Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

TECHNISCHE UNIVERSITÄT CHEMNITZ

Faculty Electrical Engineering & Informatics

A frequency-dependent cable model based on PI-sections for calculations in the time domain

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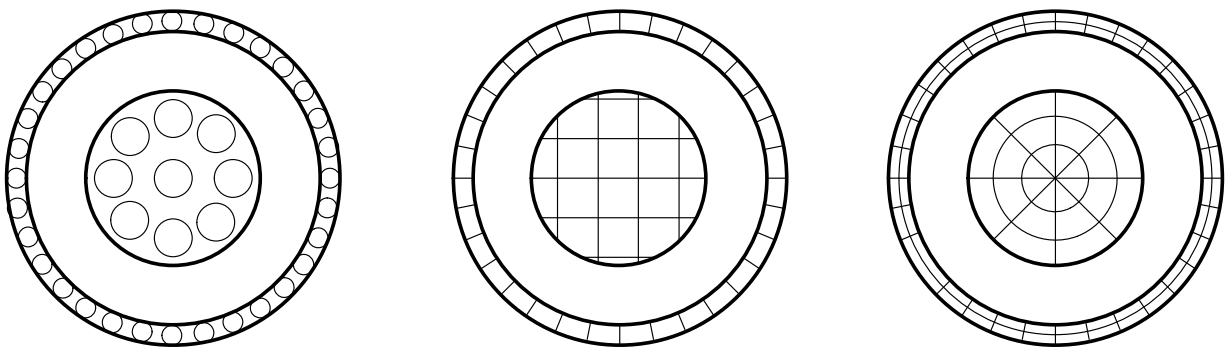
oo Content

01 Modified subconductor method

Conventional subconductor method

- **COMELLINI, subconductor method (1973)**
  - Segmentation of all conductors in considered space
  - "fixed" segmentation
  - relatively independent of Skin- and Proximity-effect

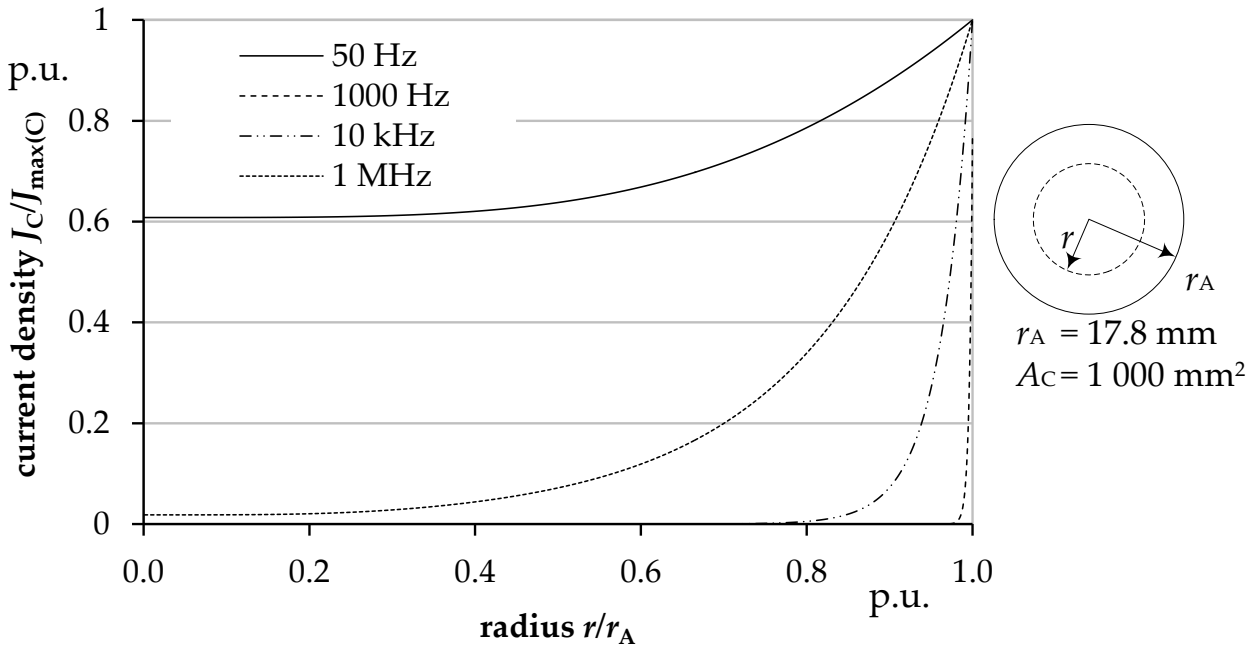


circular *square* *sector-shaped*

01 Modified subconductor method

Advanced subconductor method

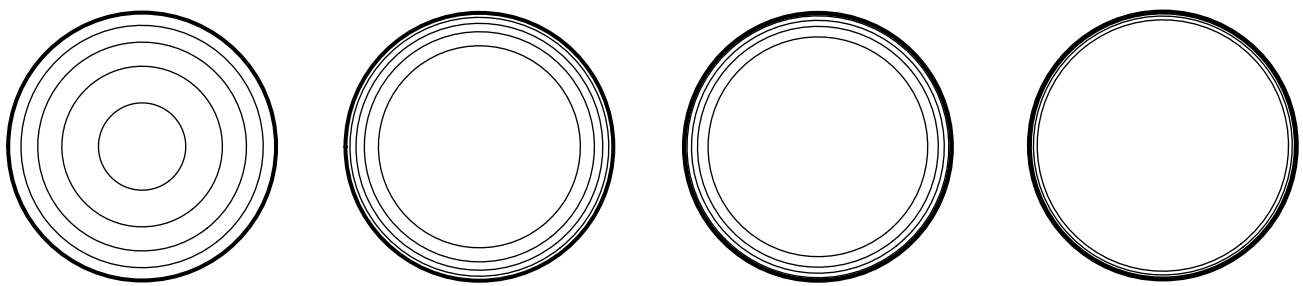
- **Applicability to f = 5 MHz**
  - Segmentation in dependence on current density $J_C / J_{max(C)}$



01 Modified subconductor method

Advanced subconductor method

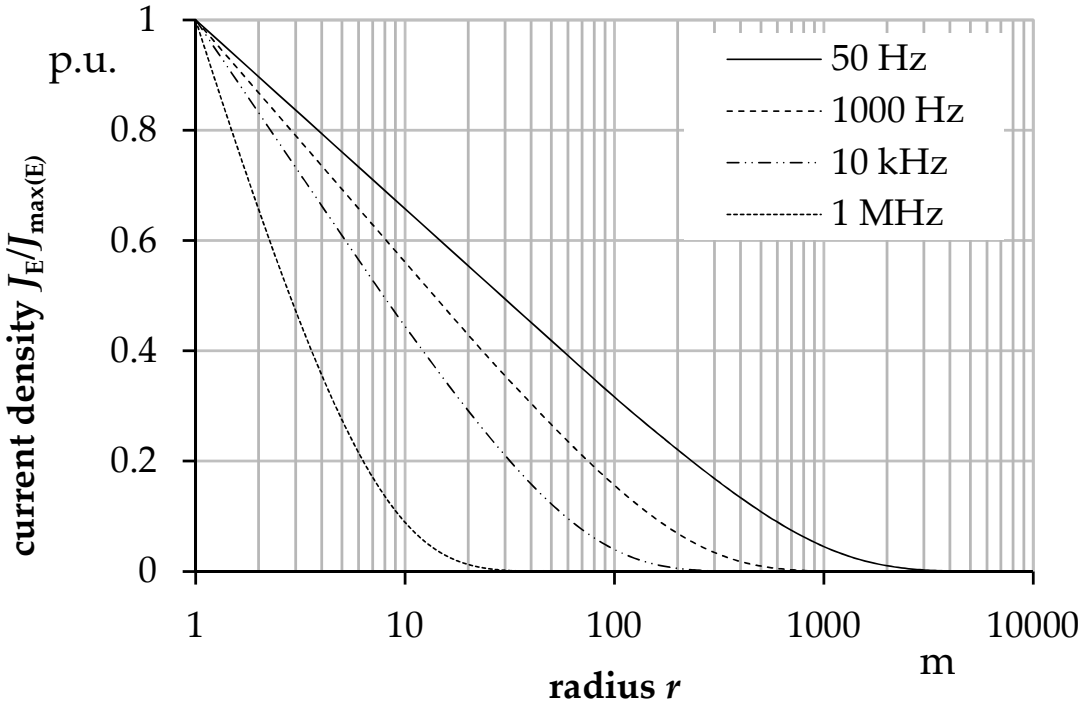
- **Segmentation in skins**



01 Modified subconductor method

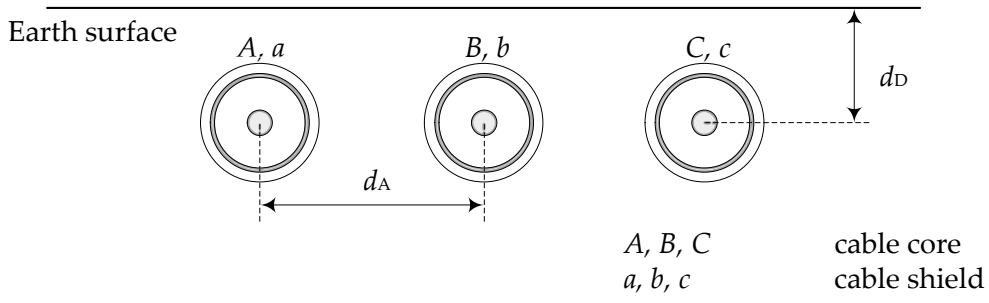
Earth segmentation

- Segmentation in dependence on earth current density $J_E / J_{max(E)}$



01 Modified subconductor method

Impedance matrix $\mathbf{Z}'_{\mathrm{SC}}$

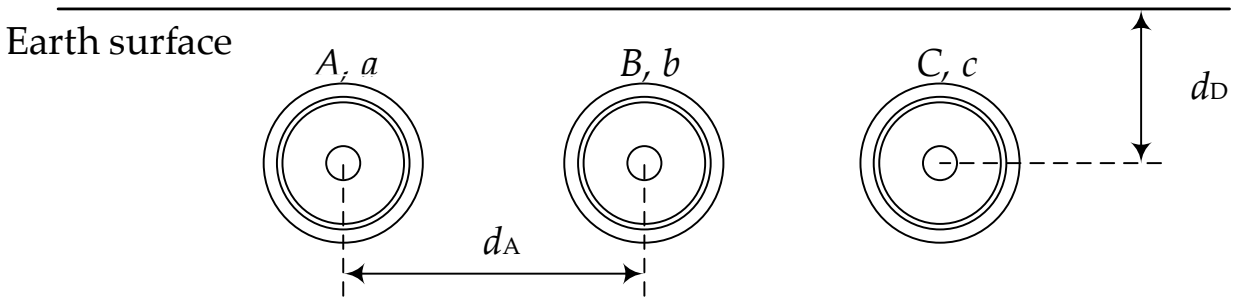


$$\mathbf{Z}'_{\mathrm{SC}} = \begin{bmatrix} \underline{Z}'_{\mathrm{AA}} & \underline{Z}'_{\mathrm{AB}} & \underline{Z}'_{\mathrm{AC}} & \underline{Z}'_{\mathrm{aA}} & \underline{Z}'_{\mathrm{aB}} & \underline{Z}'_{\mathrm{aC}} \\ \underline{Z}'_{\mathrm{BA}} & \underline{Z}'_{\mathrm{BB}} & \underline{Z}'_{\mathrm{BC}} & \underline{Z}'_{\mathrm{bA}} & \underline{Z}'_{\mathrm{bB}} & \underline{Z}'_{\mathrm{bC}} \\ \underline{Z}'_{\mathrm{CA}} & \underline{Z}'_{\mathrm{CB}} & \underline{Z}'_{\mathrm{CC}} & \underline{Z}'_{\mathrm{cA}} & \underline{Z}'_{\mathrm{cB}} & \underline{Z}'_{\mathrm{cC}} \\ \underline{Z}'_{\mathrm{aA}} & \underline{Z}'_{\mathrm{aB}} & \underline{Z}'_{\mathrm{aC}} & \underline{Z}'_{\mathrm{aa}} & \underline{Z}'_{\mathrm{ab}} & \underline{Z}'_{\mathrm{ac}} \\ \underline{Z}'_{\mathrm{bA}} & \underline{Z}'_{\mathrm{bB}} & \underline{Z}'_{\mathrm{bC}} & \underline{Z}'_{\mathrm{ba}} & \underline{Z}'_{\mathrm{bb}} & \underline{Z}'_{\mathrm{bc}} \\ \underline{Z}'_{\mathrm{cA}} & \underline{Z}'_{\mathrm{cB}} & \underline{Z}'_{\mathrm{cC}} & \underline{Z}'_{\mathrm{ca}} & \underline{Z}'_{\mathrm{cb}} & \underline{Z}'_{\mathrm{cc}} \end{bmatrix}$$

01 Modified subconductor method

Single-core cable system (XLPE)

In flat configuration

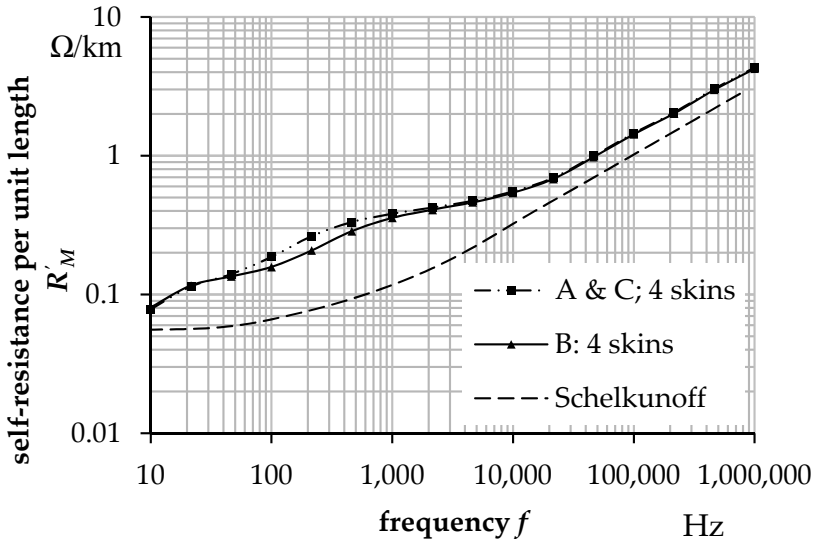


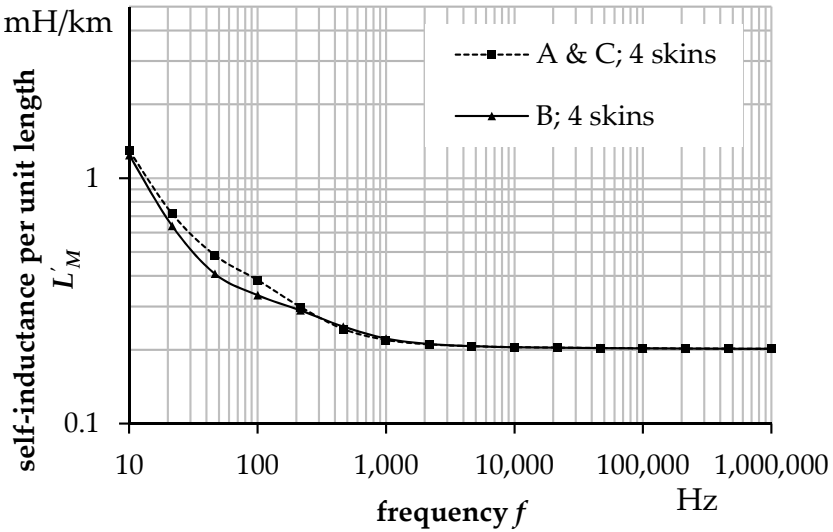
d_A = 120 mm	phase distance	A, B, C	cable core
d_D = 1 m	burial depth	a, b, c	cable shield
A_C = 1000 mm²	core cross section		
A_S = 50 mm²	shield cross section (50 wires)		

01 Modified subconductor method

Single-core cable system (XLPE)

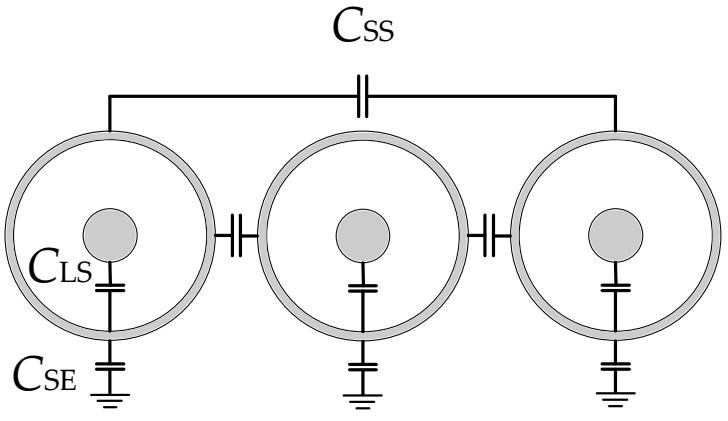
In flat configuration





01 Capacitances of cable systems

Equivalent circuit



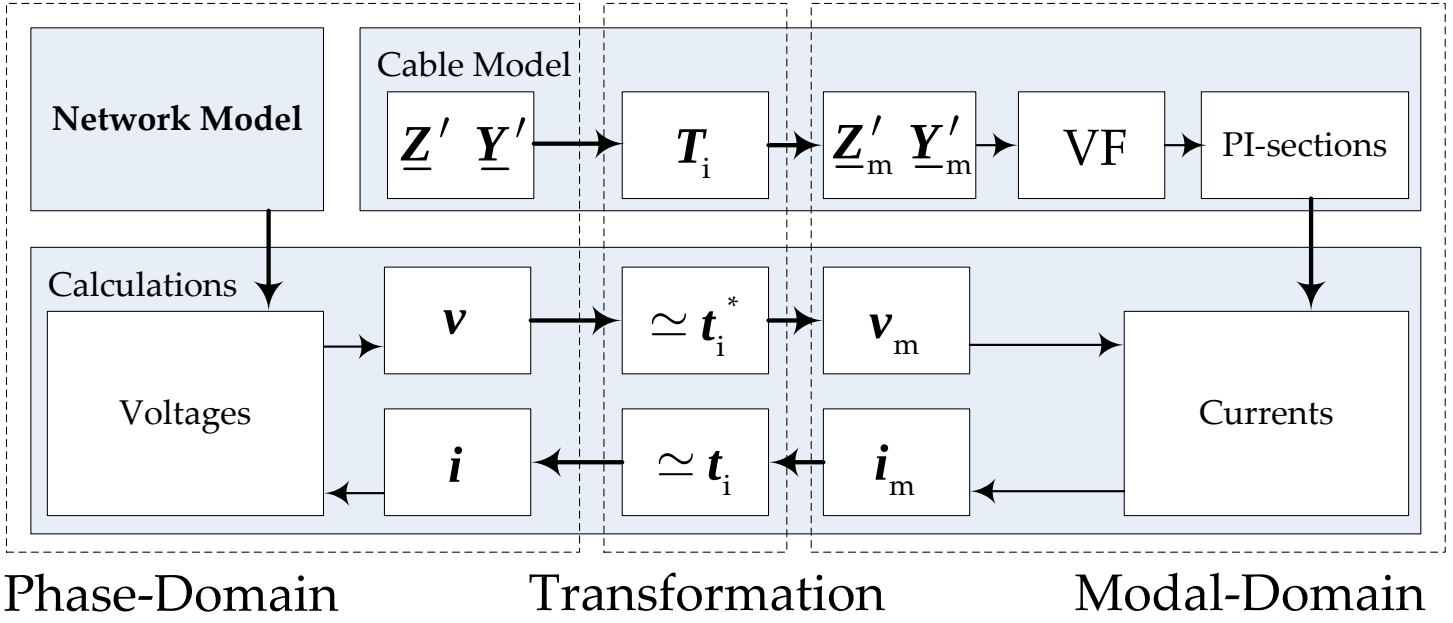
C_{LS} core-shield
C_{SS} shield-shield
C_{SE} shield-earth

- Analytical solution for core-shield capacitance C_{LS}

- Conventional algorithms
  - Charge simulation method C_{SS}, C_{SE}

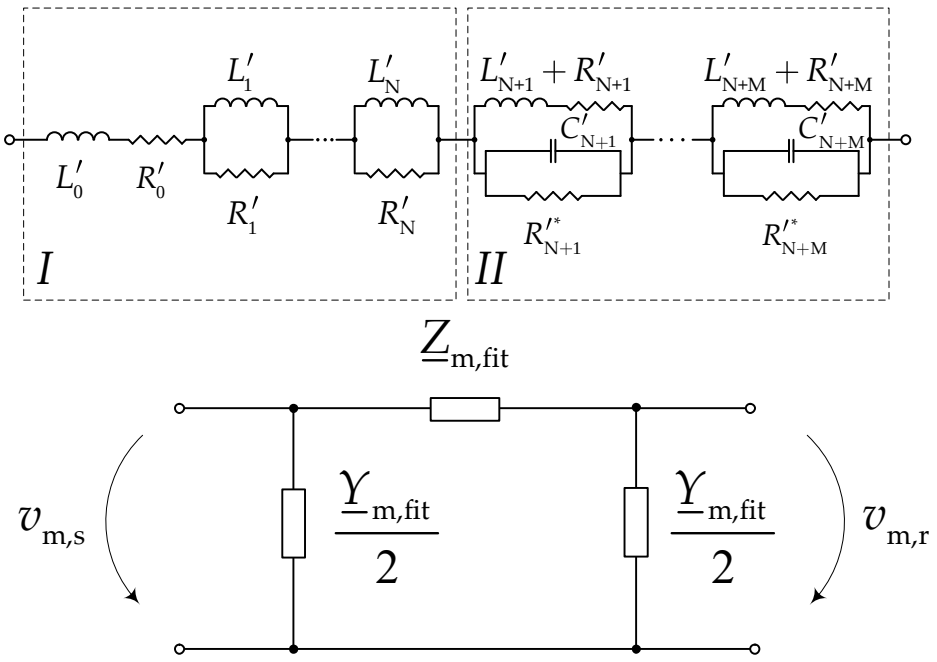
02 3phase wave propagation cable model

Principle - PI-section model



02 3phase wave propagation cable model

Frequency-dependent Impedance



Network model

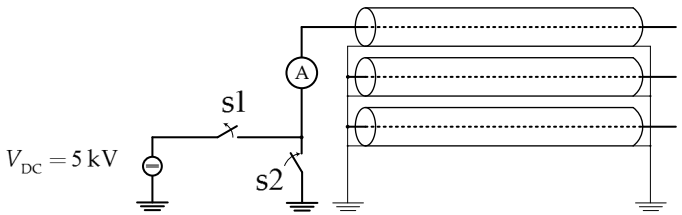
- Modal transformation
- Vector fitting
- FOSTER networks

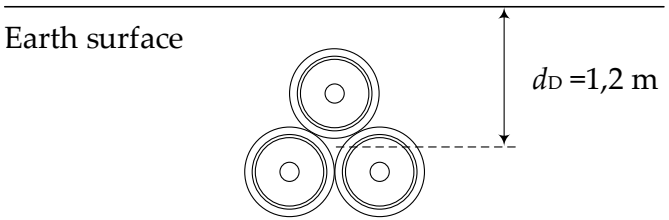
Voltage/Current Calculation

- Convolution integral
- Voltages/Currents

03 Model Verification

Measurements





Setup

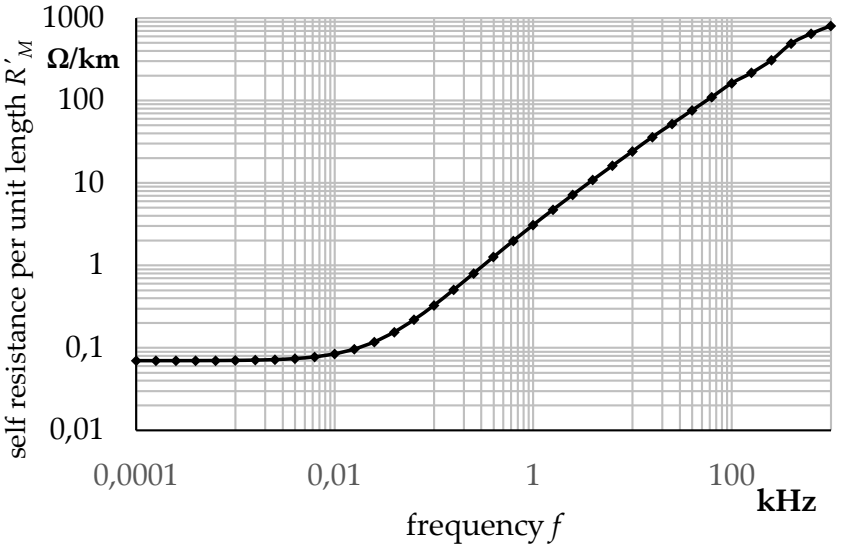
- 3phase cable system
- Trefoil, $\ell \approx 10\,km$
- Voltage $V_{DC} = 5\,kV$

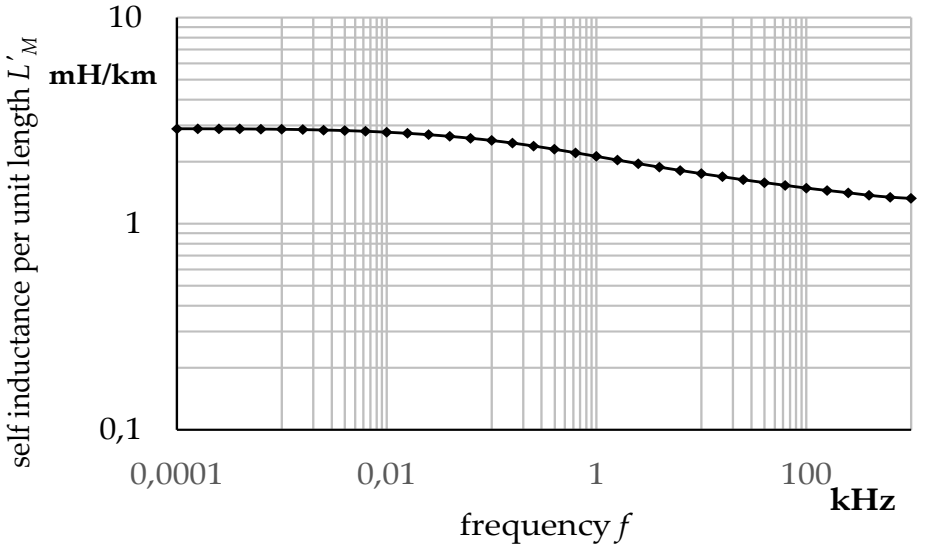
Voltage/Current Calculation

- 10, 30, 100 PI sections
- Consideration of the shields
- Consideration of the coupling

03 Model Verification

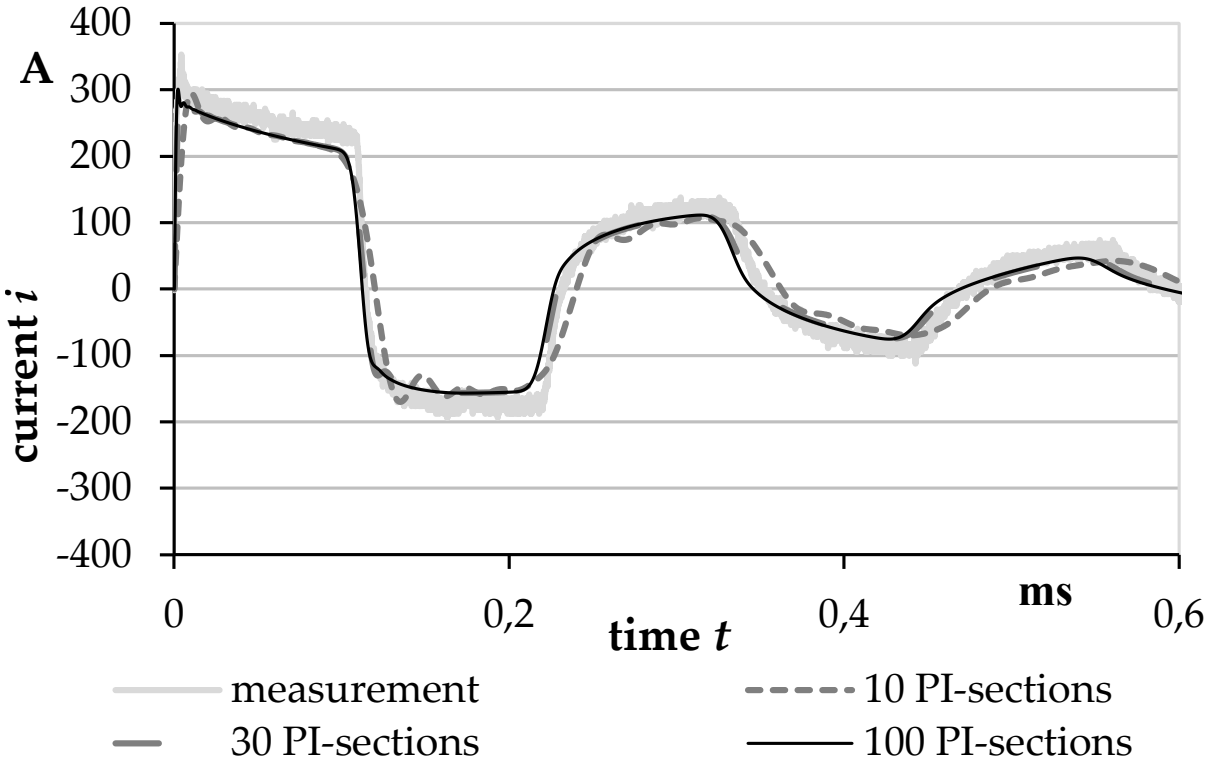
Results





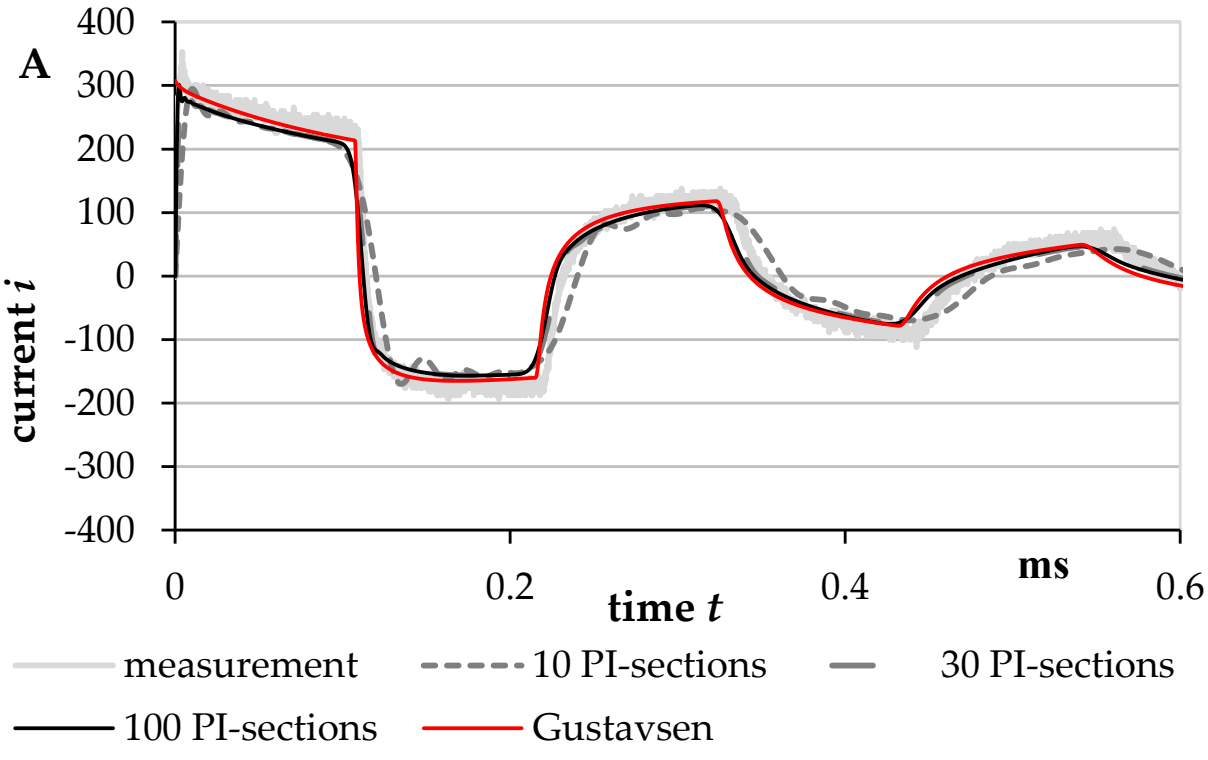
03 Model Verification

Results



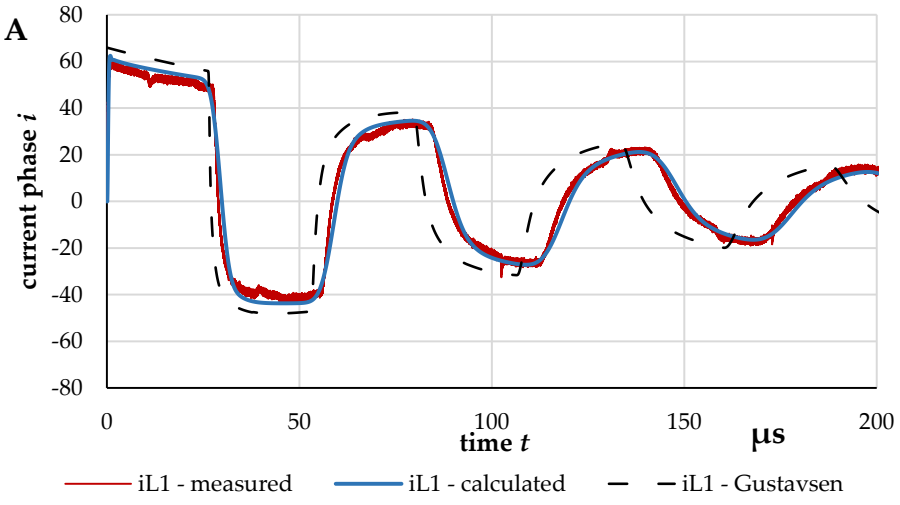
03 Model Verification

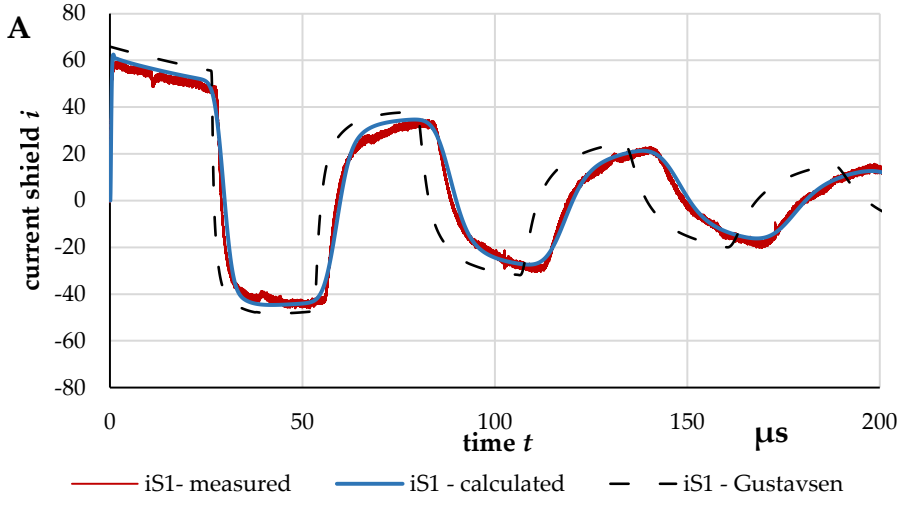
Results - Comparison to Gustavsen model

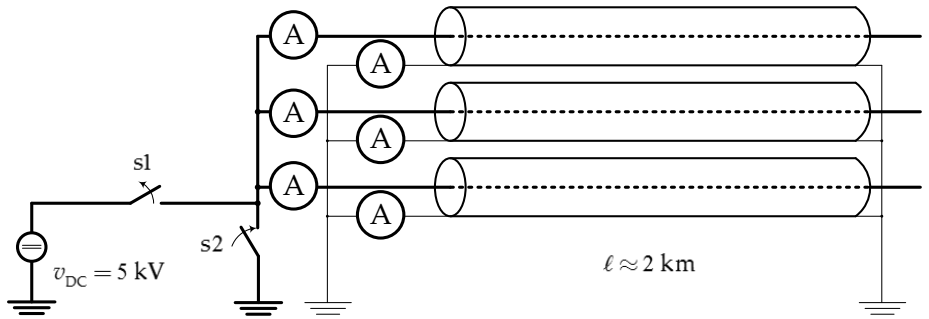


03 Model Verification

3phase measurements - phase/shields







04 Conclusions

Model

1. **Calculation of frequency-dependent cable parameters**
   - Advanced subconductor method: frequency range $f \leq 5\,\mathrm{MHz}$
   - Consideration of current distribution in cores, shields and earth
   - Handover in form impedance and admittance matrices

2. **3phase wave propagation cable model**
   - Based on PI section
   - Frequency-dependent RLC-elements in all PI-sections
   - Mathematical stable, relatively fast

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