reactance connected to neutral 0.3 p.u. calculate p.u. fault current for a

(*a*) Single line to ground fault

(*b*) Three-phase fault.

8. Calculate the single line to ground fault current for the generator if the neutral is solidly grounded. Given $X_1 = 0.58$ p.u., $X_3 = 0.25$ p.u., $X_0 = 0.1$ p.u.

9. Two generators rated 11 kV, 100 kVA having $X_1 = 0.15$, $X_3 = 0.12$, $X_0 = 0.1$ p.u. are operating in parallel a single line to ground fault occurs on the bus bar. Calculate the fault current if

(*a*) Both generator neutrals are solidly earthed ;

(*b*) only one generator neutral is solidly earthed ;

(*c*) both neutrals are isolated. (**Hint.** Refer Ex. 22.9)

10. For a generator the ratio of fault current for line to line fault and three phase faults is 0.866. The positive sequence reactance is 0.15 p.u. Calculate negative sequence reactance.

(**Hint.** Refer Ex. 22.10)

11. A fault occurs on an unloaded generator. The zero sequence component of fault current for a single line to ground fault has to magnitudes of 100 Amperes. Calculate the current in the neutral to ground connection.

12. A 3 phase 132 kV system can be represented by a solidly earthed source, feeding a 132/33 kV star delta transformer whose star point is solidly earthed. An earth fault occurs on one of the 132 kV terminals when 33 kV side is not connected to load, determine the fault current to earth and current in transformer delta winding. The sequence reactances based on 100 MVA base are as follows :

Source : P.S. Reactance 20%
N.S. Reactance 15%
Zero seq. Reactance 10%

Transformer : 15% reactance [**Ans.** 3200 A, 985 A]

23

Faults on Power Systems

Sequence Networks — Connections of Transformers — Connections of Sequence Networks — Single Line to Ground Fault — Line to Line Fault — Double Line to Ground Fault on Power Systems — Solved Examples.

23.1. Sequence Networks

The positive sequence network was considered in analysing symmetrical faults. In positive sequence network only positive sequence voltages, positive sequence impedance and positive sequence current are effective. Positive sequence network is same as impedance or reactance diagram. The negative sequence network is one in which the negative sequence voltages, negative sequence currents and negative sequence reactances exist. Negative sequence networks are very much like positive sequence networks but differ in the following aspects :

(1) Normally there are no negative sequence e.m.f. sources.

(2) Negative sequence impedances of rotating machine is generally different from their positive sequence impedances.

The phase displacement of transformer banks for negative sequence is of opposite sign to that of positive sequence.

The zero sequence network differs greatly from the positive sequence, negative sequence networks in the following aspects :

(1) Z.S. Reactance of transmission lines is higher than that for positive sequence.

(2) Equivalent circuits for transformers are different.

(3) The neutral grounding should be considered in zero sequence network.

Zero sequence networks. As the zero sequence currents in three phases (I_{a0}, I_{b0}, I_{c0}) are equal and of same phase, three systems operate like single phase as regards zero sequence currents. Zero sequence currents flow only if return path is available through which circuit is completed.

Case I. **Star Connections**

Star connection without neutral wire or neutral ground. Zero sequence currents have no return path and, therefore, the zero sequence network is open. Beyond the neutral point the zero sequence currents find infinite impedance hence no zero sequence current flows [Fig. 23.1 (*a*)].

Case II. **Star connection with solid grounding of neutral**

The zero sequence current flows through the ground connection. Hence in the zero sequence network the point N is connected directly to the reference bus [Fig. 23.1 (*b*)].

Case III. **Star connection with impedance grounding.** The neutral current $I_n = 3I_{a0}$ flows through the impedance Z_n connected between the neutral and ground. In the zero sequence network impedance $3Z_n$ is connected between N and reference, current flowing being, I_{a0}.

Case IV. Delta Connection

In delta connection the return neutral path is absent. Hence the zero sequence currents have no road to go ahead, they find the road to be suddenly stopped with infinite impedance ahead. How-

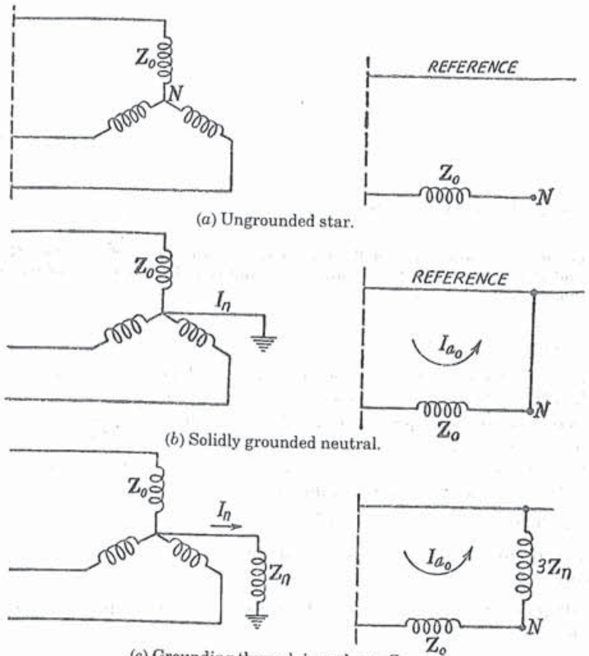


Fig. 23.1. Zero sequence equivalent circuits.

ever zero sequence currents may circulate in closed delta, if any zero sequence voltages are induced in the delta (Fig. 23.2).

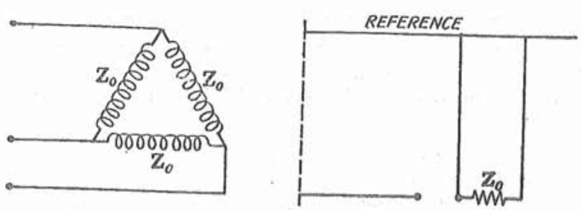


Fig. 23.2. Zero sequence circuit of delta.

Three phase transformer banks. The philosophy followed above for star and delta connection is valued for corresponding transformer connection. The zero sequence networks for different transformer connections are given in Fig. 23.3.

Example 23.1. *Fig. 23.4 represents a simple power system. Draw the positive sequence network, negative sequence network and zero sequence network.*

Connections of sequence networks. In chapter 22, we studied the unsymmetrical faults on an unloaded generator. The method consisted of connecting the sequence networks according to the type of fault. The procedure is extended to power systems. The three sequence networks are drawn. The fault point is indicated on the networks. The Thevenins's equivalents are drawn for each se-

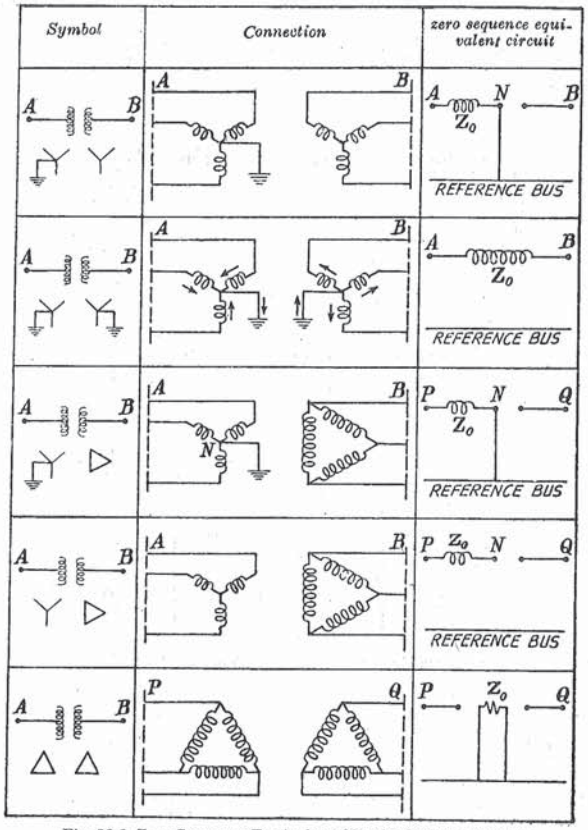


Fig. 23.3. Zero-Sequence Equivalent Circuits for Transformers.

quence network. Next, the three equivalent networks are connected in the same manner as connection of networks of single generator, *i.e.*

(1) Three Thevenin's equivalent networks are connected in series for single line to ground fault.

(2) The positive sequence equivalent and negative sequence equivalent are connected in parallel for line to line fault.

(3) The three equivalent networks are connected in parallel for double line to ground fault.

The sequence components of currents and voltage are calculated in the same way as those of generator (Ref. Ch. 22).

Example 23.2. *A synchronous generator (G) is connected synchronous motor (M). Both machine are rated at 1250 kVA, 600 V, with reactance X″ = X_2 = 10%, X_0 = 4%.*

Neutrals of both the machines are solidly grounded ; draw the sequence networks. Neglect reactance of busbars.

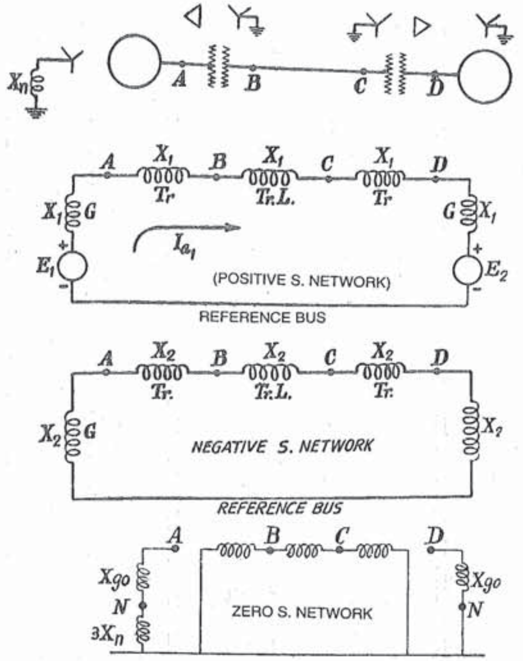
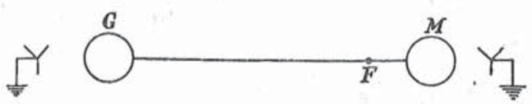
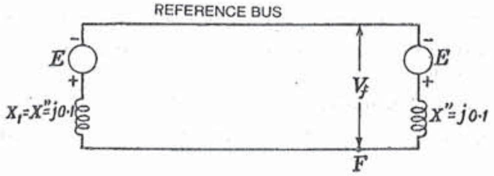


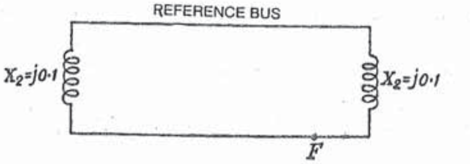
Fig. 23.4. Sequence network of Ex. 23.1.



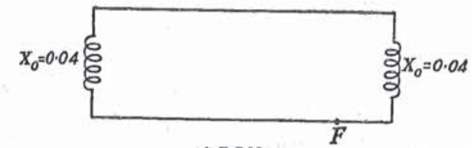
(*a*) Single line diagram.



(*b*) P.S.N.



(*c*) N.S.N.



(*d*) Z.S.N.

(*e*) Thevenin's equivalent of P.S.N. (*f*) Thevenin's equivalent of N.S.N. (*g*) Thevenin's equivalent of Z.S.N.

Fig. 23.5. For Ex. 23.2.

A fault F occurs near the terminals of the motor. Draw the Thevenin's equivalents of the sequence networks. Neglect load current.

Solution.

Base kVA = 1250 kVA

Base Voltage = 600 V

Thevenin's equivalent reactance is obtained as follows :

The e.m.f. sources are replaced by short-circuit links. The reactance of the network looked from fault points is calculated which is Thevenin's equivalent reactance. For example in P.S.N., as seen from F, there are two reactances of $j\,0.1$ p.u. each. These are in parallel. Hence Thevenin's equivalent reactance is $j0.05$ (*e*).

Example 23.3. *A single line to ground fault occurs at 'F', of Example 23.2. Calculate fault current.*

Solution. For single line to ground fault connect the three equivalent networks in series, for fault on phase a.

$$I_{a2} = \frac{V_f}{X_1 + X_2 + X_0}$$

$$= \frac{1 + j0}{j0.5 + j0.5 + j0.02} = \frac{1}{j1.02} = -j\,0.98 \text{ p.u. Amp.}$$

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

$$I_a = 3I_{a1} = 3 \times 0.98 \text{ p.u. Amp.} = 2.94 \text{ p.u. Amp.}$$

Base current in Amp.

$$= \frac{\text{Base kVA}}{\sqrt{3} \times \text{Base kV}} = \frac{1250}{\sqrt{3} \times 0.6} = 1200 \text{ Amp.}$$

∴ The fault current

$$= 1200 \times 2.94 = 3525 \text{ Amp. (r.m.s.)}$$

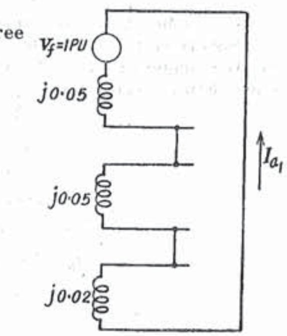


Fig. 23.6 for Ex. 23.3.

Example 23.4. *A double line to ground fault occurs at point F of the system given in Example 23.2. Calculate fault current.*

Solution. For double line to ground fault the Thevenin's equivalent networks of the three sequence networks are to be connected in parallel.

$$I_{a1} = \frac{V_f}{X_1 + \left[\dfrac{1}{\dfrac{1}{X_2} + \dfrac{1}{X_0}}\right]}$$

$$= \frac{V_f}{X_1 + \dfrac{X_2 X_0}{X_2 + X_0}} = \frac{V_f}{j0.05 + \dfrac{j0.05 \times j0.02}{j0.05 + j0.02}}$$

$$= \frac{V_f}{j0.05 + j0.0143} = \frac{V_f}{j0.0643} = \frac{1}{j0.0643} = -j15.55 \text{ p.u.}$$

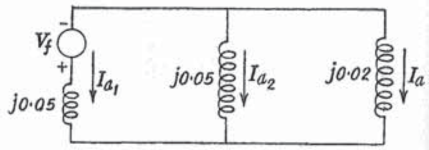


Fig. 23.7 for Ex. 23.4.

$$V_{a1} = V_f - I_{a1} X_1$$
$$= 1 + j0 - (-j15.55)\,(j0.05) = 1 - 0.775 = 0.225 \text{ p.u.}$$
$$I_{a2} = \frac{V_{a1}}{X_2} = \frac{-0.225}{j0.05} = +4.5 \text{ p.u.}$$
$$I_{a0} = \frac{-V_{a1}}{X_0} = \frac{-0.22}{j0.02} = j11.00 \text{ p.u.}$$

$\therefore$
$$I_{a1} = -j15.5$$
$$I_{a2} = +j4.5$$
$$I_{a0} = +j11.00$$
$$I_a = I_{a0} + I_{a1} + I_{a2} = 0 \text{ (Check)}$$

Fault current I_b for double line to ground fault is :

$$I_b = I_{a0} + a^2 I_{a2} + a I_{a1}$$
$$= +j11.00 + (-0.5 - j0.866)\,(j4.5) + (-0.5 + j0.866)\,(-j15.5)$$
$$= +j11.00 + [-j2.25 + 3.9] + [+j7.75 + 13.6]$$
$$= 17.5 + j16.5 = 22.7 \text{ p.u.}$$
$$I_b = 22.7 \times 1200 = 27{,}200 \text{ Amp.}$$

Example 23.5. *A line to line fault occurs on the system is Example 23.2. Calculate the fault current.*

Solution. For line to line fault, the zero sequence network is out of question, ignore it. The positive sequence networks Thevenin's equivalent and negative sequence networks Thevenin's equivalent are connected in parallel.

$$I_{a1} = \frac{V_f}{X_1 + X_2}$$
$$= \frac{1 + j0}{j0.05 + j0.05} = \frac{1}{j0.1} = -j10 \text{ p.u. Amp.}$$

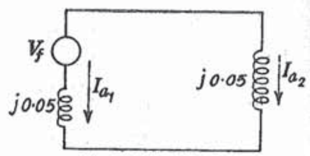


Fig. 23.8 for Ex. 23.5.

$$I_{a2} = -I_{a1} = +j10 \text{ A}$$
$$I_a = 0 + j10 - j10 = 0$$
$$I_{a0} = 0$$
$$I_b = I_{a0} + a^2 I_{a1} + a I_{a2}$$
$$= 0 + (-0.5 - j0.866)\,(-j10) + (-0.5 + j0.866)\,(+j10)$$
$$= +j5 - j8.66 - j5 - j8.66 = -j17.32 \text{ p.u.}$$
$$I_c = a I_{a1} + a^2 I_{a2} = j17.32$$

Fault current $I_c = 17.32$ p.u. $= 17.32 \times 1200 = 20{,}800$ Amp.

Example 23.6. *A single line to ground fault occurs at point P of the system shown in Fig. 23.9. Find the sub-transient fault current neglecting pre-fault current. Both machines are synchronous and rated 1250 kVA, 1600 volts with reactances $X'' = X_2 = 10\%$. Each transformer is rated 1250 kVA,*

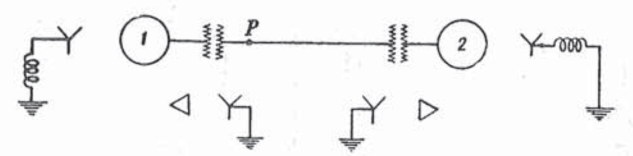


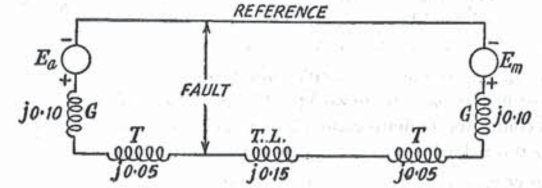
Fig. 23.9 for Ex. 23.6.

600—4160V, with leakage reactance 5%. Reactances of transmission line are $X_1 = X_2 = 15\%$, $X_0 = 50\%$ on 1250 kVA and 4.16 kV (Base Values).

Solution. Positive Sequence Network. Thevenin's equivalent impedance looked from the fault, shunting the e.m.f. sources.

$$Z_{th} = \frac{j0.15 \times j0.30}{j0.15 + j0.3} = \frac{-0.045}{j0.45} = j0.10 \text{ p.u.}$$

The load current is neglected. Hence the voltage at fault point is same as E_{a1} *i.e.*, 1 p.u. Hence Thevenin's equivalent of positive sequence networks is as follows :



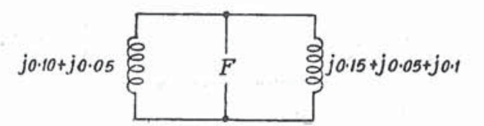


Fig. 23.10 for Ex. 23.6.

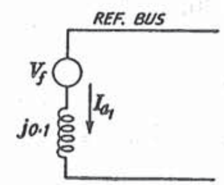


Fig. 23.11

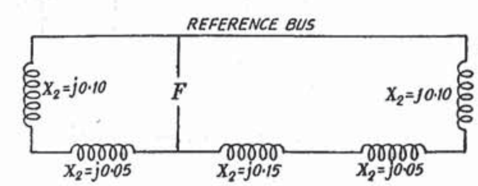


Fig. 23.12

Negative Sequence Network. The e.m.f. sources in PSN are absent in NSF. The PS reactances are replaced by *NS* reactance. Thevenin's equivalent is obtained by calculating equivalent reactance between fault points, after shunting the voltage sources.

$$Z_{th} = \frac{j0.15 \times j0.30}{j0.15 + j0.30} = \frac{-0.045}{j0.45} = j0.1$$

Zero Sequence Network

$$Z_{th} = \frac{j0.05 \times j0.55}{j0.05 + j0.55} = j\frac{0.0275}{0.6} = j0.0459 \text{ p.u.}$$

For the single line to ground fault connect the three equivalent networks in series.

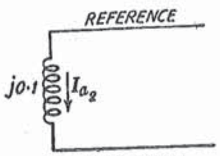


Fig. 23.13. N.S.N.

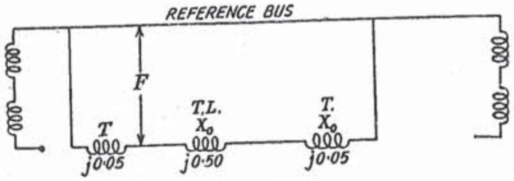


Fig. 23.14. Z.S.N.

$$I_{a1} = \frac{E}{X_1 + X_2 + X_0}$$

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

$$= \frac{1 + j0}{j0.1 + j0.1 + j0.0459} = \frac{1}{j0.2459} = -j4.06 \text{ p.u.}$$

$$I_a = 3I_{a1} = -j3 \times 4.06 = -j12.18 \text{ p.u.}$$

$$\text{Base current} \quad = \frac{\text{Base kVA}}{\sqrt{3} \times \text{Base kV}} = \frac{1250}{\sqrt{3} \times 0.6} = 1200$$

$\therefore$ Fault current $= 12.8 \times 1200 =$ **15360 A. Ans.**

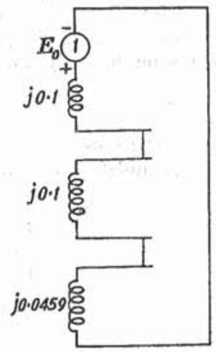
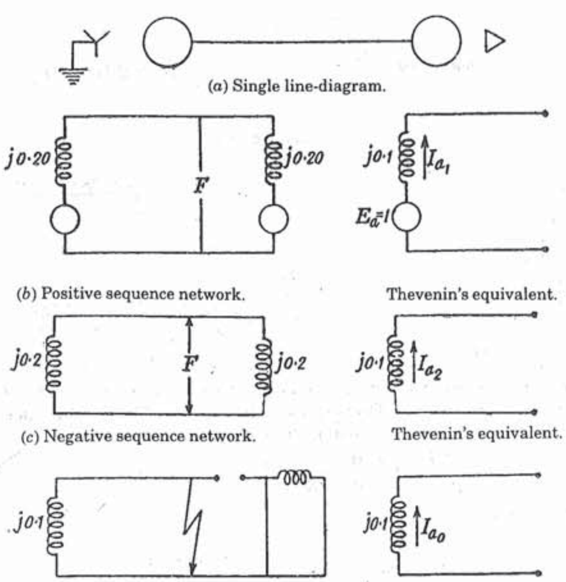


Fig. 23.15.

Example 23.7. Fig. 13.16 shows a simple system in which a star connected generator having reactances $X_1 = 0.20$ p.u., $X_2 = 0.2$ p.u., $X_0 = 0.1$ p.u. is connected to delta connected motor. Calculate the fault current for the following cases, neglecting load current.

(1) Single line to ground fault at the motor terminal.



(a) Single line-diagram.

(b) Positive sequence network. Thevenin's equivalent.

(c) Negative sequence network. Thevenin's equivalent.

(d) Zero sequence network. Thevenin's equivalent.

Fig. 23.16 for Ex. 23.7.

(2) Line to line fault at motor terminal.

Ratings are as follow :

Generator 11 kV, 1500 kVA.

Motor 11 kV, 1500 kVA.

Per unit reactances of motor are same as that of generator. Generator neutral is solidly grounded. Reactance of tie bar is negligible.

Solution. *Case I.* **Single line to ground fault (L-G).** Connect the three equivalents of sequence networks in series as in Fig. 23.17.

$$I_a = 1 + j0 \text{ p.u.}$$

$$I_a = 3I_{a1}$$

$$= \frac{3E_a}{X_1 + X_2 + X_0} = \frac{3\,(1 + j0)}{j0.1 + j0.1 + j0.1}$$

$$= \frac{3}{j0.3} = -j10 \text{ p.u.} = 10 \times \frac{1500}{\sqrt{3} \times 11} = 787 \text{ Amp.}$$

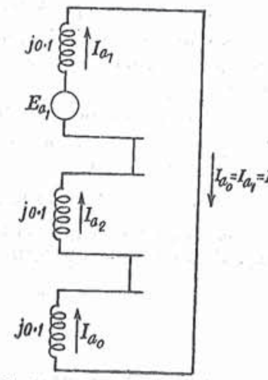


Fig. 23.17. Connection for *L-G* fault.

Case II. **L-L Fault.** Connect the positive and negative sequence reactance equivalent parallel.

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

$$= \frac{E_a}{X_1 + X_2} = \frac{1 + j0}{j0.2} = j5 \text{ p.u.}$$

$$I_{a0} = 0$$

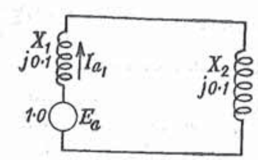
$$I_a = I_{a0} + I_{a1} + I_{a2} = 0$$

$$I_a = I_{a0} + a^2 I_{a1} + aI_{a2}$$

$$= (a^2 - a)\, I_{a1} = (1.732)\, 5 = 8.660 \text{ p.u.}$$

$$= 8.66 \times \frac{1500}{\sqrt{3} \times 11} \text{ Amp.}$$

$$= 8.66 \times 78.7 = 683 \text{ Amp.}$$



Example 23.8. *A 3-phase 37.5 MVA, 33 kV alternator having $X_1 = j0.18$ p.u., $X_2 = j0.12$ p.u. and $X_0 = j0.10$ p.u. based on its ratings is connected to a 33 kV overhead transmission line having the following reactances : $X_1 = 6.6$ ohms, $X_2 = 6.3$ ohms and $X_0 = 12.6$ ohms per conductor. A single line to ground fault occurs at the remote end of the transmission line. The alternator star point is solidly earthed. Calculate the fault current and phase voltages.*

Solution. Select base kVA and base kV.

Let Base MVA (3 phase) = 37.5 MVA

Base kV (line to line) = 33 kV.

$$\text{Base impedance} \quad = \frac{(\text{Base kV})^2 \times 1000}{\text{Base kVA}} = \frac{(33)^2 \times 1000}{37.5 \times 1000} = 29.0 \text{ ohms}$$

P.u. reactances of transmission line are

$$X_1 = \frac{j6.3}{29.0} = j0.2165 \text{ p.u.}$$

$$X_2 = \frac{j6.3}{29.0} = j0.217 \text{ p.u.}$$

$$X_0 = \frac{j12.6}{29.0} = j0.434 \text{ p.u.}$$

P.u. reactances of generator are :

$$X_1 = j0.18 \text{ p.u.}$$
$$X_2 = j0.12 \text{ p.u.}$$
$$X_0 = j0.10 \text{ p.u.}$$

Per unit reactances between generator and fault, is the sum of the generator p.u. reactances and transmission line p.u. reactances.

Total p.u. reactances are, therefore,

$$X_1 = j0.18 + j0.2170 = j0.397 \text{ p.u.}$$
$$X_2 = j0.12 + j0.2170 = j0.337 \text{ p.u.}$$
$$X_0 = j0.10 + j0.434 = j0.534 \text{ p.u.}$$

For single line to ground fault connect the three sequence networks in series (Fig. 23.19).

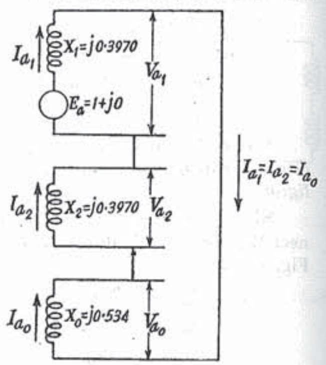


Fig. 23.19. Connection of sequence networks of Ex. 23.8.

$$I_{a1} = I_{a2} = I_{a0}$$
$$= \frac{E_a}{X_1 + X_2 + X_{g0}} = \frac{E_a}{X_1 + X_2 + X_{g0} + 3X_n}$$

Here X_n, *i.e.* the reactance between neutral point and ground is zero, since the earthing (grounding) is solid one.

Hence $\quad I_{a1} = \dfrac{1 + j0}{j0.3970 + j0.3370 + j0.534} = \dfrac{1 + j0}{j1.268} = -j0.790$ p.u.

$$I_a = I_{a1} + I_{a2} + I_{a0} = 3I_{a1} = 3 \times (-)j0.790 = -j2.370 \text{ p.u.}$$

Base current $\quad = \dfrac{\text{Base MVA}}{\sqrt{3}\text{ Base MV}} = \dfrac{37.5}{\sqrt{3} \times 0.033} = 656$ Amp.

Hence fault current I_a

$$= -j2.370 \times 656 = -j1557 \text{ Amp.}$$

Sequence voltages line to neutral at the terms of the alternator.

$$V_{a1} = E_a - I_{a1} X_1$$
$$= (1 + j0) - (-j0.791)(j0.18) = 0.858 + j0 \text{ p.u.}$$
$$V_{a2} = -I_{a2} X_2 = -I_{a1} X_2$$
$$= -(-j0.791)(j0.12) = -0.0948 + j0 \text{ p.u.}$$
$$V_{a0} = -I_{a0} X_0 = -I_{a1} X_0$$
$$= -(-j0.791)(j0.1) = -0.0791 + j0 \text{ p.u.}$$
$$V_a = V_{a1} + V_{a2} + V_{a0}$$
$$= 0.6841 \angle 0° \text{ p.u.} = 0.684 \times 33/\sqrt{3} = 13 \text{ kV}$$
$$V_b = a^2 V_{a1} + aV_{a2} + V_{a0} = 0.945 \angle -119° \text{ p.u.} = 0.945 \times \frac{33}{\sqrt{3}} = 18 \text{ kV} \angle -119°$$

Since $\quad E_a = \dfrac{33}{\sqrt{3}} = 1$ p.u. (phase)

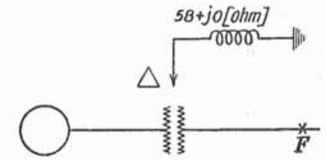
$$V_0 = aV_a + a^2 V_{a2} + V_{a0} = 0.945 \underline{/+119°} \text{ p.u.} = 18 \angle +119° \text{ kV.}$$

Example 23.9. *A generator transformer unit shown in Fig. 23.20 is on no load and the voltage on H.T. side is 70 kV when a fault occurs at F. Calculate fault currents if the fault is*

(1) 3 phase fault ;

(2) Line to line fault ;

(3) Single line to earth fault. [*Note :* Change in Voltage]



11.8 kV	11.8/66 kV	Star point
75 MVA	75 MVA	Earthed through
$X_1 = j$ 17.5%	$X_1 = j$ 10%	$58 + j0$, ohm
$X_2 = j$ 13.5%		

Fig. 23.20. of Ex. 23.9.

Solution. Let base MVA 100

p.u. reactances to this base are

$$X_{g1} = j0.175 \times \frac{100}{75} = j0.234 \text{ p.u.} \quad \text{(of Generator)}$$
$$X_{g2} = j0.135 \times \frac{100}{75} = j0.180 \text{ p.u.}$$
$$X_1 = j0.10 \times \frac{100}{75} = j\,0.133 \text{ p.u.} \quad \text{(of transformer)}$$

Zero sequence impedance of the neutral earthing resistor is given by

$$Z_{n0} = 3Z_n = 58 \times 3 = 174 + j0 \text{ ohm}$$

Base current $\quad = \dfrac{\text{Base MVA} \times 10^3}{\sqrt{3} \times \text{Base kV}} = \dfrac{100 \times 10^6}{\sqrt{3} \times 66{,}000} = 875$ A

Base voltage phase to neutral $= \dfrac{66{,}000}{\sqrt{3}} = 38{,}100$ V

Base impedance on 100 MVA, 66 kV base

$$= \frac{38{,}100}{875} = 43.5 \text{ ohm}$$

or Base impedance $\quad = \dfrac{(66)^2 \times 1000}{100{,}000} = 43.5$ ohm

$$\text{P.u. } Z_{g0} = \frac{174 + j0}{43.5} = 3.99 + j0 \text{ p.u.}$$

Pre-fault voltage at $F = 70$ kV. **Note the change in voltage**

$$= \frac{70}{60} = 1.060 \text{ p.u.}$$

Note : $\quad E_a = 1.060 + j0$ p.u.

$$X_1 = j0.367 \text{ p.u.}$$
$$X_2 = j0.313 \text{ p.u.}$$
$$Z_0 = 3.99 + j0.133 \text{ p.u.}$$

Case I. **Three phase fault** [Note use of a^2, a]

$$I_{a1} = I_a = \frac{E_a}{X_1} = \frac{1.06}{j0.367}$$
$$I_a = -j2.89 \text{ p.u.}$$
$$I_b = a^2 I_{a1} = -2.50 + j1.445 \text{ p.u.}$$
$$I_c = aI_{a1} = 2.50 + j1.445 \text{ p.u.}$$

Multiplying I_a, I_b, I_c by base current 875 A,

$$I_a = 2526 \angle -90^\circ \text{ A}$$
$$I_b = 2526 \angle +150^\circ \text{ A}$$
$$I_c = 2526 \angle +30^\circ \text{ A}$$

Case II. **Line to line fault on lines b, c.**

$$I_{a1} = \frac{E_a}{X_1 + X_2} = \frac{1.060 + j0}{j0.680} = -j1.560 \text{ p.u.}$$
$$I_{a2} = -I_{a1} = j1.560 \text{ p.u.}$$
$$I_{a0} = 0$$
$$I_a = I_{a0} + I_{a1} + I_{a2} = 0 \text{ (check)}$$
$$I_b = a^2 I_{a1} + a I_{a2} + I_{a0} = -2.7 + j0 \text{ p.u.}$$
$$I_c = a I_{a1} + a^2 I_{a2} + I_{a0} = +2.7 + j0 \text{ p.u.} = 2.7 \times 874 \text{ A} = 2360 \text{ A.}$$

Case III. **Single line to ground fault on line a.**

$$I_{a1} = I_{a2} = I_{a0}$$
$$= \frac{E_a}{X_1 + X_2 + Z_0} = \frac{1.060 + j0}{3.98 + j0.052} \text{ p.u.} = 0.255 - j0.052 \text{ p.u.}$$
$$I_a = 3I_{a0} = 0.765 - j0.156 \text{ p.u.}$$
$$I_b = a^2 I_{a1} + a I_{a2} + I_{a2} = 0$$
$$I_c = a I_{a1} + a^2 I_{a2} + I_{a0} = 0$$

I_a in amperes $= 874 \times I_a$ p.u. $= 683 \angle -11.30^\circ$.

Summary

For faults on power systems, the following procedure is adopted :

(1) Draw single line diagram of power system.

(2) Choose same kVA base for complete system. Choose different kV bases for each voltage level. Convert the reactances to p.u. reactances.

(3) Draw positive sequence network, obtain its Thevenin's equivalent. Repeat it for negative and zero sequence networks.

(4) For *L-G* fault connect the Thevenin's equivalents of the three circuits in series, proceed as in the case of fault on generator.

(5) Connect the positive sequence and negative sequence equivalent in parallel for line to line fault.

(6) Connect the three equivalent networks in parallel for double line ground fault.

The sequence components are calculated and from them, the fault current and voltages are calculated.

QUESTIONS

1. A double line to ground fault occurs on lines *b* and *c* at the point *P* in the circuit whose diagram is shown below. Find subtransient current in phase *a* of the machine. 1. Neglect prefault current. Both machines are rated at 1250 kVA, 600 V with reactances $X'' = X_2 = 10\%$; $X_0 = 4\%$ each three phase transformer is rated 1250 kV, 600 V delta/4160 V star with leakage reactances 5%. The reactance of transmission line is $X_1 = 15\%$, $X_2 = 15\%$, $X_0 = 50\%$ based on 1250 kVA, 4.16 kV = bases. Point *P* at centre of line.

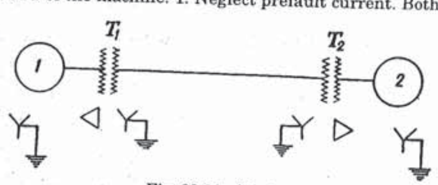


Fig. 23.21 of Q. 1.

2. A 5000 kVA, 13.8 kV generator is star-connected and grounded through a reactance of 2.5%. The reactances of generator are $X'' = X_2 = 10\%$ and $X_0 = 2.5\%$. The generator supplies a delta connected motor rated 2500 kVA, 13.8 kV with reactances $X'' = X_2 = 20\%$, $X_0 = 10\%$. A single line to ground fault occurs near the motor, find the initial symmetrical fault current. Neglect load current.

3. A 11 kV, 15 MVA generator having $X_1 = 20\%$, $X_2 = 20\%$, $X_0 = 10\%$ is connected to transformer rated 11/33 kV 15 MVA having $X_1 = 5\%$. The transformer is delta connected on L.T. side and star connected on H.T. side. Neutral of generator and transformer is solidly earthed ; calculate fault currents for

(*a*) Single line to ground fault on H.T. side L.T. side.

(*b*) Double line to ground fault on H.T. side, L.T. side.

(*c*) 3-phase fault on H.T. side, L.T. side.

4. A generator transformer unit shown in Fig. 23.22 is supplying to a h.t. line. A fault occurs in the line at point *F*. Calculate the fault current for

(*a*) 3 phase fault
(*b*) *L-G* fault
(*c*) *L-L* fault.
(*d*) 2 *L-G* fault.

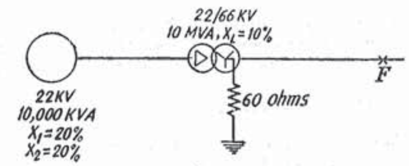


Fig. 23.22.

5. Three generators are operating in parallel.

G_1 : 15 MVA, 12 kV, $X_1 = X_2 = 20\%$
$X_0 = 10\%$

G_2 : 15 mVA, 11 kV, $X_1 = X_2 = 20\%$
$X_0 = 10\%$

G_3 : 10 MVA, 11kV, $X_1 = X_2 = 20\%$
$X_0 = 10\%$.

Neutral of G_1 grounded solidly. Neutral of G_3 is grounded through a reactance of 5% based on generator ratings. A fault occurs on generator bus. Calculate fault current for

(*a*) *L-G* fault. (*b*) 2 *L-G* fault. (*c*) *L-L* fault.

6. A star connected synchronous motor is connected directly to a generator by means of bus bar of negligible reactances.

Reactances of generator and motor are as follows :

$$X_1 = 0.2 \text{ p.u.}, X_2 = 0.2 \text{ p.u.}, X_0 = 0.1 \text{ p.u.}$$

Both rated at 11 kV, 1500 kVA.

Generator star connected with solid neutral earth.

Motor Delta connected.

Calculate fault current for terminal *L-L* fault, *L-G* fault. [**Ans.** 787 A, 683 A]