Elaadnl

Tuesday February 4th 2025

Symposium EMC of EV Charging: a Power Quality perspective

NEDERLANDSE EMC-ESD VERENIGING

VSL

National Metrology Institute

EUROPEAN PARTNERSHIP

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METROLOGY PARTNERSHIP

EURAMET

Met4EVCS

Metrology for Electric Vehicle Charging Systems

Metrology for Electric Vehicle Charging Systems

Helko van den Brom

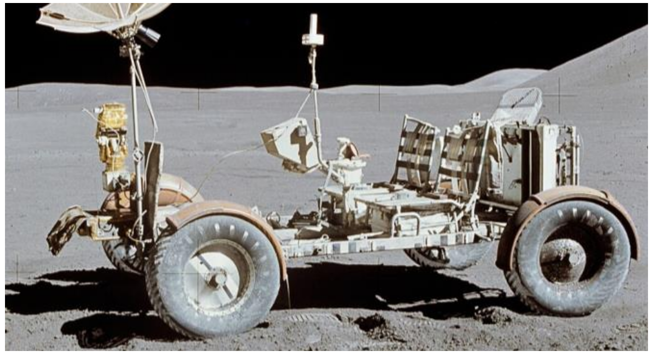
VSL B.V.

Symposium EMC of EV Charging: a Power Quality Perspective, 4 February 2025, Elaad, Arnhem (NL)

About VSL

- National Metrology Institute of the Netherlands
- Company with a public task
- 100 fte, 40 % MSc or PhD
- Calibrations, reference materials, R&D, consultancy, training
- Focus on energy and industry
- Located in Delft, the Netherlands

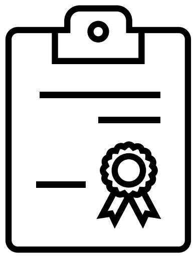
Electric vehicles



EV charging stations

Standardisation and Regulation

- IEC/CENELEC TC 13
- IEC TC 69
- OIML TC 12 “Instruments for measuring electrical quantities”
- WELMEC WG 11 “Utility meters”
- EC WgMI E01349



- IEC 61851: EV conductive charging systems, including general requirements and different charging modes
- EN 50732: Requirements for measuring systems for stationary conductive DC and AC supply equipment
- OIML G22: EVSE metrological and technical requirements, metrological controls and performance tests
- IEC 62052-11: Specifies the general requirements for electricity meters for residential and similar use.
- IEC 62053-41: Test methods for active electrical energy meters.
- EN 50470-3/4: Requirements for electricity meters for AC / DC active energy.

- MID (2014/32/EU): envisaged amendment to include EVCS

Met4EVCS consortium

23NRM06 Met4EVCS project

- 1 July 2024 – 30 June 2027
- Project website www.vsl.nl/en/met4evcs/
- Funded by the European Partnership on Metrology, co-financed from the EU's Horizon Europe Programme and by the Participating States.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EURAMET. Neither the European Union nor the granting authority can be held responsible for them.

The project has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

- Supported by European Metrology Network on Smart Electricity Grids (EMN-SEG) *www.euramet.org/smart-electricity-grids*
  - Aim: make next step in coordination of national activities; provide single point of contact for stakeholders, increase coherence in R&D efforts, maximise R&D impact
  - Activities: Strategic Research Agenda (SRA), website, newsletter, liaisons, sustainable infrastructure, training program

Met4EVCS aim and technical objectives (1)

Overall aim: the development of metrology capabilities for the traceable evaluation of EVCSs under realistic operating conditions.

- Objective 1: To define representative on-site operating conditions for EVCS
  - Onsite measurement of local grid disturbances and local grid impedance for frequencies up to 150 kHz under live grid operation
  - 5 DC and 5 AC chargers of different brands, operating modes and power levels

Met4EVCS aim and technical objectives (2)

Overall aim: the development of metrology capabilities for the traceable evaluation of EVCSs under realistic operating conditions.

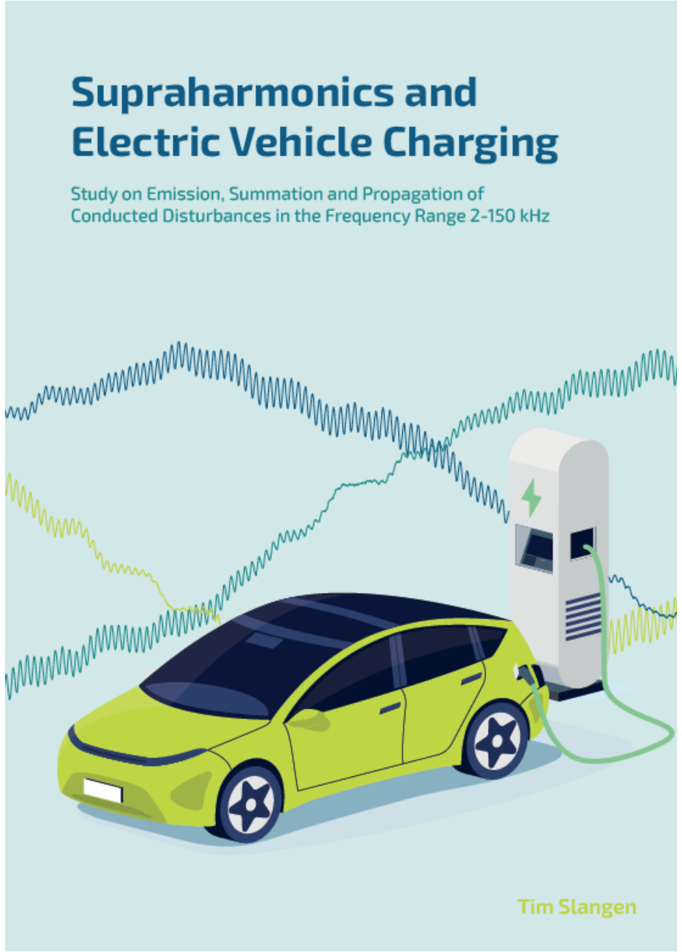
- Objective 2: To develop traceable methods and test benches for the characterisation of EVCSs under representative operating conditions for both AC and DC charging following IEC 61851-1
  - AC at 230 V up to 44 kW
  - DC up to 800 V, 500 A, 350 kW
  - Target uncertainty 0.1 % in the presence of conducted emission up to 150 kHz

Met4EVCS aim and technical objectives (3)

Overall aim: the development of metrology capabilities for the traceable evaluation of EVCSs under realistic operating conditions.

- Objective 3: To develop the required metrological infrastructure for on-site verification of EVCS energy metering
  - Target uncertainty 0.5 % under representative conditions
  - Including smart charging and bidirectional energy transfer

Recent literature examples



Electric Power Systems Research
Volume 242, May 2025, 111459

On the definition of measurement use cases for the assessment of LV grid emissions in the supraharmonic (2–500 kHz) region

Alexander Gallarreta [a], Jon González-Ramos [b], Igor Fernández [b], Itziar Angulo [c], Cédric Lavenu [d], Sebastien Gouraud [d], David de la Vega [b], Amaia Arrinda [b]

IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. 70, 2021 9001110

Comparison of Measurement Methods for 2–150-kHz Conducted Emissions in Power Networks

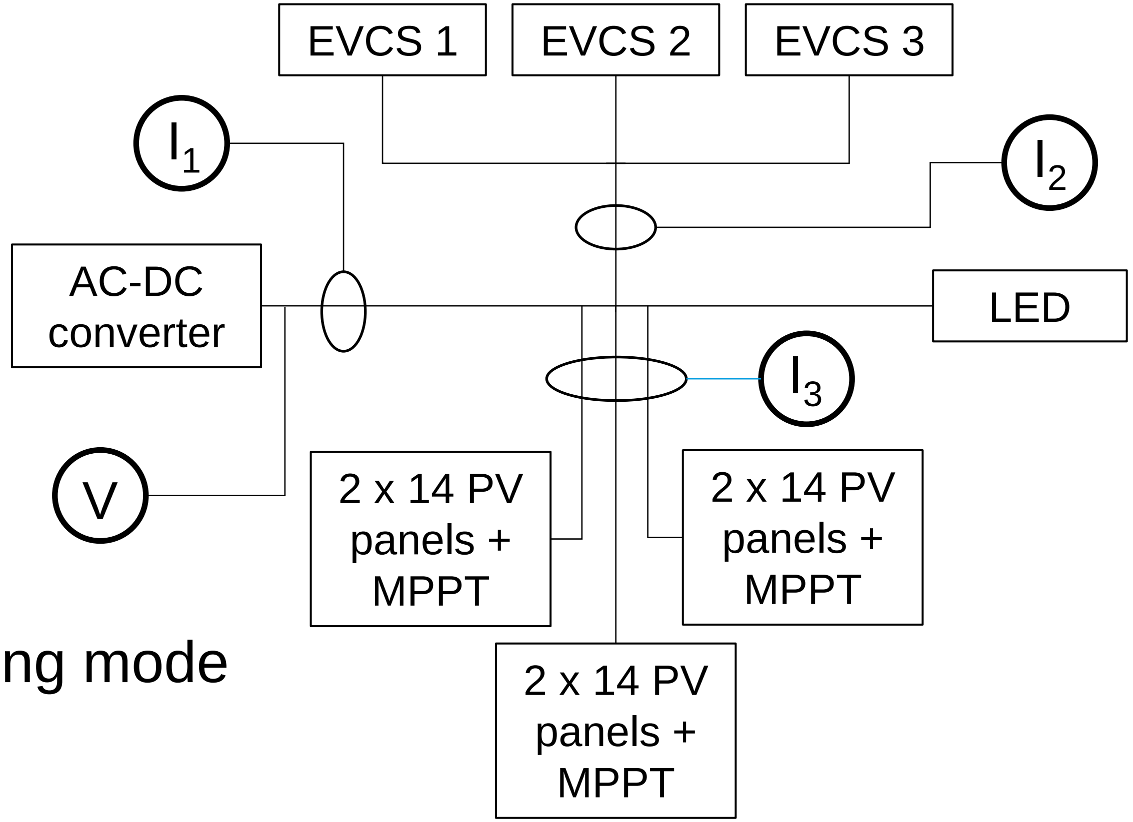
Deborah Ritzmann, Stefano Lodetti, *Member, IEEE*, David de la Vega, *Senior Member, IEEE*, Victor Khokhlov, *Member, IEEE*, Alexander Gallarreta, Paul Wright, Jan Meyer, *Senior Member, IEEE*, Igor Fernández, and Dimitrij Klingbeil

Measurement
Volume 242, Part A, January 2025, 115844

Assessment of Quasi-Stationary Power Quality Phenomena in DC Power Systems

Antonio Delle Femine [a], Daniele Gallo [a], Carmine Landi [a], Mario Luiso [a], Helko E. van den Brom [b], Ronald van Leeuwen [b]

ASR building, Utrecht (NL)



- Open parking garage
- 700 V unipolar voltage
- Grid-connected (bidirectional) or islanding mode

VSL waveform recorder

- Designed for on-site measurements at metered supply points
- DC waveform recorder:
  - Adapted 3-phase *V* & *I* recorder for 50 Hz
  - Minicomputer with dedicated software
  - 8-channel, 12-bit, 1 MSa/s digitizer (Picoscope 4824)
  - 2000 V, 1:1000, 1.0 %, 10 MHz voltage probe (Hioki 9322) with 500 kHz low-pass filter
  - Openable 200 A, 10 mV/A, 0.3 %, 500 kHz current probe (Hioki CT6843-05)
  - Pass-through 50 A, 40 mV/A, 0.03 %, 1 MHz current probe (Hioki CT6862-05)

$$U_{DC} = \frac{1}{n}\sum_{i=0}^{n-1} u_i$$

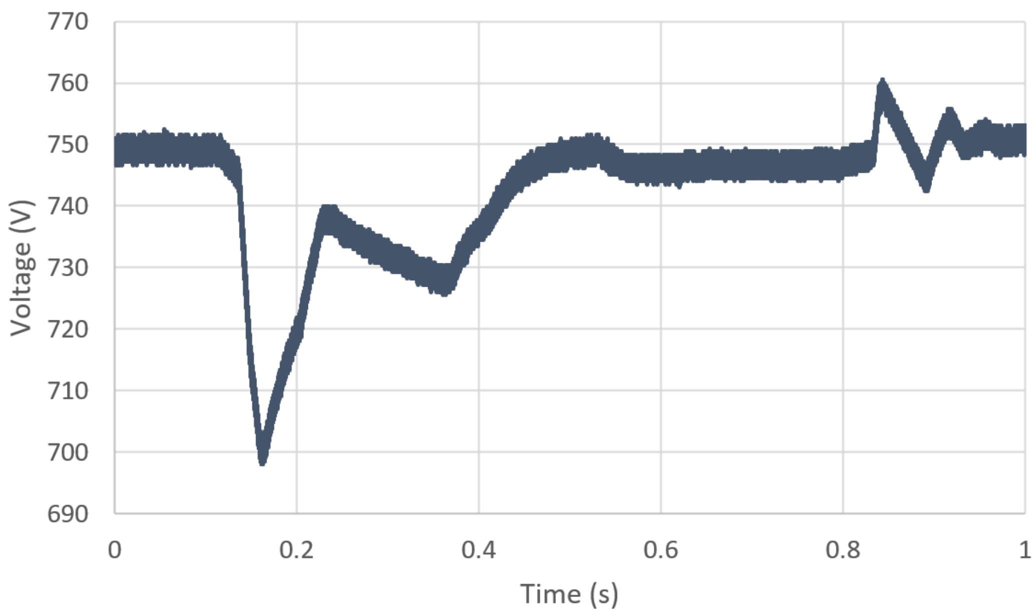
$$U_{rms} = \sqrt{\frac{1}{n}\sum_{i=0}^{n-1} u_i^2}$$

$$U_{rpl} = \sqrt{U_{rms}^2 - U_{DC}^2}$$

H.E. van den Brom, R. van Leeuwen, G. Maroulis, S. Shah, and L. Mackay, “Power Quality Measurement Results for a Configurable Urban Low-Voltage DC Microgrid”, *Energies* 2023, Vol. 16, p. 4623

ASR building, Utrecht (NL)

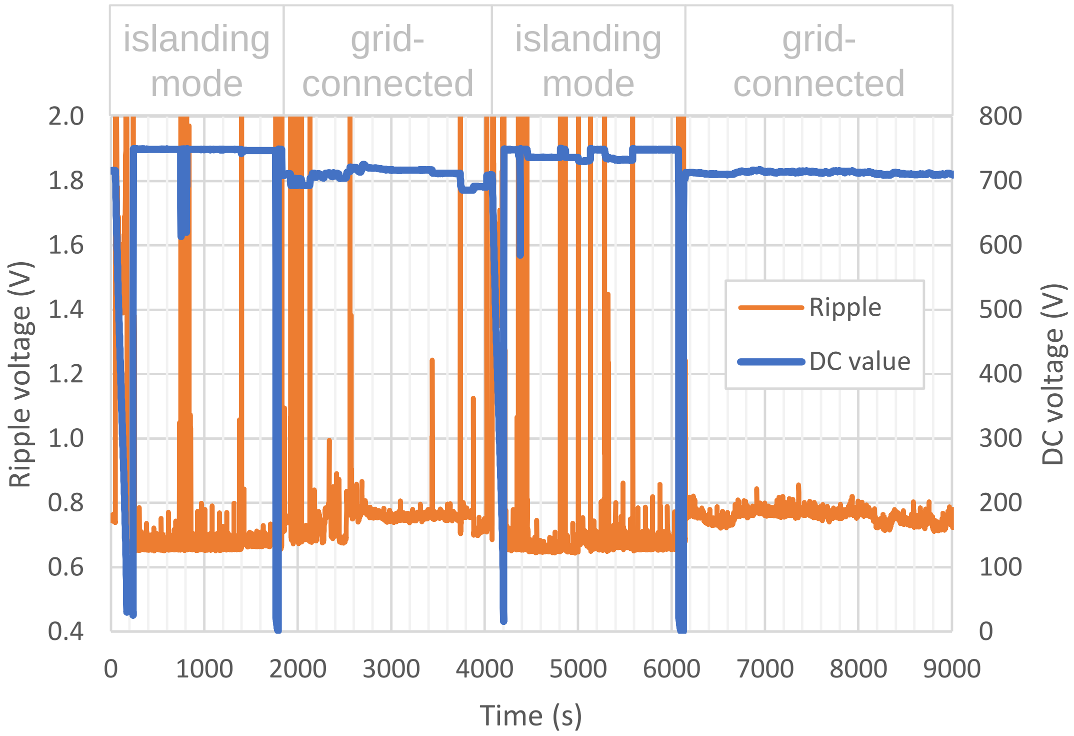
- 2.5 hours of measurements of gapless 1-second time windows, 1 MSa/s
- Partially cloudy day with sunshine, afternoon in September 2023
- Measured different situations, e.g.:
  - EV charging (islanding and grid-connected)
    - Different charging power (max 10 kW)
    - Hyundai Ioniq (CCS) / Nissan Leaf (CHAdeMO)
  - PV feeding the AC grid
  - EV feeding the AC grid

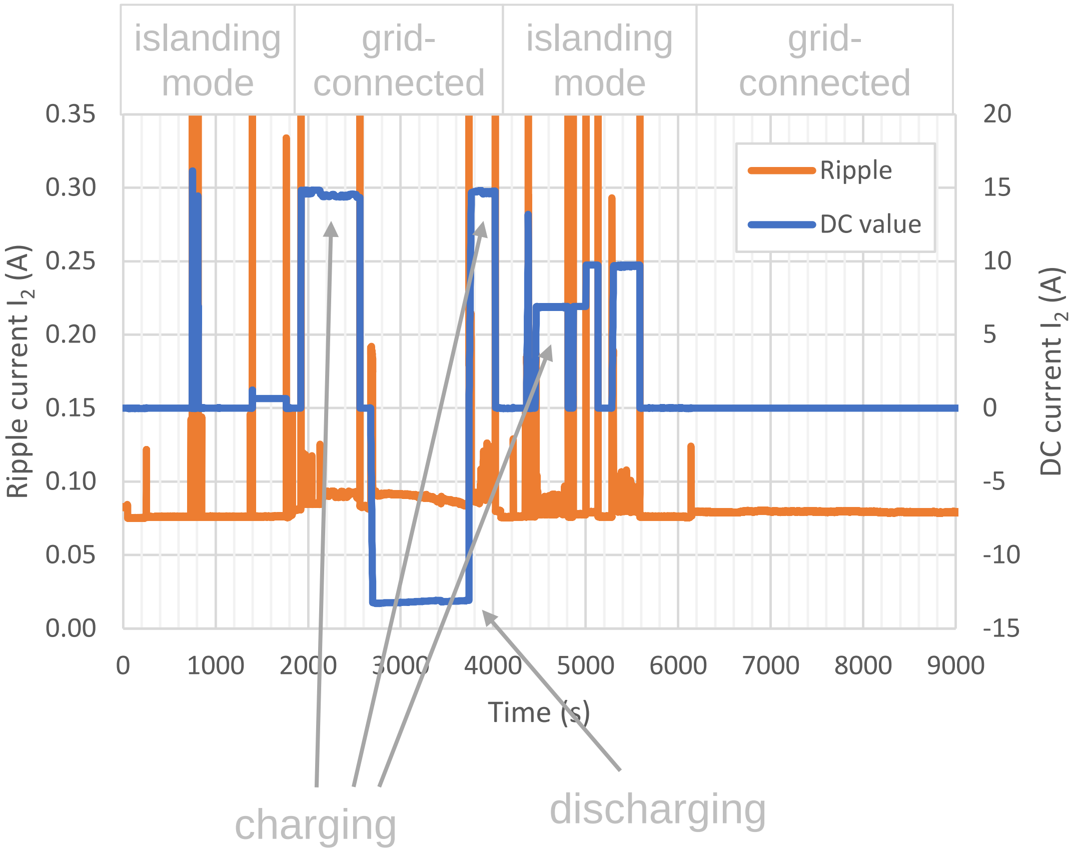


H.E. van den Brom, R. van Leeuwen, J.M. Warmerdam, and R. Schaacke, “Power Quality Measurements in a Low-Voltage DC Microgrid in an Open Parking Garage,” I2MTC, Glasgow, UK, 20-23 May 2024

ASR building: voltage and current ripple

- Voltage/current averaged over 1 s windows





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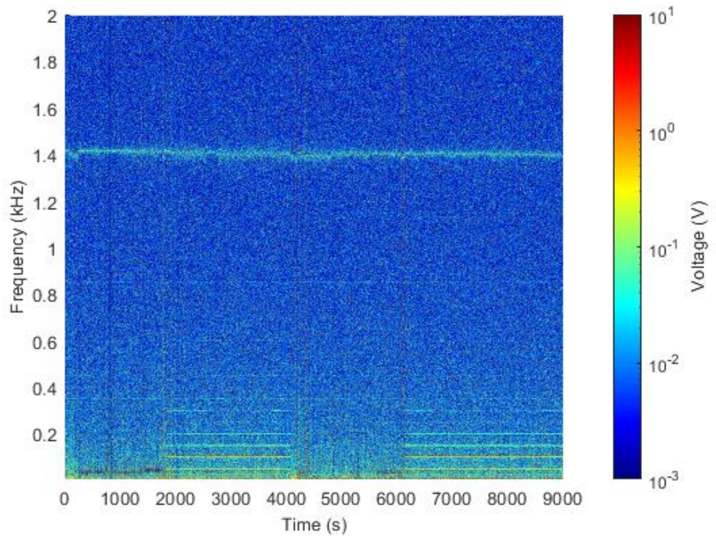
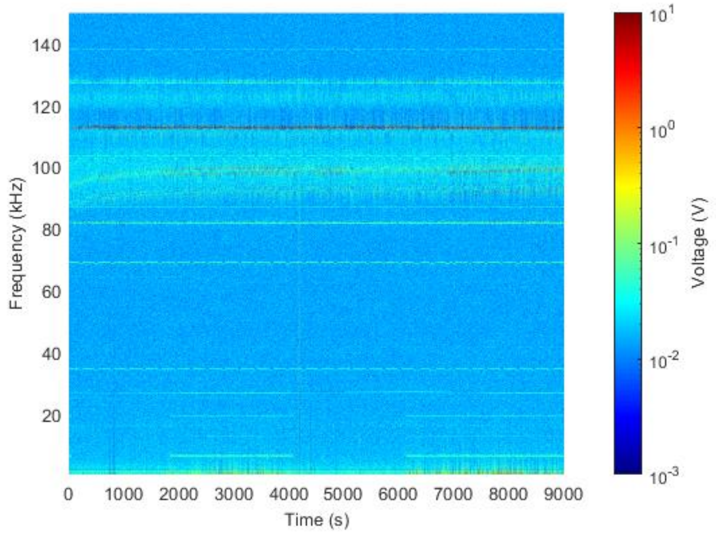
ASR building: Fourier transforms

- Fourier Transforms of voltage samples
  - 5 Hz resolution up to 2 kHz
  - 200 Hz resolution up to 150 kHz
- Spectral components in grid-connected mode:
  - Multiples of 50 Hz
  - Single tones at 7 kHz and 20 kHz
- Persistent components:
  - Tones at 1.4 kHz and several above 30 kHz
  - Major tone at 113 kHz
  - Tone below 100 kHz shows frequency drift
- No clear difference with or without charging



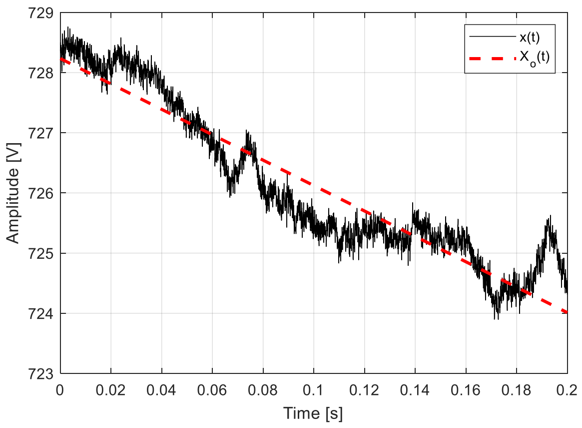


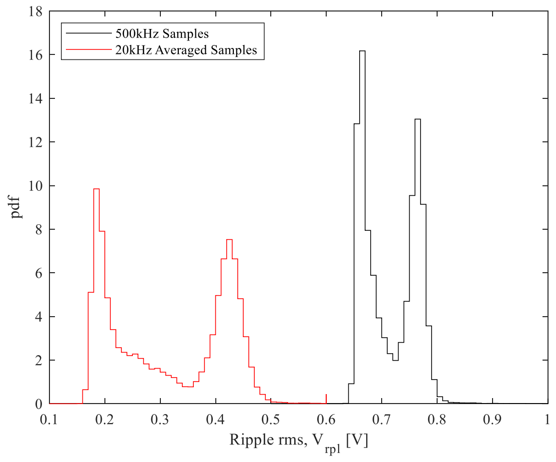
H.E. van den Brom, R. van Leeuwen, J.M. Warmerdam, and R. Schaacke, “Power Quality Measurements in a Low-Voltage DC Microgrid in an Open Parking Garage,” I2MTC, Glasgow, UK, 20-23 May 2024

ASR building: further analysis

- Further analysis performed in collaboration with Campania University:
  - Flagging and detection of events (dips/swells, transients)
  - Ripple with compensation for slow amplitude variation
  - Proposed frequency groups up to 9 kHz and 150 kHz
  - Statistical analysis (probability density, 95 % percentile, …)
  - Influence of reducing sampling rate on statistics and ripple

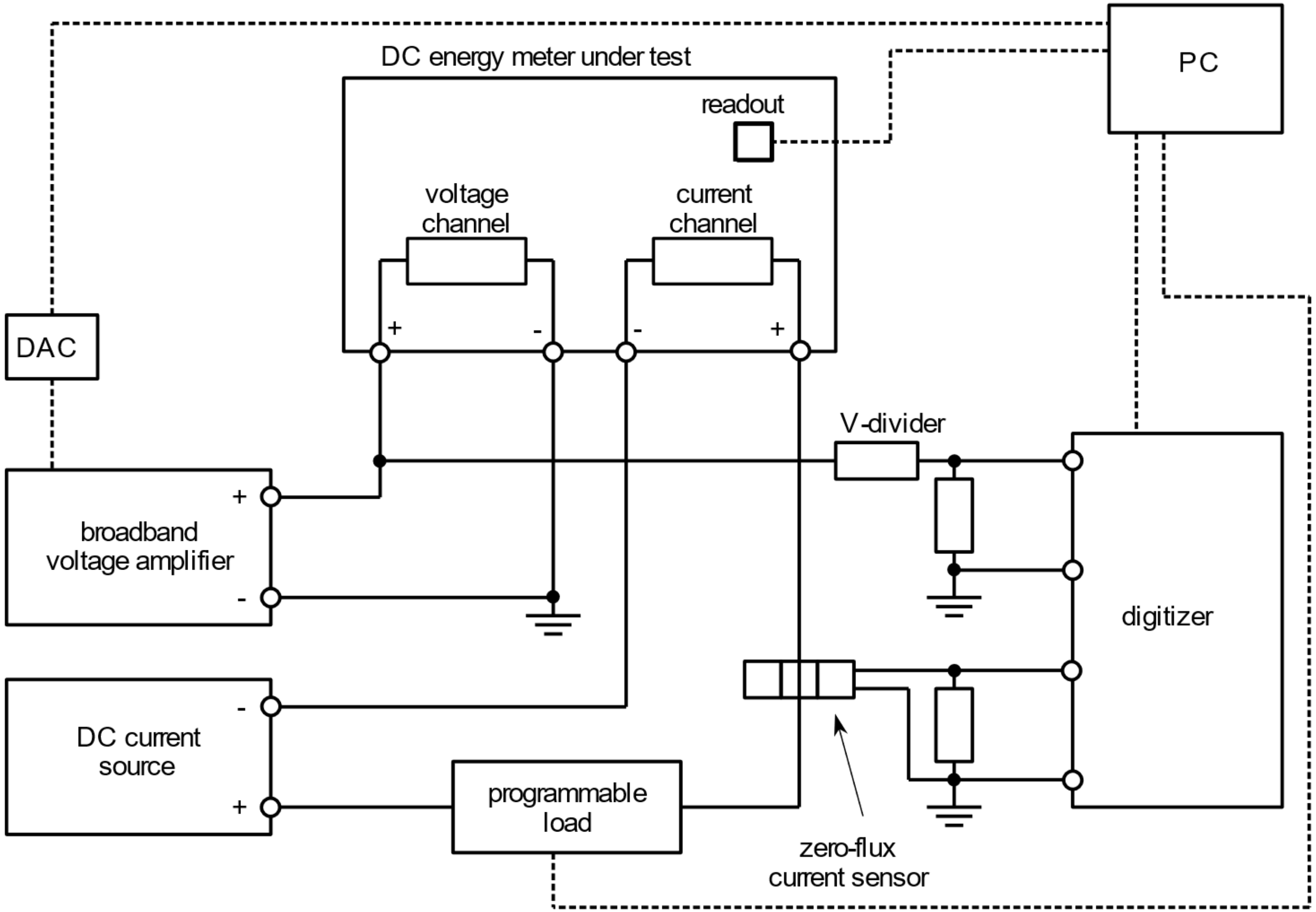
A. Delle Femine, D. Gallo, H. E. van den Brom, C. Landi, M. Luiso, R. van Leeuwen, “Assessment of quasi-stationary Power Quality phenomena in DC power systems”, *Measurement*, Volume 242, Part A, 2025, 115844





- Further analysis performed at EDF
  - Quasi-peak detection (digital-CISPR) for 9 kHz to 150 kHz

VSL reference system for AC & DC PQ

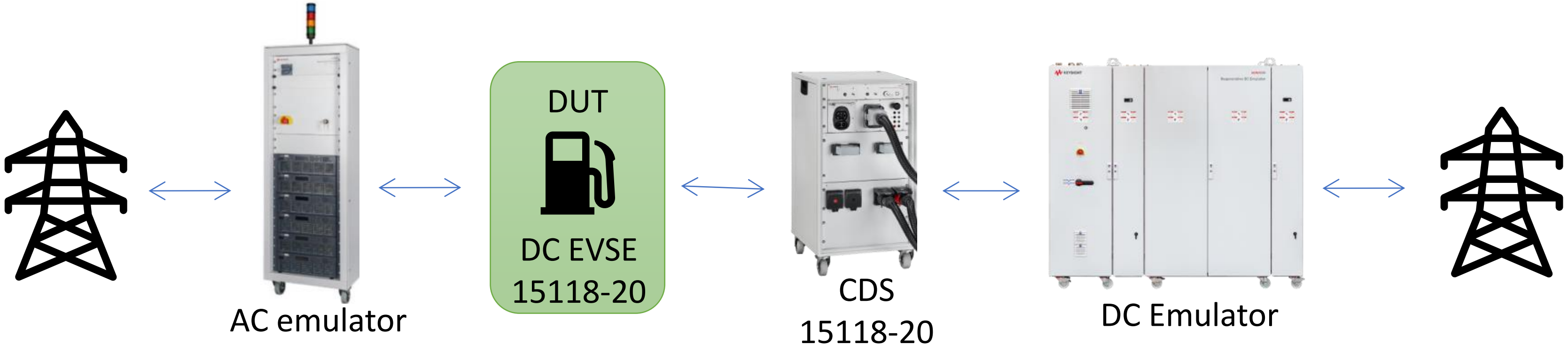


- Phantom power approach
- Broadband signals:
  - DC: 2000 V, 900 A
  - AC: 250 V, 16 A
    (can be extended to 2500 A)
  - DC to 150 kHz
- Not suitable for EVCSs
  → collaborate with Elaad

EVCS DC testbed at Elaad

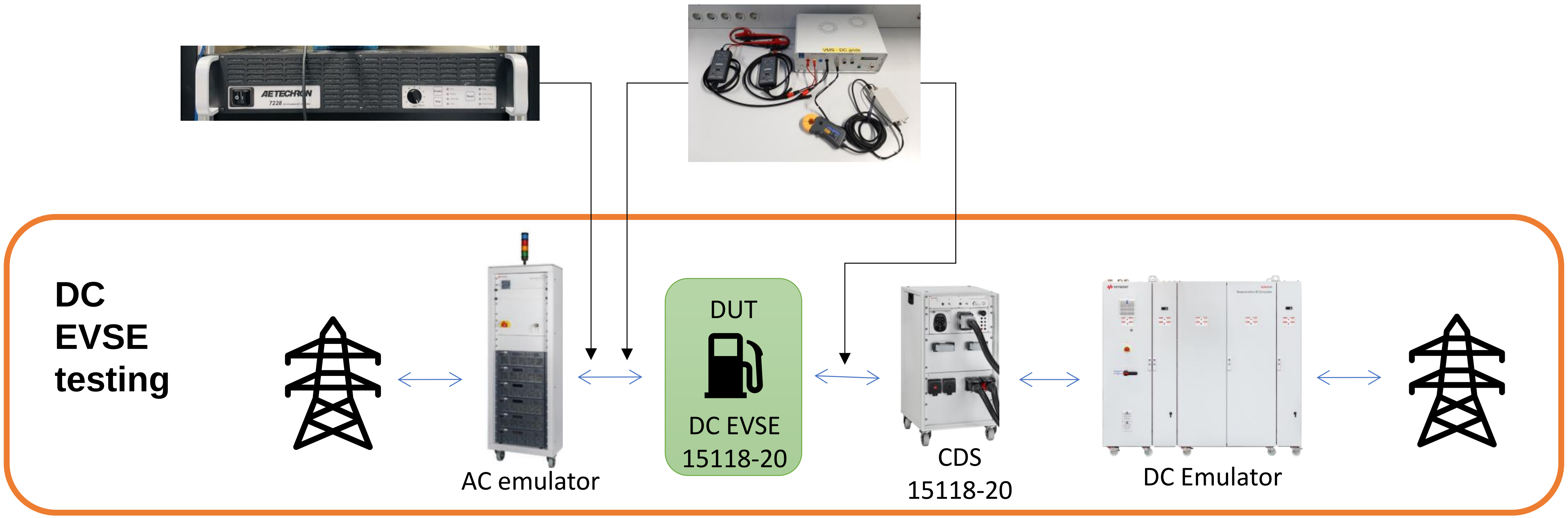
- 360 kW grid emulators; clean or controlled distorted grid for power quality testing
- EV/EVSE emulator; for communication testing, among others 15118-20 (V2G)
- 360 kW Bidirectional DC load; emulate DC charging currents both ways

DC EVSE testing



EVCS DC testbed at Elaad

- Measure AC power in and DC power out → efficiency
- Add broadband distortions up to 150 kHz
- VSL equipment, or Elaad equipment characterized & calibrated by VSL
- Data analysis with University of Twente



Next steps

- To define representative on-site operating conditions for EVCS
  - Onsite measurement of grid disturbances and grid impedance for frequencies up to 150 kHz under live operation
- To develop traceable methods and test benches for the characterisation of EVCSs
  - AC and DC charging at real-world conditions
  - Target uncertainty 0.1 %
- To develop the metrology for on-site verification of EVCS energy metering
  - Target uncertainty 0.5 %
  - Smart charging and bidirectional transfer

- Midterm workshop (end of 2025)
  - Measurements of EVCS conducted emissions and grid impedance
  - Preliminary metrological infrastructure
- Final workshop (mid 2027)
  - New metrology for energy efficiency measurements for EVs and EVCSs
  - Metrological infrastructure for EVCSs
- Ad hoc stakeholder consultation
  - Workshops to obtain feedback
  - Smaller meetings on specific topics

Want to know more?

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Monitoring Power Quality

Arthur M. Hartsuiker

Chairman of the EMC-ESD association

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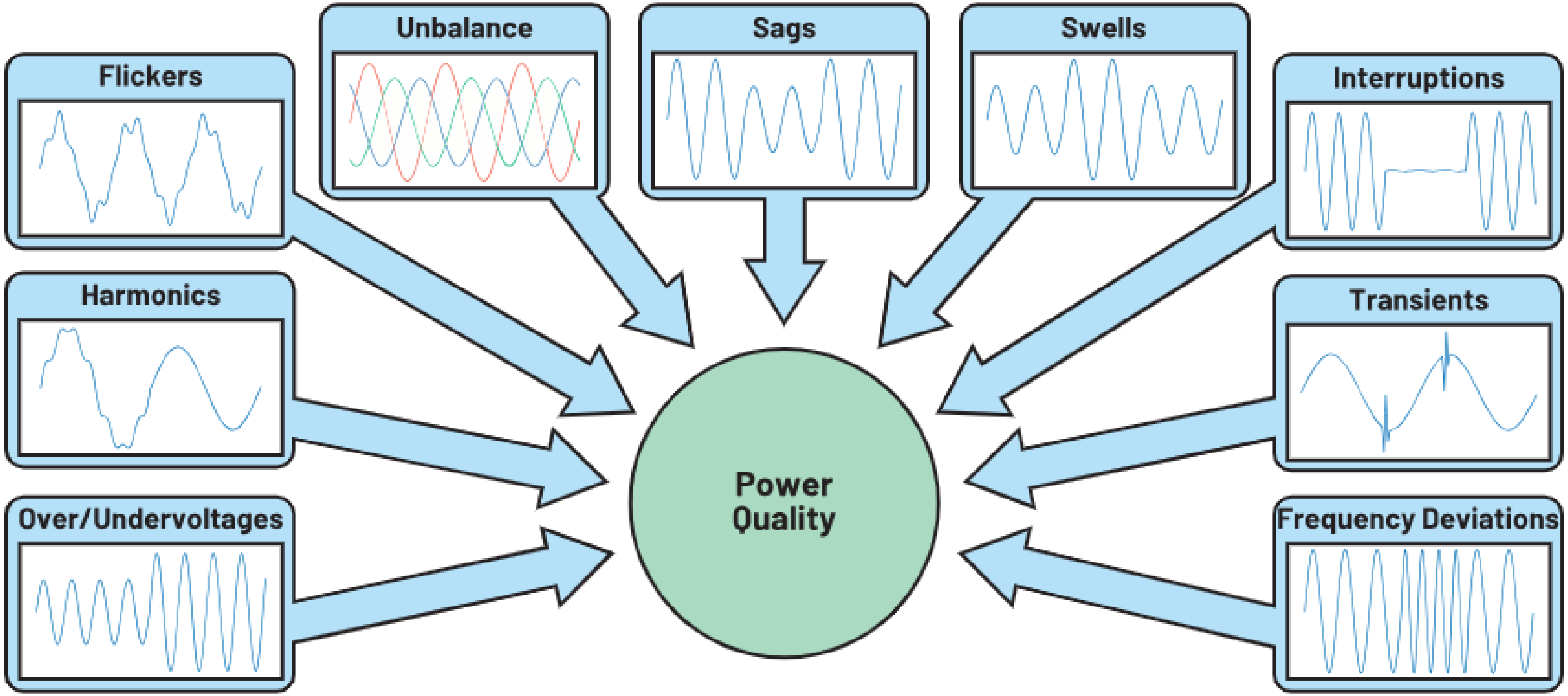


Class A PQ Power Quality analysers

Type of PQ events

- Class A dips/swells/interruptions
- Class A mains frequency
- Class A voltage harmonics
- Class A flicker – (IEC 61000-4-15)
- Class A Current harmonics
- Class A voltage and current unbalances (zero & negative seq)
- Class A Rapid Voltage changes
- 2kHz-150kHz conducted emissions – Supra-harmonics

The new IEC 61000-4-30 CLASS A standard takes the guesswork out of selecting a power quality instrument.

The standard IEC 61000-4-30 CLASS A defines the measurement methods for each power quality parameter to obtain reliable, repeatable and comparable results. It also defines the accuracy, bandwidth, and minimum set of parameters.

HF Transient capture

- Capture lightning induced surges

Those surges cause major damage to electronic equipment

- Capture HF impulses due to loads cycling, or static discharges, or faulty wiring

Can cause power supply failures, computer lock ups, memory scramble, hard disk crashes

HF Transient capture

Explaining unexplained equipment malfunction :

May 23 – 19H02

CN Rood Office Lightning strike

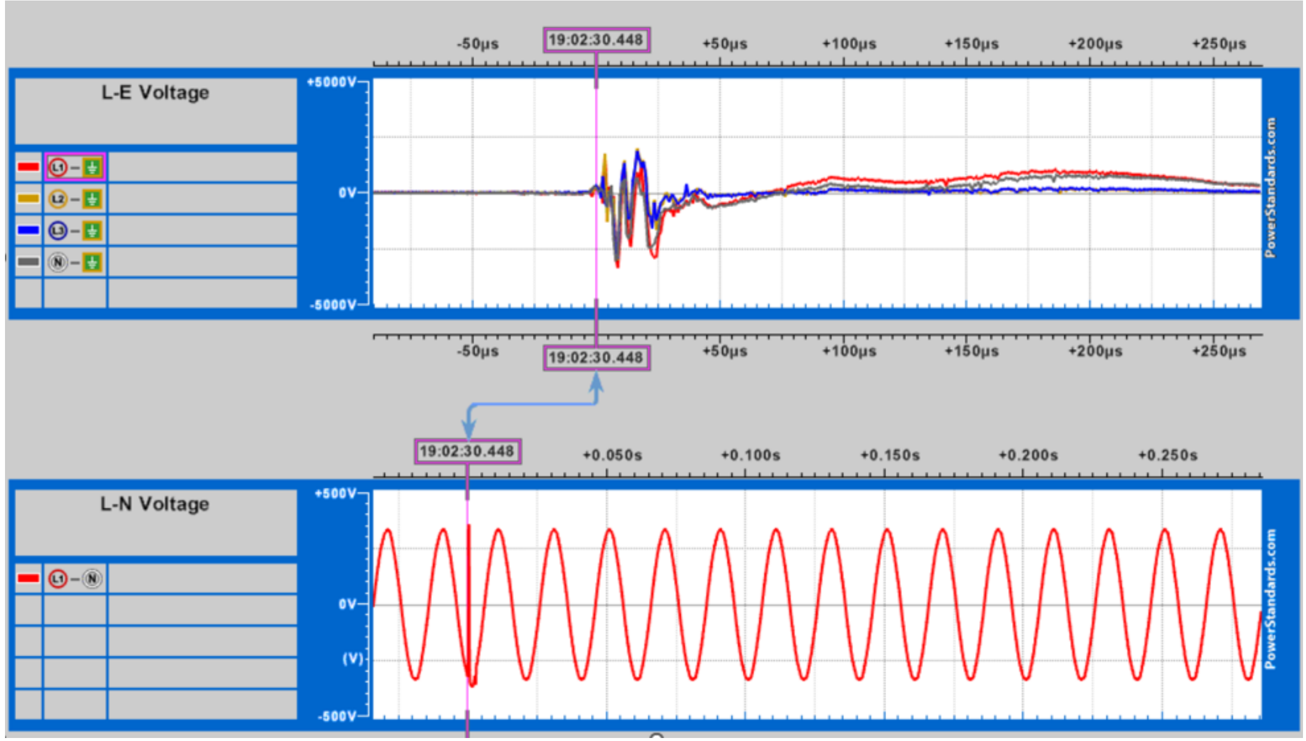
May 24 – 08H30

All internet connection dead

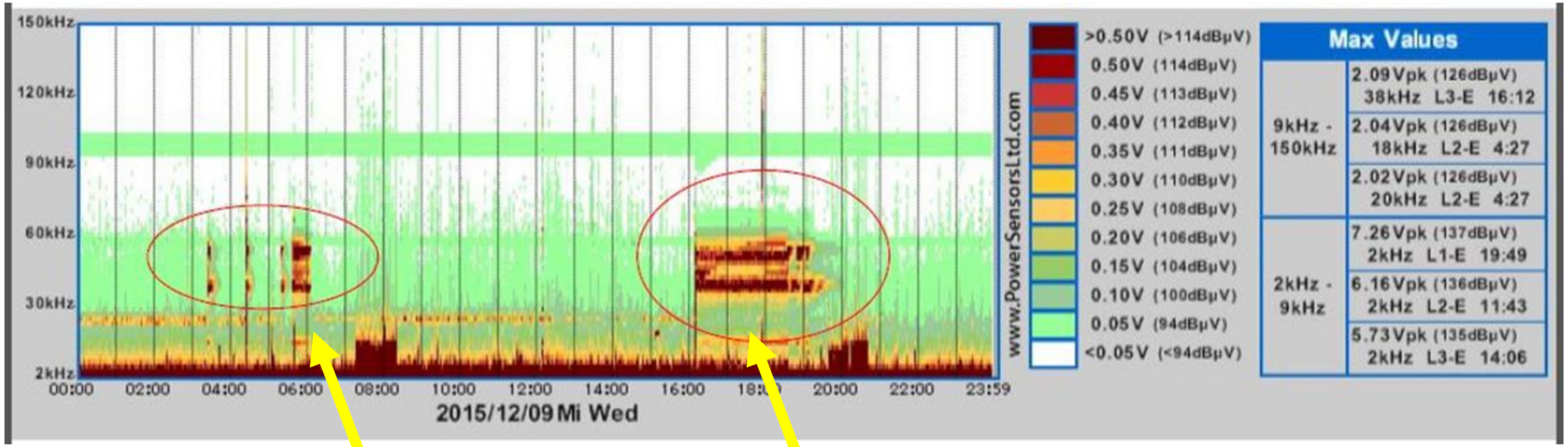
Cause was already known since

We get a mail at the time

lightning strike happened



2 kHz to 150 kHz Emissions Impact of Battery chargers

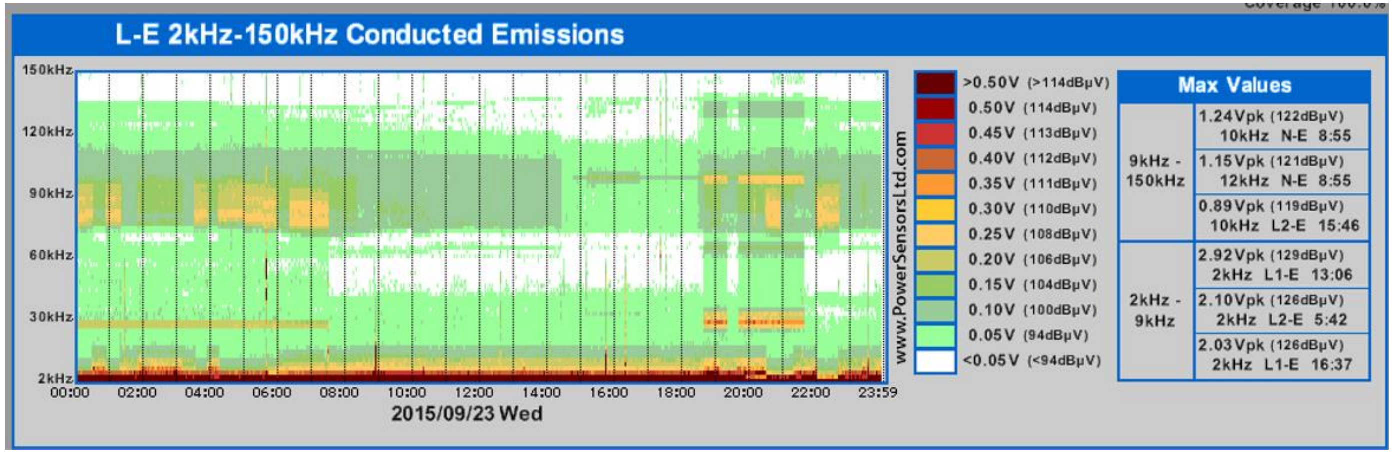


Car charge cycle

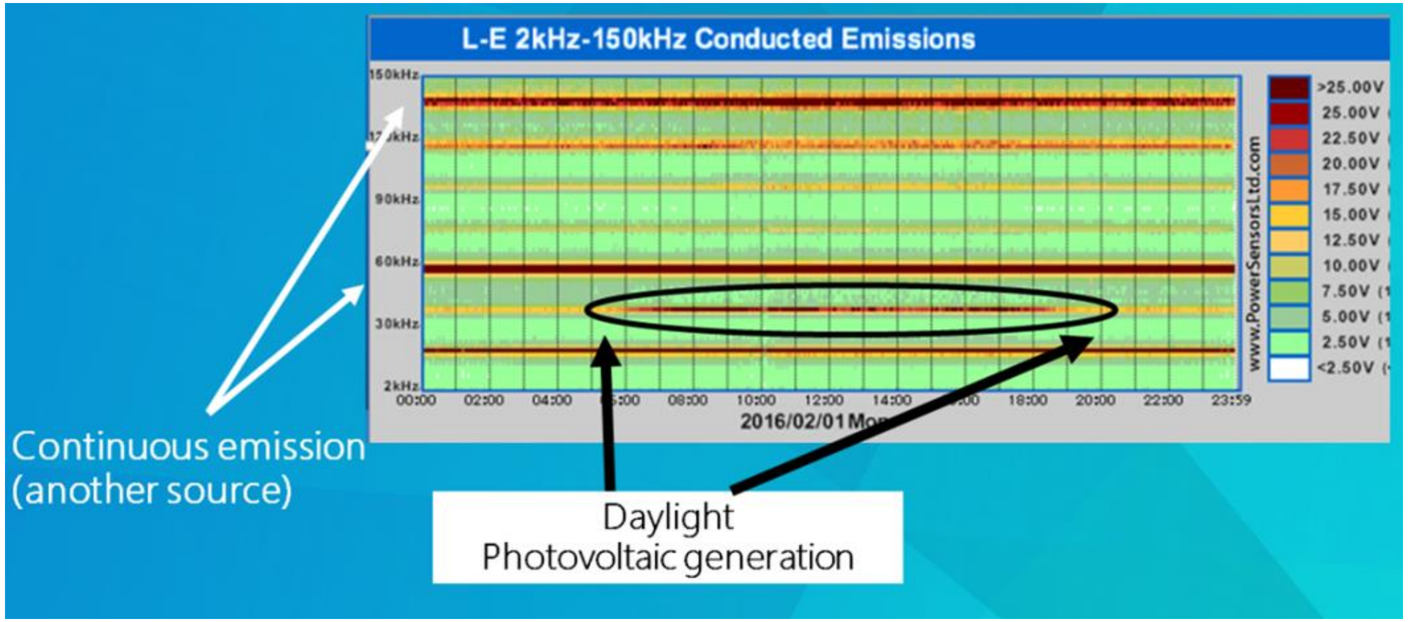
Car charge cycle

Monitoring Power Quality

Residential/commercial area
No or low PV



Residential area close to a PV inverter



Why Remote Power Quality Monitoring Holds the Key to Higher Productivity and Cost savings

- Boost workflow efficiency
- Avoid unplanned downtime
- Extend equipment lifespan
- Better understand energy consumption and costs

Boost workflow efficiency

Most facilities depend on multiple supervisors to keep operations running smoothly. But when you need large fleet of equipment or multiple facilities at the same time — it can be difficult to keep everyone on the same page.

Remote, cloud-based monitoring puts an end to this problem and accelerates your workflow efficiency by helping you:

- Easily share insights, reports and dashboards between peers to keep everyone informed and on the right course
- Monitor all your equipment and facilities, all at once
- Securely access comprehensive information from one place to manipulate and analyze data, connect dots, view trends and create visualizations
- Keep teams updated about indicators and causes of inefficiencies and power disruptions
- Stay up to date with real-time data available on all your devices
- Analyze trends over time to connect dots and inform strategies

Monitoring Power Quality

Avoid unplanned downtime

As systems become more advanced and efficient, downtime events could become more complex. Power outages aren't the only culprit. Hidden power quality issues can **damage equipment over time** — leading to unexpected system failures and a lengthy diagnostic process that may require trial and error.

With real-time power quality alerts from a remote monitoring system, you can instantly detect and diagnose power quality problems to help take the guesswork out of repairs. Plus, by monitoring events over time, recurring patterns that contribute to downtime come to light.

Unplanned downtime events cost industrial manufacturers as much as $50B annually.[1] Power quality insights can guide proactive prevention.

Extend equipment lifespan

Understanding the health of your system is critical to maintaining your equipment. A remote power monitoring system ideally should allow users to:

- Create alerts based on common issues, like system overheating, and determine their root causes — such as current overloads, unbalances, or harmonic distortion
- Monitor for power quality issues that have the most significant impact on equipment — like unbalanced loads that may damage motors or voltage deviations that disrupt sensitive equipment
- Leverage AI and machine learning to optimize diagnostics — helping you rapidly identify the direction and source of events like voltage sags

These capabilities allow you to quickly pinpoint the root cause of issues, accelerate response time and potentially prevent repeat occurrences — all to help keep equipment in peak condition for the long term.

Better understand energy consumptie and cost

On average, 30% of the energy consumed in commercial and industrial facilities is wasted — and poor power quality is one reason. Poor power factor, unbalanced or nonlinear loads, voltage fluctuations, harmonics, and other common issues can all impact system resiliency and inflate your energy bill.

With the ability to monitor and analyze energy waste and power problems over time, you can:

- Improve energy efficiency
- Lower unnecessary energy usage and costs
- Manage peak loads and reduce demand charges
- Avoid power factor penalties from utility
- Achieve your sustainability goals

Monitoring Power Quality

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Grid Impedance Measurement as a key parameter for good Power Quality and stable Grid Operation

M. Sc. Christoph Klie
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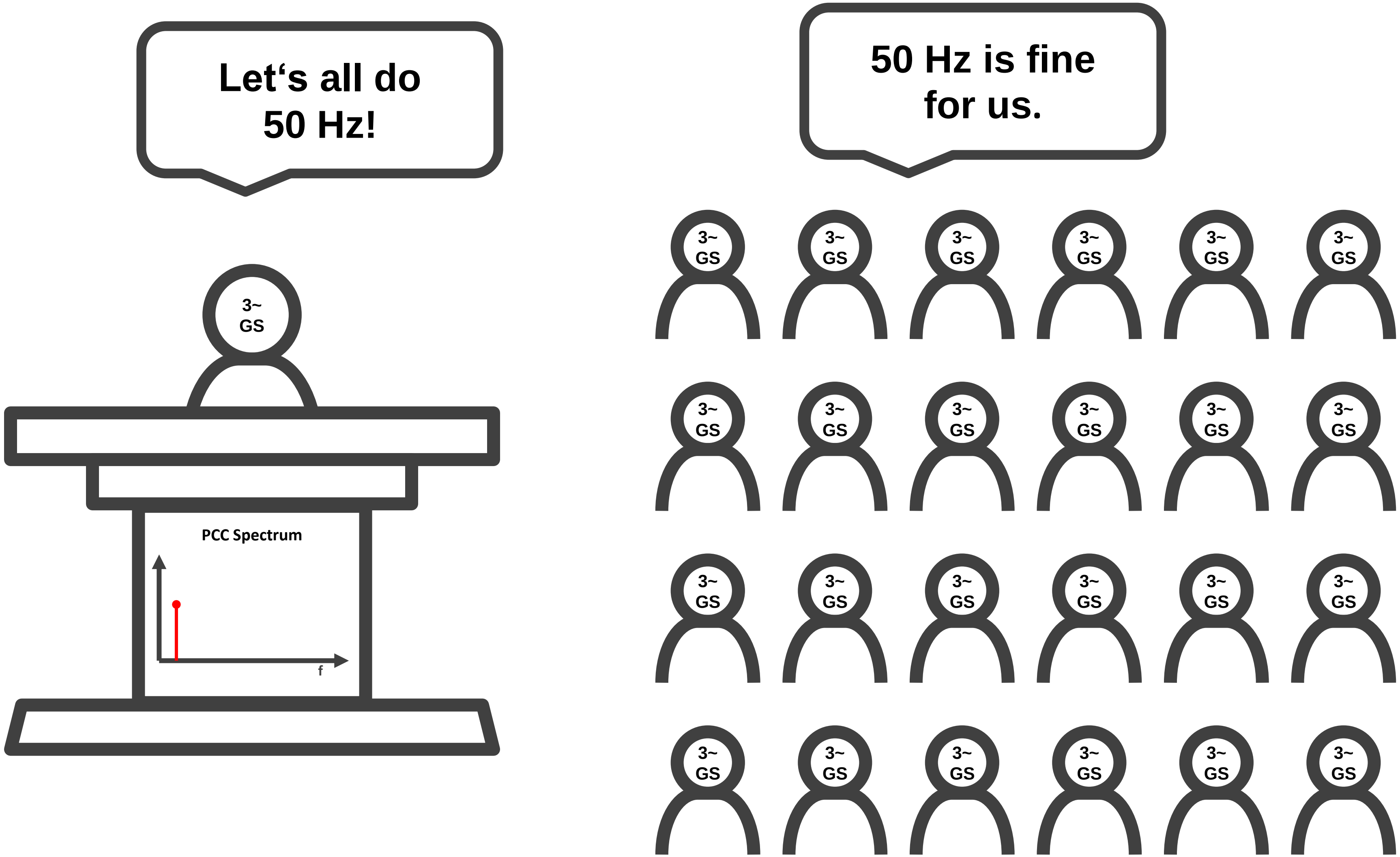
FUTURE CHALLENGES IN STABLE GRID OPERATION

morEnergy



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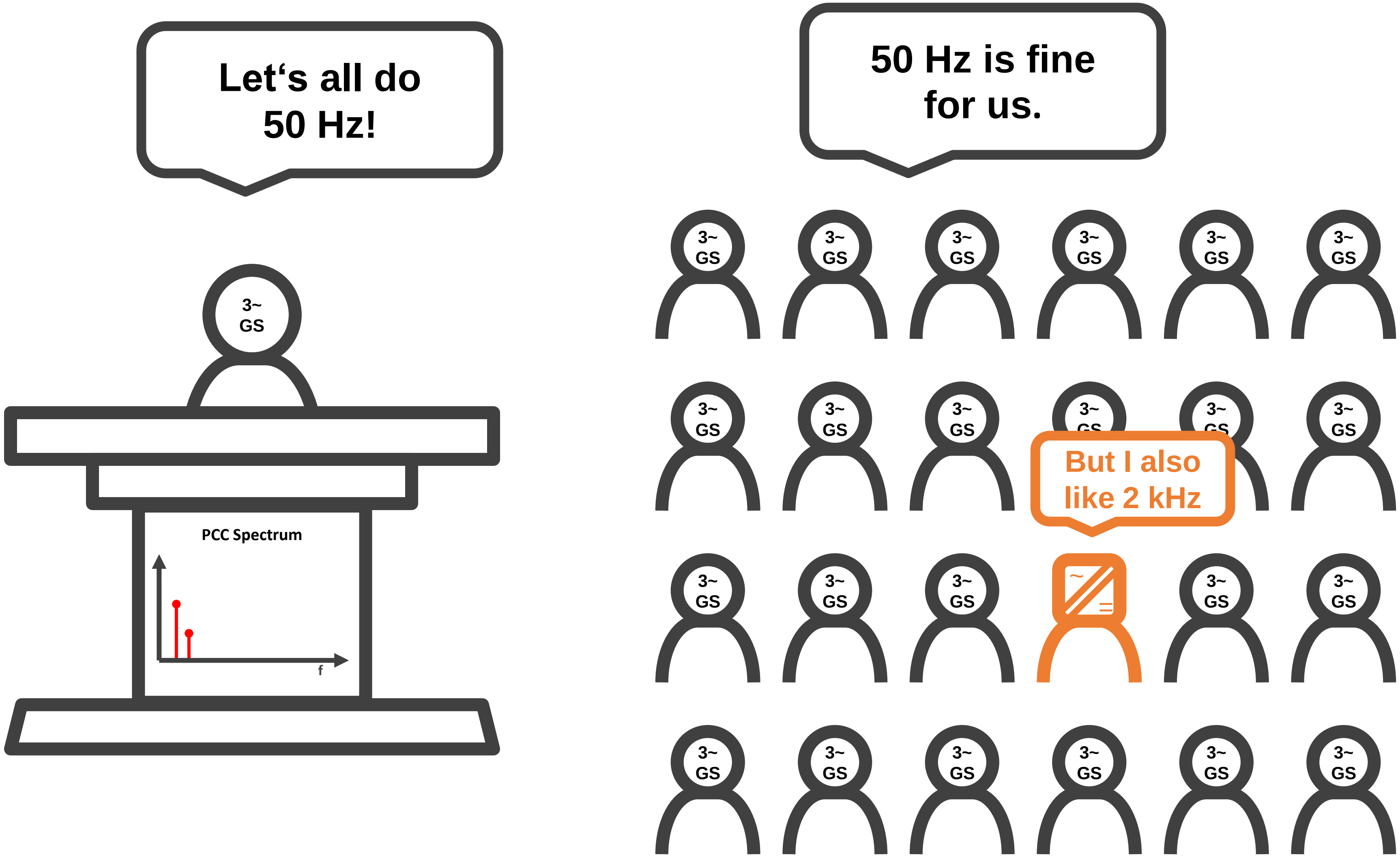

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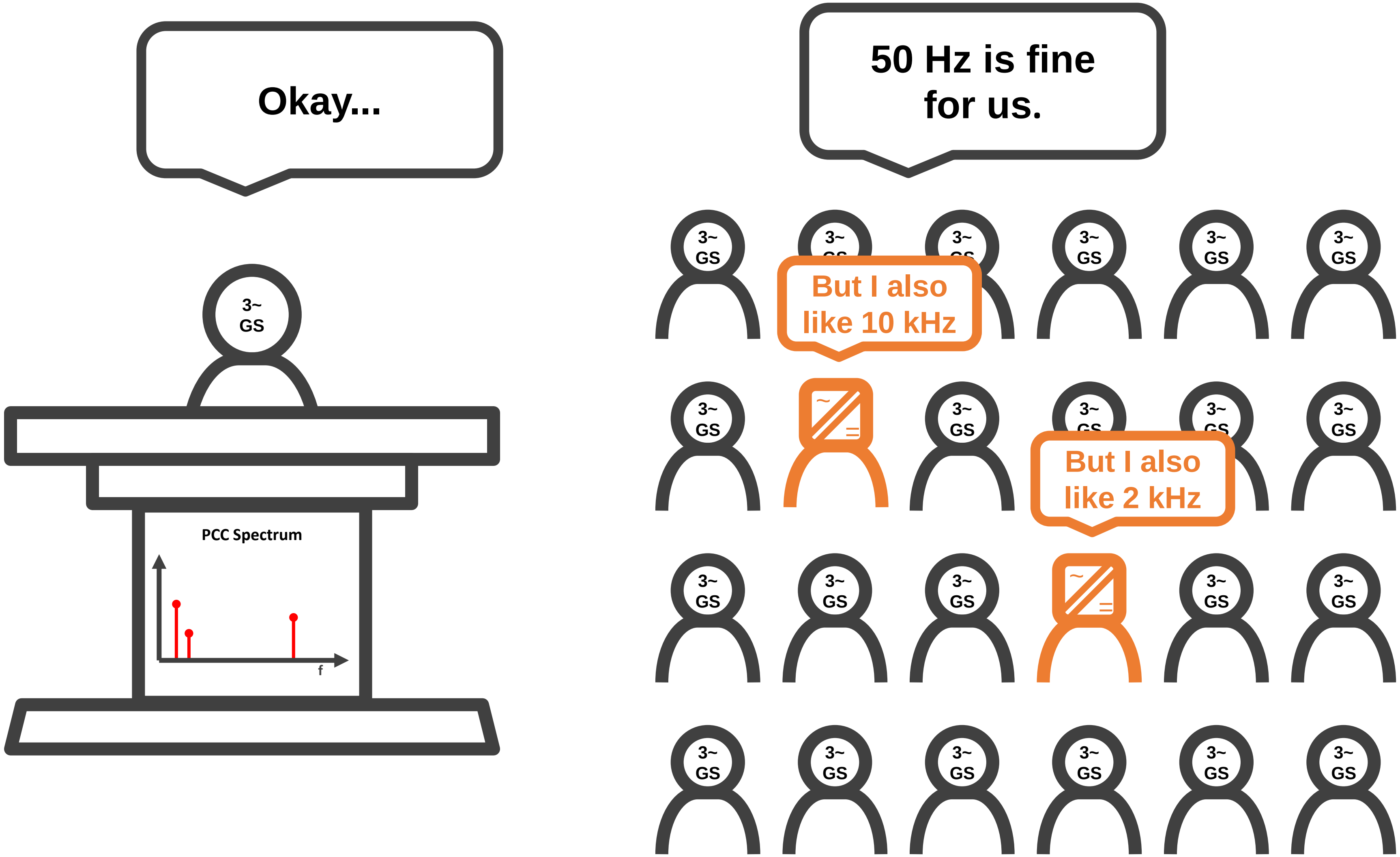

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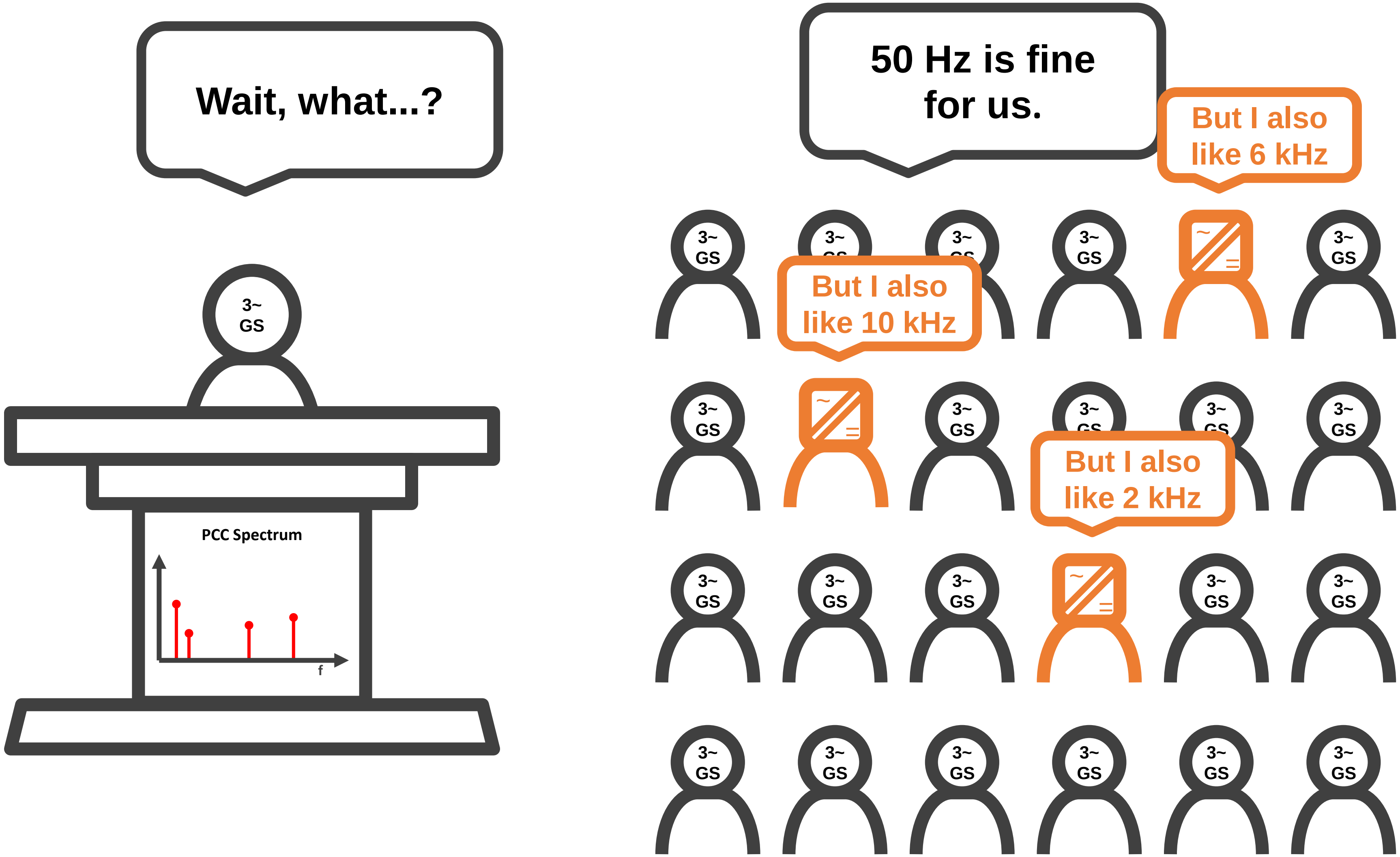

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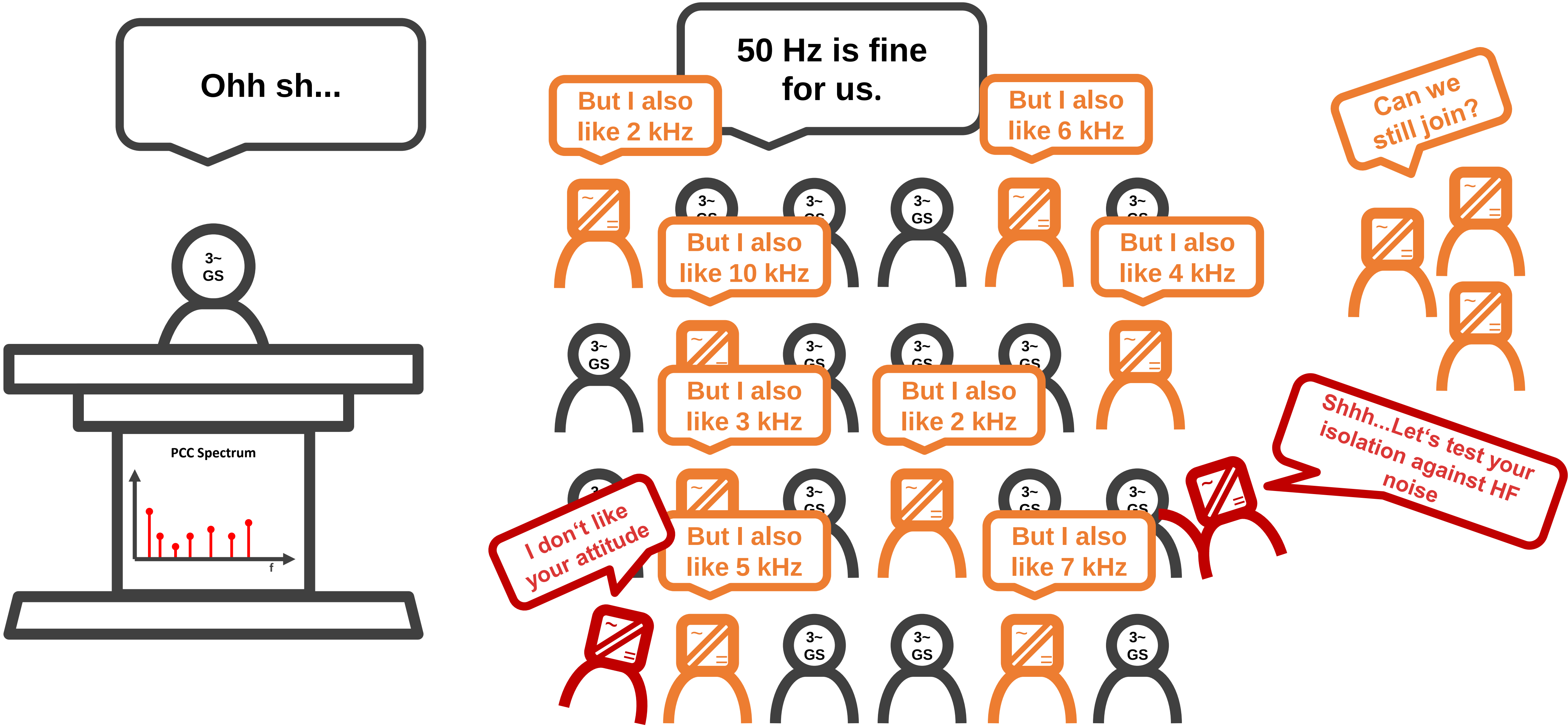

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AGENDA

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- Abstract problem visualization
- **Grid impedance in modern electrical grids**
- Impedance-based grid phenomena and usecases
    1. Damping of data signals
    2. Filter overload through harmonic interaction
    3. Switching frequency meets parallel resonance
    4. Impedance-based inverter stability in grids
    5. Evaluation of possible grid capacity for generation plant connection
- Outlook on activities and research

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FUTURE CHALLENGES IN STABLE GRID OPERATION

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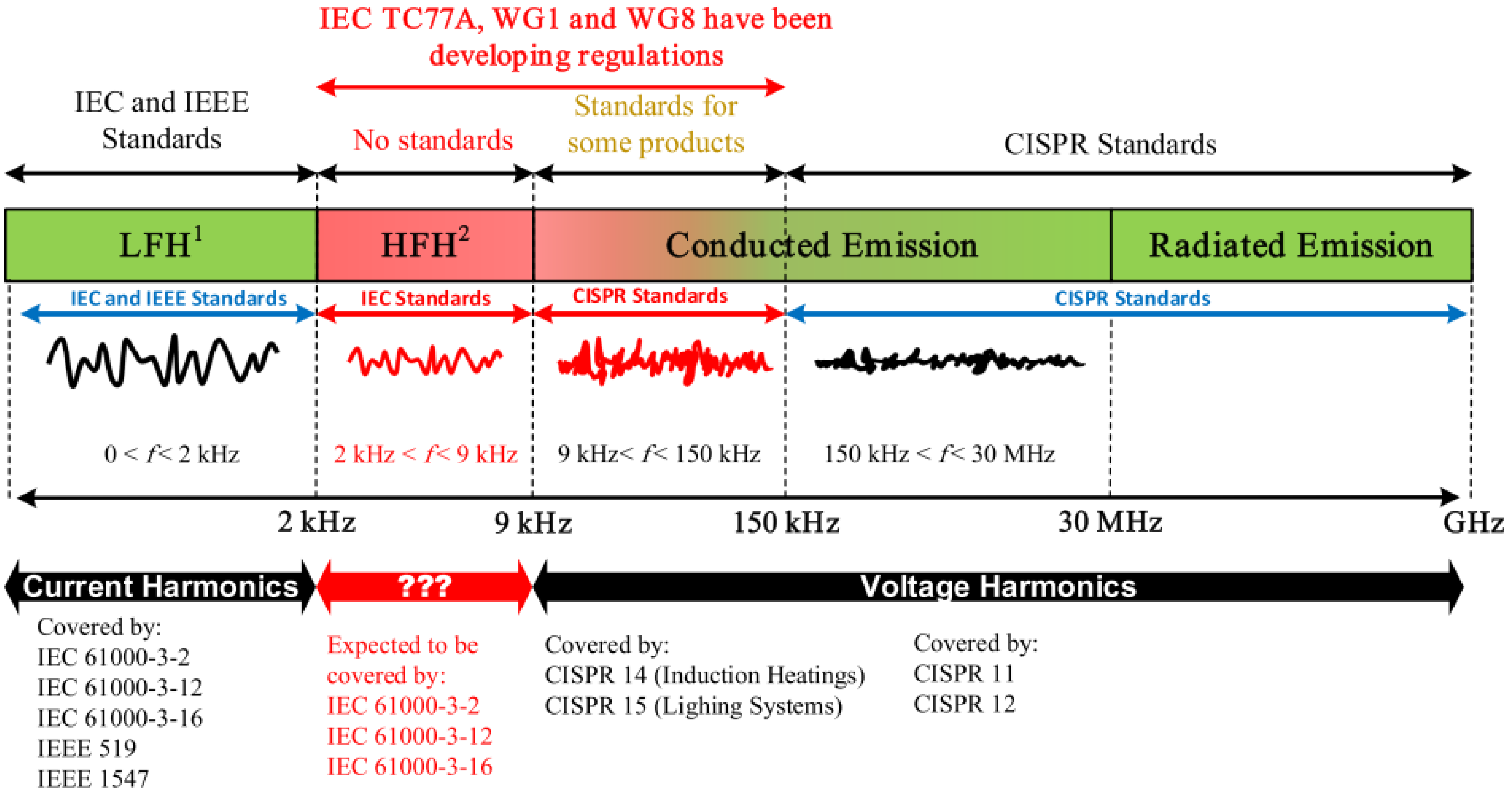
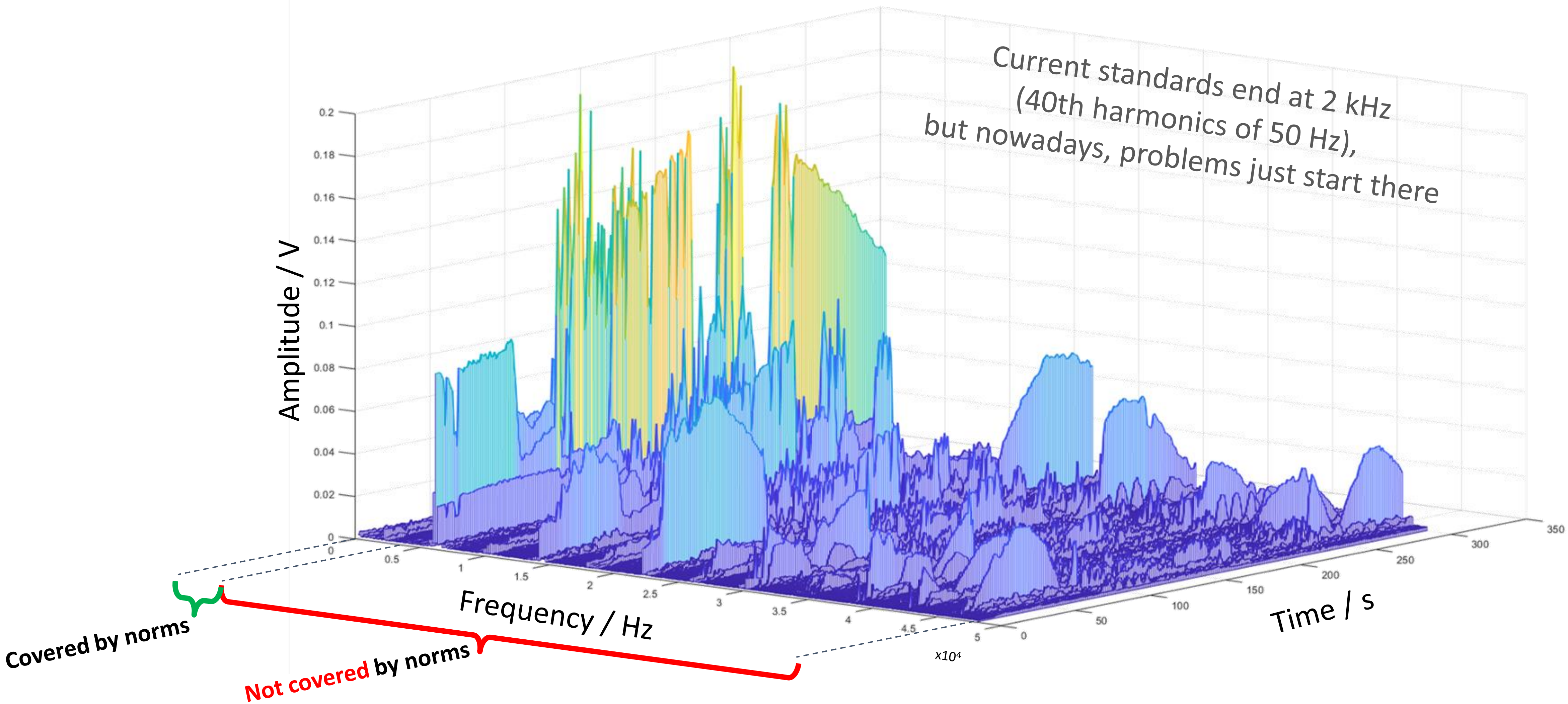


LFH: Low Frequency Harmonics
HFH: High Frequency Harmonics

[1] M. Alyannezhadi, H. Hassanpir and F. Zare, “Grid Impedance Estimation in High Frequency Range with a Single Signal Injection Using Time-Frequency Distribution”, September 2019, IET Science, Measurement & Technology, doi: 10.1049/iet-smt.2018.5617

FUTURE CHALLENGES IN STABLE GRID OPERATION



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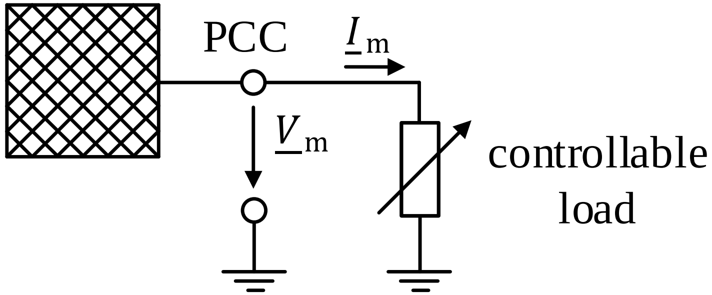
ONIS: ONLINE NETWORK IMPEDANCE SPECTROMETER

- basic formular: $Z(f) = \frac{\Delta U(f)}{\Delta I(f)}$
- grid excitation is needed

  → using an ohmic resistor



Advantages of the ONIS device

- lightweight and mobile compared to other methods
- fast measurement
- easy to operate
- three-phase
- up to 500 kHz

REASONS FOR MEASURE THE GRID IMPEDANCE

- The grid impedance is
  - a local parameter
  - time-dependent
  - difficult to simulate

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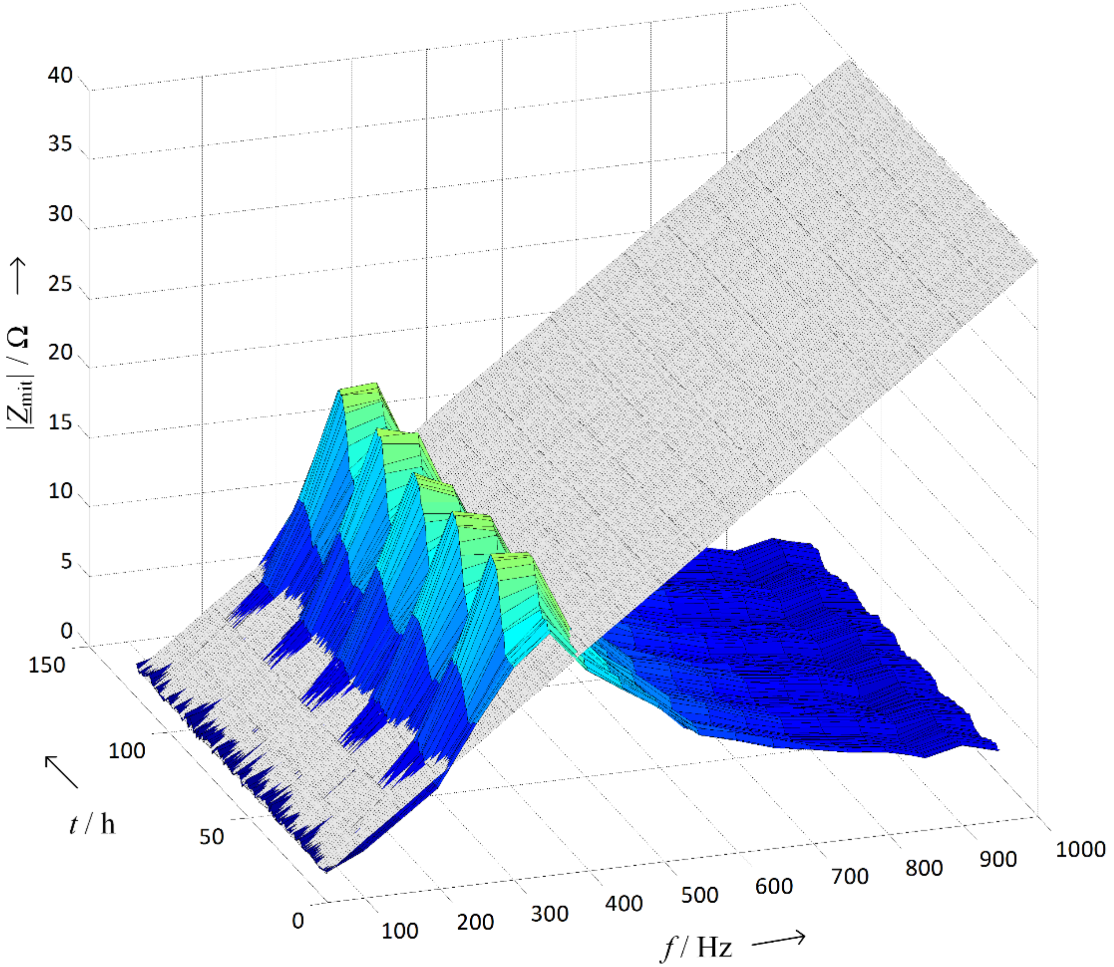
REASONS FOR MEASURE THE GRID IMPEDANCE

- The grid impedance is
  - a local parameter
  - time-dependent
  - difficult to simulate
  - imprecisely described in standards



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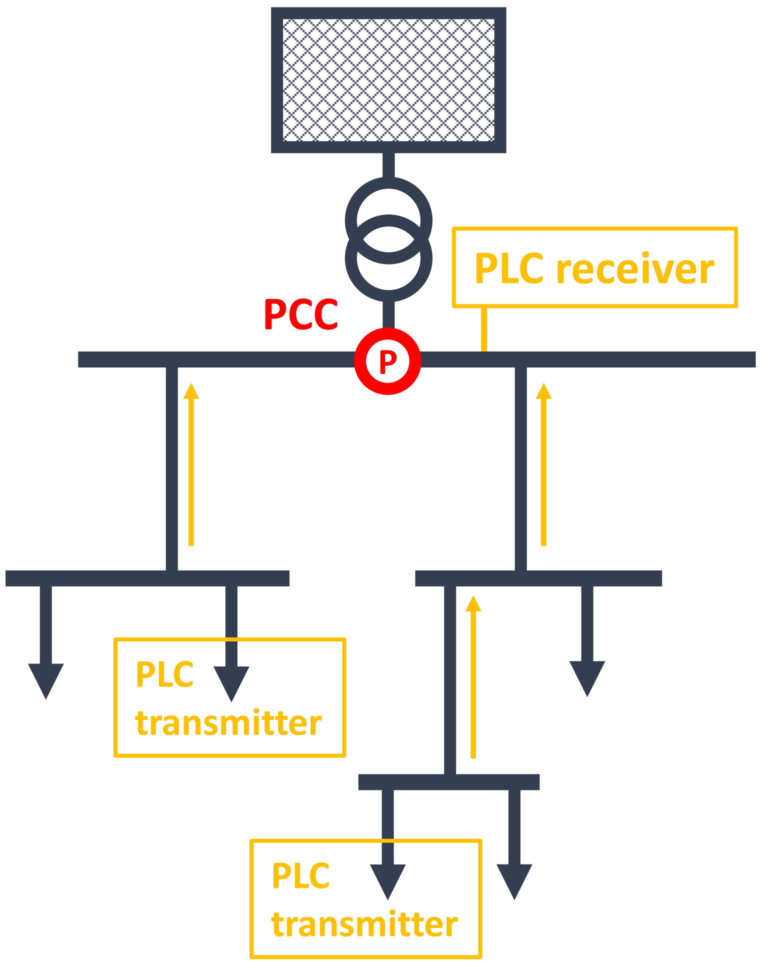
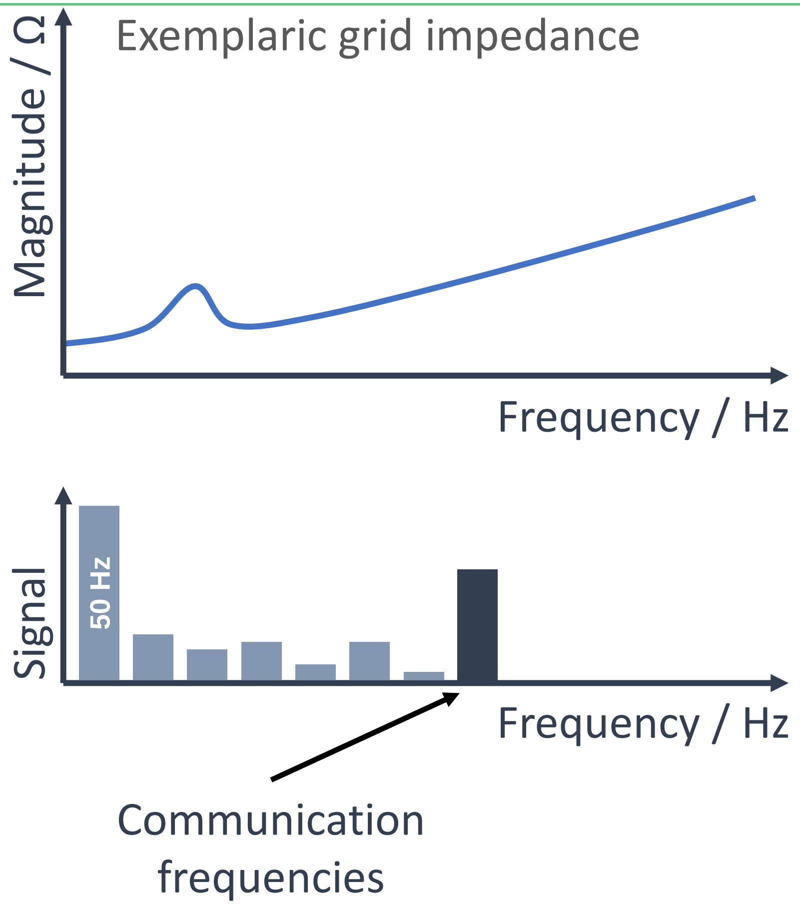
klie@morenergy.net

1. DAMPING OF DATA SIGNALS (PLC)





Typical ohmic-inductive grid impedance at PCC

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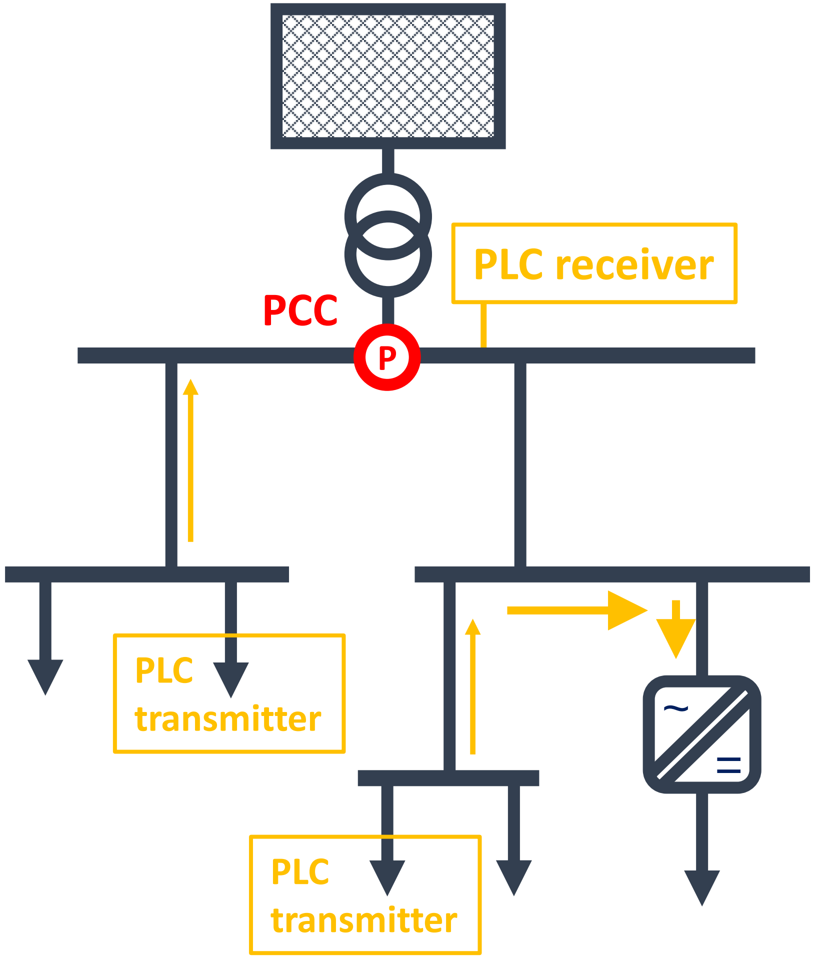

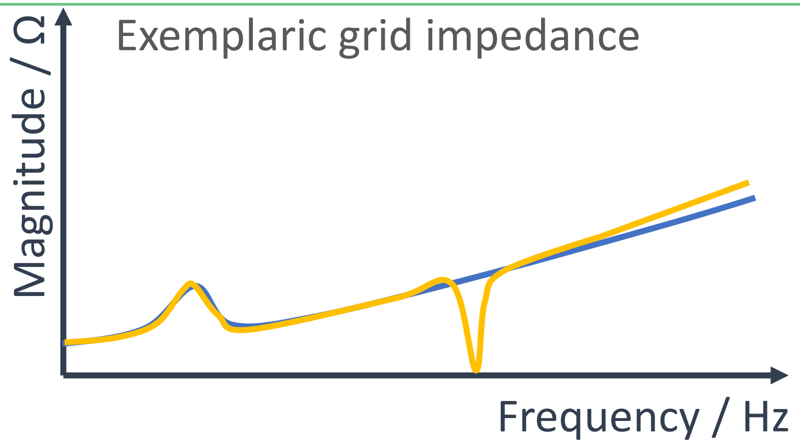

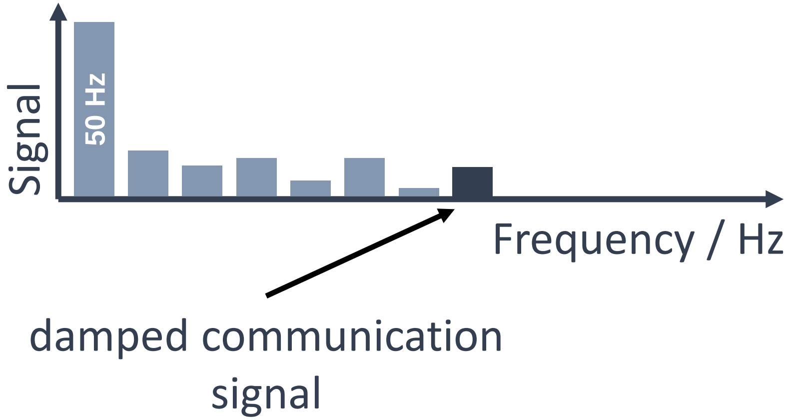

Typical ohmic-inductive grid impedance at PCC

Change in grid impedance due to one or more new power electronic system

Communication signal is sucked out so much that reliable communication is no longer possible.

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1. DAMPING OF DATA SIGNALS (PLC)

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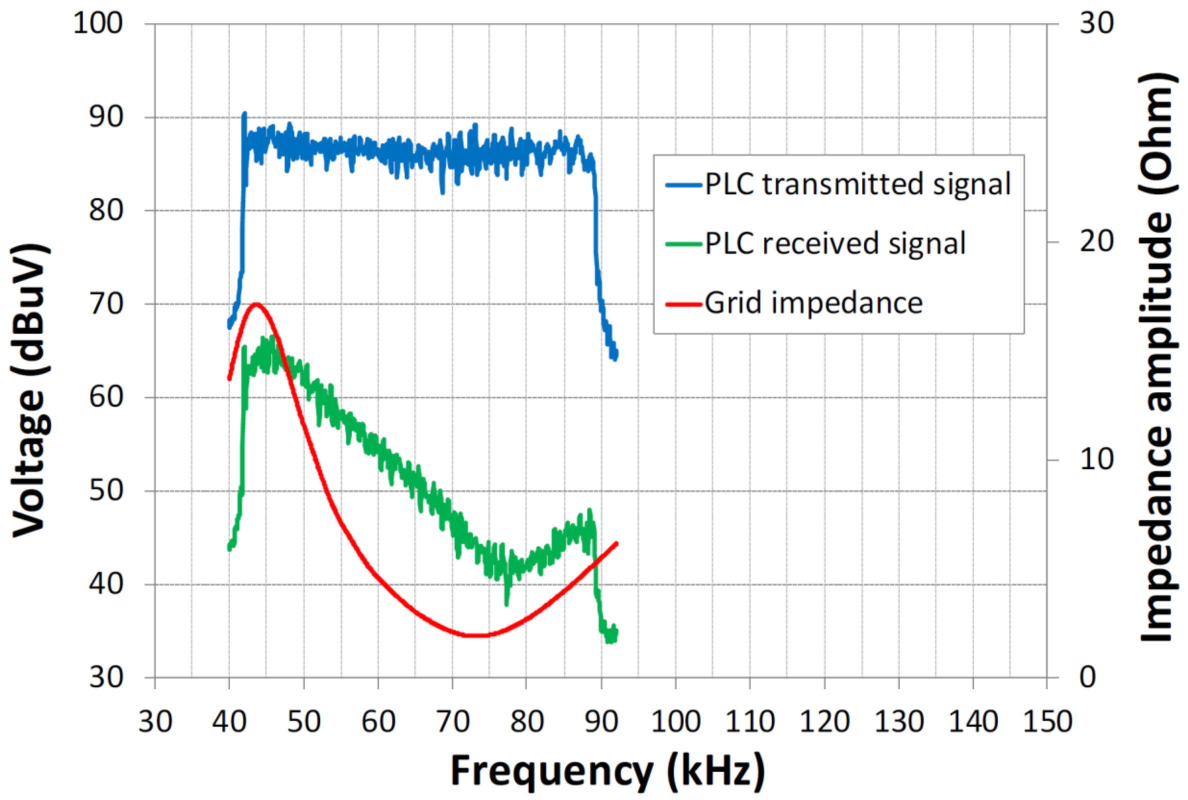
Smartmeter Rollout



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AGENDA

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- Abstract problem visualization
- Grid impedance in modern electrical grids
- **Impedance-based grid phenomena and usecases**
  1. Damping of data signals
  2. **Filter overload through harmonic interaction**
  3. Switching frequency meets parallel resonance
  4. Impedance-based inverter stability in grids
  5. Evaluation of possible grid capacity for generation plant connection
- Outlook on activities and research

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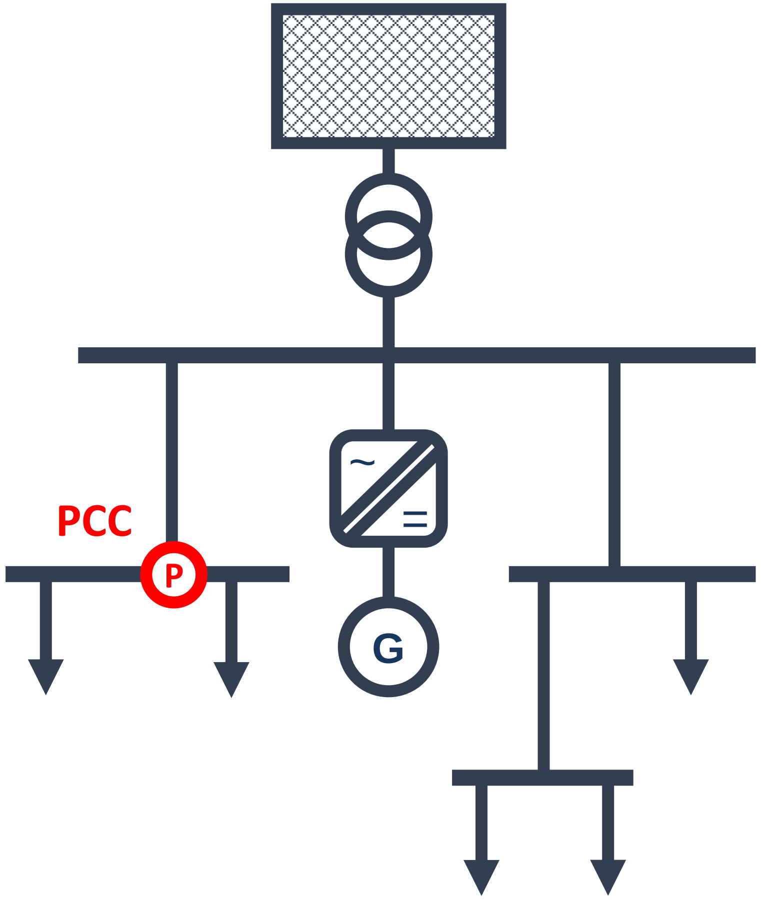
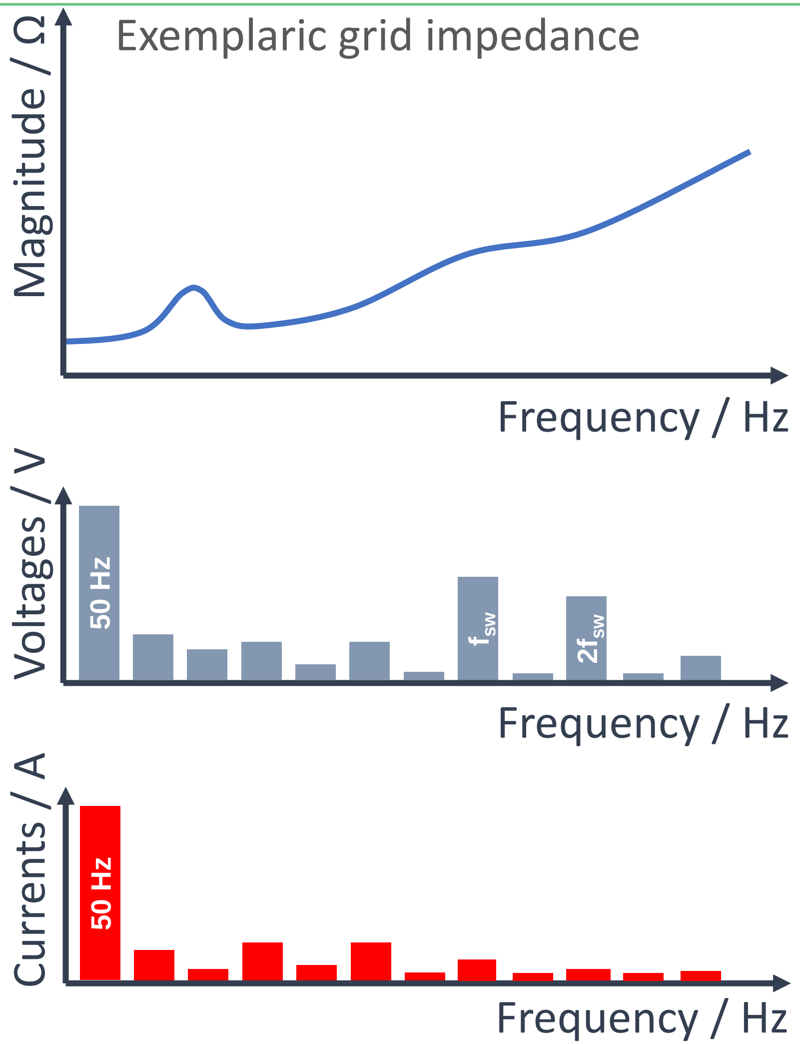
2. FILTER OVERLOAD THROUGH HARMONIC INTERACTIONS

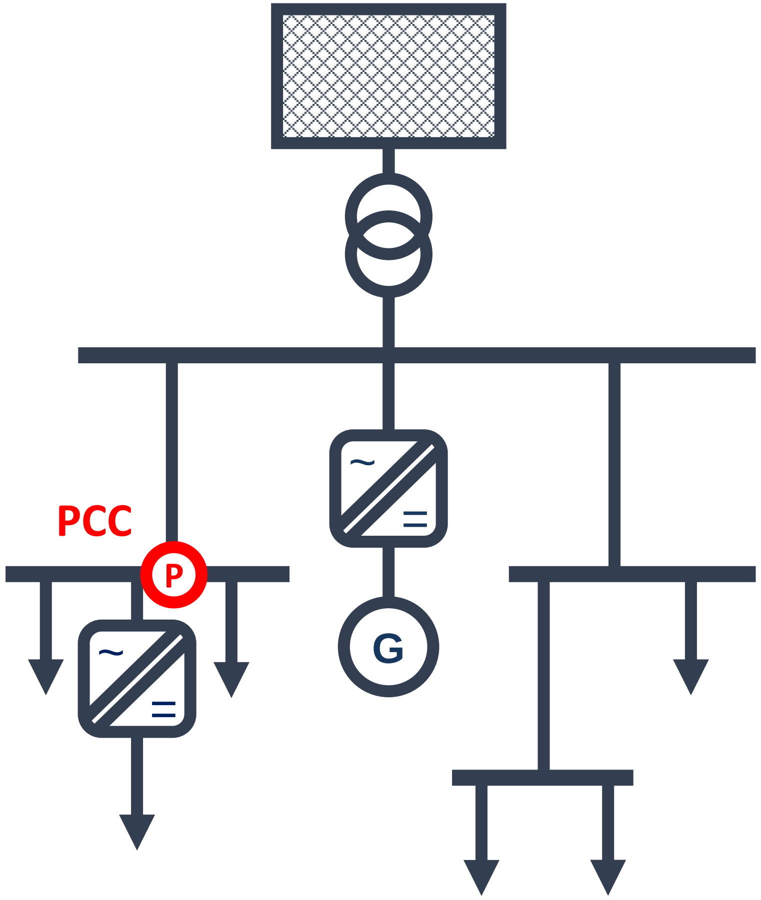


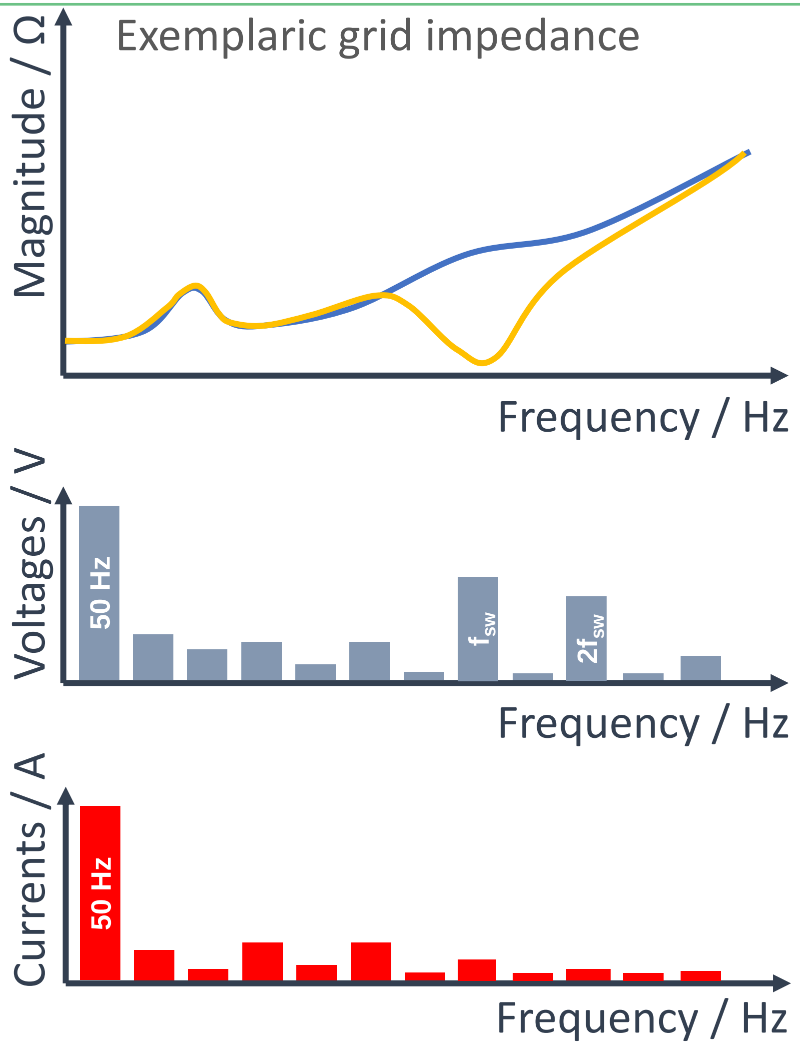


Typical ohmic-inductive grid impedance at PCC

Existing inverter causes current and voltage components at f_{sw} and its harmonics

2. FILTER OVERLOAD THROUGH HARMONIC INTERACTIONS





Typical ohmic-inductive grid impedance at PCC

Existing inverter causes current and voltage components at f_{sw} and its harmonics

Change in grid impedance due to increasing number of inverter devices (filtered)

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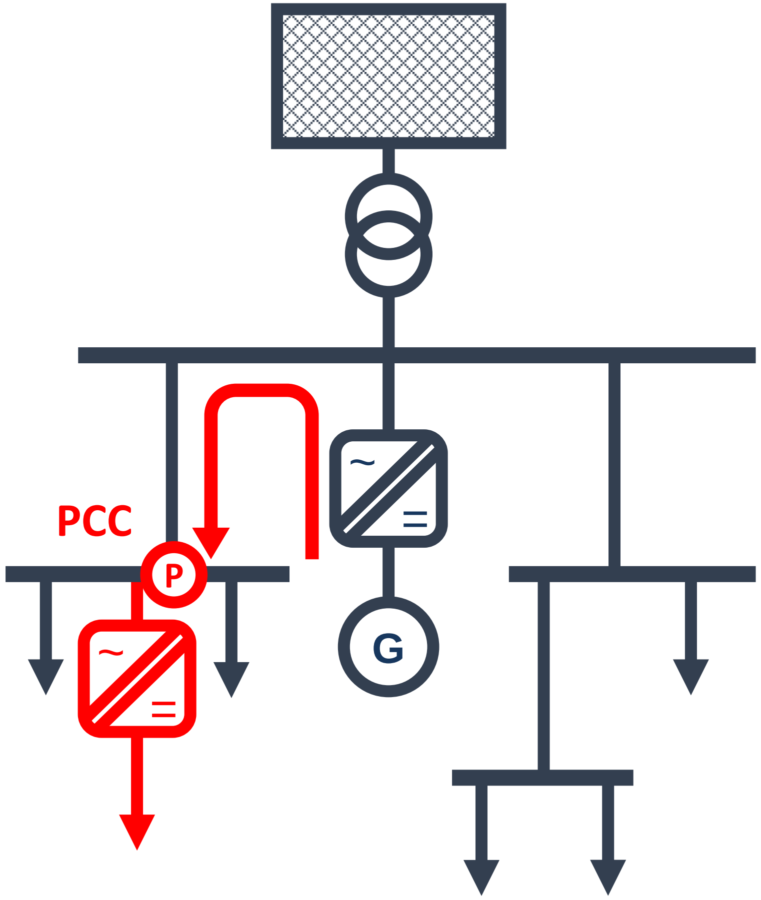

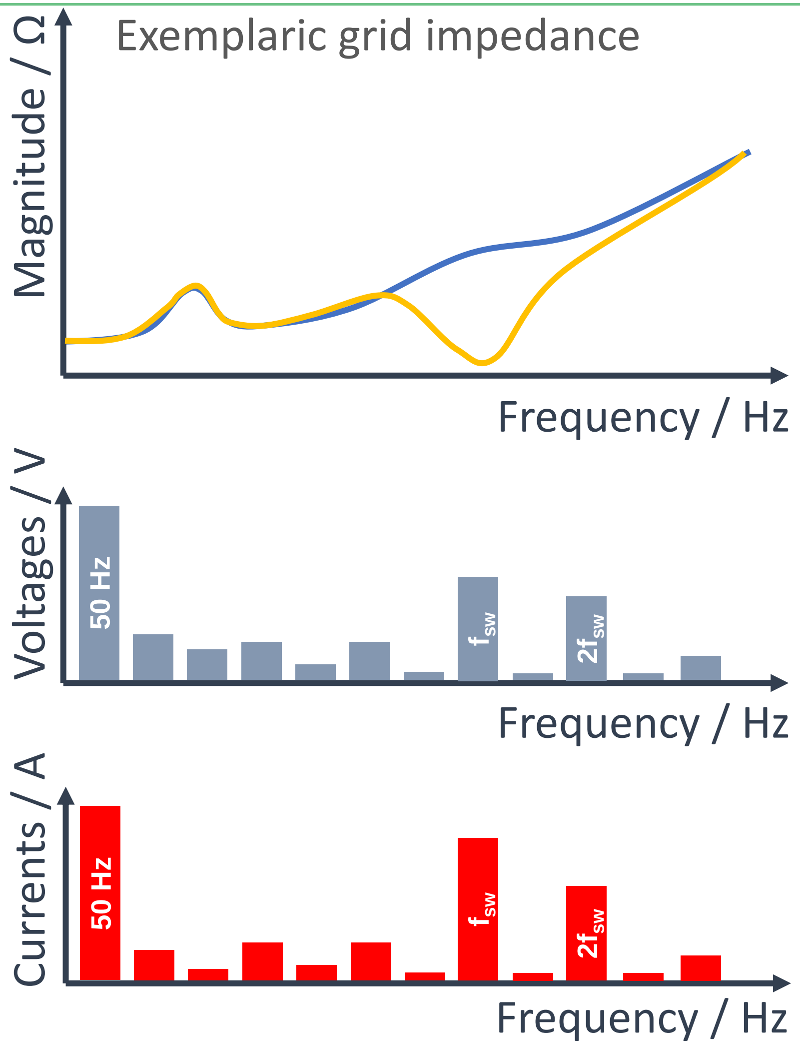

Typical ohmic-inductive grid impedance at PCC

Existing inverter causes current and voltage components at f_{sw} and its harmonics

Change in grid impedance due to increasing number of inverter devices (filtered)

High current flow due to low impedance at f_{sw}
→ Potential damage to inverter filter or grid components

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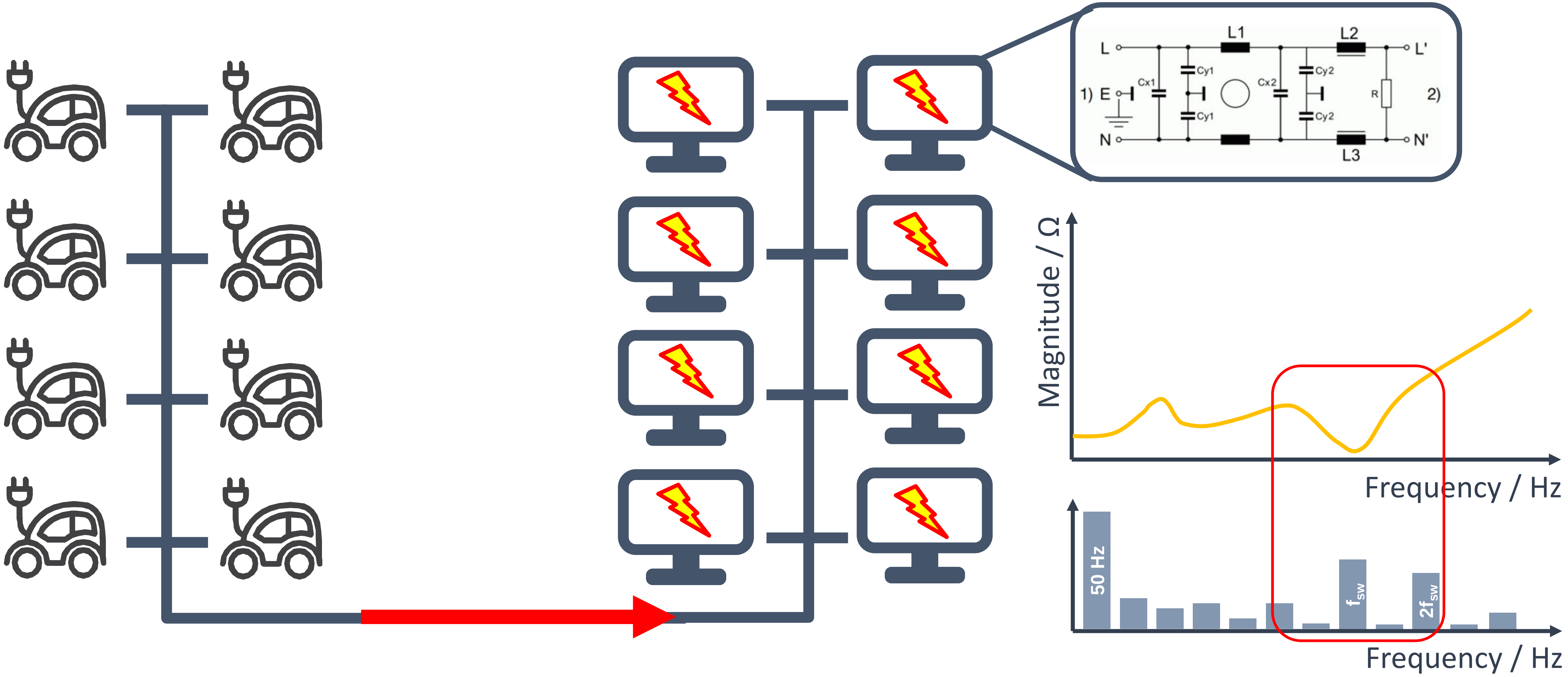
2. FILTER OVERLOAD THROUGH HARMONIC INTERACTIONS



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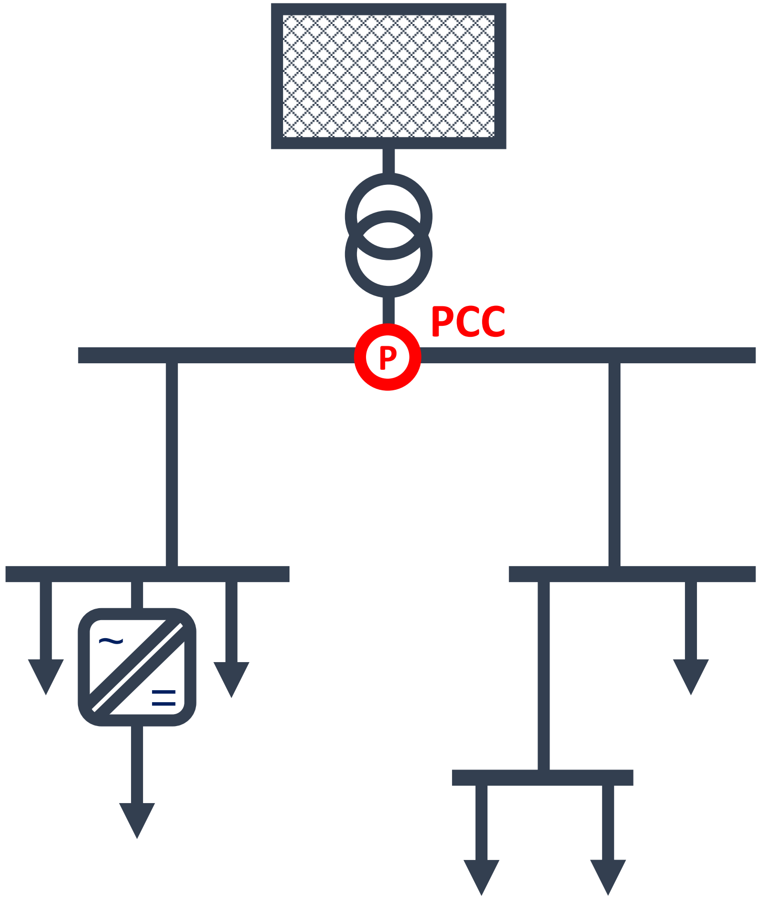
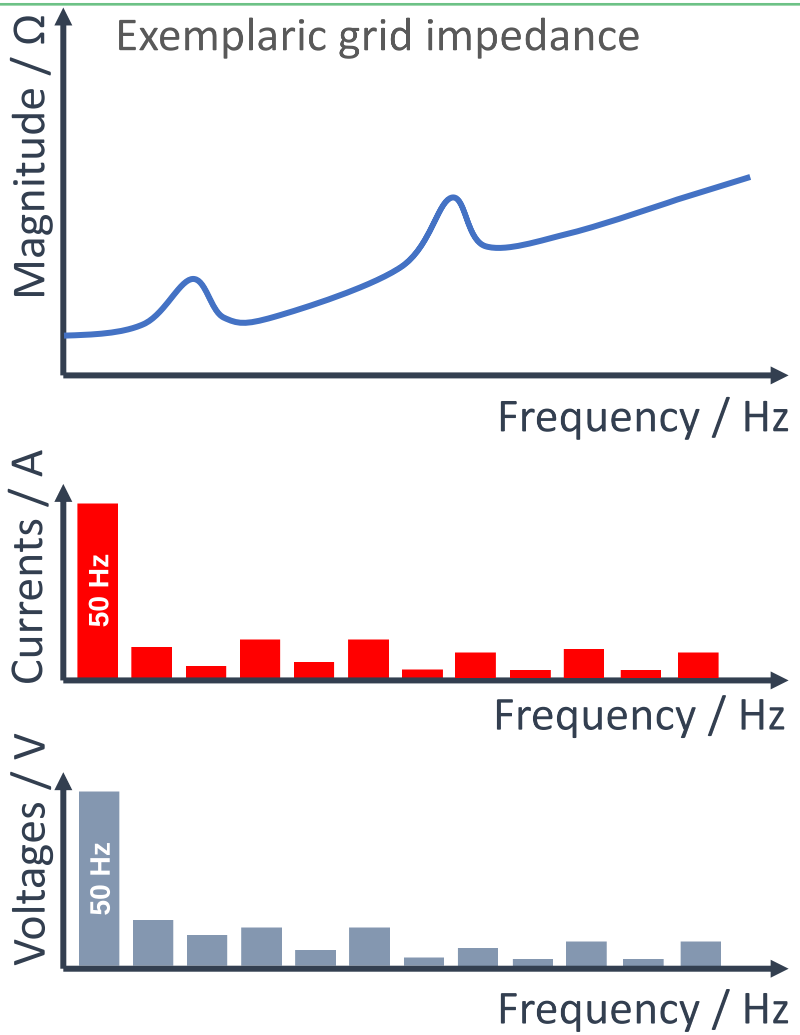
3. SWITCHING FREQUENCY MEETS PARALLEL RESONANCE





Typical ohmic-inductive grid impedance at PCC

Existing inverter causes non critical current and voltage components

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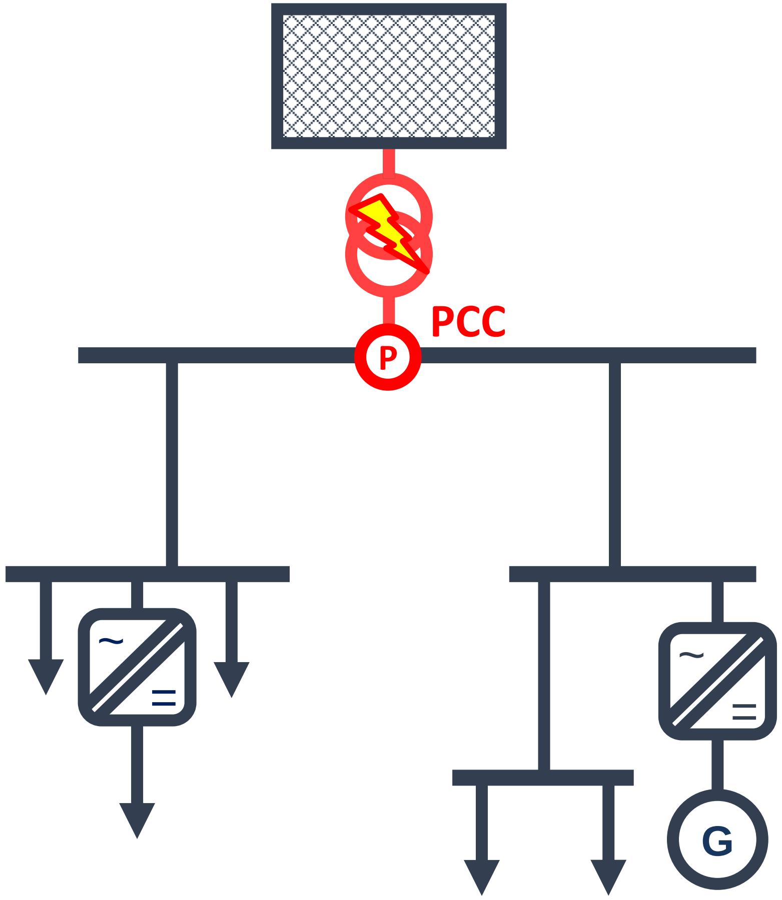

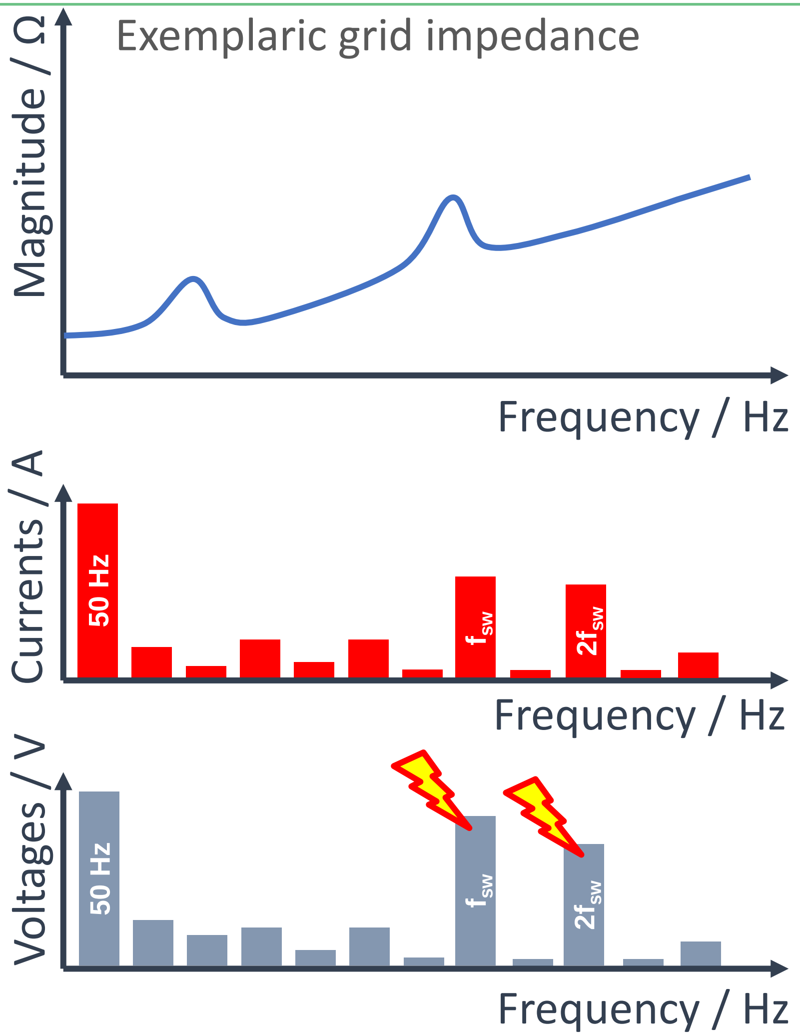

Typical ohmic-inductive grid impedance at PCC

Existing inverter causes non critical current and voltage components

Switching frequency of a new inverter meets parallel resonance of grid impedance

Critical voltage components arise due to the imprinting of currents at the switching frequency over the large grid impedance

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3. SWITCHING FREQUENCY MEETS PARALLEL RESONANCE

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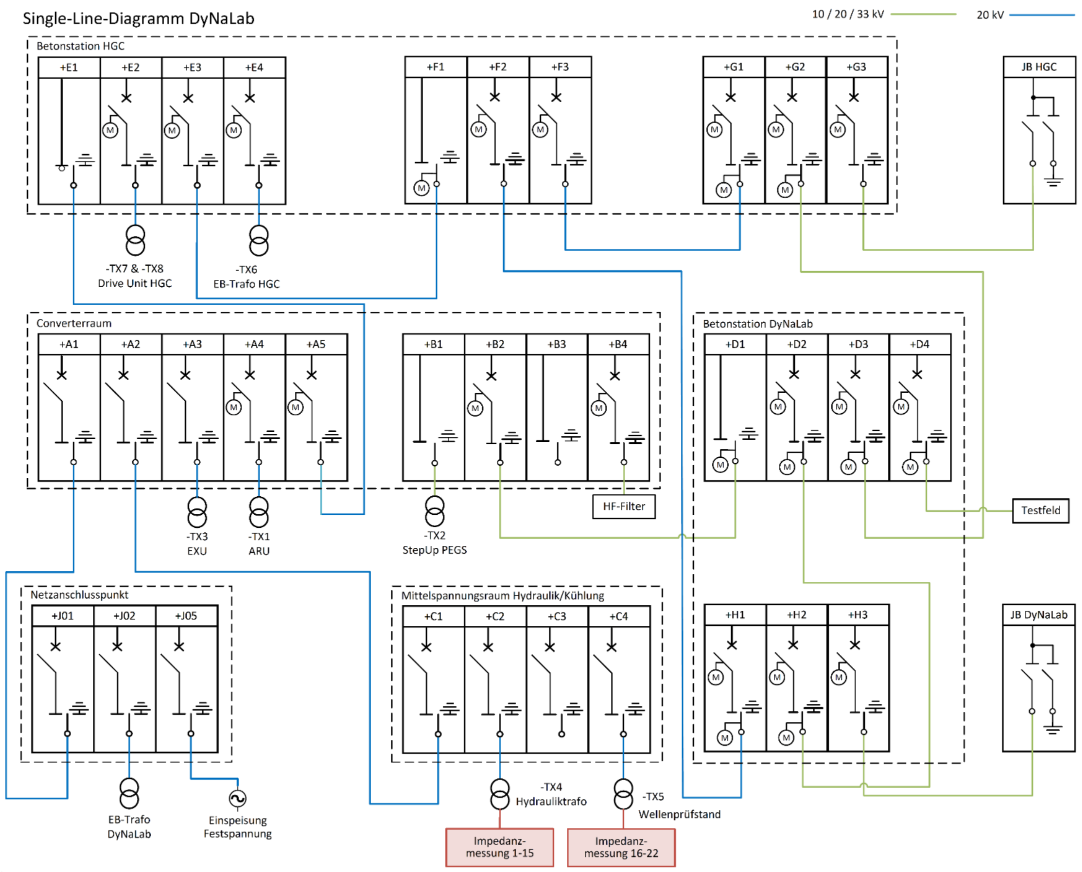

A new grid connection was installed in parallel to the old one

→ Testbench failure (protection device tripping) from time to time

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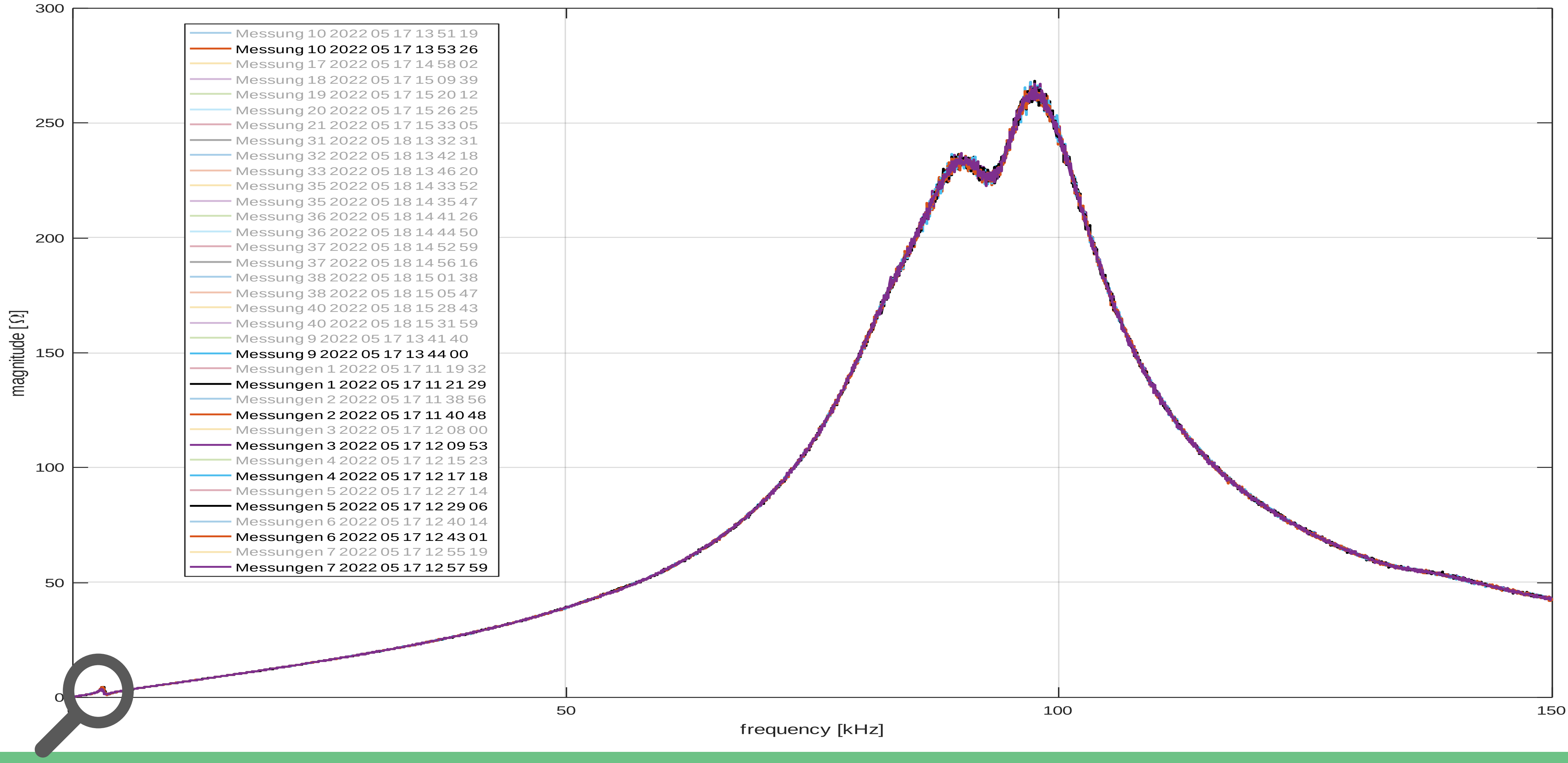

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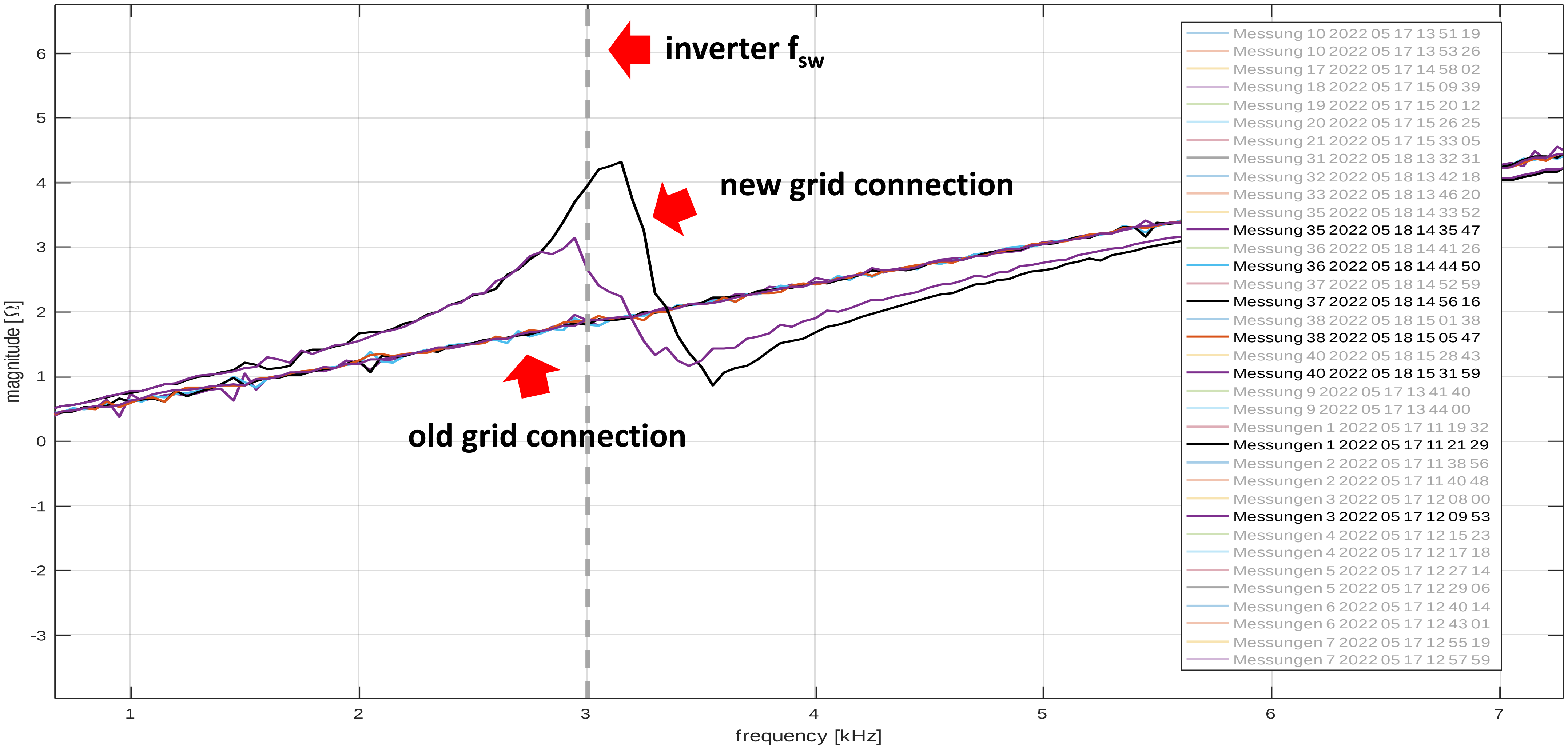

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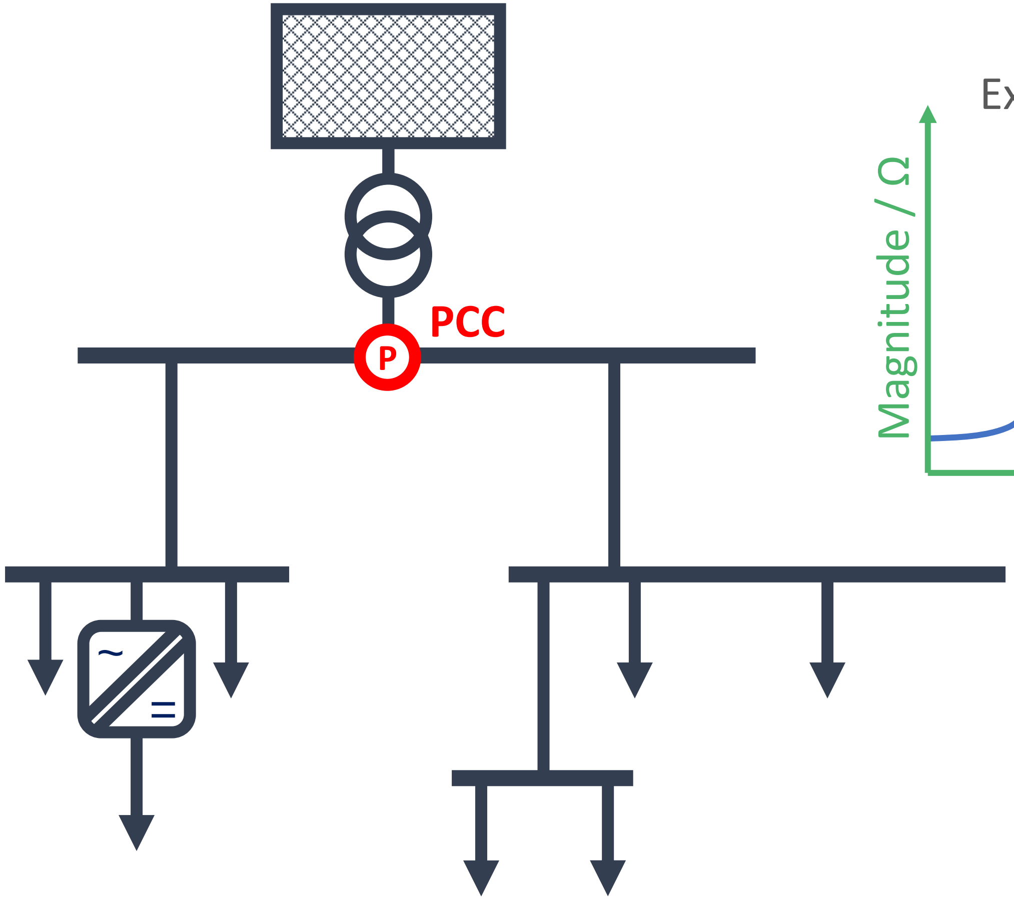
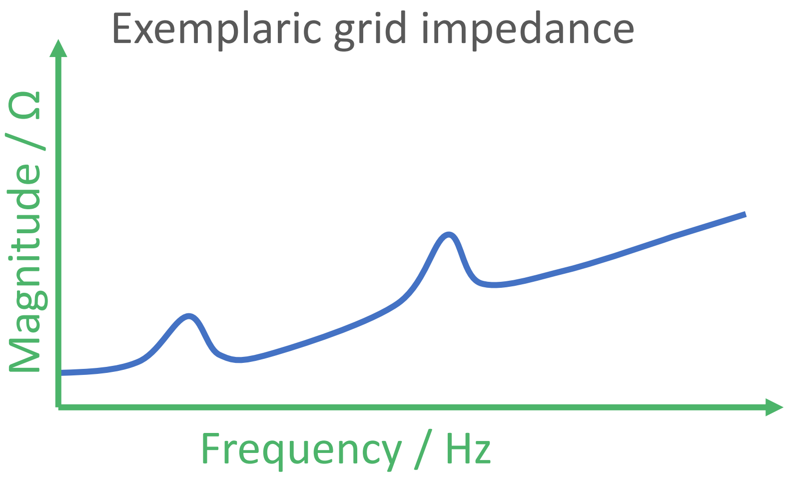
4. IMPEDANCE BASED INVERTER STABILITY IN GRIDS





Typical ohmic-inductive grid impedance at PCC

Change in grid impedance due to increasing number of inverter-coupled devices

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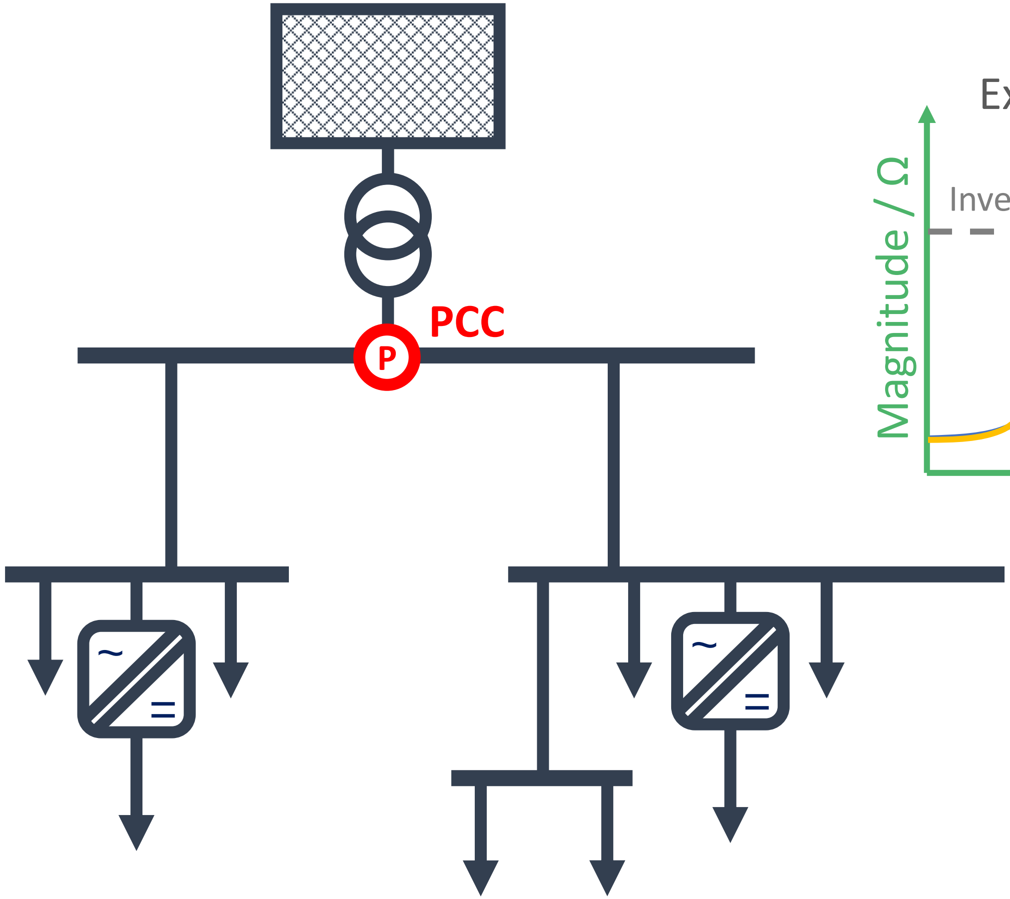
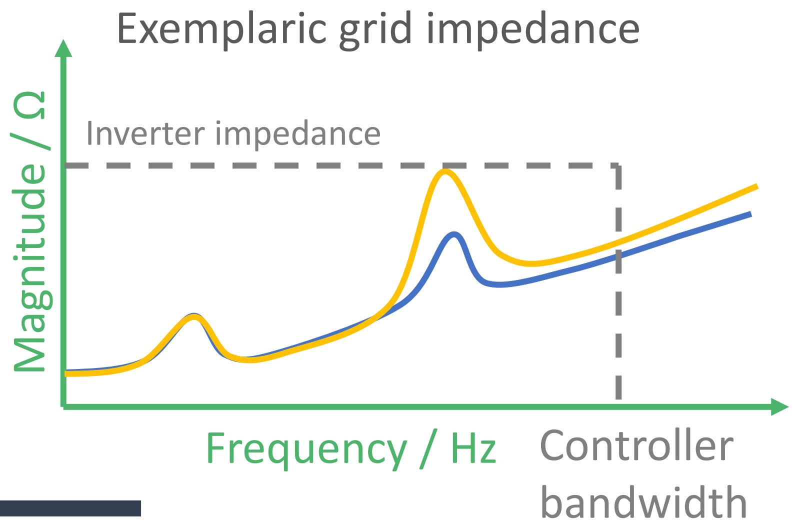
4. IMPEDANCE BASED INVERTER STABILITY IN GRIDS





Typical ohmic-inductive grid impedance at PCC

Change in grid impedance due to increasing number of inverter-coupled devices

Application of nyquist stability criterion for inverter-coupled devices

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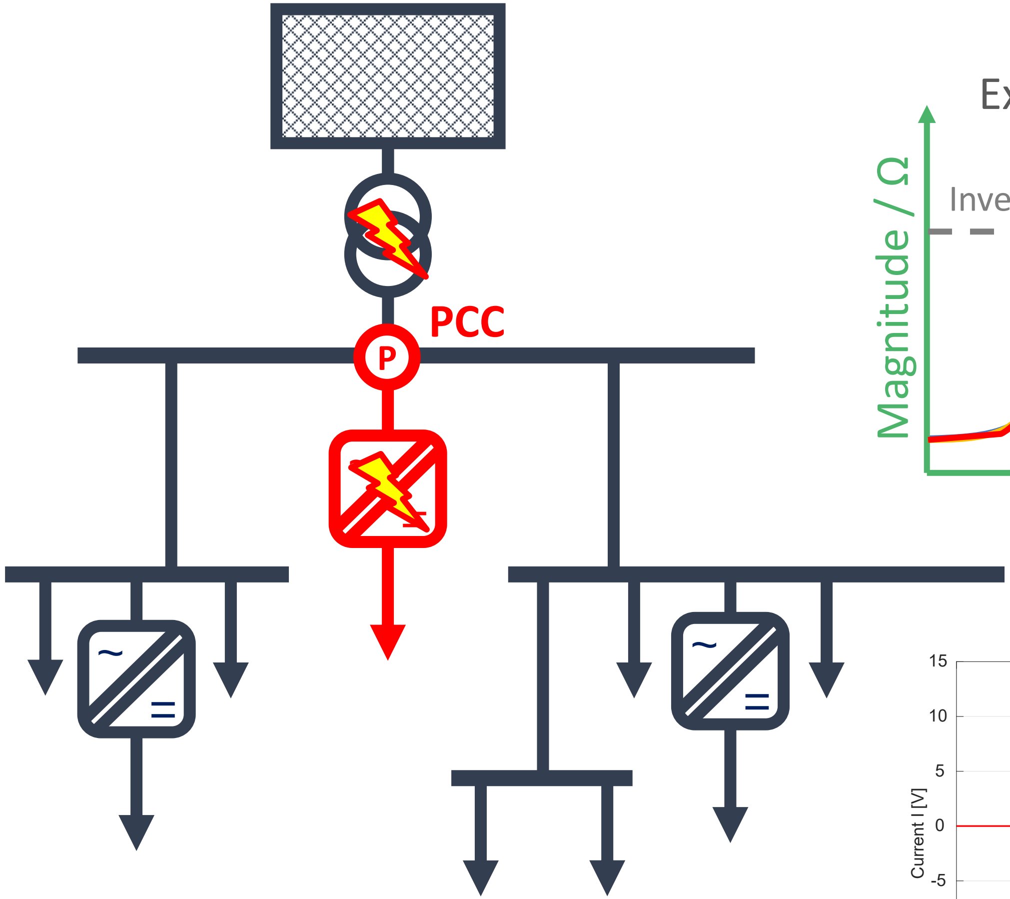
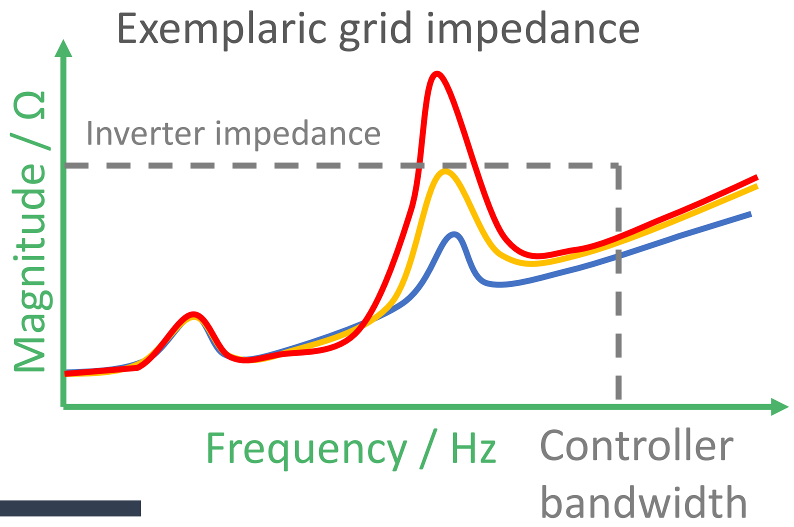
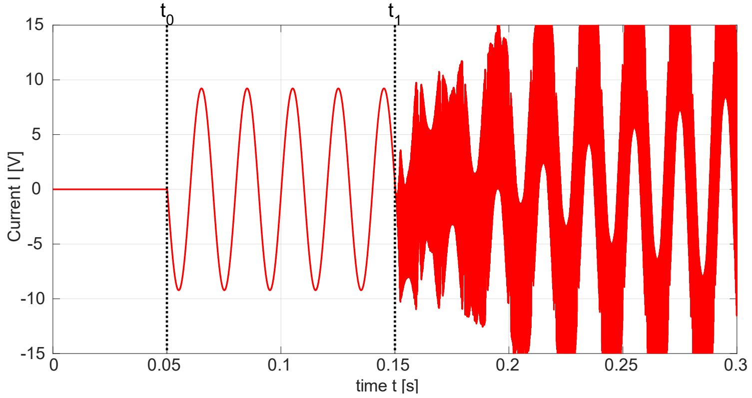
4. IMPEDANCE BASED INVERTER STABILITY IN GRIDS







Typical ohmic-inductive grid impedance at PCC

Change in grid impedance due to increasing number of inverter-coupled devices

Application of nyquist stability criterion for inverter-coupled devices

Instability of inverters for $|Z_{PCC}| \geq |Z_{INV}|$
→ Potential damage to inverters or grid components

4. IMPEDANCE BASED INVERTER STABILITY IN GRIDS

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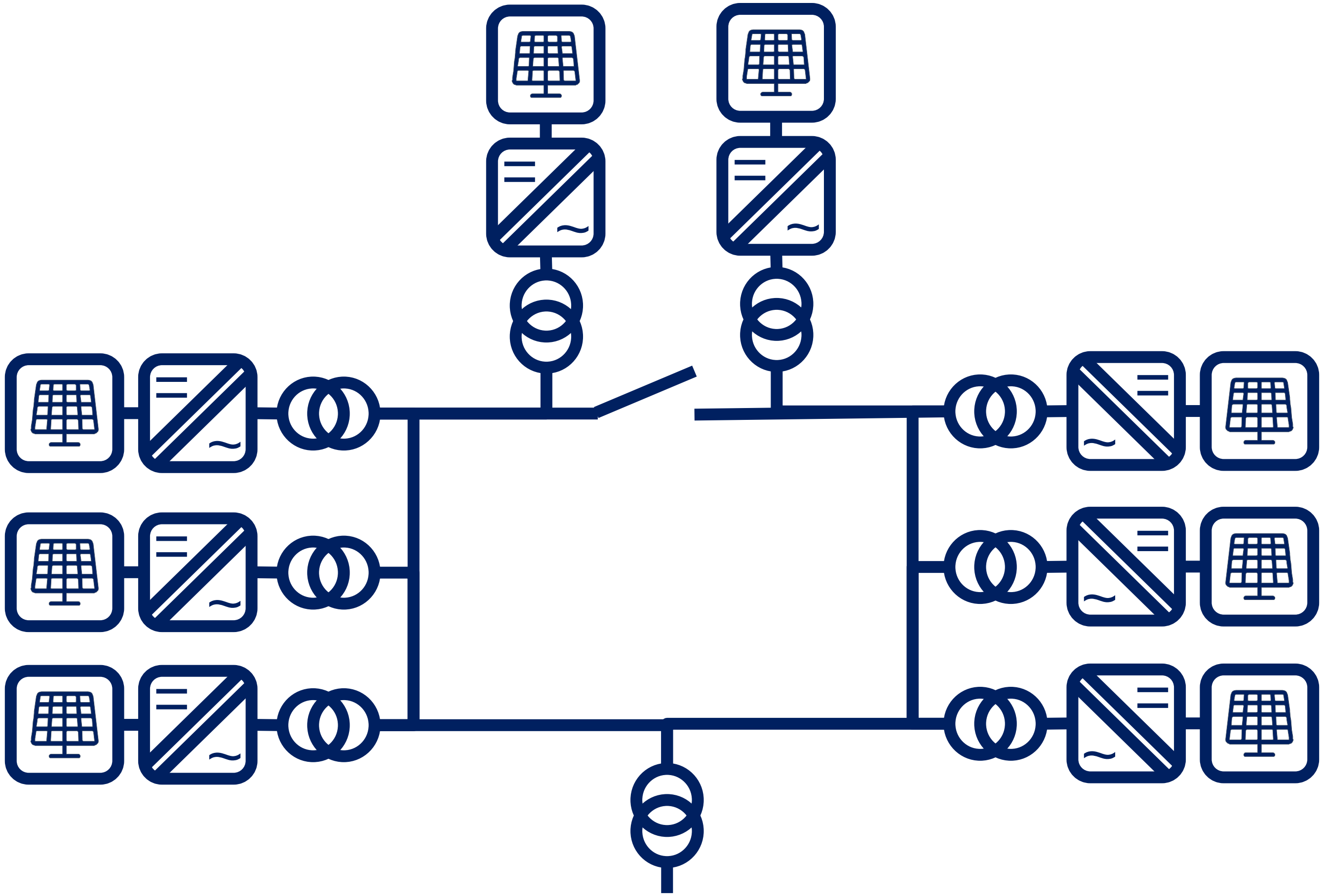

Time dependent PV-generation → time-varying grid impedance
Forced curtailment to save inverters from controller instabilites

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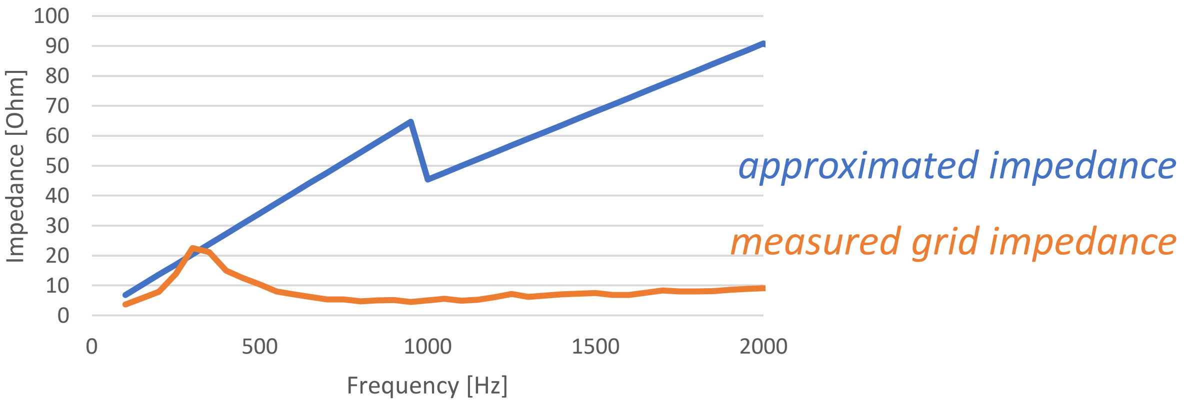
5. EVALUATION OF POSSIBLE GRID CAPACITY

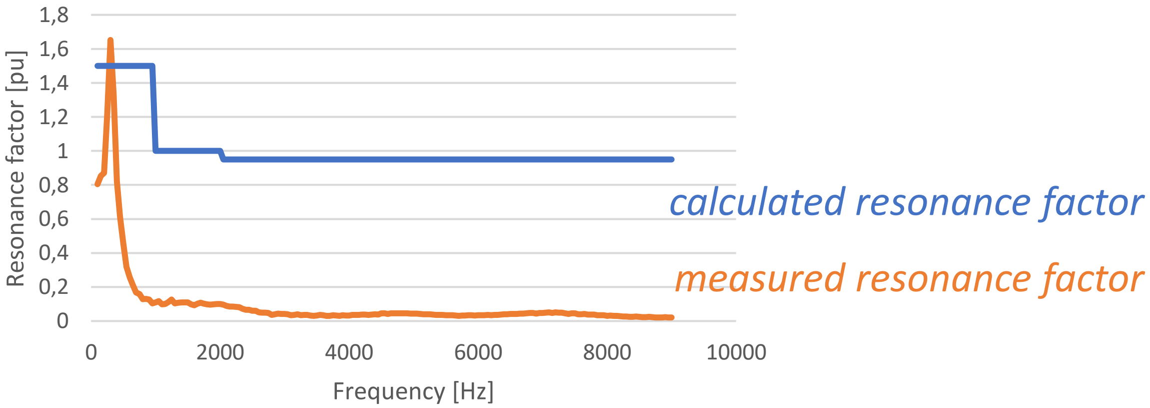
Problem:

- Certification process not passed: permissible harmonic levels of the generation plant exceeded
- Permissible harmonic levels are calculated from formulas within grid connection regulations (VDE-AR-4105, 4110, 4120)

Solution:

- Calculating of permissible harmonics using morEnergy measured grid impedances
- In most cases the impedances as well as the resonance factors are much lower than those use in the regulation documentation





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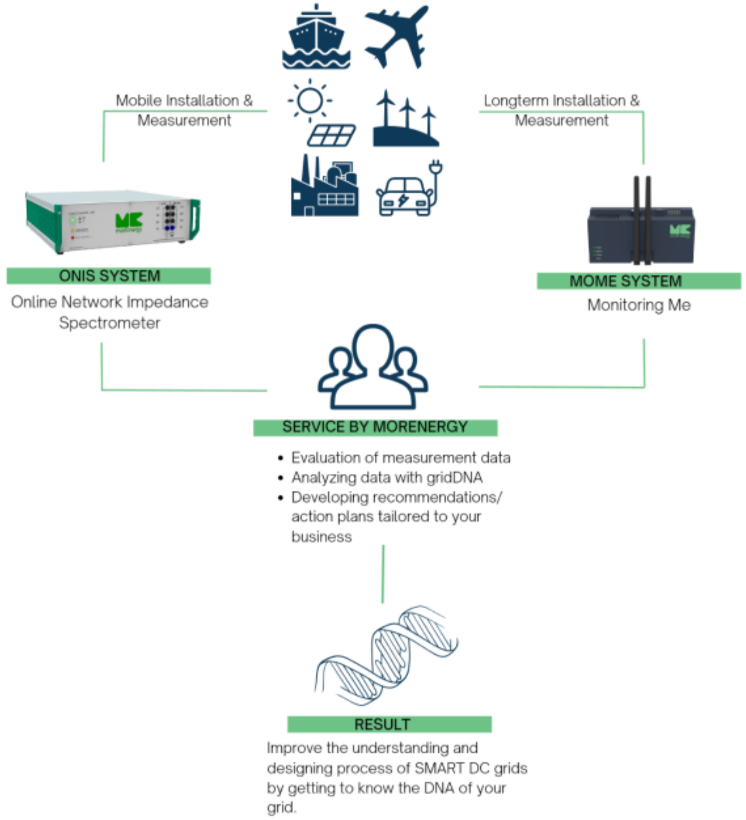
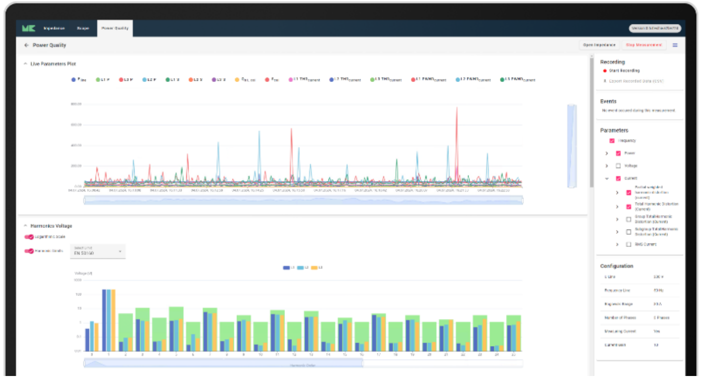
OUTLOOK ON ACTIVITIES AND RESEARCH

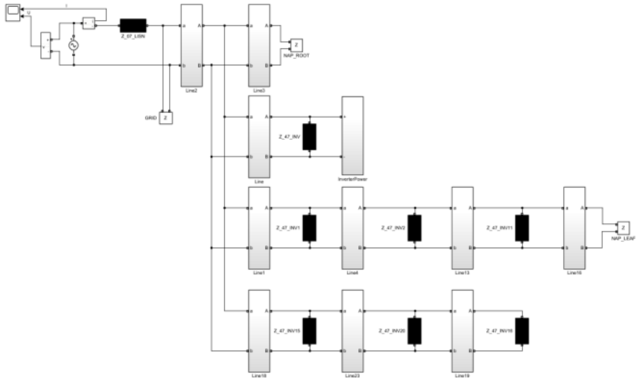
gridDNA by morEnergy

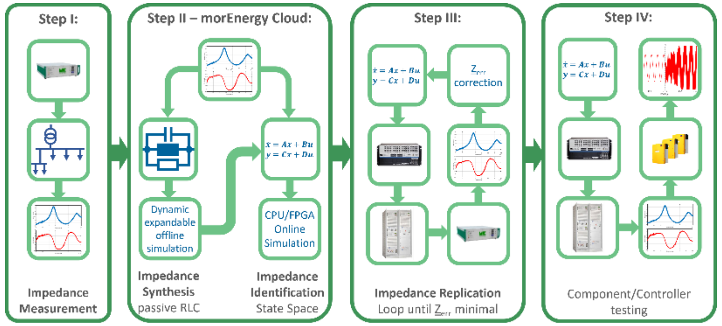


Power Quality



Grid Simulation and Impedance Replication





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Thank you for your attention!