cigre PARIS 2022

TECHNISCHE UNIVERSITÄT DARMSTADT

Study Committee B1

Insulated Cables

11072_2022

Influence of Cabling on Harmonic Voltages in a Transmission Grid using an Exemplary Test Grid

Andrea SCHAEFER, Simon MASSAT, Jutta HANSON, Gerd BALZER

Technical University Darmstadt, Germany

Motivation

- Demand of cabling rises in the German transmission grid
- Capacitive cable characteristic leads to resonance shift to lower frequencies
- Resonances may amplify characteristic harmonic voltages (3rd, 5th, 7th, 11th and 13th)
- There is a lack of practical experiences with high cable shares in intermeshed transmission grids
- The aim is to identify the influence of an increasing cable share in the transmission grid on harmonic voltage behavior

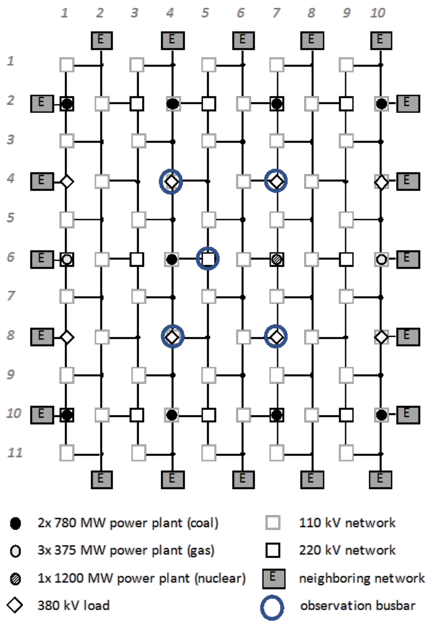

Figure 1: 380 kV honeycomb network

Method/Approach

- A large 380 kV test grid is cabled successively up to a fully cabled network
- The selection of overhead lines to be replaced is done randomly and repeated 20 times
- Each overhead line is replaced by a double-cable system
- Harmonic behavior is observed using Harmonic Load-Flow Calculations and impedance behavior is calculated with Frequency Scans at the observation busbars
- Planning levels from the IEC TR 61000-3-6 are used as limits for harmonic voltages at 380 kV

Objects of investigation

- A large homogeneous honeycomb network is set up as test grid based on a real 380 kV transmission network
- The honeycomb network exists of 110 busbars and 150 overhead lines with a length of 29 km each
- Network components are modeled frequency-dependent and homogeneously
- Harmonics are fed in by harmonic current sources at 10 kV level in the downstream networks
- Resulting homogeneous network characteristics allow observing changes in the test grid easily

Experimental setup

- Harmonic voltage measurements in the German transmission grid show very volatile behavior over time
- Assumed harmonic voltages are based on the 95th percentile of the 10 min r.m.s. measured voltages
- Harmonic current sources at 10 kV level are adjusted so that the busbar 0605 shows the targeted values

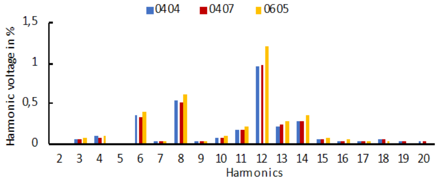

Figure 2: Harmonic voltages at the observation busbars in the honeycomb network

http://www.cigre.org

Study Committee B1

Insulated Cables

11072_2022

Influence of Cabling on Harmonic Voltages in a Transmission Grid using an Exemplary Test Grid

Andrea SCHAEFER, Simon MASSAT, Jutta HANSON, Gerd BALZER

Technical University Darmstadt, Germany

Test results

- Harmonic voltages are observed for each cabling step
- 100 scenarios are considered for each cable share
- Lower harmonics (3rd , 5th and 7th) are mainly determined by the first parallel and series resonance:
  - The first parallel resonance leads to an increase in harmonic voltages
  - The first series resonance leads to a decrease
- Frequency of the first parallel resonance depends on cable type and cable length
- 7th harmonic voltages mainly decrease because of the series resonance for low cable shares
- 11th and 13th harmonics show a wide range of the harmonic voltage for low cable shares:
  - High voltages can be traced back to parallel resonances shifted to the respective frequency
  - Very low voltage values appear if a cable is directly connected to the observation busbar
- The increasing capacitive impedance behavior leads overall to decreasing voltages for higher cable shares

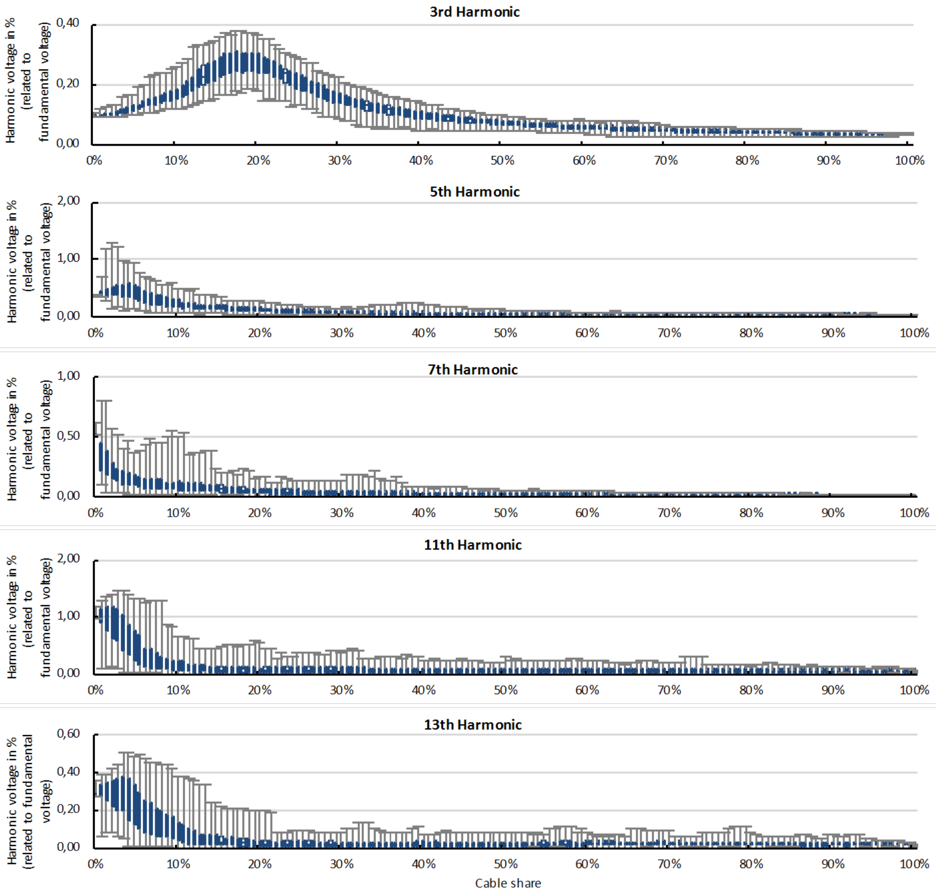

Figure 3: Harmonic voltages in % (related to the fundamental voltage) at the five observation busbars in the honeycomb network for a cable share up to 100 %

http://www.cigre.org

Study Committee B1

Insulated Cables

11072_2022

Influence of Cabling on Harmonic Voltages in a Transmission Grid using an Exemplary Test Grid

Andrea SCHAEFER, Simon MASSAT, Jutta HANSON, Gerd BALZER

Technical University Darmstadt, Germany

Exemplary test results

- Frequency-dependent impedances at two busbars are shown for selected cabling scenarios

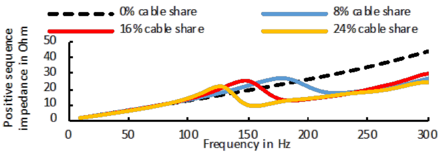

Figure 4: Frequency-dependent positive sequence impedance at busbar 0605 for cable shares of 0% - 24%

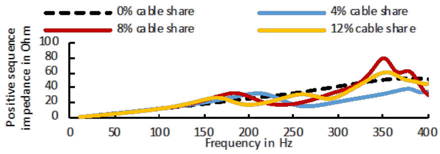

Figure 5: Frequency-dependent positive sequence impedance at busbar 0807 for cable shares of 0% - 12%

Discussion

- The cable share and the distance to the cable are identified as main influencing factors for the cabling impact:
  - Busbars directly connected to the cable system see a first parallel resonance with a high impedance leading to an increase of low harmonics
  - Distant busbars may see a resonance shift leading to increasing voltages

→ It is necessary to consider each cabling step and scenario for a comprehensive evaluation

- Low cable shares (< 20 %) can lead to a strong increase in harmonic busbar voltages
- The actual low cable share in the German transmission grid are not expected to increase greatly in the near future
- The rising number of power electronic components may increase the harmonic distortion in the future

→The increase of harmonic voltages can be critical in dependency of the harmonic background distortion and network impedance

Conclusion

- Cabling generally shifts resonances to lower frequencies due to the high cable capacitance
- Shift of first parallel resonance can increase low harmonics at low cable shares
- Resonance frequencies depend on the grid characteristics as well as on power line lengths and types
- The 11th and 13th harmonic voltages can increase due to parallel resonances shifted to lower frequencies – which is strongly grid-dependent
- The capacitive cable behavior leads in the homogeneous honeycomb network to low impedances for higher cable shares
- The investigations are carried out on a homogeneous network with very similar busbar behavior

→ In real grids, the single busbars may show a different behavior

→ Possible exceeding of the planning levels depends on the grid resonance behavior and harmonic feed-ins and cannot be answered in general

→ The harmonic voltage increase has to be investigated carefully for each busbar and cabling scenario

Future work

- Low-frequency resonances may affect other power system operations
- Transient phenomena (switching on transformers, switching off or initiation of short-circuit currents) may excite the low-frequency parallel resonance