Analysis of unsymmetrical faults

Introduction:

The unsymmetrical faults will have faulty parameters at random. They can be analyzed by using the symmetrical components. The standard types of unsymmetrical faultsconsidered for analysis include the following (in the order of their severity):

Fault Analysis

The normal mode of operation of a power system is balanced three-phase AC. However, there are undesirable but unavoidable incidents that may temporarily disrupt normal conditions, as when the insulation of the system fails at any point or when a conducting material comes in contact with a bare conductor. Then we say a fault has occurred. A fault may be caused by lightning, trees falling on the electric wires, vehicular collision with the poles or towers, vandalism, and so forth.Faults may be classified into four types. The different types of fault are listed here in the order of the frequency of their occurrence.

- Line–to–Ground (L-G) Fault
- Line–to–Line (L-L) Fault
- Double Line–to–Ground (L-L-G)Fault and
- Three-Phase–to–Ground (LLL-G) Fault.
-

Further the neutrals of various equipment may be grounded or isolated, the faults can occur at any general point F of the given system, the faults can be through a fault impedance, etc. Of the various types of faults as above, the 3-phase fault involving the ground is the most severe one. Here the analysis is considered in two stages as under:

(i) Fault at the terminals of a Conventional (Unloaded) Generator and
(ii) (ii) Faults at any point F, of a given Electric Power System (EPS).

Three-Phase Fault Analysis

Sufficient accuracy in fault studies can be obtained with certain simplifications in the model of the power system. These assumptions include the following:

1. Shunt elements in the transformer model are neglected; that is, magnetizing currents and core losses are omitted.
2. Shunt capacitances in the transmission line model are neglected.
3. Transformers are set at nominal tap positions.
4. All internal voltage sources are set equal to $1.0\angle0°$. This is equivalent to neglecting pre-fault load currents.

Three-phase fault calculations can be performed on a per-phase basis because the power system remains effectively balanced, or symmetrical, during a three-phase fault. Thus, the various power system components are represented by single-phase equivalent circuits wherein all three-phase connections are assumed to be converted to their equivalent connections. Calculations are performed using impedances per phase, phase currents, and line-to-neutral voltages.

Consider now the symmetrical component relational equations derived from the three sequence networks corresponding to a given unsymmetrical system as a function of sequence impedances and the positive sequence voltage source in the form as under:

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

These equations are refered as the sequence equations. In matrix Form the sequence equations can be considered as:

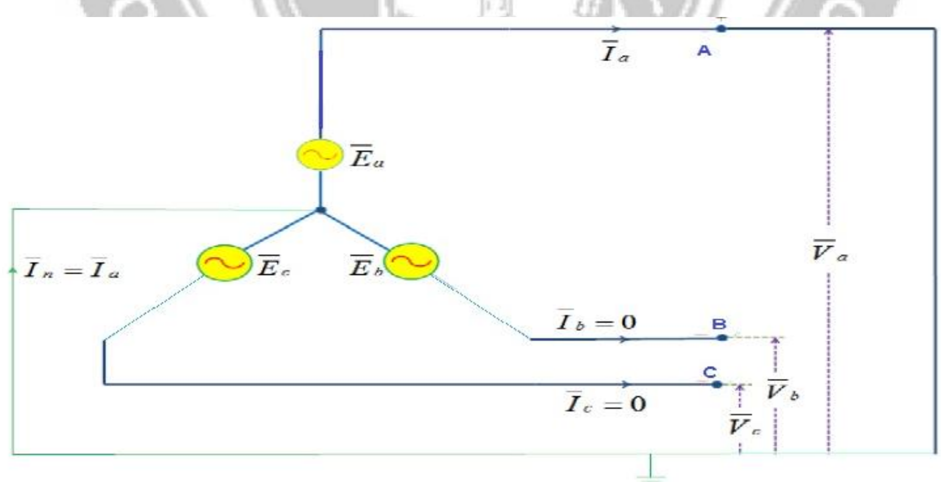
$$\begin{vmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{vmatrix} = \begin{vmatrix} 0 \\ E_a \\ 0 \end{vmatrix} - \begin{vmatrix} Z_0 & 0 & 0 \\ 0 & Z_1 & 0 \\ 0 & 0 & Z_2 \end{vmatrix} \begin{vmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{vmatrix}$$

This equation is used along with the equations i.e., conditions under fault (c.u.f.), derived to describe the fault under consideration, to determine the sequence current Ia1 and hence the fault current If, in terms of Ea and the sequence impedances, Z1, Z2 and Z0. Thus during unsymmetrical fault analysis of any given type of fault, two sets of equations as follows are considered for solving them simultaneously to get the required fault parameters:

- Equations for the conditions under fault (c.u.f.)
- Equations for the sequence components (sequence equations)

SINGLE LINE TO GROUND FAULT ON A CONVENTIONAL (UNLOADED) GENERATOR:

A conventional generator is one that produces only the balanced voltages. Let Ea, nd Ec be the internally generated voltages and Zn be the neutral impedance. The fault is assumed to be on the phase'a' as shown in figure Consider now the conditions under fault as under:



c.u.f.:

$$I_b = 0;\ I_c = 0;\ \text{and}\ V_a = 0.$$

Now consider the symmetrical components of the current Ia with Ib=Ic=0, given by:

$$\begin{vmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{vmatrix} = (1/3) \begin{vmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{vmatrix} \begin{vmatrix} I_a \\ 0 \\ 0 \end{vmatrix}$$

Solving the equation we get,

$I_{a1} = I_{a2} = I_{a0} = (Ia/3)$

Further, using above equation, we get,

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \begin{bmatrix} 0 \\ E_a \\ 0 \end{bmatrix} - \begin{bmatrix} Z_0 & 0 & 0 \\ 0 & Z_1 & 0 \\ 0 & 0 & Z_2 \end{bmatrix} \begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a3} \end{bmatrix}$$

Pre-multiplying equation throughout by [1 1 1], we get,

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

i.e., $V_a = E_a – I_a1 (Z_1 + Z_2 + Z_0) =$ zero,

Or in other words,

$I_{a1} = [E_a/(Z_1 + Z_2 + Z_0)]$

The equation (4.7) derived as above implies that the three sequence networks are

connected in series to simulate a LG fault, as shown in figure 4.2. Further we have the

following relations satisfied under the fault conditions:

1. $I_{a1} = I_{a2} = I_{a0} = (I_a/3) = [E_a/(Z_1 + Z_2 + Z_0)]$

2. Fault current If $= I_a = 3I_{a1} = [3E_a/(Z_1 + Z_2 + Z_0)]$

3. $V_{a1} = E_a - I_{a1}Z_1 = E_a(Z_2+Z_0)/(Z_1+Z_2+Z_0)$

4. $V_{a2} = - E_aZ_2/(Z_1+Z_2+Z_0)$

5. $V_{a0} = - E_aZ_0/(Z_1+Z_2+Z_0)$

6. Fault phase voltage $V_a = 0$,

7. Sound phase voltages V_b = a

$2V_{a1}+aV_{a2}+V_{a0}$; $V_c = aV_{a1}+a_2V_{a2}+V_{a0}$

8. Fault phase power: $V_aI_a^* = 0$, Sound pahse powers:

$V_bI_b^* = 0$, and $V_cI_c^* = 0$,

9. If $Z_n = 0$, then $Z_0 = Z_{g0}$,

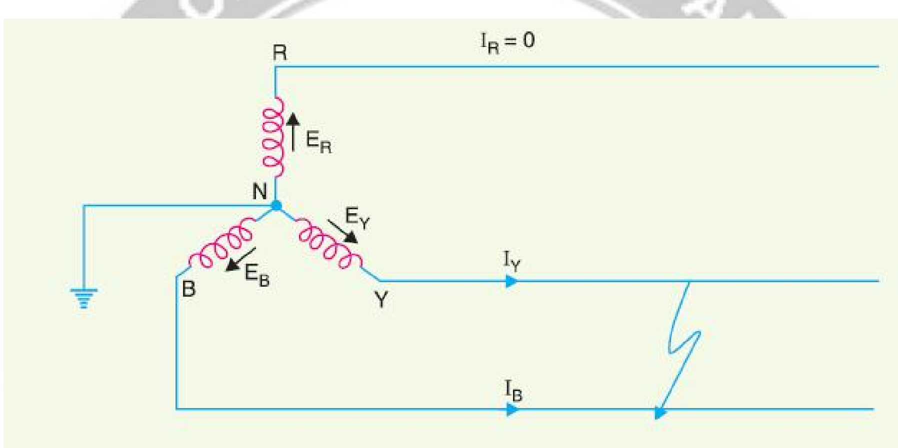
10 If $Z_n = \alpha$ then $Z_o = \alpha$.e., the zero sequence network is open so that then,

then Z_0 = 10. If Z_n = I_f=I_a=0.

LINE TO LINE FAULT ON A CONVENTIONAL GENERATOR

A line-to-line (L-L) fault involves a short circuit between two phase conductors that are assumed to be phases b and c. Therefore, there is symmetry with respect to the principal phase a. A line-to-line fault is illustrated in Fig

Consider a line to line fault between phase ‘b’ and phase ‘c’ as shown in figure, at the terminals of a conventional generator, whose neutral is grounded through a reactance.



Consider now the conditions under fault as under:

c.u.f.:

Ia = 0; Ib = - Ic; and Vb = Vc (4.8)

Now consider the symmetrical components of the voltage Va with Vb=Vc, given by:

$$\begin{vmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{vmatrix} = (1/3) \begin{vmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{vmatrix} \begin{vmatrix} V_a \\ V_b \\ V_b \end{vmatrix}$$

Solving the equation we get,

Va1 = Va2

Further, consider the symmetrical components of current Ia with Ib=-Ic, and Ia=0; given by

$$\begin{vmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{vmatrix} = (1/3) \begin{vmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{vmatrix} \begin{vmatrix} 0 \\ I_b \\ -I_b \end{vmatrix}$$

Solving above equation we get,

Ia0 = 0; and Ia2 = -Ia1

Using equation above equation, and since $V_{a0} = 0$ (I_{a0} being 0), we get

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

Pre-multiplying above equation throughout by [0 1 -1], we get,

$$V_{a1} - V_{a1} = E_a - I_{a1}Z_1 - I_{a1}Z_2 = 0$$

Or in other words,

$$I_{a1} = [E_a/(Z_1 + Z_2)]$$

The above equation derived implies that the three sequence networks are connected such that the zero sequence network is absent and only the positive and negative sequence networks are connected in series-opposition to simulate the LL fault, as shown in figure.Further we have the following relations satisfied under the fault conditions:

1. $Ia_1 = - I_{a2} = [E_a/(Z_1 + Z_2)]$ and $I_{a0} = 0$,

2. Fault current $If = I_b = - Ic = [3E_a/(Z_1 + Z_2)]$ (since $I_b = (a_2 - a)I_{a1} = 3I_{a1}$)

3. $V_{a1} = E_a - I_{a1}Z_1 = E_aZ_2/(Z_1+Z_2)$

4. $V_{a2} = V_{a1} = E_aZ_2/(Z_1+Z_2)$

5. $V_{a0} = 0$,

6. Fault phase voltages; $V_b = V_c = aV_{a1} + a_2V_{a2} + V_{a0} = (a+a_2)V_{a1} = - V_{a1}$

7. Sound phase voltage; $V_a = V_{a1} + V_{a2} + V_{a0} = 2V_{a1}$

8. Fault phase powers are V_bI_b * and V_cI_c*

,9. Sound phase power: V_aI_a* = 0,

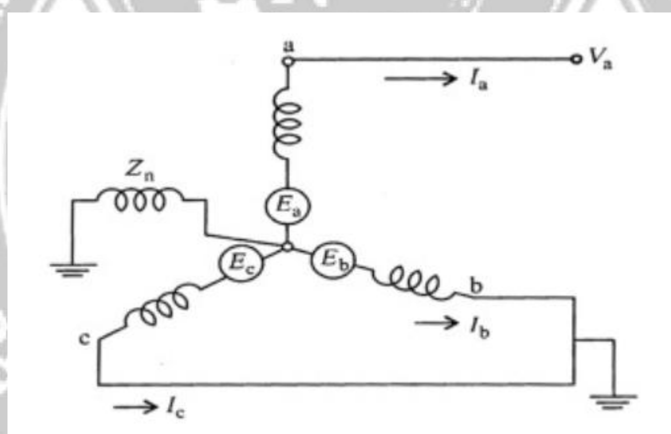
10. Since Ia0=0, the presence of absence of neutral impedance does not make any difference in the analysis.

Double Line-to-Ground Fault:

A double line-to-ground (2LG) fault involves a short circuit between two phase conductors b and c and ground. As with the line-to-line fault, there is symmetry with respect to the principal phase a.

In double line-to-ground fault, the two lines contact with each other along with the ground. The probability of such types of faults is nearly 10 %. The symmetrical and unsymmetrical fault mainly occurs in the terminal of the generator, and the open circuit and short circuit fault occur on the distribution system.

Consider line-to-line fault on phases b and c also grounded as shown in Fig.



$$I_a = 0$$
$$V_b = V_c = 0$$
$$I_b + I_c = I_F$$

$$V_{a1} = \frac{1}{3}(V_a + aV_b + a^2 V_c) = \frac{1}{3}V_a$$

$$V_{a2} = \frac{1}{3}(V_a + a^2 V_b + aV_c) = \frac{1}{3}V_a$$

Further

$$V_{a0} = \frac{1}{3}(V_a + V_b + V_c) = \frac{1}{3}V_a$$

Hence

$$V_{a1} = V_{a2} = V_{a0} = \frac{1}{3}V_a$$

But

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

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

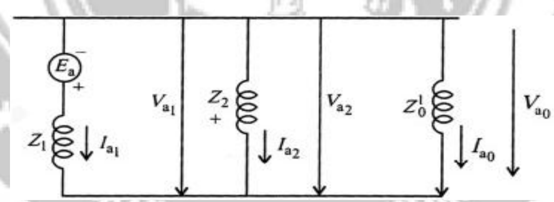
and

$$\begin{aligned} V_{a0} &= - I_{a0}Z_0 - I_F Z_n \\ &= - I_{a0}(Z_0 + 3Z_n) = - I_{a0}(Z_0^1) \end{aligned}$$

It may be noted that

$$\begin{aligned} I_F &= I_b + I_c = a^2 I_{a1} + aI_{a2} + I_{a0} + aI_{a1} + a^2 I_{a2} \\ &= (a + a^2)I_{a1}(a + a^2)I_{a2} + 2I_{a0} \\ &= - I_{a1} - I_{a2} + 2I_{a0} = - I_{a1} - I_{a2} - I_{a0} + 3I_{a0} \\ &= - (I_{a1} + I_{a2} + I_{a0}) + 3I_{a0} = 0 + 3I_{a0} = 3I_{a0} \end{aligned}$$

The sequence network connections are shown in Fig.



$$I_{a1} = \frac{E_a}{Z_1 + \frac{Z_2 Z_0^1}{Z_2 + Z_0^1}}$$

$$= \frac{E_a (Z_2 + Z_0^1)}{Z_1 Z_2 + Z_2 Z_0^1 + Z_0^1 Z_1}$$

$$V_{a2} = V_{a1}$$

$$-I_{a1} Z_2 = E_a - I_{a1} Z_1$$

$$\begin{aligned} I_{a2} &= -\left(\frac{E_a - I_{a1} Z_1}{Z_2}\right) \\ &= -\left[E_a - \frac{E_a (Z_2 + Z_0^1) \cdot Z_1}{Z_1 Z_2 + Z_2 Z_0^1 + Z_0 Z_1}\right] \cdot \frac{1}{Z_2} \\ &= \frac{-E_a Z_0^1}{Z_1 Z_2 + Z_2 Z_0^1 + Z_0^1 Z_1} \end{aligned}$$

Similarly

$$-I_{a0} Z_0^1 = -I_{a2} Z_2$$

$$I_{a0} = -I_{a2} \frac{Z_2}{Z_0^1} = \frac{-E_a Z_2}{Z_1 Z_2 + Z_2 Z_0 + Z_0 Z_1}$$

$$\begin{aligned} V_a &= V_{a1} + V_{a2} + V_{a0} \\ &= E_a - I_{a1} Z_1 - I_{a2} Z_2 - I_{a0} (Z_0 + 3Z_n) \\ &= E_a - \frac{E_a (Z_2 + Z_0)}{\Sigma Z_1 Z_2} Z_1 + \frac{E_a Z_0 Z_2}{\Sigma Z_1 Z_2} + \frac{E_a \cdot Z_2 (Z_0 + 3Z_n)}{\Sigma Z_1 Z_2} \\ &= E_a \frac{3Z_2 Z_0 + 3Z_2 Z_n}{\Sigma Z_1 Z_2} = 3E_a \left(\frac{Z_2 (Z_0 + Z_n)}{Z_1 Z_2 + Z_2 Z_0 + Z_0 Z_1}\right) \end{aligned}$$

$$\begin{aligned} V_b &= V_{a0} + a^2 V_{a1} + a V_{a2} \\ &= -I_{a0} (Z_0 + 3Z_n) + a^2 \left[E_a - I_{a1} Z_1\right] + a\left[-I_{a2} Z\right. \\ &= \frac{E_a (Z_2)(Z_0 + 3Z_n)}{\Sigma Z_1 Z_2} (Z_0 + 3Z_n) + a^2 \left[E_a - \frac{(E_a Z_2 +}{\Sigma Z_1 Z}\right. \\ &= \frac{E_a \left[Z_2 Z_0 \quad 3Z_2 Z_n\right] + a^2 E_a \left[Z_1 Z_2 + Z_2 Z_0 + Z_0 Z_1 \quad Z_2 Z_1 \quad Z_0 Z_1\right.}{\Sigma Z_1 Z_2 + a E_a Z_0 Z_2} \end{aligned}$$

$$V_b = \frac{E_a\left[Z_0Z_2+a^2Z_0Z_2+aZ_0Z_2-3Z_2Z_n\right]}{\Sigma Z_1Z_2}$$

$$= \frac{E_a\left[Z_0Z_2(1+a+a^2)+3Z_2Z_n\right]}{Z_1Z_2+Z_2Z_0+Z_0Z_4} = \frac{3\cdot E_a\cdot Z_2Z_n}{Z_1Z_2-Z_2Z_0+Z_0Z_1}$$

If $Z_n = 0;\ V_b = 0$