TEPQEV symposium: DC-Chargers

(Supra)harmonic emission and interaction

Tim Slangen

Overview

Background

Research objectives

Experimental set-up

Results

Conclusion

Overview

Based on:

- Slangen, T., Cuk, V., de Jong, E. C. W., & Cobben, J. F. G. (2022). **Harmonic Emission of EV Fast Charging Station under Different Supply- and Operating Conditions**. In *Innovative Smart Grid Technologies Europe, ISGT-Europe 2022* https://research.tue.nl/nl/publications/harmonic-emission-of-ev-fast-charging-station-under-different-sup

- Slangen, T., Cuk, V., Cobben, S., & de Jong, E. C. W. (2022). **Characterization of Supraharmonic Emission from High-Power Electric Vehicle Chargers**. In *CIRED Porto Workshop 2022: E-mobility and power distribution systems* https://doi.org/10.1049/icp.2022.0678

Background: EV-Charging methods

On-board charger (OBC)	Fast-charging station (FCS)
3-22 kW	50-350 kW
3-8 hours	15-30 minutes
Destination (home/work)	During travel (highway)
Converter in vehicle	Converter in charging station
“AC-charging”	“DC-charging”
NL: 100.000 AC-chargers	NL: 3.300 FCSs Source: RVO

Elaadnl TU/e

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Megawatt Charging System (MCS)

Session 3		
13.30	Tim Slangen, TU/e	SH-emission DC-chargers and interacti
14.00	Thomas Gerrits, Heliox	Multi-MW charging systems
14.30	Ernst Wierenga, Stedin	Implementation in grid calculation tools
15.00	drinks	

Background: literature

- FCSs can be a source of (supra)harmonic currents *(Wang e.a. 2021, Slangen e.a. 2021, Zavoda 2019, Sun e.a. 2018)*

- Especially in idle- or reduced power operation they can exceed the limit *(Chen e.a. 2021)*

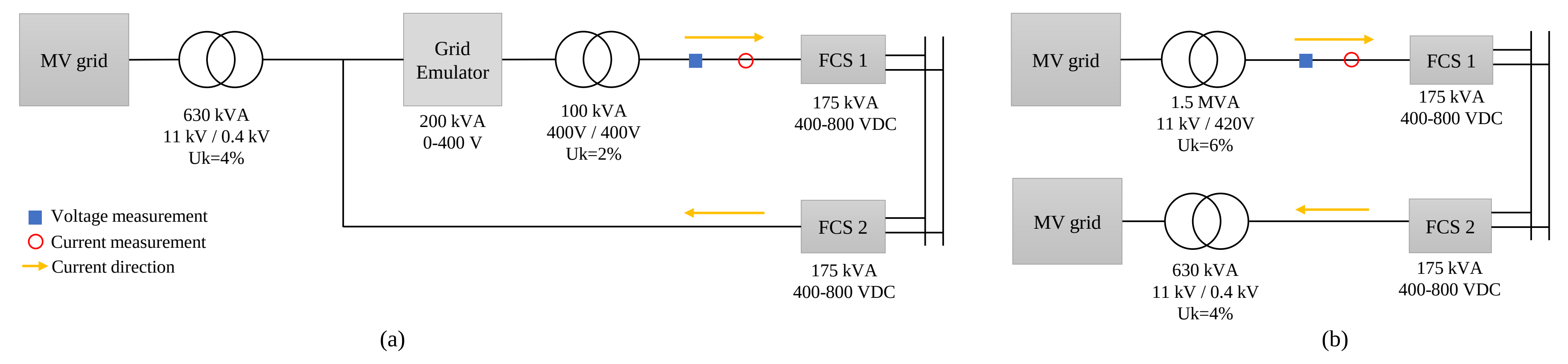
- (Supra)harmonic emission from modern power electronic devices (LEDs, PVs, household devices) can vary significantly due to
  - Different operating conditions
  - Changes in the supply voltage distortion.

  (Xiao e.a. 2017, Xu e.a. 2016, Langella e.a. 2016)

Research objectives

- Fingerprint of the harmonic and supraharmonic emission of a FCS
- i.e. providing a sensitivity analysis of the primary (supra)harmonic emission of the FCS to;
  1. The AC supply voltage harmonic distortion
  2. The DC output power
  3. The DC output voltage

Experimental set-up



(a) Harmonic injection

(b) Full power

Experimental set-up

Experimental set-up: test parameters

TABLE I
HARMONIC VOLTAGE LIMITS ACCORDING TO NEN-EN 50160 [15]

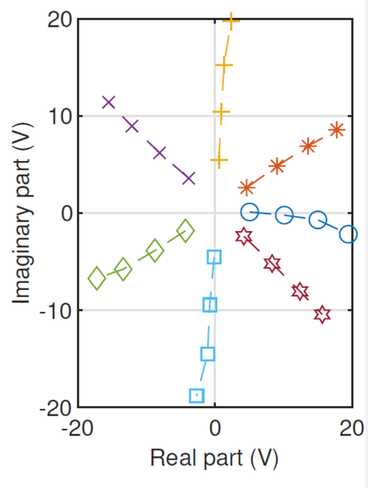
Harmonic (-)	5	7	11	13	17	19	23	25
Max. voltage (%)	6.0	5.0	3.5	3.0	2.0	1.5	1.5	1.5

TABLE II
DC OUTPUT OPERATING PARAMETERS

	500 Vdc	600 Vdc	700 Vdc	800 Vdc
25 kW	50 Adc	42 Adc	36 Adc	31 Adc
50 kW	100 Adc	83 Adc	71 Adc	63 Adc
75 kW	150 Adc	125 Adc	107 Adc	94 Adc
100 kW	200 Adc	166 Adc	142 Adc	125 Adc
125 kW	250 Adc	208 Adc	179 Adc	156 Adc
150 kW	300 Adc	250 Adc	214 Adc	188 Adc
175 kW	350 Adc	291 Adc	250 Adc	219 Adc

ρ = [25%, 50%, 75%, 100%]

θ = [0, 30, 90, 150, 210, 270, 330]



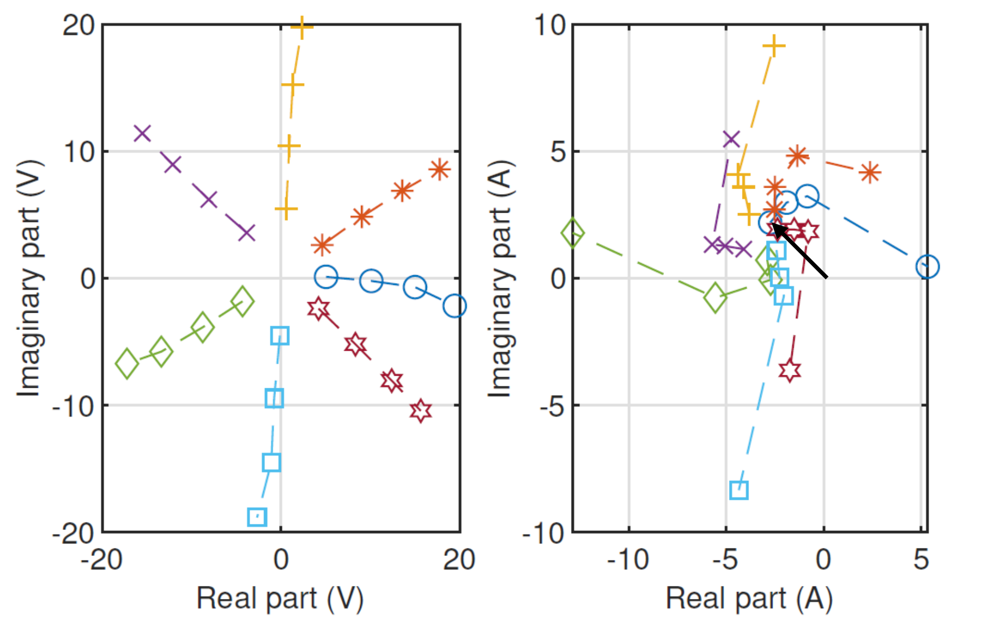
Results harmonic emission

- Effect of supply voltage distortion
- Effect of operating conditions

Reference: the nominal condition (175 kW at 800 Vdc)

Results harmonic emission: harmonic background

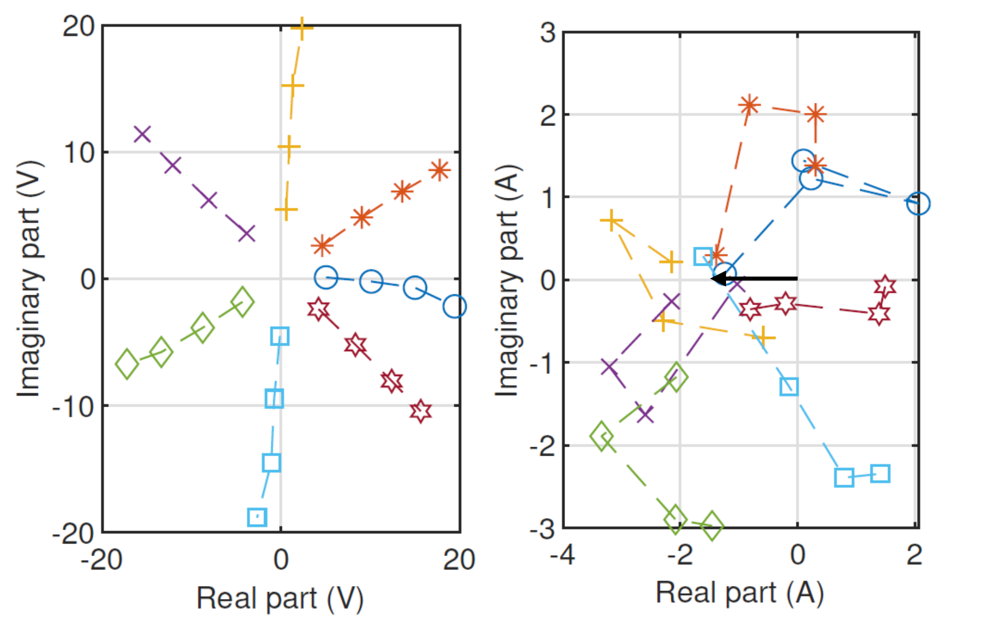
Injection of **5th** harmonic voltage (left), resulting **5th** harmonic current (right)



Primary emission at (−3 + j2 A)

Results harmonic emission: harmonic background

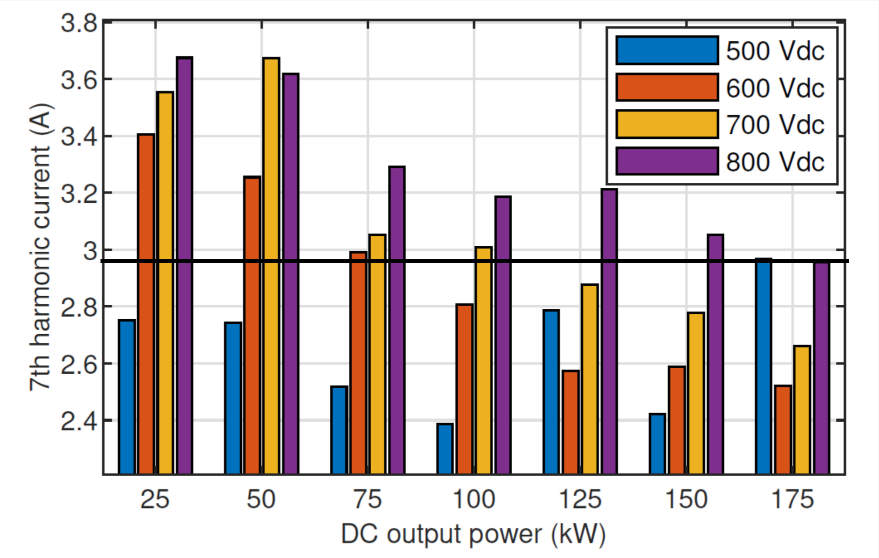
Injection of **5th** harmonic voltage (left), resulting **7th** harmonic current (right)



Primary emission at (−3 A)

Results harmonic emission: operating conditions

- Figure: 7th harmonic for different operating conditions
- DC-voltage has a significant effect on harmonic emission
  - -17% till +37%
  - Affects 5th, 7th, 11th and 13th
- DC-power has an effect on harmonic emission, but less strong
  - Only affects 7th harmonic



Results supraharmonic emission

- Effect of supply voltage distortion (still unpublished, but submitted)
  - For some SH components, there is a relation with harmonic voltage (relation LF-HF)
  - Variations between -10% till +13% compared to nominal condition

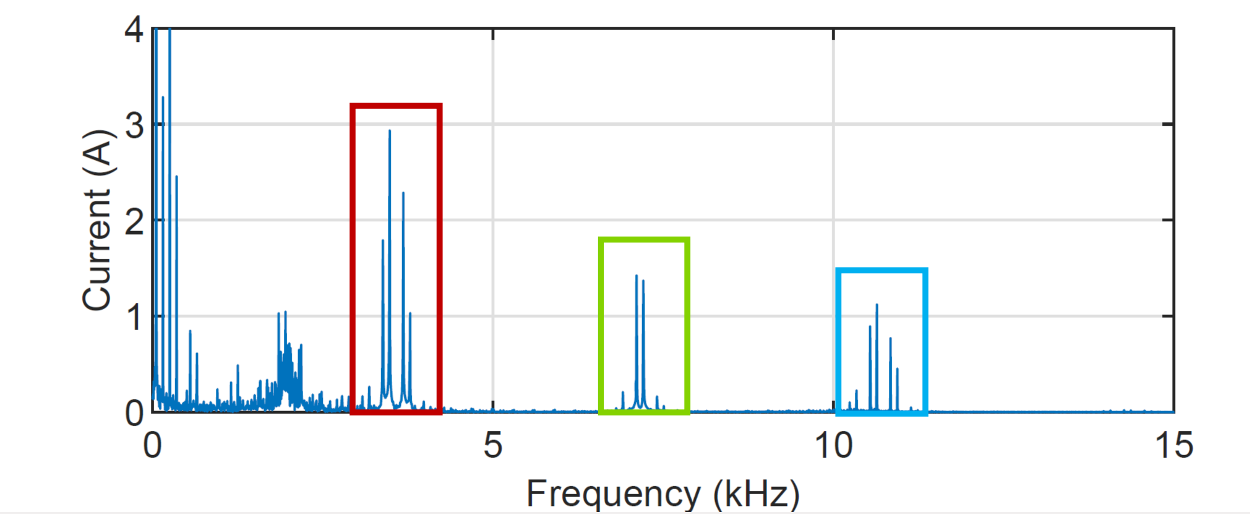
- Effect of operating condition

- Interaction

Results supraharmonic emission

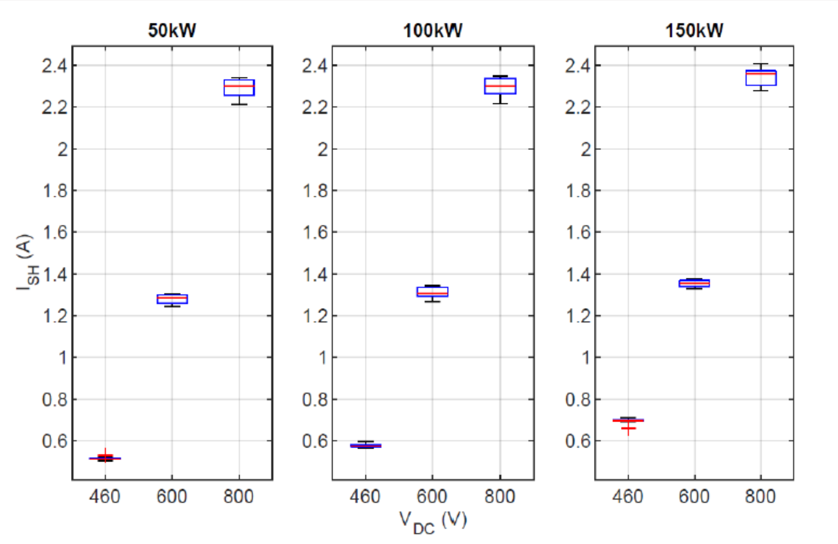
$$SHC = \sqrt{\sum_{f=f_{min}}^{f_{max}} I_f^2}\ [A]$$

SH bin 1, bin 2 and bin 3



Results supraharmonic emission: operating conditions

- Figure, emission in bin 2
- Effect of DC-voltage is significant
- DC-voltage affects SH emission
  - In bins 1, 2 and 3
  - Variations between -86% and +46% (compared to nominal)
- In contrast to other equipment (PV/small electronics), DC-power has negligible effect on the SH emission



Results supraharmonic emission: interaction

- In different set-up with FCSs in same LV-grid
- Interaction between components in bin 1
- Due to slight differences in switching frequency
- $f_{beat} = |f_1 - f_2| \approx 2$ Hz
- $T_{beat} \approx 500$ ms
- RMS vs. peak

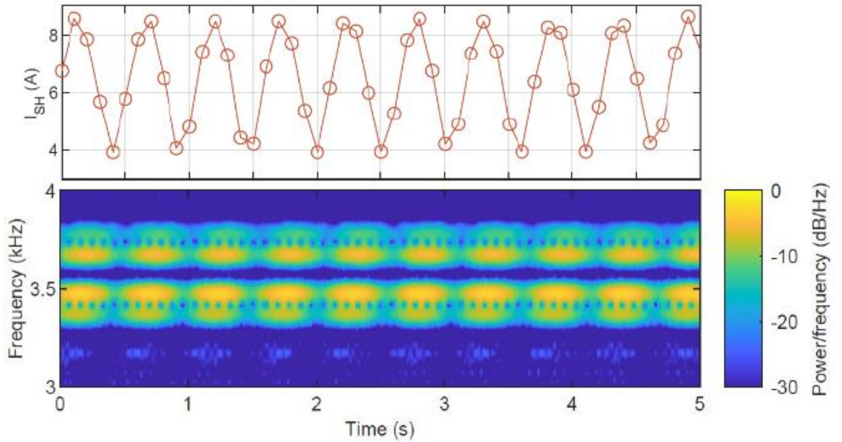


Figure 7 SH emission in 3-4 kHz band, amplitude (top) and spectrogram (bottom), 100 kW/600 V setpoint, 5 seconds.

What did we learn?

- FCSs can be a source of **harmonic and supraharmonic** emissions
- **DC-output voltage** variations have a considerable effect on both
- DC-output power slightly affects harmonic emissions
- **Supraharmonic interaction** may occur in installations with multiple identical FCSs

As a result: harmonic and supraharmonic emission of a FCSs is expected to vary during- and for different charging sessions

Recommendations

- Variations in harmonic and supraharmonic emission due to changing operating conditions, especially DC-voltage, should be considered
- Test FCSs, OBCs, and other PE devices, also at other than nominal or rated operating conditions, especially for different DC-voltages
- Include different harmonic voltages in testing and determine the relation with harmonic and SH emission
- If possible, measure DC-output voltage of the converter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Other relevant publications TEPQEV

Not discussed today

Emission EV/FCS

- Slangen, T., van Wijk, T., Cuk, V., & Cobben, J. F. G. (2020). **The harmonic and supraharmonic emission of battery electric vehicles in the Netherlands.** In *2020 International Conference on Smart Energy Systems and Technologies (SEST)*. https://doi.org/10.1109/SEST48500.2020.9203533
- Slangen, T., & Bhattacharyya, S. (2021). **Determining the Impacts of Fast-Charging of Electric Buses on the Power Quality Based on Field Measurements.** In *26th International Conference and Exhibition on Electricity Distribution (CIRED 2021*. https://doi.org/10.1049/icp.2021.1989

Effects / interference / impact

- Wang, L., Qin, Z., Slangen, T., Bauer, P., & van Wijk, T. (2021). **Grid Impact of Electric Vehicle Fast Charging Stations: Trends, Standards, Issues and Mitigation Measures - An Overview**. *IEEE Open Journal of Power Electronics*, *2*, 56-74. [9336258]. https://doi.org/10.1109/OJPEL.2021.3054601
- Slangen, T., Lustenhouwer, B., Cuk, V., & Cobben, J. F. G. (2021). **The Effects of High-Frequency Residual Currents on the Operation of Residual Current Devices**. *Renewable Energy and Power Quality Journal*, *19*, https://doi.org/10.24084/repqj19.216

Propagation

- Slangen, T., van Wijk, T., Cuk, V., & Cobben, J. F. G. (2020). **The propagation and interaction of supraharmonics from electric vehicle chargers in a low-voltage grid.** *Energies*, *13*(15), [3865]. https://doi.org/10.3390/en13153865

New ElaadNL PQ website

https://elaad.nl/onderwerpen/power-quality

In Dutch, English coming soon