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Resonance Analysis in Electrical Power Transmission Grids

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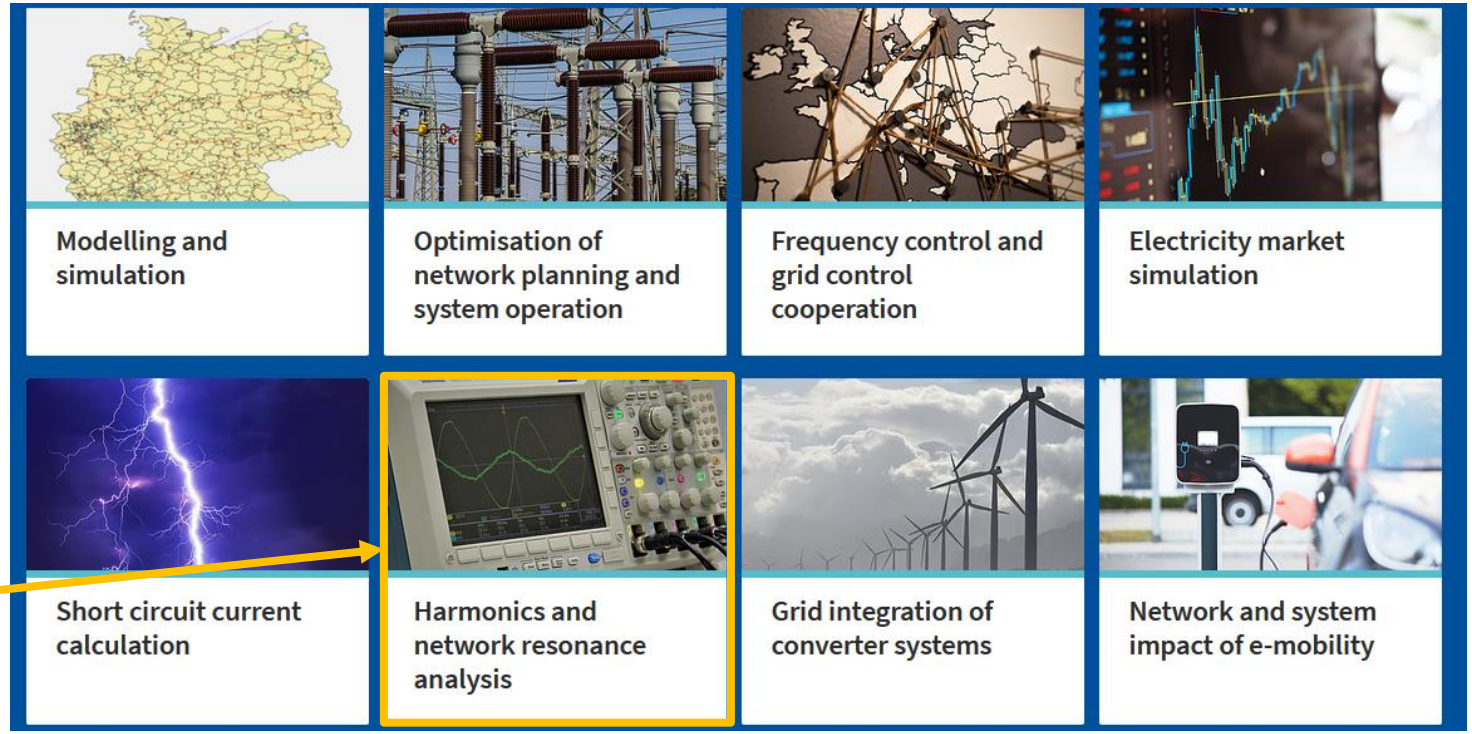
Institute of Electric Power Systems
Electric Power Engineering Section

- Associated with
  - Electric Energy Storage Systems Section
  - High Voltage Technology and Asset Management Section

- 14 researchers

- Main research topics
  - National projects
  - externally funded projects

Focussing on EHV/HV level



Agenda

- Motivation
- Resonance analysis methods
- Previous studies
- Outlook

Motivation

What drives our research?

➢ Grid resonances are expected to change

- Introduction of underground cables to the German EHV transmission grid, due to lack of residents' approval towards overhead lines
  - ➢ possess higher capacitive behaviour compared to OHL

- Increasing number of power electronic devices in EHV/HV level
  - ➢ Gain of nonlinearities and harmonic current injections

Normative framework

IEC TR 61000-3-6

- Indicative planning levels for harmonic distortion in transmission grids
- Allocation method of maximum harmonic voltage/current limits based on optimal utilization of these levels

➢ Specifications up to 50. harmonic order

VDE AR-N 4130/4120

- German technical guideline
- Defines binding basic rules for German network customers
- Allocation rule for maximum harmonic current limits

➢ Specifications up to 40. harmonic order

Analysis methods

Research aims:

- Allocation of harmonic current levels and voltage levels
- Analysis of resonance behaviour of transmission grids
- Effects of grid expansion and transformation
- Determination and improvement of modelling guidelines and analysis methods

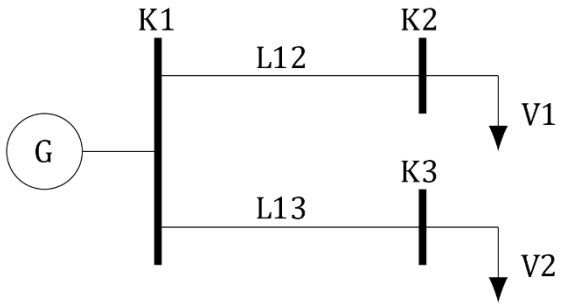
➢ Network resonance analysis methods
  - Frequency Scan Analysis
  - Resonance Mode Analysis
  - Participation Factors
  - Sensitivity Analysis

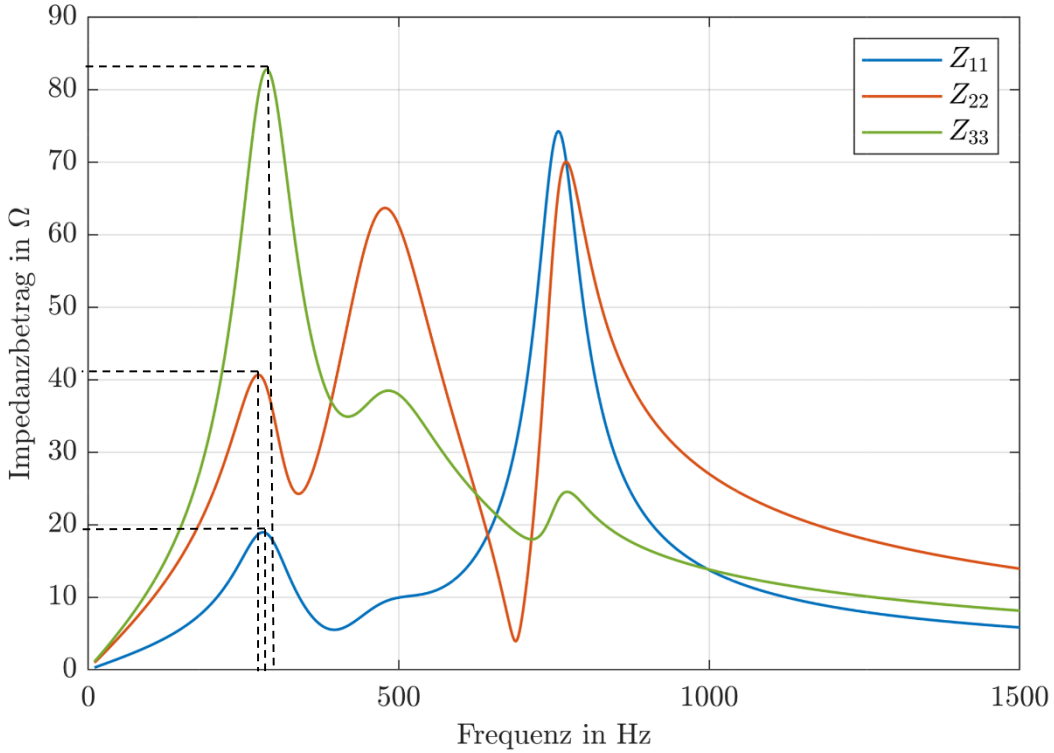
Analysis methods – Frequency Scan Analysis

- simple method of investigation
- examination of the diagonal elements of nodal impedance matrix

$$\underline{\boldsymbol{Y}}_{\mathrm{KK}}(\omega) = \begin{bmatrix} \underline{Y}_{11} & \underline{Y}_{12} & \cdots & \underline{Y}_{1n} \\ \underline{Y}_{21} & \underline{Y}_{22} & \cdots & \underline{Y}_{2n} \\ \vdots & \ddots & \ddots & \vdots \\ \underline{Y}_{n1} & \underline{Y}_{n2} & \cdots & \underline{Y}_{nn} \end{bmatrix}$$

Exemplary grid configuration:



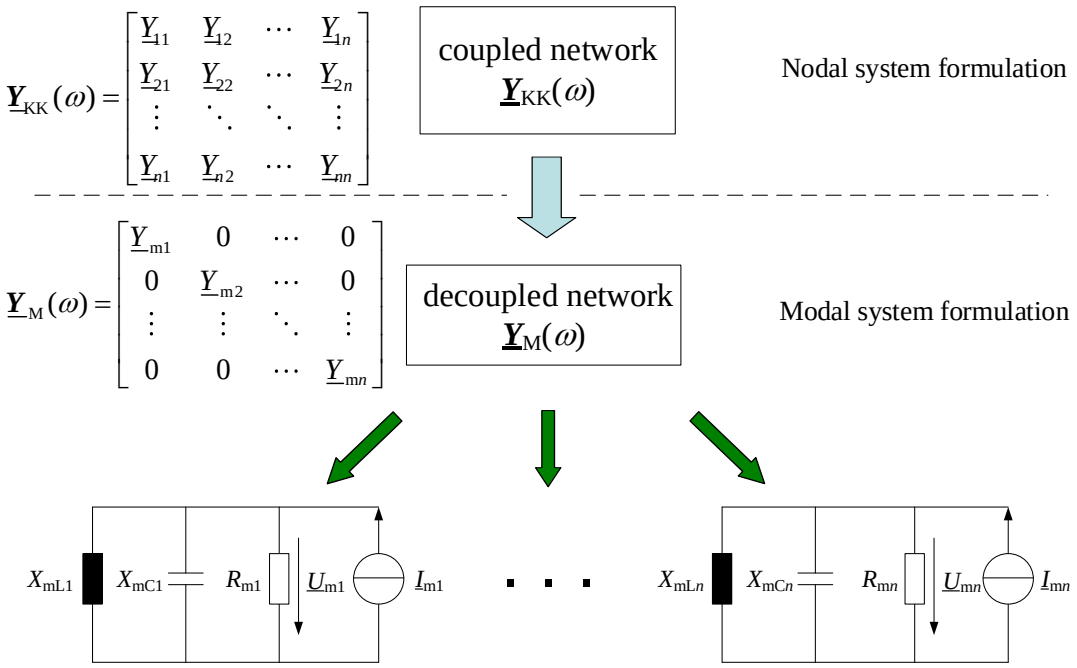


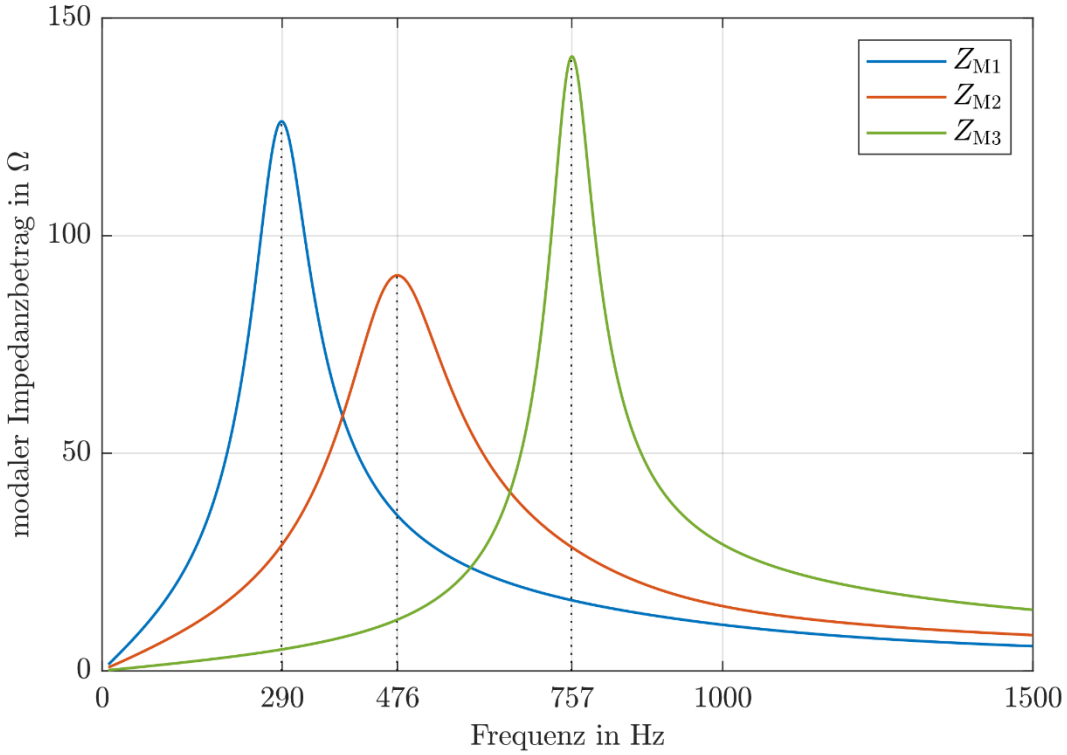
- Identification of 3 potential resonances
- different resonances overlap mutually
- characteristic values of resonances depend on observed node

Analysis methods – Resonance Mode Analysis

Resonance Mode Analysis (RMA):

- Used for clearly separable calculation of parallel and series resonances





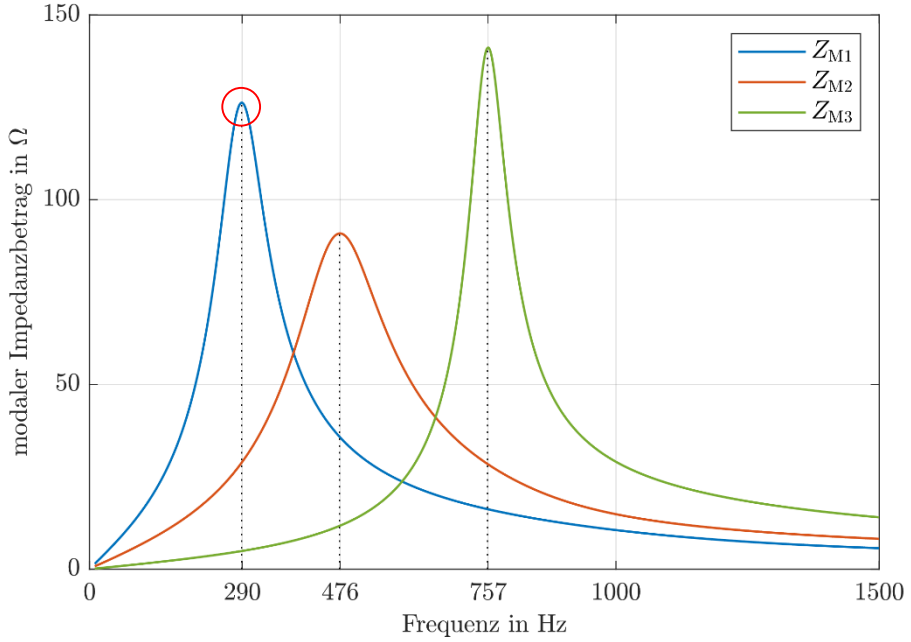
- Resonance phenomena clearly seperated via resonance frequency and modal impedance
- Modal impedances ≠ Network impedances

Analysis methods – Resonance Mode Analysis

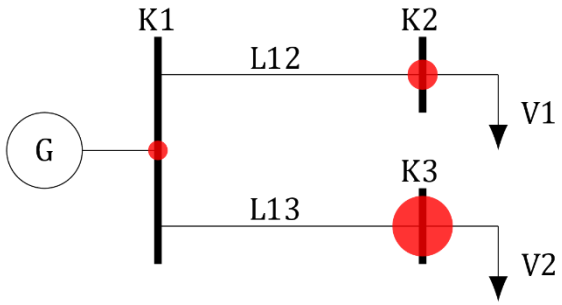
Participation Factors

- Link between modes and related network nodes
- Simple determination via eigenvectors and eigenvalues:

$$\begin{bmatrix} \underline{V}_{\mathrm{K1}} \\ \underline{V}_{\mathrm{K2}} \\ \vdots \\ \underline{V}_{\mathrm{K}n} \end{bmatrix} \approx \frac{\boldsymbol{t}_k \boldsymbol{l}_k}{\underline{Y}_{\mathrm{M}k}} \begin{bmatrix} \underline{I}_{\mathrm{K1}} \\ \underline{I}_{\mathrm{K2}} \\ \vdots \\ \underline{I}_{\mathrm{K}n} \end{bmatrix}$$



Application for mode 1 (f_r=290 Hz):



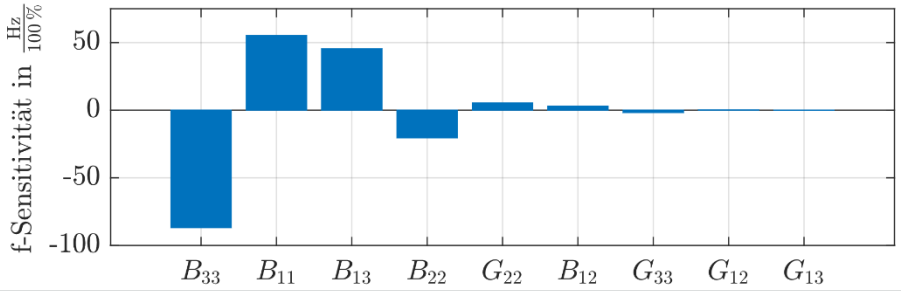
- strongest excitation expected to arise at node 3
- informative value is limited; influence of single components unknown

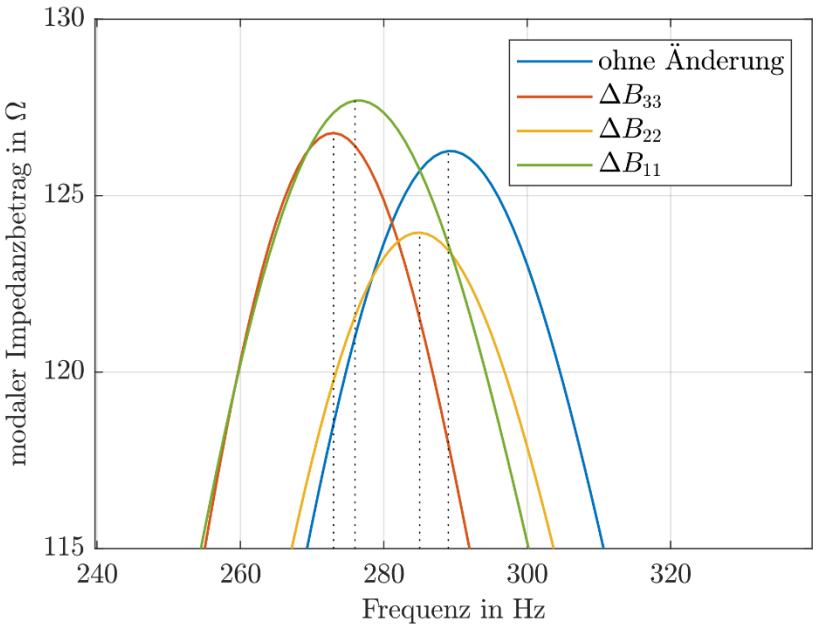
Analysis methods – Resonance Mode Analysis

Sensitivity Analysis

- Determination of influence of individual components in the network
- Sensitivity describes the shift of resonances when component α is varied
  - Variation of modal impedance ΔZ
  - Variation of resonance frequency Δf

Frequency sensitivity for mode 1 (f_r=290 Hz):



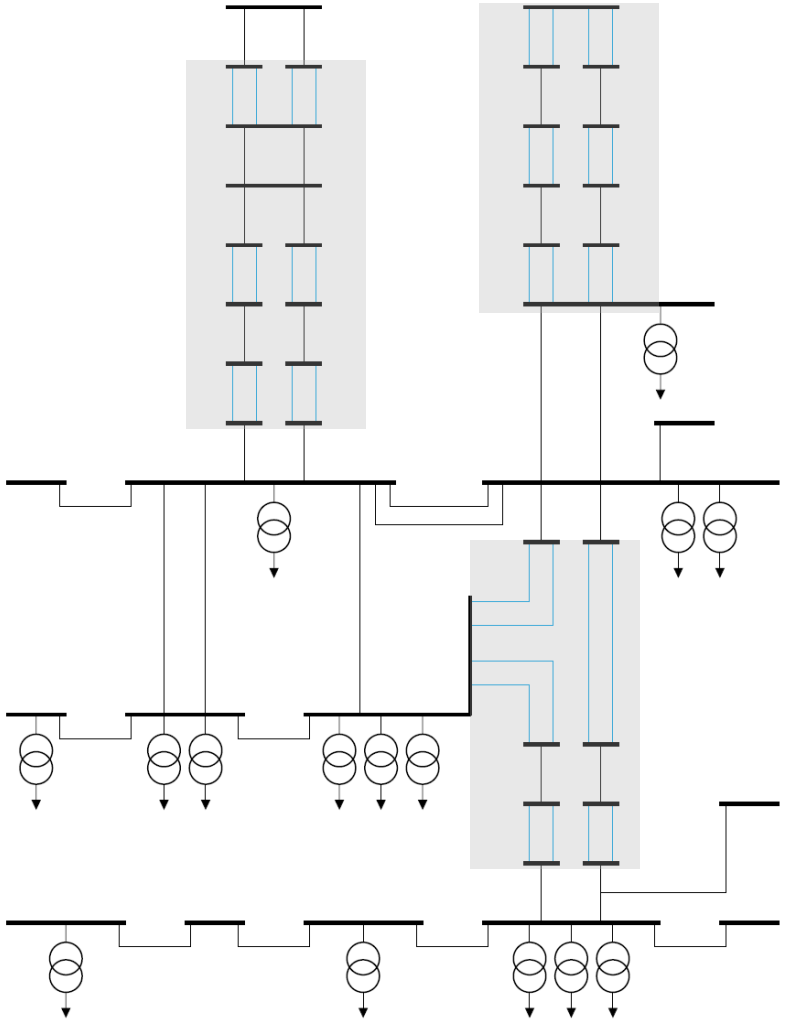


Previous studies

Effects of grid expansion with HVAC cable corridors

- study section of the German EHV transmission grid
- Including three underground cable pilot projects with hybrid lines
  - Sections of overhead lines and of underground cables

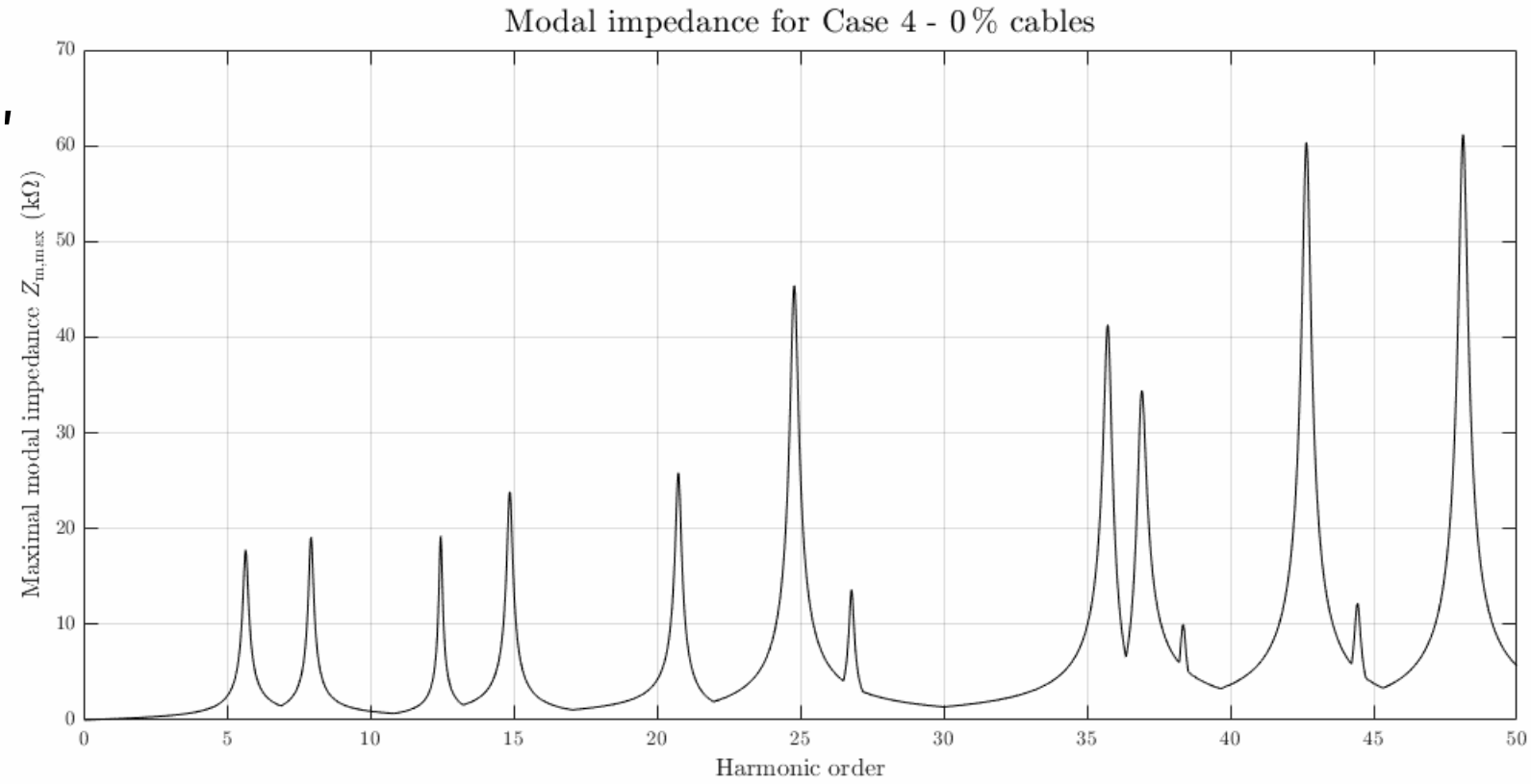
➢ Resonance behaviour expected to change
  - Higher capacitance per length
  - Two-system design



Previous studies

Effects of grid expansion with HVAC cable corridors

- With increase of cable shares in the system, resonance frequencies mainly decrease
- Cable impact on harmonic behaviour varies depending on harmonics and nodes



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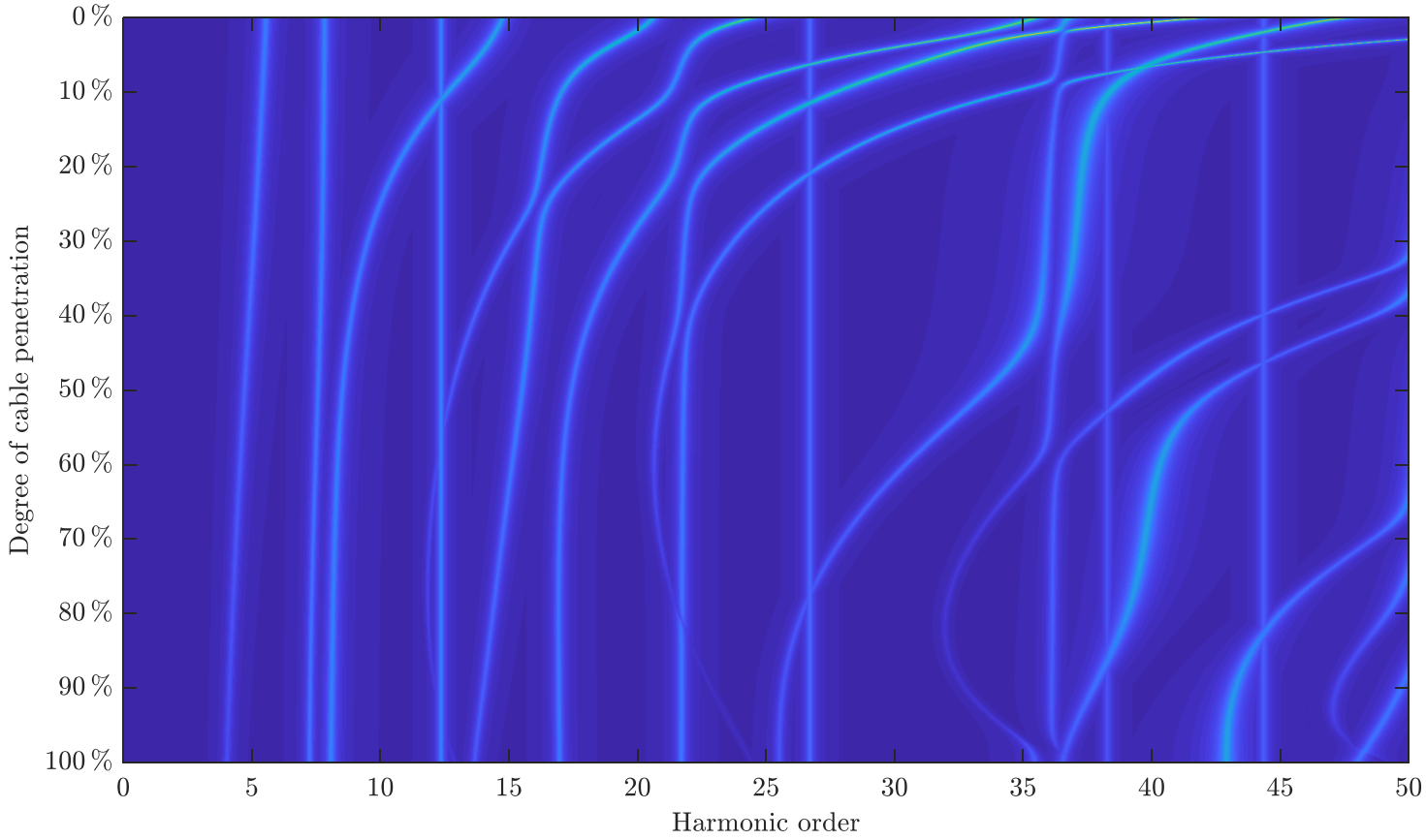
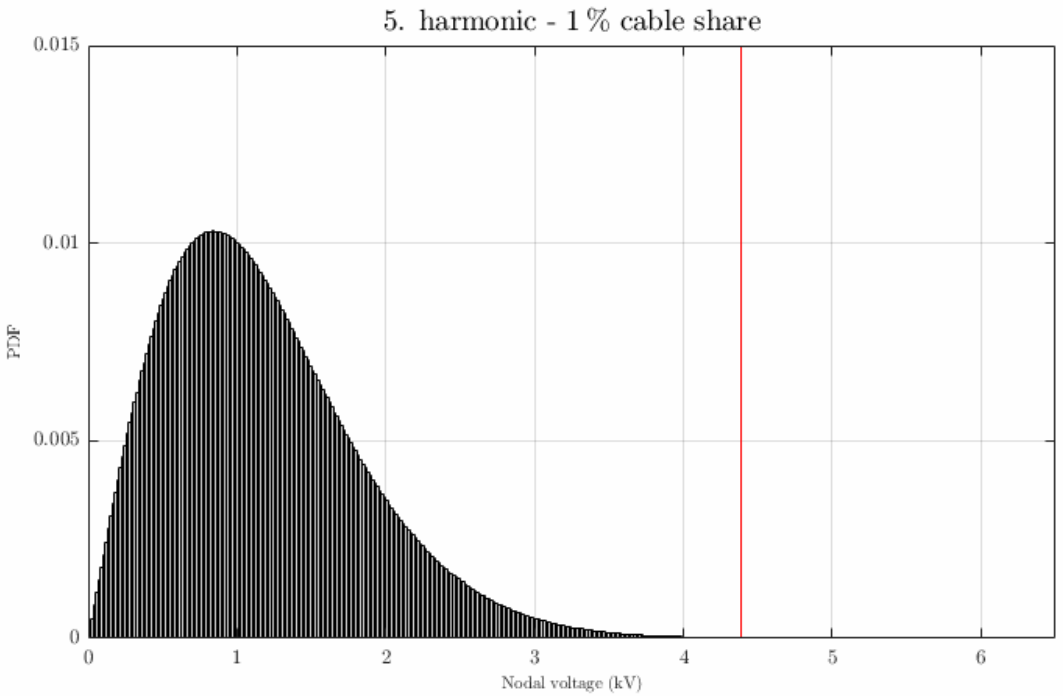


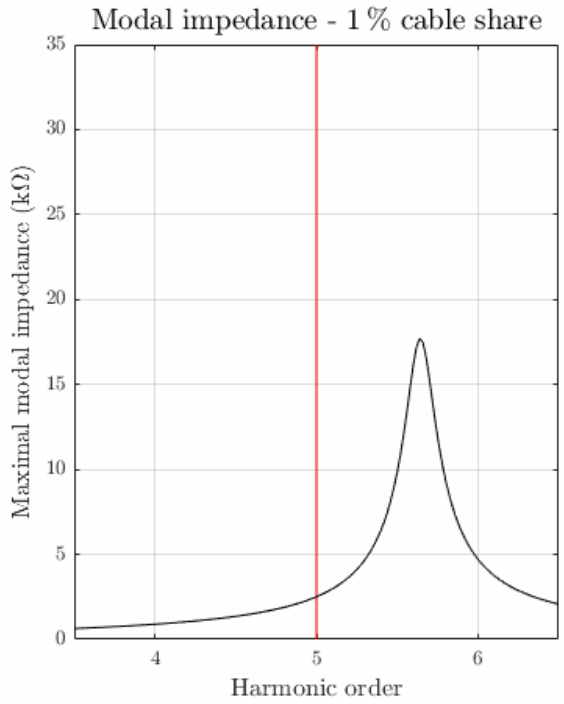
Previous studies

Probabilistic Analysis

- probabilistic calculation of harmonic voltages with various cable shares

- future grid forecasts from todays time series measurements
- using probability density functions



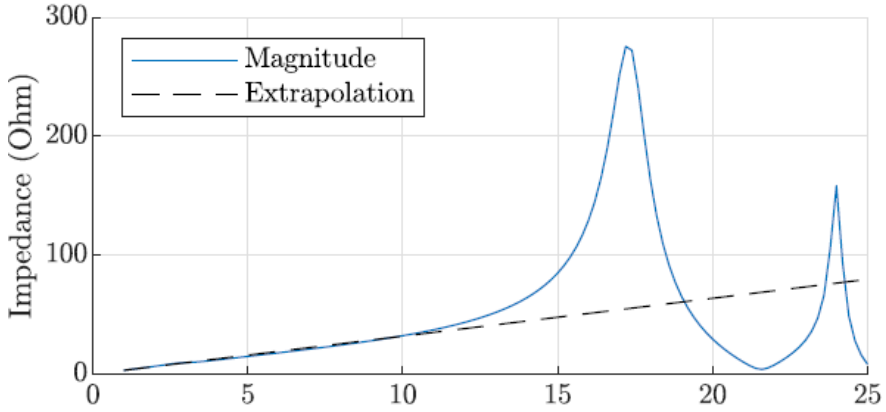


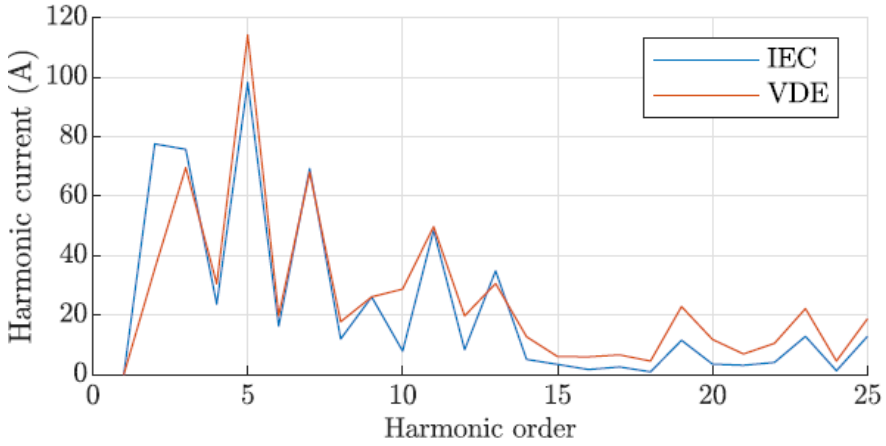
Previous studies

Allocation of harmonic emission limits

- Grid operators are confronted with the selection of suitable allocation methods to assign maximum harmonic emission limits to network customers

- Need to investigate network impedances
  - ➢ Changes due to grid expansion efforts





Outlook and upcoming research issues

- Evaluation of the study area selection
  - Stake out topological model boundaries
  - Handling of neighbouring networks
- Investigation of modelling issues and improvements
  - Modelling of downstream networks and loads
  - Modelling of PE devices (HVDC, FACTS, …)
- Enhancement of appropriate analysis instruments and methods

Thank you for your attention!

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