11/30/17

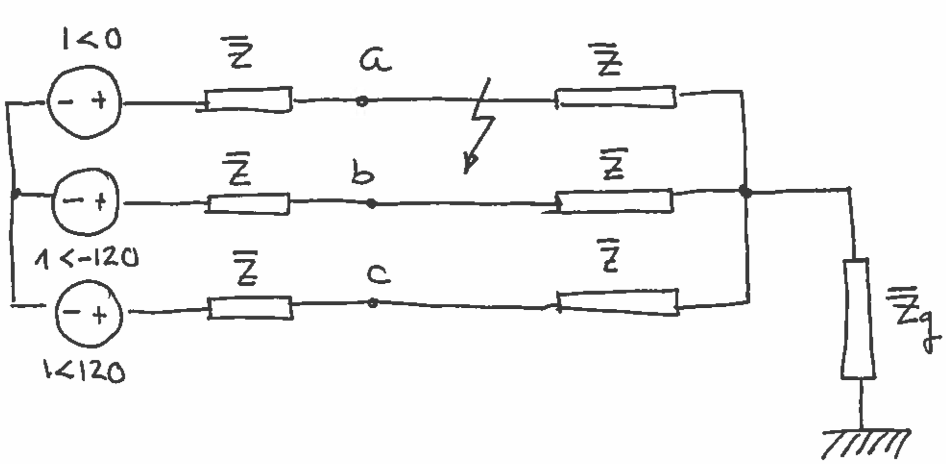
LECTURE 23

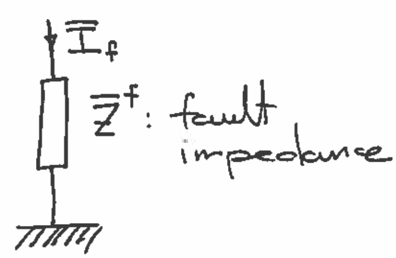
UNBALANCED SYSTEM OPERATION

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

UNBALANCED SYSTEM OPERATION

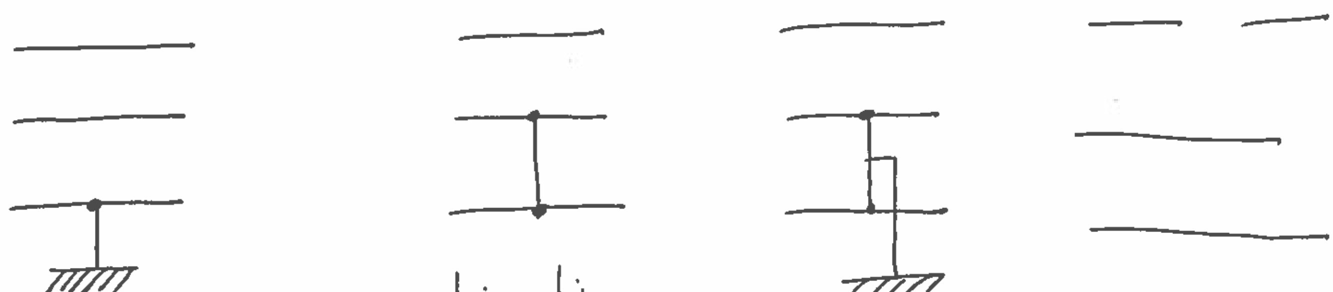
- So far, we have assumed that the power system works in a balanced condition (this goes back to the very beginning of the course)
- This is the case in the absence of faults.
- When the system operates in a balanced condition, we saw that the analysis simplifies to look at just one phase using per-phase equivalents.
- Balance operation is no longer true when a fault occurs. (except for 3Ø faults which are rare).





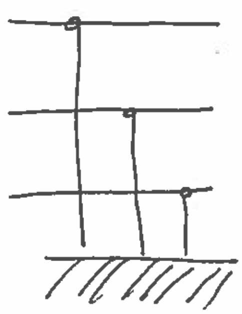
- We need analysis techniques to compute fault currents and other electrical variables.
- These techniques are then used to select appropriate circuit breaker ratings for example.

COMMON TYPES OF FAULTS



Single line-ground (SLG) | Line-line (LL) | Double line-ground (DLG) | open conductor

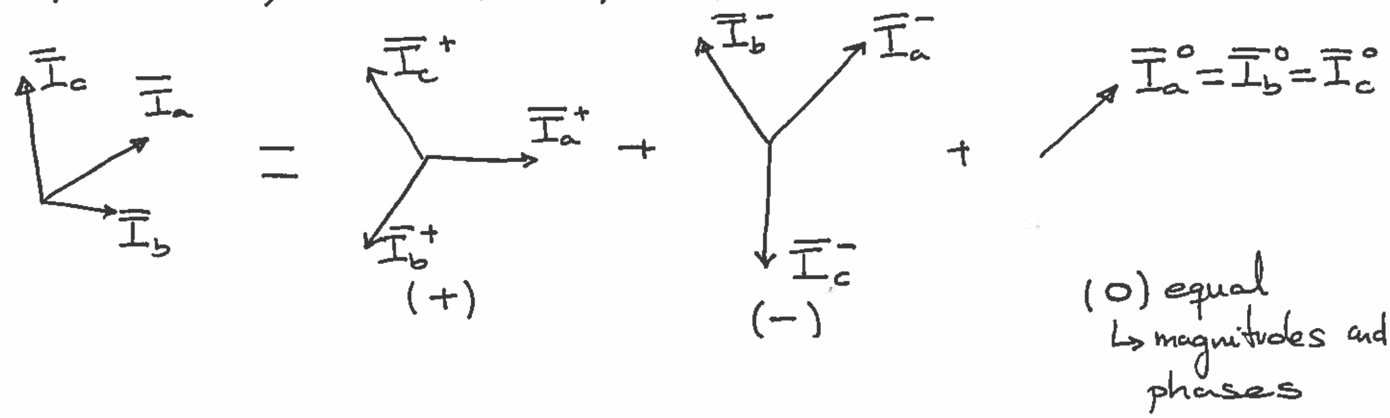
We will discuss these three in detail.



Balanced three-phase - ground -

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

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

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

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

$$\bar{I}_s \triangleq \begin{bmatrix}\bar{I}_a^0\\ \bar{I}_b^0\\ \bar{I}_c^0\end{bmatrix}$$

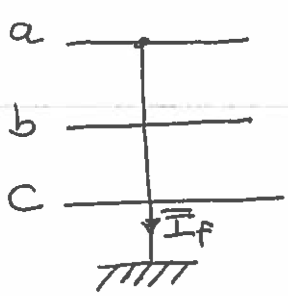
If we know $\bar{I}_a, \bar{I}_b, \bar{I}_c$, it is easy to find the symmetrical components as follows

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

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

Example : finding symmetrical components of SLG currents

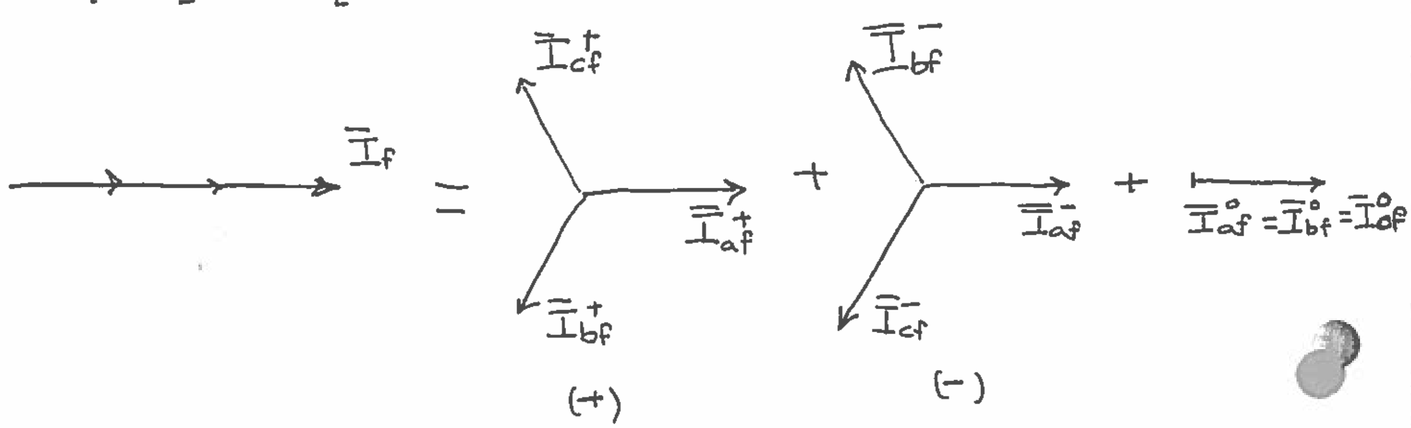
→ Suppose we are given the fault current. $\bar{I}_f$ in phase of a three-phase system



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

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

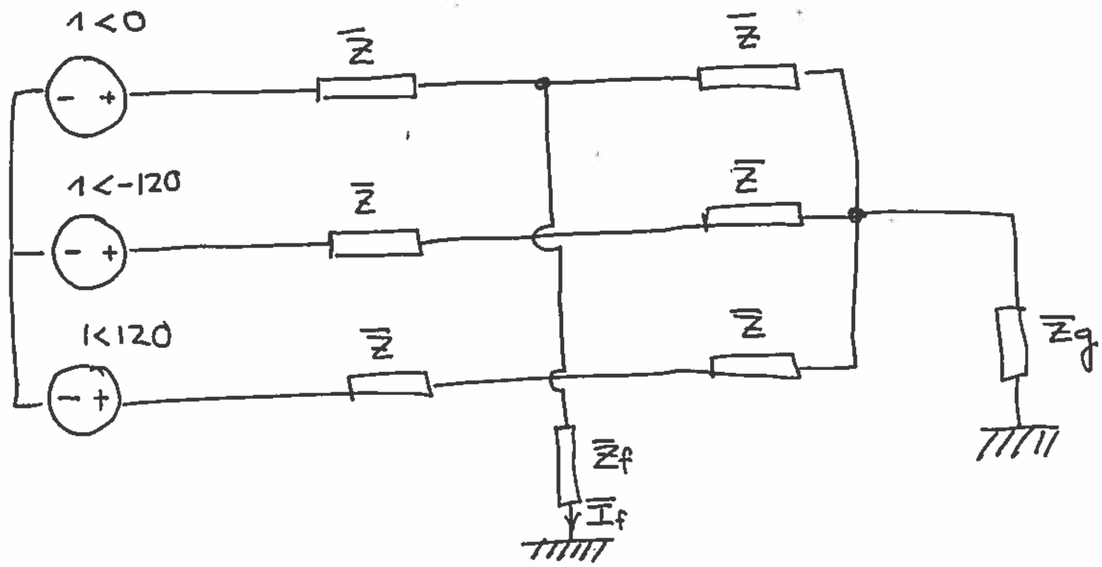
$$\begin{bmatrix} \bar{I}_{af}^{0} \\ \bar{I}_{af}^{+} \\ \bar{I}_{af}^{-} \end{bmatrix} = \frac{\bar{I}_f}{3}\begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \longrightarrow \bar{I}_{af}^{0} = \bar{I}_{af}^{+} = \bar{I}_{af}^{-} = \frac{1}{3}\bar{I}_f$$



USE OF SYMMETRICAL COMPONENTS FOR FAULT ANALYSIS

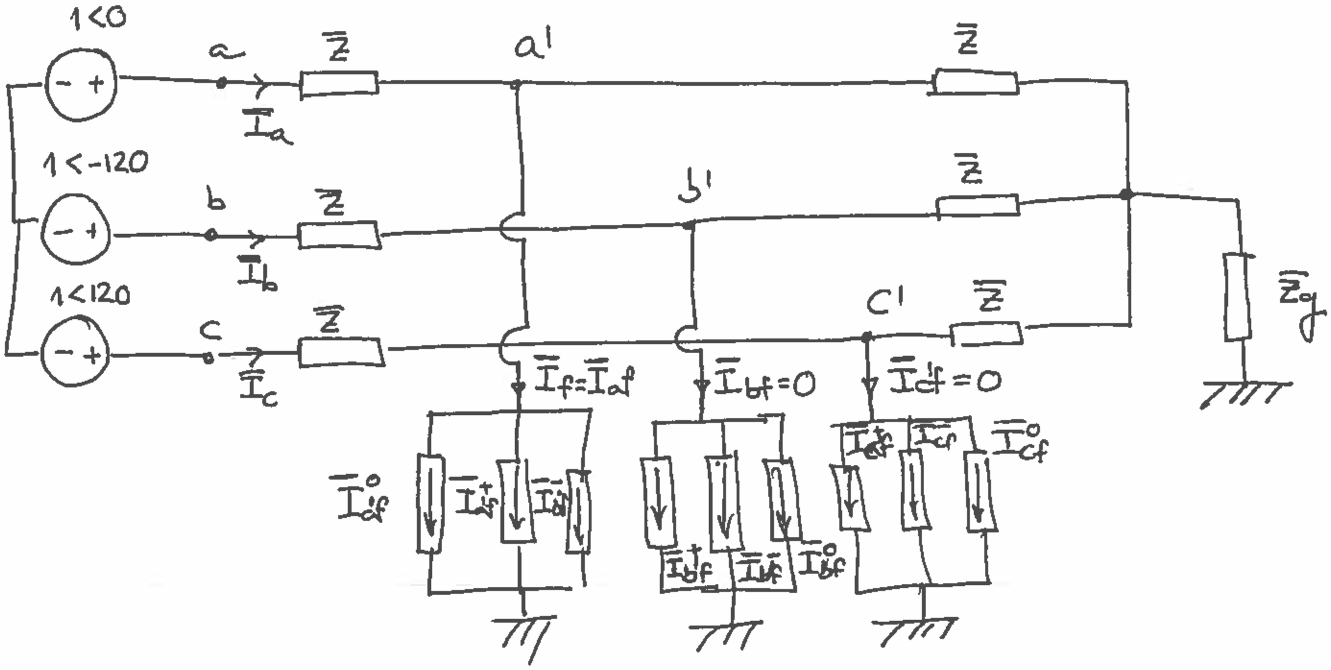
To introduce the method of symmetrical components for finding voltages and currents

LINE - GROUND FAULT

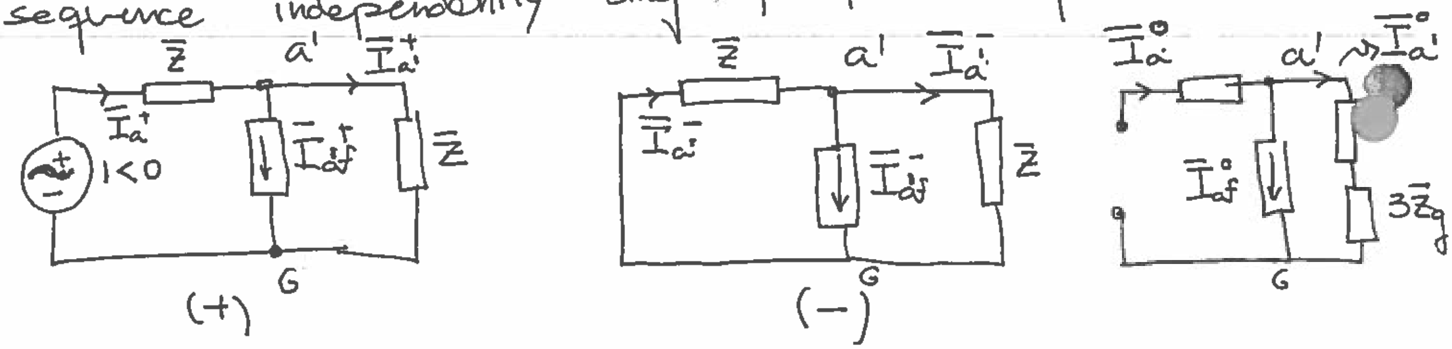


- It is obvious that we cannot use per-phase equivalents as the circuit is not symmetric.

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

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

$$\bar{I}_{a'}^0 = \bar{I}_{b'}^0 = \bar{I}_{c'}^0 : \quad \bar{V}_{a'g}^0 = \bar{Z}\,\bar{I}_{a'}^0 + 3\bar{Z}_g \bar{I}_{a'}^0$$

SEQUENCE NETWORK CONNECTIONS FOR LINE-GROUND FAULT

The use of symmetrical components is even more appealing if we make the following observation

$$\left\{\begin{array}{l} \overline{V}_{a'g} = \overline{V}^{+}_{a'g} + \overline{V}^{-}_{a'g} + \overline{V}^{0}_{a'g} \quad \text{(from superposition)} \\ \overline{I}^{+}_{af} = \overline{I}^{-}_{af} = \overline{I}^{0}_{af} = \dfrac{\overline{I}_f}{3} \end{array}\right.$$

Also: $\overline{V}_{a'g} = \overline{Z}_f \cdot \overline{I}_f = 3 \cdot \overline{Z}_f \cdot \dfrac{\overline{I}_f}{3}$

This two equations suggest that we can place the three sequence networks in series: