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Low frequency mutual inductive interference of cable systems

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Graz, 06th. December 2019

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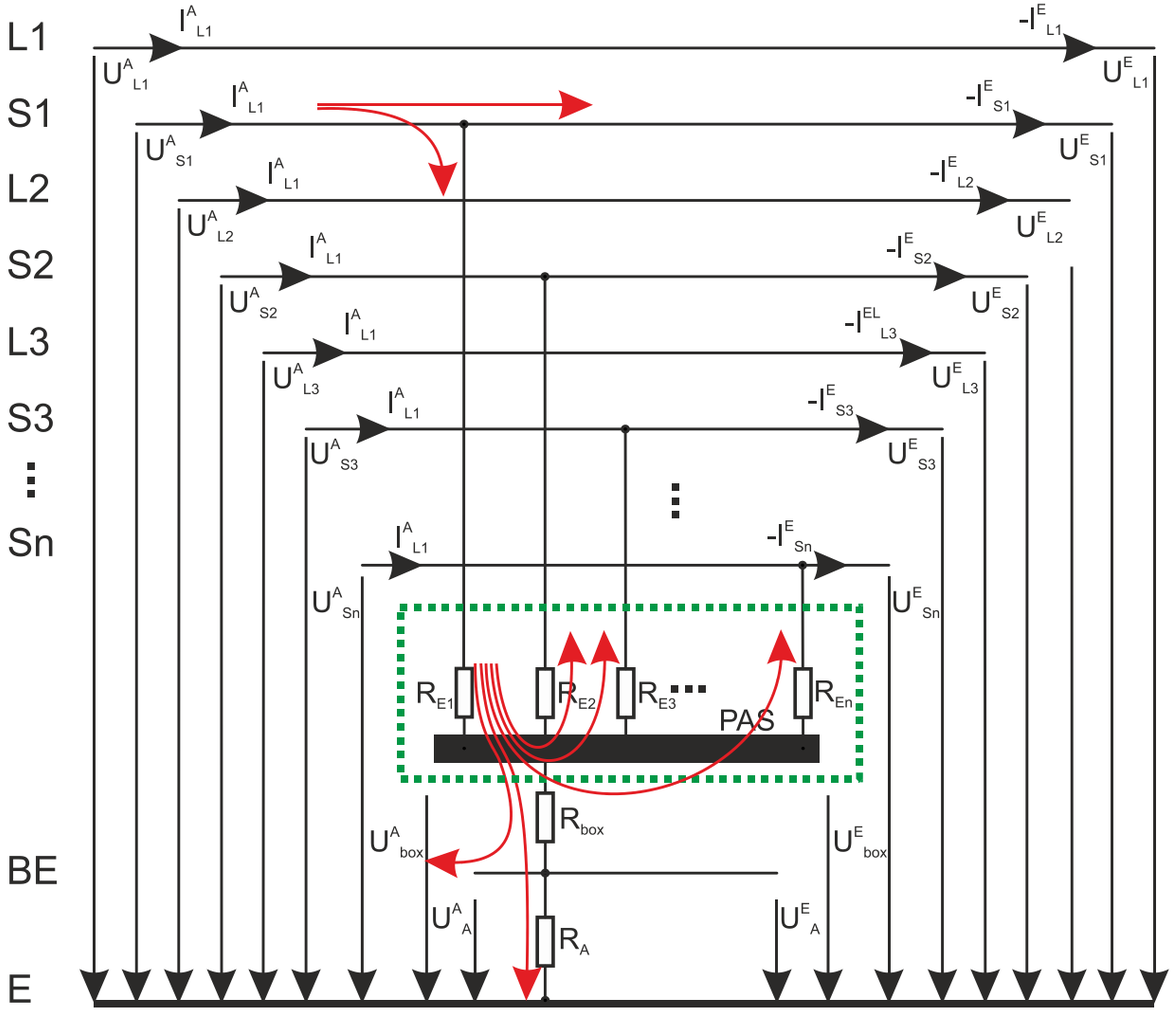
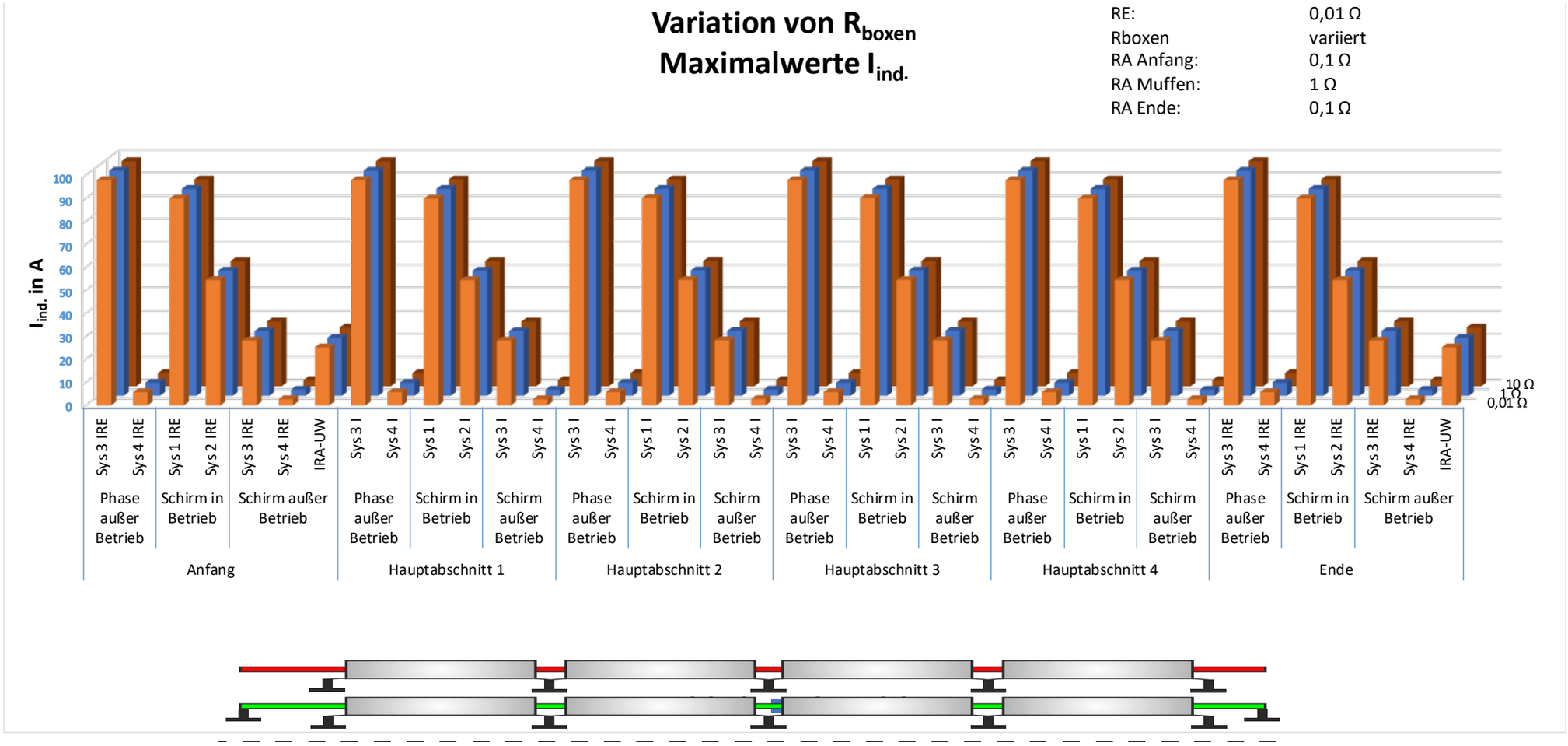
Modelling of joints and grounding sections



$$\begin{pmatrix} \begin{pmatrix} U^A_{L1} \\ U^A_{S1} \\ U^A_{L2} \\ U^A_{S2} \\ U^A_{L3} \\ U^A_{S3} \\ \vdots \\ U^A_{Sn} \\ U^A_{box} \\ U^A_{RA} \end{pmatrix} \\ \begin{pmatrix} I^A_{L1} \\ I^A_{S1} \\ I^A_{L2} \\ I^A_{S2} \\ I^A_{L3} \\ I^A_{S3} \\ \vdots \\ I^A_{Sn} \\ I^A_{RboxL} \\ I^A_{RAL} \end{pmatrix} \end{pmatrix} = \begin{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & \cdots & & & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & \cdots & & & \\ 0 & 0 & 1 & 0 & 0 & 0 & \cdots & & & \\ 0 & 0 & 0 & 1 & 0 & 0 & \cdots & & & \\ 0 & 0 & 0 & 0 & 1 & 0 & \cdots & & & \\ 0 & 0 & 0 & 0 & 0 & 1 & & & & \\ \vdots & \vdots & \vdots & \vdots & \vdots & & \ddots & & & \\ & & & & & & & & & \\ & & & & & & & & & 0 \\ 0 & & & & & & & 0 & 1 & \end{bmatrix} & \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & & & \\ & & & & & & & & & \\ & & & & & & & & & 0 \\ 0 & & & & & & & 0 & 0 & \end{bmatrix} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\ 0 & \frac{1}{R_{E1}} & 0 & 0 & 0 & 0 & \cdots & & -\frac{1}{R_{E1}} & \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\ 0 & 0 & 0 & \frac{1}{R_{E2}} & 0 & 0 & \cdots & & -\frac{1}{R_{E2}} & \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & & & \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{R_{E3}} & \cdots & & -\frac{1}{R_{E3}} & \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & & & & \\ & & & & & & & & & \\ & & & & & & & & & \\ & -\frac{1}{R_{E1}} & & -\frac{1}{R_{E2}} & & -\frac{1}{R_{E3}} & & \frac{1}{R_{box}}+\frac{1}{R_{E1}}+\frac{1}{R_{E2}}+\frac{1}{R_{E3}} & & -\frac{1}{R_{box}} \\ 0 & & & & & & & & -\frac{1}{R_{box}} & \frac{1}{R_{box}}+\frac{1}{R_A} \end{bmatrix} & \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & \cdots & & & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & \cdots & & & \\ 0 & 0 & 1 & 0 & 0 & 0 & \cdots & & & \\ 0 & 0 & 0 & 1 & 0 & 0 & \cdots & & & \\ 0 & 0 & 0 & 0 & 1 & 0 & \cdots & & & \\ 0 & 0 & 0 & 0 & 0 & 1 & & & & \\ \vdots & \vdots & \vdots & \vdots & \vdots & & \ddots & & & \\ & & & & & & & & & \\ & & & & & & & & & 0 \\ 0 & & & & & & & 0 & 1 & \end{bmatrix} \end{bmatrix} \begin{pmatrix} \begin{pmatrix} U^E_{L1} \\ U^E_{S1} \\ U^E_{L2} \\ U^E_{S2} \\ U^E_{L3} \\ U^E_{S3} \\ \vdots \\ U^E_{Sn} \\ U^E_{box} \\ U^E_{RA} \end{pmatrix} \\ \begin{pmatrix} -I^E_{L1} \\ -I^E_{S1} \\ -I^E_{L2} \\ -I^E_{S2} \\ -I^E_{L3} \\ -I^E_{S3} \\ \vdots \\ -I^E_{Sn} \\ -I^E_{RboxL} \\ -I^E_{RAL} \end{pmatrix} \end{pmatrix}$$

$$\begin{pmatrix} \underline{U_{L,S}}^A \\ \underline{I_{L,S}}^A \end{pmatrix} = \begin{bmatrix} E_n & N_n \\ A_n & E_n \end{bmatrix} \begin{pmatrix} \underline{U_{L,S}}^E \\ -\underline{I_{L,S}}^E \end{pmatrix}$$

Induced current distribution – 4 three-phase systems – 2 systems out of operation



Phase and cable shield currents – 4 three-phase systems, parallel laying and parallel operation

			Total currents	
Designation	Amplitude	Angle	Amplitude	Angle
Current in phase L1 of the three-phase cable system 1	77,14 A	-12,70 °	15,22 A	131,44 °
Current in phase L2 of the three-phase cable system 1	83,68 A	-141,13 °		
Current in phase L3 of the three-phase cable system 1	83,36 A	104,01 °		
Current in phase L1 of the three-phase cable system 2	80,01 A	-20,70 °	4,34 A	-110,33 °
Current in phase L2 of the three-phase cable system 2	77,75 A	-137,48 °		
Current in phase L3 of the three-phase cable system 2	79,09 A	103,94 °		
Current in phase L1 of the three-phase cable system 3	79,51 A	-18,29 °	3,92 A	93,68 °
Current in phase L2 of the three-phase cable system 3	75,24 A	-138,15 °		
Current in phase L3 of the three-phase cable system 3	81,47 A	103,99 °		
Current in phase L1 of the three-phase cable system 4	83,57 A	-21,22 °	16,31 A	-43,60 °
Current in phase L2 of the three-phase cable system 4	82,80 A	-136,45 °		
Current in phase L3 of the three-phase cable system 4	76,29 A	94,57 °		
Induced current in cable shield 1 of the three-phase cable system 1	19,36 A	-99,78 °	2,67 A	-175,38 °
Induced current in cable shield 2 of the three-phase cable system 1	30,77 A	110,66 °		
Induced current in cable shield 3 of the three-phase cable system 1	15,18 A	-40,82 °		
Induced current in cable shield 1 of the three-phase cable system 2	20,26 A	-97,12 °	1,25 A	-129,70 °
Induced current in cable shield 2 of the three-phase cable system 2	31,06 A	109,10 °		
Induced current in cable shield 3 of the three-phase cable system 2	15,66 A	-40,66 °		
Induced current in cable shield 1 of the three-phase cable system 3	19,95 A	-97,77 °	1,27 A	-172,38 °
Induced current in cable shield 2 of the three-phase cable system 3	31,36 A	109,03 °		
Induced current in cable shield 3 of the three-phase cable system 3	15,39 A	-40,76 °		
Induced current in cable shield 1 of the three-phase cable system 4	20,17 A	-95,99 °	1,09 A	-35,48°
Induced current in cable shield 2 of the three-phase cable system 4	30,47 A	109,31 °		
Induced current in cable shield 3 of the three-phase cable system 4	16,06 A	-35,54 °		

Summary (I)

- Key factors regarding mutual inducitve interference
  - Electrical symmetry of cable systems
    - Earthing resistances, section legth, clearances between conductors and between three-phase systems, transverse laying profile, consequent cross-bonding of cable shields and transposition of phases, number of sections divisible by three, same earthing resistances in all grounding sections
  - Influencing current
  - Geometric arrangement
  - Switching state
- Identified negligible factors regarding mutual inductive interference
  - Specific (electric) soil resistance
  - Laying depth
  - Cross-sectional area of cable shields and earth continuity conductors
  - Section and cable system length

Summary (II)

- Maximum earthing voltages are lower than 20 V
- During a single pole earth fault high (150 V) touch voltages can occur in neighbouring, switched-off systems
- In case of an single pole earth fault (without cross-bonding), up to 75% of the fault current flows through the faulty cable shield, even if there are several cable shields, earth continuity conductors and a very conductive soil
- Earth continuity conductors usually relieve cable shields, but can also lead to an increase in the induced currents
- Even with cable shields grounded on one side, a local deterioration of an earthing system leads to an increase in the cable shield voltage at the open end of the cable shield
- Without consideration of the mutual inductive interference during installation of cable lines, residual currents can occur in normal operation, which can lead to unwanted protection excitations and thus to false protection system trips of cable systems
- There is currently a gray area in Austria regarding standardization of undergroung cable systems
- Calculation model was verified by measurement results