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RESONANCE CHARACTERISTICS IN OFFSHORE WIND POWER PLANTS WITH 66 KV COLLECTION GRIDS

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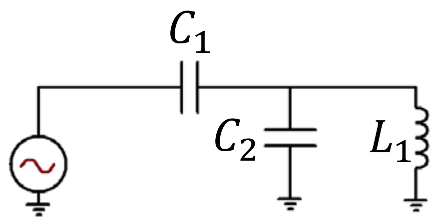
Introduction

- Doubling the collection grid voltage might provide technical or economic benefits
  - We will be seeing many 66 kV col. grids soon
- This change might influence harmonic and transient behaviour of OWPPs
- How the increase of the collection grid voltage level changes the electrical environment characteristic of an OWPP in a wide frequency range
  - What happens to resonances?

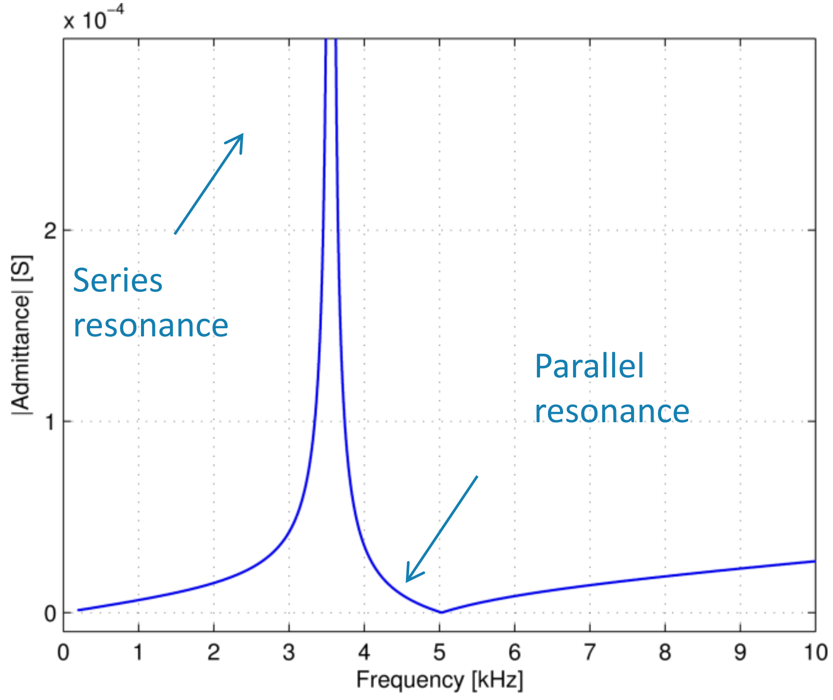


Electrical resonance

- Excitation of an electric system containing inductances and capacitances results in oscillations
  - Natural frequency:

$$f = \frac{1}{2 \cdot \pi \cdot \sqrt{L \cdot C}}$$

- Impedance/admittance frequency sweep often used to find resonances

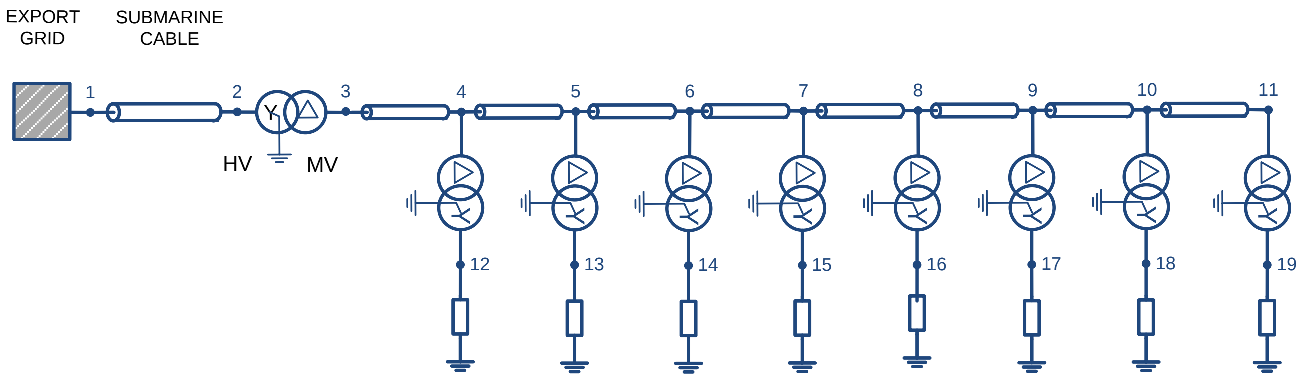


Electrical resonances (in OWPP)

- Resonance when (periodic) source has frequency similar to the circuit's natural frequency
  - Harmonics: $f < 2500$ Hz
  - Transients: Hz $< f <$ MHz
- High amplification of voltage/current due to energy exchange between electric and magnetic field
- Harmonic/transient resonances can result in anything from a lack of compliance with a grid code to a component overheating or damage

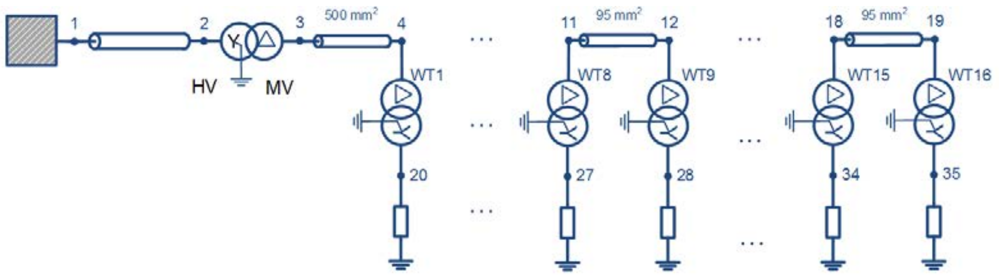
About the study

- Design and model (a simple) offshore wind power plant
  - Frequency dependent admittance matrix in Matlab, 30 Hz – 1 MHz
  - Positive sequence only
- Use of state-of-the art wide-band component models
- Create corresponding models of 33 kV and 66 kV collection grids
- Compare differences and explain where they came from



Assumptions

- 3 models:
  - 33 kV: 8 turbines /radial, 500 mm² (single cross-section)
  - 66 kV: 8 turbines /radial → smaller cable cross-section 95 mm² (single cross-section)
  - 66 kV: 16 turbines /radial → two cross-sections 95 mm² and 500 mm²
- Wind turbine: 6 MW
- Wind farm transformer: 90 MW



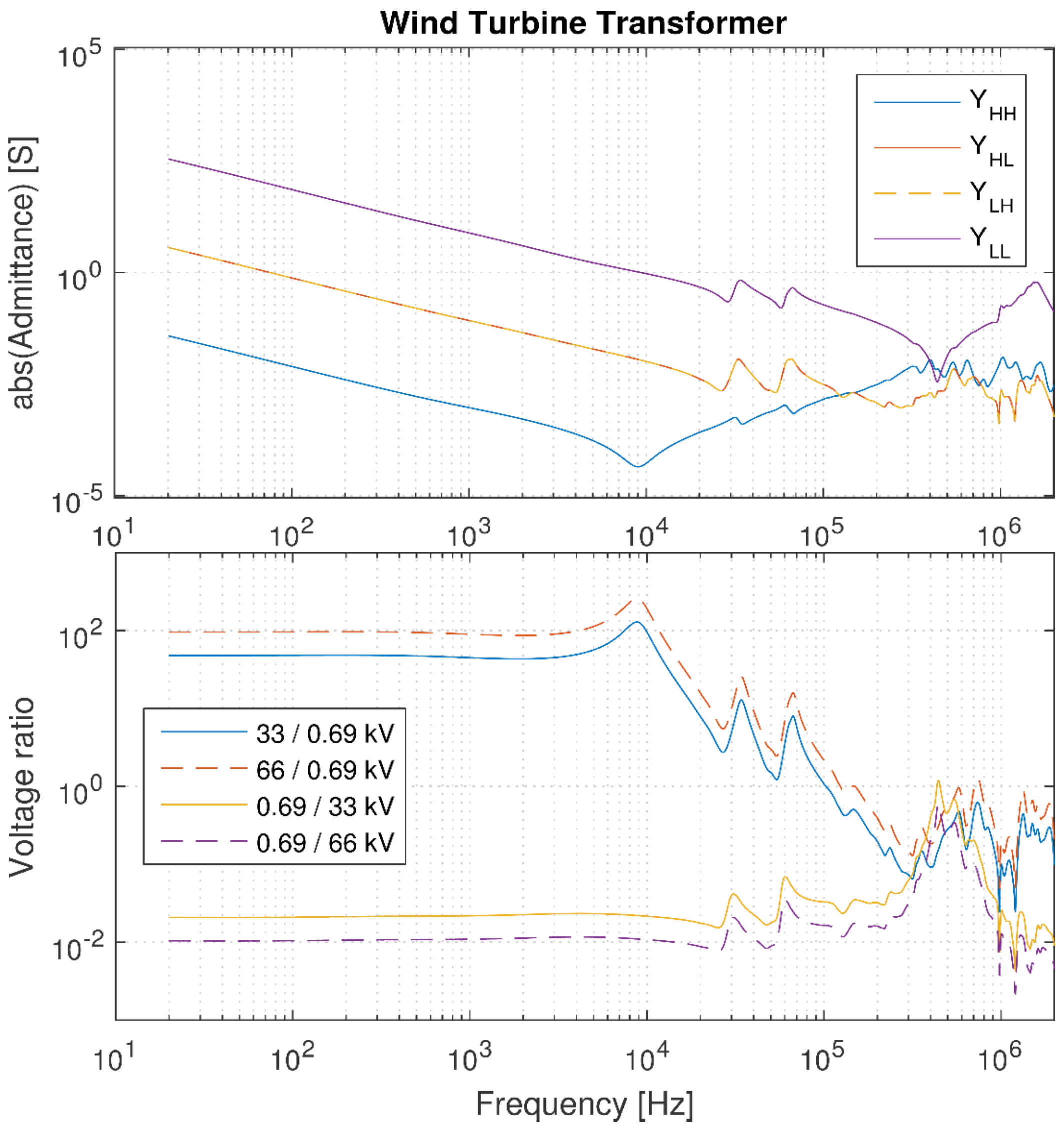
Transformer models

- Admittance matrix measurements
  - Wind turbine and wind farm transformers
  - 20 Hz – 2 MHz

$$\begin{bmatrix} I_H(\omega) \\ I_L(\omega) \end{bmatrix} = \begin{bmatrix} Y_{HH}(\omega) & Y_{HL}(\omega) \\ Y_{LH}(\omega) & Y_{LL}(\omega) \end{bmatrix} \begin{bmatrix} V_H(\omega) \\ V_L(\omega) \end{bmatrix}$$

- Admittance scaling to change voltage ratio

$$\begin{bmatrix} I_H(\omega) \\ I_L(\omega) \end{bmatrix} = \begin{bmatrix} \alpha^2 Y_{HH}(\omega) & \alpha Y_{HL}(\omega) \\ \alpha Y_{LH}(\omega) & Y_{LL}(\omega) \end{bmatrix} \begin{bmatrix} V_H(\omega) \\ V_L(\omega) \end{bmatrix}$$



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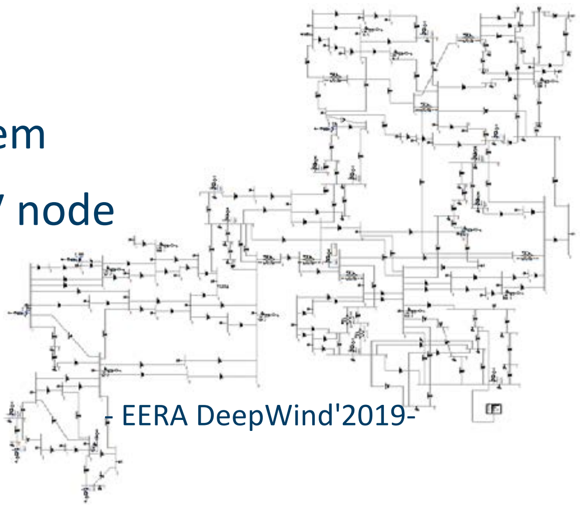
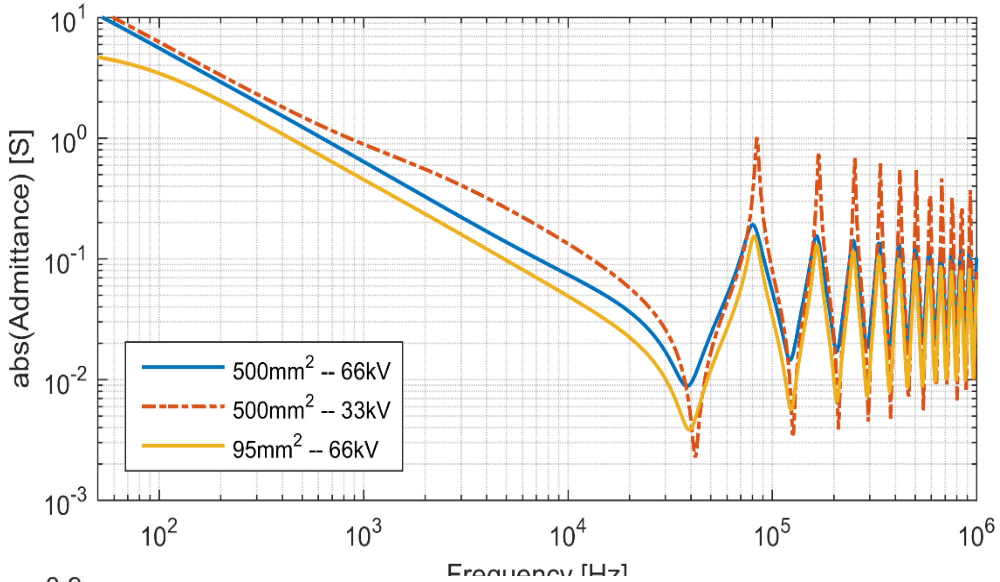
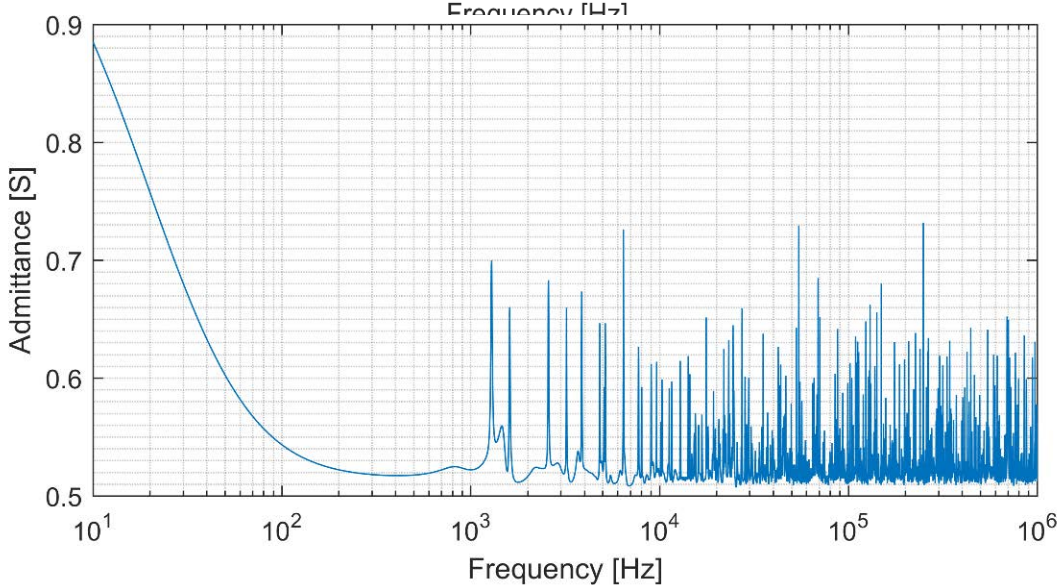
Component models

- Cables
  - Cable parameters based on material properties and dimensions
  - Freq. dependent traveling wave model. Similar to EMTPs
- Export grid
  - IEEE 118 bus reference system
  - Impedance sweep at 138 kV node

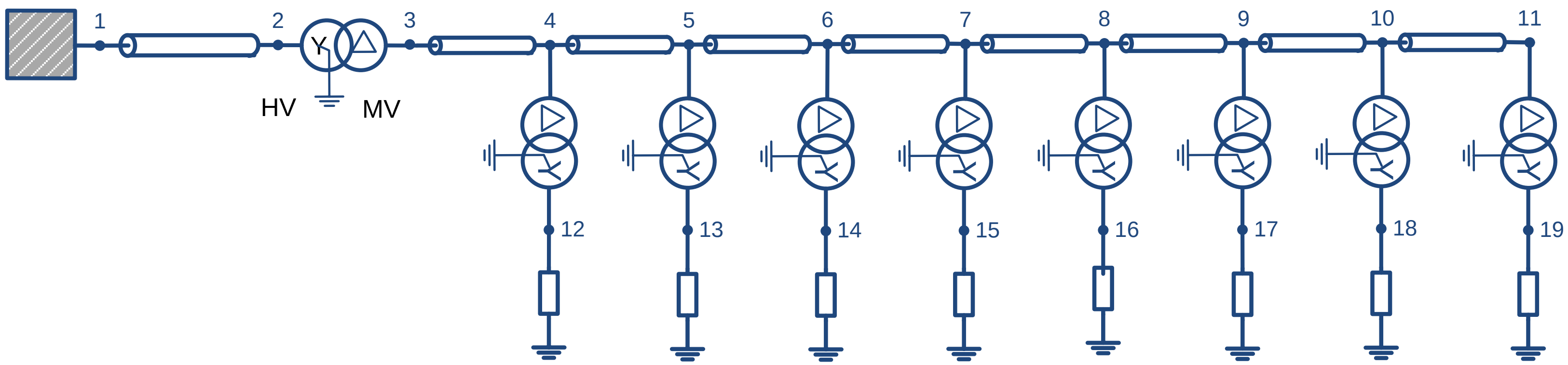


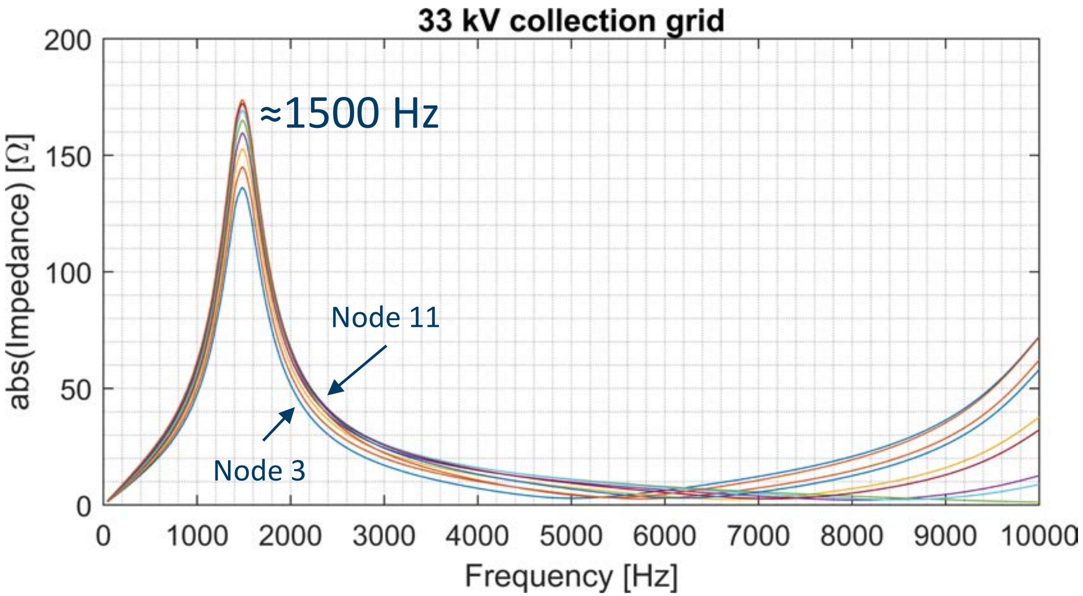


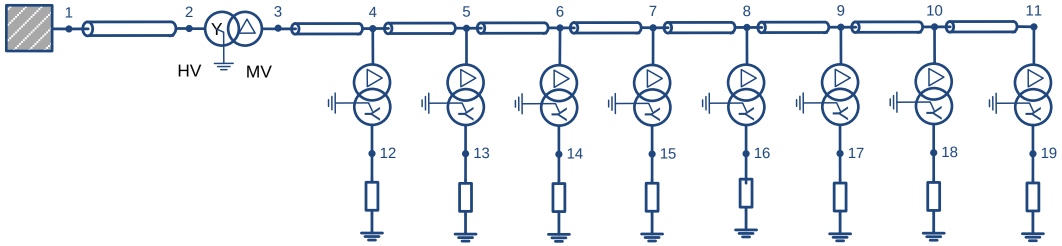


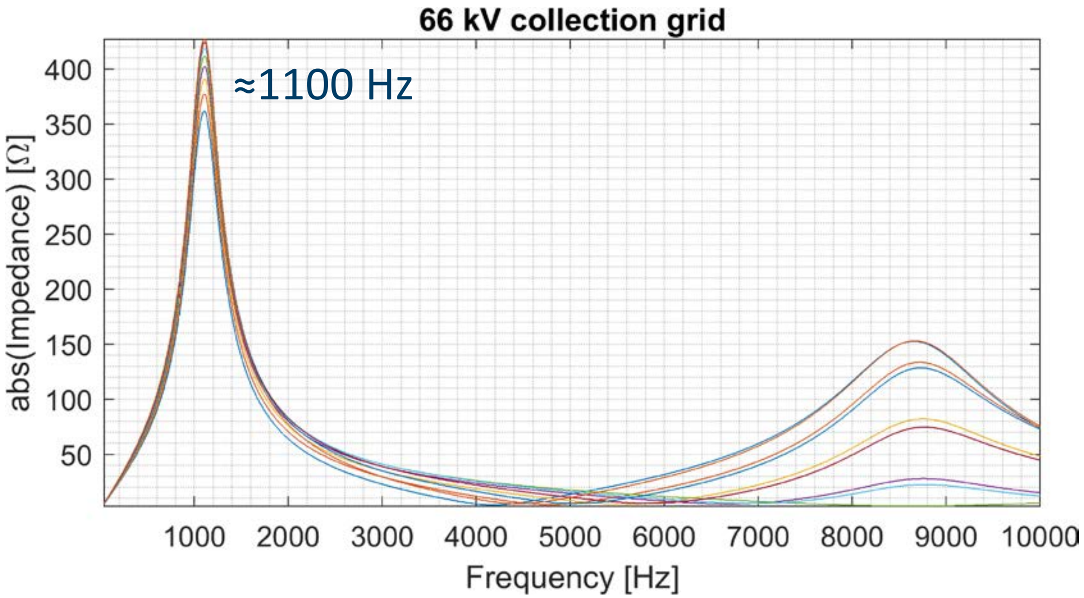
Results

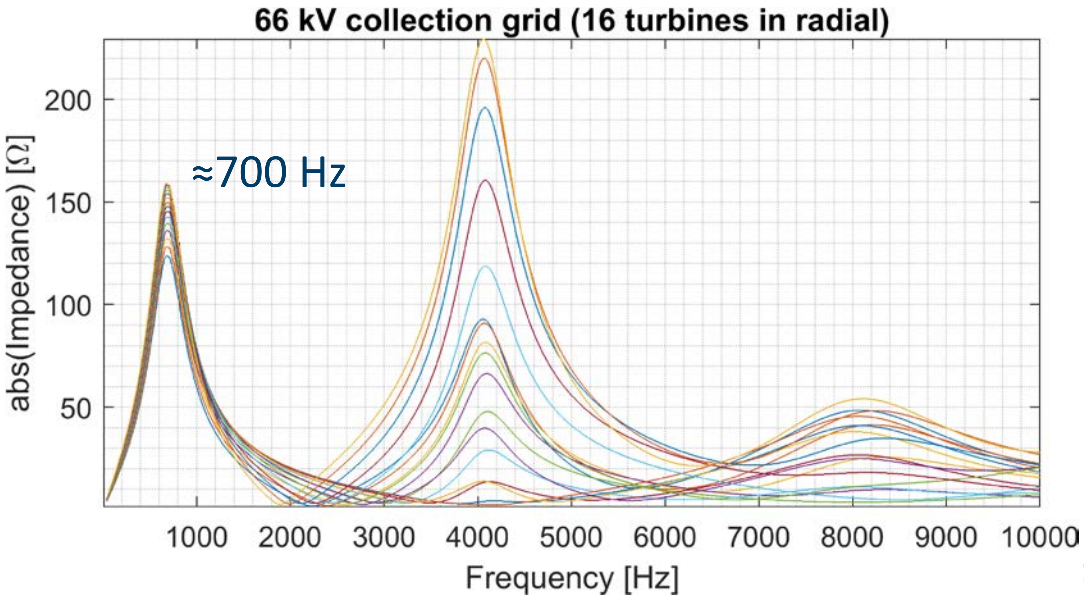
- Look at nodes 3-11
- Check driving point impedance/admittance




33 kV collection grid
≈1500 Hz
Node 11
Node 3
abs(Impedance) [Ω]
Frequency [Hz]
0
50
100
150
200
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000


1
2
3
4
5
6
7
8
9
10
11
HV
MV
12
13
14
15
16
17
18
19


66 kV collection grid
≈1100 Hz
abs(Impedance) [Ω]
Frequency [Hz]
50
100
150
200
250
300
350
400
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000


66 kV collection grid (16 turbines in radial)
≈700 Hz
abs(Impedance) [Ω]
Frequency [Hz]
50
100
150
200
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000

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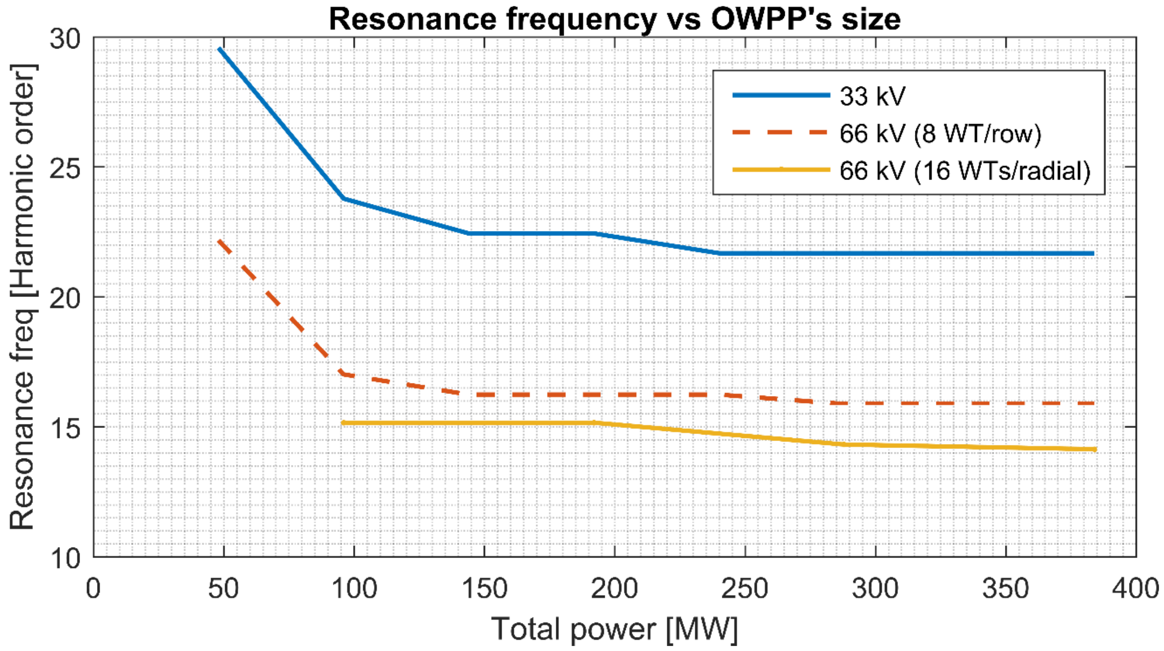
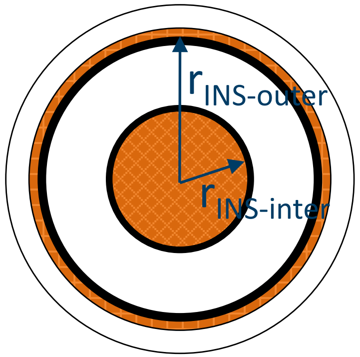
Resonance freq. vs OWPP's size

- Increased number of strings (1:8)
  - Each string approx. 50 MW
  - Park transformer scaled to total power above 90 MW
- OWPPs with 66 kV have resonances in lower order harmonic levels
- Main resonance frequency
  - Depends mostly on transformer inductance and cable capacitance



Cable capacitance…

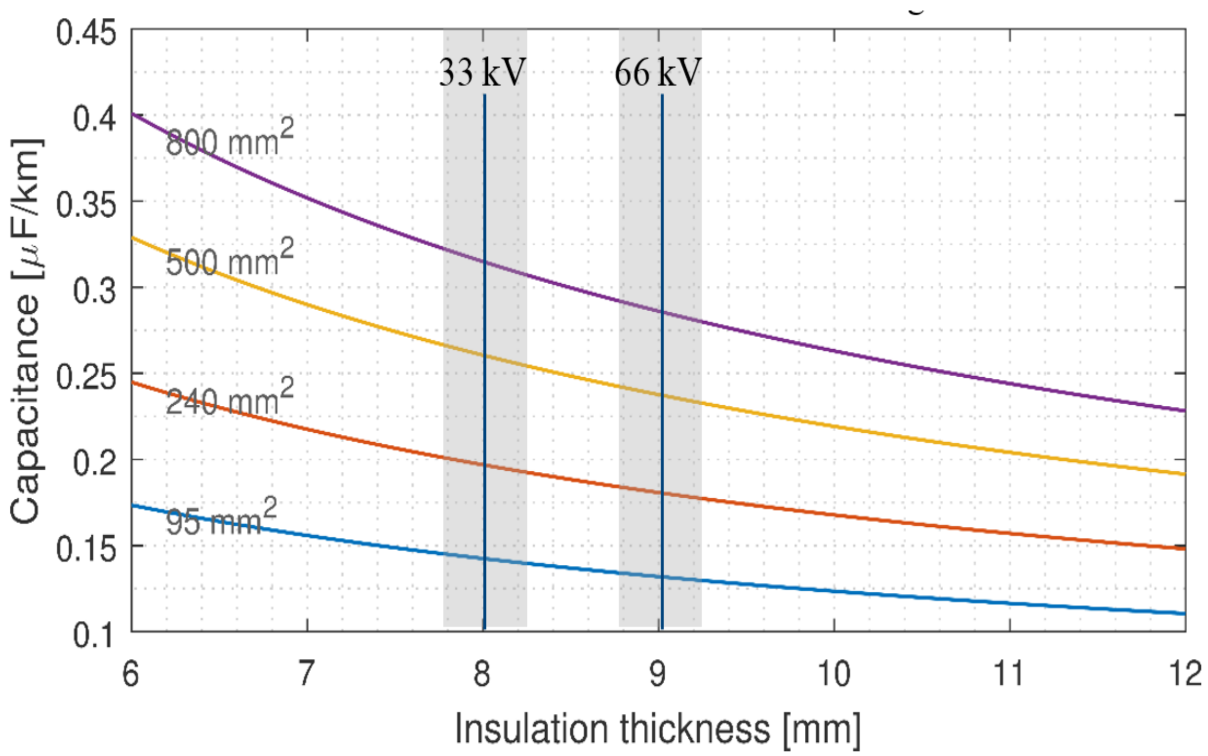
…depends on insulation material



$$C = \frac{2\pi\epsilon}{\ln \frac{r_{INS-outer}}{r_{INS-inner}}}$$

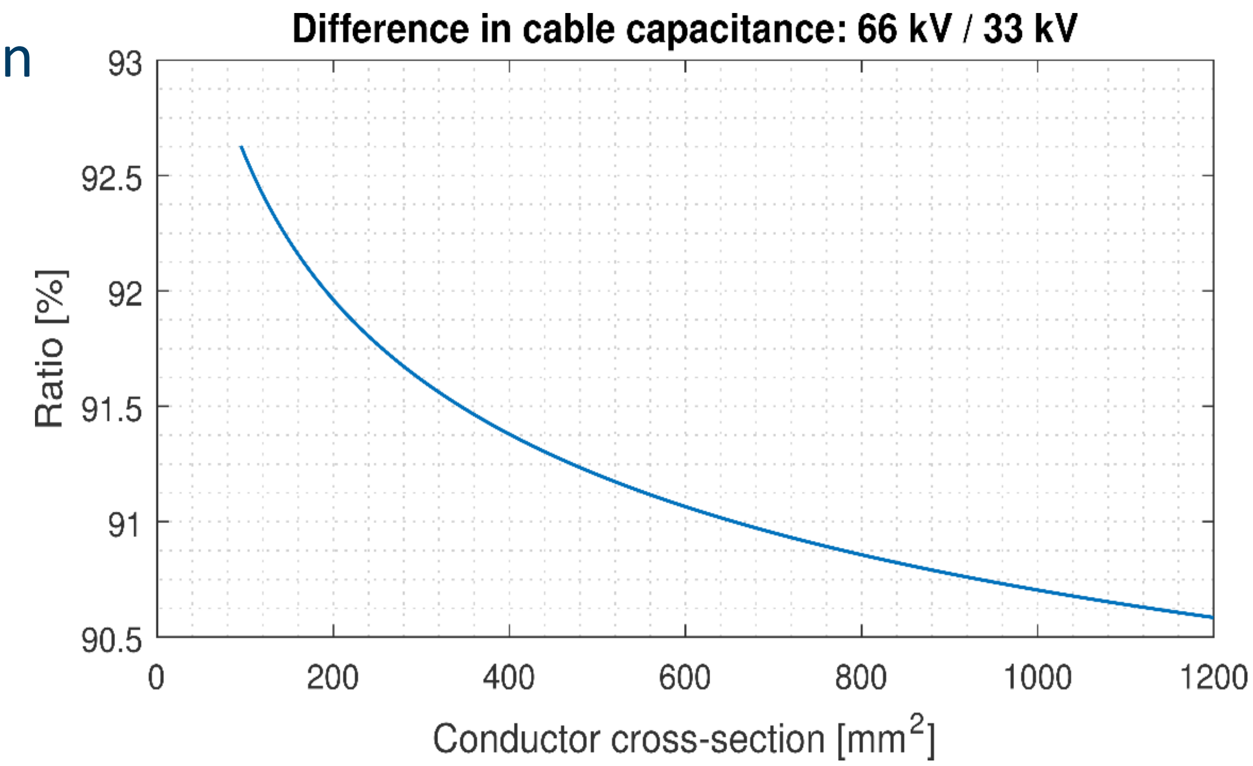
$$r_{INS-inner} = \sqrt{\frac{A_c}{\pi}}$$

$$r_{INS-outer} = r_{INS-inner} + d_{INS}$$



Difference in capacitance

- 66 kV cables capacitance is lower than capacitance of 33 kV cables for corresponding cross-sections
- The larger the conductor cross-section, the larger the difference in capacitance

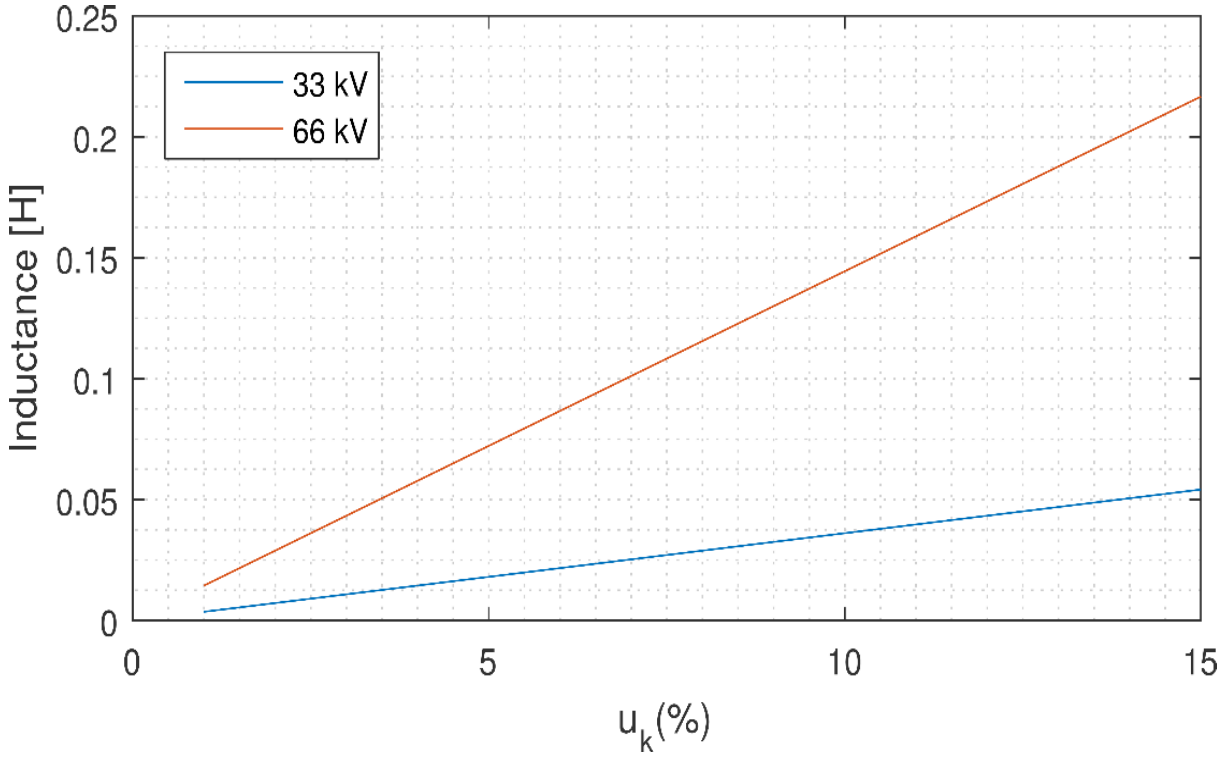


Transformer inductance

- Leakage inductance proportional to short circuit impedance

$$L_{SC} = \frac{\frac{V_p^2}{S} \cdot \frac{u_k(\%)}{100}}{2\pi f} = \frac{V_p^2}{S} \cdot \frac{u_k(\%)}{100} \cdot \frac{1}{2\pi f}$$

- Doubling the voltage quadruples the inductance, assuming the power and percent of short circuit voltage constant



Conclusions

- Change of voltage of the collection grid influences its resonance frequencies
  - Cable capacitance decreases with increase of voltage
  - Transformer inductance increases with increase of voltage
- Main resonance frequency will be shifted towards lower frequencies
  - Possible harmonic issues
  - Should be investigated by developers

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