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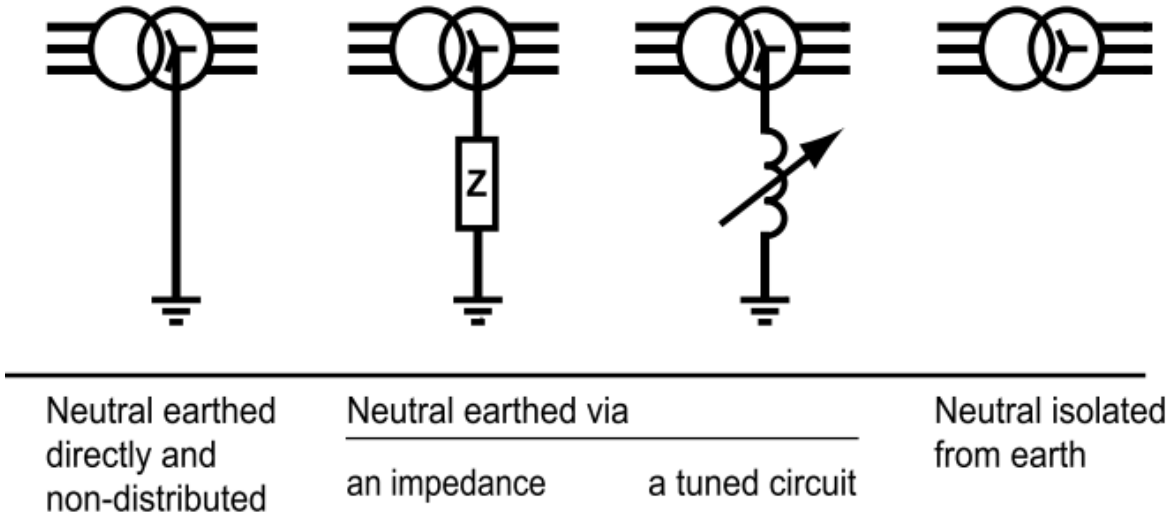
ZÁPADOČESKÁ UNIVERZITA V PLZNI

Earth faults

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Neutral earthing/grounding arrangements



3-phase fault – 3-phase short-circuit (fault current and voltages do not depend on neutral earthing)

SLTG (sigle line to ground) fault – depends on neutral earthing

- neutral directly earthed → 1-phase short-circuit
- neutral earthed via R → 1-phase short-circuit
- neutral earthed via L → earth fault
- isolated neutral → earth fault

Neutral earthing/grounding arrangements

Directly grounded networks

- HV , EHV (in Czech Republic)
- LV (400 V)

Networks grounded trough impedance

- MV
- Peterson coil – networks with overhead power lines
- Resistor – cable networks

Isolated networks

- MV – small networks, only few km
- LV (500 V), e.g. networks in mines

Kind of earth faults

According to fault resistance in fault location

- Metallic or arc earth faults: fault resistance Rp $\rightarrow$ 0 (x Ω)
- resistive earth faults: Rp $>$ 0 (100x Ω reinforced-concrete poles, x MΩ wood poles)

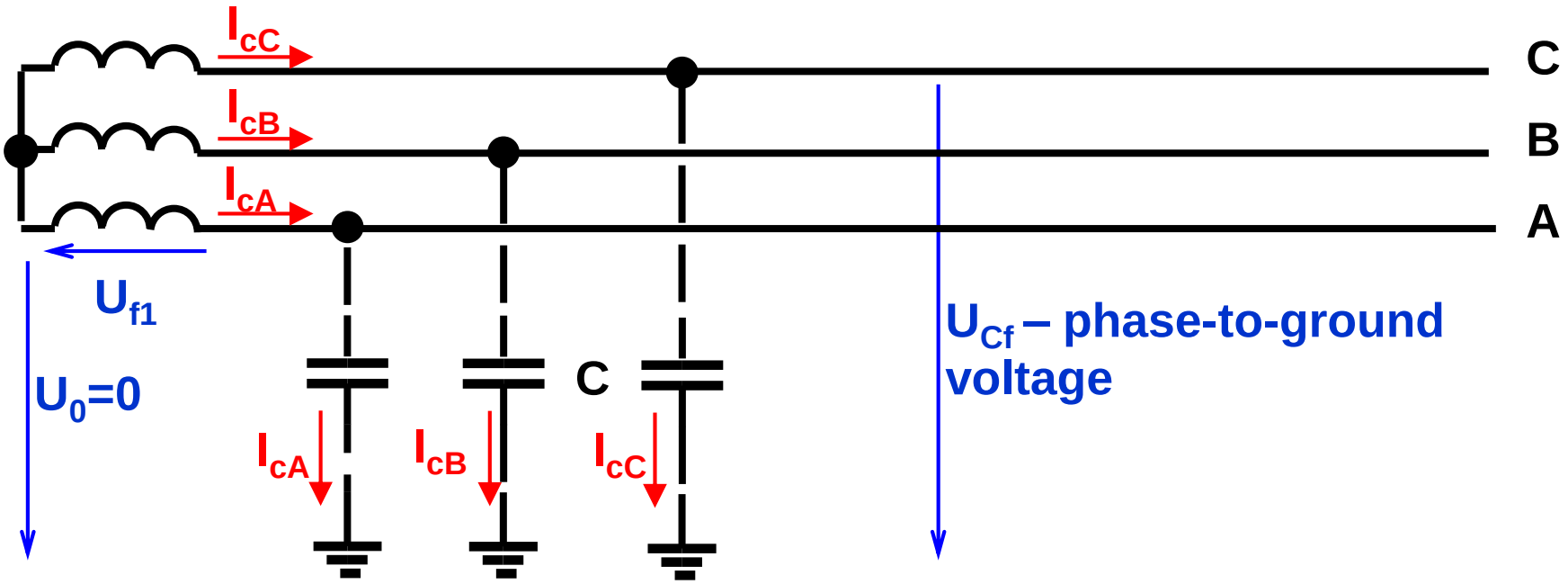
According to earth-fault duration

- permanent (x hours)
- momentary (up to 0,5 s)
- short-term (up to 5 min)
- interrupted (repeating) – the worst case, voltage increase (up to 3,5 Un)

Simplified consideration for earth-fault calculation

- open circuit
- series impedances are neglected
- only shunt capacitance is considered
- permanent fault, (Rp = 0)

Isolated networks

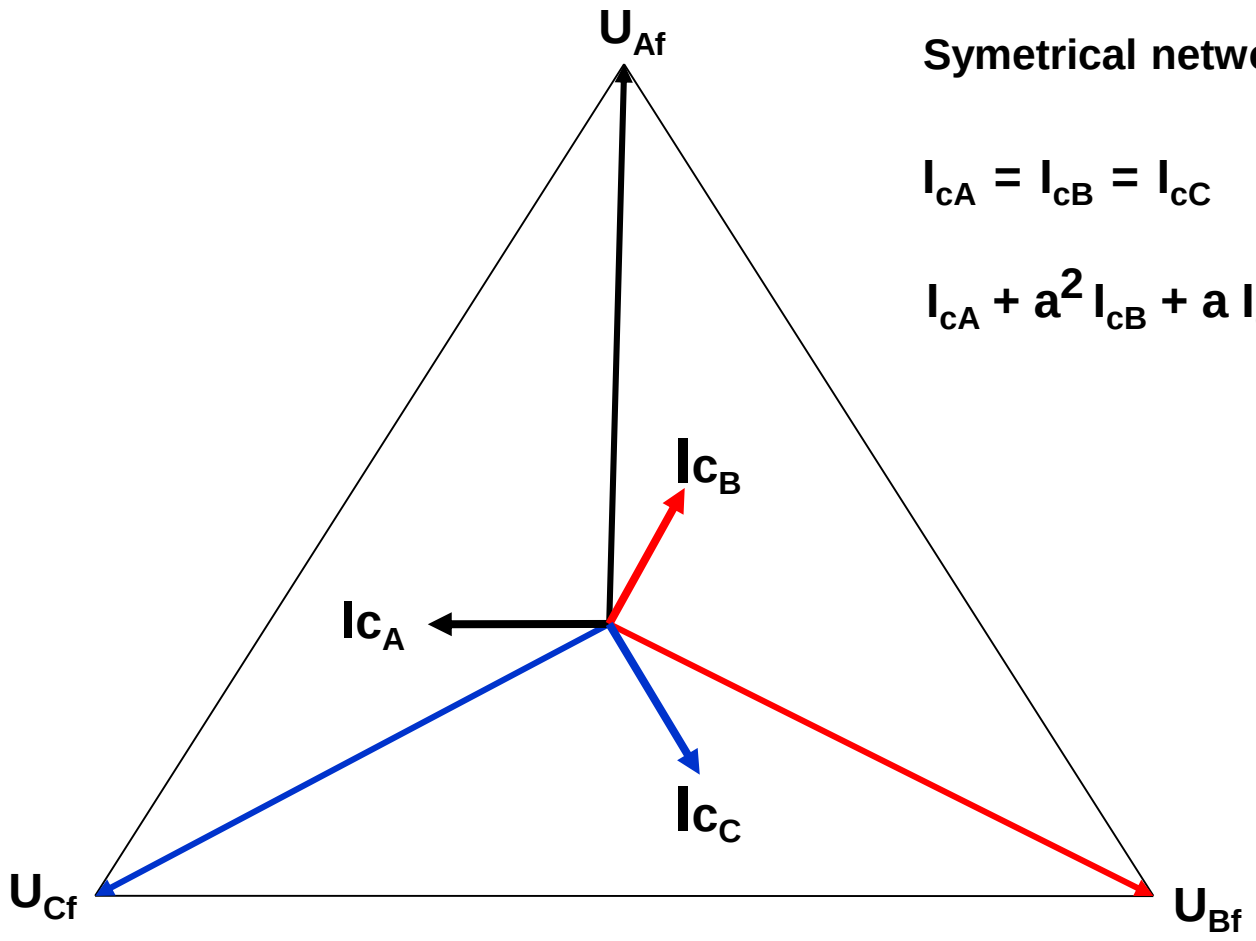


Capacitive leakage current before earth-fault occurrence

$$I_{cA} = I_{cB} = I_{cC} = \frac{U_{Cf}}{-jX_c} = j\omega C \cdot U_{Cf} = j\omega C \cdot U_f = j\omega C_k \cdot \Sigma l \cdot U_f$$

Leakage current I_c depends on network extent Σl and is about hunders of mA

Isolated networks – before fault



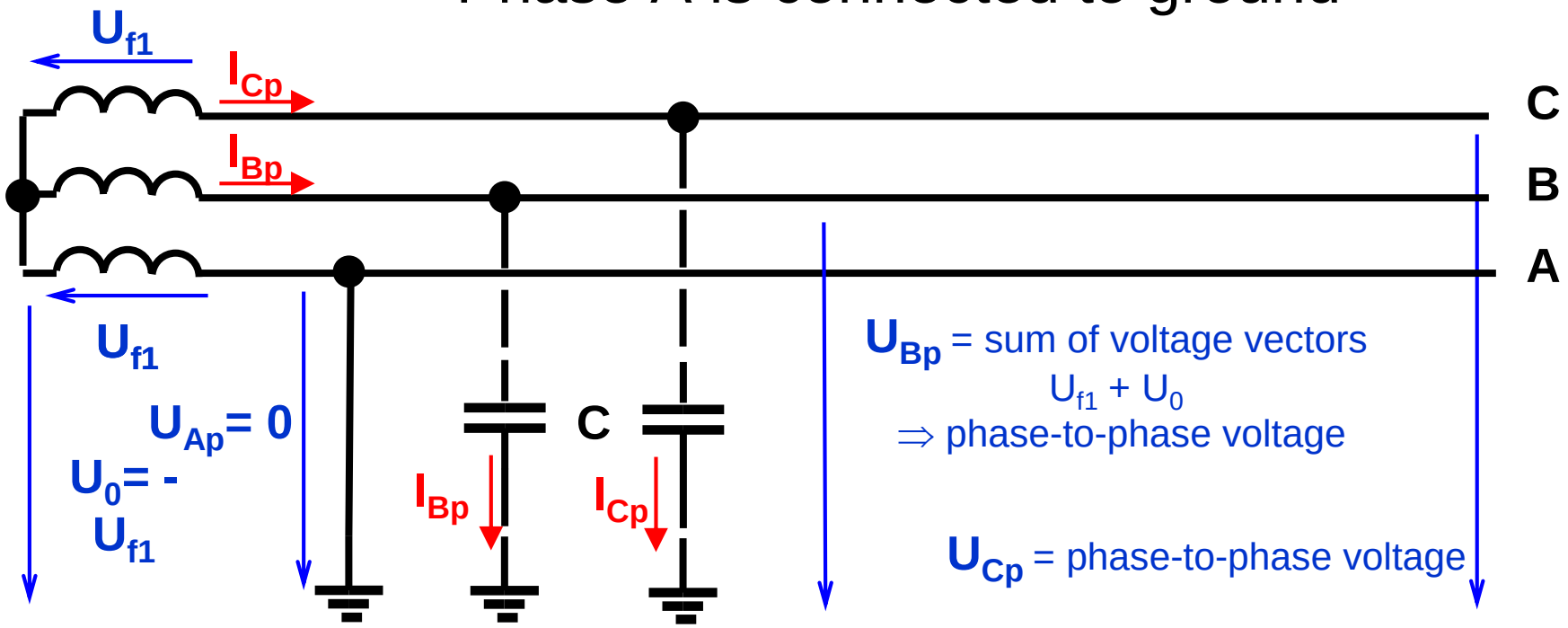
Symetrical network

$$I_{cA} = I_{cB} = I_{cC}$$

$$I_{cA} + a^2 I_{cB} + a I_{cC} = 0$$

Vector diagram of voltage and capacitive leakage currents Ic in a symetric network

Phase A is connected to ground

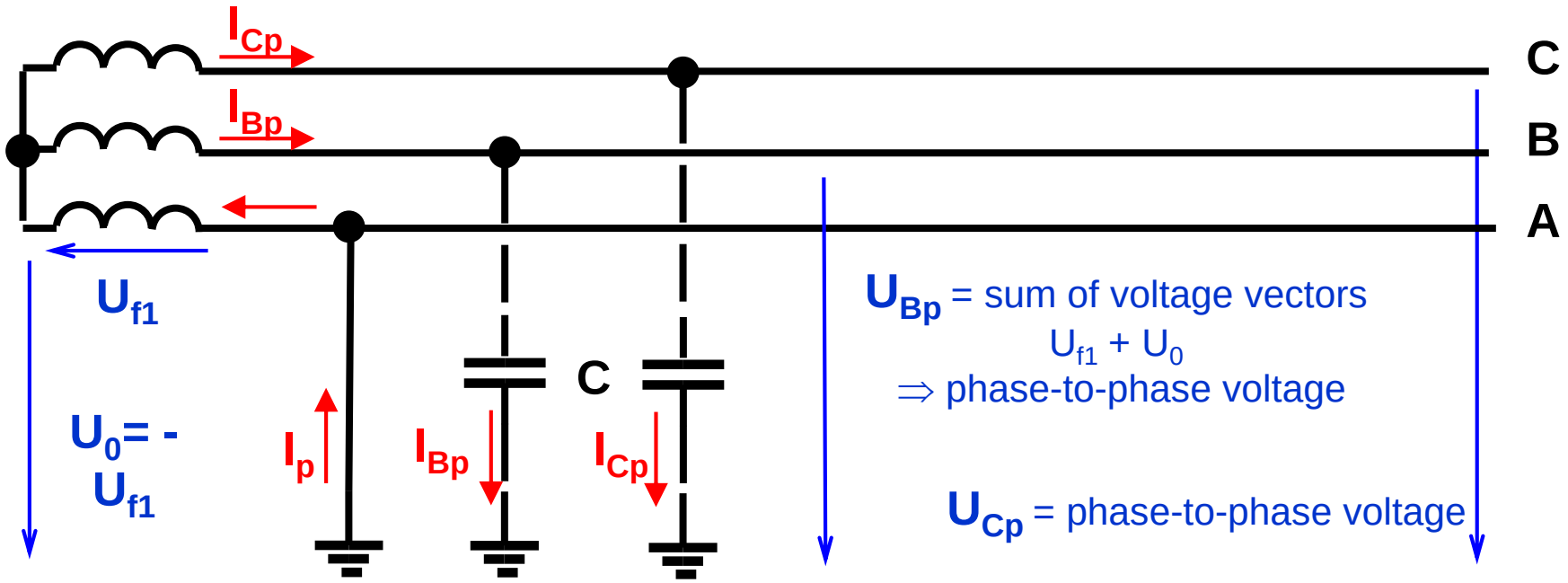


Capacitive leakage current of unaffected phases during earth-fault

$$I_{Bp} = \frac{U_{Bp}}{-jX_c} = j\omega C \cdot U_{Bp} = j\omega C \cdot \sqrt{3} \cdot U_{Bf} = \sqrt{3} \cdot I_{cB} = j\omega C \cdot \sqrt{3} \cdot U_f = I_{Cp}$$

During earth-fault, leakage current of unaffected phases is √3 times higher than current before earth-fault.

Phase A is connected to ground



Total fault current in affected phase during earth-fault
= sum of leakage currents in unaffected phases

$$I_p = \sqrt{3} \cdot I_{Bp} = \sqrt{3} \cdot j\omega C \cdot \sqrt{3} \cdot U_f = j\omega C \cdot 3 \cdot U_f = j\omega C_k \cdot \Sigma l \cdot 3 \cdot U_f$$

Fault current (x A) ⇒ arc formation with consecutive interrupted earth fault ⇒ voltage increase

Isolated networks – earth fault

U_{Bf}- phase-to-ground voltage before earth fault

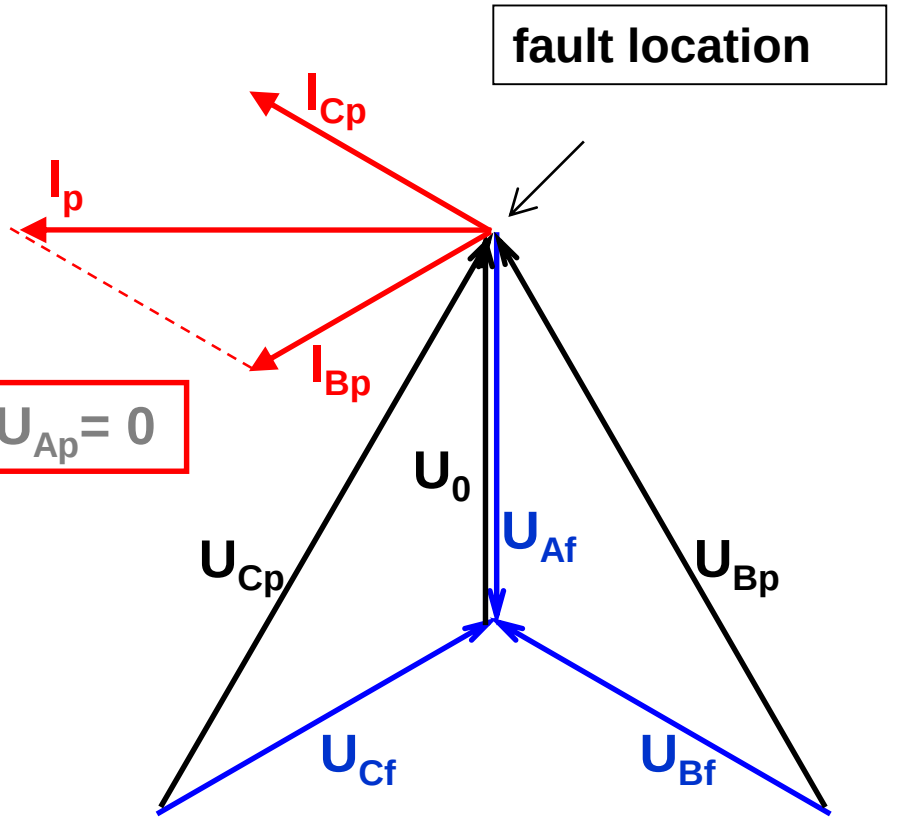
U_0 - neutral grounding voltage during earth fault $U_0 = - U_f$

U_{Ap}- voltage of phase with earth fault $U_{Ap} = 0$

U_{Bp}- phase-to-ground voltage during earth fault $U_{Bp} = \sqrt{3} * U_{Bf}$

I_{Bp}- leakage current of unaffected phase during earth fault $I_{Bp} = \sqrt{3} * I_{cB}$

I_p- leakage current of affected phase during earth fault

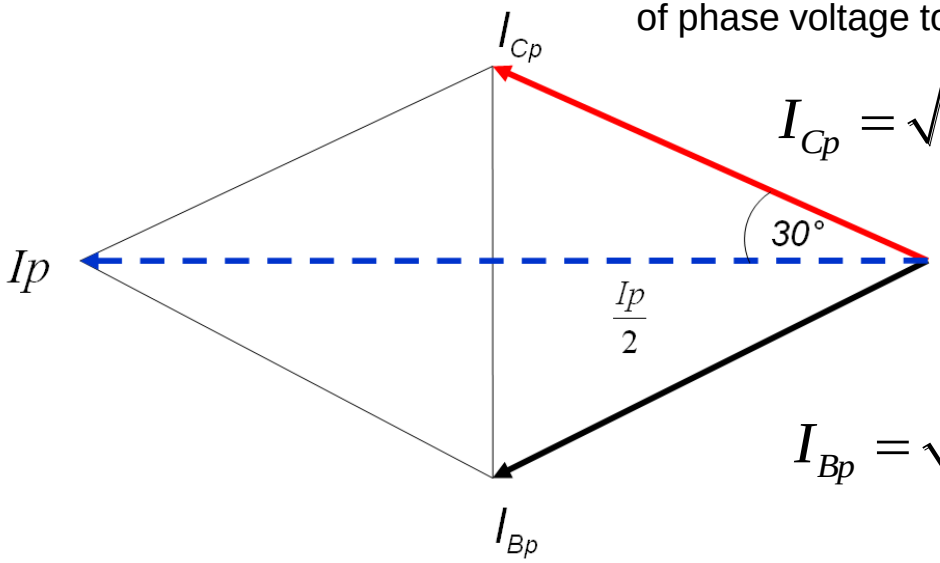


Vector diagram during earth-fault

Isolated networks – earth fault

Total fault current *Ip*

increased capacitive leakage current in phase C due to increase of phase voltage to value of phase-to-phase voltage √3 Uf



$$I_{Cp} = \sqrt{3} \cdot U_f \cdot \omega \cdot C$$

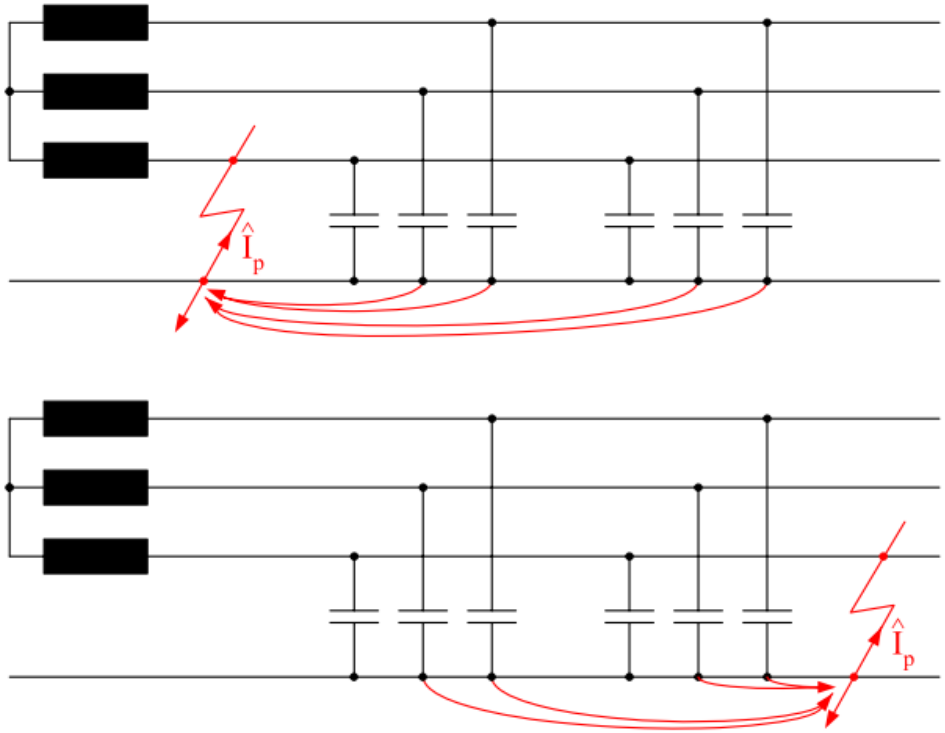
$$I_{Bp} = \sqrt{3} \cdot U_f \cdot \omega \cdot C$$

Total fault current I_p (network capacitive current)

$$\frac{Ip}{2} = I_{Cp} \cdot \sin 30^o = I_{Cp} \cdot \frac{\sqrt{3}}{2} \quad \Rightarrow \quad Ip = I_{Cp} \cdot \sqrt{3} = \sqrt{3} \cdot \sqrt{3} \cdot U_f \cdot \omega \cdot C = 3 \cdot U_f \cdot \omega \cdot C$$

Earth fault

Fault current depends on the total network extent and almost doesn't depend on the fault location distance from the transformer.



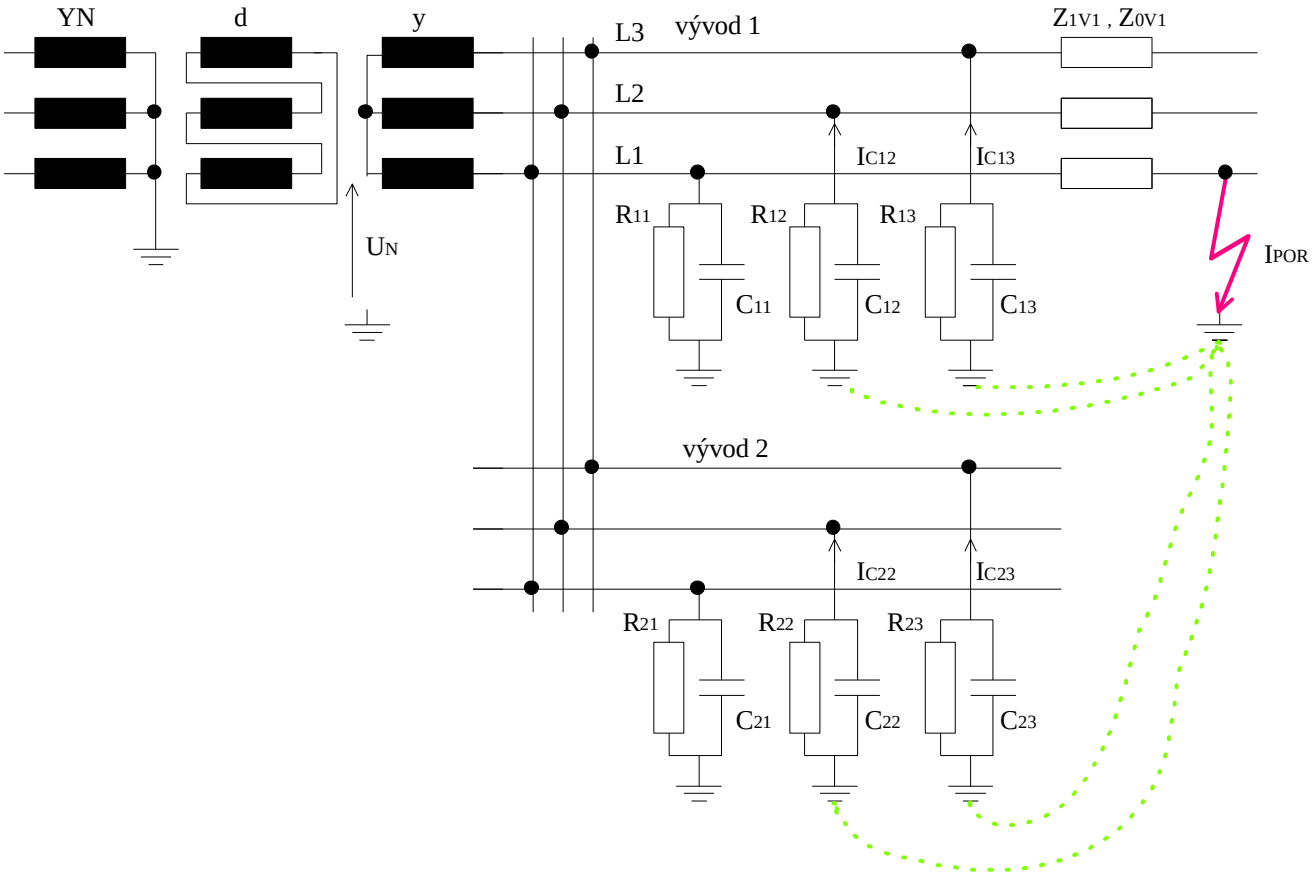
$$I_p = 3 \cdot U_f \cdot \omega C_k \cdot \Sigma l$$

Overhead 22kV networks
– current cca 0,06 A/km

Cable 22kV networks
– current cca 4 A/km

Earth fault

Total system extent – affected feeder and adjacent feeders



Earth fault



Earth-fault current compensation

Small networks, Ip < 10 A
Fault current > 5 A → electric arc occurrence → conductors, towers, insulators burning → 2ph, 3ph short-circuits (mainly in cable networks)

Interrupted earth-faults → overvoltage up to 4 Uf

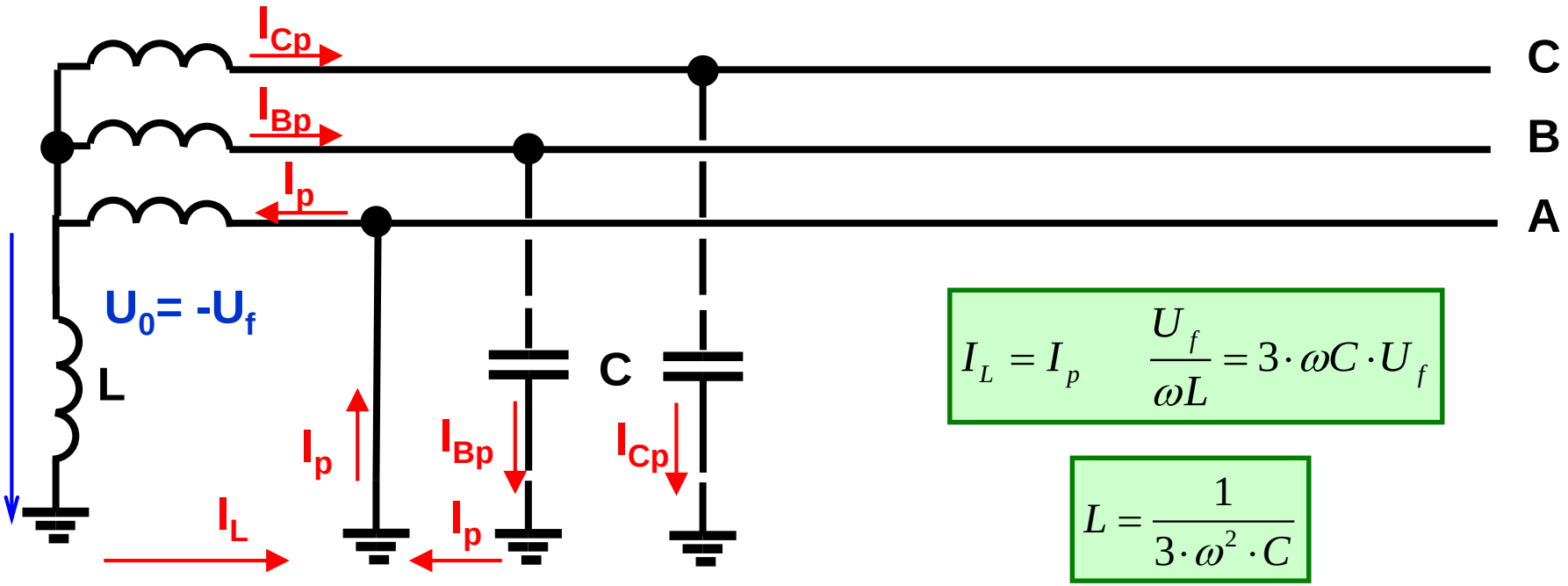
Earth-fault compensation → uninterrupted system operation (until the failure clearance, short supply outage), arc self-extinguishing (Ip < 5 A)

Results of earth-fault current compensation in fault location:

- small residual current in fault location
- reduction of power line constructions in fault location
- reduction of overvoltages during arc earth-fault extinguishing
- contact (touch) voltage in fault location is not dangerous for people.

Earth-fault current compensation is needed for networks with Ip > 10 A

Earth-fault current compensation



$$I_L = I_p \qquad \frac{U_f}{\omega L} = 3 \cdot \omega C \cdot U_f$$

$$L = \frac{1}{3 \cdot \omega^2 \cdot C}$$

Current of arc-suppression coil (Petersen coil) I_L = capacitive fault current Ip
$\Rightarrow$ no current in fault location $\rightarrow$ total compensation

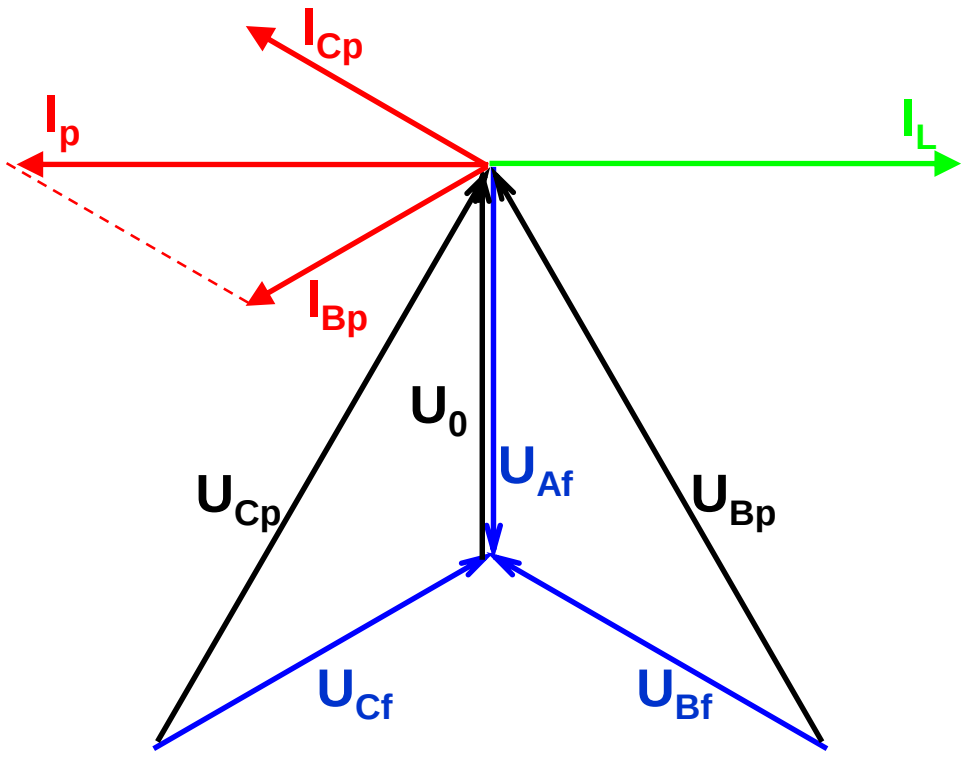
Real situation: small active residual current

- inaccurate inductance setting (error or intention)
- uncompensatable active component (power line conductance, coil resistance)
- higher harmonics

Earth-fault current compensation

Arc-suppression coil (Petersen coil)





Arc-suppression coil

1916 - Waldemar Petersen developed the Arc Suppression Coil

1917 - patent in Germany

1920 - the first installation in Europe (Castell Modame, Rom, 30 kV)

1921 - the first installation in USA (Alabama Power Company, 44 kV)


KAISERLICHES PATENTAMT.

PATENTSCHRIFT

— № 304823 —

KLASSE 21c. GRUPPE 61.

Waldemar Petersen (1880 – 1946)

- professor of Electrical Engineering

at Technischen Hochschule Darmstadt, Germany





First 40A arc suppression coil (German Museum München)
Kraftwerk Altwürtemberg AG / Operation 1917 - 1928

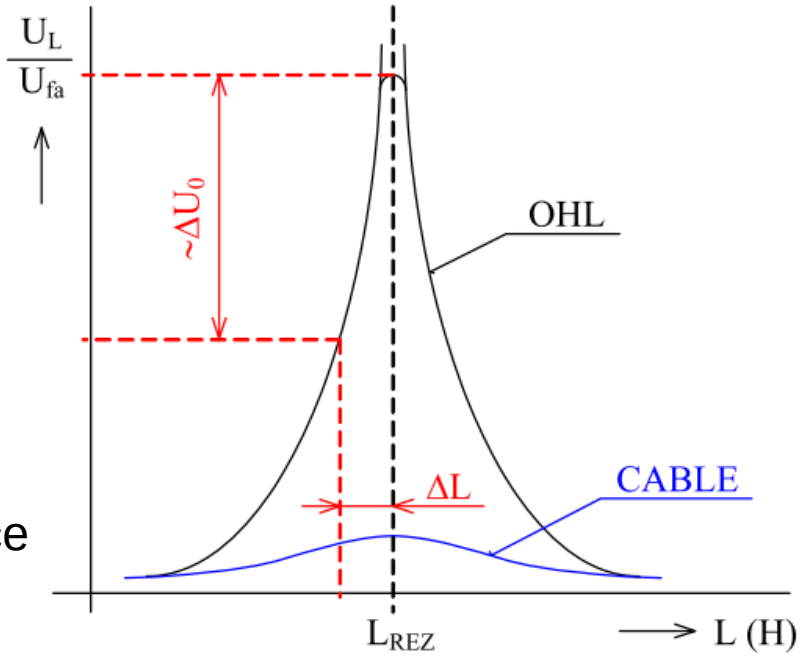
Arc-suppression coil tuning

Sizing of L by calculation.
Coil tuning in the faultless state (for given system configuration).
Tuning is done by magnetic circuit change by means of motor (air gap).

Peterson coil output

$$S_L = U_L \cdot I_L = U_L \cdot I_p = U_f \cdot 3 \cdot \omega C \cdot U_f = \omega C \cdot U_n^2$$

mainly 50% reserve – possibility to connect feeders supplied by adjacent transformer outputs – 100 x up tu 1000 x kVAr



OHL networks

- neutral grounding voltage is due to resonance too high → intended (small) detuning → considerable its reduction

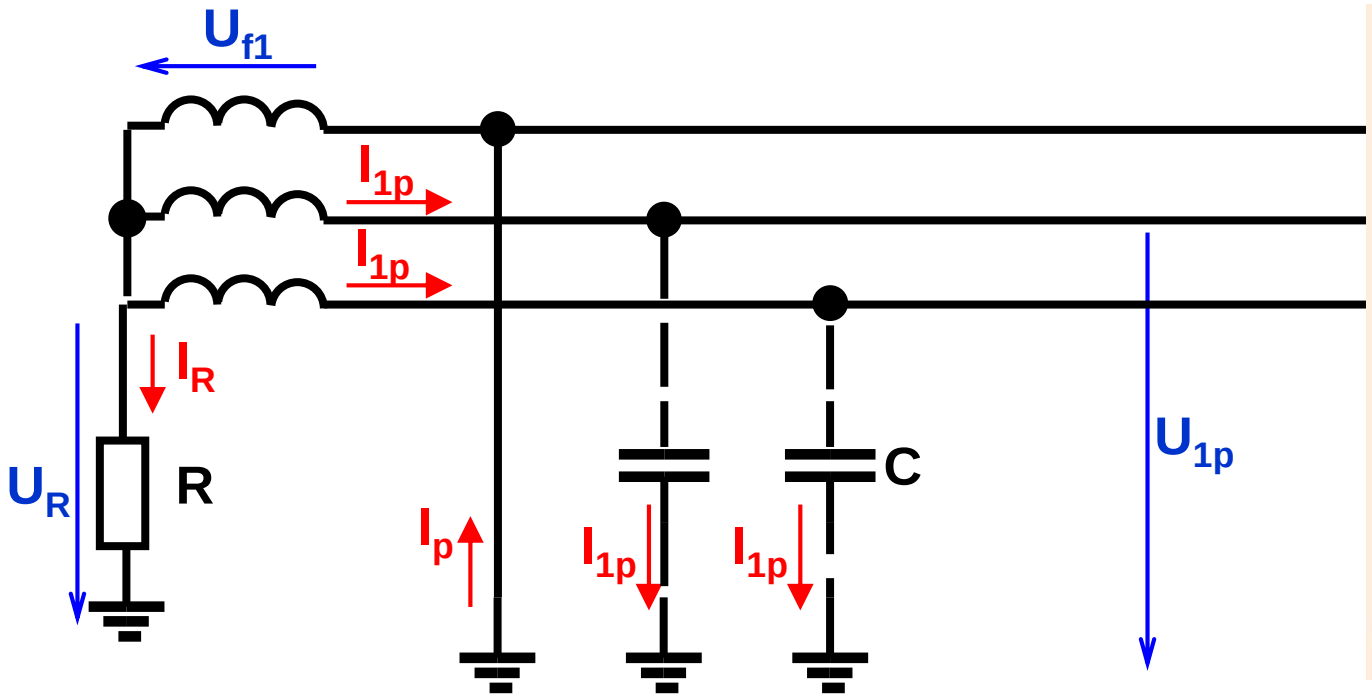
Cable networks

- small capacitive unbalance → flat curve → difficult tuning
- high capacitive fault currents (cables C= cca 300 nF/km, OHL C= 10 nF/km)

Networks grounded trough resistor R

Difficult tuning of arc-suppression coil

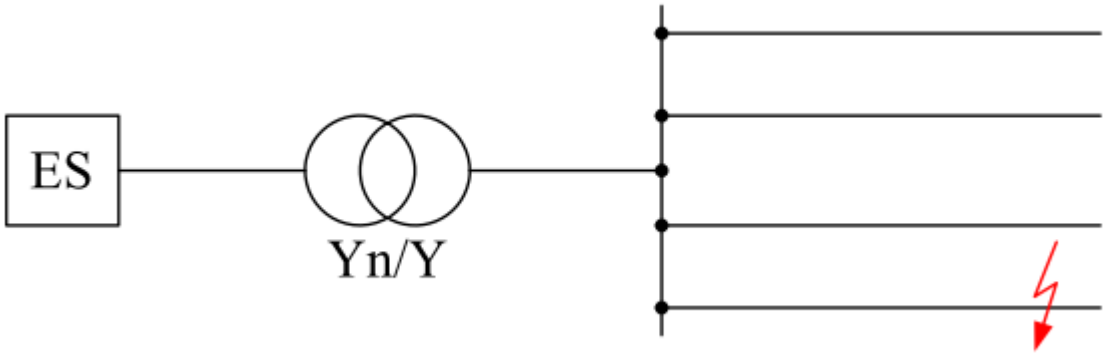
Neutral resistor (100 x Ohm)





Due to neutral resistor → 1pf short-circuit – lower short-circuit currents than in directly grounded networks → reduction of cable heating

Earth fault - example



Length of feeder 1: l_1= 95 km

Length of feeder 2: l_2= 90 km

Length of feeder 3: l_3= 100 km

Length of feeder 4: l_4= 115 km

Earth fault is 30 km far from the substation

Length of feeder = length of the main trunk + length of all branches

Capacity against the ground of the 22 kV line : C_k = 10 nF/km

Fault current in fault position:

$$I_p = 3 \cdot U_f \cdot \omega C_k \cdot \Sigma l = \sqrt{3} \cdot U_n \cdot \omega C_k \cdot \Sigma l = \sqrt{3} \cdot 22 \cdot 10^3 \cdot 314 \cdot 10 \cdot 10^{-9} \cdot (95+90+100+115) = 47,9\ A$$

Fault current is higher than 10 A $\Rightarrow$ it must be comensated by arc-suppression coil with output:

$$S_L = U_L \cdot I_L = U_{nf} \cdot I_p = \frac{22}{\sqrt{3}} \cdot 47,9 = 608,5\ kVAr$$

Due to the reserve, we choose a coil with an output of 1250 kVAr.