From Charging Hubs to Battery Systems: What Measurements Reveal About Grid Impact

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Elaadnl

- Knowledge & innovation centre
- Non profit foundation
- Cooperation of grid operators
- Elaad testlab

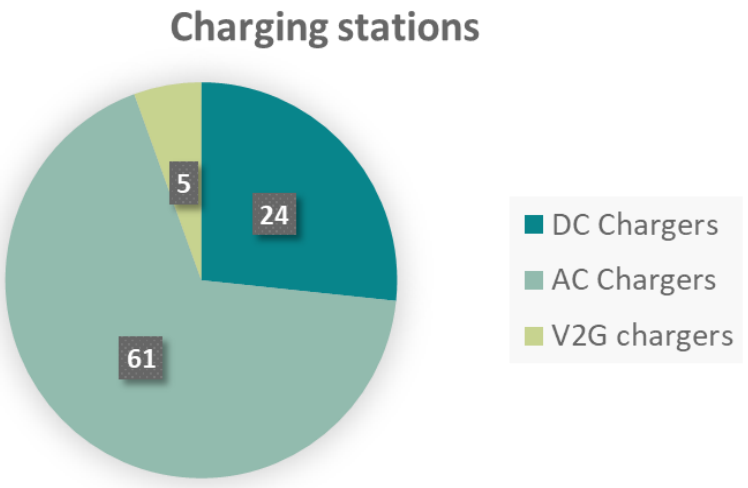
Our goal:

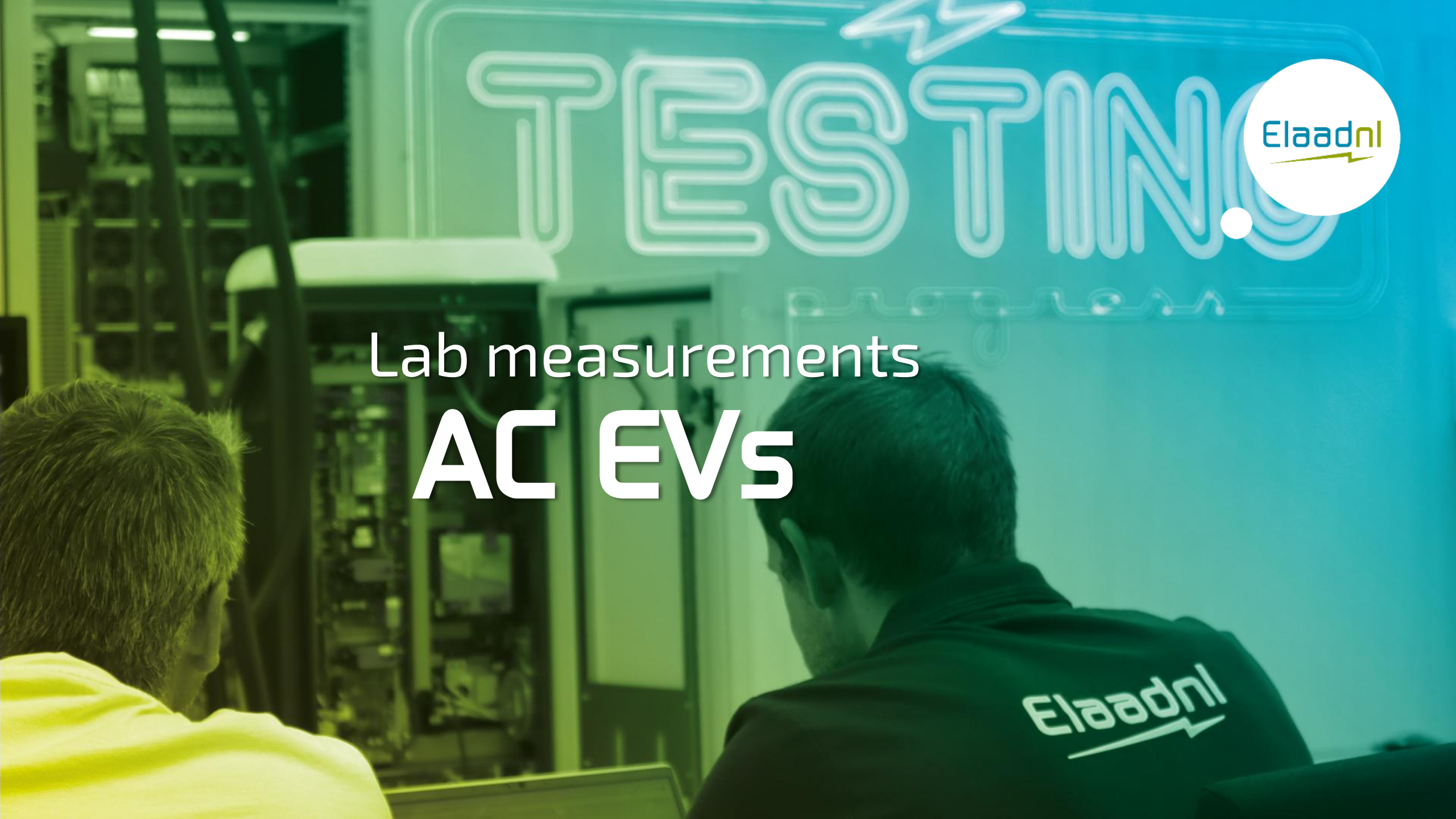
Integrating electric transportation in the electricity grid

The Elaad Testlab

- Open & free Test Lab to improve integration of EV charging and connected devices
- Focus on interoperability, controllability, power quality and cyber security
- Pre-certification, pre-normative, daily operational testing
- Sharing lessons learned for general improvement

- Different types of AC, DC and V2G chargers, heatpumps, home batteries and PV inverters
- Highly accurate lab and field measurement equipment
- 360 kW bidirectional test system from Keysight





Lab measurements

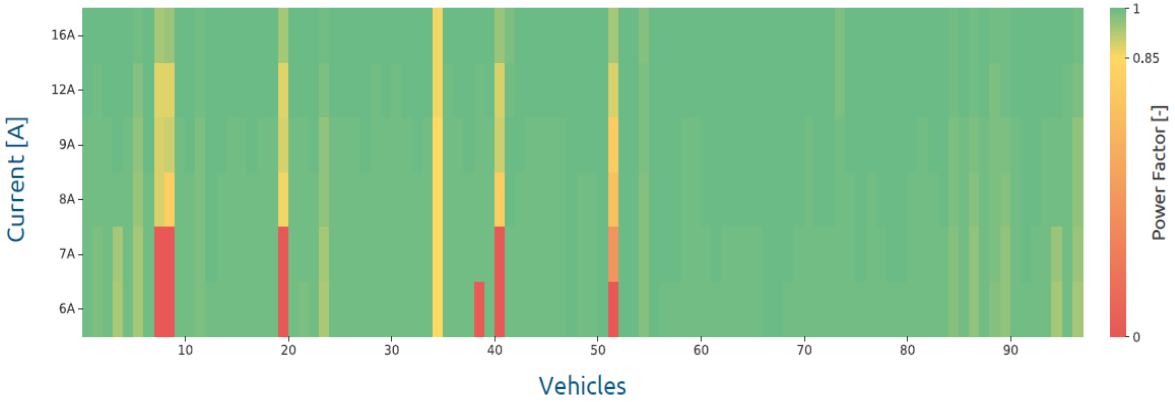
AC EVs

Power factor

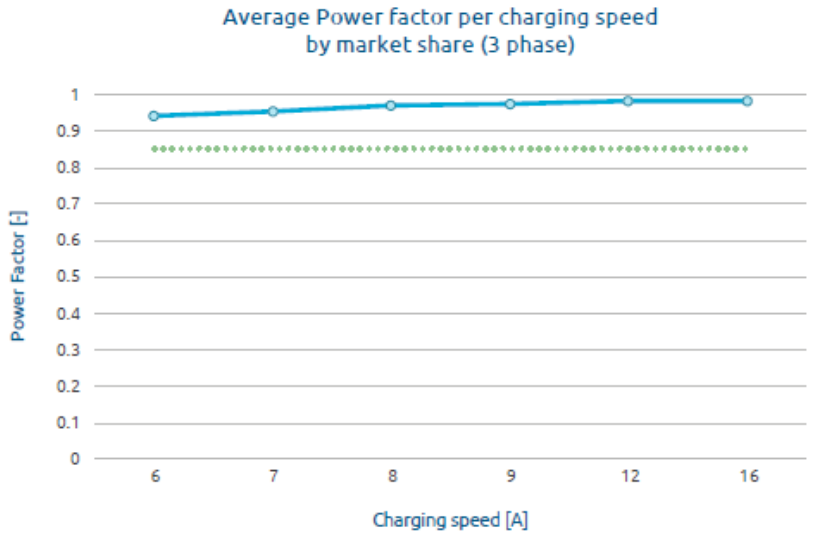
At low charging speeds PF can be lower.

- Increases charging time and reactive current in grid
- Market share, and therefore impact, of these vehicles is low

At 3 phase charging 6 vehicles out of 142 had a PF < 0,85 at lower charging speeds. Some even to 0.



Overall PF by market share slightly decreases with lower charging speeds

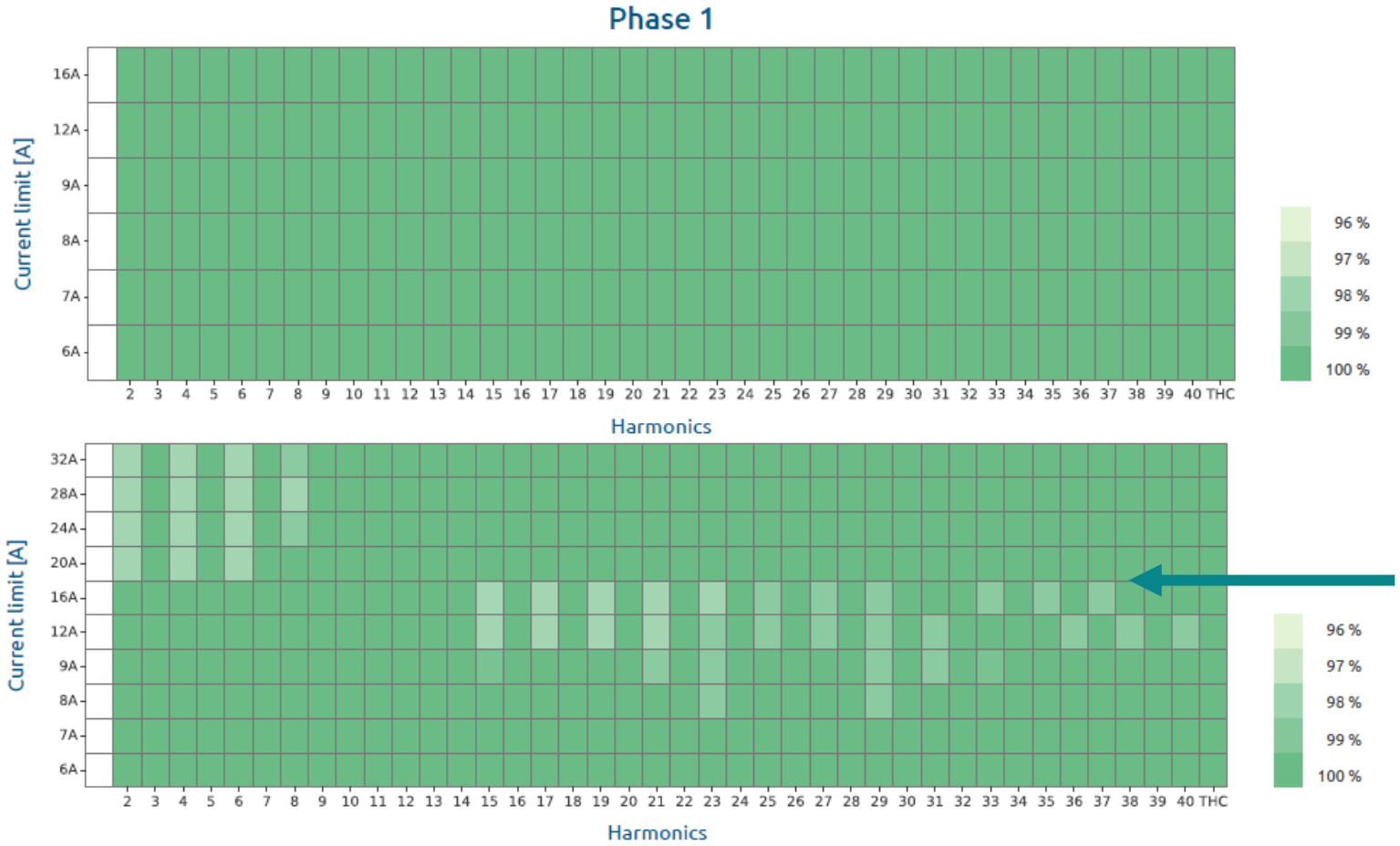


1-40 Harmonics

Harmonic limit breaches of 142 EVs

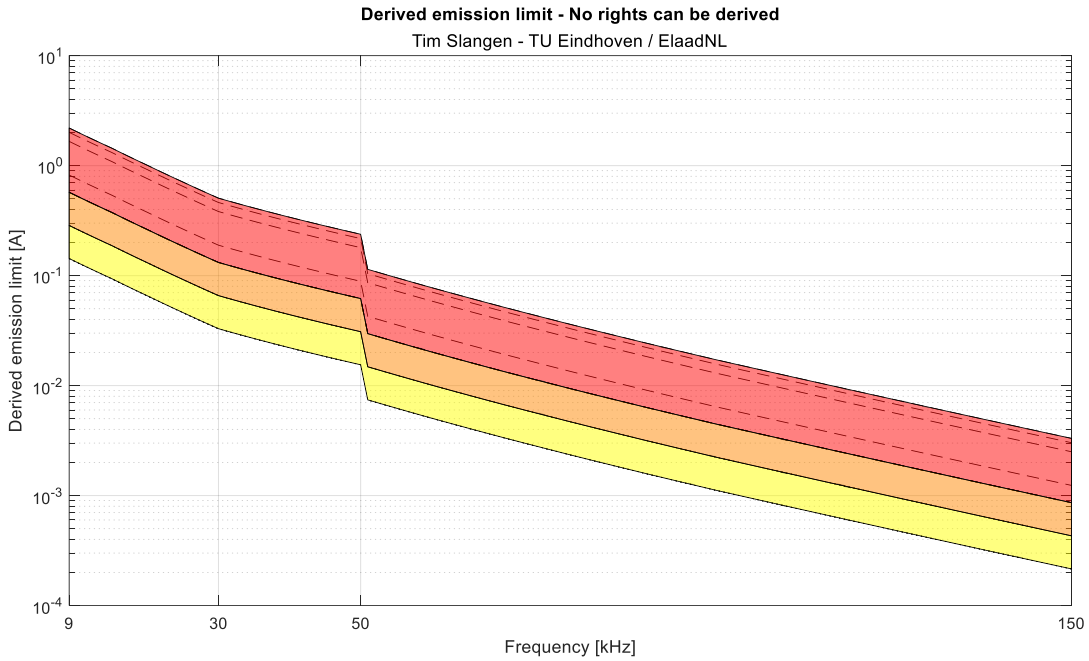
3 phase charging
Charging speed 6-16A

1 phase charging
Charging speed 6-32A



Limits
61000-3
-2 / 3-12

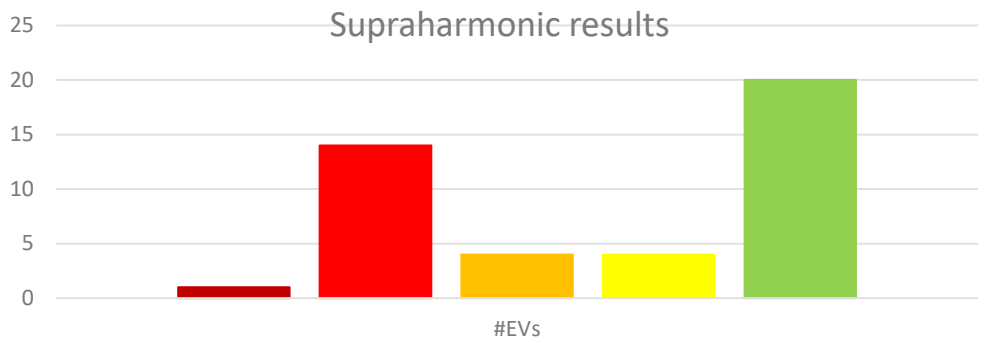
EV SH analysis



Result of TEPQEV project/PhD research
Tim Slangen

More information: https://elaad.nl/publicaties/
-> Power Quality -> TEPQEV Whitepaper

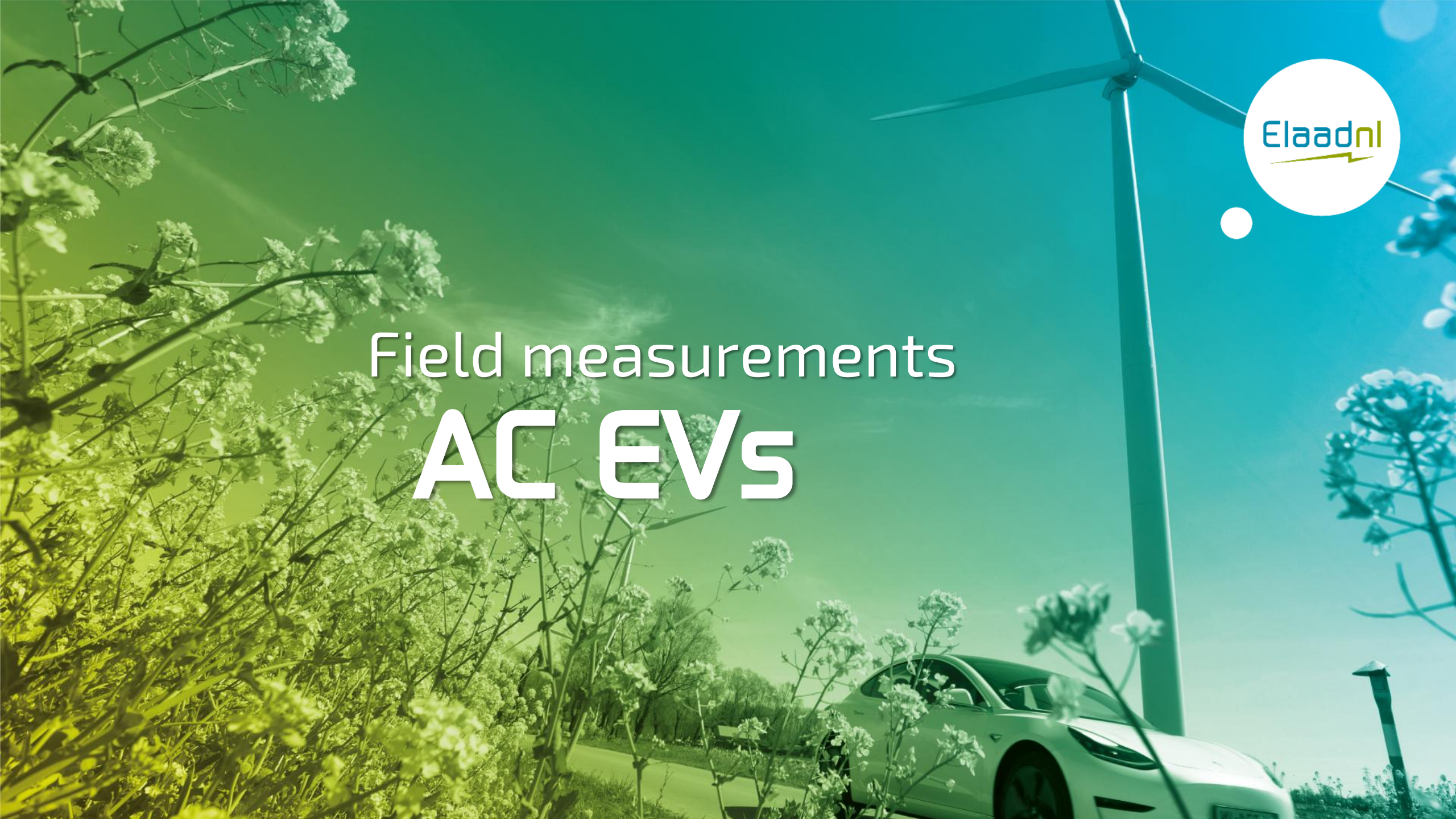
Results of analysis 1, 43 EVs



Results of analysis 2, 142 EVs

#phases	Current	Exceeds CISPR	Exceeds ½ CISPR	Exceeds ¼ CISPR
One phase	6A	21.5% (26/121)	95% (115/121)	100% (121/121)
	32A	22.3% (27/121)	81.8% (102/121)	100% (121/121)
Three phase	6A	24.2% (24/99)	94.5% (94/99)	100% (99/99)
	16A	26.3% (26/99)	88.9% (90/99)	100% (99/99)

As the test set-up used was not optimized to measure supraharmonics, these results only give an indication and cannot be used to draw conclusions.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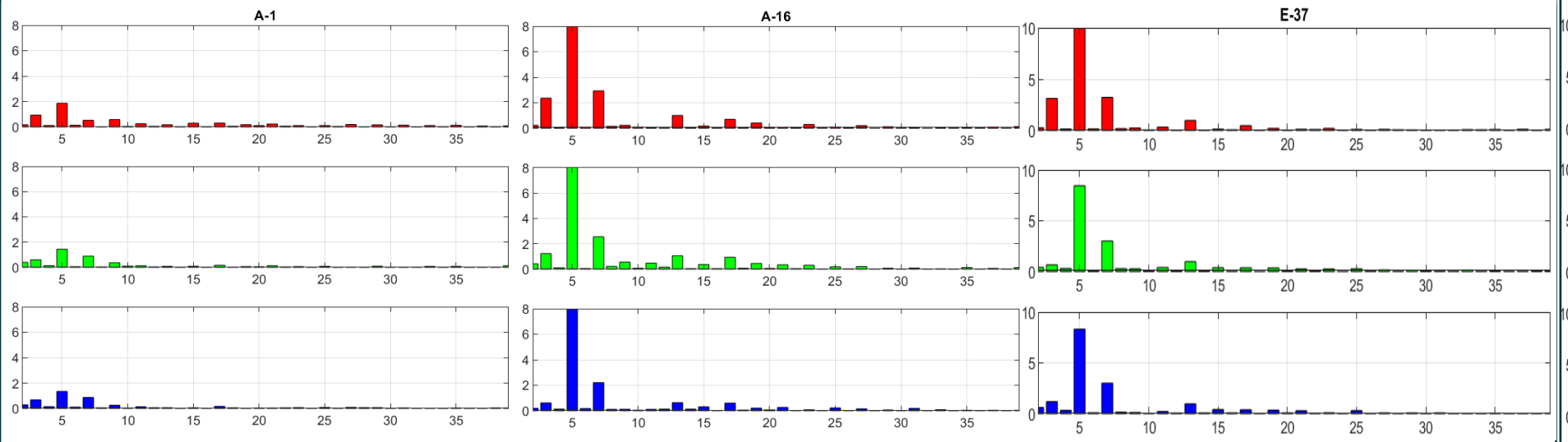
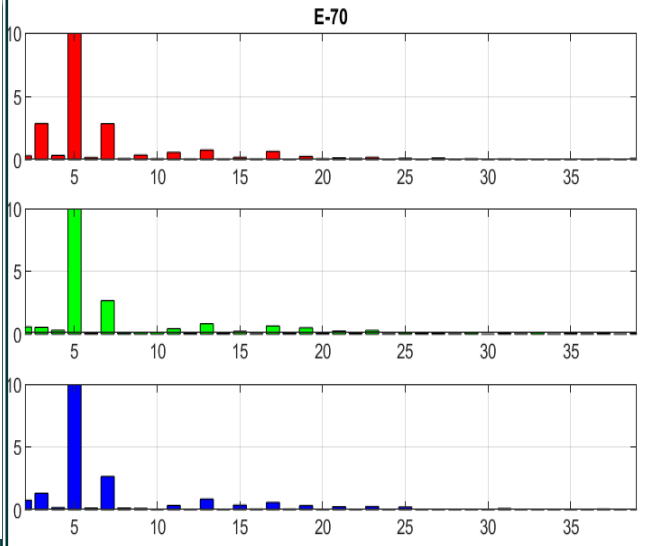
Field measurements
AC EVs

1-40 Harmonics

0 Number of EVs 40



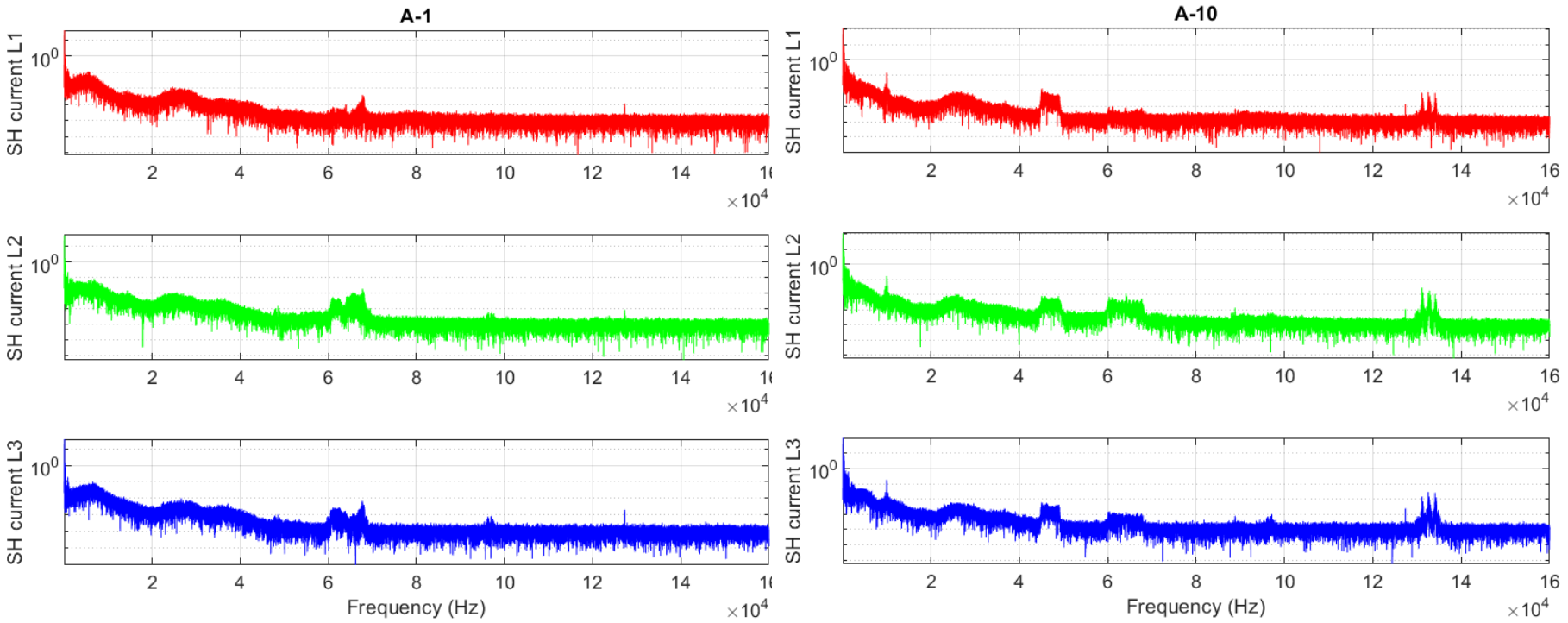
More EVs on an AC charging hub increase the amplitude of the harmonics

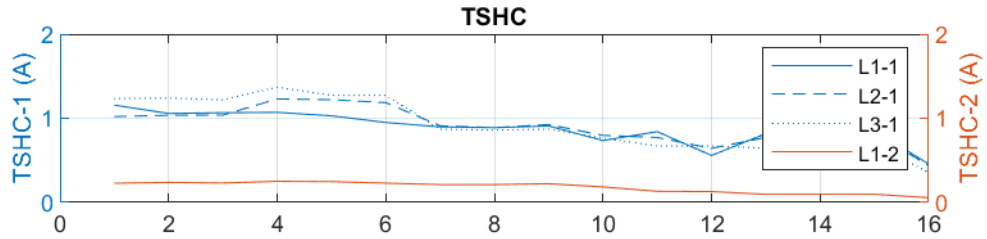


Till a maximum due to time-division charging

Supraharmonics

- SH current on more frequencies, some visible changes in amplitude
- TSHC actually decreases at the grid connection
- Possibly due to local absorption by the EVs themselves

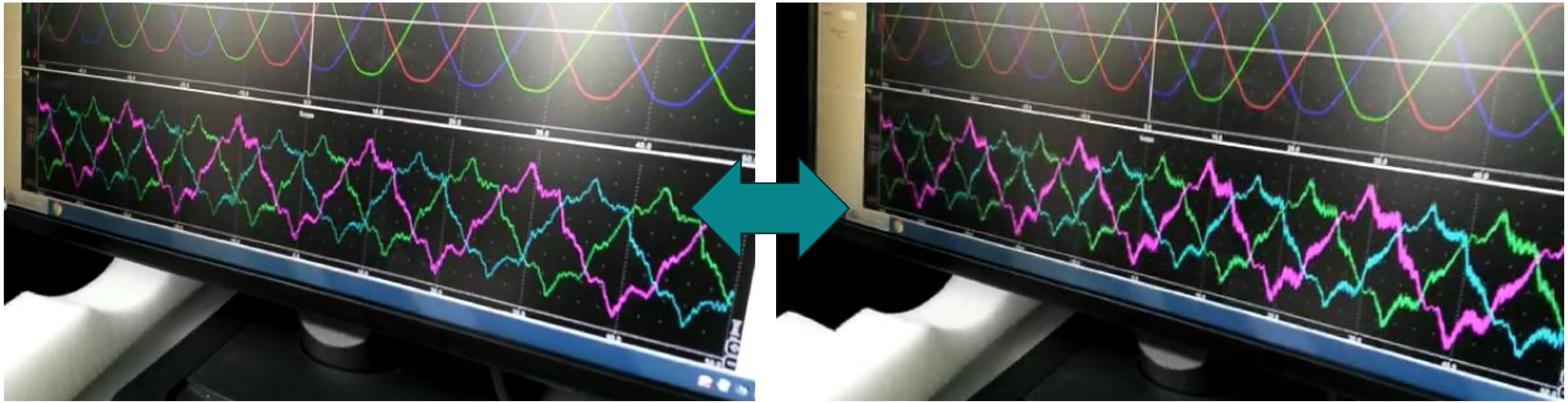


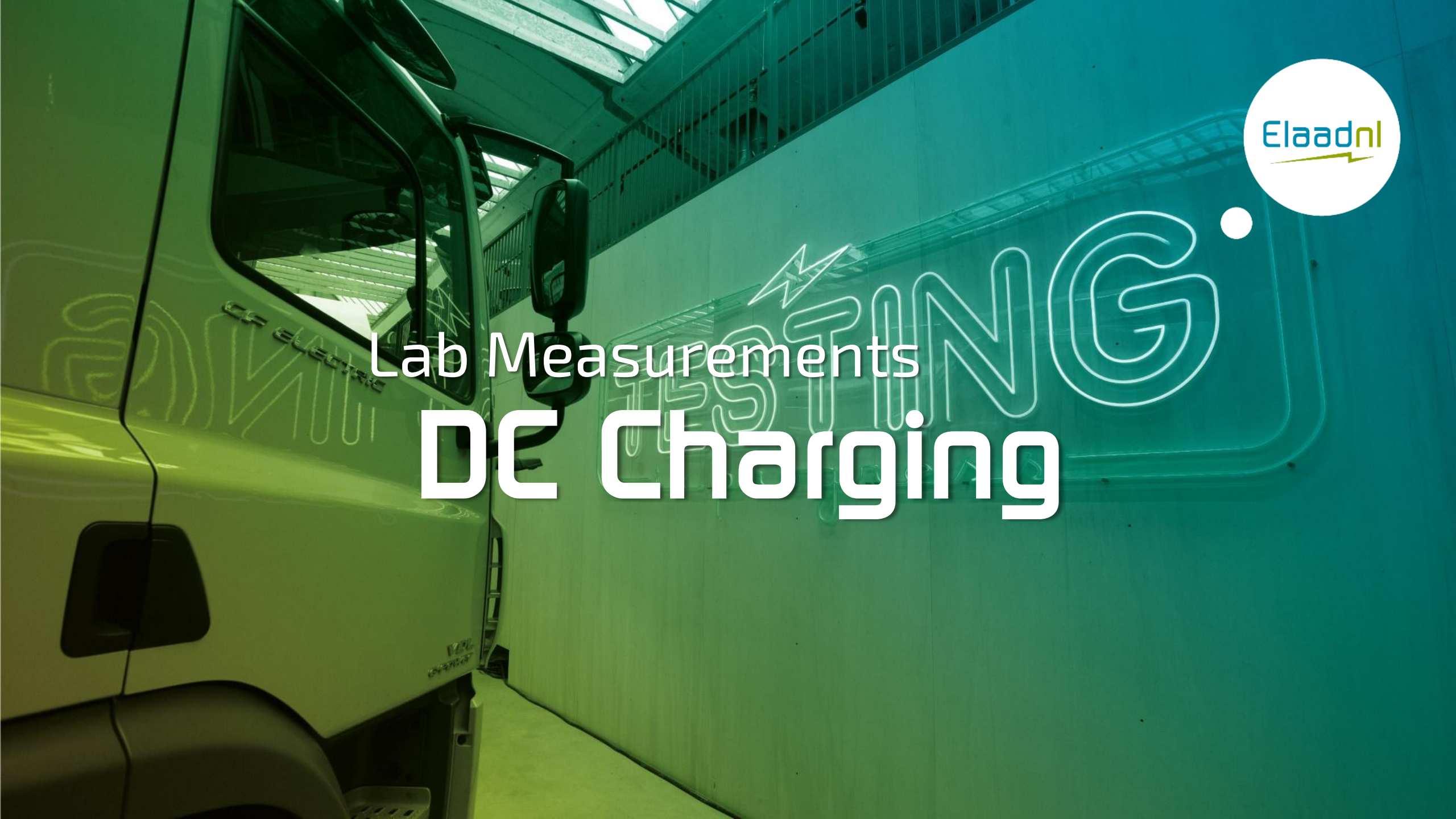


SH interactions

But what if the same vehicles are charging?

- Frequency beating



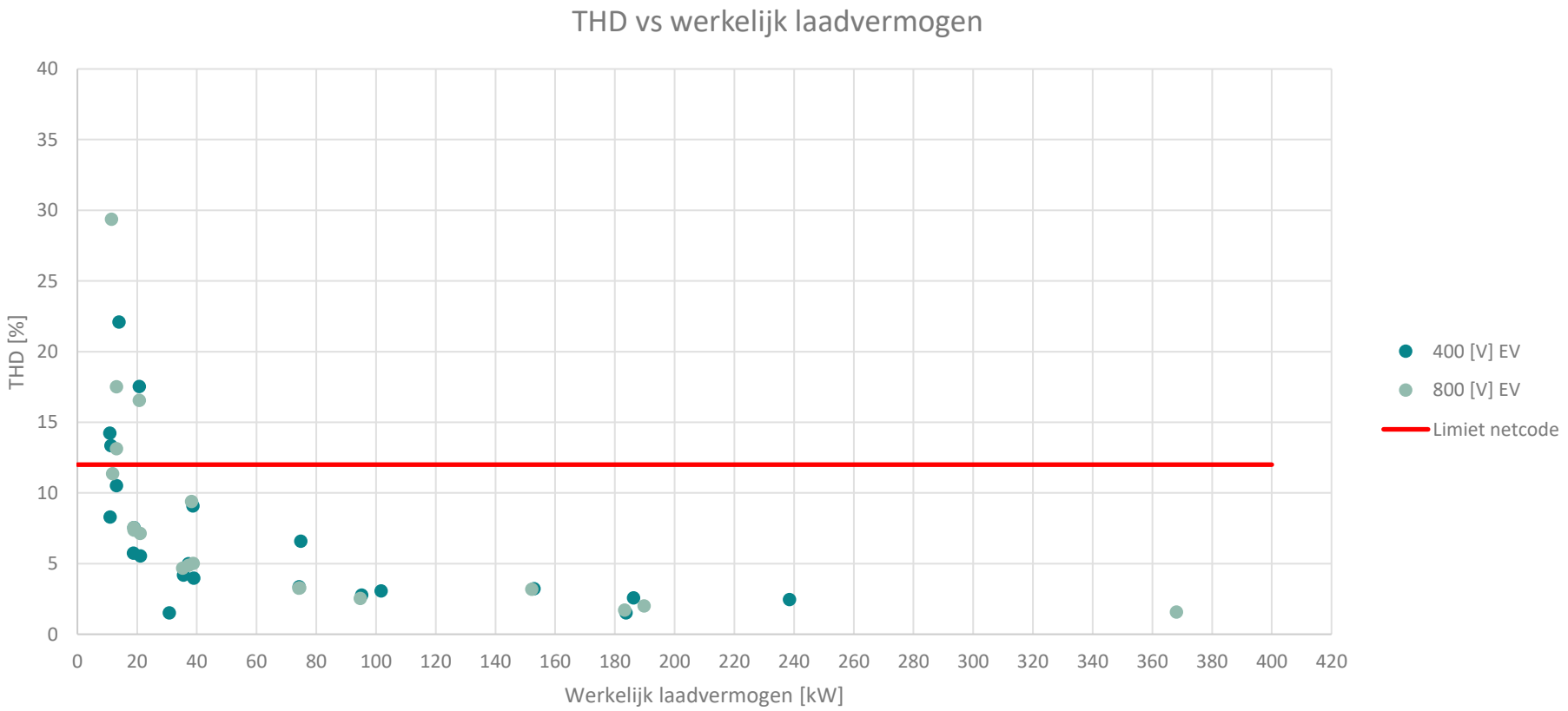


Lab Measurements

DC Charging

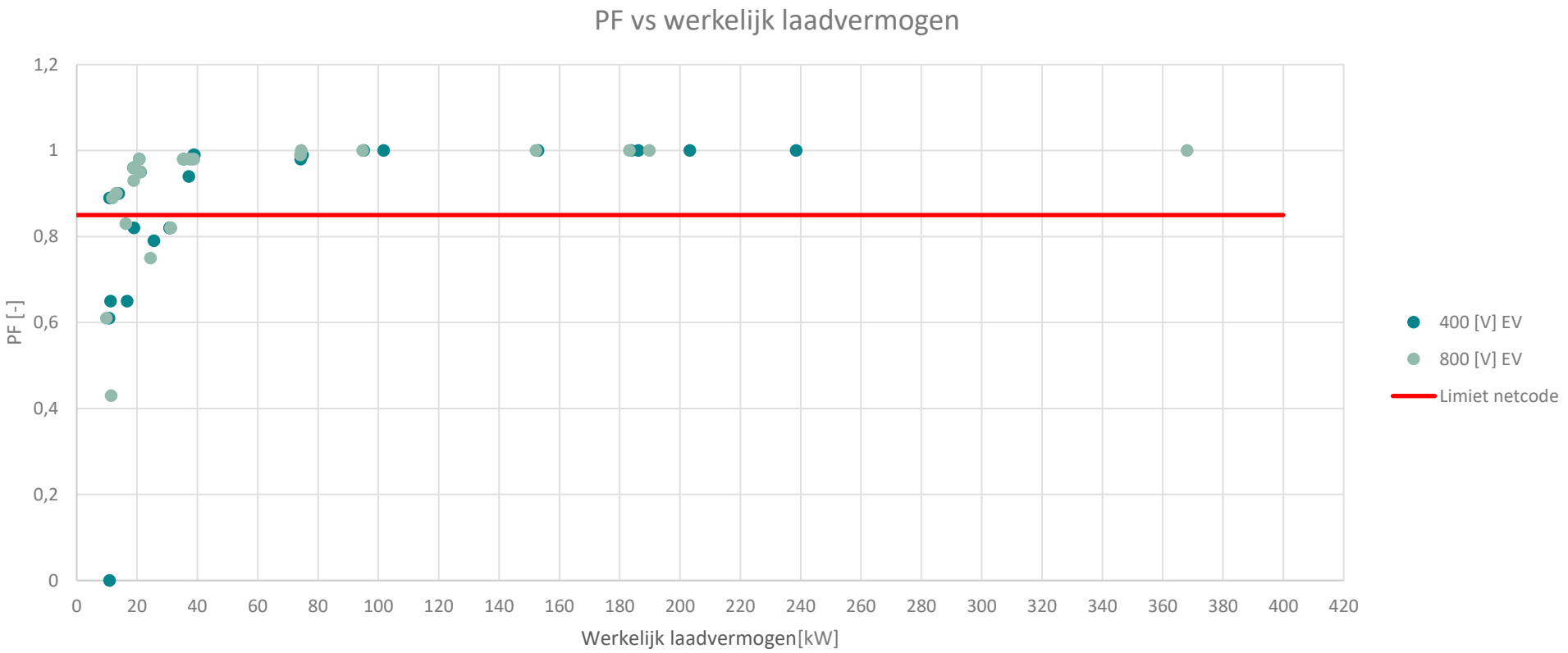
THD/power

- Based on 5 DC chargers, at 400 and 800V and multiple power levels
- THD vs active power holds up well on most power levels.
- Only when power is extremely limited, THD increases rapidly



Power factor/Power

- Power factor holds up very well during charging at most speeds
- Only at low power output (<10kW), the PF drops below 0,85 for 75% of the stations. In some cases even to ineffective values.

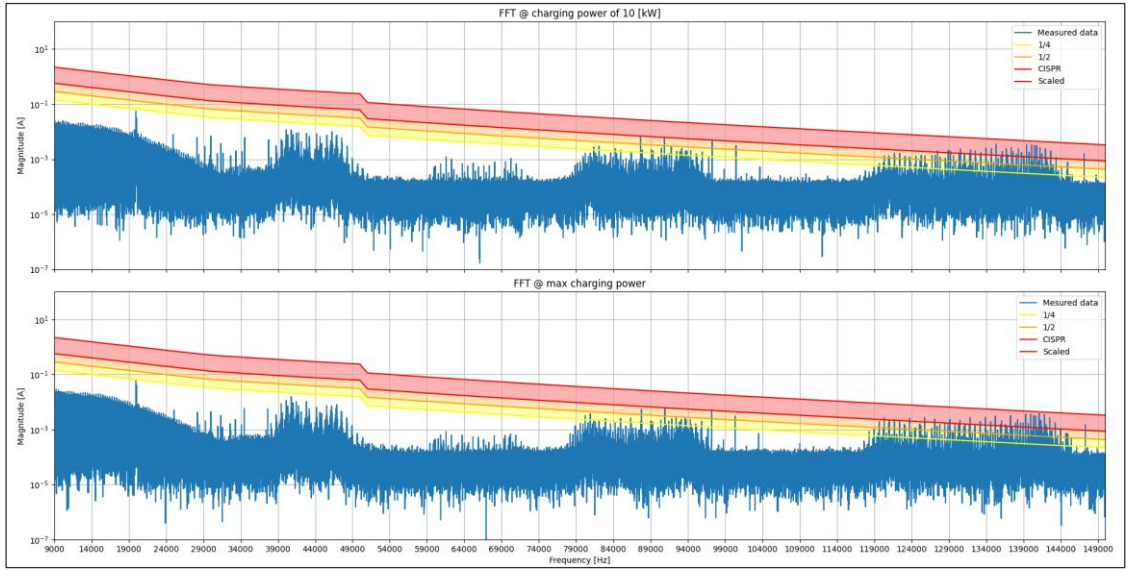


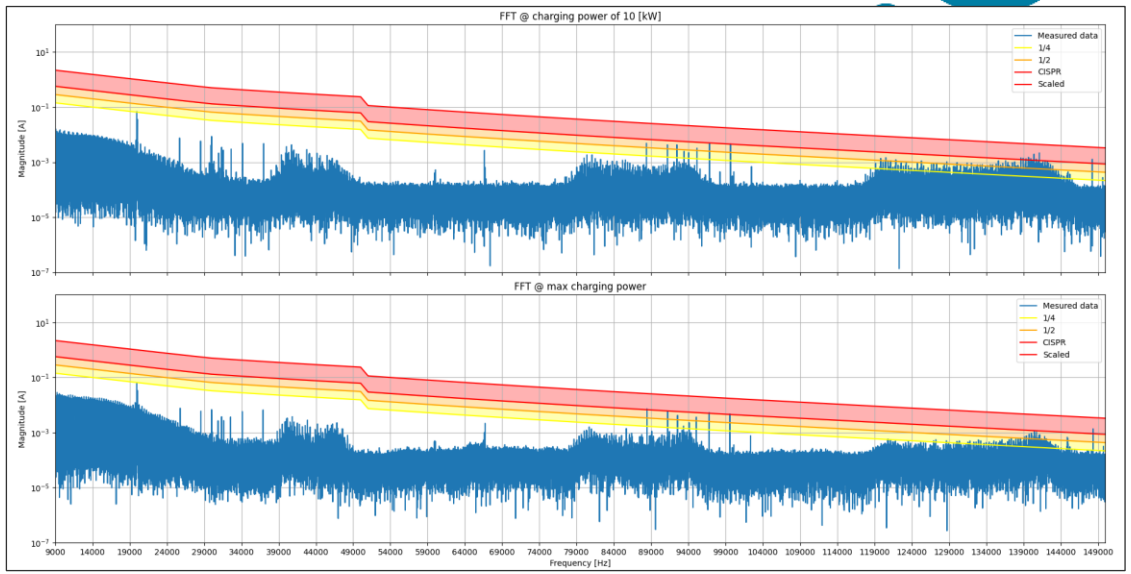
Supraharmonics FFTs

400V

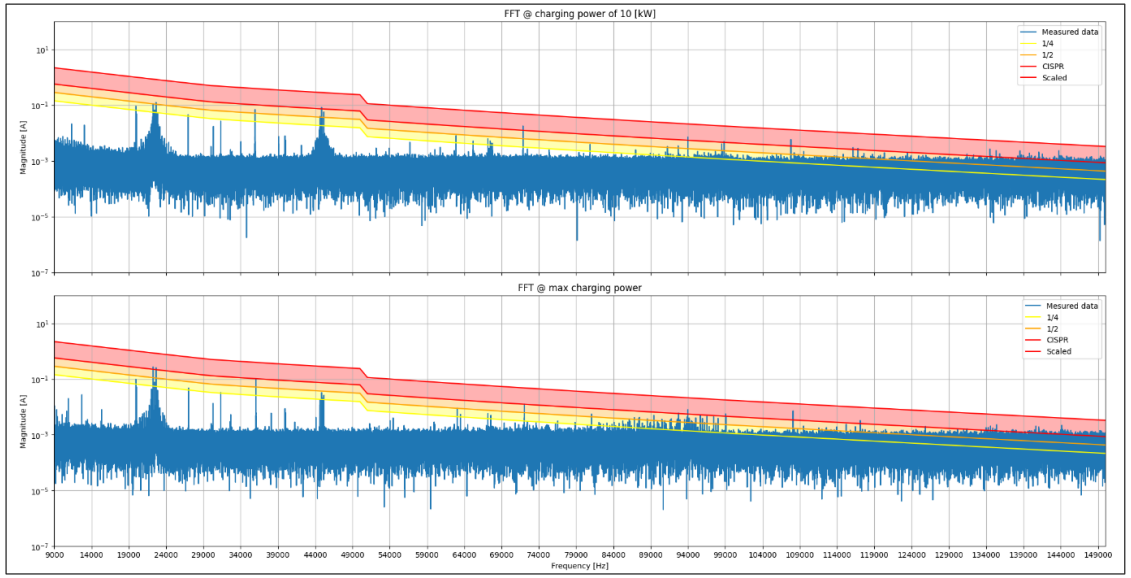
800V

DUT 1



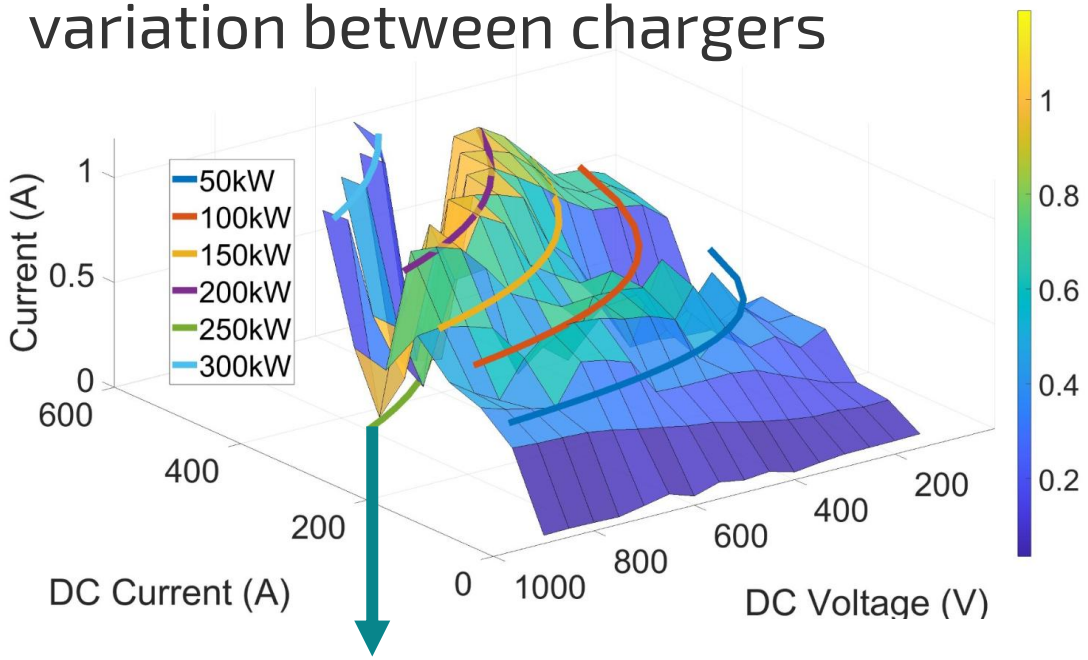


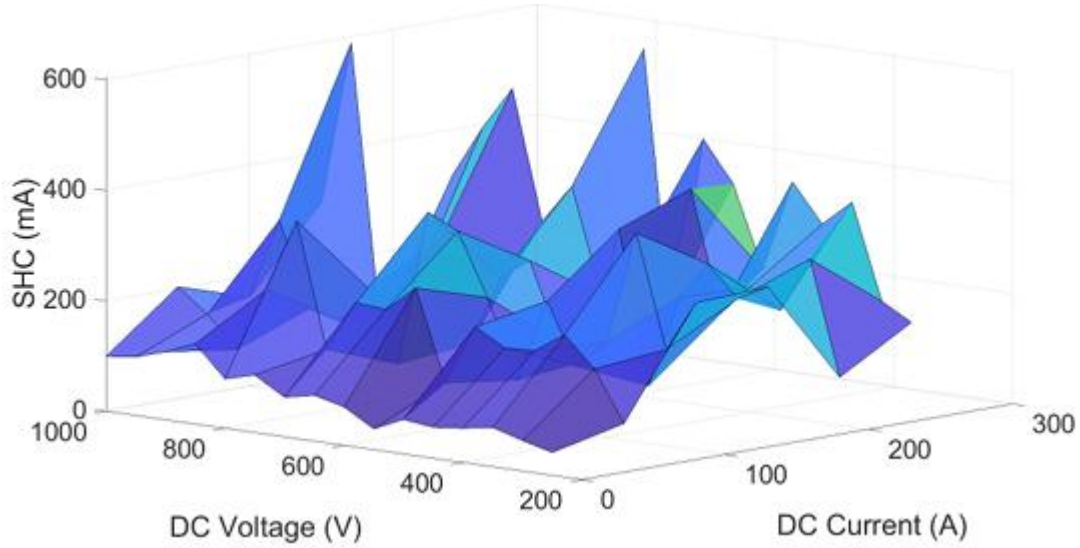
DUT 2

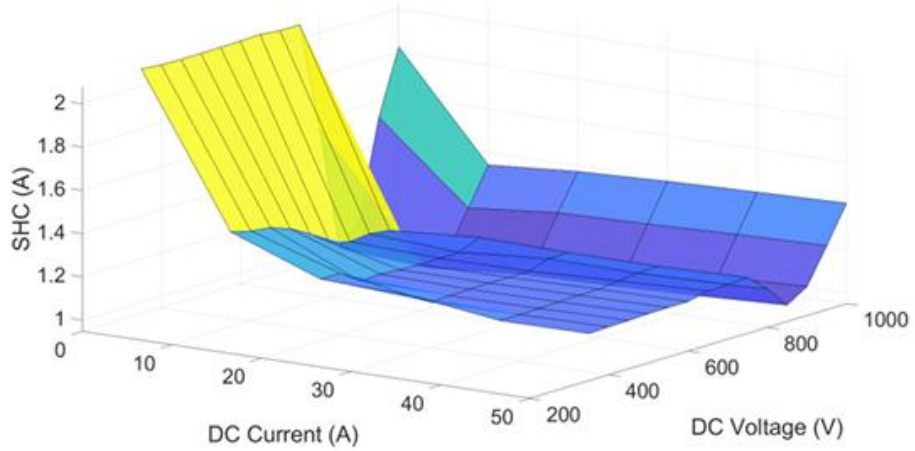


Supraharmonics 3D plots

SH emissions at different charging currents and voltages. A lot of variation between chargers



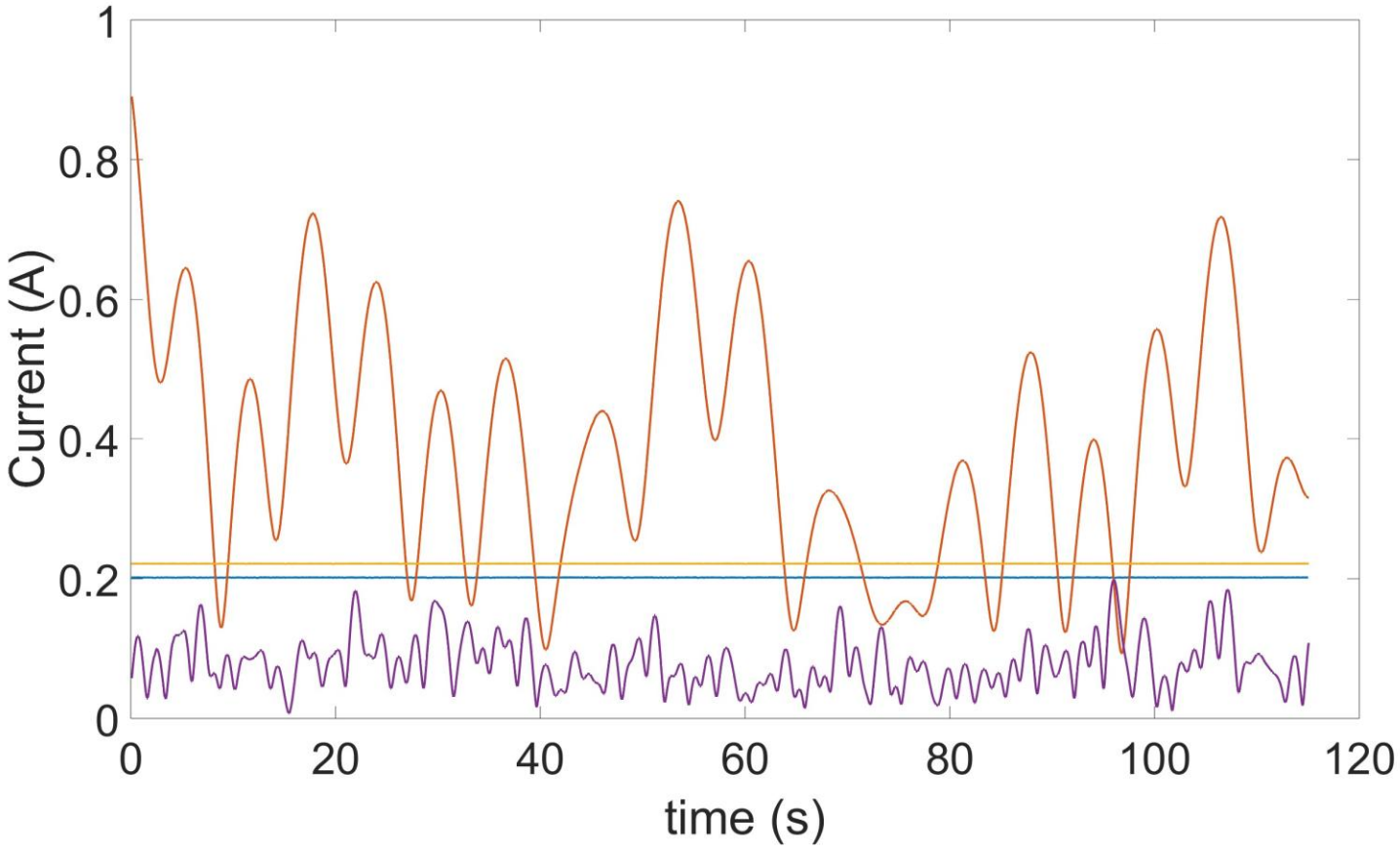




Emission limits are measured at 20% and 80% of max power.

SHs short term variation

Some DC chargers show significant variation in the SH emission over time



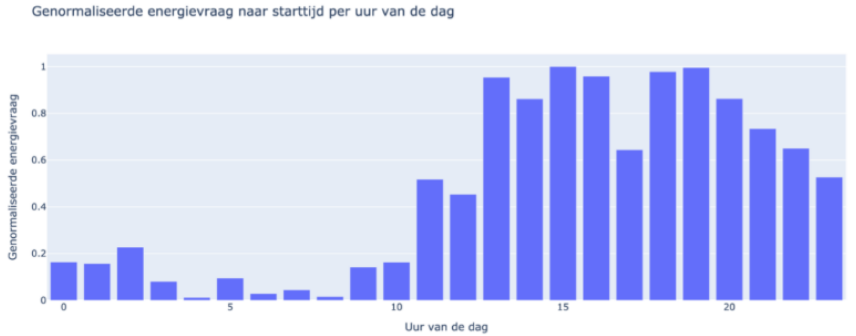
Field measurements

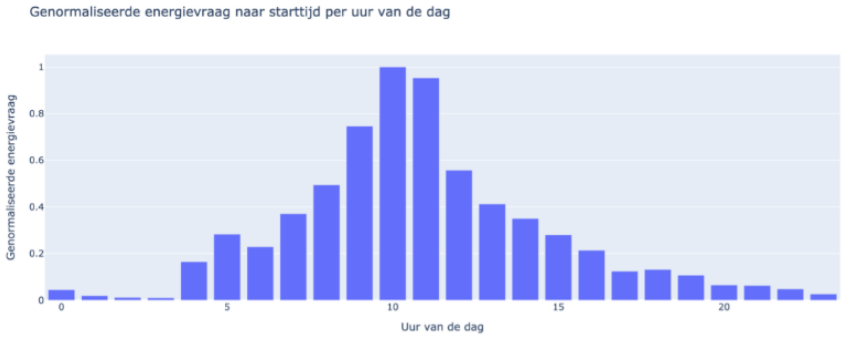
DC Charging

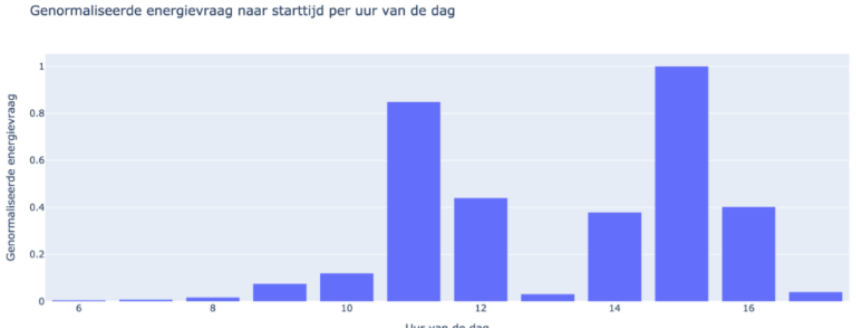
Power profiles

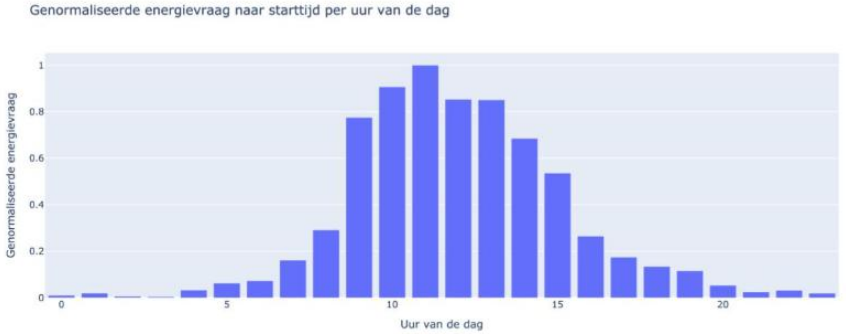
Measurements taken on 5 different DC charging hubs show very different power profiles depending on the use case;

- Truck parking
- Logistics hub
- Garbage disposal
- Highway charging







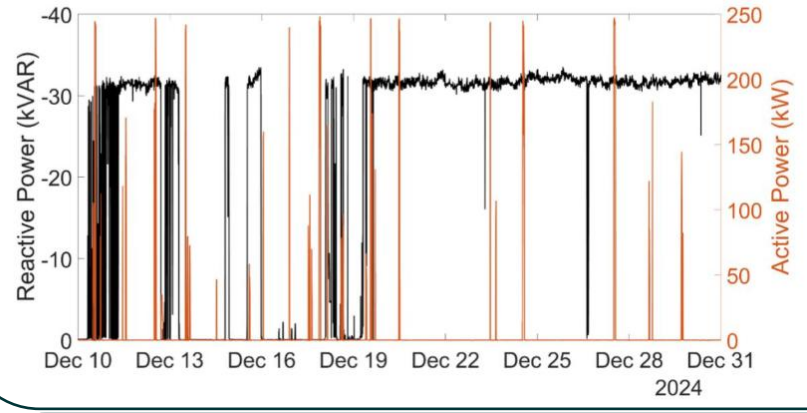


Reactive power standby

DC chargers tend to take in significant reactive power

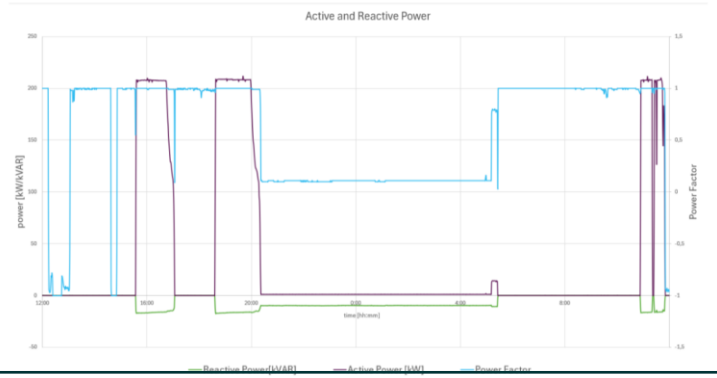
During charging

kVAR with 400 [V] EV	kVAR with 800 [V
4,77	4,92
1,41	2,3
4,94	4,89
12,48	NT
0,34	0,3

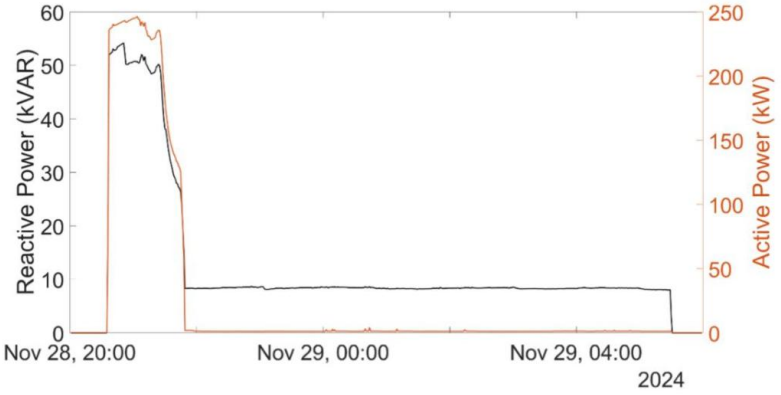


Continuously

When charging is paused by the DC charger



When EV still connected but fully charged

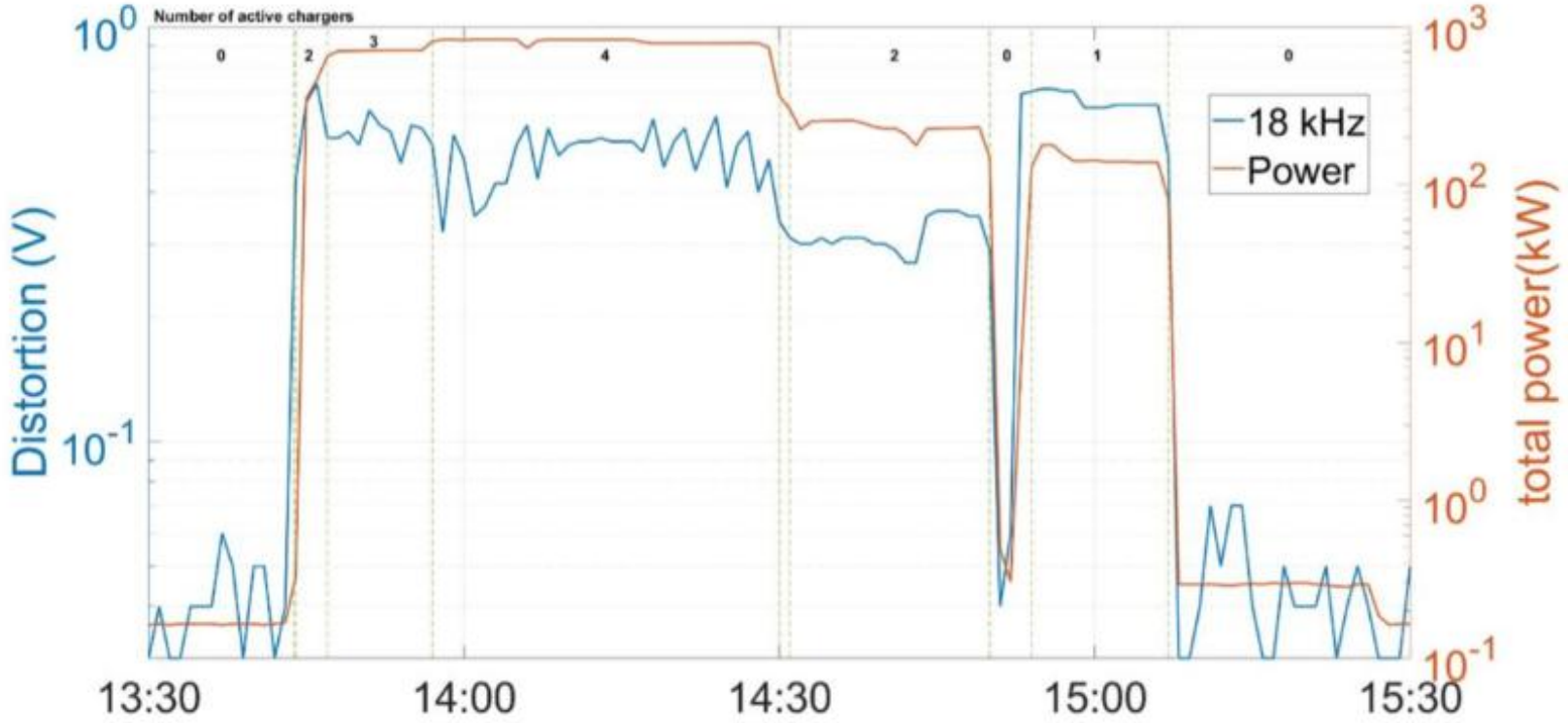


Supraharmonics

Deeper analysis of one charging hub on 18 kHz distortion

Measured at the grid connection

Chargers	0	2	3	4	2	0	1	0



- Charging increases the distortion significantly
- Distortion highest when 1 charger is active
- Simultaneous charging session do not cause noticeable more distortion and can even lower distortions

Final words

Conclusions, recommendations & next steps

Overall conclusions

AC charging:

- Low charging speeds do not lead to a significant increase of PQ emissions or lower PF.
- Individually harmonics are mostly within limits. They do add up at grid connection of charging hubs
- SH emissions are very common and in a lot of cases even cross the highest preliminary limit.
- At grid connection of charging hubs the TSHC decreases when more EVs are charging; distortions are absorbed by the EVs themselves, which can cause issues and interactions.

DC charging:

- Power profiles vary depending on use case
- THD and PF perform very well when charging. Only at very low power they cross limits
- Reactive power intake is significant, even during inactivity
- SH distortions vary widely between chargers. Power output, voltage level and time can all be variables.

Recommendations

AC charging;

- Compliance to PQ limits at all power levels should become part of certification/type approval
- If there is a THD, PF or SH interaction issue at a charging hub; use time-division charging to mitigate

DC charging:

- Depending on the use case, a DC charging hub might fit with the local power profile or not
- When a charger is inactive, disconnect the charging power path from the grid to avoid capacity loss and costs.

In general:

- SH limits for EVs and DC chargers need to be defined, formalized and added to certification
- As there is a lot of variety in the height of the SHs in different situations, a thorough test and analysis would be recommended
- Filters of devices should be designed with the ability to handle more than just their own emission

Next steps

- Battery integration testing in SEMS
- V2G and grid code pre-certification
- MCS charging, impact on PQ at MV? (FlexMCS)
- Supraharmonic immunity of DC chargers and their metering (MET4EVCS)
- Investigation of the impact of energy-intensive home devices on PQ (Netbewust normeren)
- DSO research requests, like 3,5 Hz oscillations