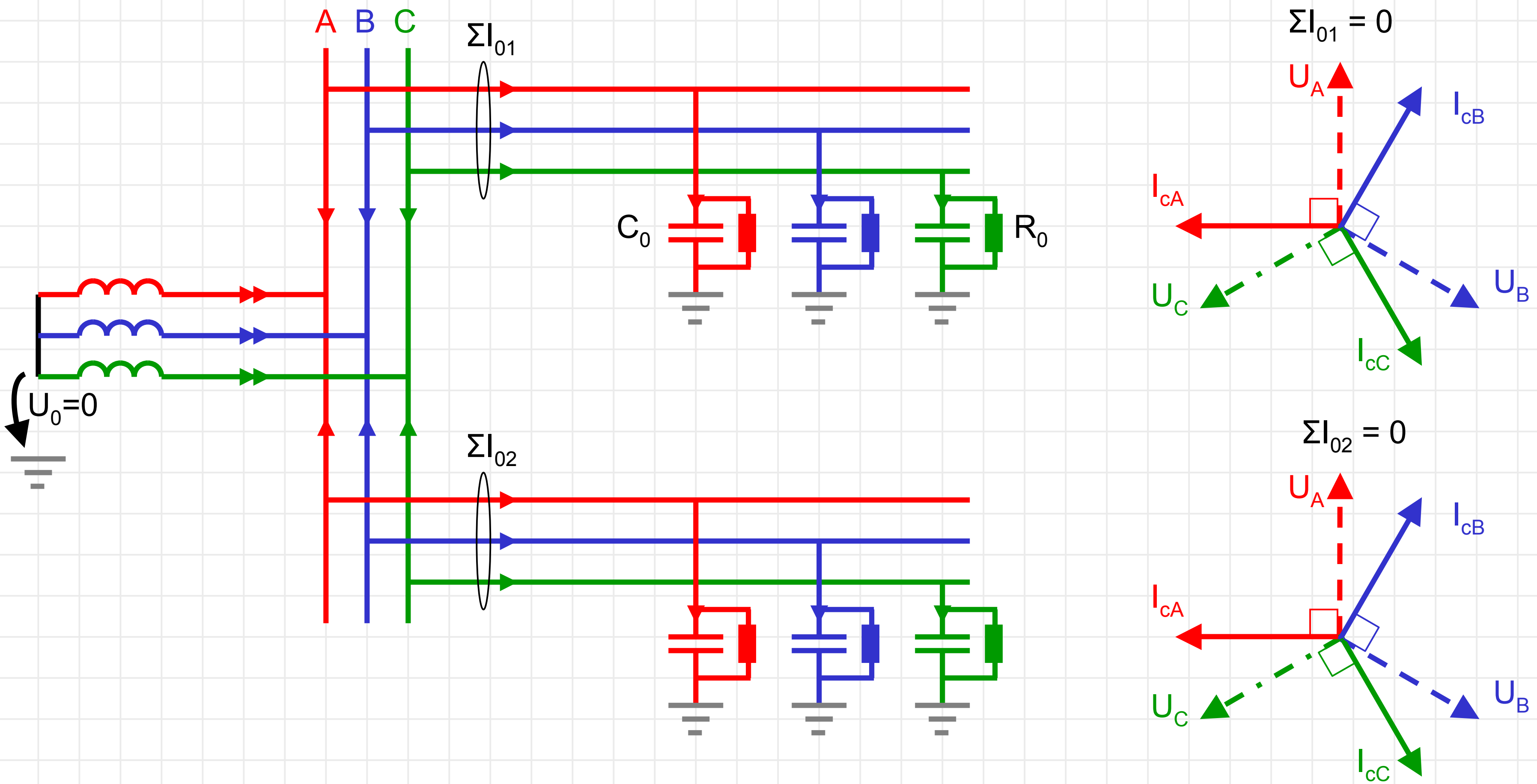
Unfaulted unearthed network

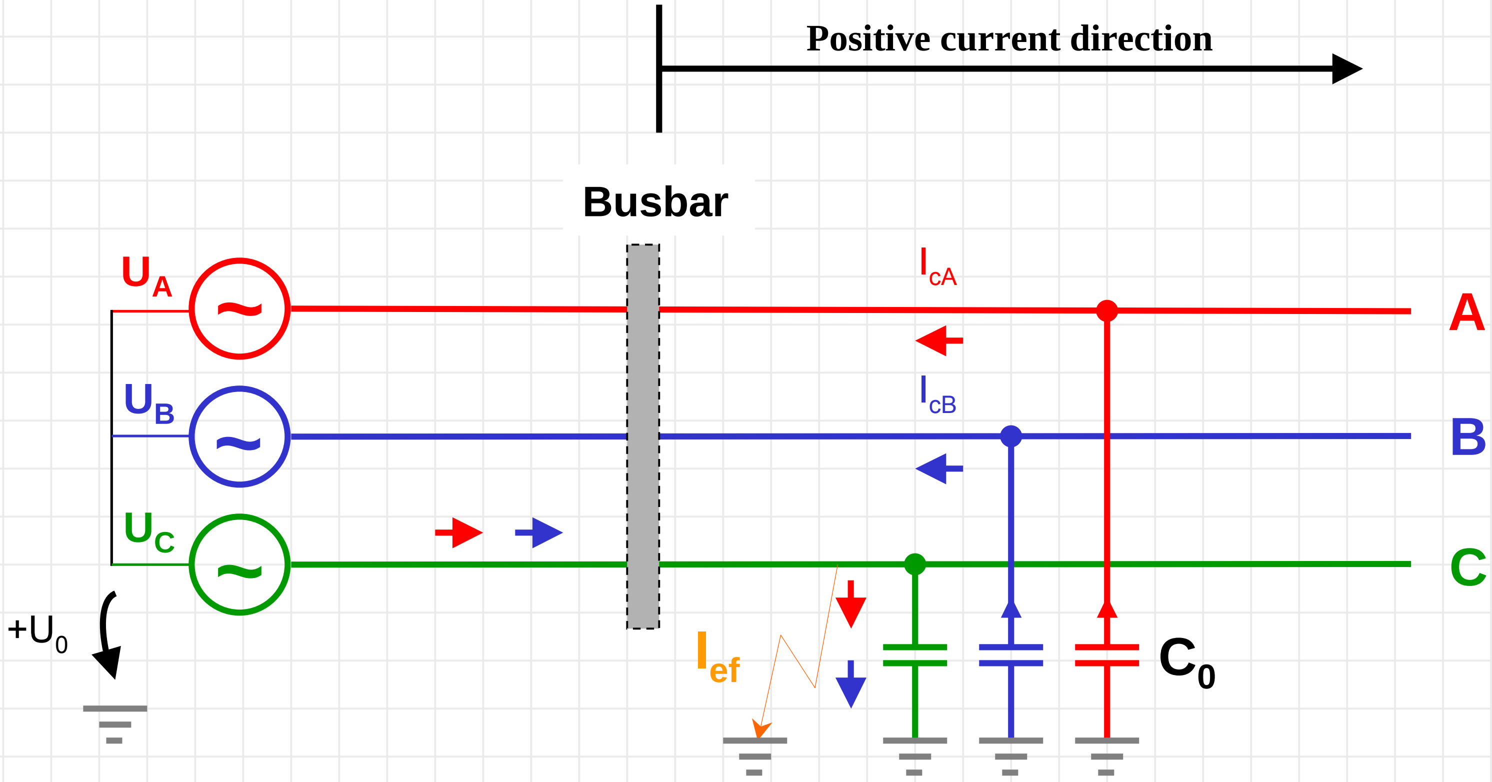


- Phase-to-ground voltages form a symmetrical system and their sum equal to zero at every time instance
- Capacitive charging currents (I_{cA}, I_{cB}, I_{cC}) flow through the phase-to-earth capacitances and form a symmetrical system
- I_0 measurement in feeder #1 (ΣI_{01}) measures the sum of the charging currents of that feeder, which equals to zero
- I_0 measurement in feeder #2 (ΣI_{02}) measures the sum of the charging currents of that feeder, which equals to zero

Single phase to earth fault in unearthed network

Single-phase to earth fault in phase C

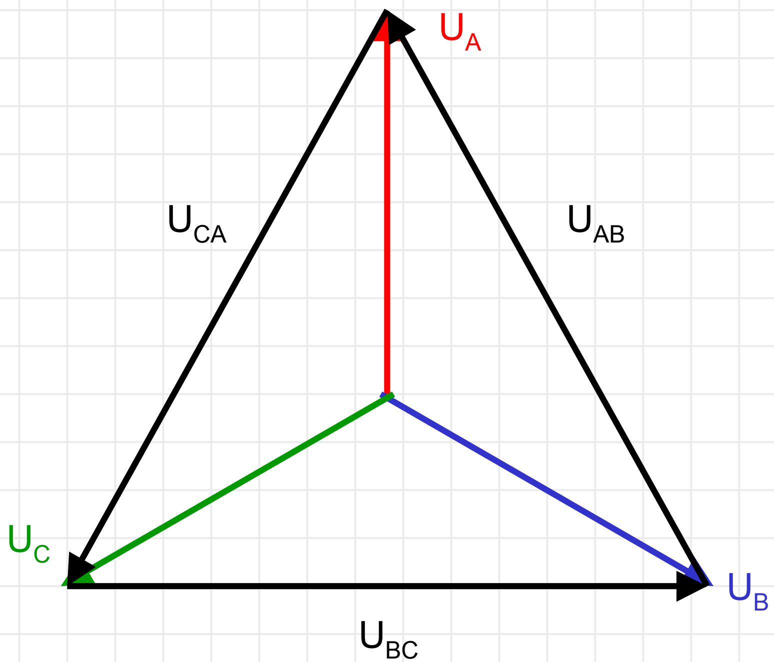
Equivalent circuit



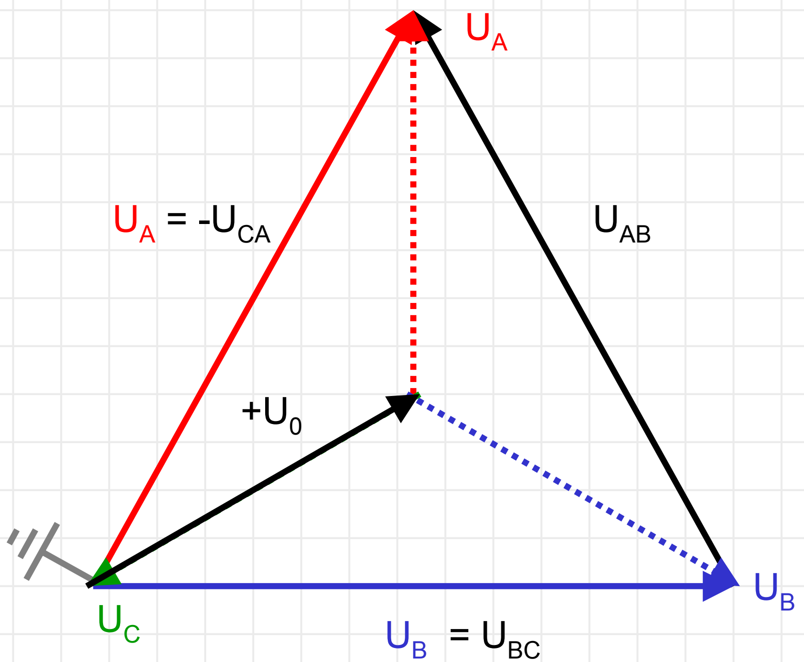
- In healty phases charging current flows **towars the busbar**
- In faulty phase the earth fault current (sum of charging currents of the healty phases) flows **towards the fault location**
- **Positive current direction is selected to be from busbar to feeders**

Single phase to earth fault in unearthed network

Single-phase to earth fault in phase C - What happens to voltages?



Voltage phasors before the fault

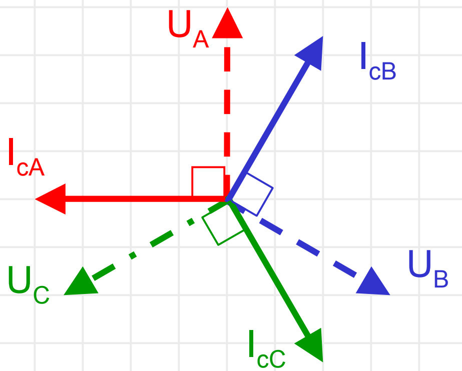


Voltage phasors after the fault

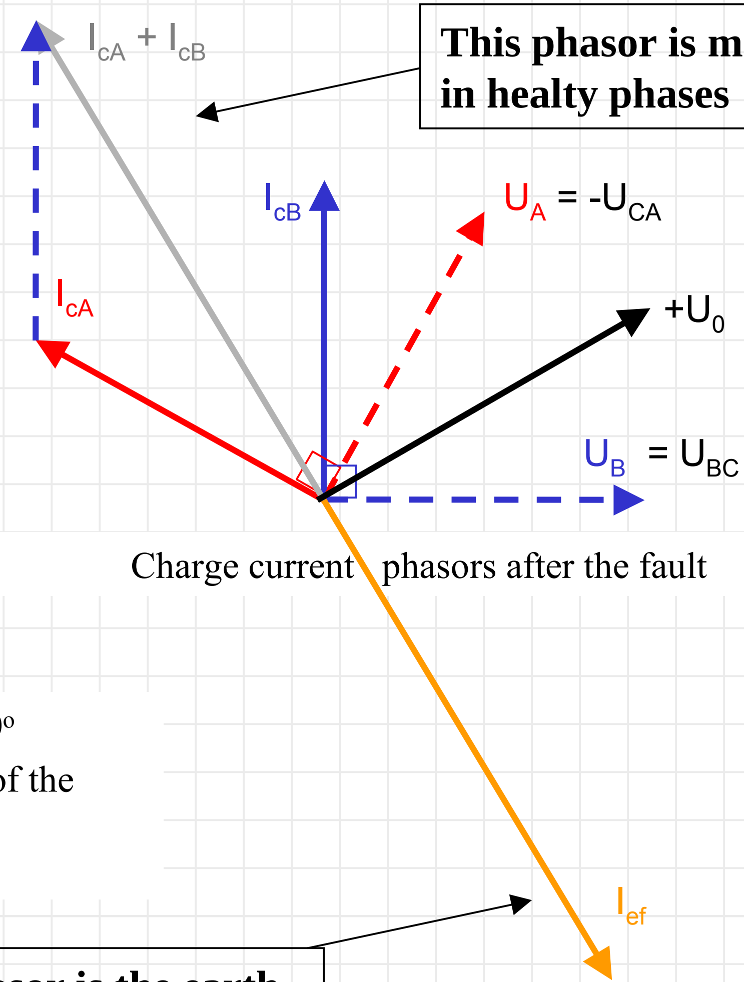
- Faulty phase voltage $U_C = 0$
- Healty phase voltages equal the line voltages
- Note the direction of the voltage $+U_0$

Single phase to earth fault in unearthed network

Single-phase to earth fault in phase C - What happens to currents ?



Charge current phasors before the fault



Charge current phasors after the fault

This phasor is measured in healty phases

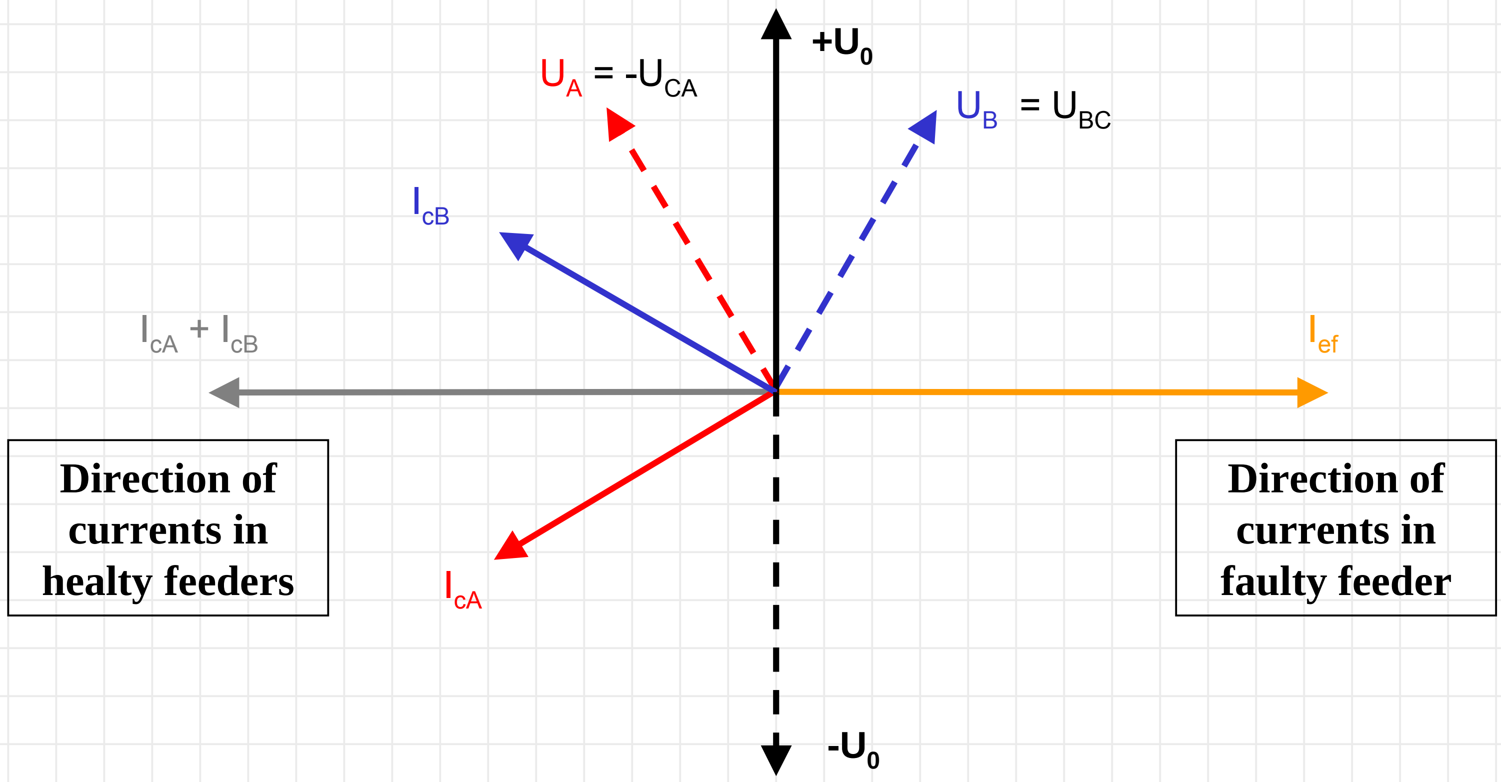
- Charging current leads corresponding phase voltage by 90°
- The direction of the earth fault current is opposite to that of the charging current in healty phases: I_{ef} vs. $(I_{cA} + I_{cB}) = 180^0$ (see figure in slide 2 !)

This phasor is the earth fault current

Single phase to earth fault in unearthed network

Single-phase to earth fault in phase C - What happens to currents ?

- By turning the **$+U_0$-phasor** in order to have it pointing upwards, the previous figure can be drawn as:

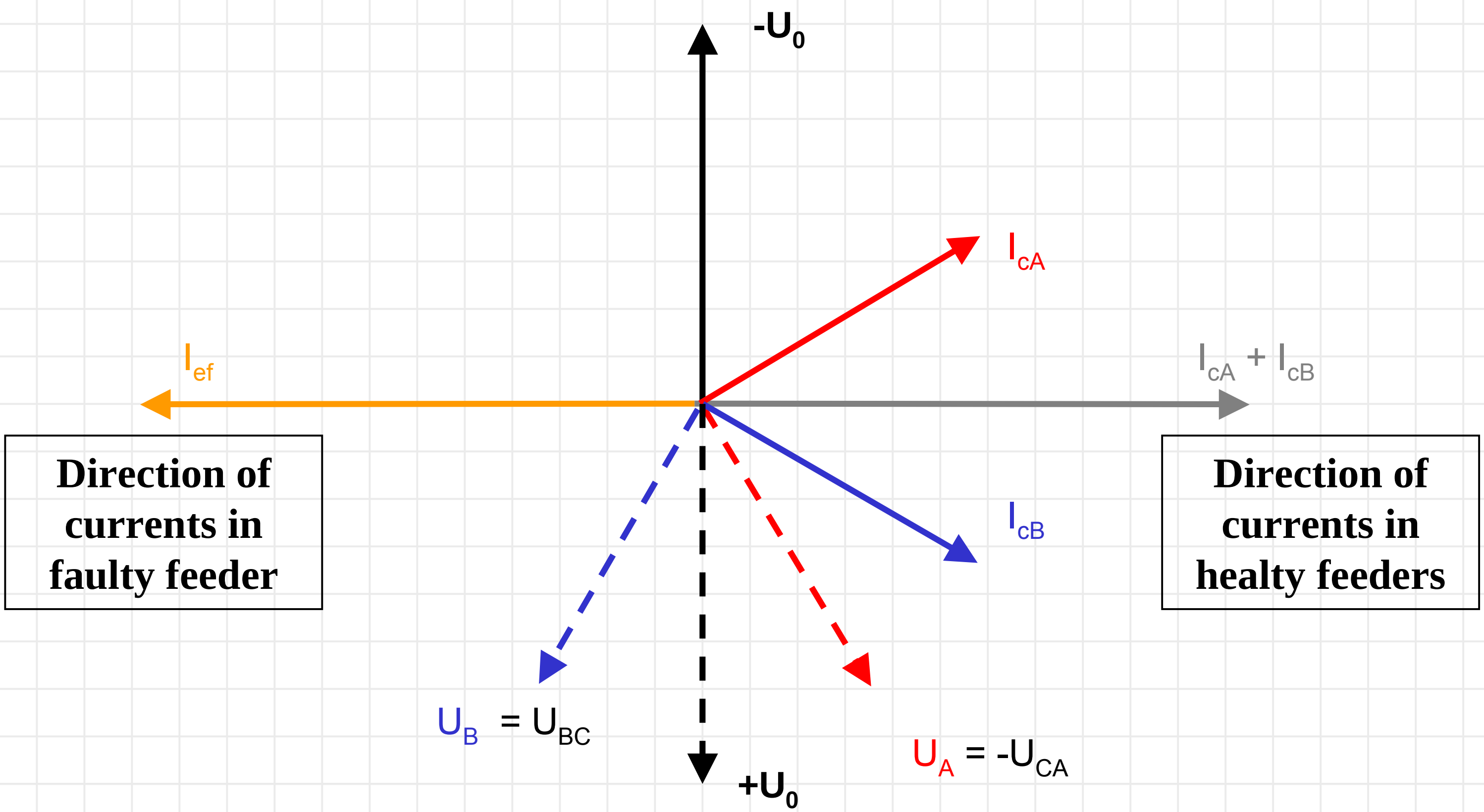


- NOTE that in REF the characteristics for directional earth fault protection are drawn using $-U_0$

Single phase to earth fault in unearthed network

Single-phase to earth fault in phase C - What happens to currents ?

- By turning the phasors so that **$-U_0$-phasor** is pointing upwards, the previous figure can be drawn as:

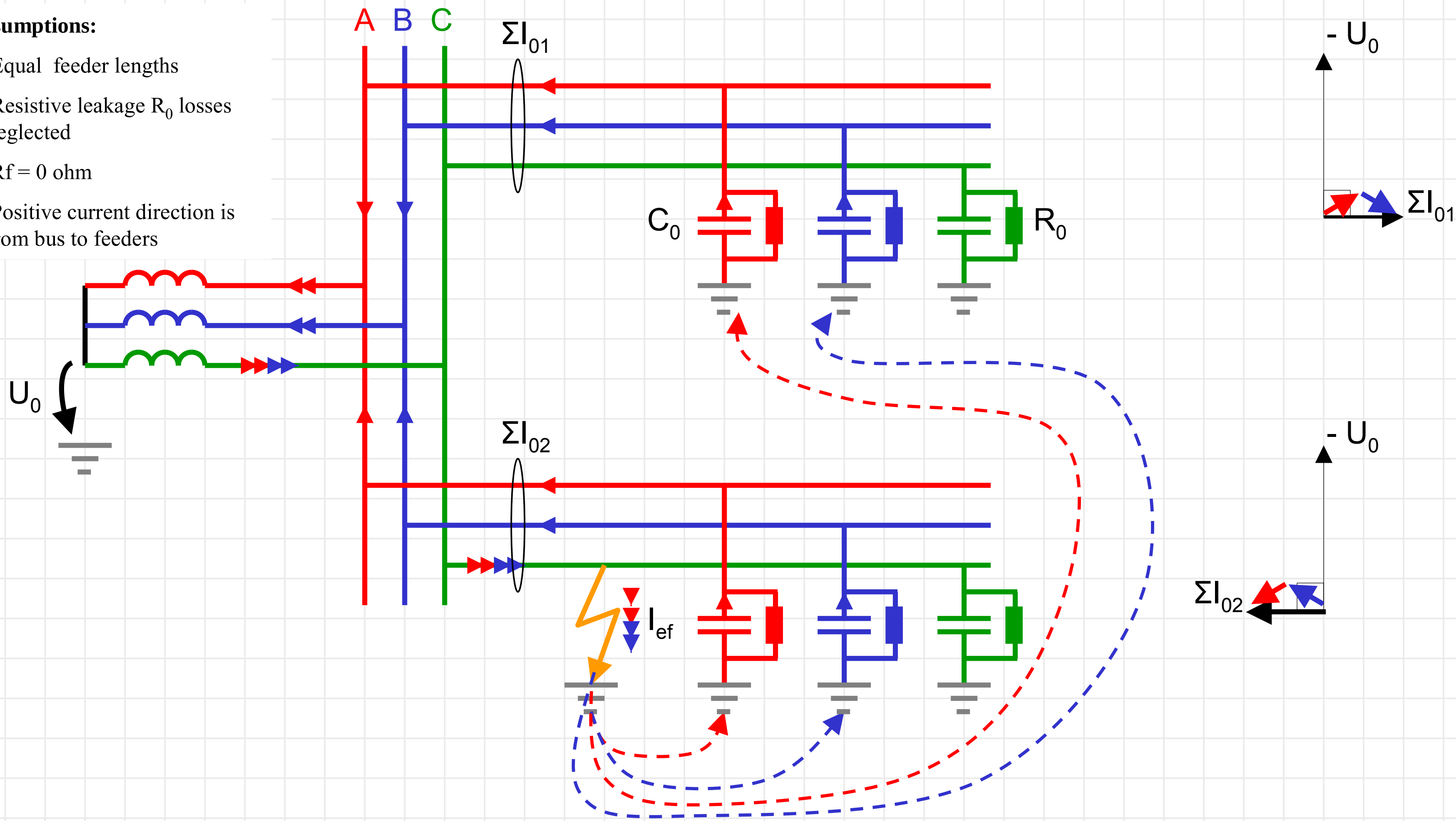


- In REF the characteristics for directional earth fault protection are drawn using $-U_0$

Earth fault in unearthed network

Assumptions:

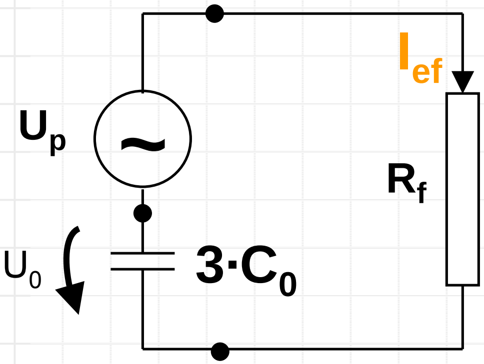
1. Equal feeder lengths
2. Resistive leakage R_0 losses neglected
3. Rf = 0 ohm
4. Positive current direction is from bus to feeders



- $\Sigma I_{02} \neq I_{ef}$
- I_0 measurement in healty feeder (ΣI_{01}) includes only charging currents (healty phases) of that feeder
- I_0 measurement in faulty feeder (ΣI_{02}) includes charging currents of the galvanically connected background network, but not the charging currents of it's own (these flow in both directions through the measurement point and cancel each other)
- Directional EF-protection is based on the angle of measured I_0 versus U_0 ($-U_0$ in REF)

Earth fault in unearthed network

Equivalent circuit



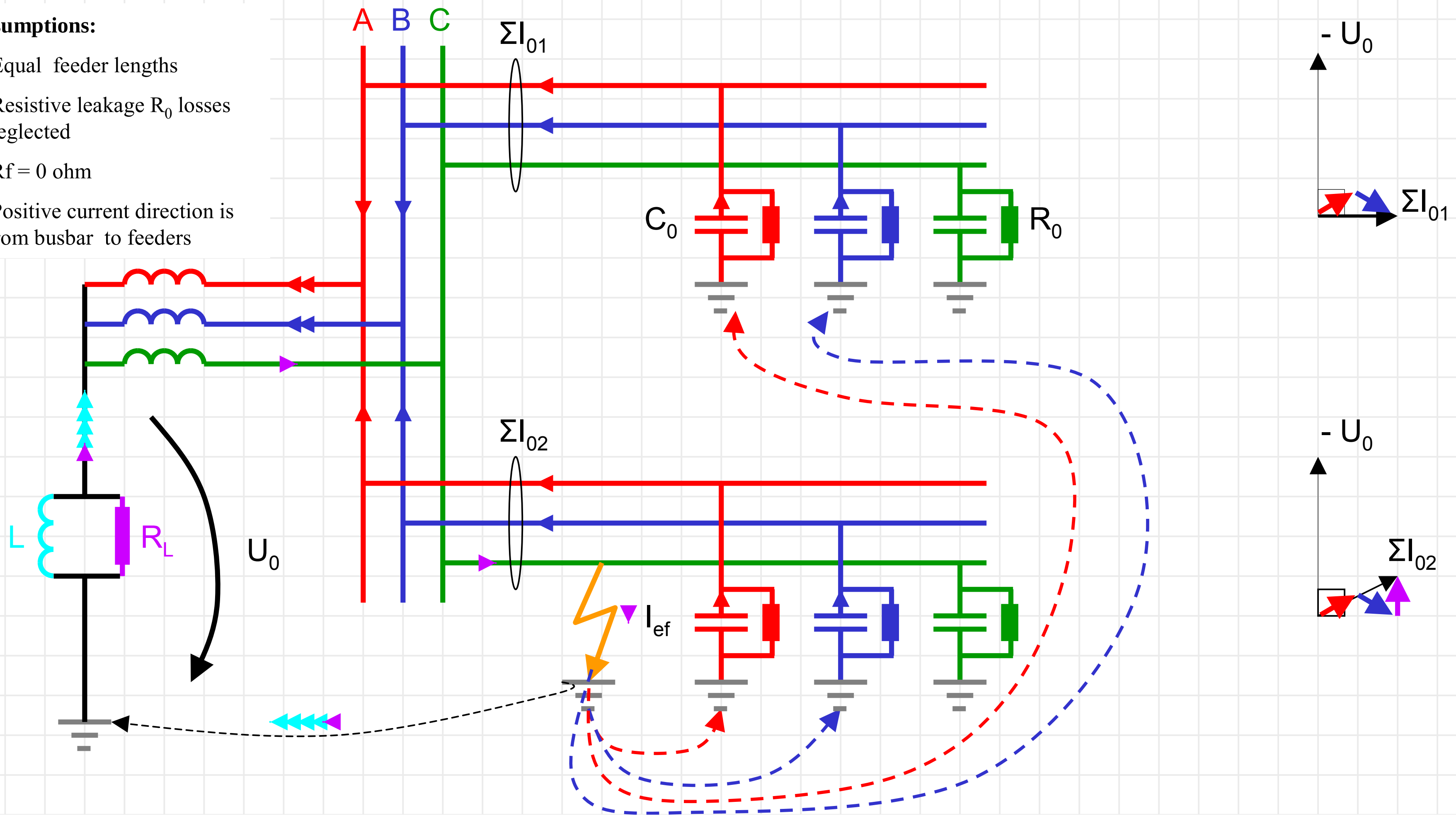
$$U_0 = \frac{I_{ef}}{3 \cdot \omega \cdot C_0} = \frac{U_p}{\sqrt{1 + (3 \cdot \omega \cdot C_0 \cdot R_f)^2}}$$

- U_0 is the voltage drop which is created when I_{ef} flows through the phase-to-earth capacitances
- R_f is **NOT** included in these!!! See equivalent circuit!!!

Earth fault in 100% compensated network

Assumptions:

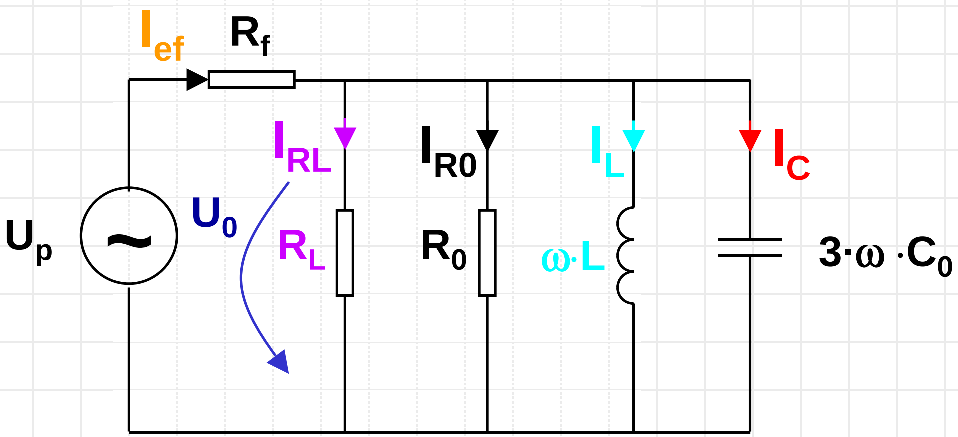
1. Equal feeder lengths
2. Resistive leakage R_0 losses neglected
3. Rf = 0 ohm
4. Positive current direction is from busbar to feeders



- Earth-fault current is cancelled by feeding an equal inductive current with a compensation coil
- I_0 measurement in healty feeder (ΣI_{01}) includes only charging currents (healty phases) of that feeder
- I_0 measurement in faulty feeder (ΣI_{02}) includes now both the resistive current created by the additonal resistor and it's own charging currents
- Directional EF-protection is based on the angle of measured I_0 versus U_0 ($-U_0$ in REF)

Earth fault in compensated network

Equivalent circuit



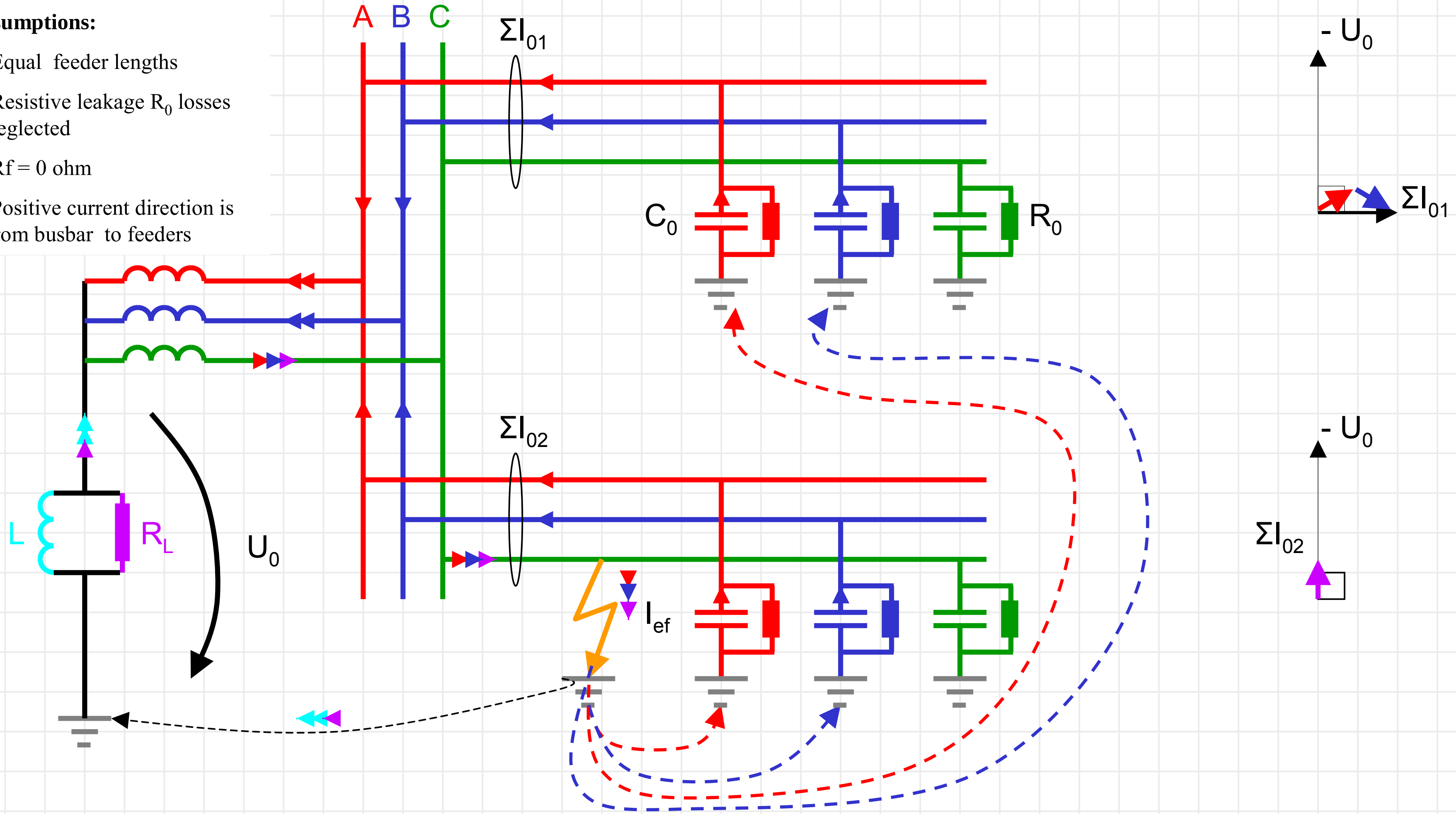
$$U_0 = \frac{I_{ef}}{\sqrt{\left(\frac{1}{R_0}\right)^2 + \left(3 \cdot \omega \cdot C_0 - \frac{1}{\omega \cdot L}\right)^2}}$$

- U_0 is the voltage drop which is created when I_{ef} flows through the impedance of the parallel connection of phase-to-earth capacitances, reactor L, additional resistor R_L and leakage resistance R_0 of the lines
- R_f is **NOT** included in these!!! See equivalent circuit!!!

Earth fault in 50% under-compensated network

Assumptions:

1. Equal feeder lengths
2. Resistive leakage R_0 losses neglected
3. Rf = 0 ohm
4. Positive current direction is from busbar to feeders

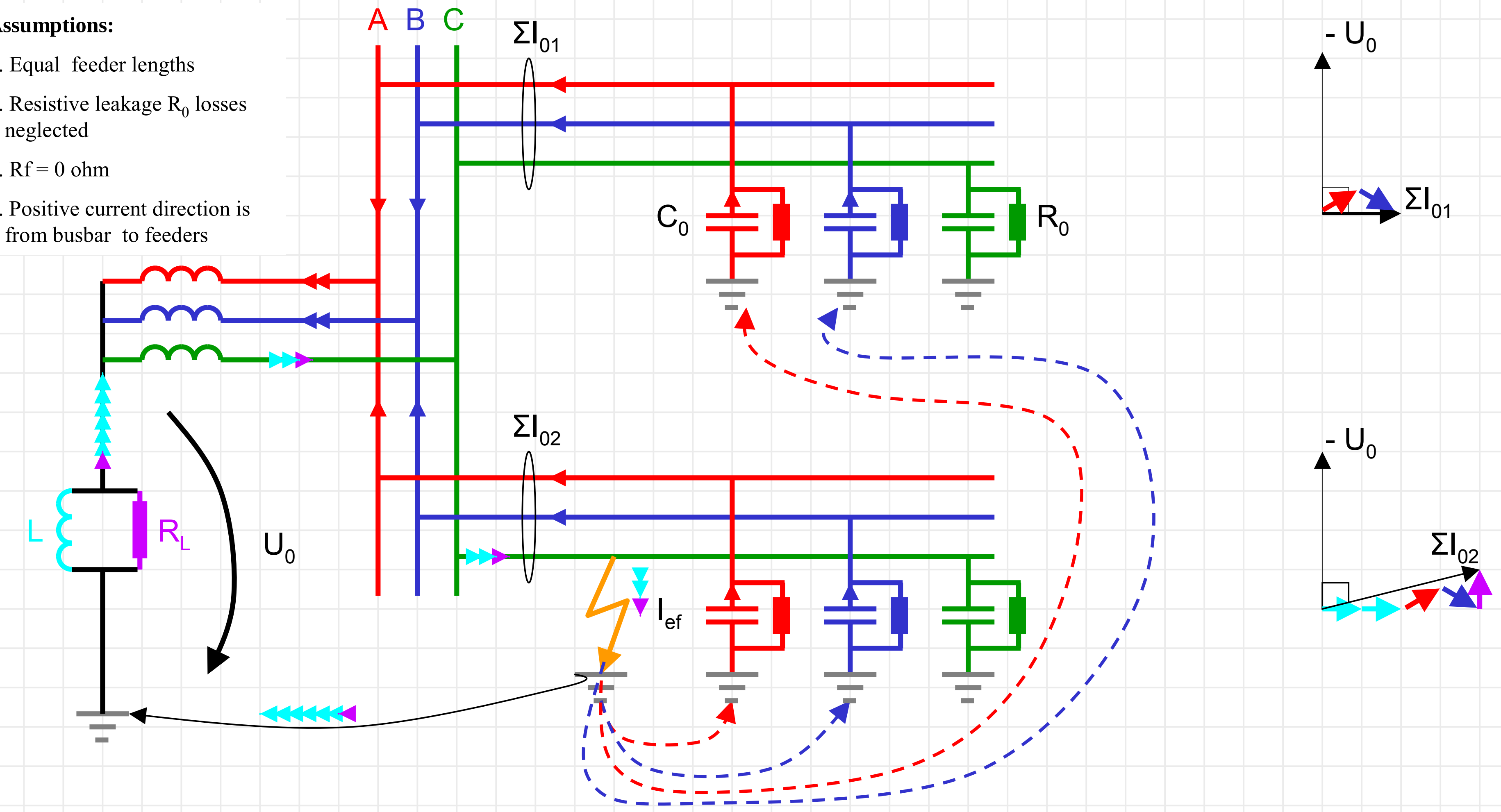


- 50% of the earth-fault current is cancelled by feeding an inductive current with a compensation coil
- I_0 measurement in healty feeder (ΣI_{01}) includes only charging currents (healty phases) of that feeder
- I_0 measurement in faulty feeder (ΣI_{02}) includes now only the resistive current created by the additonal resistor (background network's and feeders charging current flow in opposite directions in the measurement point and cancel each other)
- Directional EF-protection is based on the angle of measured I_0 versus U_0 ($-U_0$ in REF)

Earth fault in 150% over-compensated network

Assumptions:

1. Equal feeder lengths
2. Resistive leakage R_0 losses neglected
3. Rf = 0 ohm
4. Positive current direction is from busbar to feeders

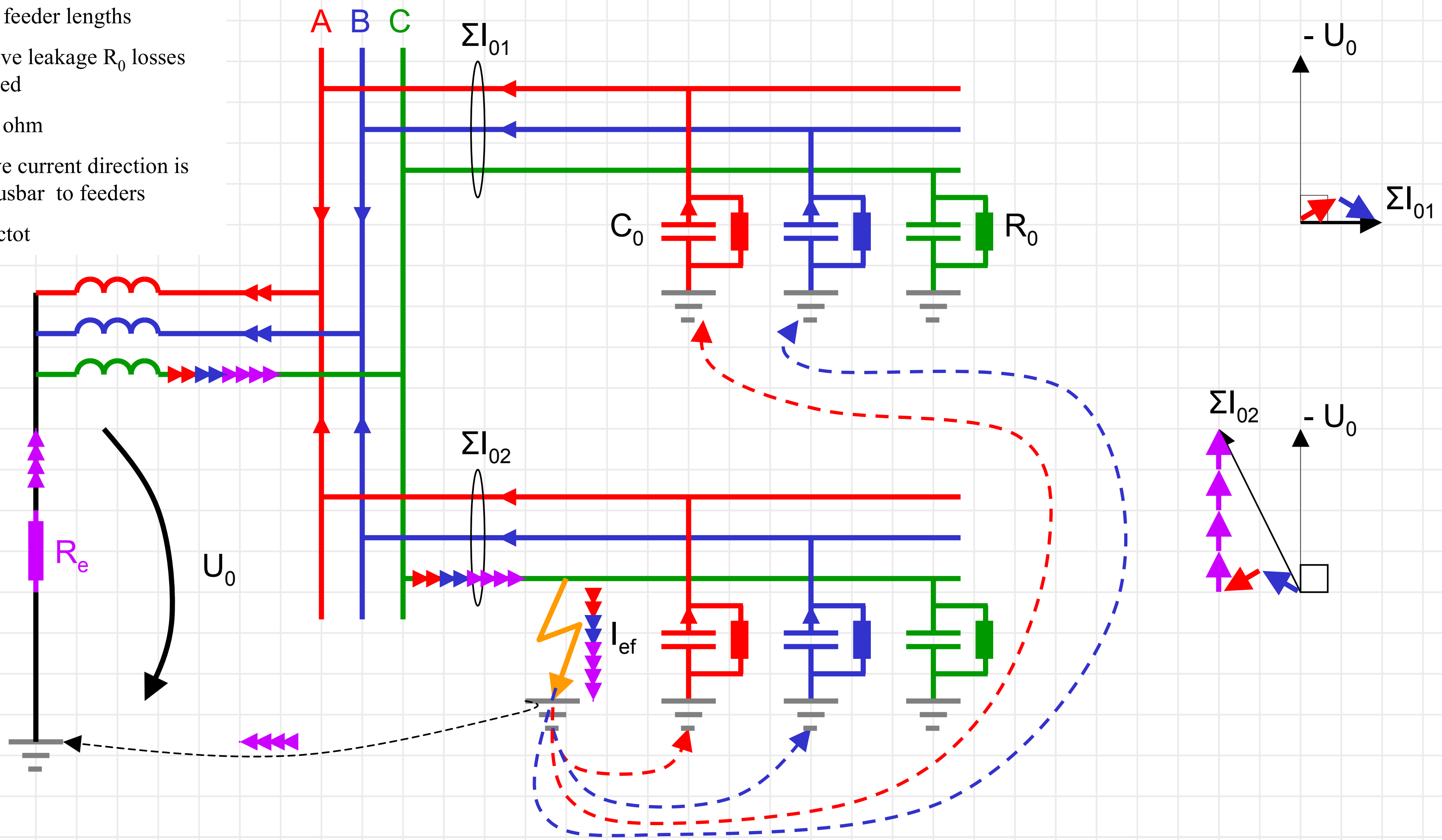


- 150% of the earth-fault current is cancelled by feeding an inductive current with a compensation coil
- I_0 measurement in healty feeder (ΣI_{01}) includes only charging currents (healty phases) of that feeder
- I_0 measurement in faulty feeder (ΣI_{02}) includes now both the resistive current created by the additonal resistor, it's own charging currents and the overrest of the inductive current
- Directional EF-protection is based on the angle of measured I_0 versus U_0 ($-U_0$ in REF)

Earth fault in high resistance earthed network

Assumptions:

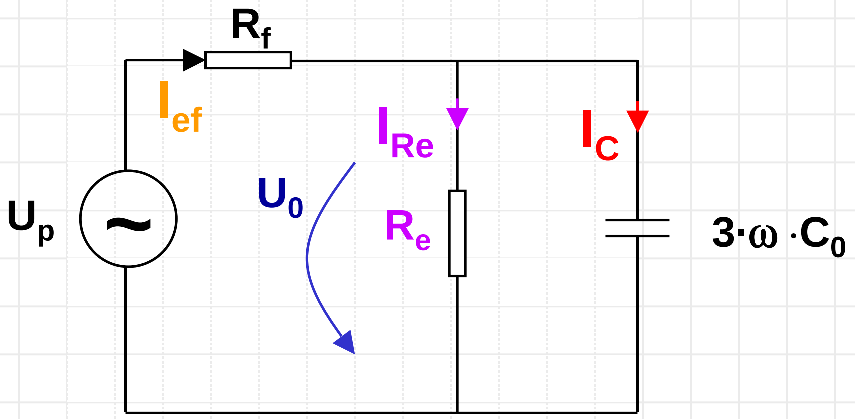
1. Equal feeder lengths
2. Resistive leakage R_0 losses neglected
3. Rf = 0 ohm
4. Positive current direction is from busbar to feeders
5. I_{Re} = Ictot



- Earth-fault current includes a resistive part defined by the size of R_e ($\leq 1/(3 \cdot \omega \cdot C_{0tot})$)
- I_0 measurement in healty feeder (ΣI_{01}) includes only charging currents (healty phases) of that feeder
- I_0 measurement in faulty feeder (ΣI_{02}) includes now both the resistive current created by the earthing resistor and capacitive charging current of the galvanically connected background network
- Directional EF-protection is based on angle of measured I_0 versus U_0 ($-U_0$ in REF)

Earth fault in high resistance earthed network

Equivalent circuit



$$U_0 = \frac{I_{ef}}{\sqrt{\left(\frac{1}{R_e}\right)^2 + (3 \cdot \omega \cdot C_0)^2}}$$

- U_0 is the voltage drop which is created when I_{ef} flows through the impedance of the parallel connection of phase-to-earth capacitances and earthing resistor R_e
- R_f is **NOT** included in these!!! See equivalent circuit!!!