7- Unbalanced Faults

Most of the faults that occur on power systems are unsymmetrical faults, which may consist of unsymmetrical short circuits, unsymmetrical faults through impedances, or open conductors. Unsymmetrical faults occur as single line---to---ground faults, line---to--- line faults, or double line---to---ground faults.

The path of the fault current from line to line or line to ground may or may not contain impedance.

One or two open conductors result in unsymmetrical faults, through either the breaking of one or two conductors or the action of fuses and other devices that may not open The three phases simultaneously.

Since any unsymmetrical fault causes unbalanced currents to flow in the system, the method of symmetrical components is very used in the analysis to determine the currents and voltages in all parts of the system after the occurrence of the fault.

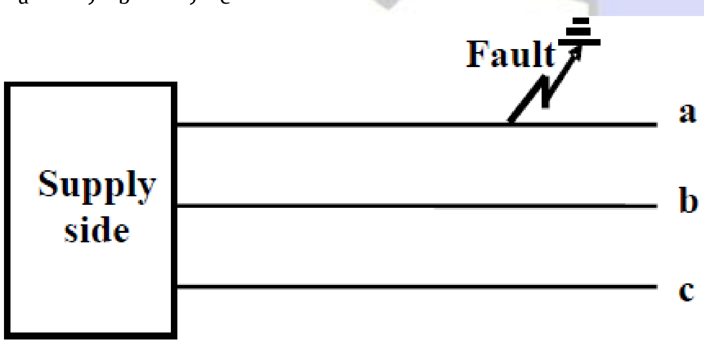
We will consider faults on a power system by applying Thévenin's theorem, which allows us to find the current in the fault by replacing the entire system by a single generator and series impedance, and we will show how the bus impedance matrix is applied to the analysis of unsymmetrical faults.

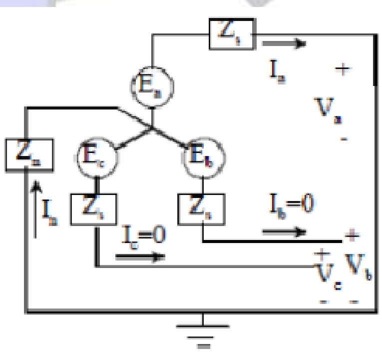
The common types of asymmetrical faults occurring in a Power System are single line to ground faults and line to line faults, with and without fault impedance.

1- Single Line-To-Ground Fault (L-G fault)

The single line to ground fault can occur in any of the three phases. However, it is sufficient to analyze only one of the cases. Looking at the symmetry of the symmetrical component matrix, it is seen that the simplest to analyze would be the phase **a**. Consider an L-G fault with zero fault impedance as shown in figure. Since the fault impedance is 0, at the fault

$V_a = 0$, $I_b = 0$, $I_c = 0$





since load currents are neglected. These can be converted to equivalent conditions in symmetrical components as follows.

$V_a = V_a^0 + V_a^1 + V_a^2 = 0$

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

giving $I_a^0 = I_a^1 = I_a^2 = I_a/3$

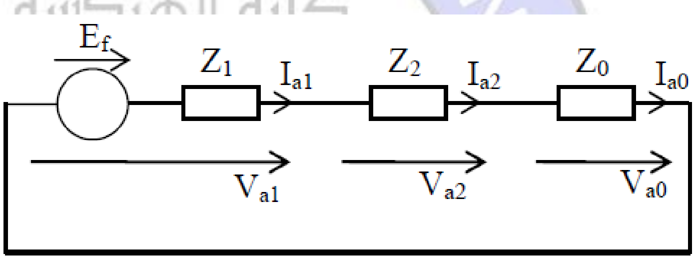
Mathematical analysis using the network equation in symmetrical components would yield the desired result for the fault current $I_f = I_a$.

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \begin{bmatrix} 0 \\ E_f \\ 0 \end{bmatrix} - \begin{bmatrix} Z_0 & 0 & 0 \\ 0 & Z_1 & 0 \\ 0 & 0 & Z_2 \end{bmatrix}\begin{bmatrix} I_{a0} = I_a/3 \\ I_{a1} = I_a/3 \\ I_{a2} = I_a/3 \end{bmatrix}$$

Thus $V_{a0} + V_{a1} + V_{a2} = 0 = -Z_0.I_a/3 + E_f - Z_1.I_a/3 - Z_2.I_a/3$

Simplification, with $I_f = I_a$, gives

$$I_f = \frac{3E_f}{Z_1 + Z_2 + Z_0}$$

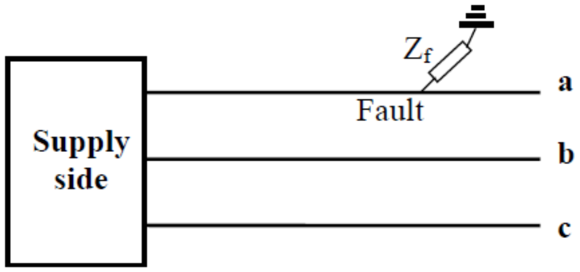


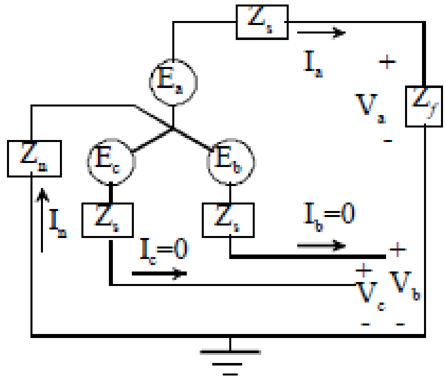
Also, considering the equations

$V_{a0} + V_{a1} + V_{a2} = 0$, and $I_{a0} = I_{a1} = I_{a2}$.

Indicates that the three networks (zero, positive and negative) must be connected in series (same current, voltages add up) and short-circuited, giving the circuit shown in figure.

In this case, I_a corresponds to the fault current I_f, which in turn corresponds to 3 times any one of the components ($I_{a0} = I_{a1} = I_{a2} = I_a/3$). Thus the network would also yield the same fault current as in the mathematical analysis. In this example, the connection of sequence components is more convenient to apply than the mathematical analysis. Thus for a single line to ground fault (L-G fault) with no fault impedance, the sequence networks must be connected in series and short circuited. Consider now an L-G fault with fault impedance Z_f as shown in figure.





at the fault

$\mathbf{V_a = I_a Z_f}$, $\mathbf{I_b = 0}$, $\mathbf{I_c = 0}$

These can be converted to equivalent conditions in symmetrical components as follows.

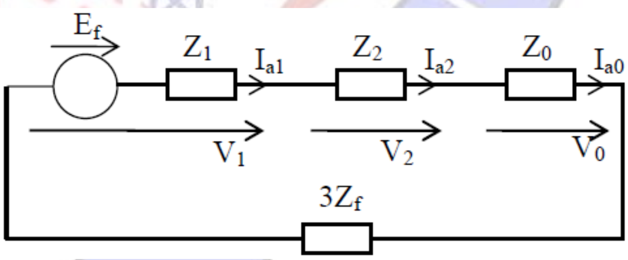
$\mathbf{V_{a0} + V_{a1} + V_{a2} = (I_{a0} + I_{a1} + I_{a2}).Z_f}$

And
$$\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix}\begin{bmatrix} I_a \\ I_b = 0 \\ I_c = 0 \end{bmatrix},$$

giving $\mathbf{I_{a0} = I_{a1} = I_{a2} = I_a/3}$

Mathematical analysis using the network equation in symmetrical components would yield the desired result for the fault current If as

$$I_f = \frac{3V_f}{Z_1 + Z_2 + Z_0 + 3Z_f}$$



Similarly, considering the basic equations, $\mathbf{I_{a0} = I_{a1} = I_{a2} = I_a/3}$,

And $\mathbf{V_{a0} + V_{a1} + V_{a2} = 3I_{a0}.Z_f}$

or $\mathbf{V_{a0} + V_{a1} + V_{a2} = I_{a0}.3Z_f}$,

would yield a circuit connection of the 3 sequence networks in series an in series with an effective impedance of 3 Zf.