Time proof
Electricity grids by
Power Quality
improvement
of Electric
Vehicles

TEPQEV

Standards for 2-150 kHz

TEPQEV whitepaper

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Management summary - Automotive

The TEPQEV-consortium has been conducting research on the impact of electric vehicles (EVs) and DC chargers on power grids, with a focus on supraharmonics (SHs). The research was motivated by a lack of specific standards and modeling tools for these devices in terms of their impact on voltage quality, as well as a lack of knowledge on SHs in general. The high powers and large expected numbers of EVs have the potential to have a substantial effect on SH current emissions, and this effect was frequently observed during tests and measurements. SHs may cause malfunctioning of domestic electronic devices, residual current devices as well as disturb the charging of other, adjacent EVs. This can become problematic if multiple EVs of the same model are charged close together; this is a concern for fleet owners. The lack of standards and incentives for manufacturers to improve power quality emissions from their products, as well as the interaction of devices at system level, makes it necessary to build mathematical models that result in specific standards and admission requirements. Summation and interaction of supraharmonics is different than for harmonics, and due to interaction, increases emission and time-varying effects can occur. The TEPQEV project partners worked on this by conducting tests and measurements on EVs, DC chargers and the power grid, and used the data to gain scientific knowledge and propose emission limits for quantifying SH effects on the grid. The proposed limit is show in Fig. 0.1.

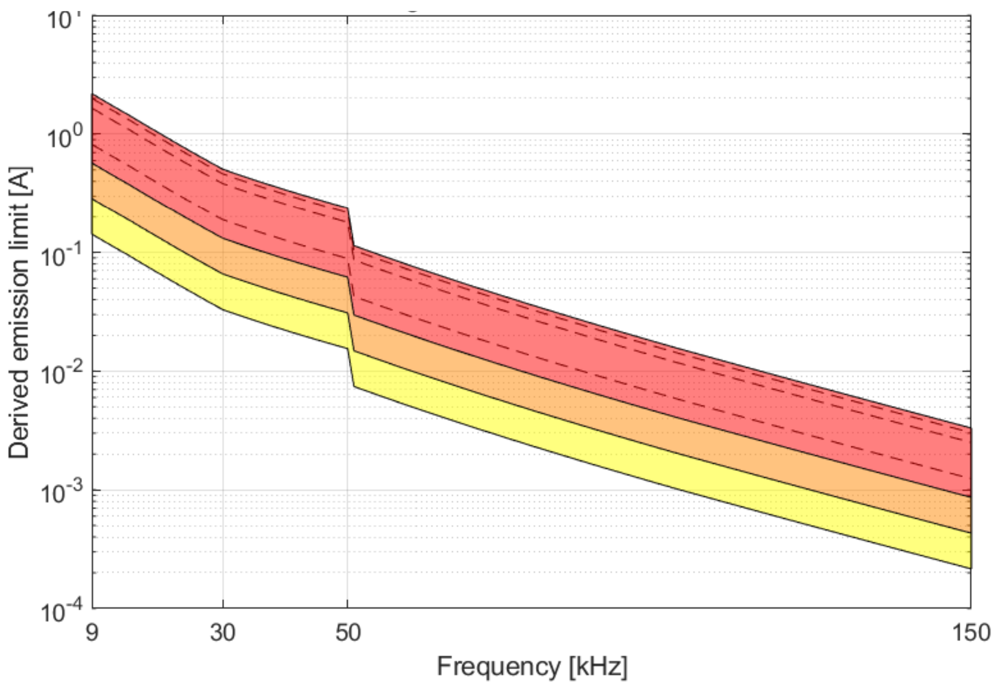

Figure 0.1: Derived emission limit at installation level for different impedance values (red), and taking into account summation of emission; 0.5-1.0 times the limit for the lowest emission (orange) and 0.25-0.5 times the limit for the lowest emission (yellow). Figure from (8).

The derived emission limit is presented in Fig. 0.1. Here, 5 regions are distinguished. Emission in the region above the red band is always (for all considered impedances) too high. The red region presents the maximum emission for the range of impedance values. Higher emission is allowed in networks with a lower impedance, according to this derivation. The orange region presents emission that is between half (0.5) times the lowest emission in the red band, and below the lower boundary of the red band. The yellow band presents 0.25 to 0.50 times the emission for the lower boundary of the red band. Emission below the bands (lower boundary of the yellow band) are considered OK, but this is not a guarantee that no interference may occur! More details are presented in Sections 2.4 and 2.5.

At the end of the project, this knowledge was used to gain insight in the percentage of tested vehicles that are within or above the proposed limits for supraharmonic emissions, as shown in Fig. 0.2. This shows that it is certainly feasible to comply with the proposed limits. The project recommends that specific standards and product requirements be established in the area of PQ impact of EVs and DC chargers, in order to avoid interference with nearby equipment or other EVs, and to mitigate the costs of grid adjustments for grid operators and society. Also, general immunity requirements for EVs, that serve as the basis for fine-tuning the emission limit, are recommended. The project also aimed to advise EV manufacturers on power quality impact of their vehicles, and to initiate the process of standardization and certification for EVs and DC chargers on power grids.

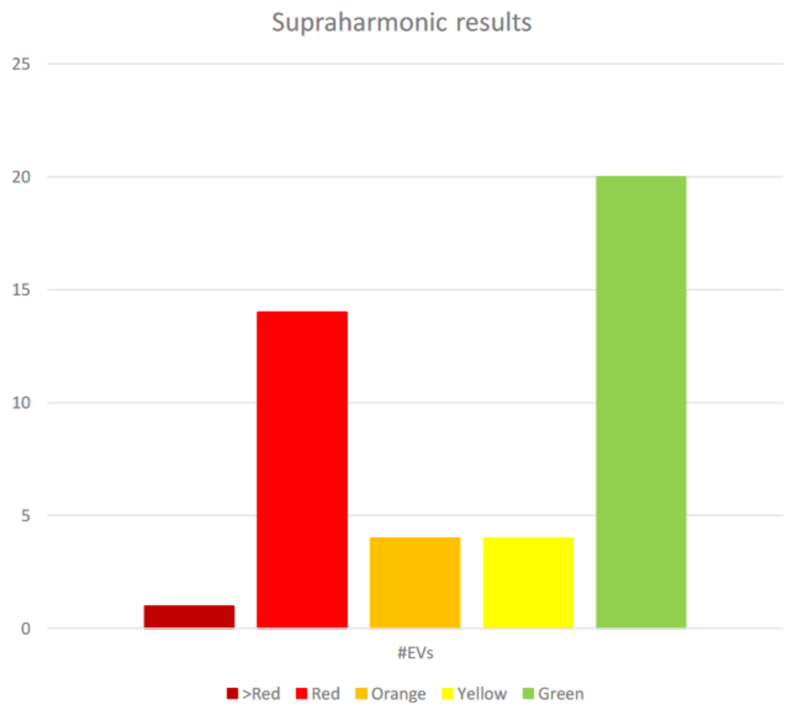

Figure 0.2: Application of emission limit to EV-measurements on 43 EVs by ElaadNL. Figure from (9).

The proposed emission limits presented in this report are based on low voltage (LV) installations with electric vehicle (EV) chargers or fast charging stations (FCSs) connected to it. It is important to note that for the connection of FCSs, a dedicated distribution transformer is typically used. However, for future megawatt charging systems (MCSs) that are connected directly to the medium voltage (MV) network, the emission limits may be different. This is due to the differences in impedance and network topology between the MV network and dedicated LV networks.

Automotive manufacturers should also be aware of the potential for stricter emissions limits in the future, and plan accordingly. The lack of clear standards at this moment in time does not mean that there will be no standards in the near future. So, it's better for manufacturers to stay informed about the latest developments and consider investing in research and development of new technologies that have the potential to reduce emissions. Furthermore, it is recommended to implement the proposed emission limits for automotive testing, as if it were the standard. Additionally, it may be beneficial for manufacturers to collaborate with other companies, organizations, and researchers to share knowledge and resources, and to pool expertise in developing new technologies and approaches to reducing power quality impact.

Management summary - Grid operators

The TEPQEV consortium has been conducting research on the impact of electric vehicles (EVs) and DC chargers on power grids, with a focus on supraharmonics (SHs). The research was motivated by a lack of specific standards and modeling tools for these devices in terms of their impact on voltage quality, as well as a lack of knowledge on SH in general. The high powers and large expected numbers of EVs have the potential to have a substantial effect on SH current emissions, and this effect was frequently observed during tests and measurements. The lack of standards and incentives for manufacturers to improve power quality emissions from their products, as well as the interaction of devices at system level, makes it necessary to build mathematical models that result in specific standards and admission requirements. The TEPQEV project partners worked on this by conducting tests and measurements on EVs, DC chargers and the power grid, and used the data to gain scientific knowledge and propose emission limits for quantifying SH effects on the grid, shown in Fig. 0.3. The limit is based on compatibility levels for voltage and impedance, and allows for maximum permissible current emissions for different impedances without exceeding these levels. The results are presented in a figure showing five regions of emission, for different network impedance values. It is not guaranteed that there is no interference possible below the limit, as most equipment still does not have immunity requirements, and for the emission of individual equipment, lower limits are recommended to avoid summation to a higher level. Overall, it is recommended that the proposed emission limits are implemented in the grid code or similar regulations. For the emission it is advised to aim for emission levels below the lowest band to minimize the risk of interference in installations with a higher impedance.

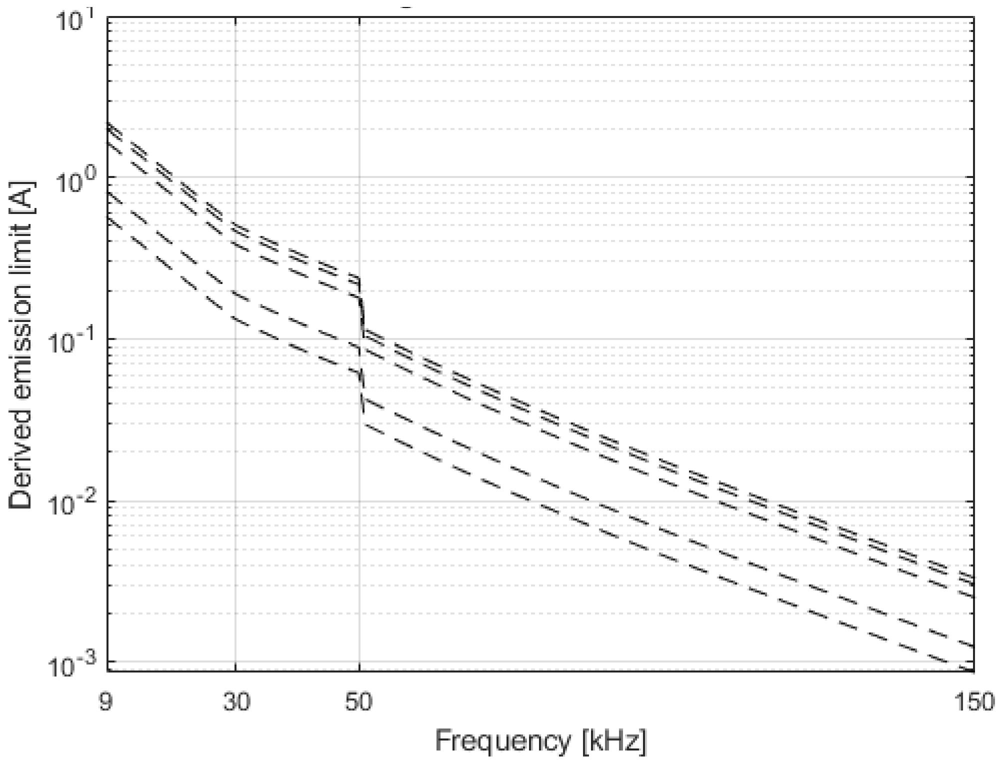

Figure 0.3: Derived emission limit at installation level for different impedance values. Figure from (8).

Despite these differences, the compatibility levels presented in the IEC 61000-2-2 standard can still be used as a fundamental guide. However, it is necessary to take into account the actual impedance values of the MV network when determining appropriate emission limits. One possible method for doing this is to scale the compatibility levels based on the actual impedance values of the MV network. This can be implemented by using the method described in the standard and adjusting it accordingly to account for the differences in network topology and impedance.

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1 | Introduction

1.1 | TEPQEV

For the past three years, the TEPQEV consortium has been investigating the impact of electric vehicles (EVs) and DC chargers on power grids, focusing on so-called supraharmonic (SH) distortion. The consortium consisted of the following parties: ElaadNL, Eindhoven University of Technology, DNV-GL Netherlands B.V./KEMA B.V., Heliox B.V., and the grid operators Enexis and Stedin.
Charging EVs involves converting alternating current (AC) from the power grid into direct current (DC) that is used to charge the EV's battery. This can be done in two ways:

- AC-charging: the charging point delivers AC to the EV after which it is converted to DC in the on-board charger, or
- DC-charging: the conversion of AC into DC takes place inside the charge point after which this DC is offered to the EV; for fast charging (with a capacity of 50 kW and above), only DC chargers are used; incidentally, smaller DC chargers are in use at companies or even homes.

The motivation for this research was a lack of specific standards and modeling tools for these devices in terms of their impact on voltage quality and a lack of standards and knowledge in terms of SH in general. These SH emissions can be produced by any device with a modern inverter, but because of the high powers and large expected numbers, EV charging is expected to have a substantial effect. Such effects were already visible during the start of the project, and during the project itself they were frequently observed during the tests and measurements. Also, the trend in the market is that EVs charge at higher power (passenger cars up to 350 kW, heavy duty vehicles 600 kW, in future even up to 3,75 MW) and that modern converters use higher switching frequencies. Higher switching frequencies are chosen because it decreases the size and weight of the convertor; advances in semi-conductor materials allow for higher frequencies and higher operating temperatures.

If devices connected to the public power grid cause unwanted PQ-effects, grid operators have additional cost and effort to keep the grid stable and within the allowed limits. These are ultimately social costs and thus an important reason for this research.

Unwanted PQ-effects are caused by the converter in the DC charging station or EV (on-board charger). The party who can best solve the problem is therefore the relevant manufacturer. However, there are no formal product requirements in this area. Moreover, the individual manufacturer cannot foresee the problems that arise when several or many different devices are connected together at system level and the network between them also exhibits frequency-dependent behavior.

It is therefore important to have specific standards, norms and product requirements in the area of PQ impact of electric vehicles and DC chargers. During the TEPQEV-project, the various project partners worked on this by conducting tests and measurements on the electric vehicles, DC chargers and on the power grid. The data gathered was used to gain scientific knowledge and to build a model for quantifying SH effects on the grid.

ElaadNL was involved as the project leader and for performing the electric vehicle tests in the ElaadNL Testlab. Apart from investigating SH distortion, pre-normative testing of EVs was the general objective. ElaadNL improved and automated its testing process as part of the TEPQEV project and used the test results to advise the EV manufacturers on the (smart) charging behaviour and power quality impact of the EV as well as on the immunity of the EV to SH voltage distortions. The collected PQ measurement data was used to gain knowledge about Supraharmonic emission levels. At the end of the project, this was also used to gain insight in the percentage of vehicles that are within or above the proposed limits. KEMA was involved as testing partner for the higher power, system level testing and performed functional tests on DC fast chargers in the Flex Power Grid Lab, in Arnhem. The results were fed into the grid models to validate dynamic behavior and the extent of harmonic emission into higher levels of the grid.

For EVs, there is currently no obligation (read: standard, code or admission requirement) that demands/requires PQ-related issues to be tested/certified before an EV enters the (European) market. For the electricity grids, it is a relatively new phenomenon that high power AC-DC converters on the demand side will enter the low-voltage grids on a large scale. This is not yet taken into account in the energy law and grid calculations. However, it was also not yet exactly clear what impact EVs have on power and voltage quality, how this translates into a possible grid impact, and where the limit values should lie in that case. The TEPQEV-project provides more clarity on this, and now the process of standardization and certification should be initiated.

1.2 | Objectives

The goal of this report is to provide an overview of the current status of standardization on the 2-150 kHz range, also known as the supraharmonic frequency range, and to give recommendations for current emission limits. The recommendations in this report are based on extensive research from 04-2019 till 10-2022 on EV-chargers in terms of emission, interaction, summations and impedance, in the scope of the TEPQEV project. A gap in standardization is identified in emission limits for supraharmonics and, more specifically, for EV chargers. Neither are available at present and this is where the TEPQEV project aims to contribute. This report gives a recommendation for a current emission limit for the supraharmonic range, based on developments and findings in the 2-150 kHz range. The proposed standards are applicable for on-board chargers of electric vehicles and FCSs connected in residential LV grids, because the findings on network impedance apply mostly to LV residential installations and not the dedicated substations where fast-charging stations (FCSs) are connected to. For FCSs in dedicated installations the network impedance will be different, and the limits should be reconsidered taking into account the different impedance and topology.

1.3 | Limitations

In this report, a proposal for a current emission limit between 2 and 150 kHz is provided. It is important to recognize the following limitations when using the proposed emission limits:

- The proposed emission limits for the 2-150 kHz range are based on a combination of existing standards for voltage compatibility and recent findings on the actual network impedance in this frequency range.
- While it is not possible to guarantee that no interference will occur at levels below the proposed limit, there is currently no known interference at values below this limit.
- The proposed emission limit is intended to apply at the installation level, meaning that individual device limits should be set significantly lower in order to avoid exceeding the overall limit when multiple devices are connected. In this research, 25% of the proposed limit is recommended.
- In other words, in this research the assumption is made that the increased emission in an installation due to summation is never exceeding a factor of 4.
- The summation and interaction of supraharmonics has not been taken into consideration in the proposed emission limit.
- Future standardization efforts may result in different (higher or lower) values for emission limits in the supraharmonic frequency range.
- No rights can be derived from the proposed emission limit values.

1.4 | Structure

This report is structured as follows. In Chapter 1 the proposal for the current emission limits, as outcome of the TEPQEV project, will be presented. The derivation of the limit is discussed based on existing voltage compatibility standards and recent findings on the 9-150 kHz network impedance by, among others, the author. Chapter 2 presents TEPQEVs recommendations on standardization for the 2-150 kHz range. An overview of existing standardization on the 2-150 kHz range is presented in Section A, and ongoing standardization that might be extended to cover the 2-150 range is presented in Section B. The chapters are divided into several sub parts on voltage compatibility, standards for conducting measurements, on intentional emission as when using power-line communication (PLC), immunity for differential and common mode disturbances and some equipment specific standards on emission. Using MATLAB[1] code the proposed emission limits was derived.

Parts of this report are built based upon existing or future publications by Tim Slangen, other researchers and external parties. These publications are used as the basis for several (sub)sections in this report. When this is the case, the corresponding reference is shown in or below the section title. Please refer to the original publications when citing text or figures from these sections, and use proper citations! The research articles are available upon request at the author. Standards from IEC, CISPR or NEN are owned by the author or the project partners, but not publicly available.

[1] MATLAB is a proprietary multi-paradigm programming language and numeric computing environment developed by MathWorks. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages. As of 2020, MATLAB has more than 4 million users worldwide. https://www.mathworks.com/products/matlab.html

2 | Proposal for current emission limits (TEPQEV)

2.1 | Brief recap on the fundamentals: compatibility

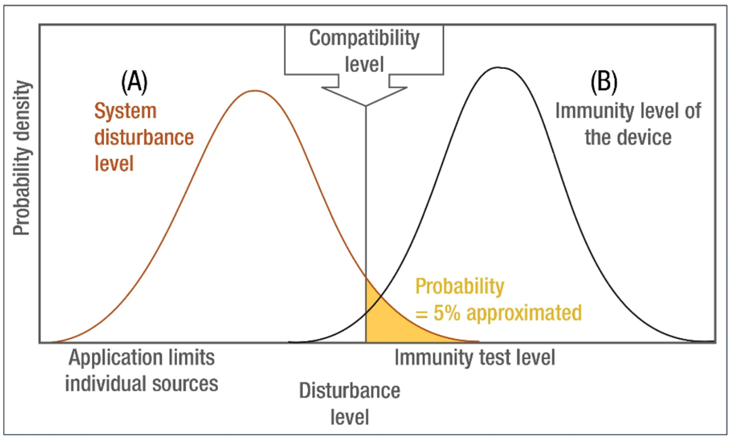

Figure 2.1: What is compatibility?

System disturbance level, the device emission limits and the immunity level are important parameters in the context of Electromagnetic Compatibility (EMC) that are related, but represent different aspects of electromagnetic interference. They define the compatibility level, which ensures that the emission and immunity are balanced such, that minimal disturbances will occur. The relation between them is shown in Fig. 2.1. In theory, the curves (A) and (B) could be separated completely, avoiding inference, but in practice this is not possible due to the high costs and the large variety of different environments.

System disturbance level refers to the strength of the electromagnetic interference present in a given environment that a system is exposed to. This interference can come from sources such as power lines, communication equipment, or other electronic devices. The system disturbance level sets the benchmark for the level of immunity required by the system to function correctly in that environment.

Device emission limits, on the other hand, refer to the maximum amount of electromagnetic emission that a device is allowed to emit into the environment. These limits are typically defined by regulatory bodies, and are intended to prevent electronic devices from causing interference with other devices or systems.

Immunity level is a measure of a device's ability to resist and operate correctly in the presence of electromagnetic interference (EMI).

2.2 | Existing voltage compatibility framework: IEC 61000-2-2 (A.1.1)

According to the IEC 61000-2-2 standard, voltage compatibility levels are provided for the supraharmonic frequency range of 2-150 kHz. While the original standard only covered the ranges of 2-3 kHz, 3-9 kHz, and 9-30 kHz, an amendment published in 2019, referred to as A2, expanded the coverage to include the ranges of 30-50 kHz and 50-150 kHz as well. These compatibility levels are depicted in Figure 2.2, with a change in slope at 30 kHz and a sudden jump at 50 kHz resulting from the separate definitions of these ranges within the standard. Note that the lowest value applies at 50 kHz. To convert from dBμV to volts, the following formula can be utilized: $V[V] = 10^{(V[dB\mu V]-120)/20}$. For instance, 129.5 dB$\mu$V is approximately equal to 3.0 V, 120 dBμV is equal to 1.0 V, 100 dBμV is equal to 0.1 V, and 89 dBμV is approximately equal to 0.03 V.

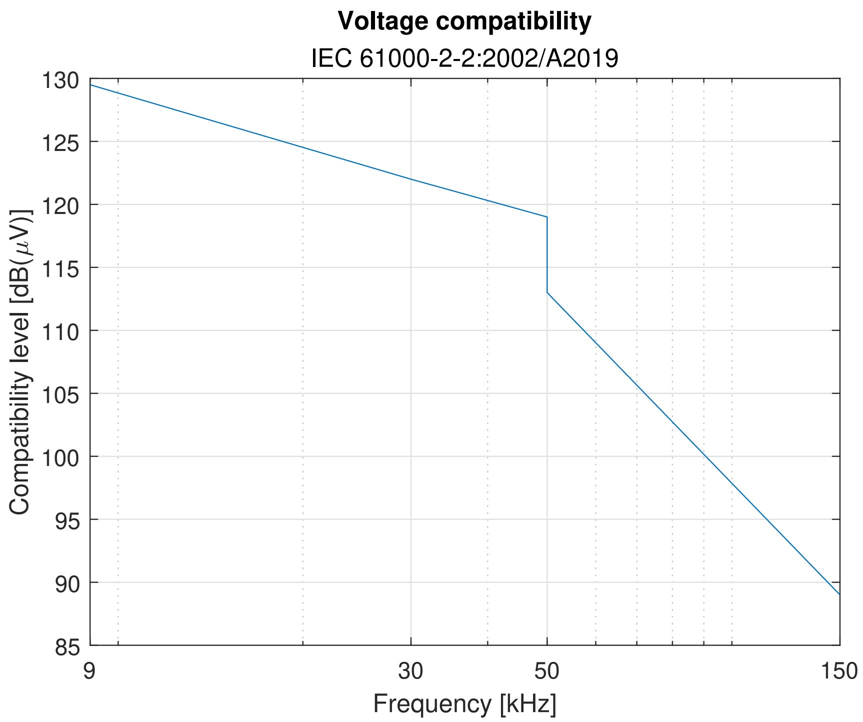

Figure 2.2: Voltage compatibility for 9-150 kHz according to IEC 61000-2-2 (A.1.1). Figure from (8)

2.3 | Recent findings network impedance 9-150 kHz

2.3.1 | CISPR-16-1-2 Reference impedance (A.3.1)

The CISPR-16-1-2 standard (A.3.1 outlines a reference impedance, referred to as Z_{CISPR}, which is utilized in laboratory settings for the testing of devices in order to achieve consistent and reproducible results. However, it is important to recognize that this reference impedance does not accurately reflect the network impedance that a device may encounter in actual use conditions. This discrepancy can lead to differences in the observed emission levels of a device when tested using Z_{CISPR} compared to when it is used in a real-world grid. For example, if the grid impedance at the supraharmonic emission frequency is lower in a particular scenario, it is possible that the emissions of the device may be higher than those observed during testing with Z_{CISPR}. Also, the resulting voltage distortion will be different due to the higher impedance and hence the device might have additional higher secondary emissions due to this, compared to a lower network impedance. In order to account for these variations, it is recommended to test devices in both a clean and distorted grid (utilizing a grid emulator) as well as in a "normal" grid. While the use of a grid emulator can provide a more representative network impedance for testing purposes, it is important to utilize a line impedance stabilization network (LISN) that accurately reflects the network impedance that a device may encounter in actual use. Studies such as (7) and (8) have demonstrated that the currently standardized LISNs do not provide a representative network impedance for the device under test, with some even providing an impedance that is up to a factor of 6 too high.

2.3.2 | IEC 60725 short-circuit/flicker impedance (A.3.2)

IEC 60725 (A.3.2) provides a reference short circuit impedance according to

$$Z_{ref} = 0.4 + 1i * 0.25 \tag{2.1}$$

and this can be used to calculate the short circuit power of a installation following:

$$S_{sc,ref} = \frac{400^2}{|Z_{ref}|} \tag{2.2}$$

which gives the IEC short-circuit power of $S_{sc,IEC} = 0.57$ MVA.

2.3.3 | Scaled CISPR impedance (Stiegler e.a. / TU Dresden) (6)

Stiegler e.a. proposes in (6) a method to scale the CISPR impedance with the short circuit level, combining the methods from CISPR-16-1-2 and IEC 60725. This impedance is calculated as follows

$$Z_{scaled} = Z_{CISPR} * (r + (1 - r)) * \frac{S_{sc,ref}}{S_{sc}} \tag{2.3}$$

with r a reduction factor of 0.25, that damps the effect of the scaling, and S_{sc} the actual short-circuit power of an installation of interest, e.g. as per grid operator specifications. In research from Stiegler e.a. (6) a range of S_{sc} values was found, based on 100+ measurements, with a median value $\overline{S}_{sc,Stiegler} = 2.7$ MVA and 99 precentile of $S^{99}_{sc,Stiegler} = 25$ MVA.

2.3.4 | Validation by measurements (Erhan e.a. / TU Eindhoven) (7)

The supraharmonic distortion levels and their propagation in low voltage networks are determined by the supraharmonic- or frequency-dependent network impedance (FDNI). Knowledge of the FDNI is limited and mainly based on assumptions, measurements to determine the actual values are uncommon and not readily available. In this research, a current injection-based measurement system was developed to measure the impedance from 10 to 150 kHz at low voltage installations, as seen in Fig. 2.3. The measurement system was validated using lab measurements and a measurement campaign at different residential- and office installations was carried out to quantify the network impedance. It was found that both the amplitude of the impedance and the resonant frequencies were highly influenced by devices connected locally. The results provided typical ranges of the FDNI in low-voltage installations and contributed to the assessment of supraharmonic impact and propagation.

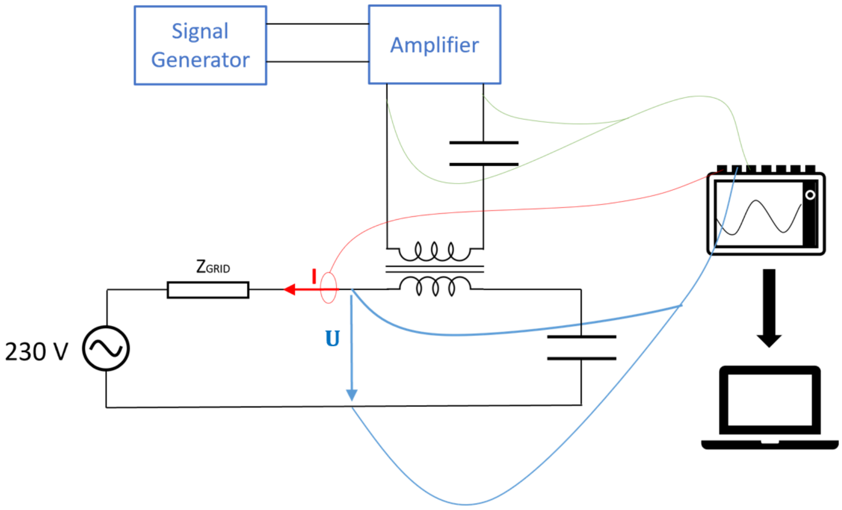

Figure 2.3: Measurement set-up, more details in (7)

Measurements at the point of connection (POC) of four households located in Eindhoven and at a charging plaza were done. At all locations, a socket connection was available right behind the POC, and therefore those were used for the measurements. In the household installations, the measurement equipment was supplied from a distant wall socket (if possible on a different phase), and an additional distance was created using an extra cable of approximately 30 meters.

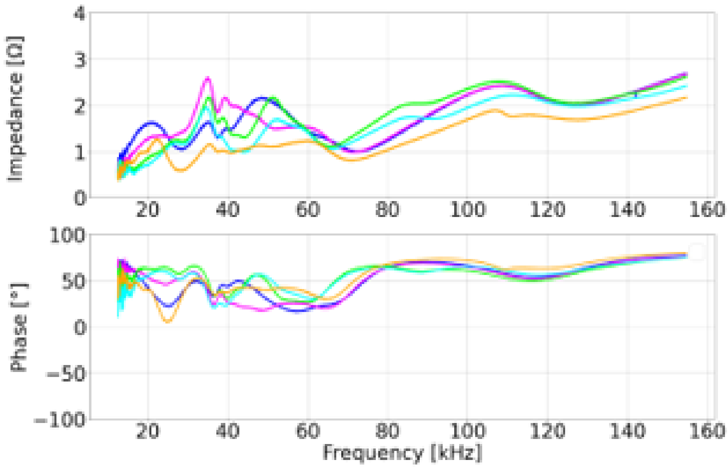

Figure 2.4: Charging plaza measurements, more details in (7)

The results are presented in Fig. 2.4 and 2.5. The impedance magnitude values at the households were similar to those obtained from measurements at the charging plaza and were not exceeding 4 Ω. The variation with frequency however was different for the four locations and was highly dependent on the loads connected inside the house and their distance from the POC. To a lesser extent, the upstream grid components and neighbouring households influenced the characteristic. The charging plaza had an estimated short-circuit power of 7.3 MVA, which resulted in an impedance characteristic that gave a good match with the estimation from Stiegler as presented in Section 2.3.3. More details can be found in(7).

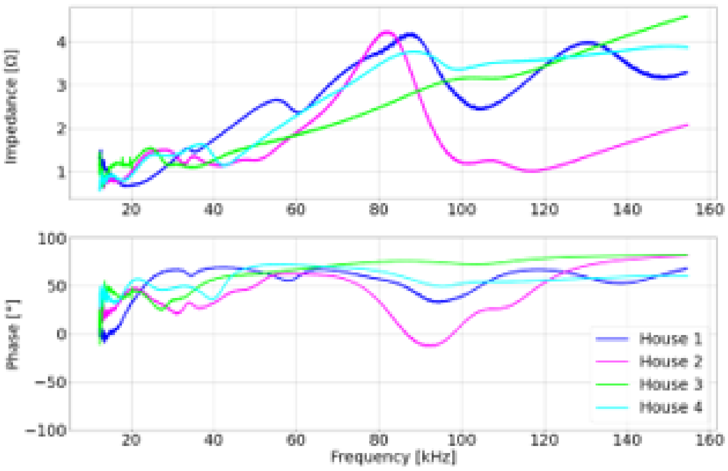

Figure 2.5: POC measurements, more details in (7)

2.3.5 | Comparison and conclusion of findings

The CISPR 16-1-2 standard proposes a defined impedance to couple the emitted disturbances in the 9-150 kHz range and the resulting disturbance voltage.
The following observations are done, based on the comparison of the impedance characteristics in Fig. 2.6:

- In the mentioned research, realistic values of the grid impedance up to 150 kHz are obtained and presented
- These values are considerably lower than the proposed standard impedance by CISPR, with a difference up to a factor 4.
- The short-circuit power by IEC 60725 is almost 5 times lower than the median in the research by Stiegler (0.57 vs. 2.7)
- Realistic impedance and short-circuit power provide a much lower network impedance than the CISPR values.

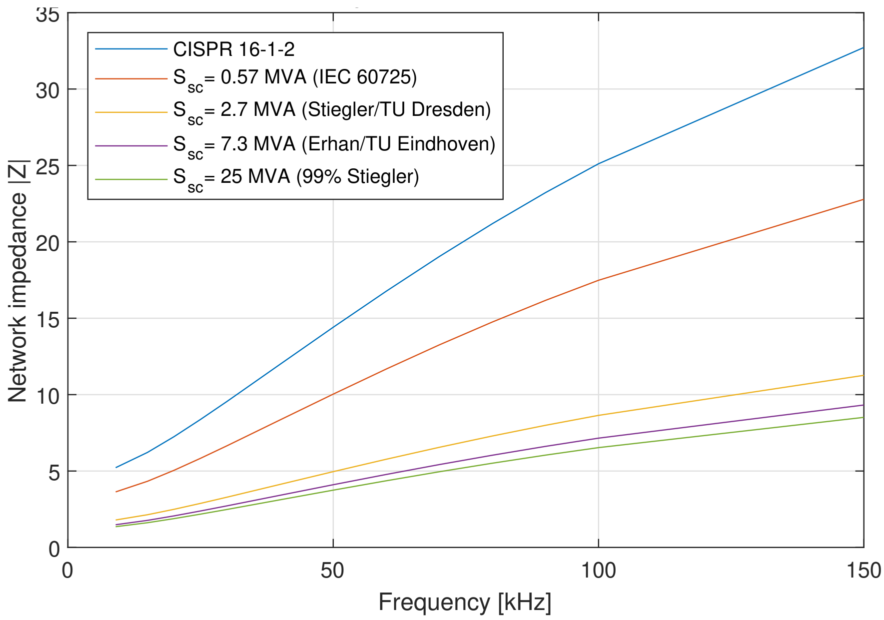

Figure 2.6: Comparison of network impedance values for different short-circuit powers, based on CISPR (A.3.1), IEC 60725 (2.3.2), Stiegler e.a. (6) and Erhan e.a. (7). Figure from (8).

2.4 | Derived current emission limit (8)

Based on the results and findings as discussed, an emission level limit can be derived. The compatibility level (A.1.1) for the voltage and the impedance results (2.3.5) lead to maximum permissible current emissions for different impedances, such that the compatibility level is never exceeded. This derivation gives the current emission from an installation, and emission from individual devices should be lower. Also, because the network impedance is different based on short-circuit levels, in theory a higher emission would be possible in a network with a lower impedance, such that the compatibility level is not exceeded.

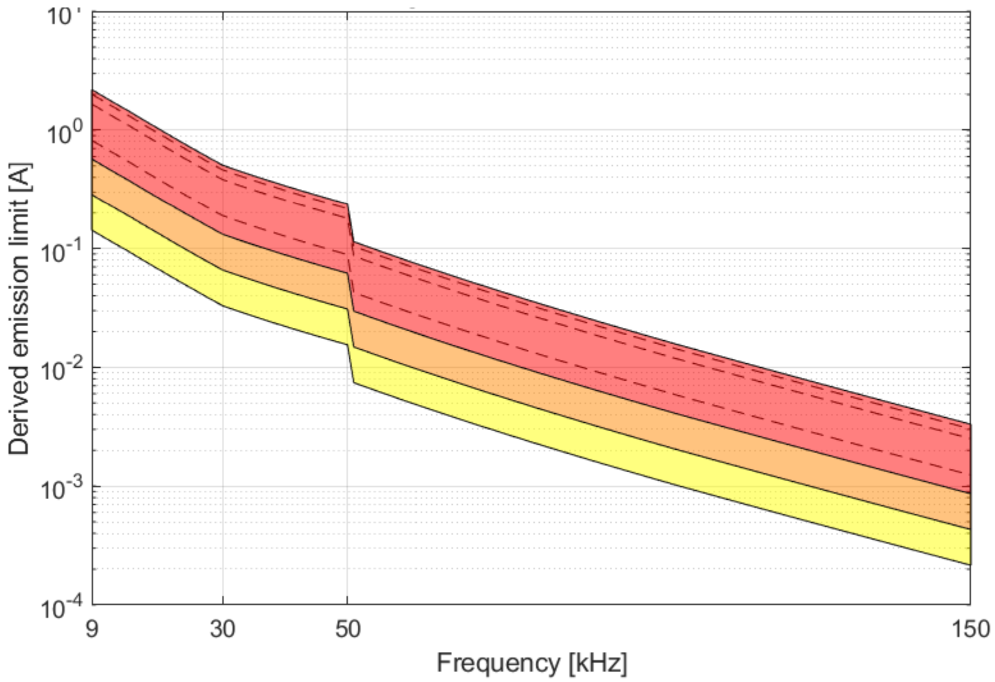

Figure 2.7: Derived emission limit at installation level for different impedance values (red), 0.5-1.0 times the limit for the lowest emission (orange) and 0.25-0.5 times the limit for the lowest emission (yellow). Figure from (8).

In this research, the result will be presented based on the range of impedance values from Fig. 2.6. The derived emission limit is presented in Fig. 2.7. Here, 5 regions are distinguished. Emission in the region above the red band is always (for all considered impedances) too high. The red region presents the maximum emission for the range of impedance values. Higher emission is allowed in networks with a lower impedance, according to this derivation. The orange region presents emission that is between half (0.5) times the lowest emission in the red band, and below the lower boundary of the red band. The yellow band presents 0.25 to 0.50 times the emission for the lower boundary of the red band.

Emission below the bands (lower boundary of the yellow band) are considered OK, but this is not a guarantee that no interference may occur! In general, it is assumed that emission below the 0.25 band (lowest band) will not lead to exceeding of the limits in the case where more devices are active simultaneously. Hence, it is assumed that summation will at worst lead to an increase in total emission of a factor 4, based on earlier research. Thus, the lowest band is chosen at a fourth of the emission limit, and considered okay. Emission in the yellow and orange band might be okay in the case where no other SH emitting devices are present in the same installation, but this assumption is difficult to make in practice.

2.5 | Application of proposed emission limit to EV measurements (9)

The proposed emission limit has been compared to measurements on 43 on-board chargers (OBCs) of EVs by ElaadNL, and detailed in 9. The result is shown in Fig. 2.8. Here, the amplitudes of the observable peaks in the FFT are used, and the highest value was taken for different charging speeds. Broadband distortion was treated in the same way as the peaks, by taking their maximum amplitude. It is shown that 20 EVs are OK (below the colored ranges), 23 in yellow or orange range, 14 in red range and one above. The suggested limits hence seem workable. EVs can be a high source of supraharmonics, but it is also possible to stay below the lowest emision limit.

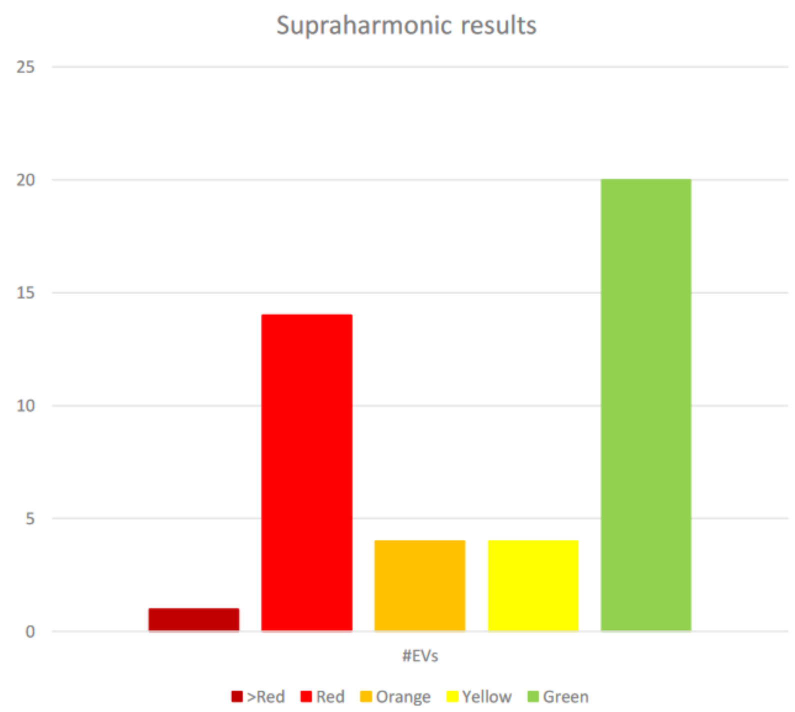

Figure 2.8: Application of emission limit to EV-measurements on 43 EVs by Elaad. Figure from (9).

3 | Recommendations / Best Practices

Based on the research and findings of the TEPQEV project, the following recommendations and best practices are proposed for ensuring the safe and reliable operation of EV chargers and the power grid in the supraharmonic frequency range of 2-150 kHz:

- Test EV chargers in both a clean and distorted grid, as well as in a ”normal” grid. This will provide a more representative picture of the device’s emissions in real-world conditions.
- Use a line impedance stabilization network (LISN) to simulate a representative network impedance for the device under test. However, it should be noted that current standardized LISNs may not provide an accurate representation of the network impedance.
- Therefore, more research on the definition of the supraharmonic network- and grid element impedance and the research and development of a new LISN specification are recommended as future research.
- Take into account the potential for summation and interaction of supraharmonics when testing EV chargers. This may have an impact on the overall emission levels of the device.
- Consider the proposed emission limit for supraharmonics in the 2-150 kHz range as a starting point for ensuring the safe and reliable operation of EV chargers and the power grid as a whole. However, it should be noted that this proposed limit is based on a combination of existing standards and research and no rights can be derived from the limits.
- Keep in mind that the proposed limit is intended to apply on an installation level, meaning that individual device limits should be set significantly lower in order to avoid exceeding the overall limit when multiple devices are connected.
- Be aware that future standardization efforts may result in different values for emission limits in the supraharmonic frequency range.
- Be aware of the limitations of the proposed emission limit, such as the fact that it does not take into consideration the potential for summation and interaction of supraharmonics.
- Measure on both small time intervals (10 periods, 200 ms) and longer time intervals (e.g. 5 or 10 seconds) in order to capture slow time variations like the beating effect.
- Measure both in frequency bands (between 200 and 2000 Hz) to capture the aggregate energy of, for instance, broadband distortion, but also with a higher resolution (1 or 5 Hz) to determine exact frequencies of distortion and small differences between them.

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A | Existing standardization

This section gives an overview of existing standardization for the 2-150 kHz range. Partly based on (2)

Snippets of the standards have been removed in this public version. Details can be found in the respective standards or at the authors of this report.

A.1 | Voltage compatibility

A.1.1 | IEC 61000-2-2, Amendment 1 and 2

A.2 | Measurements

A.2.1 | Grid and emission measurements 2-9 kHz: IEC 61000-4-7 (informative)

A.2.2 | Grid and emission measurements 9-150 kHz: IEC 61000-4-30 (informative)

A.2.3 | Emission measurement method for laboratory conditions: CISPR 16-1-1 (informative)

Method not considered. Implementation too complex and/or expensive and only meant for laboratory conditions. Also stated in A.2.2 and (2).

A.2.4 | Outcomes of the SupraEMI project

See (10)

A.3 | Reference impedance

A.3.1 | Emission and immunity measurements coupling devices: CISPR 16-1-2

A.3.2 | Reference impedance public supply network (flicker impedance): IEC 60725

A.4 | PLC

A.4.1 | Emission 3-148.5 kHz: EN 50065-1

A.4.2 | Expected levels LV up to 95 kHz: EN 50160

A.5 | Immunity

A.5.1 | Differential mode: IEC 61000-4-19

A.5.2 | Common mode: IEC 61000-4-16

A.6 | Equipement specific

A.6.1 | Emission of active in-feed converters (AIC): IEC TS 62578, Annex B (recommendation)

A.6.2 | Emission of lighting equipment 9-150 kHz: EN 55015

A.6.3 | Emission of induction stoves 9-150 kHz: EN 55014

A.6.4 | Industrial, scientific and medical equipement: EN 55011 from 9-150 kHz

B | On-going or non-existent standardization

Based on (2)

B.0.1 | PLC in MV grids, up to 3 kHz: IEC 61000-2-12 (Recommendation up to 9kHz)

B.0.2 | Summation law for low-order harmonics: IEC 61000-3-6 and IEC 61000-3-14