TECHNISCHE UNIVERSITÄT DRESDEN

DRESDEN concept

EPE 2023

Institute of Electrical Power Systems and High Voltage Engineering

Jan Meyer

Robert Stiegler, Sascha Müller, Victor Khokhlov, Elias Kaufhold, Ana-Maria Blanco

Energy Efficiency versus Power Quality

Challenges Related to Modern Power Electronics in Low Voltage Networks

23rd International Conference on Electric Power Engineering (EPE)
24th to 26th May 2023, Brno, Czech Republic

Background

General disturbance mechanism

EPE 2023

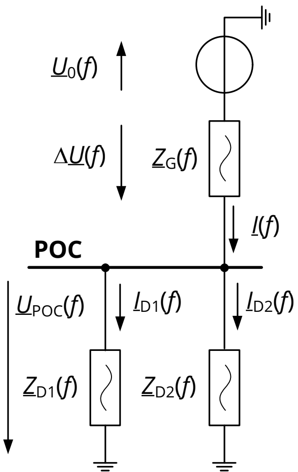
Mechanism

Device D1 draws „non-ideal" current

„Non-ideal " voltage drop at network impedance $\underline{Z}_{sc}$

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

Disturbance of device D2



Impact factors

Background Voltage

Grid-side impedance

Current (emission)

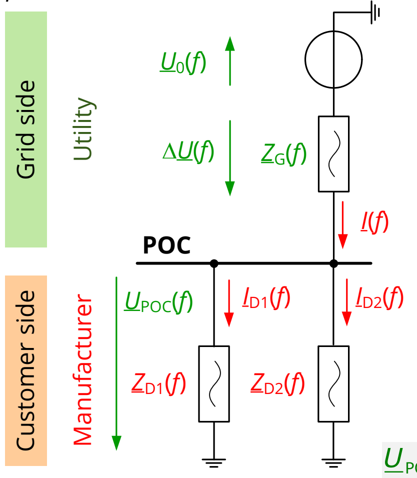
Device admittance

Background
General disturbance mechanism

Mechanism

- Device D1 draws „non-ideal" current
- „Non-ideal " voltage drop at network impedance $\underline{Z}_{sc}$
- „Non-ideal" voltage at Point of Connection (POC)
- Disturbance of device D2

Responsibilities



Impact factors

- Background Voltage
- Grid-side impedance
- Current (emission)
- Device admittance

$$\underline{U}_{POC}(f) = \underline{U}_0(f) - \underline{I}(f) \cdot \underline{Z}_G(f)$$

TECHNISCHE UNIVERSITÄT DRESDEN

Energie Efficiency vs. Power Quality
Challenges Related to Modern Power Electronics in Low Voltage Networks
Jan Meyer, 24.05.2023, EPE Conference, Brno

Slide 3

DRESDEN concept

Background
What is Quality ?

General definition:
- Characteristics of an <*object*> expressed by quantitative/measurable parameters (reference values)

Quality indices for coffee
- Color
- Intensity
- Temperature
- …

Power quality (IEC 61000-4-30 Ed.3)
- characteristics of the *electricity* (voltage, current) at a given point on an electrical system, evaluated against a set of reference technical parameters

"Ideal" waveform of voltage/current means best quality. Deviations from this ideal waveform mean disturbances (degradation of quality)

TECHNISCHE UNIVERSITÄT DRESDEN

Energie Efficiency vs. Power Quality
Challenges Related to Modern Power Electronics in Low Voltage Networks
Jan Meyer, 24.05.2023, EPE Conference, Brno

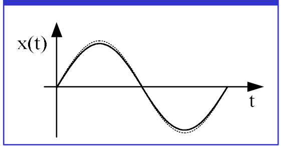
Slide 4

DRESDEN concept

Background
Power Quality characteristics

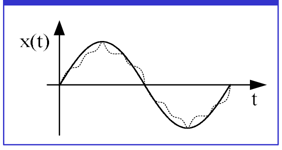
Qualification based on features of voltage and current waveform "appearance"

Magnitude



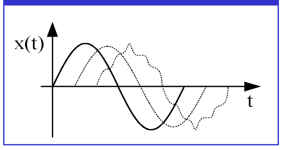
- RMS voltage

Distortion



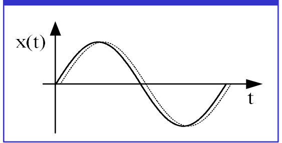
- Harmonic level

Symmetry



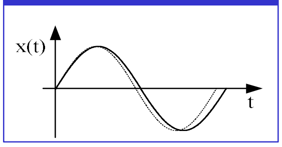
- Neg. sequence unbalance

Phase



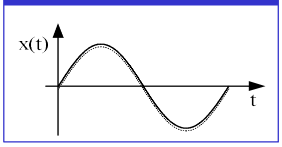
- Displacement factor

Frequency



- Power frequency

Offset



- DC

Background
Principle of EMC coordination

Ability of equipment or a system to **function satisfactorily** in its electromagnetic environment **without** introducing **intolerable** electromagnetic **disturbances** to anything in that environment

Enforced in Europe by EU directive 2014/30/EU

Need for (probabilistic) coordination of immunity and emission based on reference levels (compatibility levels)

Adequate limited Emission < Compatibility levels < Adequate limited Immunity

Critical (periodic) assessment of relevant interference mechanisms

Main objective of coordination:

Manufacturer costs + network operator costs = Minimal and fair distribution → **EMC standardization framework**

Challenges
Overview

- Significant changes on grid side and customer side driven by energy-efficiency policies including sector coupling approaches

Equipment level:

- New technologies with reduced energy demand and improved efficiency
  (e.g. Electric Vehicle charging, LED lighting, …)
  - ➢ Increase of rectifier topologies with active frontend and active Power Factor Correction

Customer level:

- Energy consumption optimization
  (PV-installations, μCHPs, battery storage systems, heat pumps, …)
  - ➢ Increase of single-phase/three-phase inverters/converters

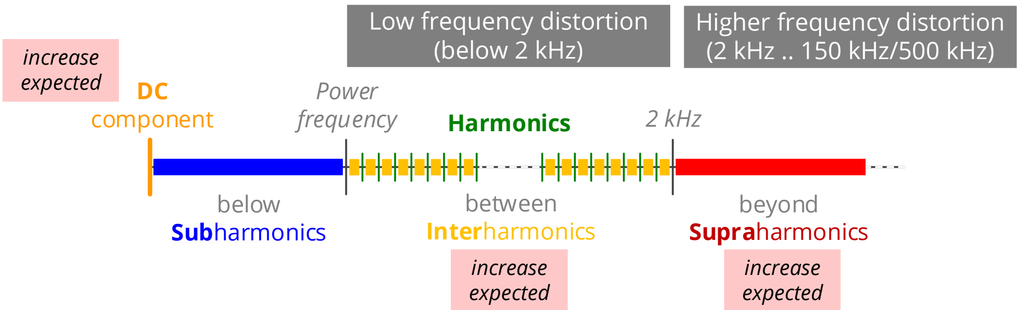
➢ **Increase of modern power electronics (higher flexibility)**

(Electric) efficiency is only considered at power frequency !
How does these development impact distortion levels in the grid ?

www.solar-solar.de

Challenges
Expected future trends in distortion

Emission:



Impedance:

- Increase of capacitances due to grid-side filter circuits expected (increasing risk of resonances below and above 2 kHz

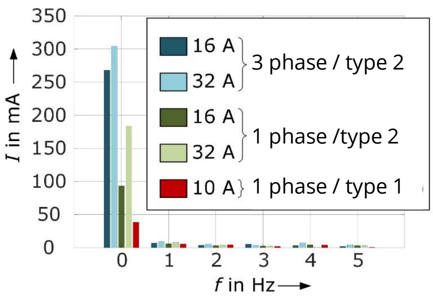
Challenges
Effects of distortion (interference mechanisms)

- Life time reduction of capacitors and motors due to additional thermal stress
- Acoustic disturbances of network elements with electromagnetic circuits (inductors, transformers or motors)
- Disturbance of power line communication and ripple control
- Increased loading of neutral conductor, higher losses in the network
- Malfunction of electronic devices (e.g. due to multiple zero-crossings, unintentional activation of touch elements)
- Flicker in modern lamps
- Malfunction of protection devices and impact on control of modern power electornic equipment
- Saturation of iron cores, e.g. on supply transformers

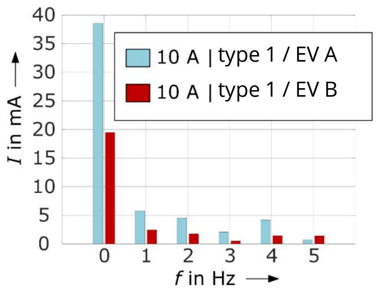
Destroyed DC-link capacitor of a UPS

Equipment level
DC emission

Different charging modes for one EV



Different EV in same charging mode

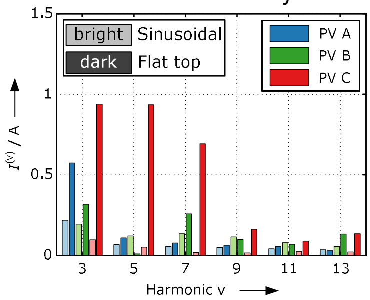


- Laboratory measurement at (undistorted) 230 V/50 Hz supply voltage (1-sec-interval)
- Significant DC component in phase current

New emission behaviour requires knowledge about possible impacts and interference mechanisms and suitable limits.

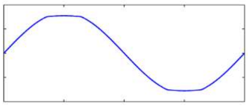
Equipment level
Harmonic emission

Current harmonics of 3 PVs



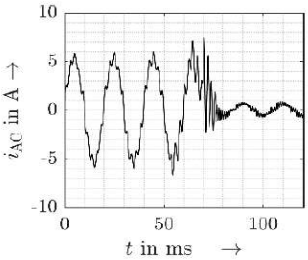
- Present test conditions require only a sinusoidal supply voltage

Flat top waveform



- Significant impact of supply voltage distortion on the harmonic behaviour
- Qualitative different behaviour compared to „classical PE devices"

Harmonic instability of a PVI

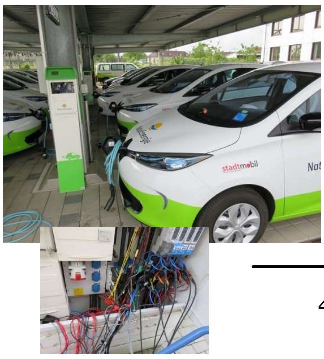


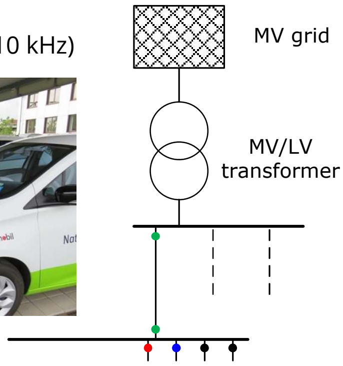
- Tripping only in presence of background distortion
- Not identified by impedance-based stability assessment

Modern, energy-efficient equipment still generates harmonics, which can by very sensitive to supply voltage distortion (new/updated standards needed).

Equipment level
Supraharmonic emission

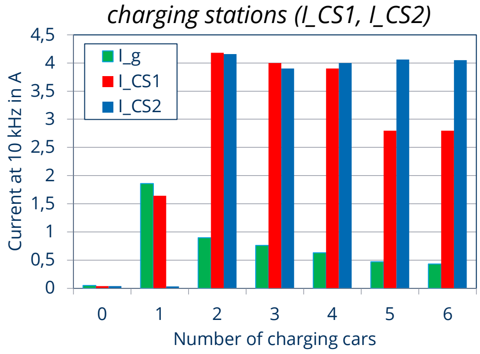
- Stepwise connection of 6 EVs of same type (switching frequency 10 kHz)





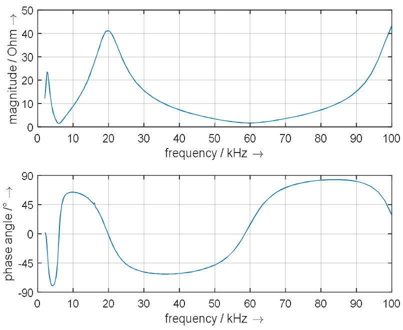
- *Measurement devices*

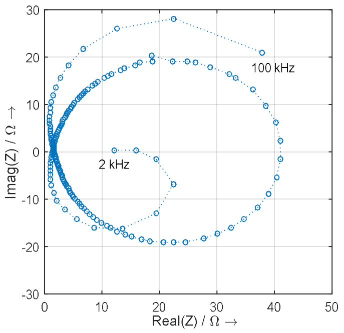
Current of feeder (I_g) and two charging stations (I_CS1, I_CS2)



Increasing emission in the frequency range 2-150 kHz requires complete standardization framework

Equipment level
Input impedance characteristic



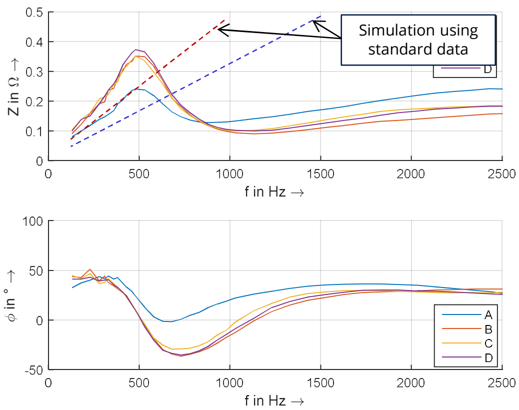


- Large frequency ranges with capacitive, low-impedance characteristic and multiple resonance points
- Similar behaviour observed for EV chargers

Increase of grid-side filter circuits with capacitive characteristic can increase the risk of resonances at lower harmonic orders

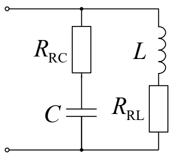
System level
Resonances in the harmonic range (1)

Measured impedance at different locations in a LV network



- Residential LV network with 240 customers with elevated disturbance levels around 10th harmonic (customer complaints about TV malfunction)
- Distinctive parallel resonance at 500 Hz (respective series resonance on MV side)
- Significant amplification of ripple control signal (just below 500 Hz)
- Standard load models not suitable for harmonic studies

New impedance model of households

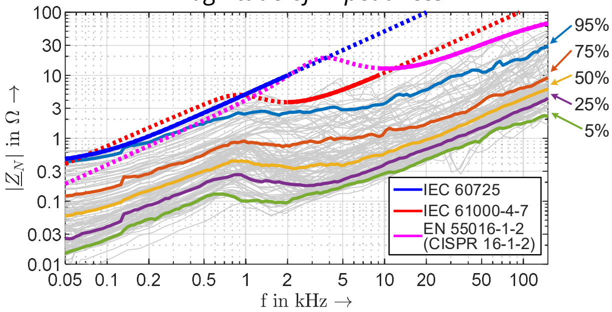


$R_{RC} \approx 0{,}5\ \Omega$
$C \approx 5\ \mu F$
$L \approx 95$ mH
$R_{RL} \approx 130\ \Omega$

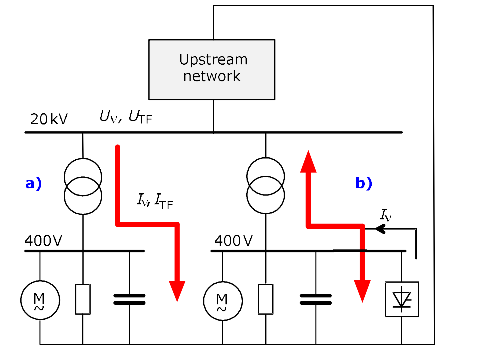
System level
Resonances in the harmonic range (2)

- Survey of grid impedance in public LV networks
- 198 loop impedances measured at 76 different sites in AT, CH, CZ and GE (25 % at transformer busbar 75 % at junction boxes)

Magnitude of impedances



Typical resonance situations in distribution networks



a) Series resonance (critical excitation: voltage)
b) Parallel resonance (critical excitation: current)

System level
Resonances in the supraharmonic range (1)

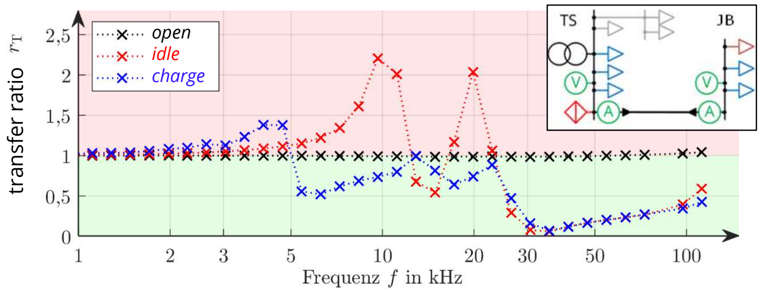
- Charging points located at transformer station (TS) and junction box (JB)
  - Slow charging points at TS
  - Fast charger (FS) at JB
- Slow charging EV at TS -> Fast charger at JB in standby mode
  - Fast charger emits annyoable noise
  - Increase of supraharmonic voltage at switching frequency of the slow charging EV at 10 kHz from 0.6 V (TS) to 2.3 V (JB) (factor of 3.8)

Source: Google Maps

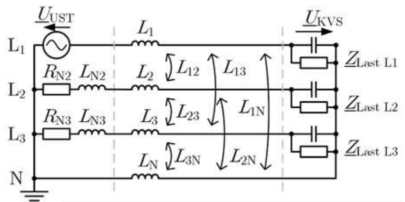
System level
Resonances in the supraharmonic range (2)

- State of the fast charger at JB:
  - Disconnected (open)
  - Standby operation (idle)
  - Charging operation (charge)
- Significant (downstream) series resonance amplification (10/20 kHz)

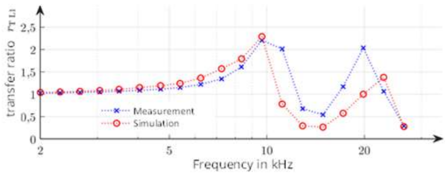
Measurement results (downstream propagation)



Simulation results

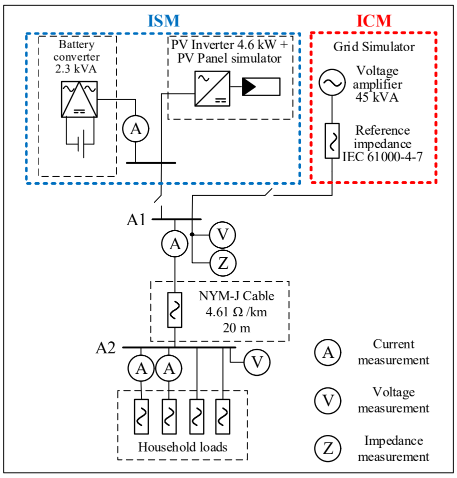


UST -> TS KVS -> JB Last -> load



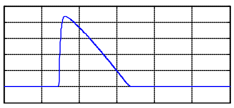
System level
100% power electronic based networks (1)

Test setup in the laboratory

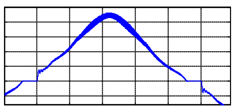


- ICM (Interconnected mode): background voltage harmonics with flat-top characteristics
- ISM (Islanded mode): Variation of contribution from PV inverter and battery converter
- Test of four different load scenarios
  L1: no PFC scenario
  L2: active PFC scenario
  L3: passive scenario (no power electronics)
  MI: mixed scenario

Current (no PFC)

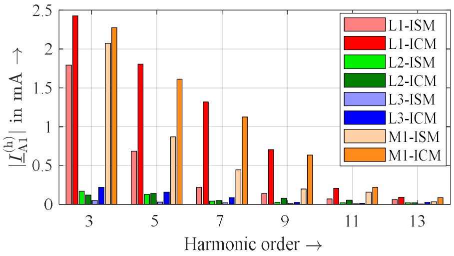


Current (active PFC)

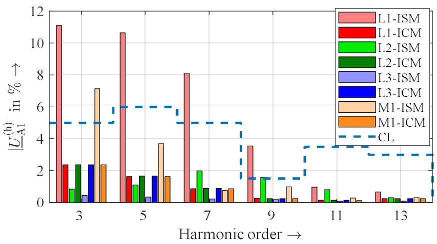


System level
100% power electronic based networks (2)

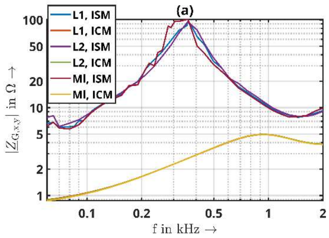
Harmonic current emission



Harmonic voltage levels



Grid-side impedance



- Current harmonics tend to be lower in ISM compared to ICM
- Voltage harmonics in ISM much more sensitive compared to ICM with some voltage harmonics above the compatibility limits (CL)
- Grid-side impedance is significantly higher for ISM with a dedicated resonance

„Grid-forming“ must consider the whole frequency range, but not only power frequency.
Revision of the meaning of short-circuit power in EMC coordination required ?

System level
Load shaving / self consumption optimization (1)

- Determination of emission limits based on "cake – concept"
  1. Share compatibility level between voltage levels (global contribution)
  2. Share global contribution between installations (and devices) connected within voltage level

System

Voltage level

Device/installation

Share of global contribution within voltage level:

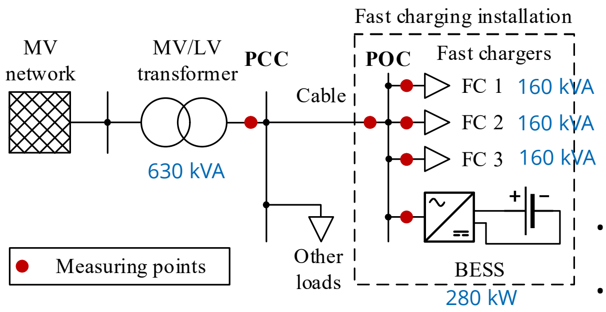
- Determination of total supply capacity (e.g. rated power of supply transformer)
- Emission limit for installation determined based on contracted power S_A in relation to total supply capacity

Simplified evaluation acc. to D-A-CH-CZ guideline

$$u_h = F_h \cdot \sqrt{\frac{S_A}{S_{SC}}}$$

System level
Load shaving / self consumption optimization (2)

Connection configuration



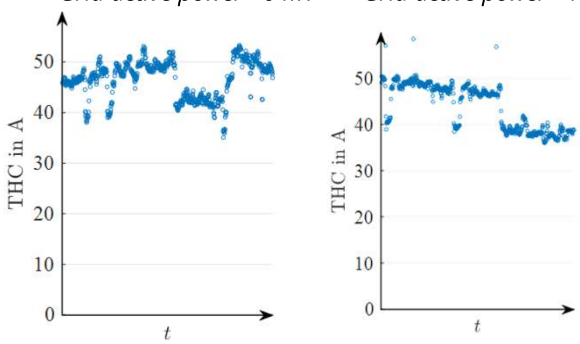
- Request for the connection of a fast charging installation with 3 fast chargers (S_r = 160 kVA)
- Contracted power of 480 kVA requested (76% of available supply capacity)

- DSO permits only a contracted power of 200 kVA due to already existing utilization/margins
- Need for a battery energy storage system (BESS) for load shaving with a power of 280 kVA

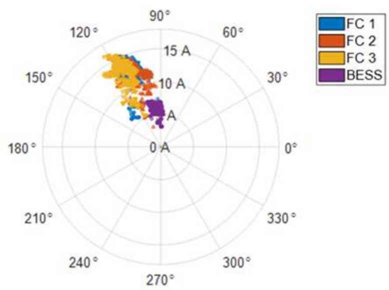
System level
Load shaving / self consumption optimization (3)

Measurement results (THC in the feeder)

Grid active power ~0 kW *Grid active power ~140 kW*



7th harmonic current
(Grid active power ~0 kW)



- High harmonic current emission independent of fundamental power of the installation
- No considerable cancellation for 7th harmonic

Feasible method to set reasonable harmonic emission limits ?

Closing thoughts

- Modern (power electronic) equipment, new customer control schemes, alternative grid design solutions require a re-thinking of classical approaches
- Impedance characteristic of modern power electronic equipment can significantly impact the network impedance
  Create awareness in standardization !
- Power Quality should become part of network planning and asset management in the future
  Create awareness at utilities !
- Efficiency is not only a matter of power frequency, but has to be considered more comprehensive (high energy efficiency not necessarily means "grid-friendly")
  Create awareness in politics !

Much more academic research required as solid basis !

Closing thoughts

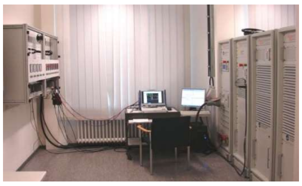
- Power Quality should never used as excuse to block new technologies, but it should also not be forgotten (unwanted child issue)
- Coexistence of old and new technologies is required for a smooth transitions to modern power grids

Thank you for your attention !

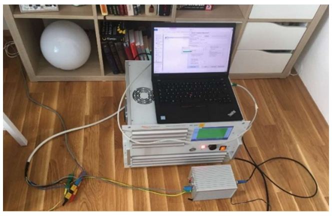
Laboratory measurement of heating due to supraharmonics

Field measurement in a solar plant

Field test of distributed charging



Lab stand for equipment testing



Measurement of grid impedance at an outlet

TECHNISCHE UNIVERSITÄT DRESDEN

Energie Efficiency vs. Power Quality
Challenges Related to Modern Power Electronics in Low Voltage Networks
Jan Meyer, 24.05.2023, EPE Conference, Brno

Slide 25

DRESDEN concept