We take care of it.

Power Quality

Simultaneous charging of electric vehicles

Influences on the electrical grid

As part of an extensive measurement campaign, Technical University Bingen (THB) examined simultaneous charging of ten charging stations for electric vehicles (EVs) during last summer. The main objective was the analysis of charging current and switching frequencies as well as grid unbalances due to unevenly distributed loads. The evaluation showed that violations of power quality standards occurred in some cases. This indicates that the observation of power quality will become more and more important in the future and charging power electronics must be further improved.

Special publication

Introduction

The study »Power Quality in der Elektromobilität« from the year 2013 showed that more than 25 % of the examined EV's violate current harmonic thresholds during their charging process [1].

Today charging technology in electric vehicles has improved significantly, so exceedances of limit values have become much less frequent. The only connection condition that is still most often violated is asymmetry during single-phase charging of electric vehicles. In some cases, a single-phase charging power of up to 7 kW can be reached.

At mass-produced EV models, violations of power quality standards only occur if the charging electronics are faulty. The highest levels of harmonic currents appear at retrofitted electric vehicles with simple rectifier systems consisting of diodes with capacitive or inductive smoothing in DC circle.

The evaluation according to the VDN technical standard summarizes all relevant harmonic generators of a system with regard to the emissions to be expected at the common grid connection point. Both the individual harmonic currents and the totality of all harmonic currents are calculated using the distortion factor of the fundamental THD.

Power quality analyzers and fault recorders from A. Eberle in Nuremberg are used to measure the currents and voltages during charging. The sampling frequency of the PQ-Box 200 lies at 40.96 kHz, so that signal decomposition from DC to 20 kHz is possible.

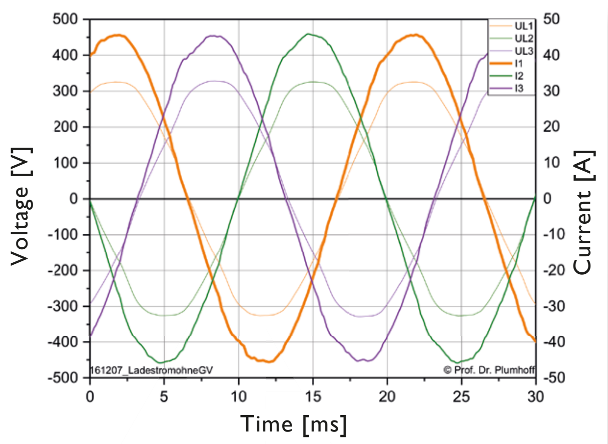

Figure 1: Charging current without limit violation (32.4 A).

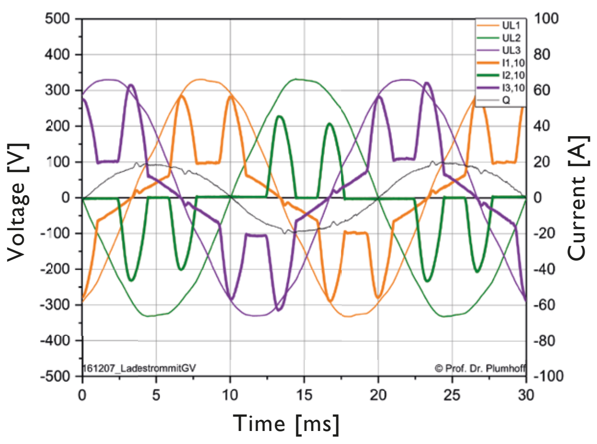

Figure 2: Charging current with capacitive smoothing (retrofitted EV).

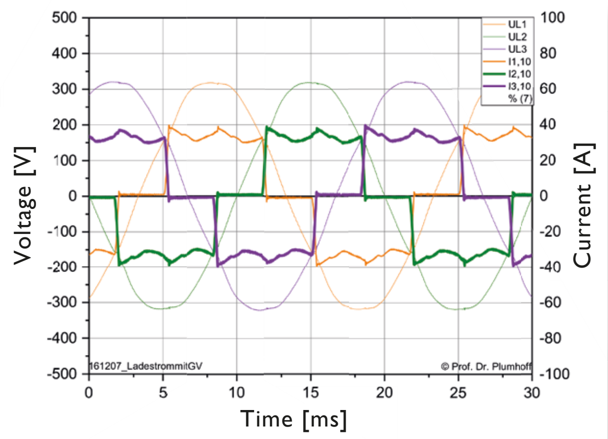

Figure 3: Charging current with inductive smoothing (retrofitted EV).

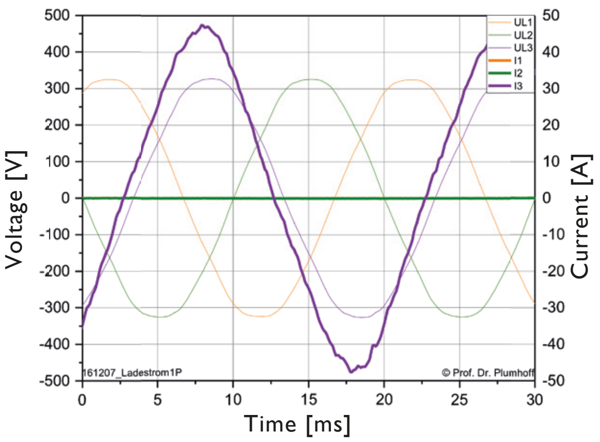

Figure 4: Unbalanced charging currents - single-phase.

Quality of current

Charging points 1 to 8 are equipped with CEE sockets (32 A), of which the first four are brought together after approximately 30 meters. 63 A distributor plugs are connected to charging points 9 and 10 so that charging can be performed via Schuko, CEE or type 2 connection. All charging processes with the exception of two have complied with the limit values according to the D-A-CH-CZ guideline. This implies that all electric vehicles built as a series production and most converted electric vehicles show no limit value violations in the current flow.

Figures 1 to 4 show the different charging currents of electric vehicles. Norm-compliant as well as limit value-exceeding curves can be seen. In one case it is a simple capacitive smoothing, in the other case it is a simple inductive smoothing. Table 1 shows the evaluation of the two current curves exceeding the limit values. The first current signal with simple capacitive smoothing shows the expected high THD value of 118 %. The second current signal with simple inductive smoothing produces a THD value of 30 %.

	1. Capacitive equalisation		2. Inductive equalisation	
Harmonic	DACH-CZ	Charging current	DACH-CZ	Charging current
H1		26,2 A		27,0 A
H3	3,0	2,1 A	2,0	0,4 A
H5	7,6	11,0 A	5,0	4,9 A
H7	5,0	8,7 A	3,3	5,0 A
H11	2,5	4,9 A	1,7	2,7 A
H13	2,0	3,0 A	1,3	2,5 A
H17	1,0	0,8 A	0,7	1,8 A
H19	0,8	1,1 A	0,5	1,5 A
H21	0,5	0,2 A	0,3	0,2 A
H23	0,5	0,8 A	0,3	1,2 A
H25	0,5	0,5 A	0,3	1,1 A
THD	31,6	118 %	20,8	30 %

Table 1: Harmonic currents and THDI - EVs with limit violations.
1.) Short-circuit power at AP 5487; rated power 22 kVA.
2.) Short-circuit power at AP 2385; rated power 22 kVA.

Fig. 5 shows the charging current of an EV that charges single-phase with approximately 7 kW. It is known that there are some power supply companies that have no problem with this kind of load but there are also suppliers who reject the connection of such an asymmetrical load (greater than 4.6 kVA).

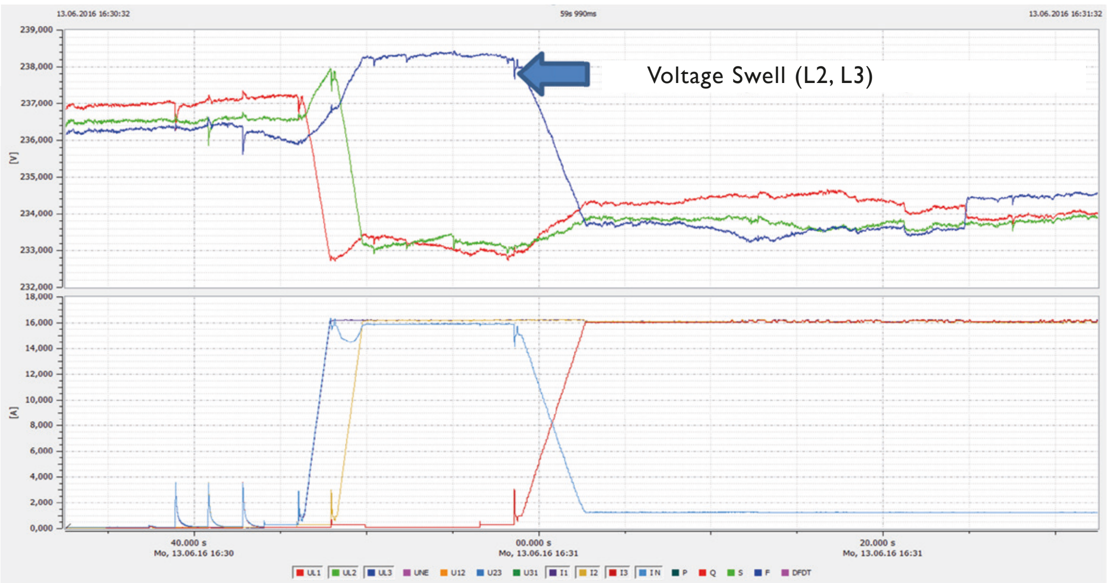

Figure 5: RMS value at the start of charging process (e.g. Mercedes Benz B-Class).

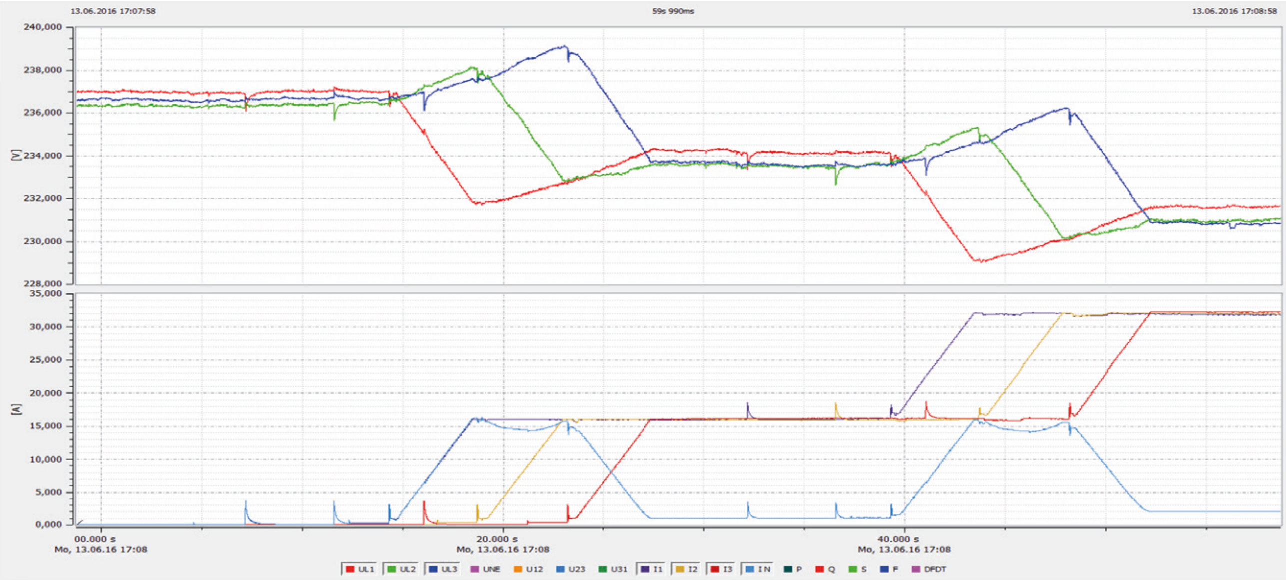

Figure 6: Start-up of a charging process - time-shifted phases.

Usually, the charging processes start with all phases involved. But there are also some series vehicles, which are designed in such a way, that one phase after the other is switched on (Fig. 6).

At the very beginning of the charging process, the EV's charging current lies at 16 A and gradually increases to 32 A. Due to the strong asymmetry, the neutral conductor is temporarily exposed to the phase current and increases the neutral conductor-to-earth voltage. This leads to a slight increase in the voltage of the unloaded phases.

Among the 50 EVs to be charged this afternoon are two which showed faulty charging electronics (Fig. 7). This leads to the question whether the electronics itself should report such a fault or whether there should be a periodic error check.

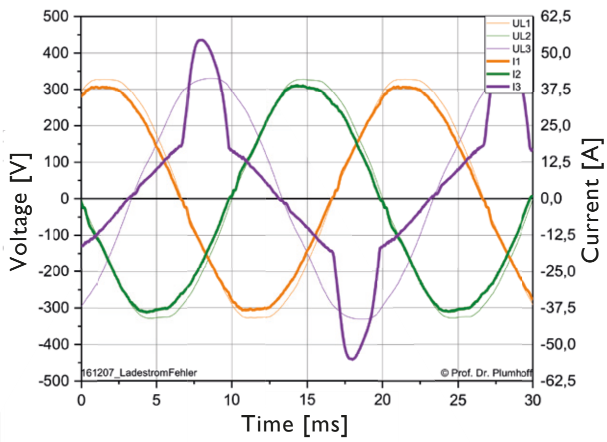

Figure 7: Faulty charging current.

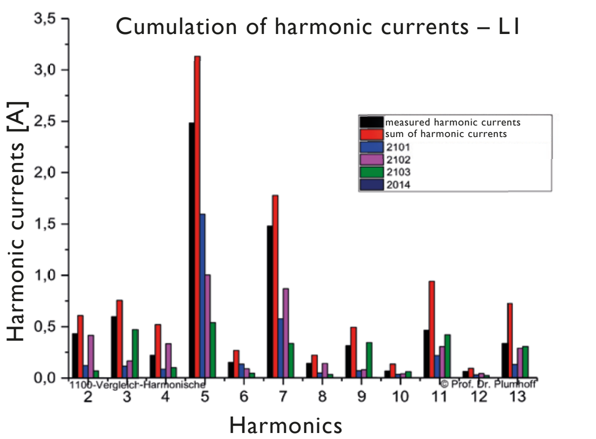

Figure 8: Harmonics of current and their addition: 4 different e-mobiles, linear addition and measured addition.

Harmonics of current

The first four measuring points (2101 to 2104) are brought together after approximately 30 meters in one connection (1100). So the currents of the measuring points 2101 to 2104 are recorded as a sum at measuring point 1100. At the time of the measurement, the current at measuring point 2104 is equal to zero. The currents at the measuring points 2101, 2102, 2103 and 1100 are shown in Figure 8 as harmonic spectrum. The arithmetic sum of the three currents is shown in red and the measured sum of the three currents is shown in black. The difference between these two currents leads to the conclusion that the harmonic currents of the different charging stations have different phase angles and thus partially extinguish each other.

Supraharmonics of voltage

High switching frequencies are also emitted to the electrical grid by power electronics of EVs as can be seen in Fig. 9 and Fig. 10. In this regard, very clear differences showed up between the various manufacturers. The measurement of the emitted noise from the switching frequencies of the different manufacturers has been one of the main objectives of the measurement campaign. However, this investigation turned out to be problematic. Although each vehicle was connected to a separate supply line and CEE socket, all switching frequencies of the neighboring vehicles showed up in voltage and current of the presently measured vehicle. This means that every vehicle and its power electronics represent an electromagnetic disturbance sink for supraharmonic frequencies and absorb these disturbance levels.

As a result, it is not so simple anymore to determine the cause of these supraharmonics disturbances by analyzing the current spectrum at a measuring point. It has also appeared that vehicles may disturb each other to such an extent that the charging process is interrupted.

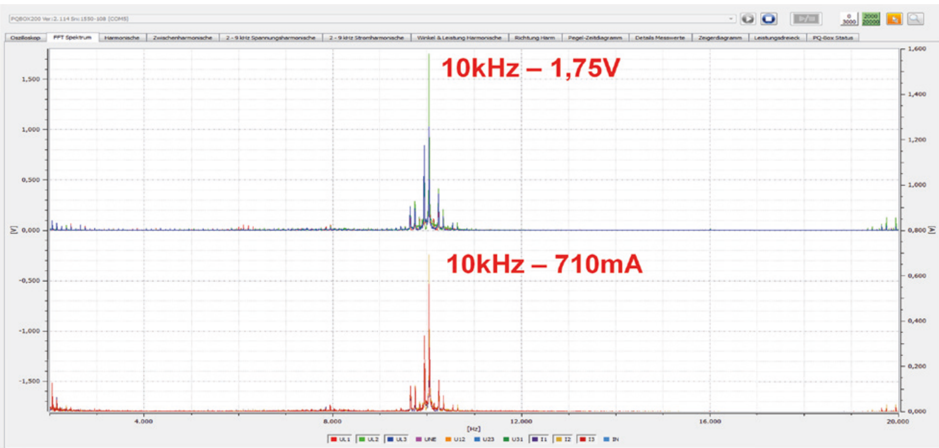

Figure 9: Spectral analysis of voltages and currents up to 20 kHz: This EV shows a switching frequency of 10 kHz.

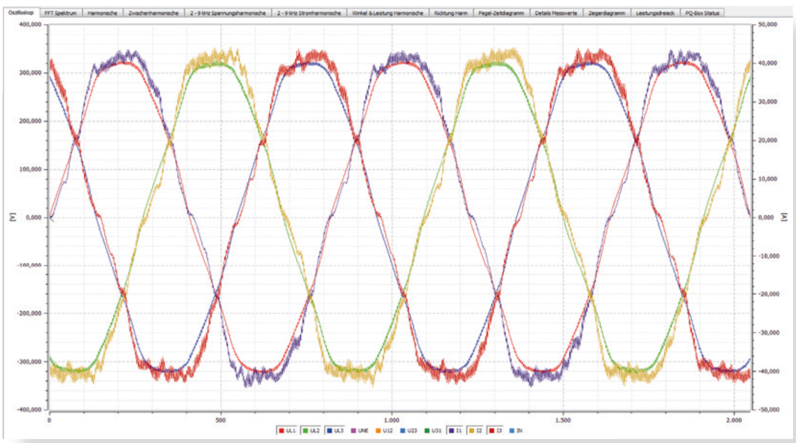

Figure 10: Oscilloscope picture of current and voltage: The switching frequencies of 10 kHz are clearly visible.

Propagation of supraharmonics in the electrical power grid

Figures 11 and 12 clearly show that the amplitude of the supraharmonics decreases with the distance from the EV to the transformer. These disturbance levels decrease more at higher frequencies than at lower frequencies. Hence the measurement at the transformer shows its maximum value at 8 kHz, while measurement at distribution level is dominated by 10 kHz values.

At the moment there are no limits for the emission of noise from EVs in the frequency range from 2.5 kHz to 150 kHz. This range is also not regulated for the public network. The standards IEC 61000-3-2 (Class A) up to 16 A and IEC 61000-3-12 (unbalanced devices R_{sce} = 33) from 16 A to 75 A currently apply to EVs.

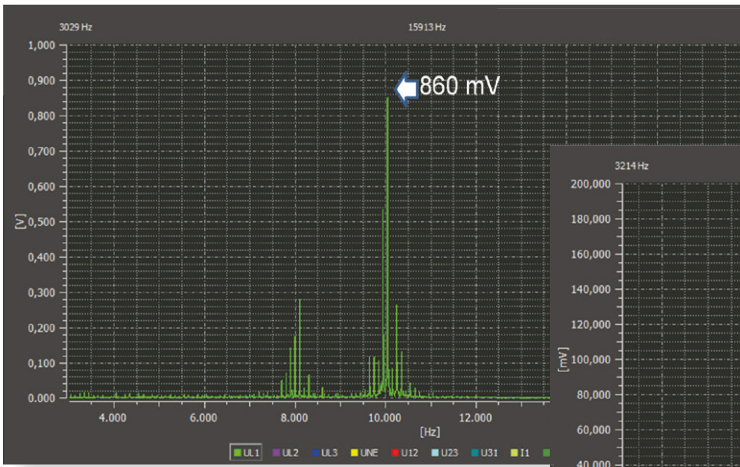

Figure 11: Signal level and switching frequencies at the sub-distribution UV III.

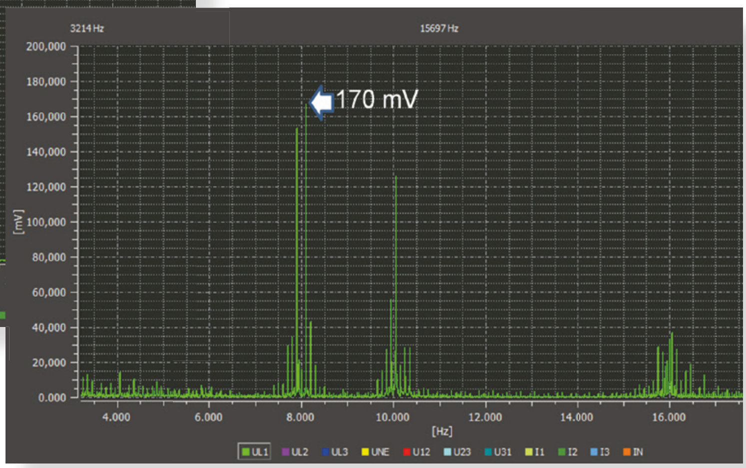

Figure 12: Signal level of the switching frequencies directly at the TH-Bingen transformer.

Transient switching peaks

While starting the charging process, almost all examined EVs showed transient peaks in voltage and current (Fig.13). The largest voltage transient measured had a value of 400 V and was determined at a sampling frequency of 1 MHz. The highest inrush current peak had a value of 150 A.

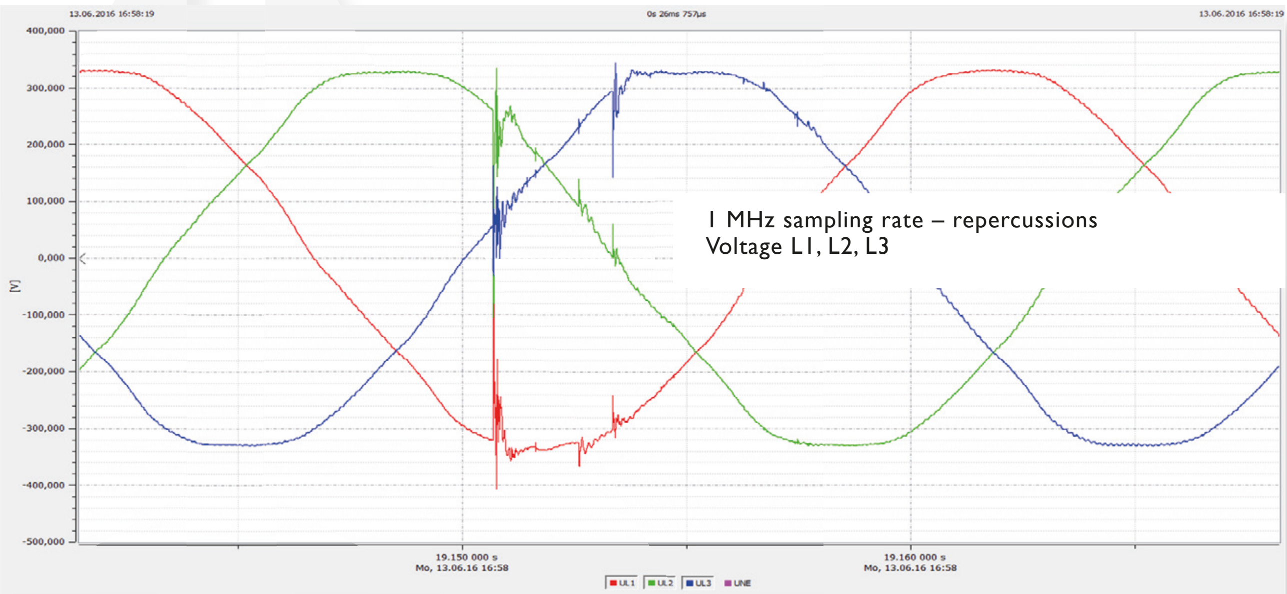

Figure 13: Voltage transients at all three phases.

Summary

Some electric vehicles are charged single-phase with a power of significantly more than 4.6 kVA (during the measurement campaign with up to 7.2 kVA).

High-frequency disturbances are generated by the EVs in a very different range. However, all vehicles also act as disturbance sink and absorb these supraharmonics from the network. All vehicles generate a strong voltage transient at the moment of switching on the power. This could also disrupt other end-users.

Current harmonics of different EV manufacturers add up in the grid, but not as strongly as in a linear addition. All series manufactured vehicles did not violate the limit values of current harmonics up to the 50th order.

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Literature

[1] Thomas, Timo; Plumhoff, Peter A.: Studie Power Quality in der Elektromobilität – Auswirkungen der Ladeinfrastruktur von Elektrofahrzeugen auf die Netzqualität. FH Bingen, 2013

[2] VDN: Technische Regeln zur Beurteilung von Netzrückwirkungen. 2. Ausgabe 2007

[3] DIN EN 61000-3-2 (VDE 0838-2):2015-03: Elektromagnetische Verträglichkeit (EMV) – Teil 3-2: Grenzwerte – Grenzwerte für Oberschwingungsströme(Geräte-Eingangsstrom ≤ 16 A je Leiter) (IEC 61000-3-2:2014)

[4] DIN EN 61000-3-12 (VDE 0838-12):2012-06: Elektromagnetische Verträglichkeit (EMV) – Teil 3-12: Grenzwerte –Grenzwerte für Oberschwingungsströme, verursacht von Geräten und Einrichtungen mit einem Eingangsstrom > 16 A und ≤ 75 A je Leiter, die zum Anschluss an öffentliche Niederspannungsnetze vorgesehen sind (IEC 61000-3-12:2011)

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