

## **Analysis of unsymmetrical faults at generator terminals: LG, L and LG**

### **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.

1. **Single line-to-ground fault (SLG)**
2. **Line-to-line fault (L-L)**
3. **Double line-to-ground fault (2LG)**
4. **Balanced three-phase fault**

Fault calculations provide information on currents and voltages in a power system during fault conditions. Short-circuit currents are computed for each relay and circuit breaker location and for various system contingency conditions, such as lines or generating units out of service, in order to determine the minimum and maximum fault currents. This information is useful to the engineer in selecting circuit breakers for fault interruption, selecting relays for fault detection, and determining the relay setting, which is referred to as relay coordination. The proper selection and setting of protective devices ensure minimum disruption of electrical service and limit possible damage to the faulted equipment.

### **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.

### **Single Line-to-Ground Fault**

A single line-to-ground (SLG) fault is the most commonly occurring unsymmetrical fault. It may be caused by a vehicular accident causing one of

the phase conductors to fall and come in contact with the earth, or it may be caused by tree branches, or it could be caused by flashovers across dusty insulators during rain-showers. A single line-to-ground fault is illustrated in Fig. 1.

Assuming that pre-fault currents are negligible, the SLG fault is described by the following voltage and current relationships.

$$V_a=0 \quad \text{..... (1)}$$

$$I_b=I_c=0 \quad \text{..... (2)}$$

The sequence components of the short-circuit current are found by using following equation. Thus,

$$\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} [I_{a0}] \quad \text{..... (3)}$$

Therefore, it is seen that the sequence components of the current are all equal to each other; that is,

$$I_{a0}=I_{a1}=I_{a2}= (1/3)I_a \quad \text{..... (4)}$$

The voltage of the principal phase a may be expressed in terms of its sequence components as

$$V_a=V_{a0}+V_{a1}+V_{a2}=0 \quad \text{..... (5)}$$

By applying KVL to figure 2, we can obtain the following equation:

$$E_{a1}-I_{a1}(Z_1+Z_2+Z_0)=0 \quad \text{..... (6)}$$

The expression for  $I_{a1}$  is obtained from Eq. 6, and using Eq. 4 provides the expressions for  $I_{a2}$  and  $I_{a0}$  as follows:

$$I_{a1}=E_{a1}/Z_1+Z_2+Z_0=I_{a2}=I_{a0} \quad \text{..... (7)}$$

The short-circuit current  $I_a$  is found as the sum of its sequence components; thus,  $I_a=I_{a0}+I_{a1}+I_{a2}=3E_{a1}/Z_1+Z_2+Z_0$  ..... (8)

Equations 4 and 5 indicate that the sequence networks are to be interconnected in series for a single line-to-ground fault.

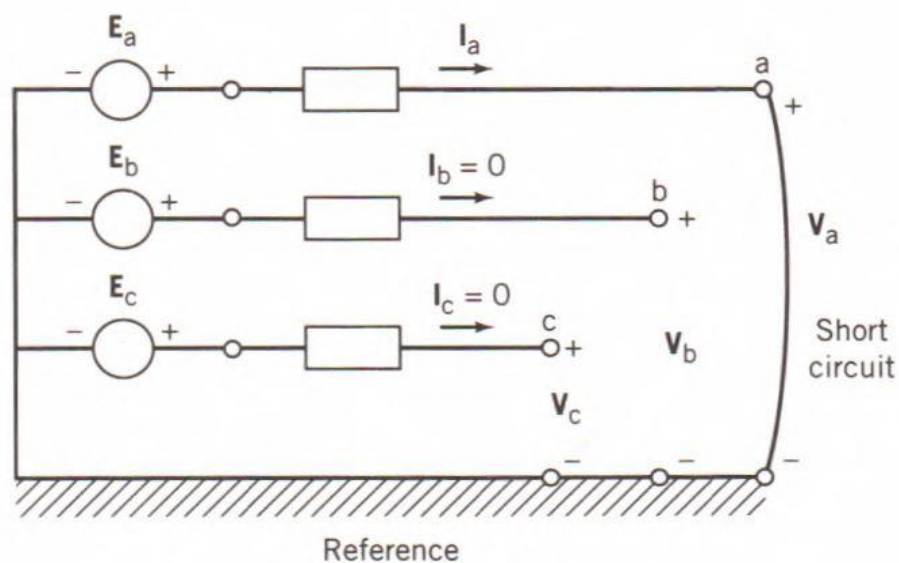


Figure1: A single line-to-ground fault.

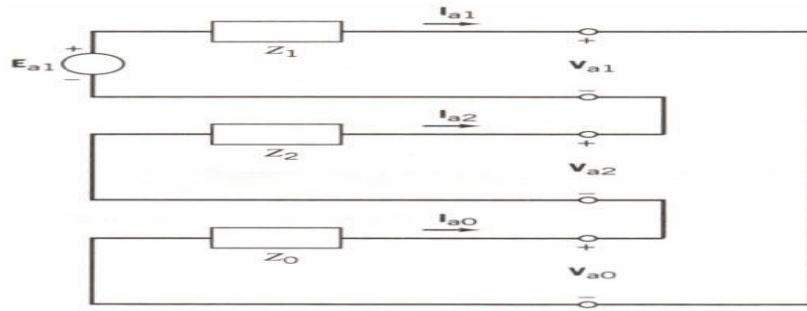


Figure 2: Interconnection of sequence networks of the single line to ground fault

### Line-to-Line Fault

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. 3.

Assuming that pre-fault currents are negligible, the voltage and current relationships describing the line-to-line fault are given by

$$V_b = V_c \quad \dots\dots\dots (9)$$

$$I_b = -I_c; I_a = 0 \quad \dots\dots\dots (10)$$

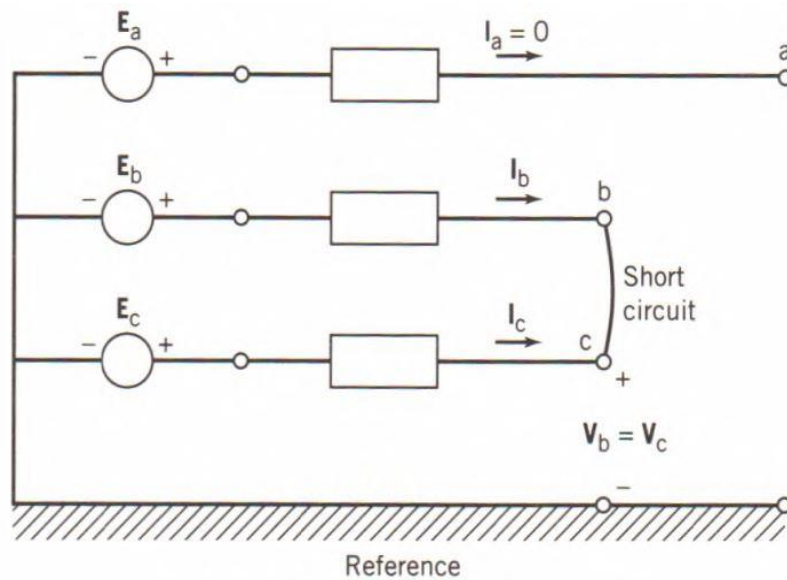


Figure 3: A line-to-line fault.

The sequence components of the short-circuit current are found by using the following Equation. Thus,

$$\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 0 \\ (a - a^2) I_b \\ (a^2 - a) I_c \end{bmatrix} \quad \dots\dots\dots (11)$$

Therefore, it is seen that the negative-sequence component of the current is equal to the negative of its positive-sequence component; that is,

$$I_{a2} = -I_{a1} \quad \dots\dots\dots (12)$$

The voltages of the shorted phases, b and c, may be expressed in terms of the sequence components as follows:

$$V_b = V_{a0} + a^2 V_{a1} + a V_{a2} = 0 \quad \text{..... (13)}$$

$$V_c = V_{a0} + a V_{a1} + a^2 V_{a2} = 0 \quad \text{..... (14)}$$

Subtracting Eq. 14 from 13 gives

$$V_b - V_c = (a^2 - a) V_{a1} + (a - a^2) V_{a2} \quad \text{..... (15)}$$

Because  $V_b$  and  $V_c$  are equal, Eq. 15 reduces to zero and yields

$$V_{a1} = V_{a2} \quad \text{..... (16)}$$

Equations 12 and 16 indicate that the positive- and negative-sequence networks are to be interconnected in parallel for a line-to-line fault.

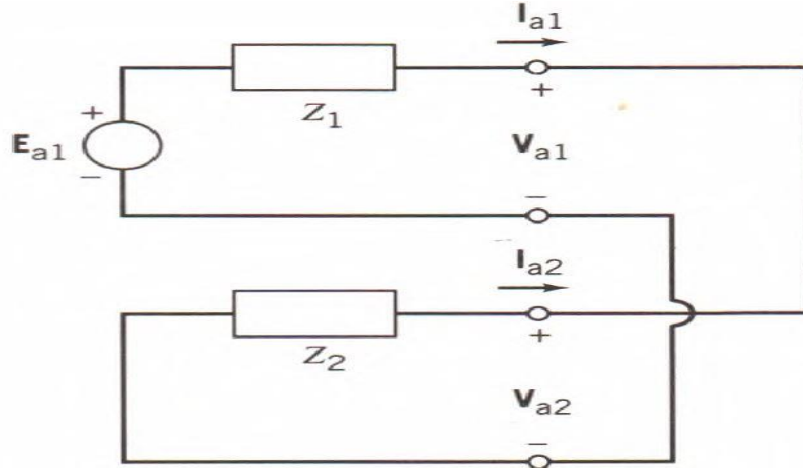


Figure 4: Interconnection of sequence networks for a line-to-line fault.

### 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. For a 2LG fault with pre-fault currents assumed negligible, the voltage and current relationships are given by the following:

$$V_b = V_c = 0 \quad \text{..... (17)}$$

$$I_a = 0 \quad \text{..... (18)}$$

The sequence components of the voltage at the fault location are found by using following equation. Thus,

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_a \\ 0 \\ 0 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} V_a \\ V_a \\ V_a \end{bmatrix} \quad \text{..... (19)}$$

Therefore, it is seen that the sequence components of the voltage at the fault are all equal; that is,

$$V_{a1} = V_{a2} = V_{a0} \quad \text{..... (20)}$$

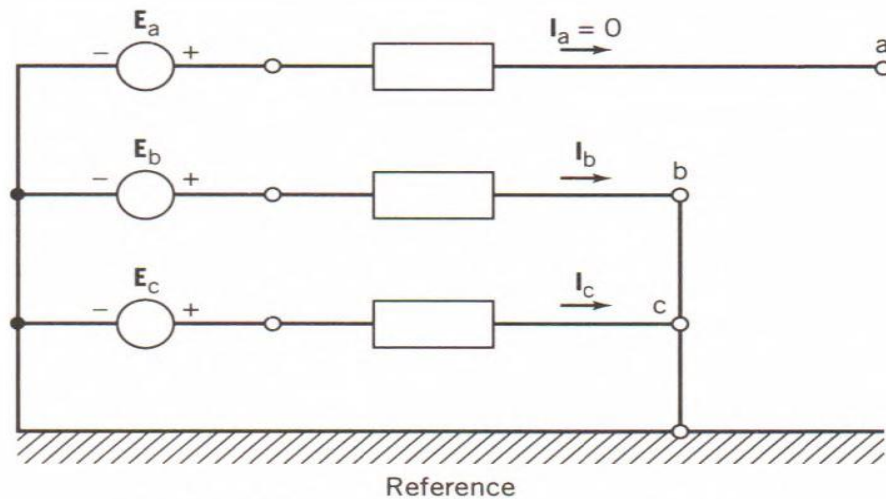


Figure 5 A double line-to-ground fault.

Neglecting pre-fault load currents, the current in phase a may be expressed as  $I_a = I_{a0} = I_{a1} = I_{a2} = 0$  ..... (21)

Equations 20 and 21 indicate that the three sequence networks are to be interconnected in parallel for a double line-to-ground fault.

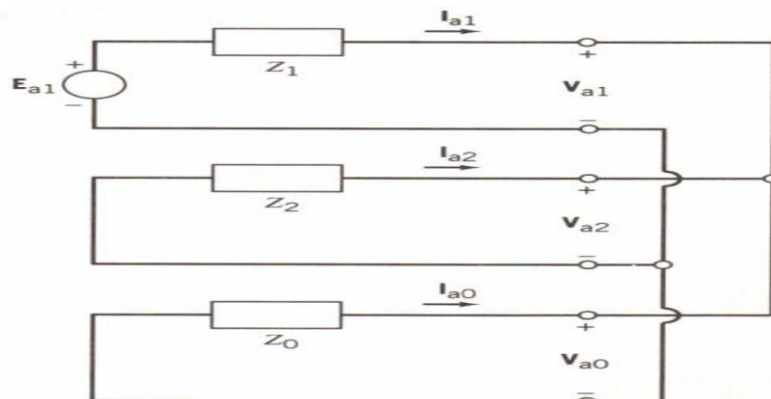


Figure 6: the interconnection of sequence networks for a double line to ground fault