

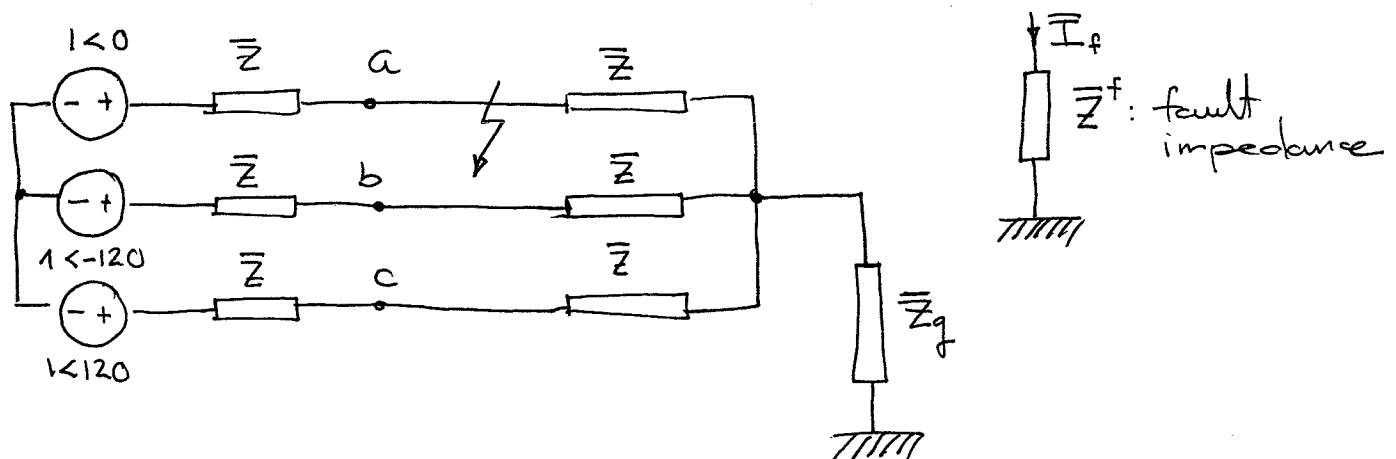
LECTURE 24

UNBALANCED SYSTEM OPERATION

- COMMON TYPES OF FAULTS
- METHOD OF SYMMETRICAL COMPONENTS
- USE OF SYMMETRICAL COMPONENTS FOR FAULT ANALYSIS

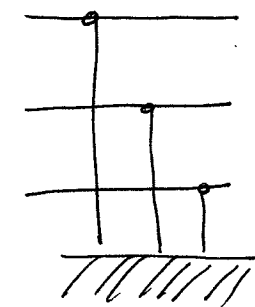
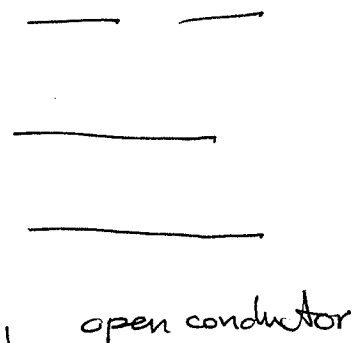
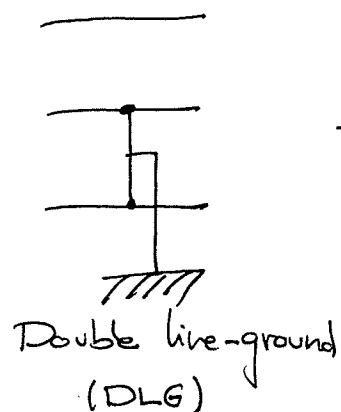
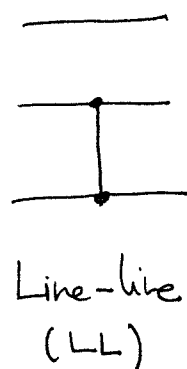
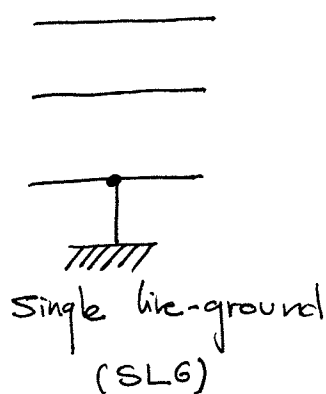
UNBALANCED SYSTEM OPERATION

- So far, we have assumed that the power system works in a balanced condition (this goes back to the very beginning of the course)
- This is the case in the absence of faults.
- When the system operates in a balanced condition, we saw that the analysis simplifies to look at just one phase using per-phase equivalents.
- Balance operation is no longer true when a fault occurs (except for $\exists \emptyset$ faults which are rare).



- We need analysis techniques to compute fault currents and other electrical variables.
- These techniques are then used to select appropriate circuit breaker ratings for example.

COMMON TYPES OF FAULTS



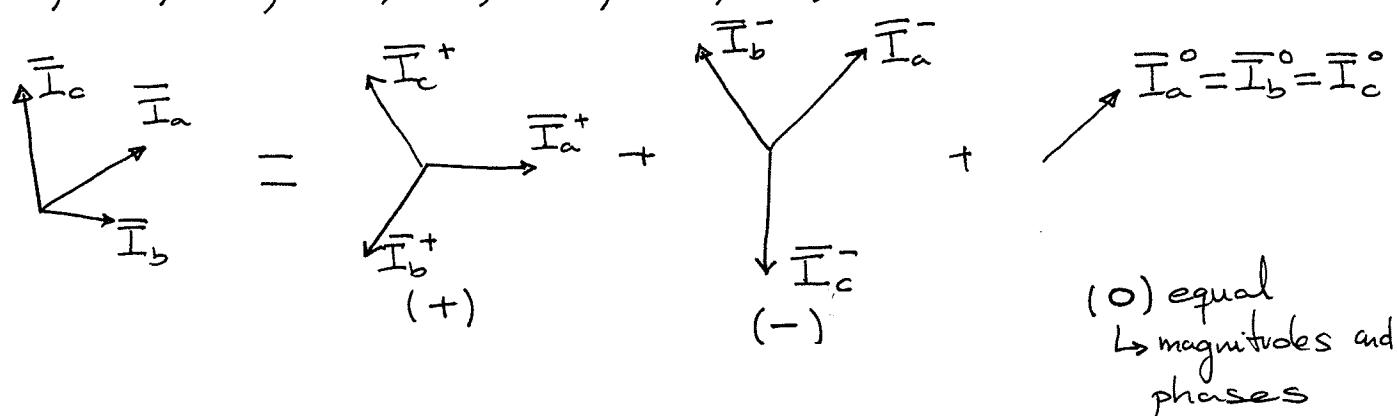
Balanced three-phase.

METHOD OF SYMMETRICAL COMPONENTS

() - Due to Fortesque, it is the main engine to analyze unbalanced power systems.

- The method of symmetrical components allows to represent any set of three phasor, say $\bar{I}_a, \bar{I}_b, \bar{I}_c$ in terms of nine symmetrical components:

$\bar{I}_a^0, \bar{I}_a^+, \bar{I}_a^-, \bar{I}_b^0, \bar{I}_b^+, \bar{I}_b^-, \bar{I}_c^0, \bar{I}_c^+, \bar{I}_c^-$



In matrix form

$$\begin{bmatrix} \bar{I}_a \\ \bar{I}_b \\ \bar{I}_c \end{bmatrix} = \begin{bmatrix} \bar{I}_a^0 \\ \bar{I}_b^0 \\ \bar{I}_c^0 \end{bmatrix} + \begin{bmatrix} \bar{I}_a^+ \\ \bar{I}_b^+ \\ \bar{I}_c^+ \end{bmatrix} + \begin{bmatrix} \bar{I}_a^- \\ \bar{I}_b^- \\ \bar{I}_c^- \end{bmatrix}$$

Define $\alpha = 1 \angle 120^\circ$

As we know

$$\bar{I}_b^+ = \alpha^2 \bar{I}_a^+$$

$$\bar{I}_b^- = \alpha \bar{I}_a^-$$

$$\bar{I}_c^+ = \alpha \bar{I}_a^+$$

$$\bar{I}_c^- = \alpha^2 \bar{I}_a^-$$

$$\begin{bmatrix} \bar{I}_a \\ \bar{I}_b \\ \bar{I}_c \end{bmatrix} = \underbrace{\begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix}}_{\bar{A}} \begin{bmatrix} \bar{I}_a^0 \\ \bar{I}_a^+ \\ \bar{I}_a^- \end{bmatrix}$$

$$\bar{I} \triangleq \begin{bmatrix} \bar{I}_a \\ \bar{I}_b \\ \bar{I}_c \end{bmatrix}$$

$$\bar{I}_s \triangleq \begin{bmatrix} \bar{I}_a^0 \\ \bar{I}_a^+ \\ \bar{I}_a^- \end{bmatrix}$$

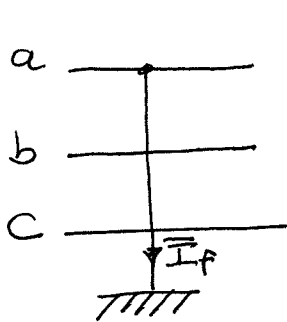
If we know $\bar{I}_a, \bar{I}_b, \bar{I}_c$, it is easy to find the symmetrical components as follows

$$\bar{I} = \bar{A} \cdot \bar{I}_s \longrightarrow \bar{I}_s = \bar{A}^{-1} \cdot \bar{I} \quad \text{where}$$

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

Example: finding symmetrical components of SLG currents

→ Suppose we are given the fault current $\bar{I}_f$ in phase of a three-phase system

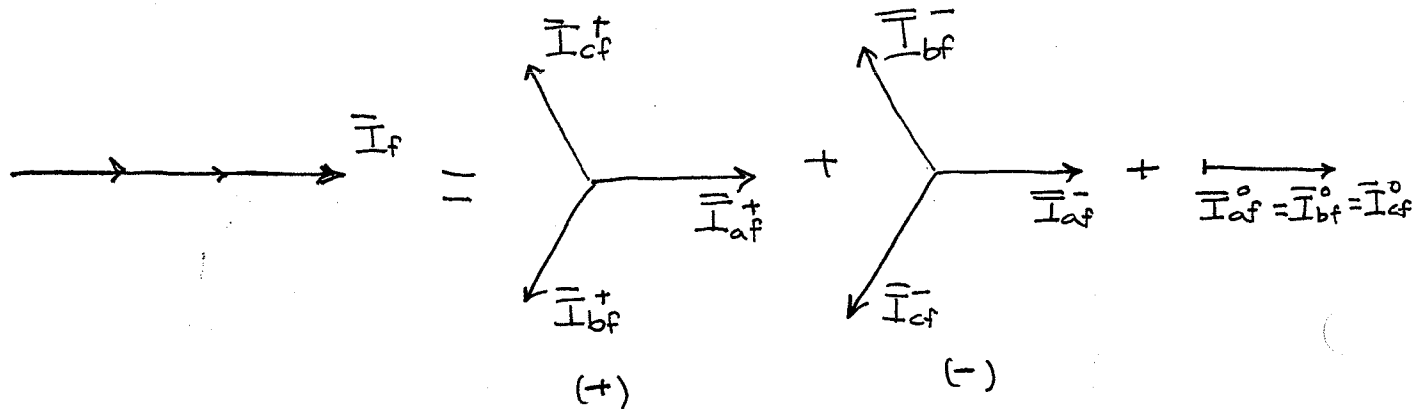


$$\bar{I} = \begin{bmatrix} \bar{I}_f \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} \bar{I}_{af}^0 \\ \bar{I}_{af}^+ \\ \bar{I}_{af}^- \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix} \begin{bmatrix} \bar{I}_f \\ 0 \\ 0 \end{bmatrix}$$

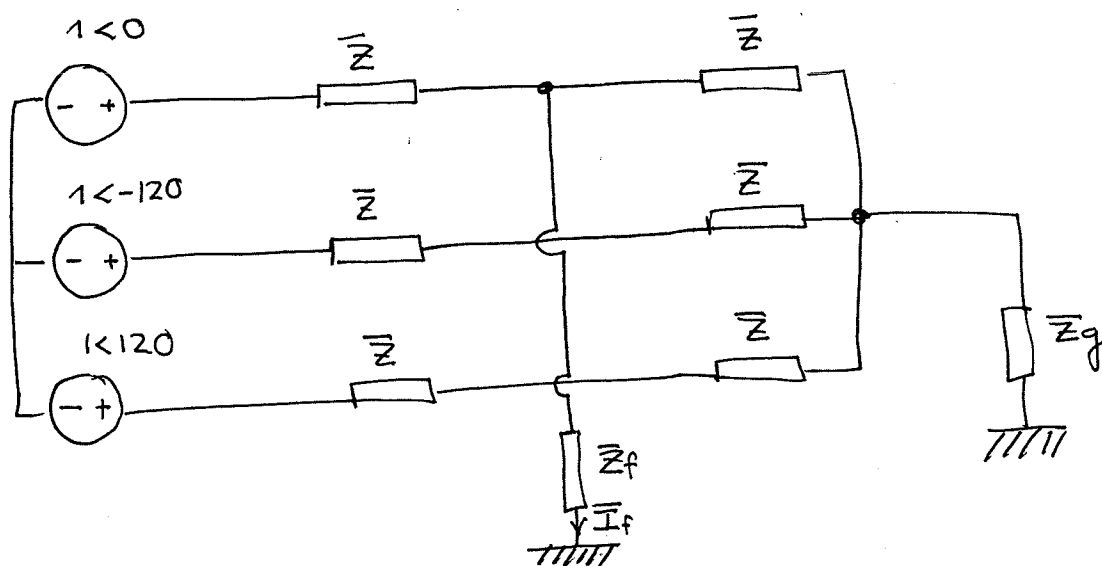
$$\begin{bmatrix} \bar{I}_{af}^0 \\ \bar{I}_{af}^+ \\ \bar{I}_{af}^- \end{bmatrix} = \frac{\bar{I}_f}{3} \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$$

$$\rightarrow \bar{I}_{af}^0 = \bar{I}_{af}^+ = \bar{I}_{af}^- = \frac{1}{3} \bar{I}_f$$

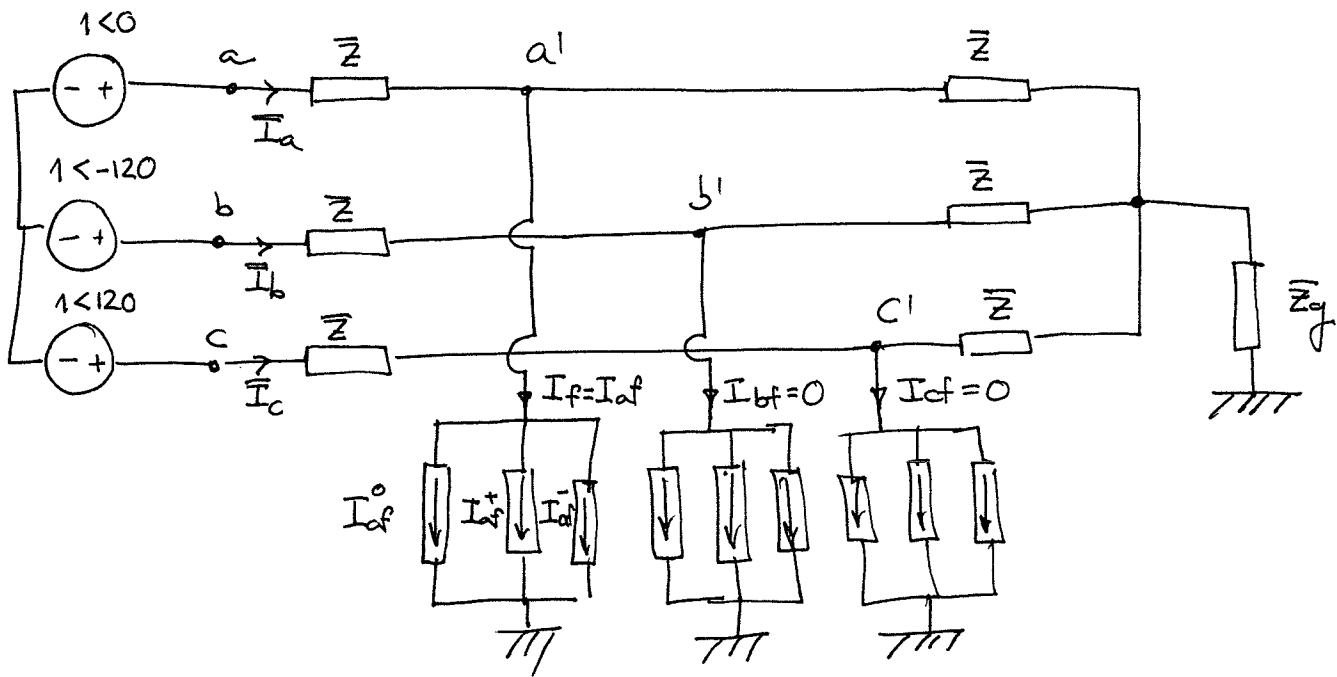


USE OF SYMMETRICAL COMPONENTS FOR FAULT ANALYSIS

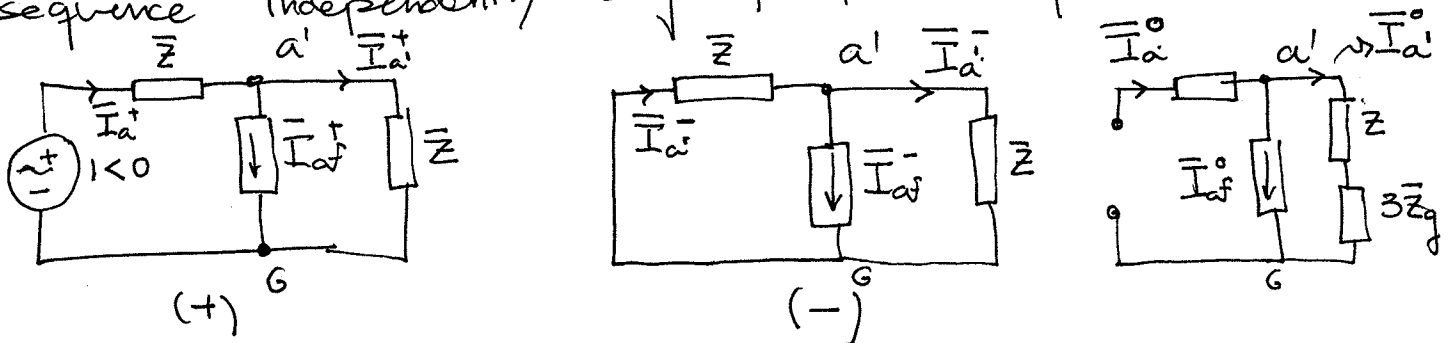
To introduce the method of symmetrical components for finding voltages and currents



- It is obvious that we cannot use per-phase equivalents as the circuit is not symmetric.
- Let's replace the impedance by a current source of the same magnitude as $\bar{I}_f$ and write the current through each phase of the fault using symmetrical components.



We can apply superposition and solve each sequence independently using per-phase equivalents



- The voltage source of the (+) sequence is obvious
- The SC in the (-) replacing the voltage source is also intuitive (this is how we do it in superposition)
- The OC in the (0) is not so intuitive:

$\bar{I}_a^0 = \bar{I}_b^0 = \bar{I}_c^0$, but since the neutral (on the source) is isolated $\bar{I}_a^0 + \bar{I}_b^0 + \bar{I}_c^0 = 0 \Rightarrow$

$$\Rightarrow \bar{I}_a^0 = \bar{I}_b^0 = \bar{I}_c^0 = 0$$

$$\bar{I}_a^0 = \bar{I}_b^0 = \bar{I}_c^0 : \bar{V}_{a'g} = Z \bar{I}_a^0 + 3Z_g \bar{I}_a^0$$