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A proposed framework for 2-150 kHz measurement methods

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Talk Outline

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

- Background
  - Need and requirements for a new normative grid measurement method
- Review of existing methods
  - Features and limitations of existing methods
- Overview of proposals developed by SupraEMI project

Background

Status quo of standardisation (9-150 kHz)

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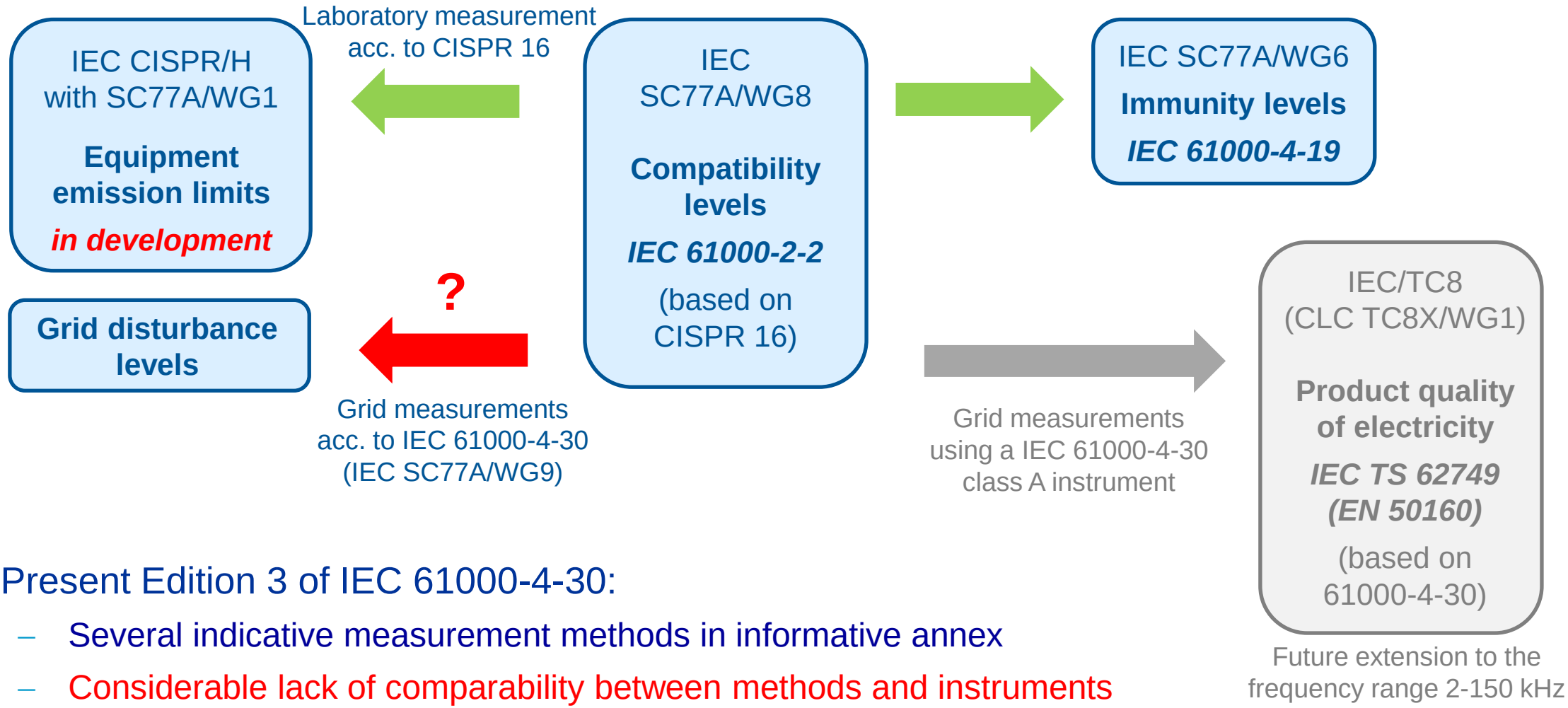

- Present Edition 3 of IEC 61000-4-30:
  - Several indicative measurement methods in informative annex
  - Considerable lack of comparability between methods and instruments

Background
What do utilities need?

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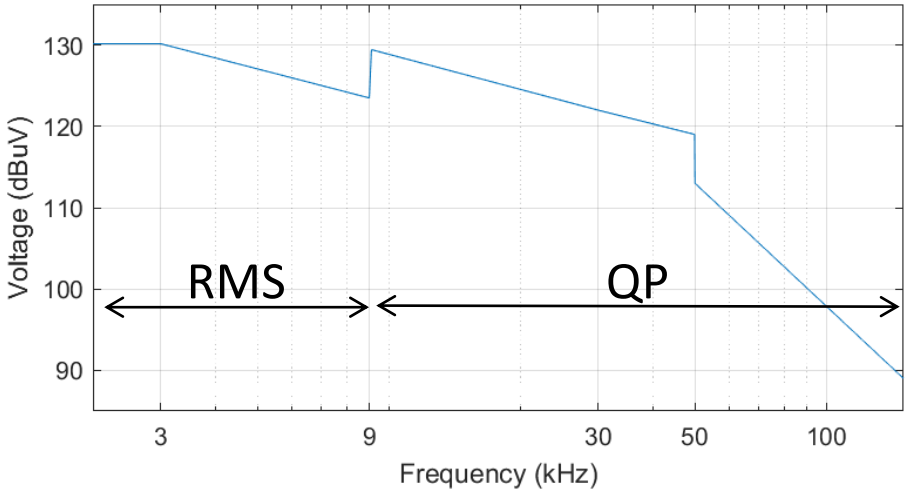
Measurements in the frequency range 2-150 kHz become more and more a daily business of utilities **for many use cases**:

- ✓ Comparison of disturbance levels with compatibility levels
  - Compatibility levels defined in IEC 61000-2-2
  - Bandwidth of 200 Hz
  - 2-9 kHz: rms values as in IEC 61000-4-7 Annex B
  - 9-150 kHz: quasi-peak (QP) values as in CISPR 16-1-1



- ✓ Study of propagation of emission
- ✓ Identification of possible disturbing sources
- ✓ Evaluation of product quality (future)

Background

What do utilities need?

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Measurement method and instruments must

1. provide **comparable results** for all use cases
   - ✓ overall accuracy requirement: 10%
2. represent the **relevant disturbance mechanisms**
   - ✓ thermal impact – RMS values representative of signal energy
   - ✓ malfunctions – MAX values
3. be able to measure **time characteristics** of voltages and currents
4. remain **affordable**
   - ✓ low computational complexity and memory requirements

Review of existing methods

Standard methods

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- Present Edition 3 IEC 61000-4-30 Annex C lists 3 methods under consideration:

2 kHz to 9 kHz	**Method A - according to IEC 61000-4-7 Ed.2 Annex B (informative)** ▪ Measure gapless 200 ms intervals (no synchronization to power frequency required) ▪ Calculate DFT → 5 Hz frequency step ▪ Grouping into 200 Hz bands
9 kHz to 150 kHz	**Method B - according to IEC 61000-4-30 Ed.3 Annex C (informative)** ▪ Acquire 32 times 0.5 ms intervals per 10/12 cycle interval ▪ Calculate DFT → 2 kHz frequency step ▪ Calculate average, minimum, and maximum per 10/12 cycle interval
	Method C - according to CISPR 16-1-1 (normative for laboratory measurements)

Review of existing methods

Method C according to CISPR 16

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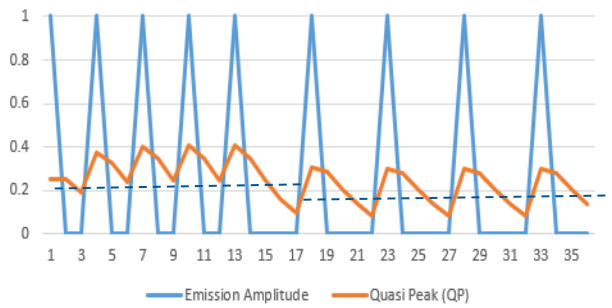
- CISPR 16 Objective → Protection of radio transmission from interference
- Historically analogue EMI receiver
  - Super-heterodyne
  - Long measurement time
  - Sequentially scanning of the frequency band
  - Based on analogue components
  - Tolerances of electronic components
- Measurement setup → Laboratory setting using Line Impedance Stabilization Network (LISN)

- More recently, digital FFT-based instruments for simultaneous measurement of the frequency range
- Detectors: Peak (P), Quasi Peak (QP), Average (A) and RMS
- For steady (non-fluctuating) emissions, P=QP=A=RMS
- For fluctuating emissions: P≥QP≥RMS≥A



- The QP value depends on repeat rate of an emission, → the faster it repeats, the higher the QP value

Review of existing methods

Method C according to CISPR 16

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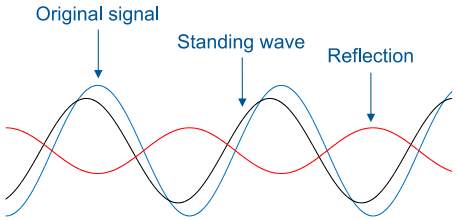
Black box approach

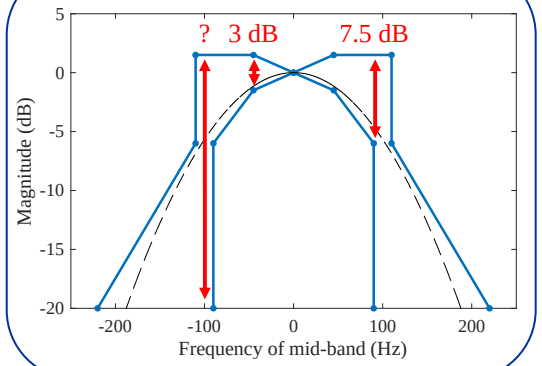
A compliant CISPR 16 quasi-peak receiver must fulfil:

Voltage Standing Wave Ratio (VSWR)

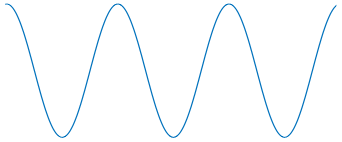
Related to receivers input impedance



Frequency selectivity

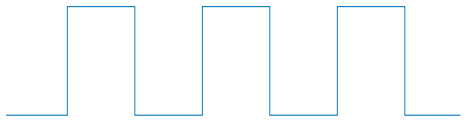


Tolerances for stationary sine-waves



Accuracy of ±**2 dB**
(-21/+26 %)

Specific response to a pulse train test



Accuracy of ±**1.5 dB**
(-16/+19 %)

Many different CISPR 16 compliant implementations are possible

CISPR 16-1-1 does not provide a fixed implementation

Review of existing methods
Comparison

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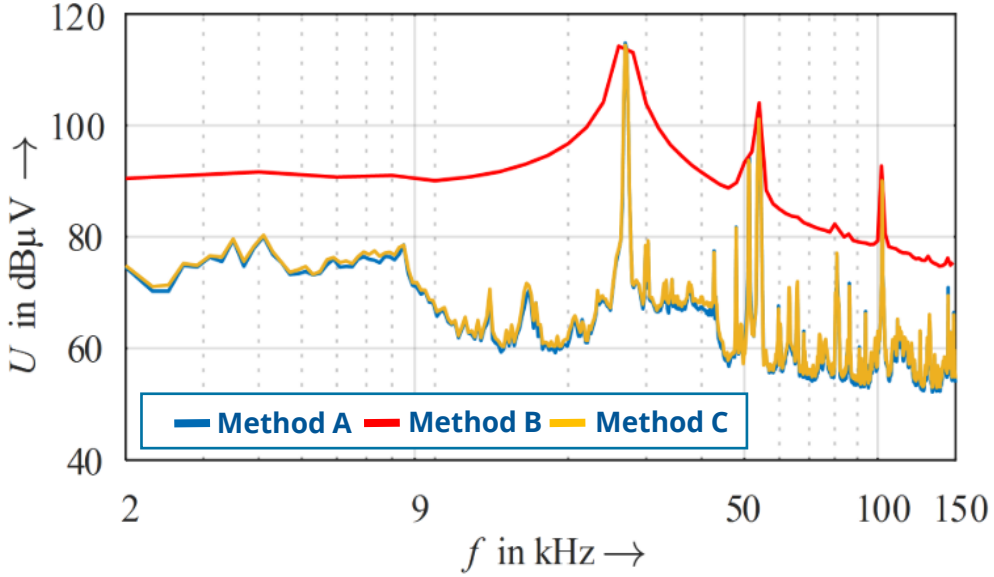
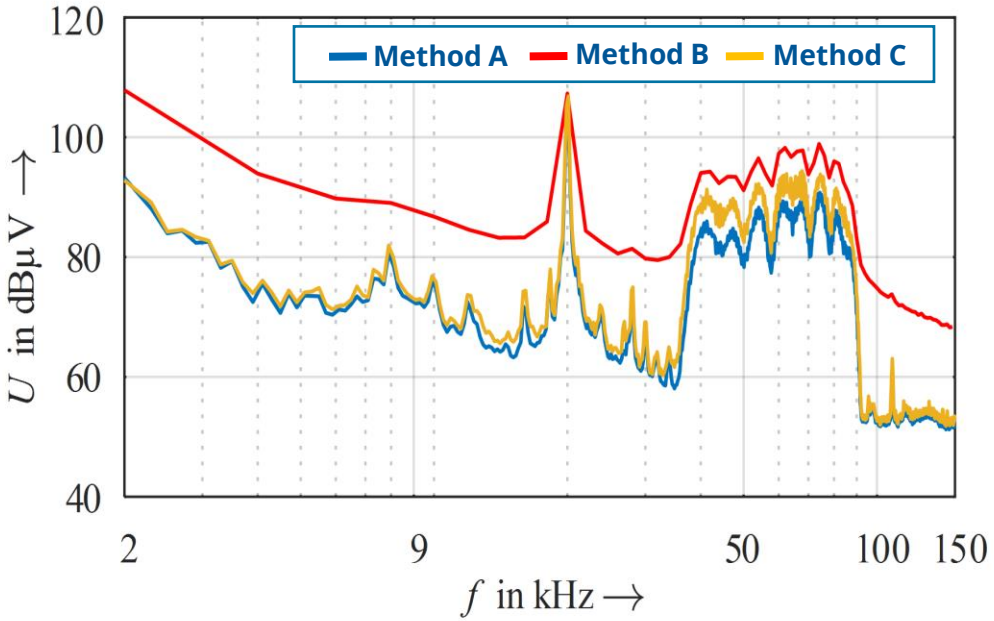
- *Method A:* Extension of IEC 61000-4-7 Annex B (200-Hz-bands)
- *Method B:* IEC 61000-4-30 Annex C proposal (2-kHz-bands)
- *Method C:* Digital CISPR 16 method (200-Hz-bands)

EV charger emission in the laboratory



PV inverter emission and PLC signal at a customer terminal



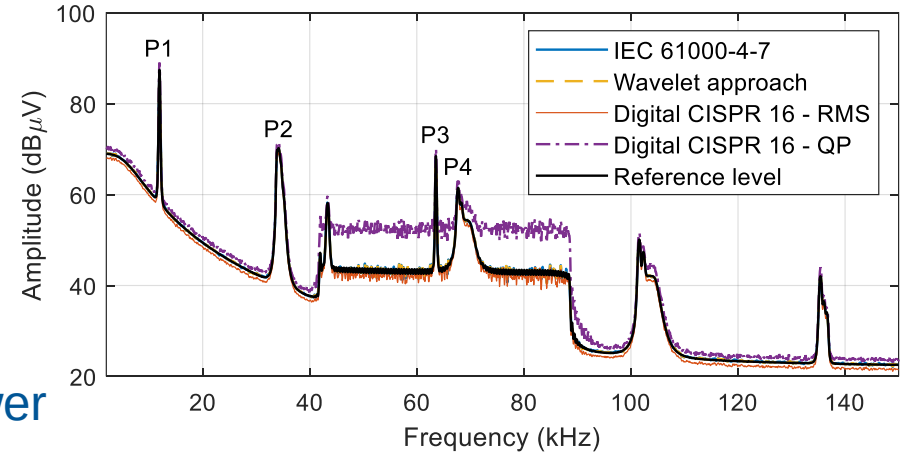
Methods A and C:
- Similar characteristics with A tending to be lower than C

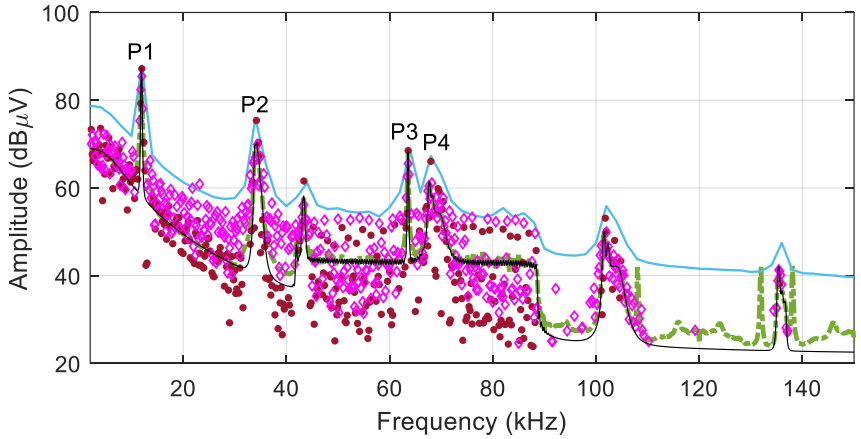
Method B:
- Tends to provide highest values due to the larger frequency band
- Significant higher noise level results in missing low magnitude components

Review of existing methods
Comparison

Alternative methods have been proposed:

- **Wavelet Approach** (Lodetti et al., 2020)
  - Wavelet packet decomposition by recursive filtering and downsampling
- **Subsampling Technique** (Mendes et al., 2019)
  - Bandpass filtering by analogue filter bank → sampling at lower frequency → DFT → compressive sensing
- **Multiple Measurement Vectors Compressive Sensing** (S. Zhuang et al., 2019)
  - DFT → multiple measurement vectors model → sparse approximation algorithm:
    1. Orthogonal Matching Pursuit (OMP)
    2. Sparse Bayesian Learning





D. Ritzmann et al., "Comparison of Measurement Methods for 2-150-kHz Conducted Emissions in Power Networks," IEEE Trans. Instrum. Meas., vol. 70, 2021, doi: 10.1109/TIM.2020.3039302.

Review of existing methods

Selection of candidate methods

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- **IEC 61000-4-30** — 2 kHz resolution not comparable with IEC 61000-2-2 compatibility levels
  Lack of accuracy and reproducibility due to unspecified gaps
- **IEC 61000-4-7** — High accuracy with respect to signal energy and thermal impact
- **Digital CISPR 16** — Quasi-peak values comparable to compatibility levels
- **Wavelet approach** — Results comparable to IEC 61000-4-7 Annex B
- **Subsampling approach** — NIE emissions can be identified with lower sampling of subbands
- **Compressive sensing** — Capable of increasing frequency resolution while maintaining 0.5 ms time resolution, further development for non-sparse wideband emissions

Review of existing methods

Selection of candidate methods

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Comparison showed that different methods fulfill different requirements

Focus on representation of thermal impact & comparison against IEC 61000-2-2 compatibility levels

IEC 61000-4-7 Annex B

Digital CISPR 16

Review of existing methods

Limitations of candidate methods

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- Both candidate methods need adaptations for grid measurement application

- Limitations of method according to **IEC 61000-4-7 Ed.2 Annex B**:
  - 200 ms window – memory requirements too high at sampling rates >300 kHz
  - Grouping method is not symmetrical around centre frequency (c.f. harmonics <2 kHz)
  - Non-overlapping frequency bands – narrowband emissions can be underestimated

Review of existing methods

Limitations of candidate methods

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		Limitations of CISPR 16 in LV grid
CISPR 16 Objective	Protection of radio transmission from interference	Never considered for grid measurements
Historically analogue EMI receiver	Black box approach	No fixed implementation of the measurement method
	Super-heterodyne meter	Long measurement time
	Sequentially scanning of the band	
	Based on analogue components	Large tolerances are allowed
Measurement setup	Laboratory setting using Line Impedance Stabilization Network (LISN)	The setup based on a LISN not feasible in the LV grid

Proposals for a normative framework

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- SupraEMI: Two proposals have been developed from candidate methods

Digital CISPR 16

Selected implementation
Based on CISPR 16-1-1 and CISPR/TR 16-3

Rationale
- CISPR 16 is part of the established EMC framework
- Improve reproducibility by fixing parameters

Light Quasi-Peak

New method
Based on adaptation of 2-9 kHz method in IEC 61000-4-7 Annex B

Rationale
- Extend principles of IEC 61000-4-7 to 150 kHz
- Provide RMS and MAX values reflective of PQ interference
- Lower computational complexity than CISPR 16

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Thank you for your attention!