

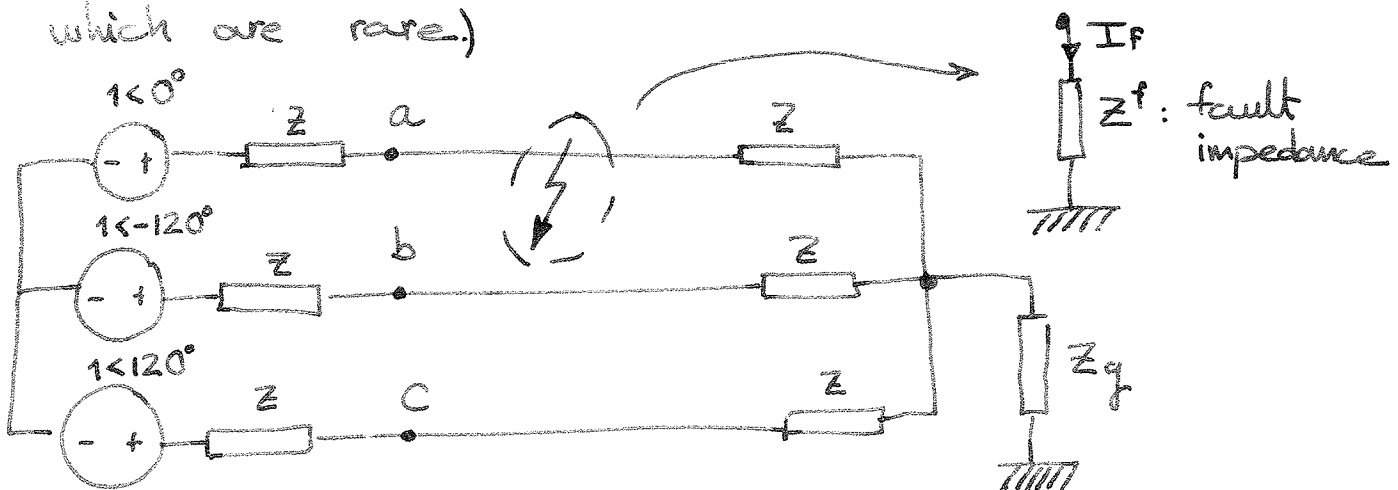
LECTURES 24 & 25

UNBALANCED SYSTEM OPERATION

- COMMON TYPES OF FAULTS
- METHOD OF SYMMETRICAL COMPONENTS
- USE OF SYMMETRICAL COMPONENTS FOR FAULT ANALYSIS
- SEQUENCE NETWORK CONNECTIONS FOR DIFFERENT TYPES OF FAULTS

UNBALANCED SYSTEM OPERATION

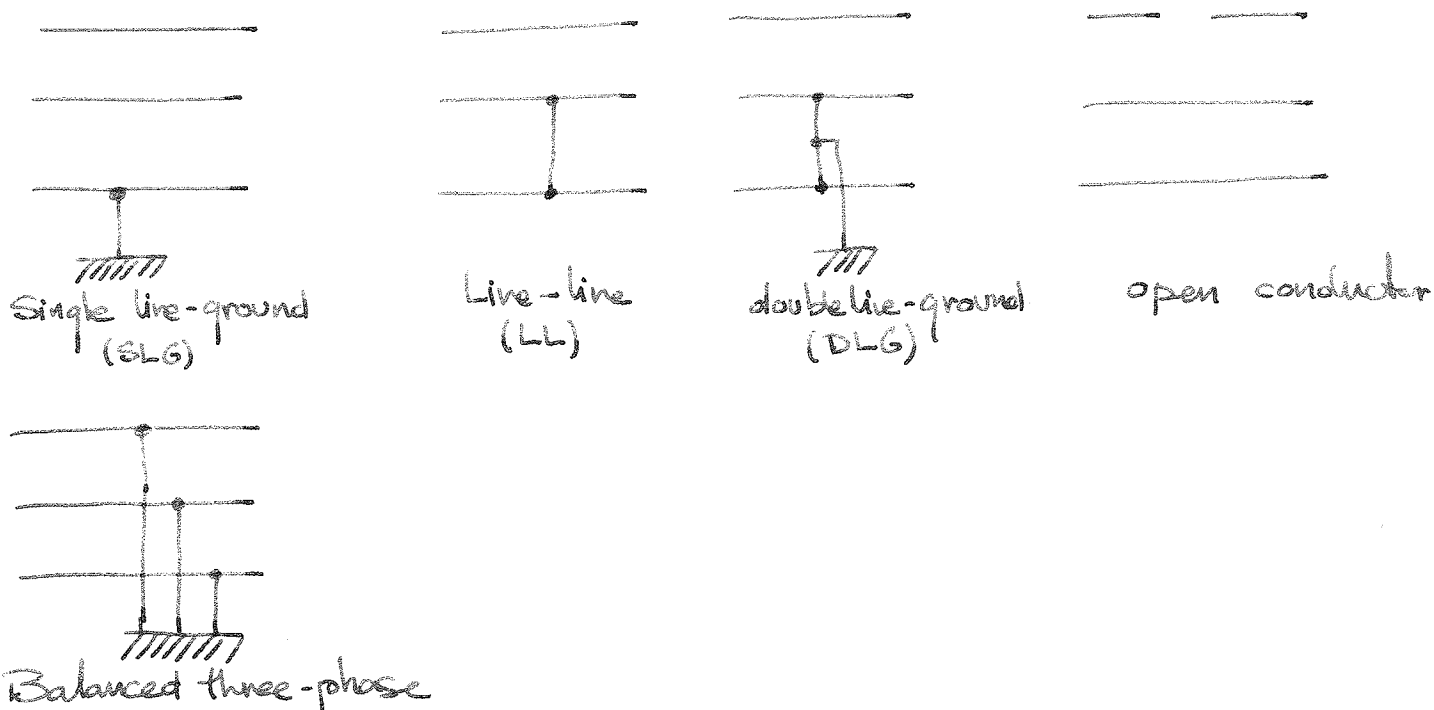
- So far, we have assumed that the power system works in a balance condition.
- This is the case in the absence of faults.
- When the system works in a balance condition, we saw that the analysis simplifies to look at just one phase using per-phase equivalents.
- Balanced operation is no longer true when a fault occurs (except for 3 ϕ faults which are rare.)



We need analysis techniques to ~~open~~ compute fault currents and other electrical variable.

These techniques are then used to select appropriate circuit breaker ratings for example.

COMMON TYPES OF FAULTS



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 phasors, say I_a , I_b , and I_c in terms of nine symmetrical components: $I_a^0, I_a^+, I_a^-, I_b^0, I_b^+, I_b^-, I_c^0, I_c^+, I_c^-$

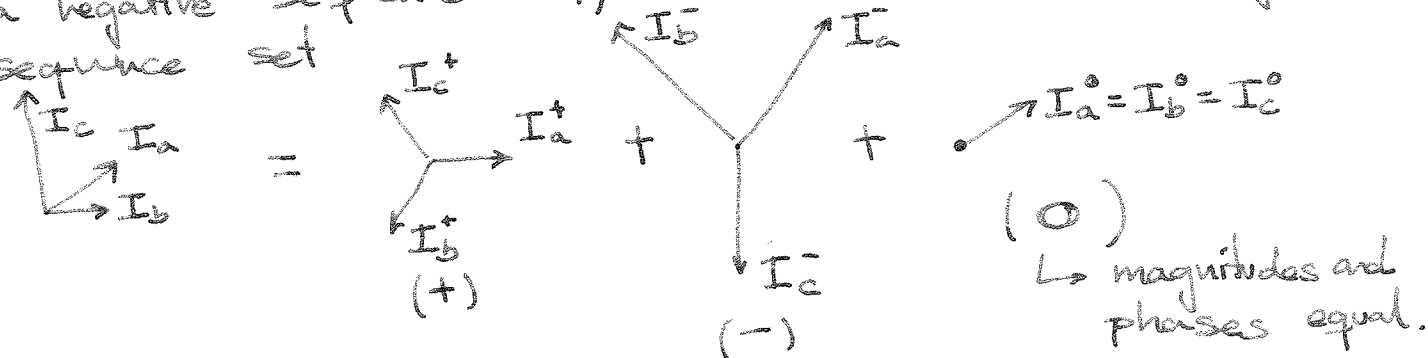
where

$$I_a = I_a^0 + I_a^+ + I_a^-$$

$$I_b = I_b^0 + I_b^+ + I_b^-$$

$$I_c = I_c^0 + I_c^+ + I_c^-$$

with $\{I_a^0, I_b^0, I_c^0\}$ a zero-sequence set, $\{I_a^+, I_b^+, I_c^+\}$ a positive sequence set, and $\{I_a^-, I_b^-, I_c^-\}$ a negative sequence set



In matrix form:

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} I_a^0 \\ I_b^0 \\ I_c^0 \end{bmatrix} + \begin{bmatrix} I_a^+ \\ I_b^+ \\ I_c^+ \end{bmatrix} + \begin{bmatrix} I_a^- \\ I_b^- \\ I_c^- \end{bmatrix}$$

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

As we know $I_b^+ = \alpha^2 I_a^+$ $I_c^+ = \alpha I_a^+$
 $I_b^- = \alpha I_a^-$ $I_c^- = \alpha^2 I_a^-$

so:

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} I_a^0 \\ I_a^+ \\ I_a^- \end{bmatrix} : \begin{matrix} I = \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \\ I_s = \begin{bmatrix} I_a^0 \\ I_a^+ \\ I_a^- \end{bmatrix} \end{matrix} : I = A I_s$$

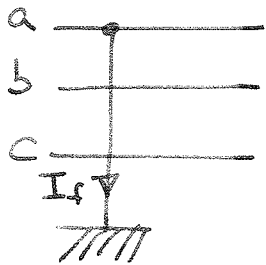
Then If we know I_a, I_b, I_c , it is easy to find the symmetrical components as follows:

$$I = A \cdot I_s \rightarrow I_s = A^{-1} \cdot I \quad \text{where}$$

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

Example: finding symmetrical components of SLG fault currents.

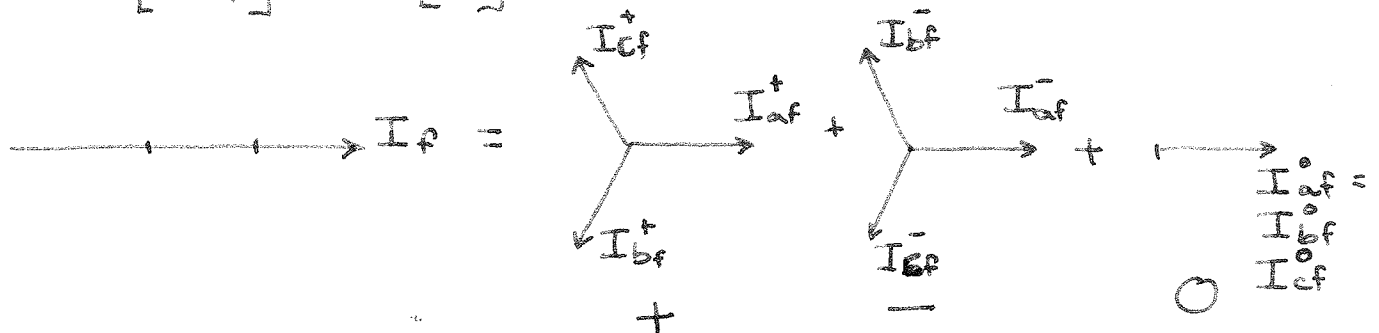
→ Suppose we are given the fault current I_f in phase a of a three phase system.



$$I = \begin{bmatrix} I_f \\ 0 \\ 0 \end{bmatrix}$$

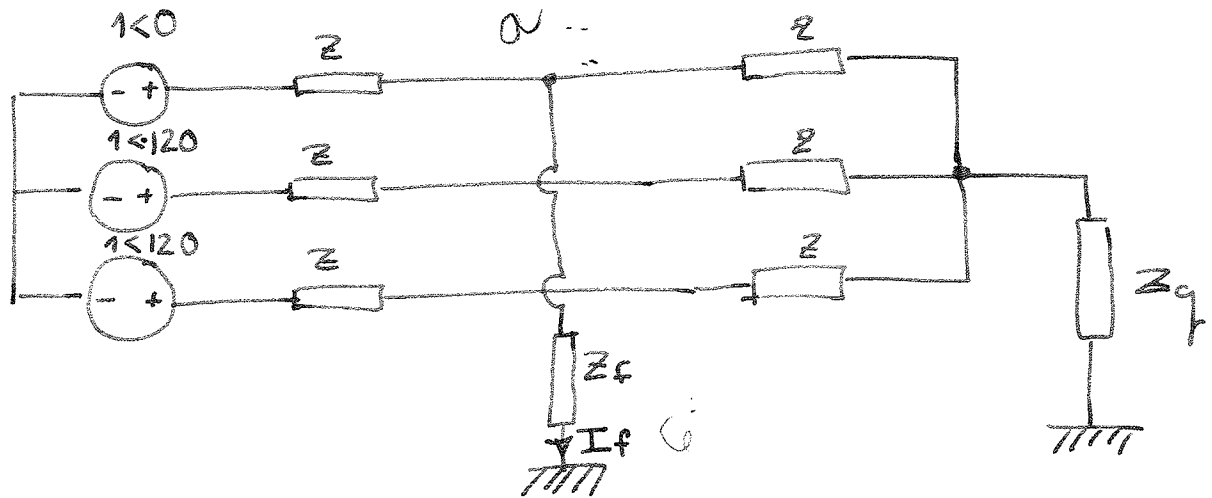
$$\begin{bmatrix} I_{af}^0 \\ I_{af}^+ \\ I_{af}^- \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix} \begin{bmatrix} I_f \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} I_{af}^0 \\ I_{af}^+ \\ I_{af}^- \end{bmatrix} = \frac{I_f}{3} \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \rightarrow I_{af}^0 = I_{af}^+ = I_{af}^- = \frac{1}{3} I_f$$

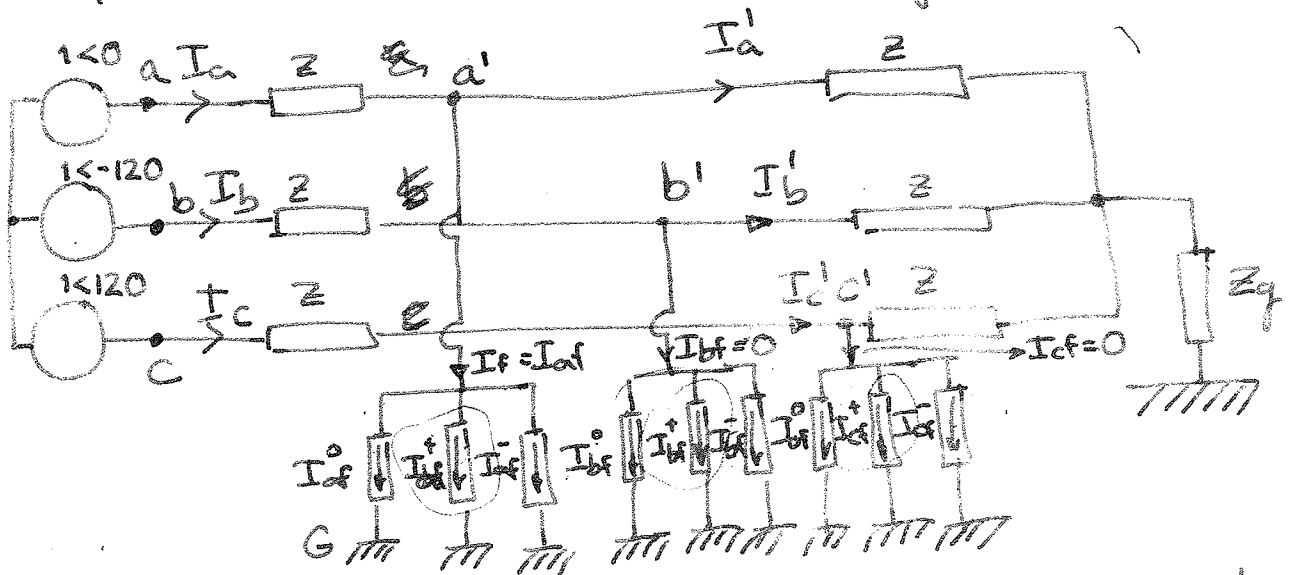


USE OF SYMMETRICAL COMPONENTS FOR FAULT ANALYSIS

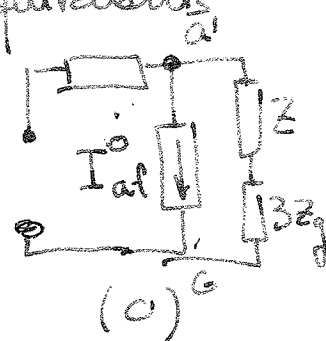
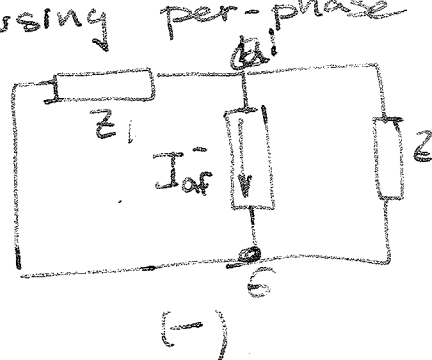
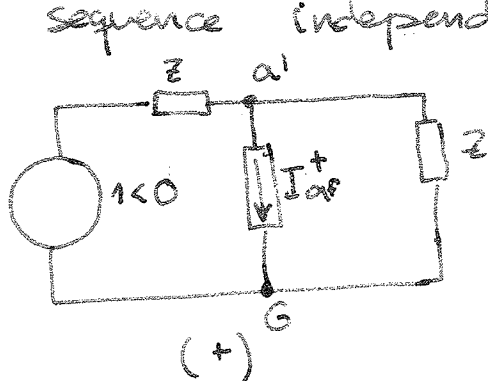
To introduce the method of symmetrical components for finding voltages and currents in faulted systems, consider the circuit below



- It is obvious that we can not use per-phase equivalents as the circuit is not symmetric.
- Let's replace the impedance by a current source of the same magnitude as I_f and write the current through each phase of the fault using symmetric 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.

$I_a^0 = I_b^0 = I_c^0$, but since the neutral is isolated

$$I_a^0 + I_b^0 + I_c^0 = 0 \rightarrow I_a^0 = I_b^0 = I_c^0 = 0.$$

$$I_a^0 = I_b^0 = I_c^0 = 0$$

$$V_{a'g} = Z \cdot I_a^0 + 3Z_g I_a^0$$

SEQUENCE NETWORK CONNECTIONS FOR DIFFERENT TYPES OF FAULTS

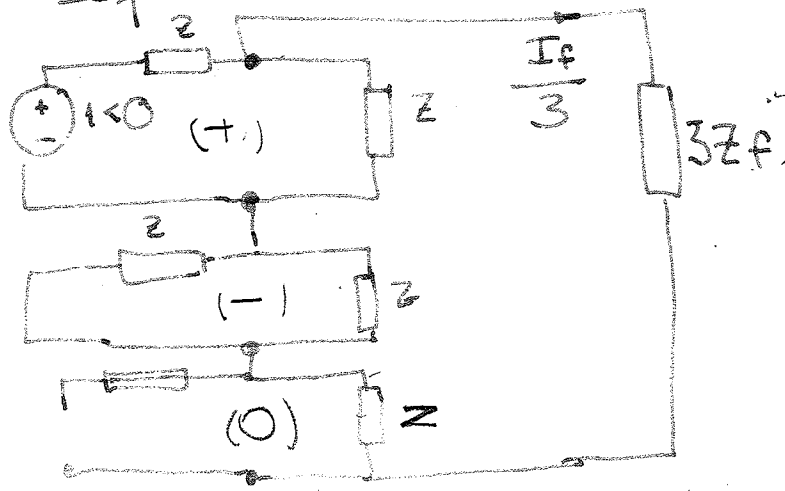
The use of symmetrical components is even more appealing if we make the following observation

$$V_{a'g} = V_{a'g}^+ + V_{a'g}^- + V_{a'g}^0 \quad (\text{from the superposition})$$

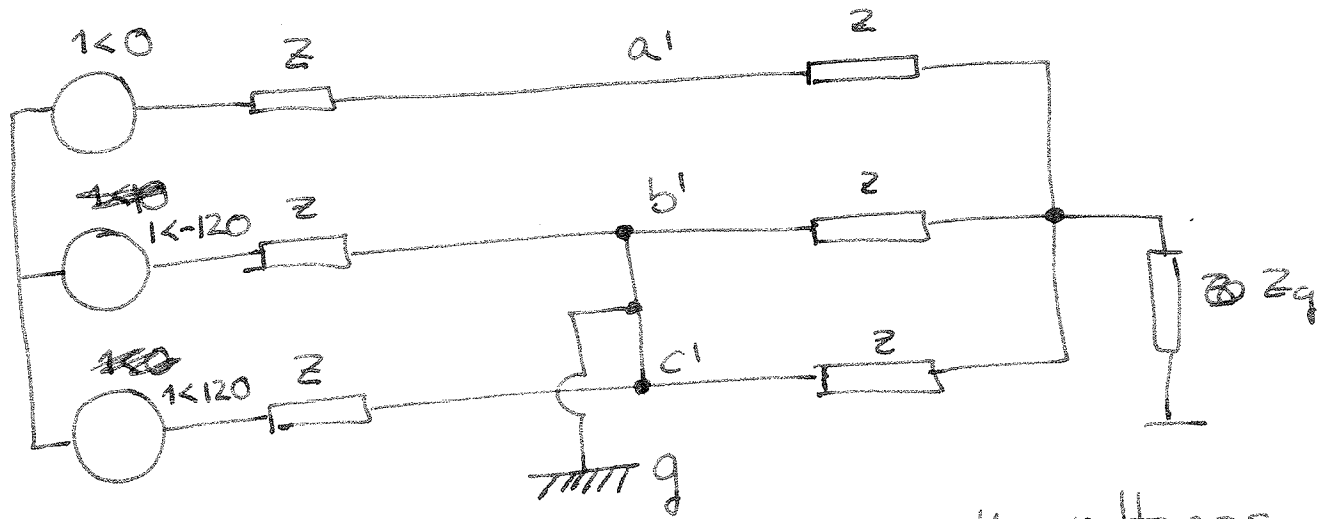
$$I_{af}^+ = I_{af}^- = I_{af}^0 = \frac{I_f}{3}$$

$$\text{Also: } V_{a'g} = Z_f \cdot I_f = 3 \cdot Z_f \cdot \frac{I_f}{3}$$

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



DOUBLE LINE-GROUND FAULT



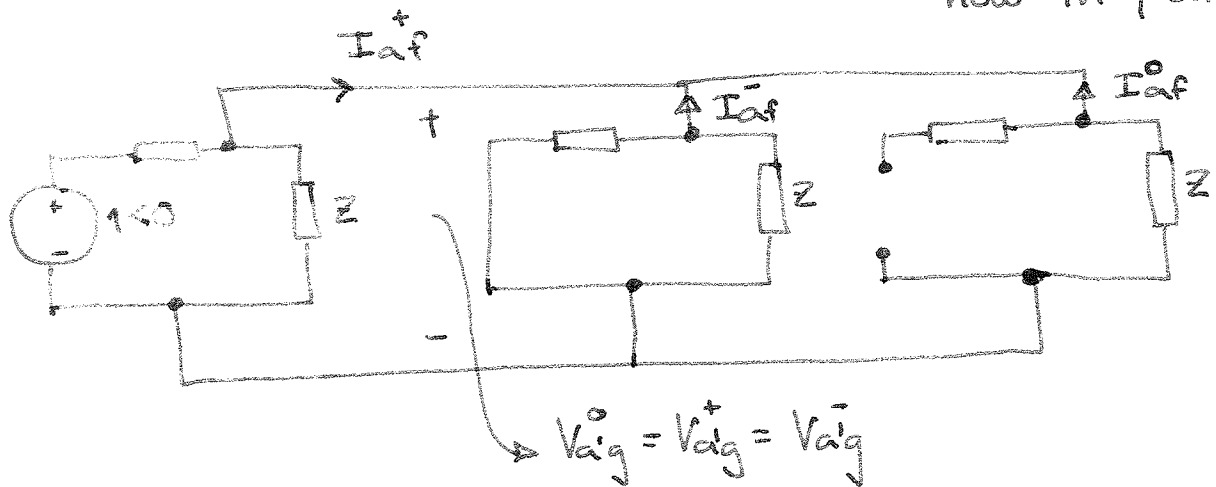
In this $V_{b'} = V_{c'} = 0$ so, we use the voltages, instead of currents:

$$\begin{bmatrix} V_{ag} \\ V_{ag}^+ \\ V_{ag}^- \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix} \begin{bmatrix} V_{ag} \\ 0 \\ 0 \end{bmatrix}$$

$$\Rightarrow V_{ag}^0 = V_{ag}^+ = V_{ag}^-$$

$$I_{af} = I_{af}^0 + I_{af}^+ + I_{af}^- = 0$$

these two equations suggest that the sequence networks are now in parallel



LINE-LINE FAULT

It is easy to see that the 'o' sequence network needs to be left out of the analysis

