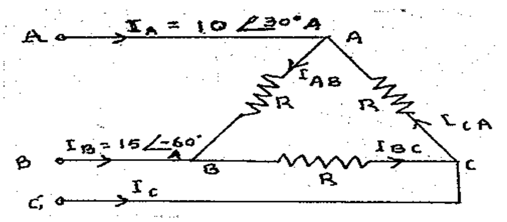
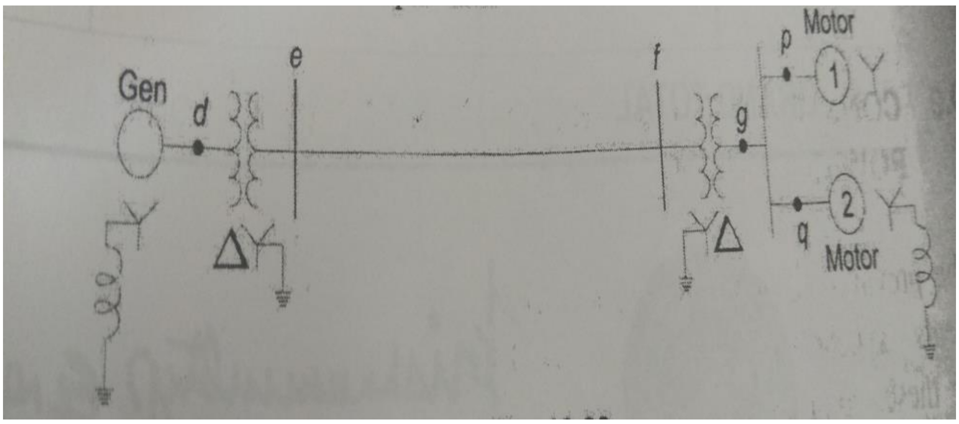
Internal Assesement Test - II

Sub:	Power System Analysis							Code:	15EE62
Date:	16/04/2018	Duration:	90 mins	Max Marks:	50	Sem:	6	Branch:	EEE
Answer Any FIVE FULL Questions									

		Marks	OBE CO	OBE RBT
1a	Prove that a balanced set of 3 phase voltages will have only positive sequence components of voltages.	[5]	CO3	L2
1b	With the help of relevant vector diagrams for voltages and currents, establish the phase shift of symmetrical components in Y Δ transformers.	[5]	CO3	L2
2	Draw the interconnected sequence networks for L-G fault in an unloaded generator with and without fault impedance Z_f clearly indicating positive ,negative and zero sequence impedance,symmetrical components of voltages and currents.Also write the expressions for the fault current	[10]	CO4	L3
3	A delta connected balanced resistive load is connected across an unbalanced 3 phase supply as shown in fig. With currents in the line A and B specified, find the symmetrical components of line currents. Also find the symmetrical components of delta currents.	[10]	CO3	L3



		Marks	OBE CO	OBE RBT
4	25 MVA ,11 kV ,three phase generator has a sub transient reactance of 20%.The generator supplies two motors over a transmission line with transformers at both ends as shown in single line diagram. The motors have rated inputs of 15 and 7.5 MVA, both 10 kV with 25% sub transient reactance. The three phase transformers are both rated 30 MVA, 10.8/121 kV, connection Δ Y with leakage reactance of 10 % each. The series reactance of the line is 100 ohms.	[10]	CO3	L3



	Zero sequence reactance for the generator and motors are 0.06 p.u. Current limiting reactors of 2.5 ohms each are connected in the neutral of the generator and motor 2 .The zero sequence reactance of the transmission line is 300 ohms. Draw the positive sequence, negative sequence and zero sequence networks of the system with reactances marked in per unit.			
5a	Derive an expression for 3 phase power in terms of symmetrical components.	[5]	CO3	L2
5b	Derive phase currents of unbalanced system in terms of sequence currents.	[5]	CO3	L3
	Draw and explain about the positive, negative and zero sequence network of an unloaded synchronous generator.		CO3	L2

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	-	-

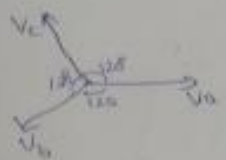
Cognitive level	KEYWORDS
L1	List, define, tell, describe, identify, show, label, collect, examine, tabulate, quote, name, who, when, where, etc.
L2	summarize, describe, interpret, contrast, predict, associate, distinguish, estimate, differentiate, discuss, extend
L3	Apply, demonstrate, calculate, complete, 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*

Solutions:

1a)

Prove that a balanced set of three phase voltages will have only positive sequence components of voltages only.



V_a, V_b, V_c — phase voltages of balanced 3φ system

$V_b = a^2 V_a$

$V_c = a V_a$

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} V_a \\ a^2 V_a \\ a V_a \end{bmatrix}$$

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} V_a + a^2 V_a + a V_a \\ V_a + a^3 V_a + a^3 V_a \\ V_a + a^4 V_a + a^2 V_a \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 0 \\ 3V_a \\ 0 \end{bmatrix} =$$

ie) $$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \begin{bmatrix} 0 \\ V_a \\ 0 \end{bmatrix}$$

ie) $V_{a0} = 0$

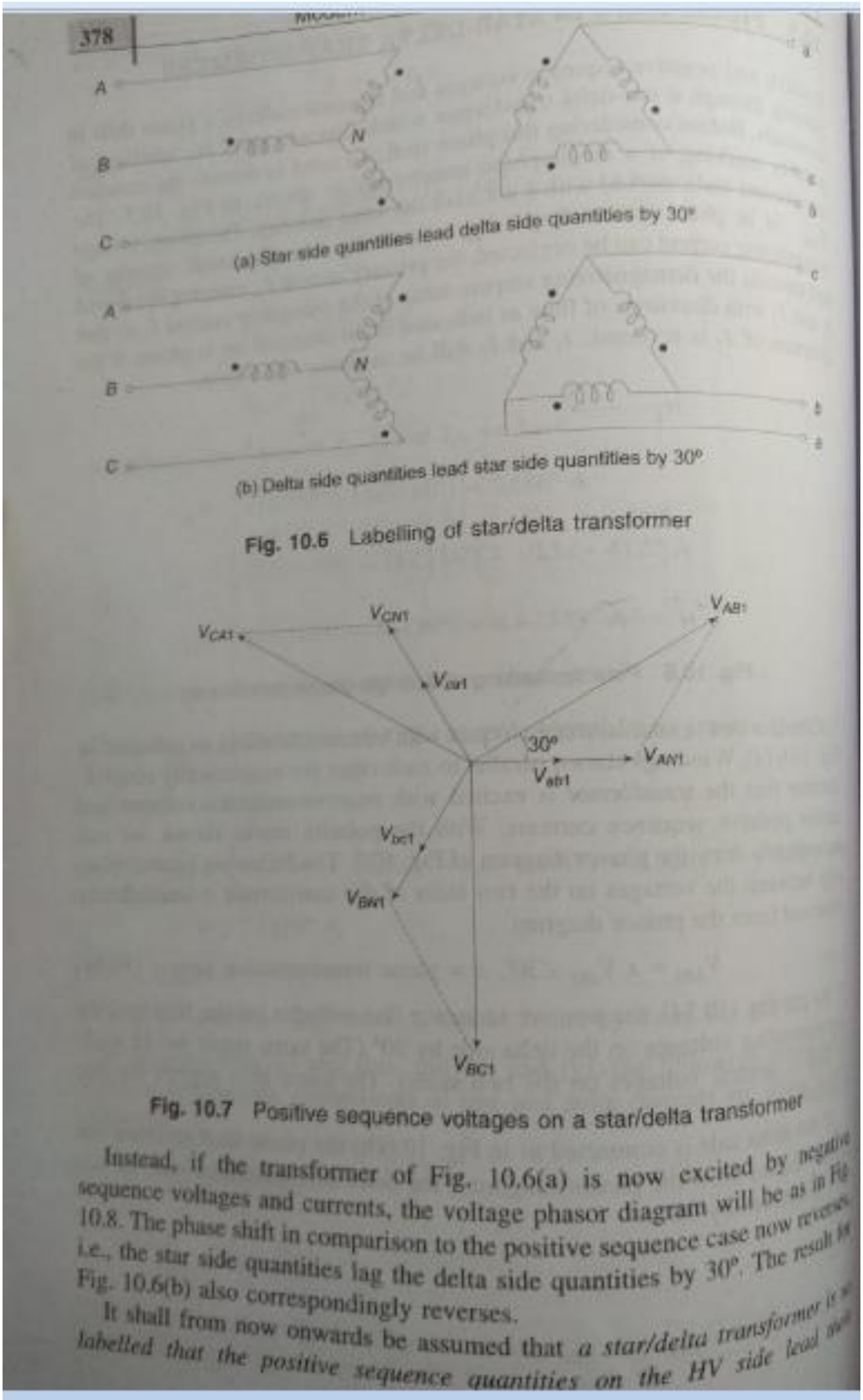
$V_{a1} = V_a$

$V_{a2} = 0$

Proves that a balanced set of three phase voltages will have only positive sequence voltages. Negative and zero sequence components are always absent in a balanced system.

It holds good for a balanced

1b)


378

A
B
C
N

(a) Star side quantities lead delta side quantities by 30°

A
B
C
N

(b) Delta side quantities lead star side quantities by 30°

Fig. 10.6 Labelling of star/delta transformer

V_{CA1} V_{CN1} V_{AB1} V_{ca1} 30° V_{AN1} V_{ab1} V_{bc1} V_{BN1} V_{BC1}

Fig. 10.7 Positive sequence voltages on a star/delta transformer

Instead, if the transformer of Fig. 10.6(a) is now excited by negative sequence voltages and currents, the voltage phasor diagram will be as in Fig. 10.8. The phase shift in comparison to the positive sequence case now reverses, i.e., the star side quantities lag the delta side quantities by 30°. The result for Fig. 10.6(b) also correspondingly reverses.

It shall from now onwards be assumed that *a star/delta transformer is so labelled that the positive sequence quantities on the HV side lead the*

1b)

corresponding positive sequence quantities on the LV side by 30°. The reverse is the case for negative sequence quantities wherein HV quantities lag the corresponding LV quantities by 30°.

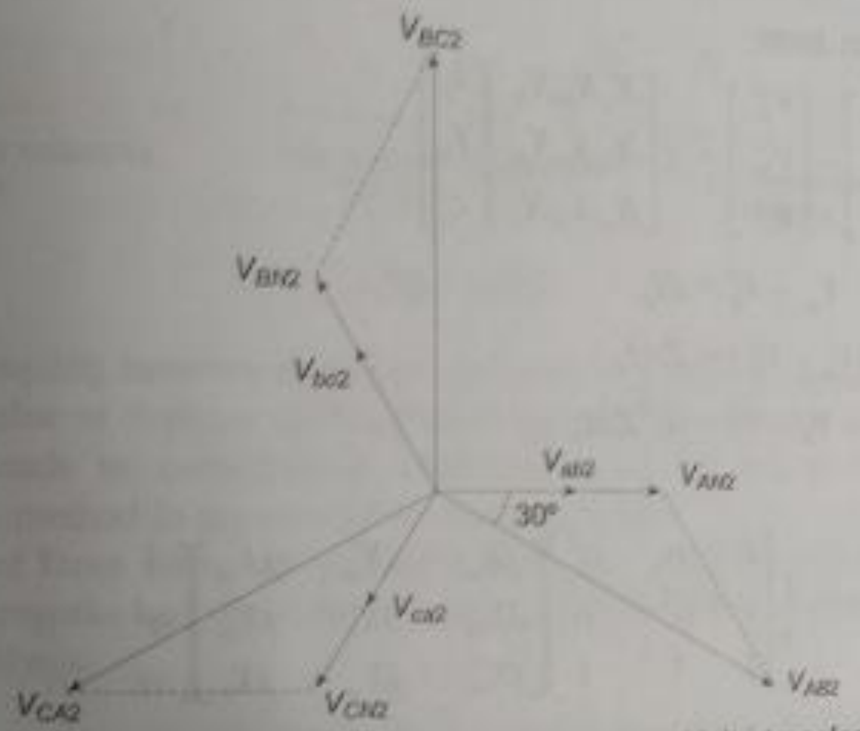
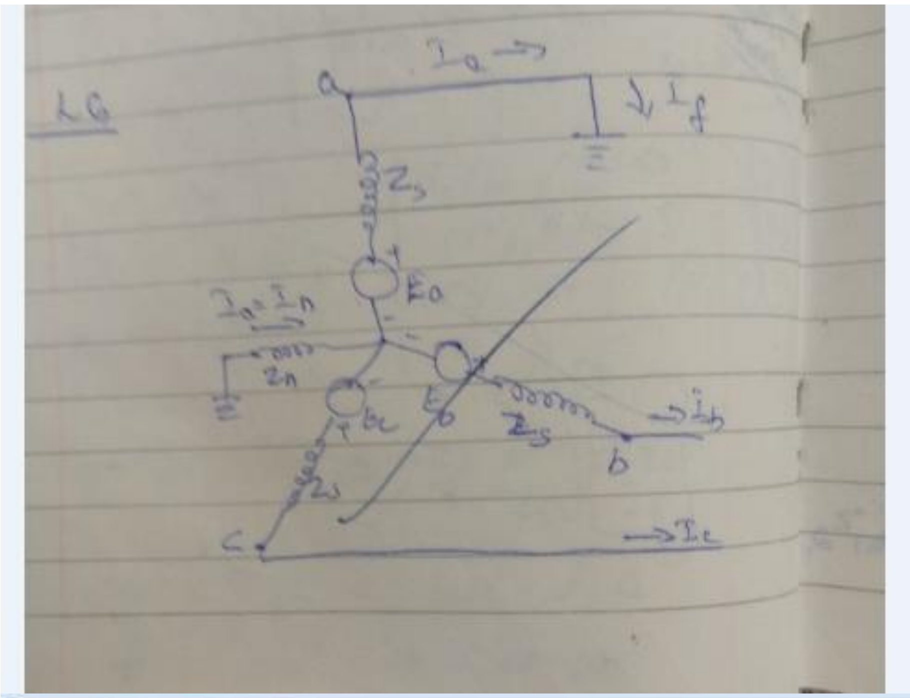


Fig. 10.8 Negative sequence voltages on a star/delta transformer

TRANSMISSION LINES

2)



circuit model ~~of~~ for

single line to ground fault on an unloaded Y connected generator with its neutral grounded through a reactance. Here phase a is shorted to ground. The fault current $I_f = I_a$ since the generator is unloaded the current in other phases are zero.

$$I_b = 0, \; I_c = 0, \; V_a = 0$$

sym components

$$\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

sub $I_b = I_c = 0$.

$$\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ 0 \\ 0 \end{bmatrix}$$

$$I_{a0} = I_{a1} = I_{a2} = I_a/3$$

From sequence n/w's of the generator we get

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \begin{bmatrix} 0 \\ E_a \\ 0 \end{bmatrix} - \begin{bmatrix} Z_0 & 0 & 0 \\ 0 & Z_1 & 0 \\ 0 & 0 & Z_2 \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix}$$

sub $I_{a0} = I_{a1}$, $I_{a2} = I_{a1}$

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \begin{bmatrix} 0 \\ E_a \\ 0 \end{bmatrix} - \begin{bmatrix} Z_0 & 0 & 0 \\ 0 & Z_1 & 0 \\ 0 & 0 & Z_2 \end{bmatrix} \begin{bmatrix} I_{a1} \\ I_{a1} \\ I_{a1} \end{bmatrix}$$

$V_{a0} = -Z_0 I_{a1}$

$V_{a1} = E_a - Z_1 I_{a1}$

$V_{a2} = -Z_2 I_{a1}$

on adding

$V_{a0} + V_{a1} + V_{a2} = -I_{a1} Z_0 + E_a - Z_1 I_{a1} - I_{a1} Z_2$

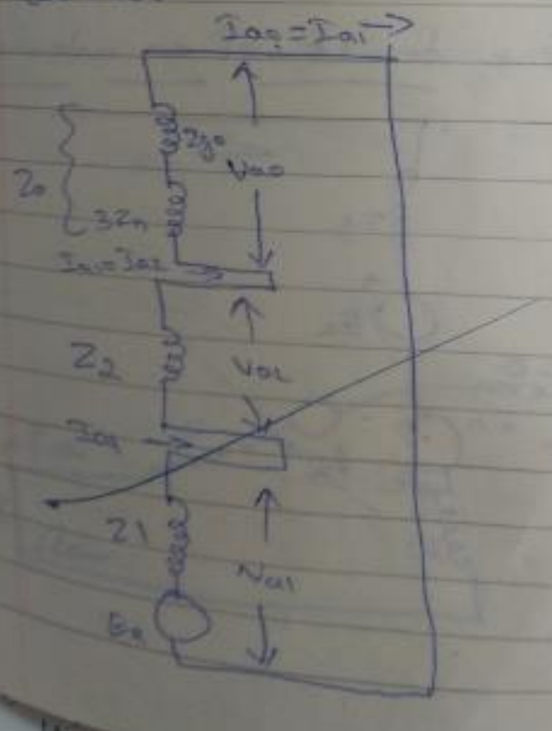
Phase a is shorted to ground.

$V_a = V_0 + V_{a_1} + V_{a_2} = 0$

$-I_{a_1}Z_0 + E_a - I_{a_1}Z_1 - I_{a_2}Z_2 = 0$

$\therefore I_{a_1} = \dfrac{E_a}{Z_1 + Z_2 + Z_0}$

from this eqn the ckt can be drawn like this



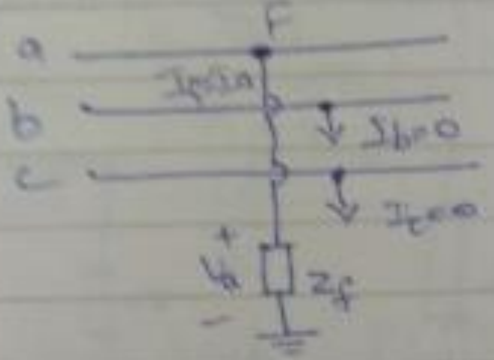
I_{a1}
$I_{a2} =$

If the neutral of the generator is not grounded, the zero sequence nw is open circuited and Z_0 is infinite. Then $I_{a_1} = I_{a_2} = I_{a_0} = 0$. No path exists for the flow of current in the fault unless the generator neutral is grounded.

$I_f = I_a = 3I_{a_1}$

Faults on a power system

Single line to ground fault



$I_b = 0, \; I_c = 0, \; V_a = I_a Z_f$

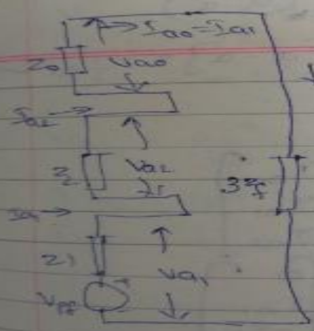
$$\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ 0 \\ 0 \end{bmatrix}$$

$I_a = 3 I_{a1}$

$V_a = V_{a0} + V_{a1} + V_{a2} = Z_f I_a = 3 Z_f I_{a1}$

$$I_{a1} = \frac{V_{pf}}{(Z_0 + Z_1 + Z_2) + 3Z_f}$$

$$I_f = I_a = 3 I_{a1} = \frac{3 V_{pf}}{(Z_1 + Z_2 + Z_0) + 3Z_f}$$



$V_{a1} = V_{pf} - Z_1 I_{a1}$

$V_{a0} = -Z_0 I_{a1}$

$V_{a2} = -Z_2 I_{a1}$

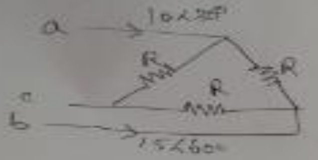
3)

$= \frac{1}{3}(I_A + I_B + I_C)$

$= \frac{1}{3}[I_C - I_B + I_A - I_C + I_B - I_A]$

$= 0$

(2) A delta connected balance resistive load is connected across an unbalanced 3φ supply as shown in fig. Find the sym. components of line currents and delta current.



$I_a + I_b + I_c = 0$

$I_c = -(I_a + I_b) = 18\angle 155° A$

$I_{a1} = \frac{1}{3}[I_a + a I_b + a^2 I_c]$

$= 13.9\angle 61.8° A$

$I_{a2} = \frac{1}{3}[I_a + a^2 I_b + a I_c] = 4.6\angle 24° A$

$I_{a0} = \frac{1}{3}[I_a + I_b + I_c] = 0$

$I_{a1} = j\sqrt{3}\, I_{A1}$ (i.e.) $I_{A1} = \frac{I_{a1}}{j\sqrt{3}} = 8\angle -48.9° A$

$I_{a2} = -j\sqrt{3}\, I_{A2}$ (i.e.) $I_{A2} = \frac{I_{a2}}{-j\sqrt{3}} = 2.6\angle 338° A$

$I_{A0} = 0$

4)

... 11 kV in the generator circuit requires a 25 MVA base in all other circuits and the following voltage bases.

Transmission line voltage base $= 11 \times \dfrac{121}{10.8} = 123.2$ kV

Motor voltage base $= 123.2 \times \dfrac{10.8}{121} = 11$ kV

The reactances of transformers, line and motors are converted to pu values on appropriate bases as follows:

$$\text{Transformer reactance} = 0.1 \times \frac{25}{30} \times \left(\frac{10.8}{11}\right)^2 = 0.0805 \text{ pu}$$

$$\text{Line reactance} = \frac{100 \times 25}{(123.2)^2} = 0.164 \text{ pu}$$

$$\text{Reactance of motor 1} = 0.25 \times \frac{25}{15} \times \left(\frac{10}{11}\right)^2 = 0.345 \text{ pu}$$

$$\text{Reactance of motor 2} = 0.25 \times \frac{25}{7.5} \times \left(\frac{10}{11}\right)^2 = 0.69 \text{ pu}$$

The required positive sequence network is presented in Fig. 10.23.

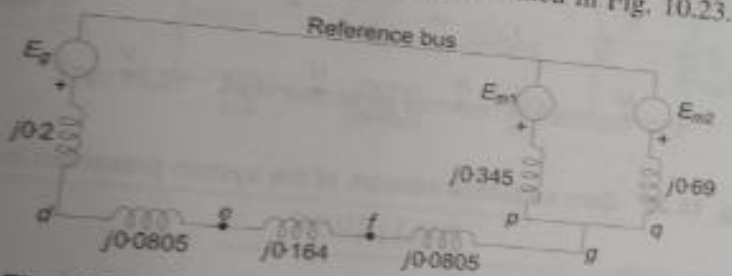


Fig. 10.23 Positive sequence network for Example 10.3

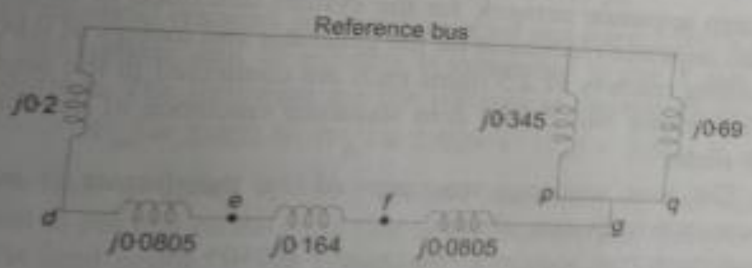


Fig. 10.24 Negative sequence network for Example 10.3

Since all the negative sequence reactances of the system are equal to the ositive sequence reactances, the negative sequence network is identical to the generator and motor No. 2. The zero sequence reactance of the transmission line is 300 ohms.

Solution The zero sequence reactance of the transformer is equal to its positive sequence reactance. Hence

Transformer zero sequence reactance = 0.0805 pu

Generator zero sequence reactances = 0.06 pu

$$\text{Zero sequence reactance of motor 1} = 0.06 \times \frac{25}{15} \times \left(\frac{10}{11}\right)^2 = 0.082 \text{ pu}$$

ge sources. The negative

in Fig. 10.25, sketch

26.

ed in Fig. 10.25

$$\text{Zero sequence reactance of motor 2} = 0.06 \times \frac{25}{7.5} \times \left(\frac{10}{11}\right)^2 = 0.164 \text{ pu}$$

$$\text{Reactance of current limiting reactors} = \frac{2.5 \times 25}{(11)^2} = 0.516 \text{ pu}$$

Reactance of current limiting reactor included in zero sequence network $= 3 \times 0.516 = 1.548$ pu

$$\text{Zero sequence reactance of transmission line} = \frac{300 \times 25}{(123.2)^2} = 0.494 \text{ pu}$$

The zero sequence network is shown in Fig. 10.27.

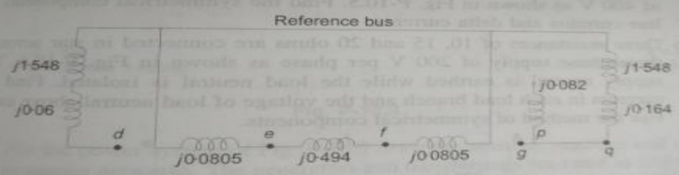


Fig. 10.27 Zero sequence network of Example 10.5

PROBLEMS

5a)

Power in terms of symmetrical component

Total complex power into a 3φ circuit is $S = P + jQ$

$$= V_a I_a^* + V_b I_b^* + V_c I_c^*$$

$$S = \begin{bmatrix} V_a & V_b & V_c \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}^* = \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}^T \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}^*$$

$$= \left[A V_{sy} \right]^T \left[A I_{sy} \right]^*$$

$$= A\, V_{sy}^{T} A^{T} I_{sy}^{*}$$

$$A^{T} A^{*} = 3\begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix}$$

$$= 3\begin{bmatrix}V_{a0} & V_{a1} & V_{a2}\end{bmatrix}\begin{bmatrix}I_{a0}\\ I_{a1}\\ I_{a2}\end{bmatrix}^{*}$$

Sum of powers of 3 symmetrical components equals the phase powers.

complex power $= P + jQ =$

$$(V_a I_a^{*} + V_b I_b^{*} + V_c I_c^{*})$$

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$$a^{*} = a^{2}$$
$$(a^{2})^{*} = a$$

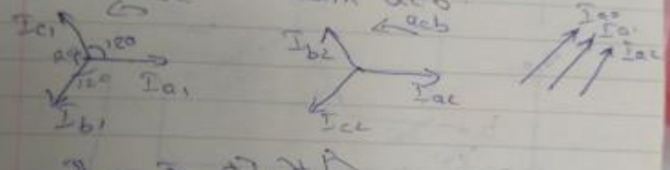
5b)

Symmetrical components of unbalanced current vectors

I_a, I_b, I_c – Unbalanced current vectors.

I_{a1}, I_{b1}, I_{c1} – +ve sequence components with abc

I_{a2}, I_{b2}, I_{c2} – -ve sequence components with acb



$$I_a = I_{a0} + I_{a1} + I_{a2}$$
$$I_b = I_{b0} + I_{b1} + I_{b2}$$
$$I_a = I_{a0} + I_{a1} + I_{a2}$$
$$I_b = I_{a0} + a^2 I_{a1} + a I_{a2}$$
$$I_c = I_{a0} + a I_{a1} + a^2 I_{a2}$$

$$\begin{bmatrix}I_a\\ I_b\\ I_c\end{bmatrix} = \begin{bmatrix}1 & 1 & 1\\ 1 & a^2 & a\\ 1 & a & a^2\end{bmatrix}\begin{bmatrix}I_{a0}\\ I_{a1}\\ I_{a2}\end{bmatrix}$$

$$I_p = A I_{sy}$$

6)

Positive Sequence Impedance and Network

Since a synchronous machine is designed with symmetrical windings, it induces emfs of positive sequence only, i.e. no negative or zero sequence voltages are induced in it. When the machine carries positive sequence currents only, this mode of operation is the balanced mode discussed at length in Chapter 9. The armature reaction field caused by positive sequence currents rotates at synchronous speed in the same direction as the rotor, i.e., it is stationary with respect to field excitation. The machine equivalently offers a direct axis reactance whose value reduces from subtransient reactance (X''_d) to transient reactance (X'_d) and finally to steady state (synchronous) reactance (X_d), as the short circuit transient progresses in time. If armature resistance is assumed negligible, the positive sequence impedance of the machine is

$$Z_1 = jX''_d \text{ (if 1 cycle transient is of interest)} \tag{10.46}$$

$$= jX'_d \text{ (if 3-4 cycle transient is of interest)} \tag{10.47}$$

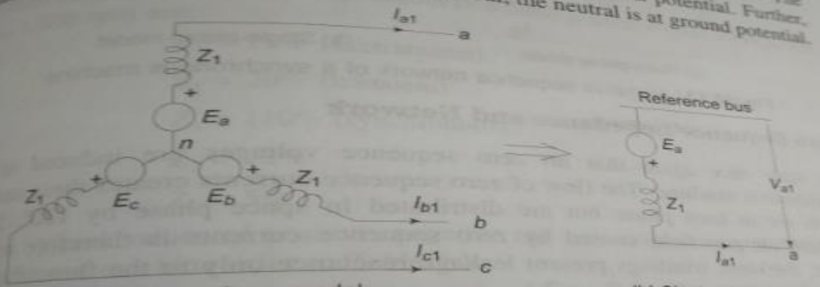
$$= jX_d \text{ (if steady state value is of interest)} \tag{10.48}$$

If the machine short circuit takes place from unloaded conditions, the terminal voltage constitutes the positive sequence voltage; on the other hand, if

*This can be shown to be so by synchronous machine theory [5].

the short circuit occurs from loaded conditions, the voltage behind appropriate reactance (subtransient, transient or synchronous) constitutes the positive sequence voltage.

Figure 10.12a shows the three-phase positive sequence network model of a synchronous machine. Z_n does not appear in the model as $I_n = 0$ for positive sequence currents. Since it is a balanced network it can be represented by the single-phase network model of Fig. 10.12b for purposes of analysis. The reference bus for a positive sequence network is at neutral potential. Further, since no current flows from ground to neutral, the neutral is at ground potential.



(a) Three-phase model (b) Single-phase model

Fig. 10.12 Positive sequence network of synchronous machine

With reference to Fig. 10.12b, the positive sequence voltage of terminal a with respect to the reference bus is given by

$$V_{a1} = E_a - Z_1 I_{a1} \tag{10.49}$$

Negative Sequence Impedance and Network

It has already been said that a synchronous machine has zero negative sequence induced voltages. With the flow of negative sequence currents in the stator a rotating field is created which rotates in the opposite direction to that of the positive sequence field and, therefore, at double synchronous speed with respect to rotor. Currents at double the stator frequency are therefore induced in rotor field and damper winding. In sweeping over the rotor surface, the negative sequence mmf is alternately presented with reluctances of direct and quadrature axes. The negative sequence impedance presented by the machine with consideration given to the damper windings, is often defined as

$$Z_2 = j\frac{X''_q + X''_d}{2}; \; |Z_2| < |Z_1| \tag{10.50}$$

Negative sequence network models of a synchronous machine, on a three-phase and single-phase basis are shown in Figs. 10.13a and b, respectively. The reference bus is of course at neutral potential which is the same as ground potential.

From Fig. 10.13b the negative sequence voltage of terminal *a* with respect to reference bus is

$$V_{a2} = -Z_2 I_{a2} \qquad (10.51)$$

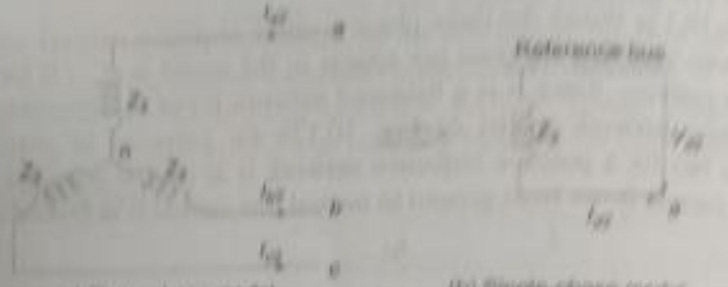
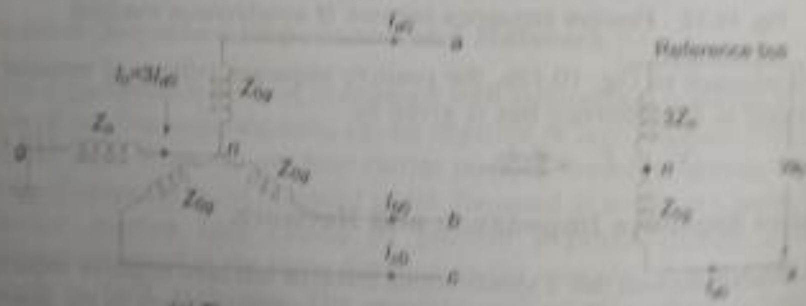


Fig. 10.13 Negative sequence network of a synchronous machine

Zero Sequence Impedance and Network

We state once again that no zero sequence voltages are induced in a synchronous machine. The flow of zero sequence currents creates three mmfs which are in time phase but are distributed in space phase by 120°. The resultant air gap field caused by zero sequence currents is therefore zero. Hence, the rotor windings present leakage reactance only to the flow of zero sequence currents ($Z_{0g} < Z_2 < Z_1$).



10.14 Zero sequence network of a synchronous machine

Zero sequence network models on a three- and single-phase basis are shown in Figs. 10.14a and b. In Fig. 10.14a, the current flowing in the impedance Z_n between neutral and ground is $I_n = 3I_{a0}$. The zero sequence voltage of terminal *a* with respect to ground, the reference bus, is therefore

$$V_{a0} = -3Z_n I_{a0} - Z_{0g} I_{a0} = -(3Z_n + Z_{0g}) I_{a0} \qquad (10.52)$$

where Z_{0g} is the zero sequence impedance per phase of the machine.

Since the single-phase zero sequence network of Fig. 10.14b carries only per phase zero sequence current, its total zero sequence impedance must be

$$Z_0 = 3Z_n + Z_{0g} \qquad (10.53)$$

in order for it to have the same voltage from *a* to reference bus. The reference bus here is, of course, at ground potential.

From Fig. 10.14b zero sequence voltage of point *a* with respect to the reference bus is

$$V_{a0} = -Z_0 I_{a0} \qquad (10.54)$$