Mains impedance measurements and defining Artificial Mains Networks for 2-150 kHz EMC testing

J. Meyer, R. Stiegler, V. Khokhlov, University of Technology Dresden, DE

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Background
Mechanism and definition

Device D1 draws „non-ideal“ current

„Non-ideal“ voltage drop at network impedance $Z_{sc}$

„Non-ideal“ voltage at Point of Connection (POC)

Disturbance of device D2

Frequency-dependent network impedance:
- Combination of impedance of the grid and impedance of electrical appliances (customers) connected to the grid

Important for:
- EMC coordination
- Simulation of emission propagation
- Solving customer complaints
Network impedance
Impact of grid-side and device-side

- Impedance characteristic determines propagation of emission and levels of disturbance
- **Below 2 kHz:**
  Grid-side impedance usually significant lower than device-side impedance
  -> grid-side impedance dominates the network impedance
- **Above 2 kHz:**
  Impedance of (closeby) electrical appliances is comparable or lower than grid-side impedance
  -> device-side impedance dominates the network impedance

Frequency-dependent input impedance of a PV inverter for roof-top application
Network impedance
Impact on propagation (upstream)

Emission propagation

\[ I_{D1-Gr}^{(sh)} = I_{D1}^{(sh)} \frac{1}{1 + \frac{Z_{Gr}^{(sh)}}{Z_{D2}^{(sh)}}} \]

\[ I_{D1}^{(sh)} = I_{qb1}^{(sh)} \frac{1}{1 + \frac{Z_{Gr}^{(sh)}}{Z_{D2}^{(sh)}}} \]

Current of supplying feeder (I_g) and two charging stations (I_CS1, I_CS2)

- Grid current reduces with increasing number of EVs
- Current between EVs increases

One device can change the situation completely

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Network impedance
Impact on propagation (downstream)

Emission propagation

\[ U_{P OC}^{(sh)} = U_{bg}^{(sh)} \left( \frac{1}{1 + \frac{Z_{Gr}^{(sh)}}{Z_{D par}^{(sh)}}} \right) \]

- Significant damping of PLC signal level during the day time

One device can change the situation completely
Network impedance
Importance for definition of emission limits

Definition of compatibility levels

**Voltage**

< 9 kHz

**Derivation of emission limits**

Voltage

Specified as current

\[ I_{\text{lim}}(f) = \frac{U_{\text{lim}}(f)}{Z(f)} \]

> 9 kHz

Specified as Voltage

at a reference impedance

**IEC 61000-4-7 (Annex B)**

**CISPR 16-1-2 (Line Impedance Stabilization Network)**
Laboratory representation
IEC 61000-4-7 (Annex B)

Equivalent circuit

- Specification as loop impedance
- Adaption necessary for assessment of emission of „true“ 3-phase devices
Laboratory representation
CISPR 16-1-2 Line Impedance Stabilization Network (LISN)

- 50 Ω / 50 μH + 5 Ω artificial mains V-network,
- Symmetrical impedances between phase (P), neutral (N) and earth (E)

- Decoupling of the EUT from the mains supply
- Ensuring the specified impedance at the EUT terminal

Suitability of LISN for representation of network impedance in public low voltage grid?
Survey of network impedance
Measurement campaign

- **Objectives:**
  
  Representative set of network impedance measurements in public low voltage networks

- **Framework:**
  
  Measurement together with 13 DSO’s:
  
  • Switzerland (4), Austria (3), Czech Republic (1), Germany (5)

  Selection of networks:
  
  • At least one urban ("stronger") and one rural ("weaker") network per DSO
  • Short circuit power at the final sites provided by DSO
  • Accessibility of the measurement sites
Survey of network impedance
Selection of measurement sites

- **Criteria:**
  - High short circuit power ($S_{sc}$): transformer station (TS)
  - Low $S_{sc}$: junction box (JB) at farthest feeder
  - Optional: additional JB in the middle of the network

- **Measurement sites:**
  198 single measurements at 76 measurement sites:
  - 25% at transformer stations (TS)
  - 75% at junction boxes (JB)

Comparison of $S_{sc}$:
- Comparable ranges of $S_{sc}$ between countries
- Higher $S_{sc}$ of sites in Switzerland
- Lower $S_{sc}$ of sites in Czech Republic
Measurement results
Results for one network

Measurements at different sites of the network

Measurement at house terminal:
- Lowest loop impedance
- Clear capacitive behaviour
- Dominate impact of customer appliances connected to the network

Opposite behavior compared to frequencies below 2 kHz
Measurement results
Overview of all measurements

- Large variation range (about 2 decades) with several distinct resonances
- Almost all measurements are below reference impedances
  - feasible for calculation of emission limit of “small” devices
  - conservative for calculation of emission limit of “larger” devices or installations

\[ z_{u,k}(f) = \left( \frac{\sum_{i=1}^{3} Z_i(f)}{3} \right)^{-1} \cdot 100\% \]

- Low diversity for 75% of measurement sites (\( z_{u,k}(f) < 20\% \))
- High diversity at higher frequencies and resonance frequencies

IEC 61000-4-7
CISPR 16-1-2
95%
75%
50%
25%
5%

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Summary

Network impedance above 2 kHz:
• Large variation range
• Conservative representation by reference impedances (IEC 61000-4-7, CISPR 16-1-2)
• Weak link to short-circuit power
• Dominate impact of customer appliances

Future work:
• Survey of network impedance at points of house connection
• Measurement of P-E and N-E network impedances to verify symmetrical behaviour of LISN
Thank you for your attention!
Questions?

Contact:
Jan Meyer
jan.meyer@tu-dresden.de