Calculation of Cable Parameters for Different Cable Shapes

Comsol Conference 2008, Hannover, Germany

Hannover,
05.Nov.2008

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Høgskolen i Telemark

Calculation of Cable Parameters for Different Cable Shapes

- Motivation
- Point of focus (transmission lines)
- Approach of estimating parameters using COMSOL Multiphysics
- Verification
- Conclusions

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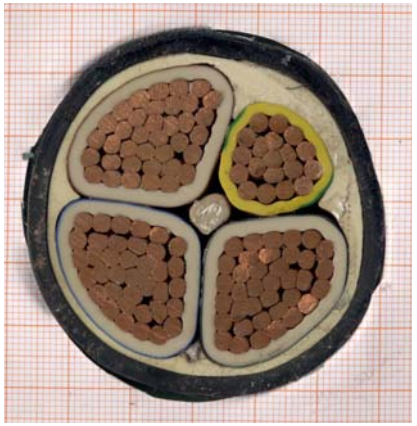
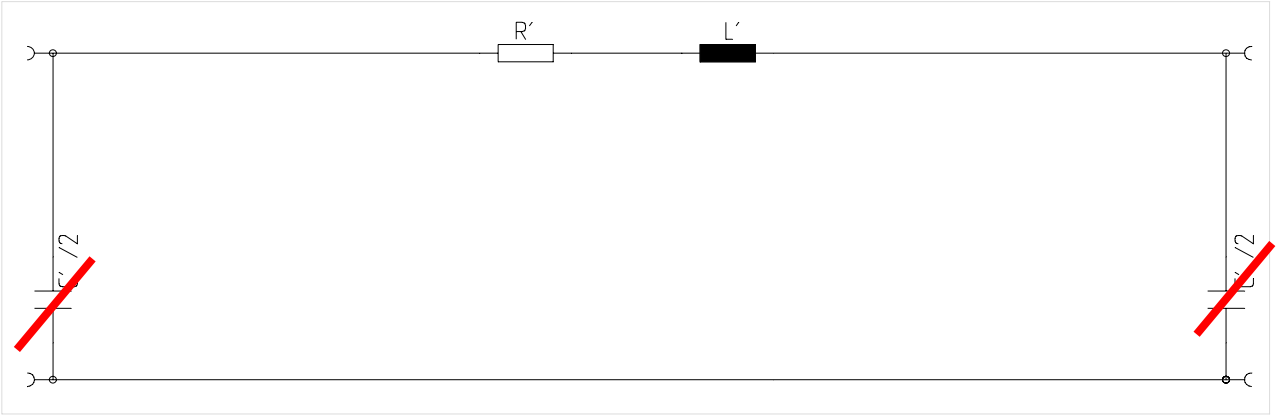
Established

- Conventional power flow analysis for the fundamental component
- Considering balanced load
  - Single phase equivalent circuit diagram

model and available parameters





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- Embedded generation, mainly based on wind-power, has achieved higher level of penetration → scattered harmonic excitation
  - Demand on Higher Harmonic Analysis Methods (scientific work):
    - Resonance mode analysis
      - All-phase and full-state dynamic models
      - For all Power System Components (generator,motor, lines, transformer, reactor, cap-banks) involved in Harmonic Resonance-Phenomena

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Validation of Harmonic-Analysis Methodology in Laboratory-Scale

1. Synchronous Generator
2. Generator Protection
3. Transformer

...

5. Line Segments and Busses

...

8. SCADA (Siemens WinCC)
9. Tap Changeable Transformer
14. Transient Grid Analyser

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- Embedded generation, mainly based on wind-power, has achieved higher level of penetration → scattered harmonic excitation
  - Demand on Higher Harmonic Analysis Methods (scientific work):
    - Manufacturers also require such detailed knowledge for customer fulfillment

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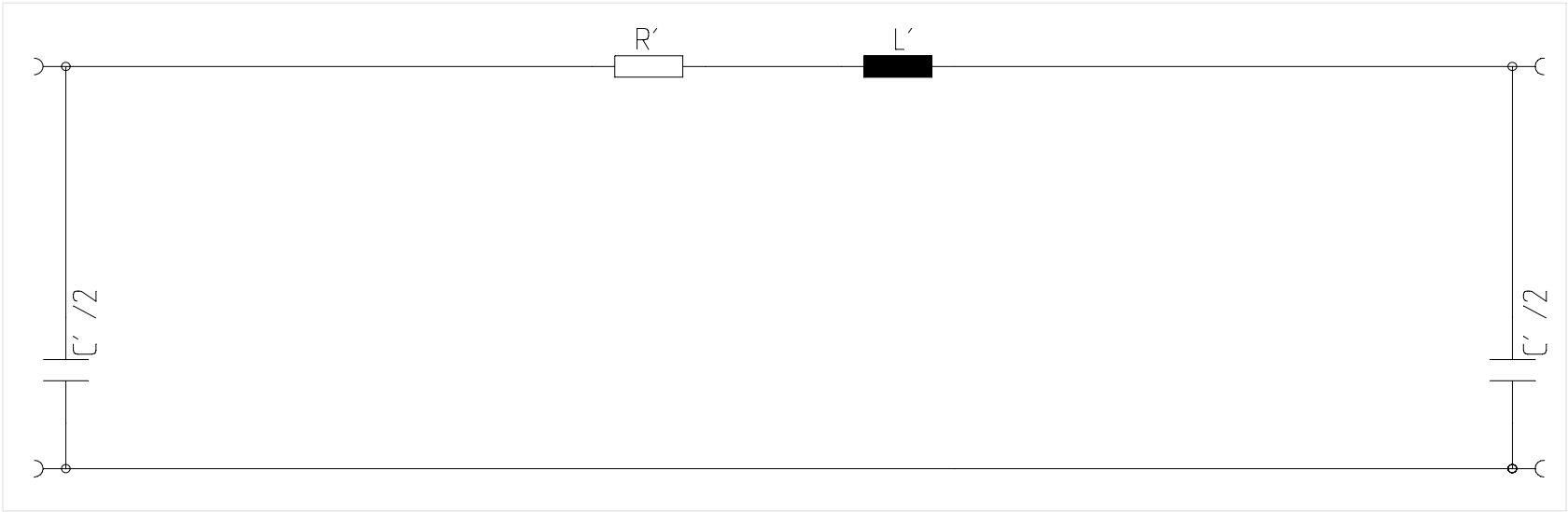

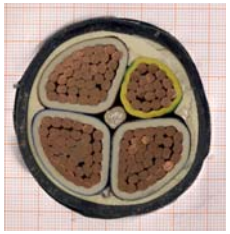

- R‘ L‘ C‘ → R‘(f) L‘(f) C‘(f)

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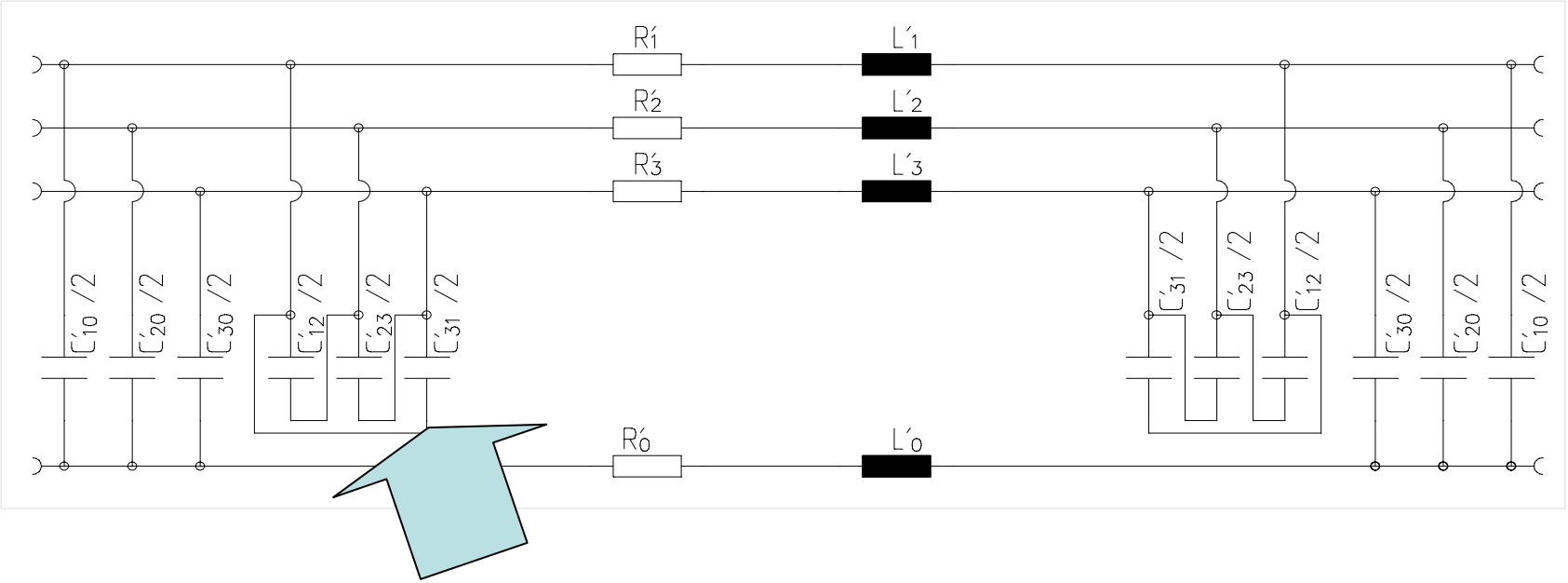

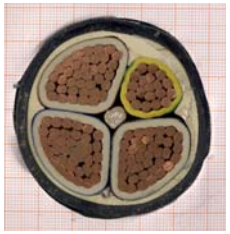

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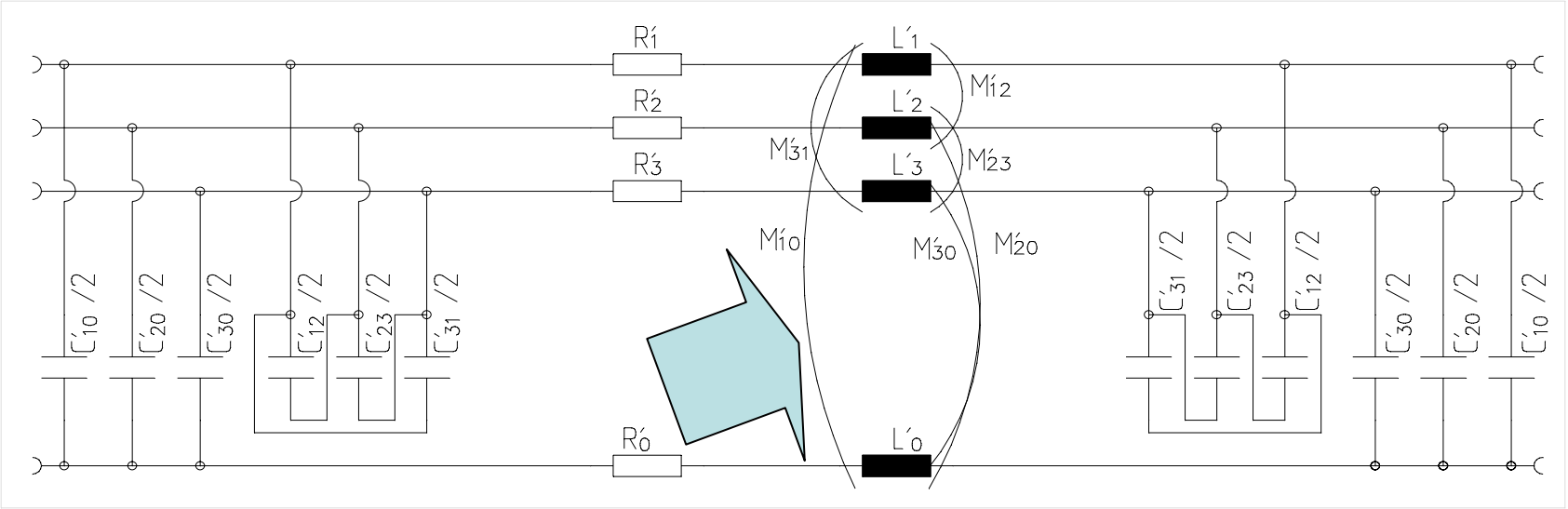

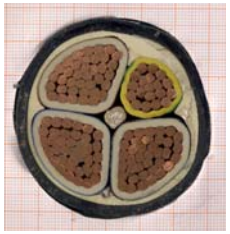

$$\begin{bmatrix} R'_1+L'_1 & M'_{12} & M'_{13} & M'_{10} \\ M'_{21} & R'_2+L'_2 & M_{23} & M'_{40} \\ M'_{31} & M'_{32} & R_3+L_3 & M'_{30} \\ M'_{01} & M'_{02} & M_{03} & R'_0+L'_0 \end{bmatrix}$$

- skin and proximity effect R‘(f) L‘(f)

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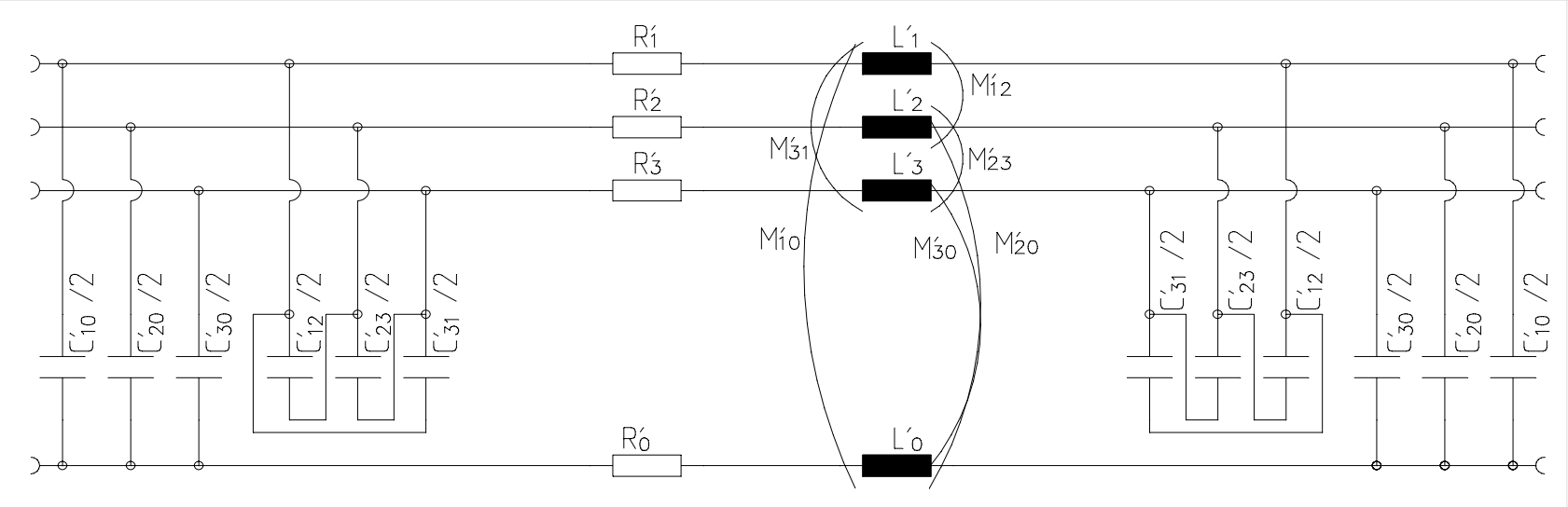

R‘ L‘ C‘ → R‘(f) L‘(f) C‘(f)

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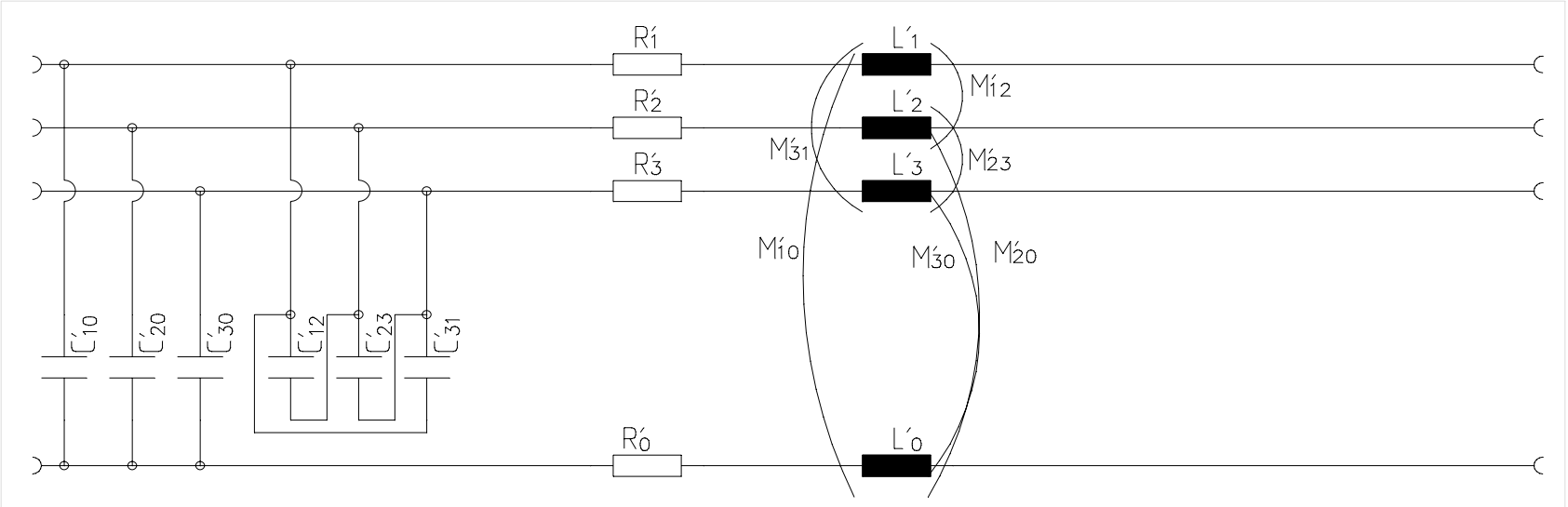

R‘ L‘ C‘ → R‘(f) L‘(f) C‘(f)

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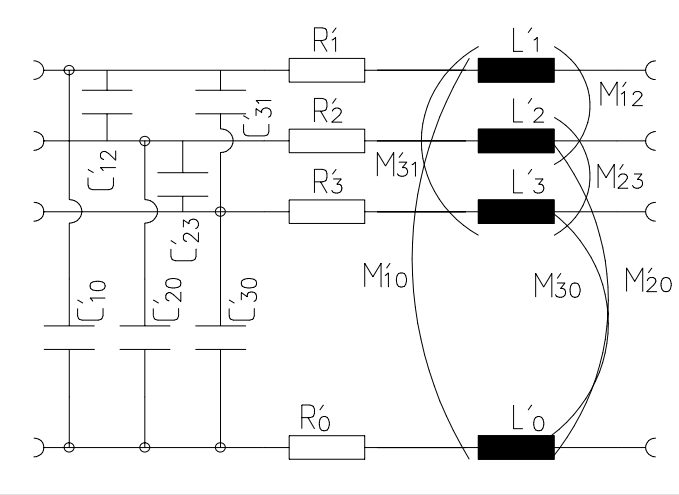
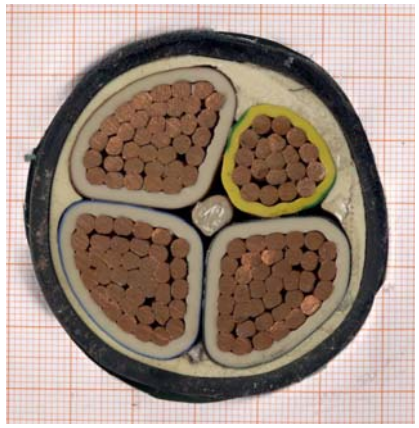
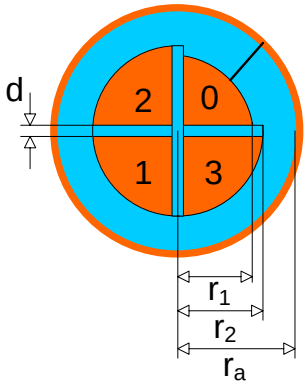


calculation of the cable parameters with two separat steps

- Capacitances using „Electrostatic“ modul
- Resistances and Inductances using “AC-Electromagnetic” modul





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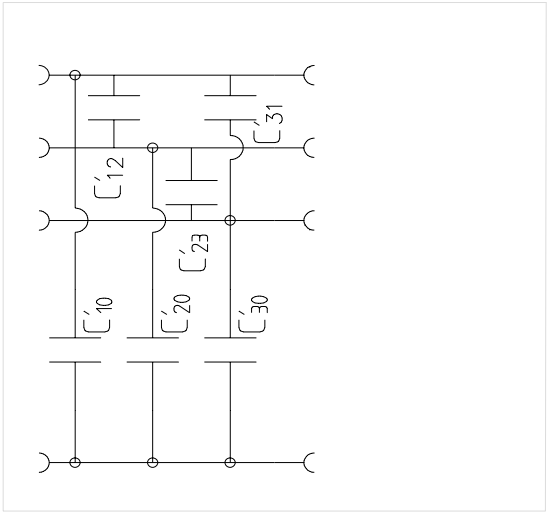

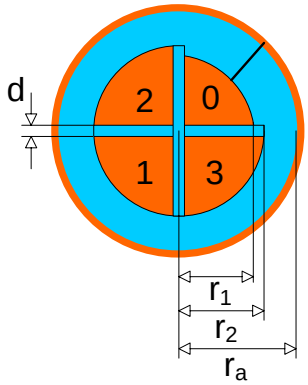

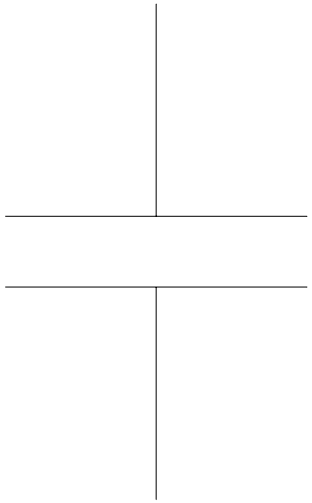

$$W = \frac{1}{2} C \bullet U^2$$

$$C = \frac{2}{U^2} \bullet W$$

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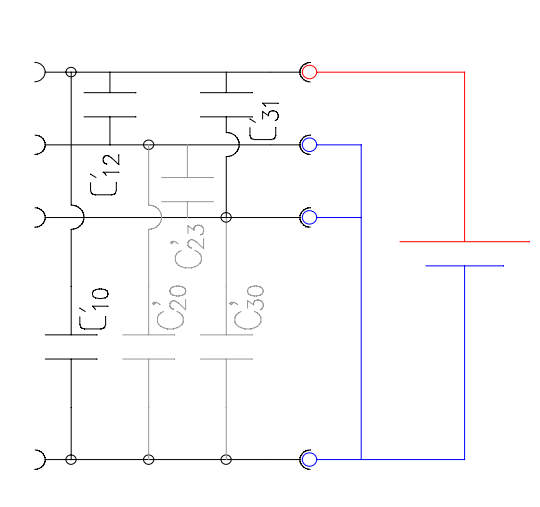

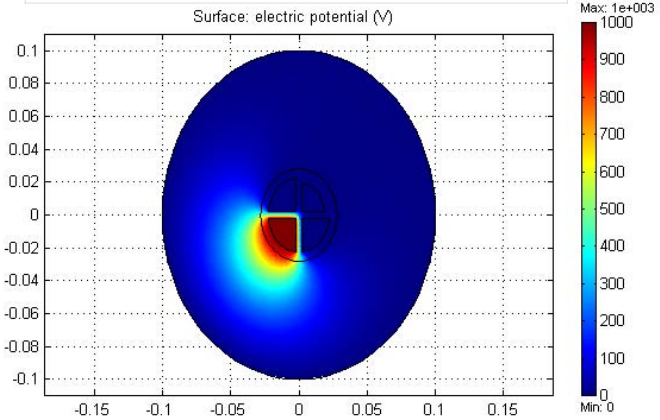

$$\begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 1 \\ & & & & & \\ & & & & & \\ & & & & & \\ & & & & & \\ & & & & & \end{bmatrix} \bullet \begin{bmatrix} C_{10} \\ C_{30} \\ C_{30} \\ C_{12} \\ C_{23} \\ C_{31} \end{bmatrix} = \frac{2}{U^2} \begin{bmatrix} W_{e1} \\ \\ \\ \\ \\ \end{bmatrix}$$

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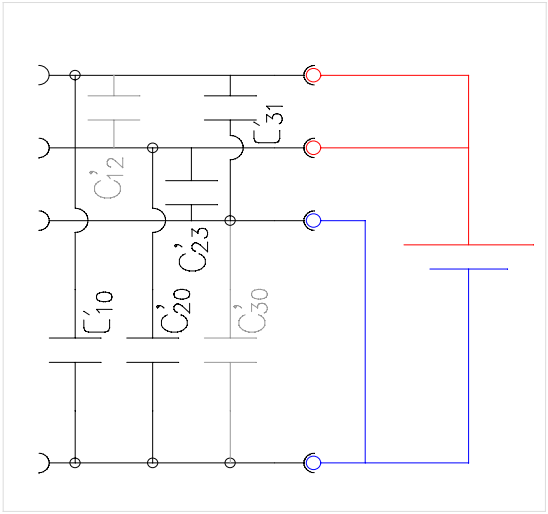

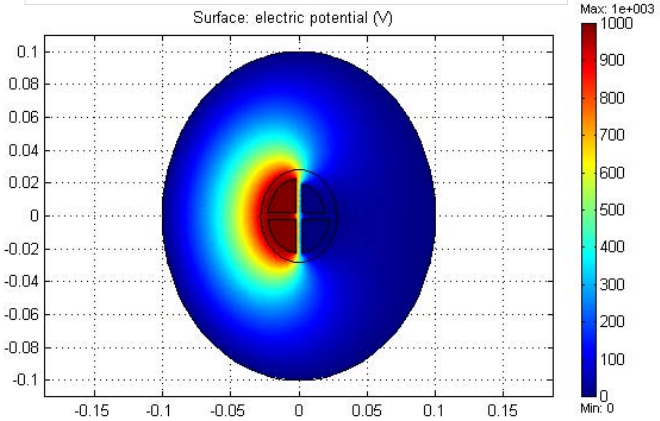

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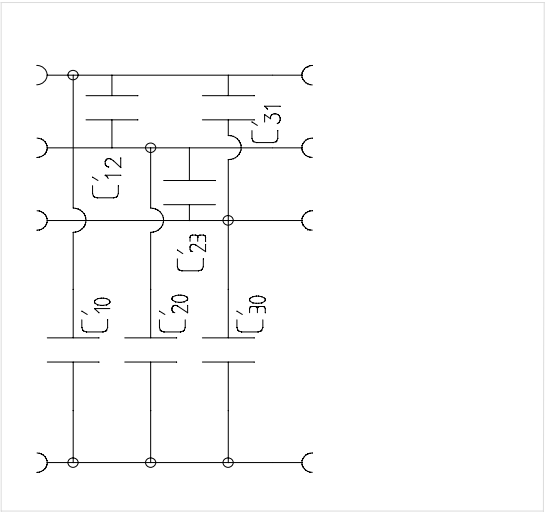

$$\begin{pmatrix} C'_{10} \\ C'_{20} \\ C'_{30} \\ C'_{12} \\ C'_{23} \\ C'_{31} \end{pmatrix} = \begin{pmatrix} 146 \\ 17.4 \\ 146 \\ 147 \\ 147 \\ 7.24 \end{pmatrix} \frac{nF}{km}$$

$$\begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 1 & 0 & 1 \\ 1 & 0 & 1 & 1 & 1 & 0 \end{bmatrix} \bullet \begin{bmatrix} C_{10} \\ C_{30} \\ C_{30} \\ C_{12} \\ C_{23} \\ C_{31} \end{bmatrix} = \frac{2}{U^2} \begin{bmatrix} W_{e1} \\ W_{e2} \\ W_{e3} \\ W_{e4} \\ W_{e5} \\ W_{e6} \end{bmatrix}$$

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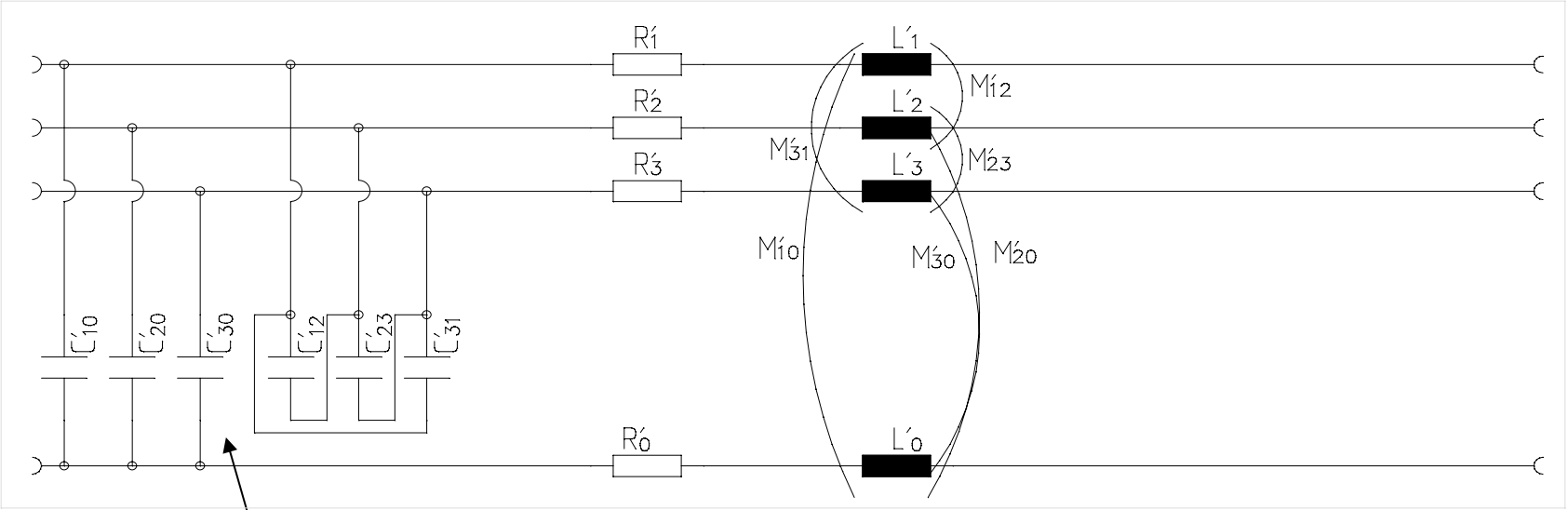

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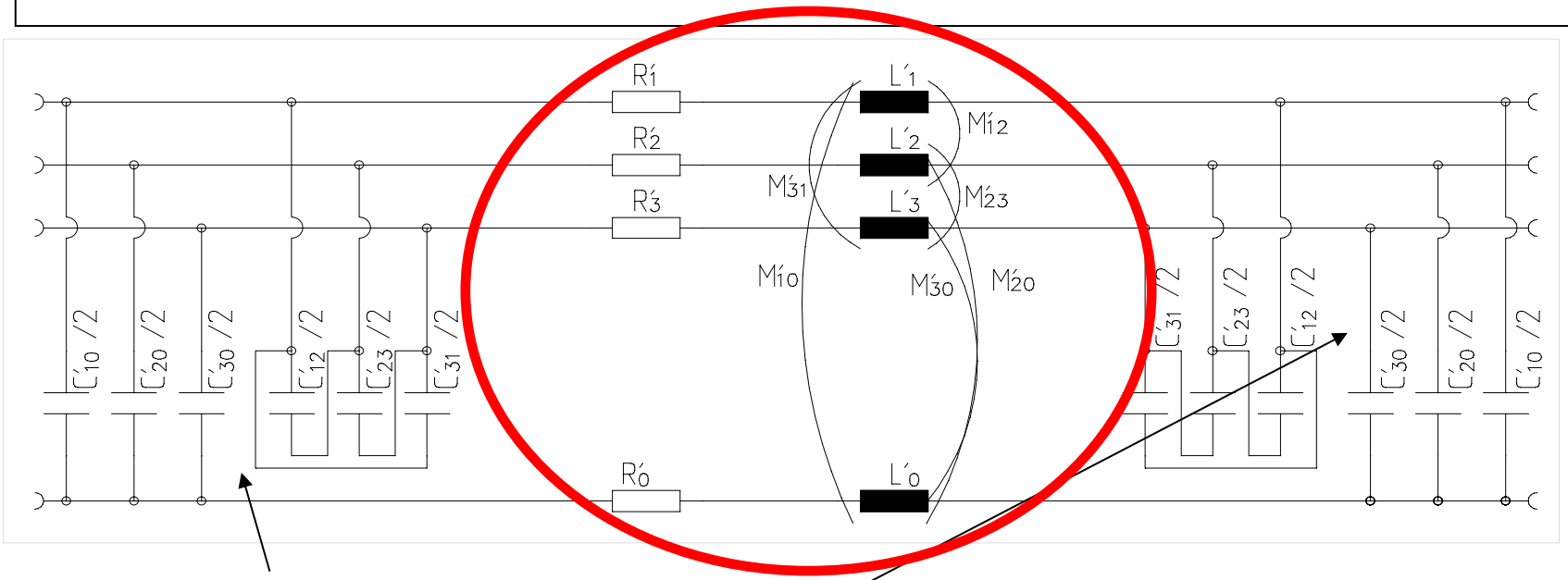

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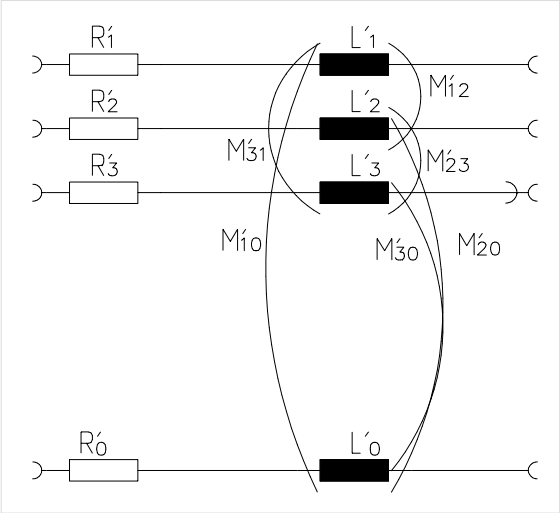

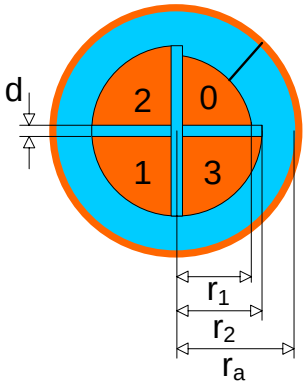

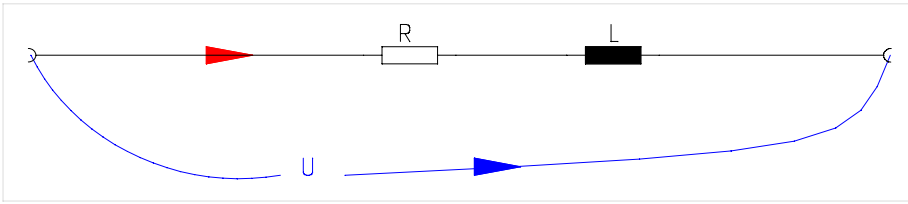

$$\underline{Z} = \frac{\underline{U}}{\underline{I}}$$

$$\underline{Z} = \underline{R} + j\omega\underline{L}$$

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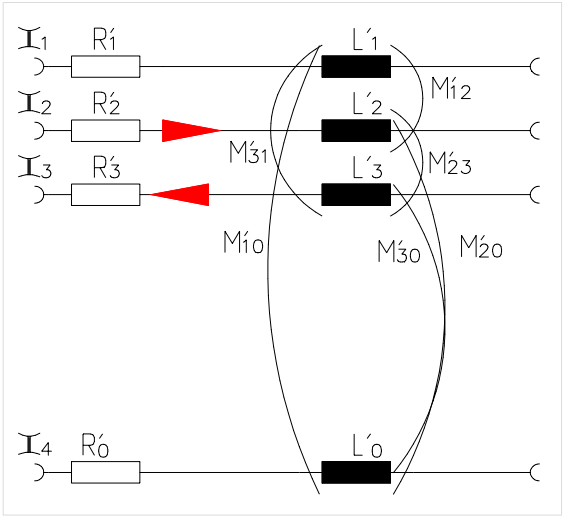

$$I\_ist2 = \iint \vec{S} d\vec{A} = -I\_ist3$$

side condition

Global Equations

Equation: f(u, ut, utt, t) = 0

States | Weak

Name (u)	Equation f(u,ut,utt,t)	Ini
U_err3	-I_ist3-I_soll	0
U_err2	I_ist2-I_soll	0

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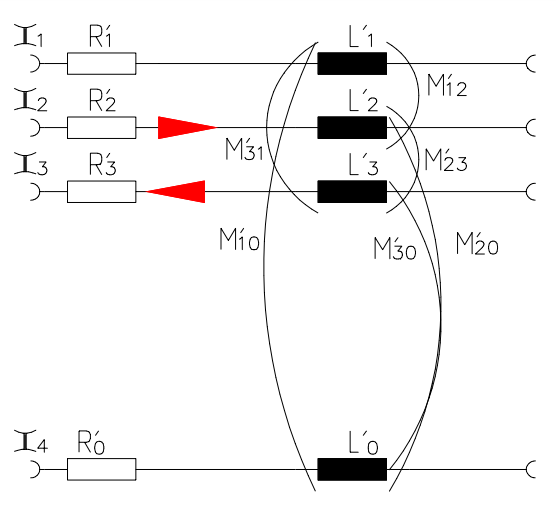
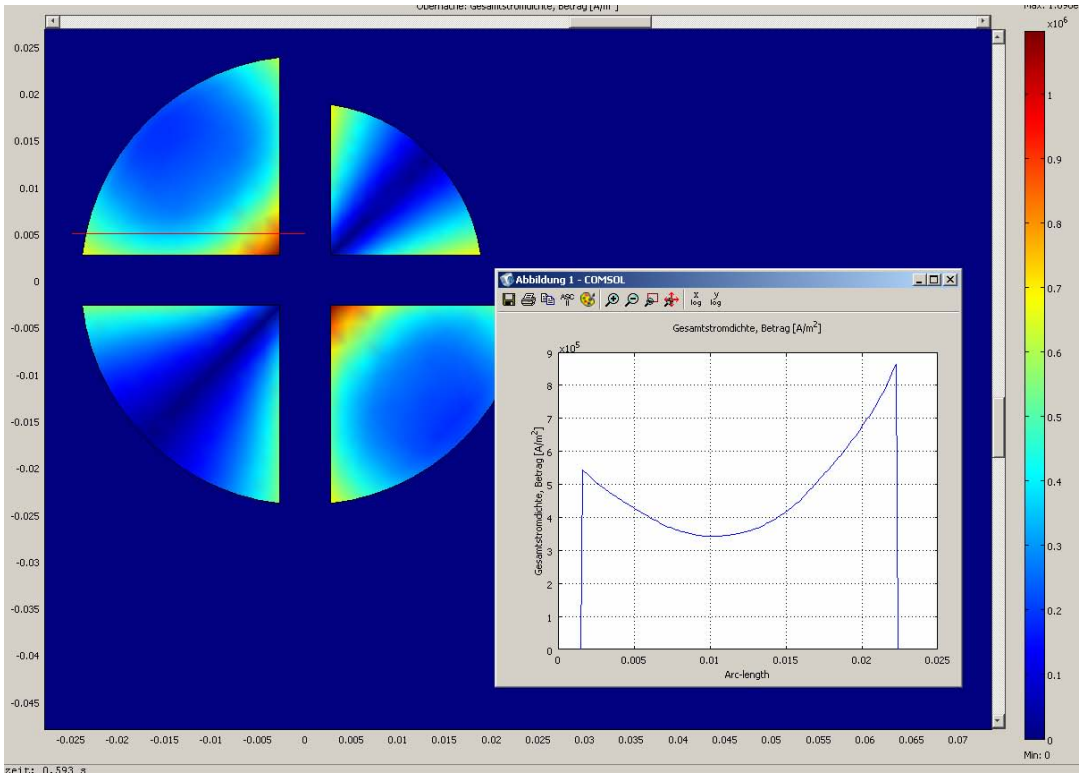


$$I\_ist2 = \iint \vec{S} d\vec{A} = -I\_ist3$$



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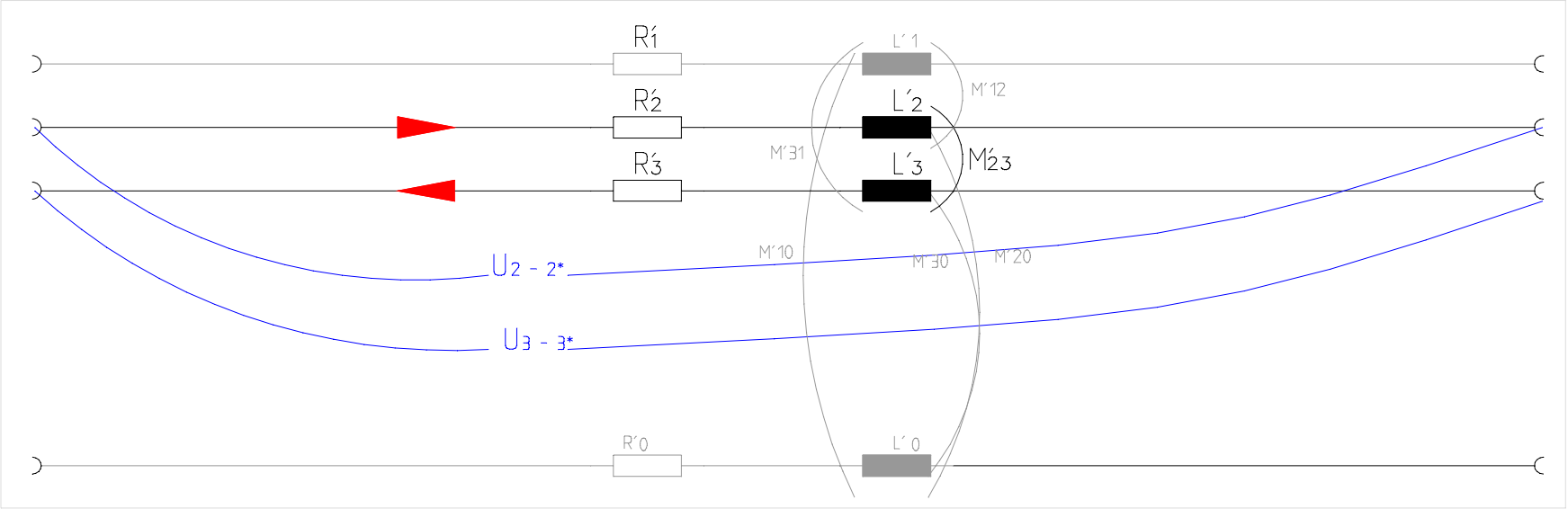

$$U_k = \left(R_k + j\omega L_k\right) I_k + \sum_{\substack{l=0 \\ l \neq k}}^{3} M_k I_l$$

$$U_{2-2^*} = I_2\left(R_2\right) + j\omega I_2\left(L_2\right) - j\omega I_1\left(M_{12}\right) - j\omega I_3\left(M_{23}\right) - j\omega I_0\left(M_{20}\right)$$

$$U_{3-3^*} = I_3\left(R_3\right) + j\omega I_3\left(L_3\right) - j\omega I_1\left(M_{13}\right) - j\omega I_2\left(M_{23}\right) - j\omega I_0\left(M_{30}\right)$$

case $I_1 = I_0 = 0$

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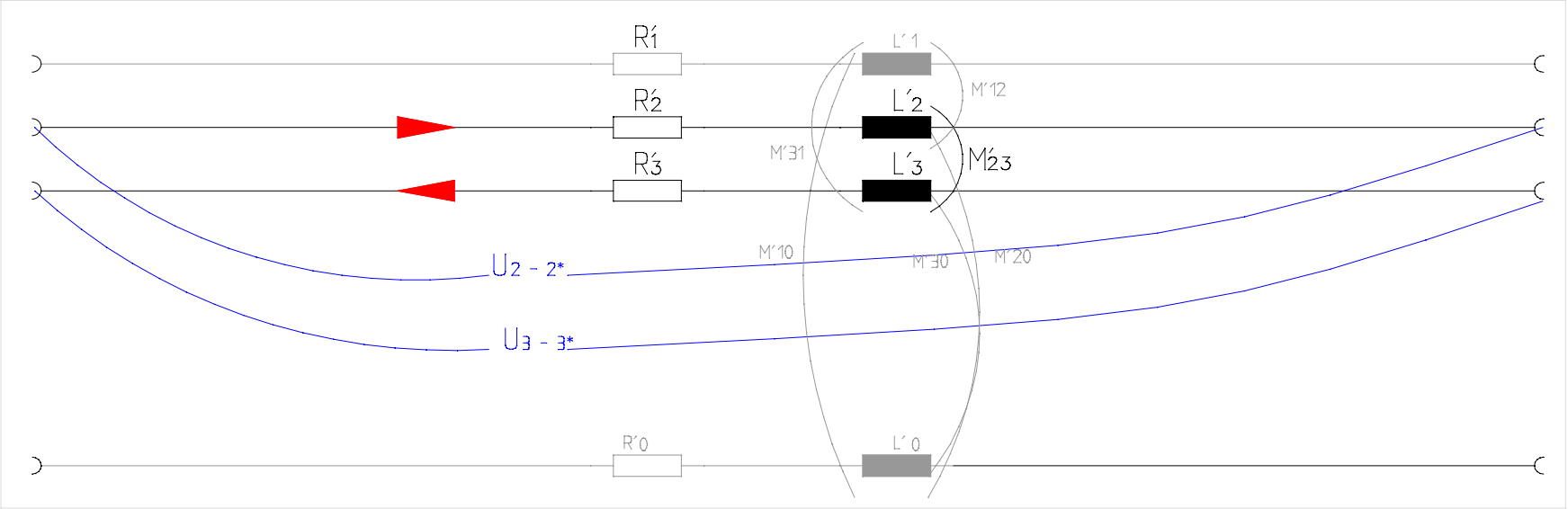

$$Z_{2-2^*} = \frac{U_{2-2^*}}{I_2} = R_2 + j\omega(L_2 - M_{23}) = \frac{U\_err2}{I\_ist2}$$

$$Z_{3-3^*} = \frac{U_{3-3^*}}{I_3} = R_3 + j\omega(L_3 - M_{23}) = \frac{U\_err3}{I\_ist3}$$

case $I_1=I_0=0$

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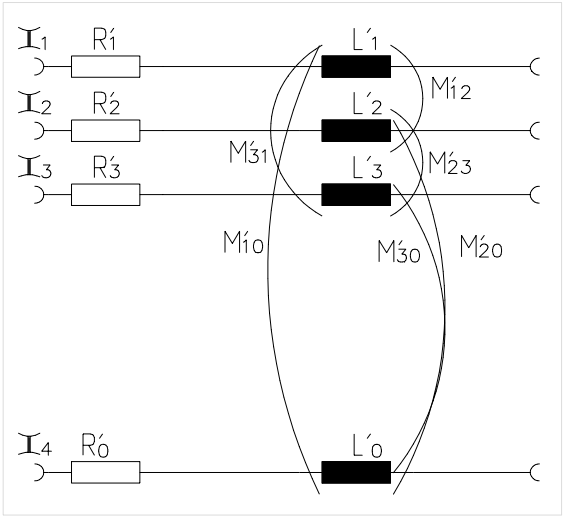

$$\begin{bmatrix} R_1 + j\omega L_1 & j\omega M_{12} & j\omega M_{13} & j\omega M_{20} \\ j\omega M_{21} & R_2 + j\omega L_2 & j\omega M_{23} & j\omega M_{40} \\ j\omega M_{31} & j\omega M_{32} & R_3 + j\omega L_3 & j\omega M_{30} \\ j\omega M_{01} & j\omega M_{02} & j\omega M_{03} & R_0 + j\omega L_0 \end{bmatrix}$$

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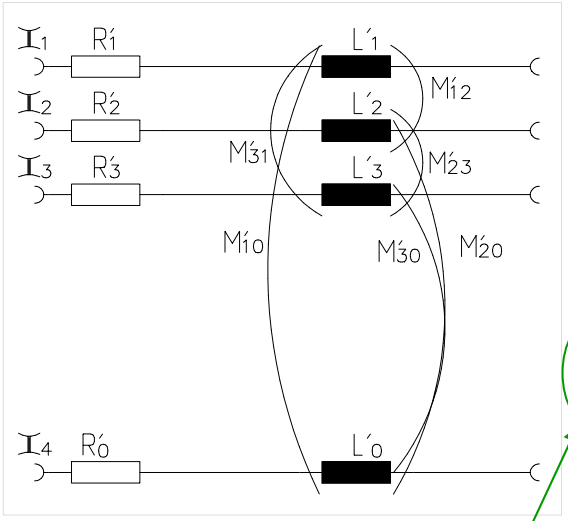

$$I \bullet \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \bullet \begin{bmatrix} R_1 + j\omega L_1 \\ -j\omega M_{12} \\ -j\omega M_{13} \\ -j\omega M_{10} \\ R_2 + j\omega L_2 \\ -j\omega M_{23} \\ -j\omega M_{20} \\ R_3 + j\omega L_3 \\ -j\omega M_{30} \\ R_0 + j\omega L_0 \end{bmatrix} = \begin{bmatrix} U_1 \\ U_1 \\ U_1 \\ U_2 \\ U_2 \\ U_2 \\ U_3 \\ U_3 \\ U_3 \\ U_0 \end{bmatrix}$$

Global Equations

Equation: f(u, ut, utt, t) = 0

States | Weak

Name (u)	Equation f(u,ut,utt,t)	Ini
U_err3	-I_ist3-I_soll	0
U_err2	I_ist2-I_soll	0

Postprocessing/

Global Variables

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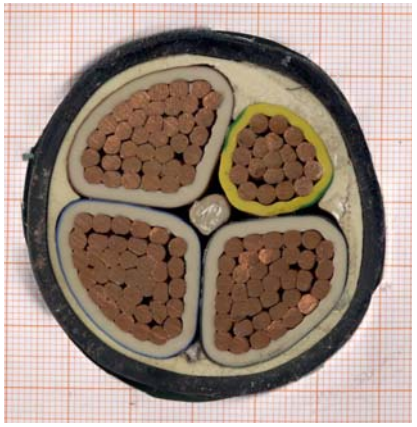

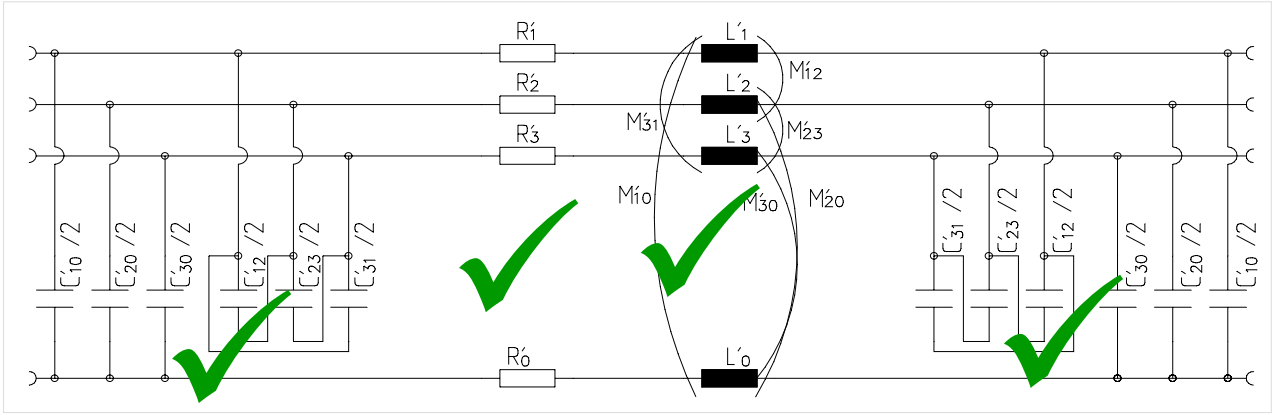

Comsol Multiphysics program and the modules

„Electrostatic“

„AC Electromagnetic“

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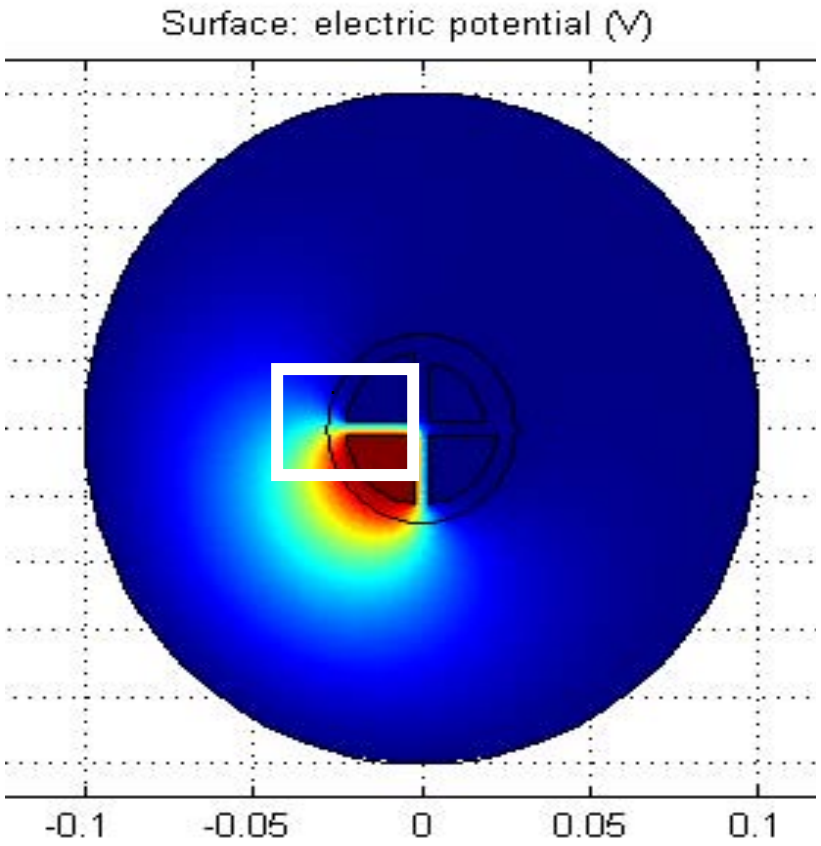
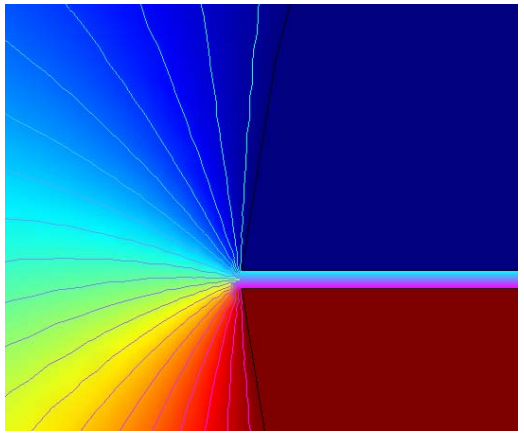
- Motivation
- Point of focus (transmission lines)
- Approach of estimating parameters using Multiphysics
- Verification
- Conclusions

Calculation of Cable Parameters for Different Cable Shapes





$$d = 5.7mm \rightarrow d_{Kontr} = 0.2mm$$

$$\frac{W_{Kontr}}{W_{FemLab}} = \frac{2.150 \cdot 10^{-3}\ \text{Ws/m}}{2.205 \cdot 10^{-3}\ \text{Ws/m}}$$

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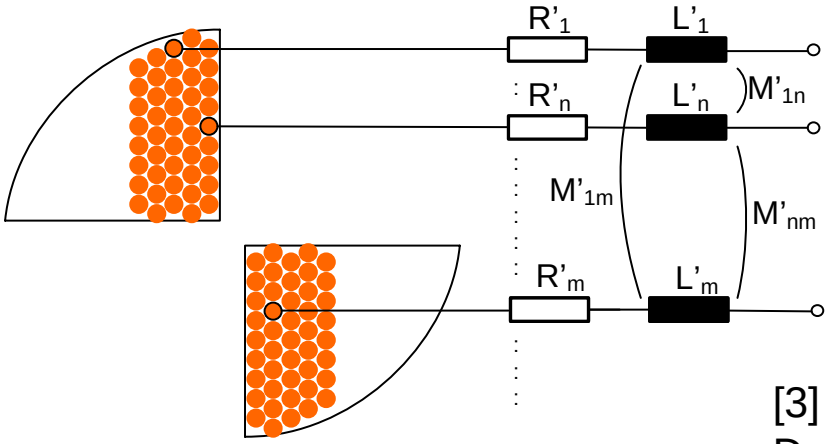

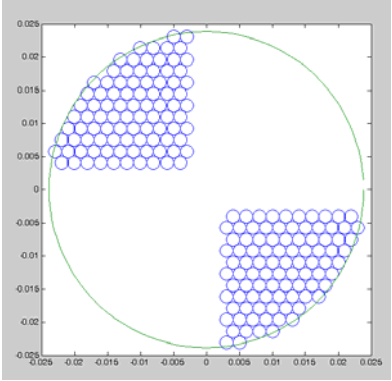

[3] Jung-Hsiang Wang; Modeling of Frequency-Dependent Impedance of the Third Rail Used in Traction Power Systems, IEEE Trans. on Power Delivery, Vol. 15, No. 2, April 2000

[4] Alexander W. Barr; Calculation of Frequen-cy-Dependent Impedance for Conductors of Rec-tangular Cross Section, AMP Journal of Techno-logy Vol. 1 November, 1991

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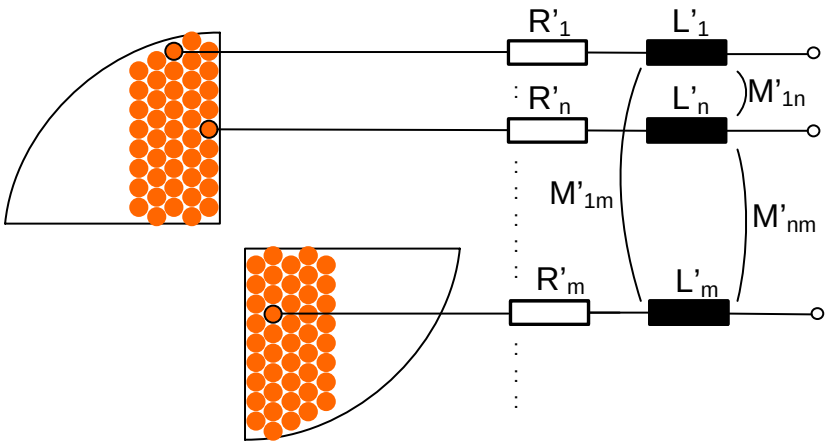

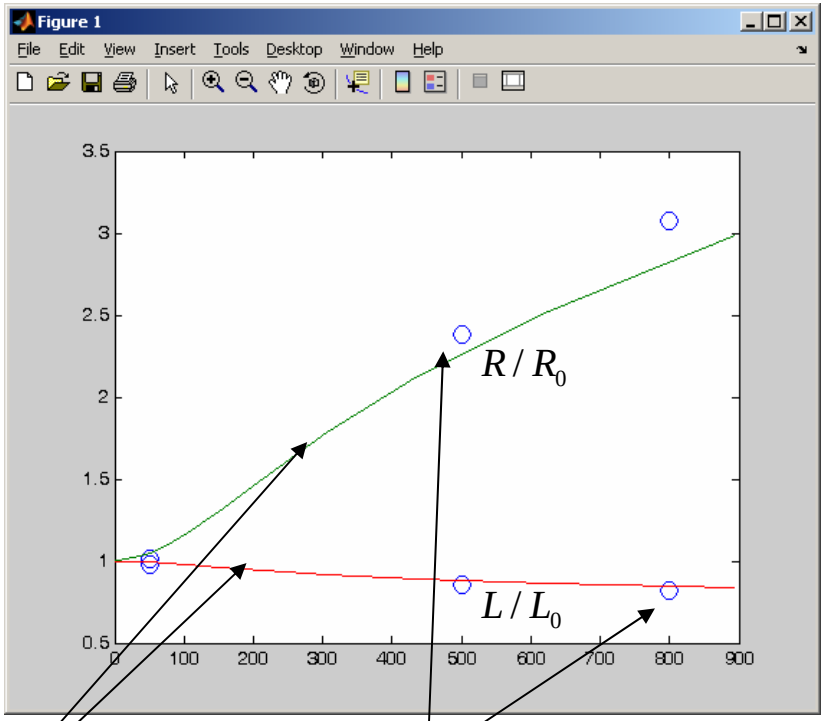

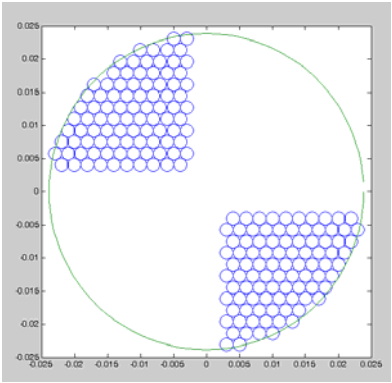

o Results Femlab

- Results Partial wire method

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- Comsol Multiphysics modules „Electrostatic“ and „AC Electromagnetic“
  - enable us to characterize the electrical parameters of cables for different frequencies
  - Impedance values can be verified
    - using partial wire methods for inductances
    - simplified ideal models for capacitances
  - helpfull for scientific and industrial work