Balanced and Unbalanced Faults

6

Per Unit System

When the power network consist of more than one equipment having different rating, the network is analysed by modelling all equipment as a single model, so that the number of network equation to be solved is only one so that time required to sovle the problem will be less.

$$\text{Per unit value} = \frac{\text{Actual value in some units}}{\text{Base or reference value in same units}}$$

Note:

In transformer primary side p.u. reactance is always equal to secondary side p.u. reactance.

Remember:

- Out of 4-system quantities (kVA, kV, current and impedance) only two are independent. It is convenient to select the base value of kVA and kV and calculate the base values of other two.
- Ratio of 2-base unit give another base quantity

$$\frac{V_{base}}{I_{base}} = Z_{base}$$

- In transformer primary side p.u. reactance is always equal to secondary side p.u. reactance.

❑ Base Current

$$\text{Base current} = \frac{\text{Base kVA}}{\sqrt{3} \times \text{Base kV}} \text{ A (in 3-}\phi\text{ system)}$$

❑ Base Impedance

$$\text{Base impedance} = \frac{\text{Line to neutral value of base voltage}}{\text{Base current}}$$

$$\text{Base impedance} = \frac{(\text{Base kV})^2}{\text{Base MVA}}\ \Omega$$

- Per unit reactance

$$X_{pu} = X_{(actual)} \frac{I_{base}}{V_{base}}$$

$$X_{pu} = X_{(actual)} \frac{(MVA)_{base}}{(kV)^2_{base}}$$

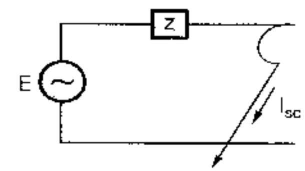
- Per unit impedance referred to new base

$$= \begin{bmatrix} \text{Per unit impedance} \\ \text{referred to old base} \end{bmatrix} \begin{bmatrix} \frac{\text{Base kV}_{old}}{\text{Base kV}_{new}} \end{bmatrix}^2 \begin{bmatrix} \frac{\text{Base kVA}_{new}}{\text{Base kVA}_{old}} \end{bmatrix}$$

- Short circuit kVA

$$\text{Short circuit kVA} = \text{Rated or base kVA} \times \frac{100}{\%Z}$$

$$EI_{sc} = EI \times \frac{100}{\%Z}$$

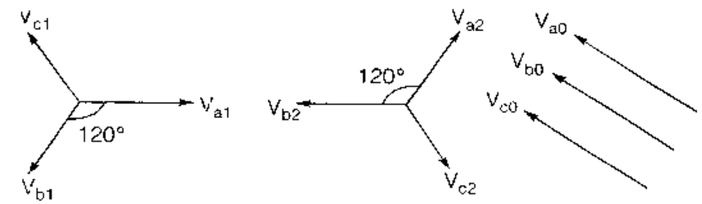


where,
E = Rated voltage
I = Rated current
Z = Internal impedance

Symmetrical Components

- A positive sequence, set of three symmetrical voltages (i.e. all numerically equal and all displaced from each other by 120°) having the same sequence 'abc' as the original set and denoted by V_{a1}, V_{b1} and V_{c1}.
- A negative sequence, set of three symmetrical voltages having the phase sequence opposite to that of the original set and denoted by V_{a2}, V_{b2} and V_{c2}.
- A zero sequence, set of three voltages, all equal in magnitude and in phase with each other and denoted by V_{a0}, V_{b0} and V_{c0}.

$$V_a = V_{a1} + V_{a2} + V_{a0}$$
$$V_b = V_{b1} + V_{b2} + V_{b0}$$
$$V_c = V_{c1} + V_{c2} + V_{c0}$$



where, V_a, V_b, V_c are the three-phase voltages

$$V_{b1} = \alpha^2 V_{a1} \quad V_{c1} = \alpha V_{a1}$$
$$V_{b2} = \alpha V_{a2} \quad V_{c2} = \alpha^2 V_{a2}$$
$$V_{b0} = V_{a0} \quad V_{c0} = V_{a0}$$

where, Operator $\alpha = 1\angle 120°$

Phase voltages in matrix form

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} V_{a_0} \\ V_{a_1} \\ V_{a_2} \end{bmatrix}$$

$$[V_{abc}] = [A][V_{012}] \qquad [V_{012}] = [A]^{-1}[V_{abc}]$$

where, $A = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix}$ and $A^{-1} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix}$

Complex Power

Total complex power in a 3-ϕ circuit

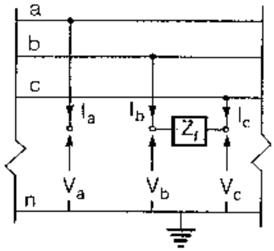
$$S = [V_{abc}]^T [I_{abc}]^* = 3[V_{012}]^T [I_{012}]^*$$

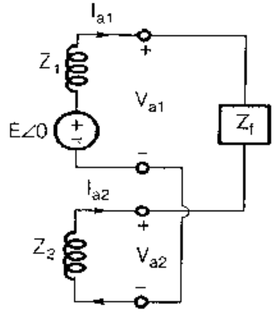
where,
$[V_{012}]$ = Symmetrical component matrix
$[V_{abc}]$ = Unsymmetrical phasor matrix

$$[Z_{012}] = [A]^{-1}[Z_{abc}][A]$$

Remember:

For almost all power system components the matrix $[Z_{abc}]$ is not diagonal but possess certain symmetries. These symmetries are such that $[Z_{012}]$ is diagonal either exactly or approximately.





- Fault current

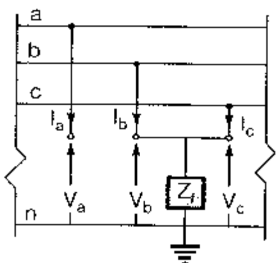
$$\boxed{I_f = I_b = -I_c = \frac{-j\sqrt{3}\,E}{Z_1 + Z_2 + Z_f}}$$

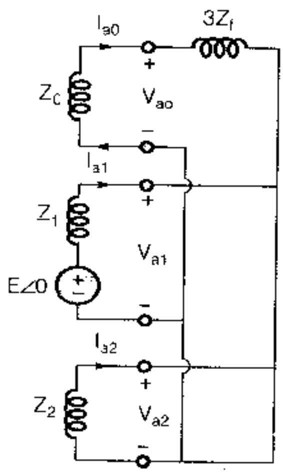
Double line to ground fault (LLG fault)

Terminal conditions

$$I_a = 0,\ V_b = V_c = (I_b + I_c)Z_f$$

$$\boxed{I_{a1} = \frac{E}{Z_1 + \dfrac{Z_2(Z_0 + 3Z_f)}{Z_2 + Z_0 + 3Z_f}}}$$





- Fault Current

$$\boxed{I_f = I_b + I_c}$$