TECHNISCHE UNIVERSITÄT DRESDEN

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

Needs and challenges related to a normative method for grid measurements in the frequency range 2-150 kHz

Jan Meyer, Technische Universität Dresden, DE
EMPIR SupraEMI - WP1 team

EMC Professional Talk – IEEE Denmark EMC Chapter
Online, 28.10.2021

Interference case example
Situation

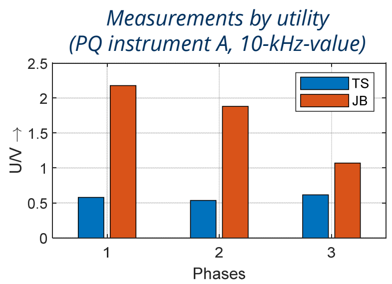
- Public low voltage grid in a German city
- Fast (DC) charging station at junction box (JB), Slow (AC) charging points at MV/LV transformer station (TS)
- Specific car charges at TS + fast charger in standby-mode:
  - Fast charger emits annoying noise

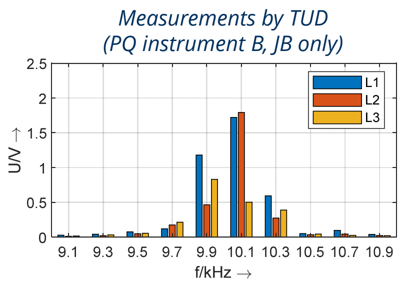
Source: Google Maps

Interference analysis requires (grid) measurements

Interference case example

Measurement results





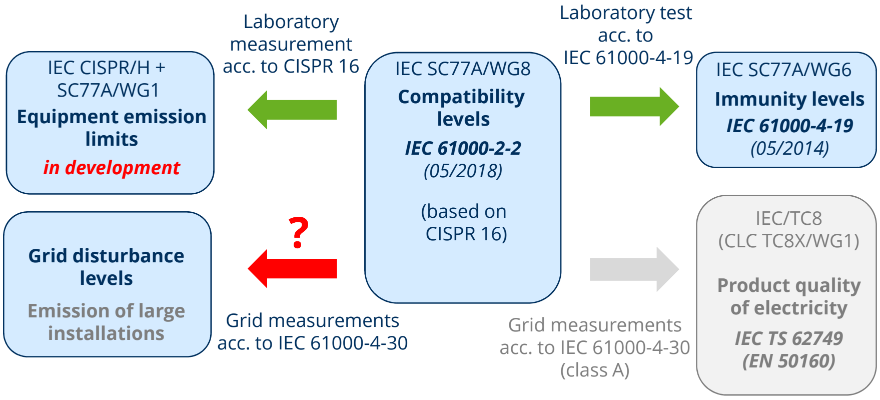
- Utilities measure to:
  - Identify root cause of interference
    (Switching frequency emission of the charger at 10 kHz)
  - Compare disturbance levels with applicable
    limits (product quality, compatibility level)
    Application of PQ instrument acc. to IEC 61000-4-30 class A

Measured values of different instruments should be comparable

Status quo of EMC standardization (9-150 kHz)

Overview

- Framework for EMC coordination of conducted, differential-mode, non-intentional emission (NIE):



Future extension to 2-150 kHz expected

- Product quality specification is not related to EMC,
  but should be derived from / coordinated with it (compatibility levels)

Status quo of EMC standardization (9-150 kHz)
Some more details

Present edition of IEC 61000-2-2 (compatibility levels):
- Reference for emission limits and immunity levels (have been established before)
- Compatibility levels defined in terms of CISPR 16 Quasi-peak (QP) in coordination with definition of emission limits for equipment by CISPR
- (Almost) solely designed to protect mains communication systems from NIE
- Suitability for assessment of grid disturbance levels seems not being properly considered:
  - Note 2 in Scope of IEC 61000-2-2:
    The measurement methods of disturbance levels are outside the scope of this document.

Present edition of IEC 61000-4-30 (measurement methods):
- Several indicative measurement methods in informative annex
- No guidance for a preferred method
- Considerable lack of comparability between PQ instruments in the field

Status quo of EMC standardization (9-150 kHz)
Features of indicative methods in present IEC 61000-4-30

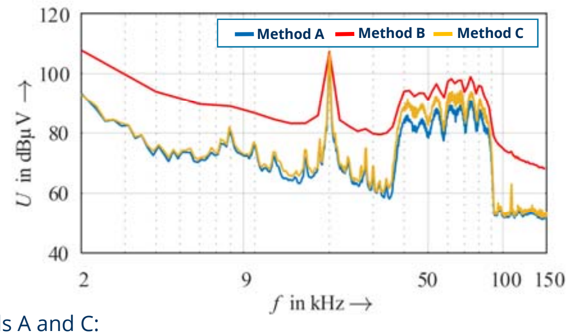
	A based on IEC 61000-4-7	B new proposal for IEC 61000-4-30	C CISPR 16
Frequency range	2 – 9 (150) kHz	9 – 150 kHz	9 kHz – 150 kHz (CISPR Band A)
Principle	DFT	DFT	Spectrum analyser (heterodyne principle)
Measurement interval	200 ms	0.5 ms	20 ms
Bandwidth	200 Hz	2000 Hz	200 Hz
Signal coverage	100 %	8 %	(≫) 100 %
Overlapping	no	no	yes (time and frequency)

- Different instruments in the market available based on methods A and B, partly with individual adaptions

Status quo of EMC standardization (9-150 kHz)

Comparison of indicative methods

Site with PV installation and narrowband PLC



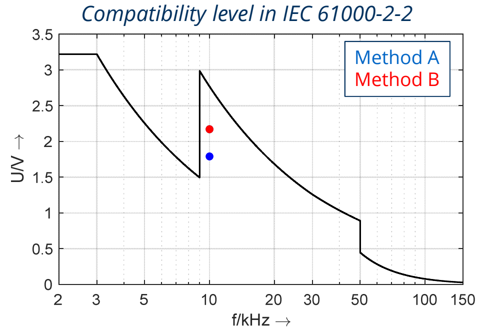
- Methods A and C:
  - Similar characteristics with A tending to be lower than C (at 20kHz -0.6 dB, at 54 kHz -4.1 dB)
- Method B:
  - Tends to provide highest values due to the different (larger) bandwidth
  - Significant higher noise level results in missing low magnitude components

Status quo of EMC standardization (9-150 kHz)

Assessment for interference case

- Comparison of (maximum) value in the 10kHz range with the compatibility level (Method C measurement not available)

Compatibility level in IEC 61000-2-2



- „Sudden" jump of compatibility levels at 9 kHz just due to different laboratory test conditions (impedances)
- Disturbance levels seem below the limit, but interference is still observed

Open questions:

- Can existing compatibility levels be feasibly applied to grid disturbance levels ?
- What measurement method should be used ?

SupraEMI: pre-normative research project
Overview

Purpose: Support standardization with necessary input to develop an widely agreed method for grid compliance assessment in the frequency range 2-150 kHz

- Start date: May 2019 for 3 years
- *National Metrology Institutes:*
  NPL (UK), LNE (FR), VSL (NL) and METAS (CH).
- *University Partners*:
  TU Dresden (DE), UPV/EHU (ES) and U of Campania (IT).
- *Chief Stakeholder*:
  Dr. Michael Schwenke, IEC77A WG9 Convener
- *More information at*:
  http://empir.npl.co.uk/supraemi/

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

SupraEMI: pre-normative research project
Working packages

A new normative method for grid measurements
- Develop measurement algorithms
- Specify new method for standardization bodies
- Specify instrument prototype

WP leader: NPL **WP1**

A laboratory comparison of the new method and existing methods
- Selection of set of household equipment
- Comparison of measurements using CISPR 16, IEC 61000-4-7 and new method

WP leader: VSL **WP2**

Comparison of appliance emission between laboratory and grid
- Measurements (equipment and existing levels) at different points with typical grid characteristics
- Compare lab and grid measurements

WP leader: LNE **WP3**

Verification of reference impedance approaches by grid measurements
- Develop grid impedance measurement system
- Measure impedance in different grids

WP leader: TUD **WP4**

Possible grid measurement method

Some concerns about grid application of CISPR 16

- CISPR 16 is for laboratory testing:
  - Setup inherently includes line impedance stabilization network (LISN) (symmetrical impedance between L-E and N-E)
  - Manual 2-stage approach (EUT specific, time limited) (1: initial screening based on Max detector, 2: detailed scan using QP detector)
- QP does not reflective for relevant interference mechanisms:
  - Protection of radio transmission from interference
  - No consideration of thermal impact and malfunctions
- Tolerances up to ±2dB (about ± 25%)
  - Significant flexibility and ambiguity in the method definition
- Computational effort
  - High computational effort compared to other methods

Open questions:

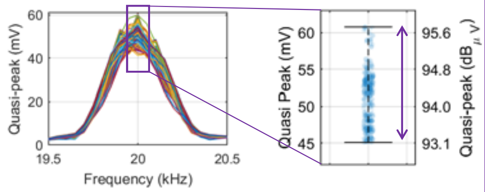
- How reproducible is the method?
- What is the additional computational effort compared to „classical" method?
- How long-term (continuous) measurements should be performed? (Can a grid just be treated as an EUT in the lab?)

Possible grid measurement method

CISPR16: Reproducibility

Comparison of 358 compliant implementations

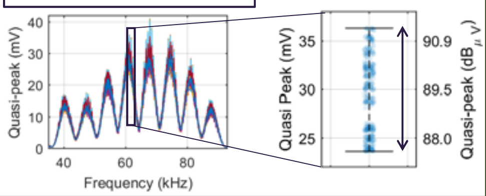
Constant emission (PV)



Max dif. = 15.7 mV / Median = 51.7 mV = **30.4%**

Max dif. = 2.6 $dB_{\mu V}$
Median = 94.3 $dB_{\mu V}$

Variable emission (PLC)



Max dif. = 12.7 mV / Median = 29.9 mV = **42.4%**

Max dif. = 3.7 $dB_{\mu V}$
Median = 89.5 $dB_{\mu V}$

- Accuracy requirements permit range of values, BUT what is the "true" value ?

Possible grid measurement method
Computational costs

	IEC 61000-4-7 200 ms	CISPR 16 100 Hz step	CISPR 16 50 Hz step
Sampling frequency	327.68 kHz	409.6 kHz	409.6 kHz
Window length	200 ms	20 ms	
Single FFT size	65,536	8,192	
Number of FFTs per 200 ms	1	181	
Number of final frequency components	710	1410	2820
$\frac{\text{Number of operations}}{\text{Number of operations for Method A}}$	**1**	**22**	**28**
FFT stage	82%	72%	58%

- Number of operations for digital CISPR 16 implementation exceeds IEC 61000-4-7 (further reduction for IEC 61000-4-7 for shorter window length)
- Main drivers:
  - overlap increases number of FFTs
  - number of parallel quasi-peak detectors

Possible grid measurement method
Long-term measurements: established methodologies (IEC 61000-4-7)

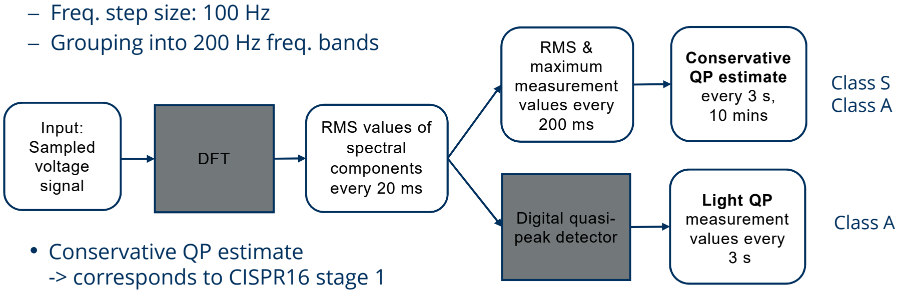
	Harmonics (interharmonics)	Emission in the range 2-9 kHz
Measurement		
Interval	10/12 cycles	200 ms
Results	$U_{\text{RMS}}^{(h,ih)}$, $I_{\text{RMS}}^{(h,ih)}$, THDu, THDi subgroup values	$U_{\text{RMS}}^{(b)}$, $I_{\text{RMS}}^{(b)}$ 200-Hz-bands
Aggregation		
Common Intervals	150/180 cycles, 10 min	3s, 10 min
Method	RMS and Maximum	
	• *RMS values: (thermal) stress of components* • *Max values: perceptible malfunctions*	
Evaluation	• Comparison of weekly 95th percentile of 10-minute-values • Comparison of daily 99th percentile of 3-s-values	

"Compatibility" of new method highly beneficial

Possible grid measurement method

Proposal to IEC SC77A WG9

- Motivation: design a method that meets the requirements for grid measurements and enables comparison with CL
- Similar principle as Method A (IEC 61000-4-7, 2-9 kHz range)
  - Measurement interval: 20 ms rectangular window
  - Time overlap: 0% (no overlap)
  - Freq. step size: 100 Hz
  - Grouping into 200 Hz freq. bands

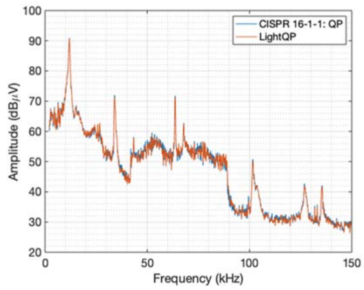


- Conservative QP estimate
  -> corresponds to CISPR16 stage 1
- Light QP
  -> corresponds to CISPR16 stage 2

Possible grid measurement method

Features of the proposal (1)

- Light QP values are comparable to digital CISPR 16 QP values

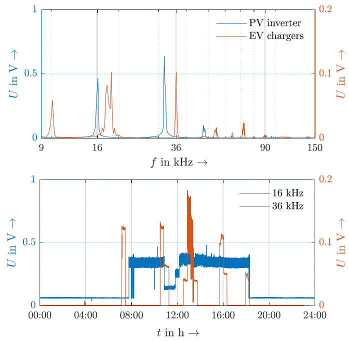


- Lower computational complexity than CISPR 16 means potential for cheaper instruments
- Compatibility to the present methodology for long-term measurements (availability of time characteristics)
- RMS and Maximum values representative of important interference mechanisms

Possible grid measurement method

Features of the proposal (2)

- Implementation of methods on a hardware platform (Light QP still ongoing)
- Measurement of multiple EV chargers in urban network (one working day)
- Measurement of PV inverter in a rural network (one week)

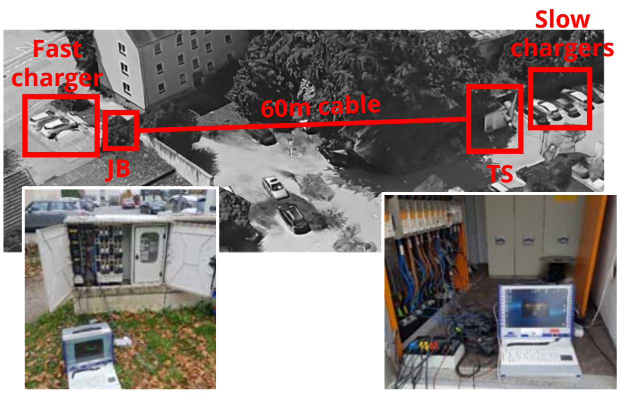


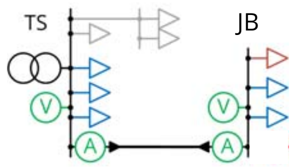
	EV charger (3-s-aggregation)			PV inverter (10-min-aggregation)	
	10 kHz	**18 kHz**	**36 kHz**	**16 kHz**	**32 kHz**
Compatibility level	2.8 V	2.1 V	1.1 V	2.2 V	1.2 V
CISPR 16-1-1, U_{QP}	75 mV	178 mV	166 mV	579 mV	786 mV
Conservative QP estimate	90 mV *(+19%)*	219 mV *(+23%)*	202 mV *(+22%)*	745 mV *(+29%)*	987 mV *(+26%)*

Interference case example

Propagation measurement

- Injection of frequency sweep at begin (TS) and end (JB) of cable
- GPS-synchronized recording of waveform data (1MS/s, 16 Bit) at TS and JB followed by offline processing



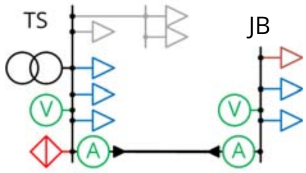


Injection device

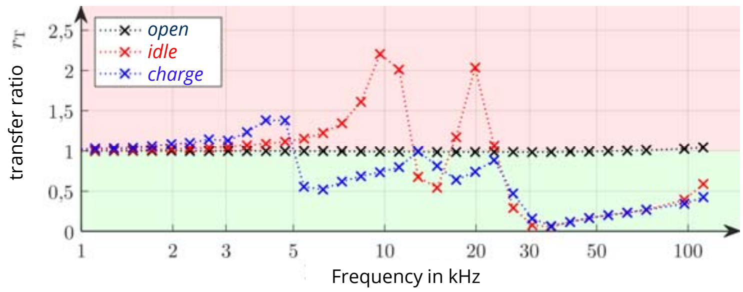
Interference case example

Measurement results for downstream propagation

- Different operating conditions of the fast charger at JB (Disconnected/Open, Standby, Charging)
- Significant amplification at 10 kHz due to series resonance
- Effective damping in upstream direction



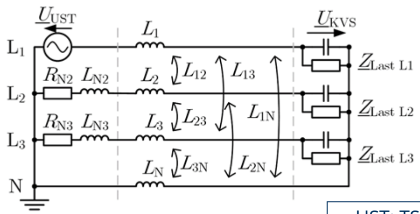
Measurement results



Interference case example

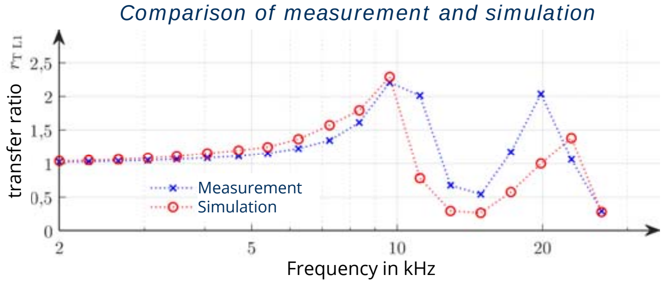
Simulation and comparison with measurements results

- Simplified model of fast charging station, cable and coupling by other connected loads
- Simulation of a single-phase injection
- Good match up to first resonance



UST: TS
KVS: JB
Last: load

Comparison of measurement and simulation



Conclusion

Some final (personal) thoughts …

- What accuracy and reproducibility is required for a class A instrument ?
  - ±5% … ±10% seems to be more reasonable compared to about ±25%
- What indices should be reported ?
  - RMS and Maximum values
  - Individual frequency bands and integral values
  - QP values only, if no other way is acceptable for compliance assessment
  - Currents should also be measured (correlation with voltages must be possible)
- What aggregation method should be used ?
  - Keep time characteristics and commonly used aggregation stages (3s, 10min)
- Should there by additional guidance on interpretation of compatibility levels ?
  - Use of simpler methods/indices along with a (conservative) translation factor
  - It is questionable if a grid can be treated similiar to a EUT
- Is only a strict CISPR 16 compliant implementation and assessment acceptable ?
  - Possibly high implementation costs might not justify this at least for class S

Needs and challenges related to a normative method for grid measurements in the frequency range 2-150 kHz 21

Thank you for your attention

Laboratory measurement of heating due to supraharmonics

Field test of distributed charging

Measurement in a solar plant

Lab stand for equipment testing

Grid impedance measurement

Measurement in a central charging infrastructure

Contact:
jan.meyer@tu-dresden.de