

## 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 faults considered 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.
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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  $1.0\angle 0^\circ$ . 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 referred as the sequence equations. In matrix Form the sequence equations can be considered as:

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

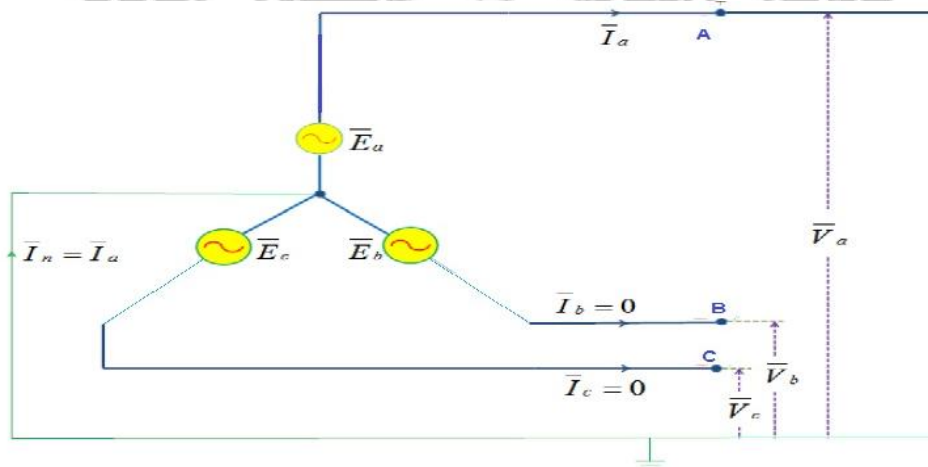
This equation is used along with the equations i.e., conditions under fault (c.u.f.), derived to describe the fault under consideration, to determine the sequence

current  $I_{a1}$  and hence the fault current  $I_f$ , in terms of  $E_a$  and the sequence impedances,  $Z_1$ ,  $Z_2$  and  $Z_0$ . 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  $E_a$ , and  $E_c$  be the internally generated voltages and  $Z_n$  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  $I_a$  with  $I_b=I_c=0$ , 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,

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

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,

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

$$\text{i.e., } V_a = E_a - I_a/3 (Z_1 + Z_2 + Z_0) = \text{zero,}$$

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

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

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

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:  $V_a I_a^* = 0$ , Sound phase powers:

$V_b I_b^* = 0$ , and  $V_c I_c^* = 0$ ,

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

10 If  $Z_n = \alpha$  then  $Z_0 = \alpha$ . e., the zero sequence network is open so that then,

then  $Z_0 = \infty$ . If  $Z_n = 10$ . If  $Z_n = 10$ ,  $I_f = I_a = 0$ .

