Short Circuit Currents in 6-500 kV Electrical Networks Containing Cable Lines

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Overhead line (OHL)

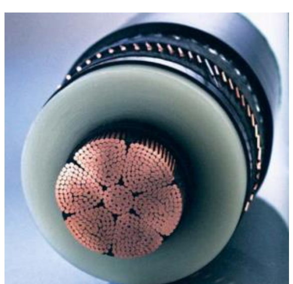
Underground cable line (CL)

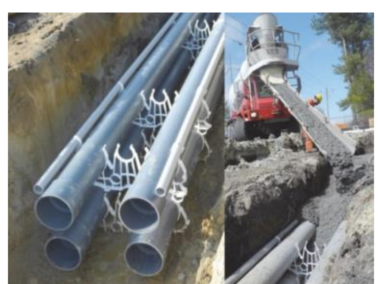
In the high-voltage power grid, the total length of OHLs was many times greater than of CLs. Therefore, errors in the modelling of CLs had never led to noticeable problems for the grid.

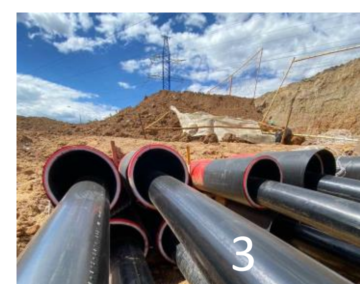
However, in recent years, the number of CLs has grown so noticeably that we have to ask ourselves the question: **"Do we calculate correctly power grids with modern cable lines?"**

Why is the number of cables growing?

1. **Cities are growing**, and overhead lines should be removed underground (it's safer for people, it's more beautiful).
2. Europe launched a "**green transition**" (there is more and more "green" energy; many solar/wind parks need to be connected to the power grid).
3. Modern cables with **XLPE insulation** are convenient for installation compared to the old oil-filled paper-insulated cables.
4. New **cable ducts** (pipes) have come to the market. They help to protect cables from mechanical damage and aggressive environment, and also they increase the speed of installation/repair/replacement of cables.
5. A new method has come – **the horizontal directional drilling** (HDD), allowing cables to be laid in cities without the need to dig trenches.
6. A new design has appeared that provides an easy/cheap/compact connection of overhead and cable lines (so called "**transition towers**").



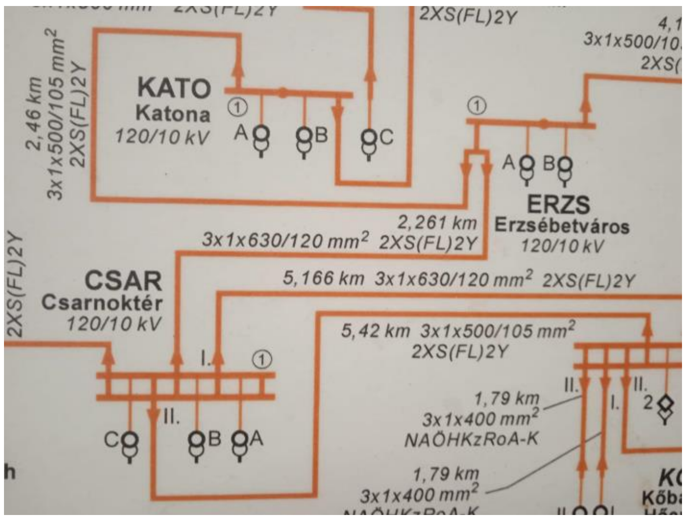




How cables affect short circuit currents?

The active and inductive impedances (R and X) of a cable line are always several times lower than those of an overhead line of the same length.

Replacing overhead lines with cables leads to an increase in short circuit currents.



In large cities, short circuit currents in 132 kV and 230 kV cable networks can reach 40-50 kA or more!

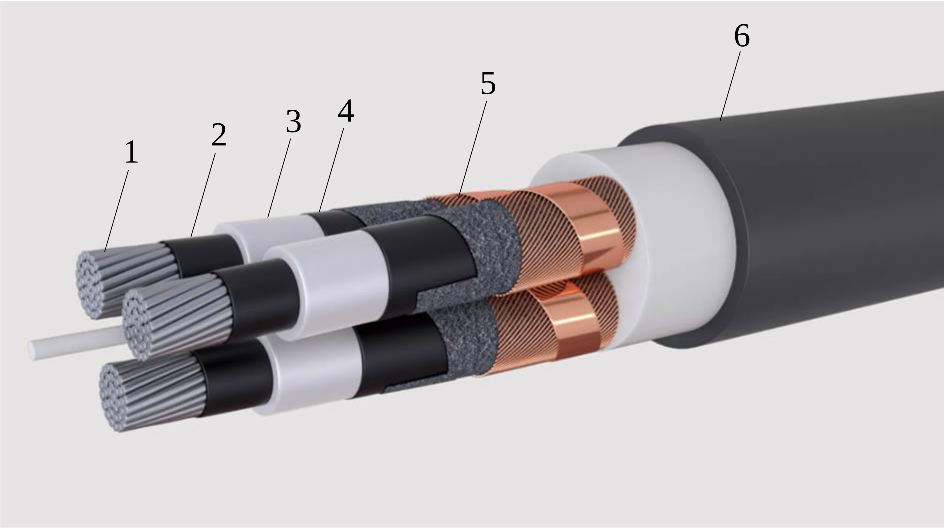
If currents are too high, it is necessary to divide one large grid into several separate fragments, otherwise there is a serious risk of damage to circuit breakers and equipment.

Grid dispatchers must constantly monitor short circuit current using the "power flow" software.

Being able to correctly calculate the impedances R and X of cable lines is extremely important for urban high-voltage grids (132-230 kV), especially with a ring structure.

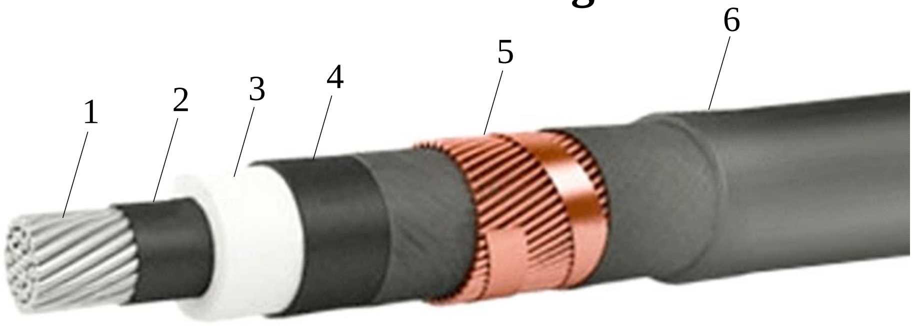
Typical cable designs

6-35 kV three-core cables



1 – core
2 – semiconductive layer
3 – insulation
4 – semiconductive layer
5 – screen of each phase
6 – outer sheath

6-35 kV and 110-500 kV single-core cables



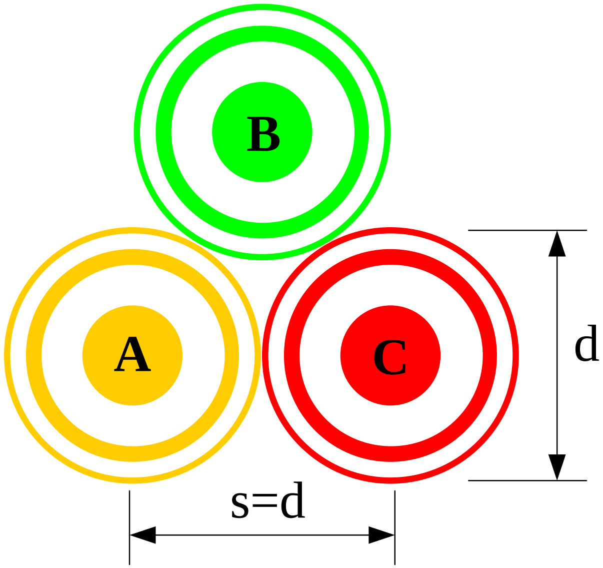
1 – core
2 – semiconductive layer
3 – insulation (XLPE)
4 – semiconductive layer
5 – screen
6 – outer sheath

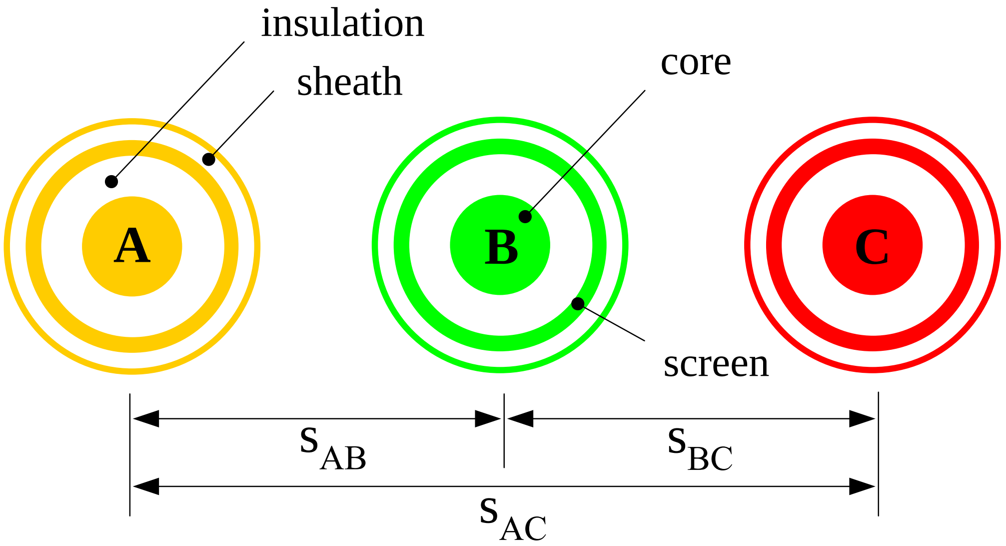
Single-core cable is the most spread type of cables!

Mutual arrangement of three single-core cables

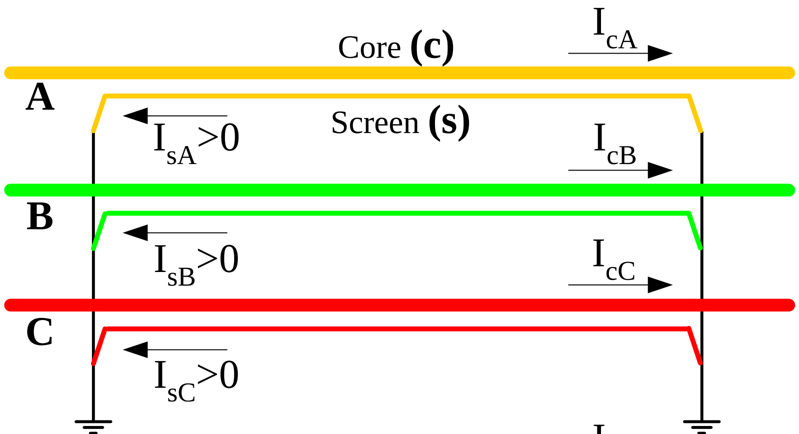
Trefoil formation

Flat formation (in a row)



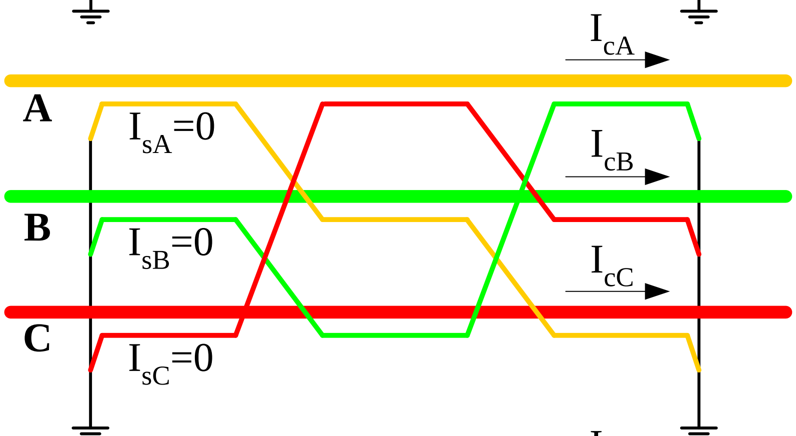


Main types of screens' bonding and grounding



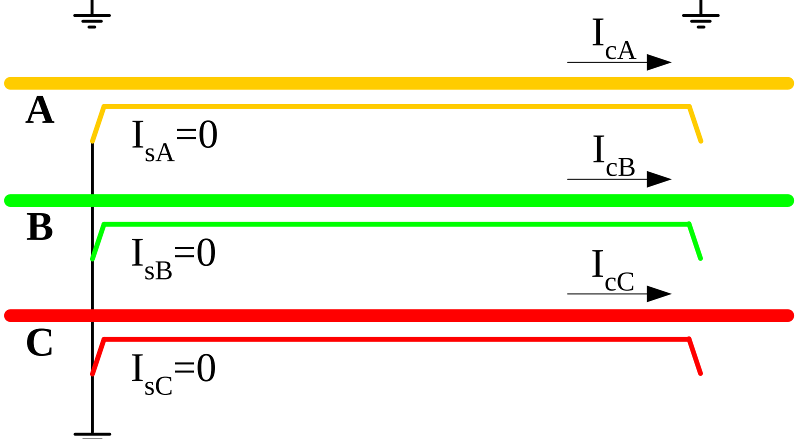
Both-side bonding/grounding:

There are **induced 50 Hz currents in the screens**, which heat cables, cause additional power losses.



Screens' cross-bonding:

There are **no induced 50 Hz currents** in the screens, and a cable line has reduced power losses, that is an increased admissible core current of the line



Single-side bonding/grounding:

There are **no induced 50 Hz currents** in the screens, and a cable line has reduced power losses, that is an increased admissible core current of the line

Longitudinal impedances of the cable line

Overhead lines and cable lines have the longitudinal impedances:

- Positive sequence: **R1, X1** (or inductance L1)
- Negative sequence: **R2, X2** (or inductance L2) – equal to R1, X1, L1
- Zero sequence: **R0, X0** (or inductance L0)

Such impedances are needed to calculate the normal operating modes of the network and to calculate short circuit currents.

The problem with cable lines is that impedances depend on:

- Bonding/grounding type of cable screens,
- Cross-section of the screen, and its material (Cu, Al).

Information from cable catalogues

Error #1:

They assume that positive and zero sequences have the same impedance:

$R0/R1 = 1$,

$X0/X1 = 1$.

Error #2:

They assume that impedances do not depend on:

- Bonding/grounding type of cable screens,
- Cross-section of the screen, and its material.

If we take 10 of the World's largest manufacturers of 6-500 kV cables, then in all 10 their catalogues we will find these two errors (#1 and #2).

There are only two formulae in a typical cable catalogue

Active impedance:

$$R_{11}^{*} = K_{skin} \cdot \frac{\rho_C}{F_C}$$

where F_C – the cross-section of the core;
ρ_C – the resistivity of the core material (depends on the temperature at which it is necessary to determine the cable parameters);
K_{skin} – the coefficient of the surface (skin) effect depending on the core cross-section F_C (for copper core $K_{skin} = 1 \div 1.15$, for aluminum core $K_{skin} = 1 \div 1.06$).

Inductive impedance:

$$L_{11}^{*} = L_{int}^{*} + \frac{\mu_0}{2\pi} ln\left(\frac{S_{CL}}{r_1}\right)$$

where $\mu_0 = 4\pi \cdot 10^{-7}$ H/m – the magnetic constant;
S_{CL} – the average distance between the cable axes along the cable route;
r_1 – the radius of the core;
$L_{int}^{*} = 0.05 \cdot 10^{-6}$ H/m is the core internal inductance.

After converting all values from the dimension of H/m to the dimension of mH/km:

$$L_{11}^{*} = 0.05 + 0.2 \cdot ln\left(\frac{S_{CL}}{r_1}\right)$$

Next to these formulae for R and L, there is no information about the main details:

- Is it a positive sequence or a zero sequence?
- What is the bonding/grounding type of cable screens?
- What is the cross-section of the screen, and its material?

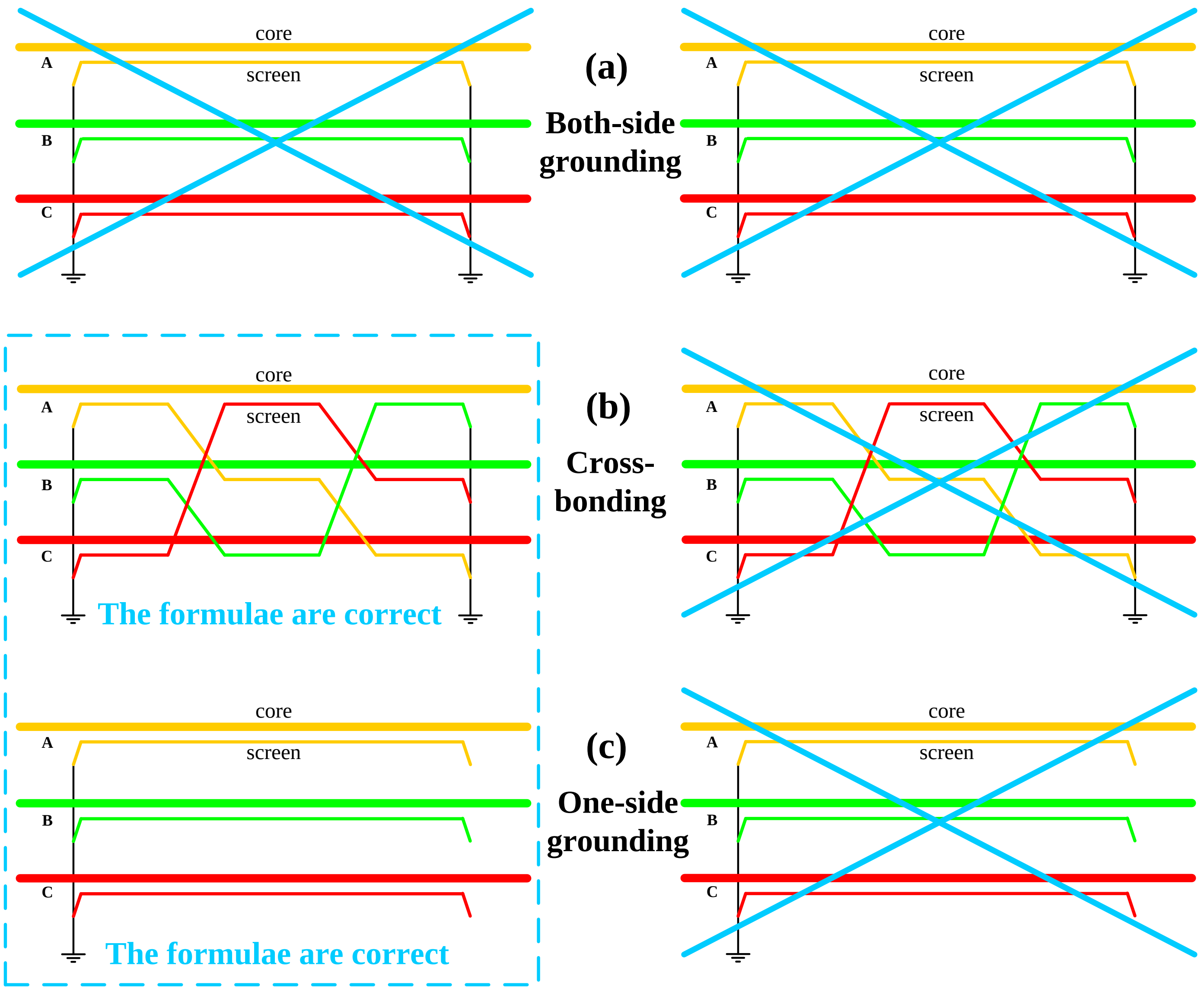
Obviously, these formulae do not take into account key factors and cannot be widely used.

The use of such formulae can lead to significant errors in the calculation of:

- Normal operating modes of the network having cable lines;
- **Short circuit currents** in the network having cable lines.

When are the "well-known" formulae for R and L correct?

Positive (1) sequence: **Zero (0) sequence:**



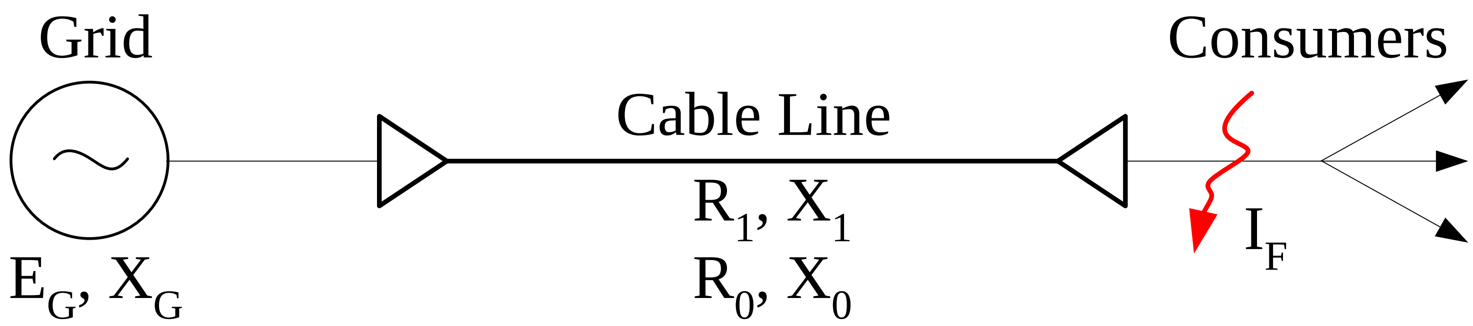
Correct longitudinal parameters of the cable line

Screen bonding/ grounding type	Positive sequence *(catalogues are not for both-side grounding)*		Zero sequence *(zero sequence is not equal to positive)*	
	R_1	X_1	R_0/R_1	X_0/X_1
One-side grounding	R_{11} (well-known formula from cable catalogue)	X_{11} (well-known formula from cable catalogue)	$3 \div 15$	$4 \div 25$
Cross-bonding			$2 \div 30$	$0.25 \div 2$
Both-side grounding	$(1.01 \div 5) \cdot R_{11}$	$(0.45 \div 0.99) \cdot X_{11}$	$1 \div 20$	$0.5 \div 2$

Cable line longitudinal impedances R and X depend on:

- Sequence (positive or zero),
- Bonding/grounding type of cable screens,
- Cross-section of the screen, and its material.

A test circuit for the calculation of short circuit currents



Two types of faults (F) were considered at the end of the cable line:

- Three-phase short circuit,
- Single-phase short circuit.

Two types of cable impedances were used in calculations:

1. From cable catalogues (“wrong” impedances),
2. From the book “High Voltage Cable Lines” (M. Dmitriev, 2024, 690 pages).

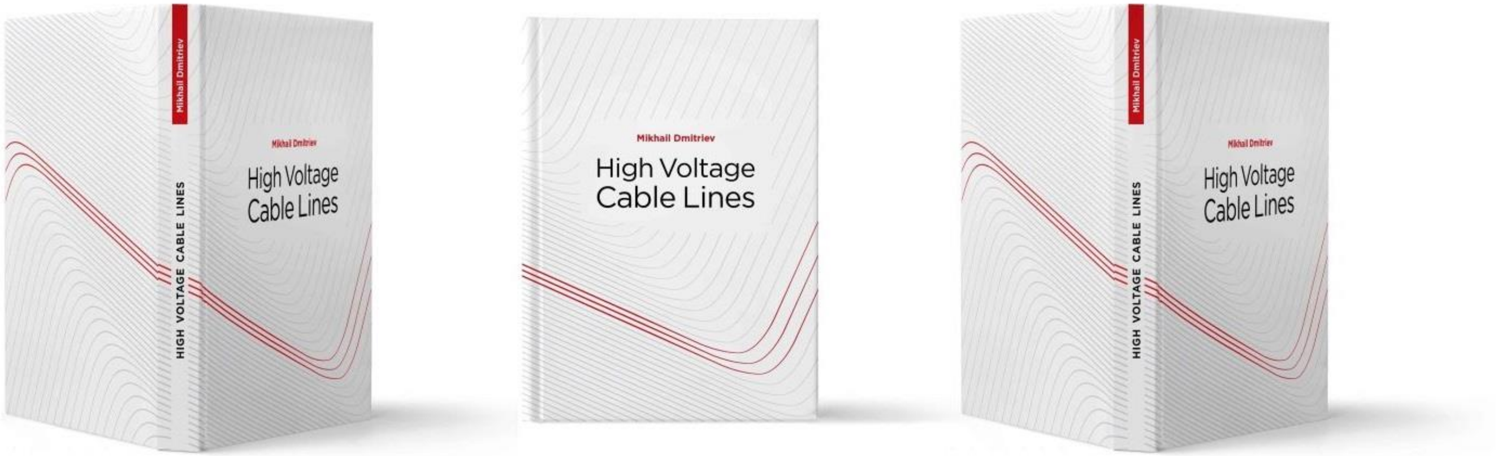
It was shown that, depending on the impedances (1 or 2) included in the calculations, **the short-circuit currents in the test circuit vary up to 35%**

1. The real short circuit currents in the grid can be up to 30-35% higher than the values calculated using wrong cable impedances.
2. It is important to check cable catalogues, regulatory documents, and algorithms of software for calculating short circuit currents.
3. **It is not recommended to trust the cable software, which does not require the following basic source data from the user:**
    - Bonding/grounding type of cable screens,
    - Cross-section of the screen, and its material.

References

✓ “High Voltage Cable Lines” (M. Dmitriev, 2024, 690 pages):
https://voltplace.com/

✓ LinkedIn public group “High Voltage Cable Lines”:
https://www.linkedin.com/groups/9507385/



Thank you !