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How to better integrate EVs, EVSEs and the grid

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Executive Summary

To ensure the successful integration of electric vehicles and charging stations with the electricity grid, the Elaad Testlab tests electric vehicles and charging stations on interoperability, smart charging and power quality emissions and immunity. The main recommendations that come out of these tests: the correct implementation and interpretation of the standards, improvement suggestions to have less of an impact on the power quality of the grid, and to be more immune to distortions on the grid.

1 Introduction of the Elaad Testlab

To ensure the successful integration of electric vehicles (EVs) and charging stations (EVSEs) with the electricity grid, the ElaadNL non-profit research organization, founded and funded by the Dutch electricity grid operators, has set up the Elaad testlab. Here EV and EVSE manufacturers can bring their devices and have them tested for free on interoperability, smart charging, V2G and power quality. The Elaad testlab is a unique location, with specialized testing and measuring equipment and newly derived testing protocols based on the more than 14 years of charging experience at ElaadNL. The Elaad testlab uses the obtained knowledge during testing to advise charging improvements to the manufacturers and to collect “Best practices” and “common mistakes” which are shared in this document. This way the Elaad Testlab wants to help the EV manufacturers to give a better charging experience to their customers with a reduced impact on the electricity grid. Also, the lessons learned are used to prepare the grid operators for the increase in e-Mobility and to improve the standardization and certification of EVs.
To acquire the knowledge the Elaad Testlab performs several tests, of which the following ones will be further explained in this manuscript.

- Interoperability testing
- Smart charging testing
- Power quality emission testing
- Power quality immunity testing

The main focus of this paper is on AC charging via basic mode 3 communication. In the following chapters each type of test will be explained in detail and the most important observations and recommendations to EV manufacturers will be shared. At the end of the document the next steps the Elaad Testlab is taking regarding EV tests and implementing the lessons learned will be shared.

2 Tests and Recommendations

2.1 Interoperability

2.1.1 Test method

At the Elaad Testlab there are currently (May 2025) 47 AC EVSEs and 20 DC EVSEs present. These are used for interoperability testing with the EVs that visit the lab. Each EVSE is capable of communicating via at least OCPP 1.6 with our backoffice system and different protocols are used to communicate with the EVs. Most commonly the AC EVSEs use mode 3 communication, while the DC chargers use ISO 15118-2 or DIN SPEC

70121. Some AC and DC EVSEs are able to communicate via ISO 15118-20, which also supports bidirectional charging.

2.1.2 Observations

During the interoperability tests a regular charging session and a smart charging session are activated. During these tests it is observed that most EVSE – EV combinations are able to do regular and smart charging. A short pause is also initiated during the smart charging session, and there are some differences in how the EVSEs activate the pause when using Mode 3 communication. Most create a 100% PWM signal, but other EVSEs create a state E or F. Also, some EVSEs perform the “”wake up mechanism for legacy vehicles” as described in the IEC 61851-1 by creating a state E or F state. if the EV does not restart charging after the pause end has been signaled by the EVSE by restarting the PWM signal (state B1 to B2).
During DC charging the EVSE and EV share their maximum and minimum current and voltage levels. Sometime a mismatch occurs between those. For instance, some EVSEs have a minimum charging speed of 5A because the metering below that becomes too inaccurate, while some EVs want a minimum of 0.

2.1.3 recommendations

Regarding mode 3 AC charging there are differences between how EVSEs pause the session; via state B1, E or F. Also, some EVSEs implement the “wake up mechanism for legacy vehicles” as described in the IEC 61851-1 for waking up EVs that do not respond to a B1/B2 change via a state E or F, but not all. So do not rely on this legacy wake up mechanism for restarting after a charging pause.
Regarding DC charging; be aware that voltage and current minimum and maximum levels are strict and can be the reason for a charging issue. Therefore, an EV should match the limitations given by the EVSE if technically capable.

2.2 Smart charging

2.2.1 Test method

The Elaad testlab has created an automated test service to test the AC mode 3 Smart charging behaviour of EVs. The tests are performed using a grid emulator, to make sure the grid is constant at a perfect 230V 50 Hz, and the current and mode 3 measurements are performed using a Dewetron DEWE-800 with a 1 MS sampling rate. During the test different smart charging scenarios are executed which represent different real world usage scenarios of smart charging; Fluctuating charging speed test, Intermittent charging and Delayed and paused charging.

2.2.2 Observations

During the tests it was observed that some EVs do not keep the current below the PWM max at all current levels, are too slow in reducing the current or opening S2 when required, or are not able to start charging again after single, multiple or longer pausing periods.

2.2.3 Recommendations

Therefore Elaad recommends the EV manufacturers to test their smart charging behaviour using the Elaad Smart charging test scenarios, which can be found below;

Fluctuating charging speed test

The fluctuating charging speed scenario is a general test to find if the EV its charging speed is always below the maximum allowed by the EVSE and if it responds in time according to the maximum time limits. The EV shall adjust its maximum current drawn to be equal to or below the maximum current indicated by the PWM duty cycle within 5 seconds after the EVSE signals the new maximum via the PWM signal. Also, the EV needs to stop drawing current within 3 seconds after the EVSE stops the PWM signal and afterwards the EV has 3 seconds to open its S2 switch.
The test scenario as shown in figure 1 can be used to test the EV’s ability to cope with fluctuating charging speeds and to check if the EV response to PWM changes is accurate and in time. It is recommended to take 1 minute for each step to allow the charging speed to stabilize for the check against the maximum current allowed. In the first part a selection of charging currents is tested, first increasing then decreasing . Experience teaches that at the lower charging speeds it is more likely there is a higher current intake than allowed, therefore these are checked in more detail. In the second part the response time of the EV on larger drops in charging speed to 6A or 0A are tested.

If an EV is able to charge on different speeds when charging on 1 phase or 3 phases, it is advised to perform the test for both scenarios.

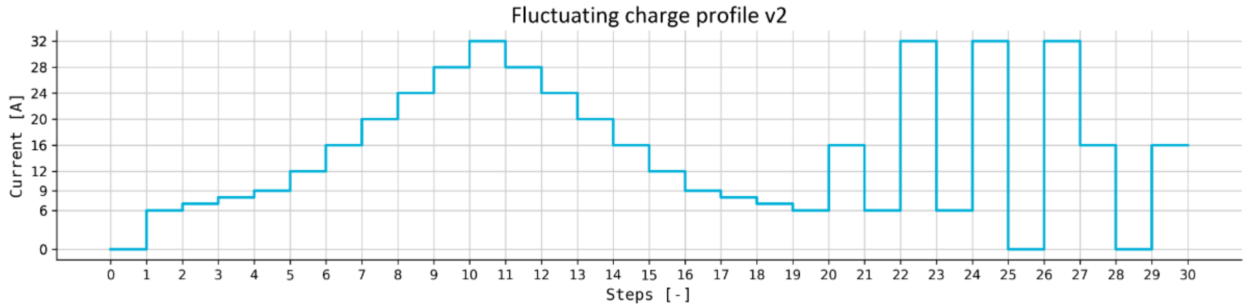

Figure 1: Fluctuating charge speed test profile

Delayed and paused charging
Delaying a charging session means no charging is allowed right from the start, while pausing means the charging is interrupted. Charging can be delayed or paused for a longer period of time, for instance to lift the charging over the evening electricity usage peak. As this peak commonly occurs between 17:00 and 23:00, it is recommended to test the ability of an EV to be able to charge after being paused for 6 hours and being delayed for 6 hours. It is also recommended to make sure the 12V or 24V battery is not drained during longer pausing periods.

Intermittent charging
Intermittent charging means a charging session is paused multiple times. This can, for instance, be the case when charging using solar energy on a partly cloudy day, or when charging at a charging hub where alternately EVs are charged or paused to keep total power below the maximum of the grid connection. To test this scenario it is recommended to set up a charging session with multiple charging and pausing periods. During the charging periods the charging speed is recommended to be set at the minimum of 6A, as this is more realistic if the charging is intermittent because of low solar energy production. It is recommended to perform this test two times using different time lengths for the periods. The time per period commonly used for alternately charging EVs at a charging hub is 15 minutes, so using this period length +1 minute to take into account time randomization is recommended. Regarding the number of pauses it is recommended to use at least a total of 25 pausing periods, as this number is commonly reached when alternately charging overnight using 15 minute periods. For testing the charging on intermittent solar scenario, a time length of 1 minute per period is advised because of the quick changes in the amount of available power that are possible in the real world.
An example of an intermittent charging test profile can be found in figure 2.

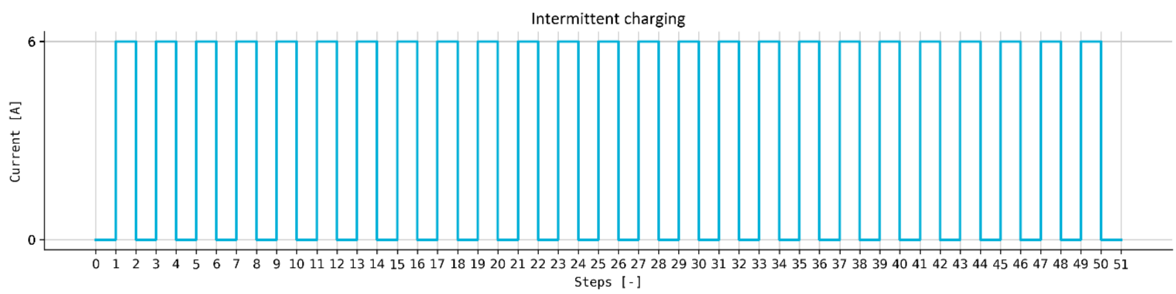

Figure 2: Intermittent charging test profile

2.3 Power Quality emissions

2.3.1 Test method

During the smart charging tests detailed measurements of the currents on all three phases are performed using the 1 MS sampling rate Dewetron DEWE-800 data acquisition measurement computer in combination with LEM IT65-S current transducers. These measurements are analyzed on Power Quality emissions, examples of those can be seen in figure 3. As the tests are performed using a grid emulator, the grid is constant at a perfect

230V 50 Hz, and any emissions found can be linked to the device under test.

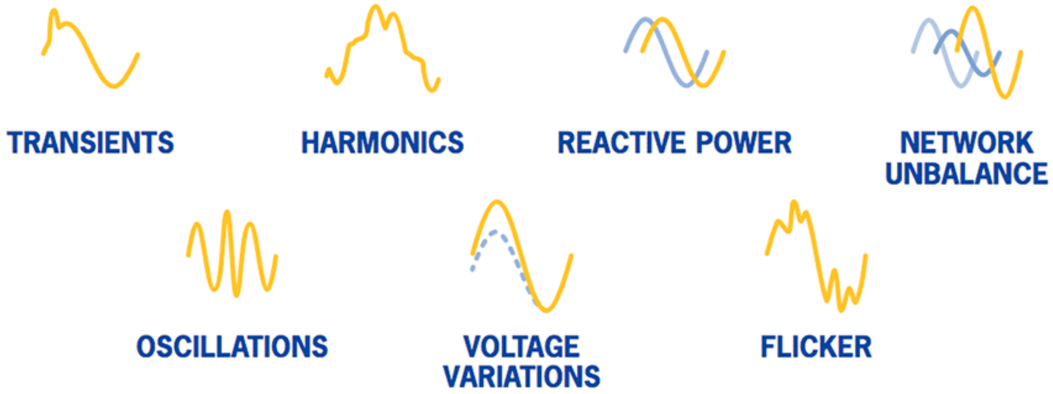

Figure 3: some examples of distorted voltage or current sinus waves which can become power quality issues

2.3.2 Power factor explanation

Reactive currents are currents that are transported, but are out of phase when compared to the voltage. This means they cannot be used to generate power or, in this case, to charge the EV. The ratio of reactive current is shown via the power factor which shows the ratio between the real currents and the reactive currents. The lesser the reactive currents, the higher the Power factor. The Dutch DSOs demand that the power factor of an installation must be at least 0.85 (see article 2.27 from the Dutch "Netcode Elektriciteit") at voltage up to 50kV at a scale from 0 to 1. Typically, the higher the power factor, the better. Both because the grid capacity will be used more efficiently and the EV will be charged faster.

2.3.3 Power factor observations

During the smart charging tests the power factor is measured at different current levels. It is observed that some EVs have a lower power factor than 0.85 at the lower current levels. In one case an EV even had a power factor of 0 when 6A was the communicated maximum charging current, which means no real charging was going on while it seemed like the EV was charging.

2.3.4 Power factor recommendations

When EVs are tested on smart charging, the power factor should also be measured and considered. This value should always be higher than 0.85 and preferably (close to) 1.

2.3.5 Harmonics and THD explanation

A harmonic is a distortion with a frequency that is a multiple of the ground frequency of the signal and lays on top of the ideal waveform. See figure 4 for a visual explanation.

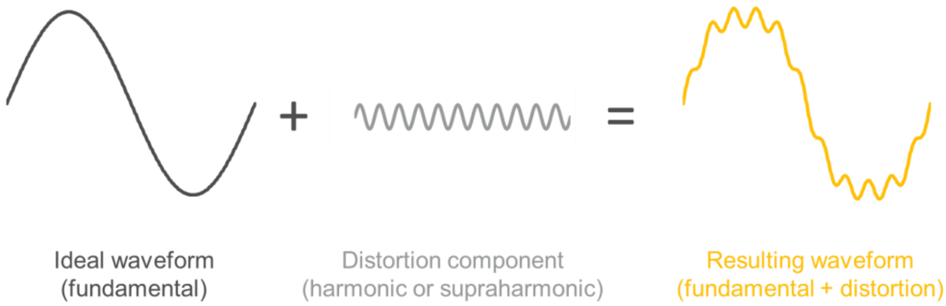

Figure 4: harmonic distortion

These distortions can cause overheating and malfunctioning of grid assets. The IEC 61000-3-2 standard defines the harmonic current limits for electronic equipment rated up to 16A operating at its nominal, or rated, current. The IEC 61000-3-12 standard defines the harmonic current limits for equipment rated 16A - 75A operating at its rated current. In both standards a limit for several single harmonics and the Total Harmonic Distortion (THD) are defined.

2.3.6 Harmonics and THD observations

In both standards, a single operating point is used for compliance testing. However, the charging power of EVs can be controlled which can significantly alter the behavior of the equipment emissions, especially when lowering the charging power. It is observed that practically all EVs are compliant to the relevant standard at the nominal current level, but at lower current operation points both single harmonics and the THD can be higher than the allowed limits.

2.3.7 Harmonics and THD recommendations

For both standards, an option would be to create a new category of controllable loads which include EVs. For these kind of devices, harmonic limits at different operating points could be set as a percentage of the drawn current. The compliance tests should then be adapted to address several operating points.

2.3.8 Supraharmonics explanation

Any modern AC/DC converter, like used in EVs or DC EVSEs, switches on high frequencies that can lead to the emission of Supraharmonic distortions. These are high frequency distortions in between 2 and 150 kHz which can cause overheating and malfunctioning of electronic components, devices, and distribution grid assets. Little is known about the propagation of these emissions and no formal emission, immunity and testing standards have been defined yet. Furthermore, although grid impedance is related to frequency, how Supraharmonic frequencies affects the grid is under-researched. Research in this area is essential to determine how Supraharmonic currents propagate through the grid, how much these currents have negative effects on grid components or other electronic devices and what the limits in future standards should be.

2.3.9 Supraharmonics observations

The measurements Elaad performs during the testing show that there are multiple EVs and EVSEs that emit these Supraharmonic distortions. Using the preliminary limits defined in the TEPQEV research project[1], see figure 5, these have been analyzed and about half of the tested devices emit distortions that are above these preliminary limits, see figure 6.

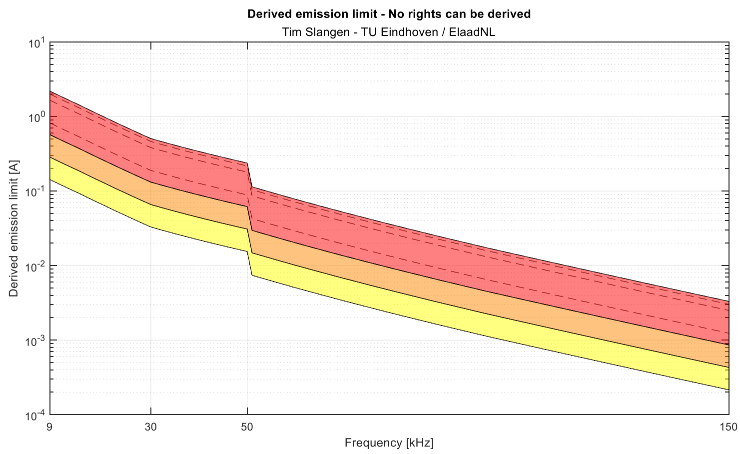

Figure 5: TEPQEV preliminary Supraharmonic limits. Red is over the limit, orange at the limit, yellow slightly under the limit

[1] https://elaad.nl/en/projects/tepqev/

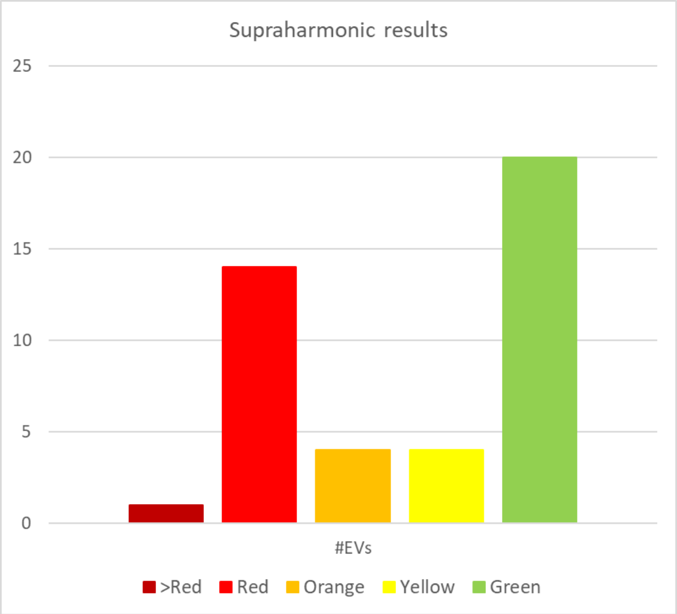

Figure 2: SH emission from 44 EVs. >Red: over the red limit band, Green: under the yellow limit band

2.3.10 Supraharmonics recommendations

Supraharmonics emissions to the grid can be prevented by using the right kind of filter in de AC/DC converter. Therefore it is recommended that the converters have a filter that is tuned to the switching frequency of the converter. In addition, during the TEPQEV research it was noticed that these filters also absorb distortions coming from other EVs. Therefore it is recommended to use filter components of good quality and specified for at least a 2x higher Supraharmonic current than the device's own emission.

2.4 Power Quality immunity

2.4.1 Test method

As the Elaad Testlab uses a grid emulator during the charging tests, the grid specifics can also be changed during the tests. Using the limits in standards like the 61000-4 series and the NEN-EN50160, the immunity of the EV or EVSE to changes of the grid voltage can be tested and observed.

2.4.2 Observations

EV testing in the ElaadNL testlab revealed that some EVs were affected by the changes in the grid voltage. When distorting the grid with harmonics, some EVs stopped charging or the amount of reactive current increased enough to go over the maximum allowed current by the EVSE. It has also been observed that some EVs increase their current intake above the maximum allowed by the EVSE when the voltage is lowered to its lower allowed limit.

2.4.3 Recommendations

To avoid EV charging issues during grid distortion or voltage fluctuations, it is firstly recommended that the EV is tested on compliance to the relevant standards. These only check the ride-through ability though, therefore it is also recommended to make sure that the EV keeps the current in all occasions below the signaled maximum charging current by the EVSE. This can for instance be done by a measurement in the EV of the true current intake and adjust the power intake for that.

3 Next steps

The Elaad Testlab is using the lessons learned to create awareness, to help to improve the charging standards for EVs and to ensure certification of the charging behavior becomes a requirement during the homologation process of an EV. The Elaad Testlab has therefore joined the UNECE workgroup 5 Informal Task Force on E-Mobility and the UN ECE Fast and smart charging cluster.

Furthermore, to keep up with the latest developments the Elaad Testlab is currently expanding its testing capabilities to include bidirectional charging test, as this is an important new feature of EVs that can have a positive impact on balancing the power in the grid. Therefore, a testing system has been acquired, which is capable of using ISO 15118-20 communication and is capable of bidirectional power transfer. Using this system the Elaad Testlab can test the ISO 15118-20 communication and bidirectional functionality of an EV, its power quality emissions and immunity when feeding back energy to the grid, and the compliance to the Requirements for Generators (2.0); a set of European and national rules any device feeding back energy to the grid needs to comply to.

4 References

[1] International Electrotechnical Commission [IEC] (2017) *IEC 61851-1:2017 Electric vehicle conductive charging system - Part 1: General – Annex A.5.3*

[2] ElaadNL (2023, August 14). *TEPQEV Research on supraharmonic distortions by EV-charging* https://elaad.nl/en/projects/tepqev/

5 Presenter Biography

Thijs van Wijk is the technical lead of the ELaad testlab. Thijs has more than 13 years of experience with electric vehicles and charging infrastructure. At the moment Thijs is integrating 15118-20 communication, V2G and RfG code compliance in the Elaad test process and discussing the certification of those in several working groups. Also, Thijs is active as an expert in several Power Quality related projects. Thijs has a bachelor's degree in electrical engineering (HAN, 2004) and a master's degree in innovation sciences (TU/e, 2006).