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In-Field High-Power EV Charging Infrastructure Testing and Maintenance

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Summary

The FKFS presents a novel concept for a high-power mobile test vehicle that contains the necessary measurement technology and energy system as a solution for testing the functionality and safety of high-power charging ports of 350 kW and beyond in HPC stations – comparable with advanced lab test systems. This mobile lab comprises electric safety tests including power quality, potential injury risks and the technical health state of the charging poles.

Keywords: Charging, calibration, EVSE, EVSE-Testing, high power charging, power validation

1 Introduction

In the last few years, the electric vehicles (EV) share from the automotive market is rapidly and continuously increasing. Nearly every second EV in the EU has been newly registered within the year 2021 [1]. Therefore, the EVs count close to 900,000 in the EU in 2021 [2]. In Germany, for example, in the period between 2011 and 2021, the number of passenger EVs has increased by approximate 134 times [3]. Therefore, larger charging parks are necessary for many EVs to cover long distances, among other things. However, this rapid growth in electric vehicles is not accompanied by a similar rate of growth in the charging infrastructure. Throughout Germany, around 35,750 charging points for electric vehicles were installed by the end of 2021, which represents only a growth factor of 16 within 10 years [4]. In Europe in 2021 there were more than 330,000 normal and high-power public recharging points installed [5], [6]. By 2030 that number is expected to grow to over 500,000 public recharging points, 50,000 of which are openly available DC-Charging points and 60,000 highway high power charging (HPC) stations [7]. Nevertheless, those numbers do not reflect the number of charging stations that are in operation.

After the charging station has been checked once before its initial operation, further periodic checks follow to check the charging station for safe operation. Due to aging, functional impairments and safety issues can occur. These periodic tests can be expanded to include additional measured values using the test system. Accordingly, regular checks of the functionality and safety of charging points is necessary for the market success of e-mobility. Therefore, several measuring devices are available on the market. However, these devices just focus on one aspect of the charging station evaluation. To extent this, it is crucial to consider the effects of active high power transmission from a HPC station on its functionality and safety. This means that the tests should take place under load, which is not the case in the market-available test systems. The combination of functionality and safety tests allow a wide collection of measuring data. Therefrom test cases can be deducted which offer added value in the future.

Fig 1 gives an overview of the different measuring tasks with a selection of measuring parameters. This comprehensive data collection of a charging station provides the basis for detailed investigations.

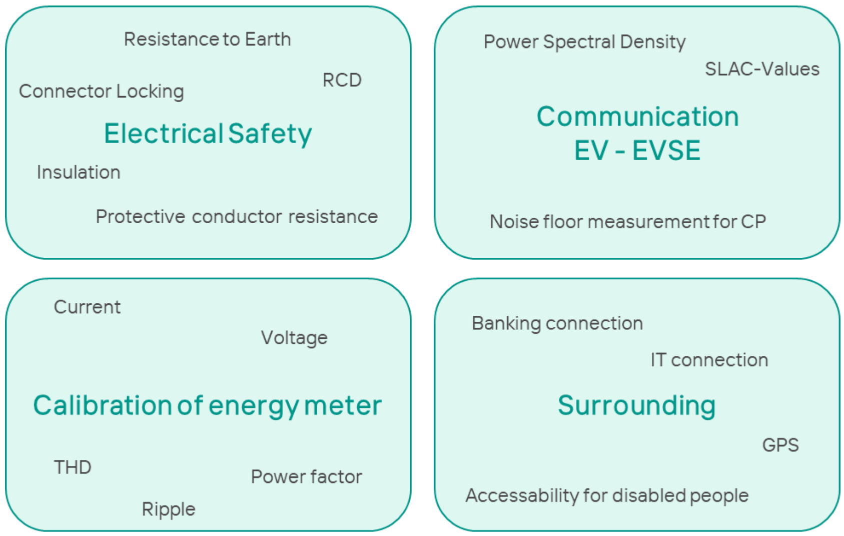

Figure 1: Measuring tasks of test system

To consider special cases and gain more data, the system contains a modular designed energy sink unit (ESU), which is described in chapter 2.1.

The Research Institute for Automotive Engineering and Powertrain Systems Stuttgart (in German FKFS) presents a novel concept for a high-power mobile test vehicle that contains the necessary measurement technology and energy system as a solution for the aforementioned challenges and requirements. This concept, shown in Fig. *2* consists of a test vehicle including the measurement devices, and an extensional test system as energy sink.

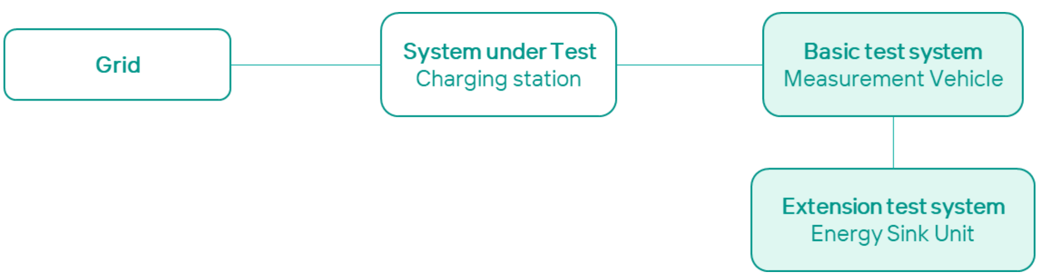

Figure 2: System overview

This modular setup has the advantage of high flexibility in adapting to different scenarios and measurement environments.

The test system allows investigations of AC and DC charging processes. The prototype is able to handle 350kW charging power and 500A charging current. Among others, a permanent observation of the temperature in the connectors guarantee a safe operational thermal state. [8]

Moreover, the vehicle includes a fully equipped workplace for the control of the test and of the documentation. The generated large amount of data during the automated test must be analysed and evaluated. For this purpose, methods of classic analysis are combined with graphic representation of the results. The data-assisted analysis will simplify the assessment of the system. The results of the test are filtered and evaluated in real time. Even small inadequacies will be recognized and reported to the operator. Afterwards a report will be generated automatically and the measurement data will be stored.

2 Energy and power management

2.1 Concept for the Charging Energy Sink

For ideal controllability of the energy storage, repeatability of the measurement and minimal measurement impact, is advised to design a dedicated energy storage or dissipation system for the measurement vehicle. In case of storing the energy multiple certification tests have to be conducted, such as safety tests according to LV 123 and LV 124, technology protection tests as per ECE R100 and transportation safety tests as per UN 38.3.

Due to time constraints another concept for storing the energy charged during testing was adopted. With a Man-in-the-Middle (MiM) concept, where the measurement vehicle is the middle man and a homologated EV is used as energy storage, there is minimal certification and no additional overhead for designing the chemical energy storage required.

The concept of MiM for the first prototype delivers therefore high energy storage capacity at no additional freight weight for the measurement vehicle (MV, Fig *3*). Also, the energy storage capacity can be chosen to be in about one order of magnitude. But the EV has to be chosen according to the desired maximum charging power and must accept AC and DC charging for the measurements.

As stated above with a homologated EV as energy storage and charging power sink the repeatability of the measurements might be impacted. Therefore, careful preconditioning of the EV has to be ensured so that the tests are always conducted in the same State of Charge (SoC) range and with comparable battery temperatures. Therefore, a battery preconditioning system has to be present in the EV. Controlling the SoC at the beginning of the measurement can be done by the MV itself if the initial starting SoC is below the measurement SoC-range. So, the MV acts as a regular Electric Vehicle Supply Equipment (EVSE) up until the SoC of the vehicle lays in the required range, where then the MV automatically starts the measurements. Probable imbalances between the EV battery cells cannot be reliably mitigated without interfering with the EVs homologation.

Additionally to the separation of the power path for measurements in the MV, the signalling path has to be separated for the MiM-system as well. In order for the MV to monitor the charging power demand, as well as control and potentially limit the charging power itself, the high-level communication (HLC) and the basic signalling has to be separated within the MV. So, the MV in case of the MiM-concept has to be client to the EVSE and server to the EV while the MV internally is functioning as a gateway.

Fig. *3* gives a rough overview of the power and communication paths of the test system. If the MV is used with the ESU, the EV simulator communicates with the charging station, whereas the power manager communicates with the battery management system (BMS). The EVSE simulator is used, when it comes to MiM measurements with the MV.

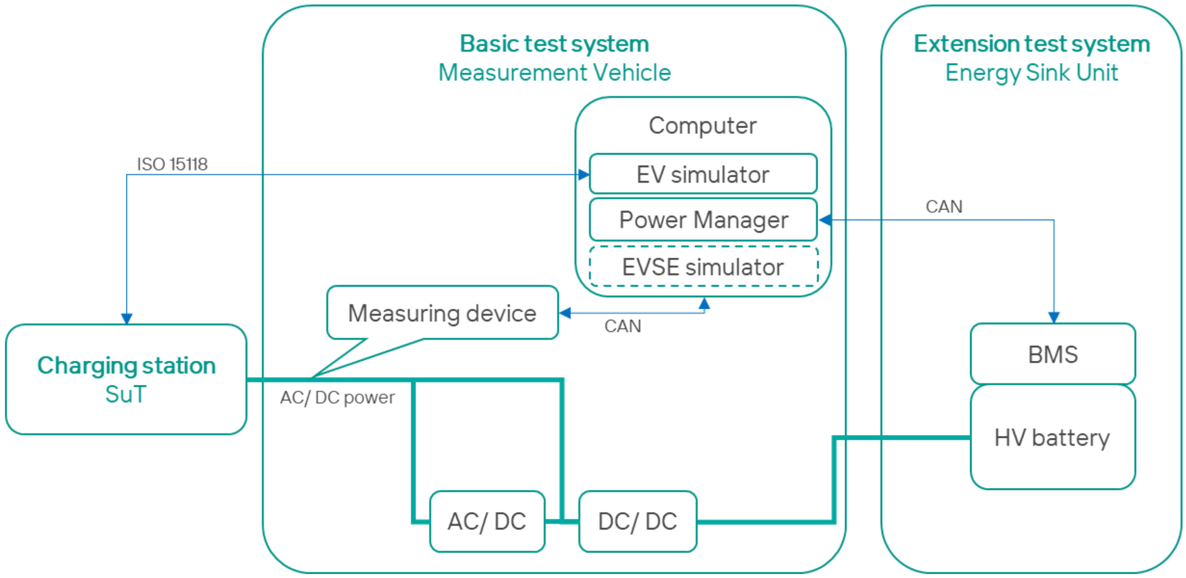

Figure 3: Test system overview

Ultimately the MiM-concept yields measurement experience and measurement optimisation techniques so that the assumptions in chapter 2.2 can be validated and potentially revised in order to reduce size, weight and cost of the energy storage unit for the final test system. Measurement optimization techniques, that reduce the measurement time and relevant requirements for the energy storage unit, can faster switch between measurement modes, have faster data processing and reduced necessity for measurement repetitions.

2.2 Charging Power Path to the Energy Sink

A charging power of up to $22\ kW$ AC and $350\ kW$ DC is targeted for the first prototype. $50\ kW$ and $150\ kW$ DC-EVSEs with $400\ V$ and $800\ V$ charging also need to be testable. $350\ kW$ will be only testable with $800\ V$ charging voltage and respectable battery system voltage as the following calculations will demonstrate.

The minimal voltage of a nominal $3.7\ V$ Li-NMC usually lays within $2.5\ V$ and $3.0\ V$, for EV purposes a worst case of $3.0\ V$ can be reasonably assumed. If the cell voltage falls below $3\ V$, slower precharge needs to be conducted before fast charging can occur [9]. Therefore about 80% of the nominal cell voltage U_N and subsequently battery voltage can be expected for the lowest possible SoC in with fast charging can be conducted. For the aforementioned $350\ kW$ maximum charging power P_{max} with the formular

$$I_{max} = {}^{P_{max}}/_{(U_N * 0.8)} \tag{1}$$

a maximum charging current I_{max} of

$$I_{max} = {}^{350\ kW}/_{(800\ V * 0.8)} \approx 547\ A \tag{2}$$

is to be expected. As of the writing of this paper charging inlets and outlets are only rated up to $500\ A$ peak under the condition of active connector temperature monitoring. Therefore, full rated power measurements can only be conducted at higher SoC and later in the measurement process, when slower charging power measurements were conducted prior. Furthermore, it is trivial to see that $350\ kW$ charging powers cannot be accomplished with a $400\ V$ EV battery system with current components-off-the-shelf.

As stated above, the MiM concept will over time yield more accurate measurements and therefore reduce measurement and consequently charging durations. With a detailed overview over the measurement procedure in practice, the specification of the sink for the charging energy can subsequently be narrowed down. But to get a better understanding of the final energy sink unit reasonable assumptions for the final measurement system can be made.

At the beginning of the measurement procedure the EV, the MV and the EVSE have to be connected. At this point in the measurement chain no power is flowing, so that general measurements, measurements of the basic signalling and a power spectral density (PSD) measurement of the noisefloor present on the CP line between MV and EVSE can be conducted. Expected is that most of the possibly relevant external high frequency (HF) disturbers can be measured this way, except very sporadic disturbances. After these $0\ kW$ measurements, the ISO 15118 precharge phase for DC fast charging can be started in order for the EVSE and the EV to match output and battery voltage levels.

After the $0\ kW$ phase, a charge power with $50\ kW$ will be applied in order to prewarm the EVSE, validate the measurement setup and get some general measurements. This $50\ kW$ phase is expected to last about 15 minutes. The exact timing is scope of current investigations and will be finalized with the knowledge gained from the MiM concept prototype.

Lastly an upto $350\ kW$ fast charge power (FCP) phase is conducted. Therein the PSD of the noisefloor present on the CP line between MV and EVSE will be measured. Expected is, that if this FCP phase PSD measurement is compared against the $0\ kW$ phase PSD most of the EVSE internal sources of HF-noise can be isolated. This noise isolation can be beneficial in causal research of unexpected charge disruptions. For an exemplary cause of an unexpected charge disruption see [10].

Additionally to the PSD measurements in the FCP phase the actual peak power, the current and voltage ripple coming from the EVSE shall be measured to validate the EVSE claims and to monitor the innocouesness of the EVSE for any given EV battery [11].

Therefore, one key parameter for engineering the energy sink unit is as following:

$$E_{charge} = 15\ kWh \tag{3}$$

wherein E_{charge} is the amount of energy the energy sink unit has to receive during a full measurement procedure in combination with the maximum charging current I_{max} specified in (2). If an energy storage unit according to chapter 2.3 is chosen, the actual capacity has to be overprovisioned to account for imperfect SoC management at the start of the measurement, State of Health (SoH) decrease during lifetime and to ensure possible fast charging over the duration of all the measurements.

AC charging tests are handled similarly with a $0\ kW$ and a $22\ kW$ phase where all the measurements take place. The energy sink unit will be specified to fit the DC charge measuring procedure presuming that AC charging will be less demanding.

2.3 Energy storage and dissipation

In order to decide on a concept for the final energy sink unit, the energy storage and dissipation have to be considered. Energy storage can be conceptualized as a battery trailer that can be coupled with the MV, the concept for immediate dissipation entails actively cooled DC-Load. A concept for storing the energy with a trailer and charging other EVs subsequently is preferred. This allows for spatial and temporal disconnection of storage and dissipation and modularized the concept, so that dissipation in urban environments can be done via EV charging. In rural environments where EV charging for dissipation cannot be relied on, the dissipation can be done via a DC-Load or via ISO 15118-20 RPT (reverse power transfer) in a safe and controlled manner. This modularization also leaves the possibility to swap combined storage and dissipation trailers for higher availability of the MV and better usage of the personell.

Storing the charging energy has obvious environmental and running cost benefits in contrast to dissipating all the charging energy immediately as heat. But dissipation has benefits in weight, initial purchase und longevity.

But safety has to be considered as well. For a battery as an energy sink unit extensive tests and certifications have to be conducted, for the immediate dissipation concept the heat output of the system as to be accounted for. With an immediate dissipation system, indoor tests for example in a car park, cannot be conducted.

Another problem with an energy storage solution arises if the C-Rate of the battery system is taken into account. In order for the system to be as light weight, as small and as cost effectively as possible and to minimize safety risks involved with increased cell counts and energy capacities, the battery capacity has to be minimized. If $E_{charge} = 15\ kWh$ and an energy capacity overprovisioning factor (see chapter 2.2) of 2 is chosen, even for a maximum EVSE output of $150\ kW$ the expected mean C-Rate (cell current over cell capacity) will be ~ 5. Current off-the-shelf Li-NMC cells range even with active cooling at a C-Rate of 1 to at max 2. With the expected measurement time optimization techniques gained from the MiM prototype an even lower E_{charge} can be accomplished with a resulting further increase of the expected C-Rate of the battery system.

For chemical energy storage Li-NMC, Lithium-Iron-Phosphate (LiFePo), Lithium-Titanate-Oxide (LTO) and Supercaps were considered. While Li-NMC as detailed above cannot serve those high C-Rates expected Supercaps are two orders of magnitude below Li-NMC in gravimetric and volumetric energy density [12]. Therefore, for Supercaps the bottleneck is not the C- Rate but the maximum freight weight or trailer weight of the MV to store the charging energy. If the measurement duration optimization techniques can reduce the measurement time and therefore E_{charge} by an order of magnitude Supercaps might become an anticing alternative.

This leaves LiFePo and LTO as possible chemical energy storages for the energy sink unit. LiFePo has the advantage that it is broadly available, comparably cheap to Li-NMC per kWh and that the necessary battery management systems (BMS) can usually be easily adapted from Li-NMC systems. LTO on the other hand can be charged with even higher C-Rates than LiFePo (~ 10 for LTO, $\sim 4-5$ for actively cooled LiFePo), but are harder to come by, have a lower gravimetric energy density and need specialized BMSs compared to LiFePo. But both cell types are substantially safer in case of misuse, have a wider temperature range and resist rapid deformation or cell damage better than Li-NMC.

3 Examination aspects

3.1 Electrical Safety

At the beginning of the DC charging process, the charging station checks the insulation resistance. If the minimal permissible insulation resistance is not exceeded, the charging station informs the vehicle that the charging process cannot begin. In this case, there is no charging process possible and the charging station enters shutdown mode [8].

According to [8], the threshold results from the DC output voltage according to formula 4

$$R_{insulation} \geq 100\Omega/V \cdot U_{rated} \tag{4}$$

Regular checks of the insulation resistance allow early detection of a non-functional charging station. For this purpose, existing measurement technology is used, which allows automation of the test evaluation and test execution.

Furthermore, the test system indirectly offers the possibility of monitoring the condition of the connector. An increased contact resistance leads directly to higher temperatures in the connectors [13].

Although the temperature in the connector is also monitored by the charging station during DC charging [8], the vehicle itself also monitors the temperatures in the connector. As soon as $120°C$ are exceeded, the charging process is stopped.

Also aging has bearing on the temperature in the connector. This is subject of further investigation at the FKFS. The higher the contact resistance determined, the worse the condition of the connector. This happens, for example, through corrosion of the plug contacts. Higher contact resistances of the mating surfaces in turn cause an increased temperature input during charging and are therefore to be avoided or recognized early.

3.2 Energy meter

Another measurement field of the test system is the investigation of the energy meter. With the increasing number of charging stations, there is growing interest in correctly determining the payment or the amount of energy supplied. A distinction must first be made between two different types of energy meters: Electromagnetic electricity meters and electrical electricity meters. A study by [14] shows that that the most common errors in electronic meters are caused by external environmental influences and operation outside the calibration limit. In return, measurement errors in electromagnetic electricity meters are mainly caused by external fields and voltage influences.

In addition to checking the calibration of the electricity meters, the selected measurement technology also allows the electricity quality to be checked. Electric vehicles can abort or even prevent the charging process due to poor network quality. The criteria used here are the Total Harmonic Distortion (THD) for AC charging processes and the ripple for DC charging processes. According to [15], the THD for voltages is determined using equation 5.

$$THD = \frac{\sqrt{\sum_{h=2}^{50} V_h^2}}{V_1} \cdot 100\% \tag{5}$$

The recommended limit values are determined based on the voltage level and should not exceed the values in Table 1.

Table 1: Voltage Distortion Limits [15]

	Total Harmonic Distortion (THD) %
≤ 69 kV	5.0
69,001 kV ≤ U ≤161k V	2.5
≥ 161,001 kV	1.5

3.3 Basis Communication

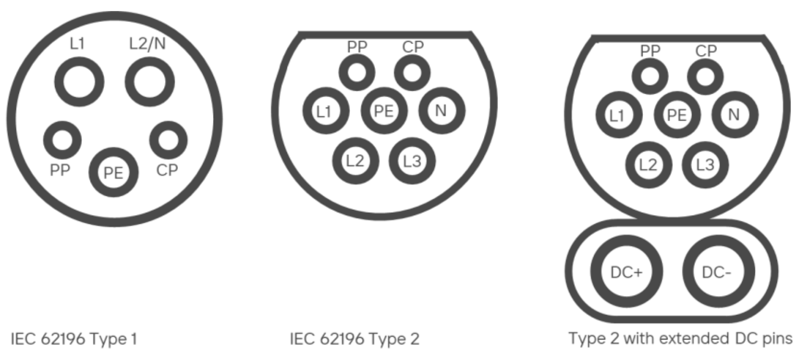

Figure 4: IEC 62196 Connectors [16]

As seen on Fig. 4 connectors according to IEC 62196 [16] have 3 (Type 1) or 5 (Type 2) pins for typical power connection, but they also add two smaller pins. These small pins are used to identify the connector and communicate between the charging station and the vehicle. The pin for connector detection is called the proximity pin (PP) and the pin with fed through wire for communication is called the control pilot (CP). One of the pins, resembling those for power transmission, is reserved for the Protective Earth (PE), so that a connection between the vehicle and the charging station via the charging cable grounds the vehicle.

Communication for AC charging with the connector types of IEC 62196 [16] is defined in IEC 61851. This communication uses the wires of CP and PE. Among other things, this ensures that PE is connected to the vehicle as long as the communication is active. If the vehicle is disconnected from grounding, communications will also be disrupted and the ground fault will be detected.

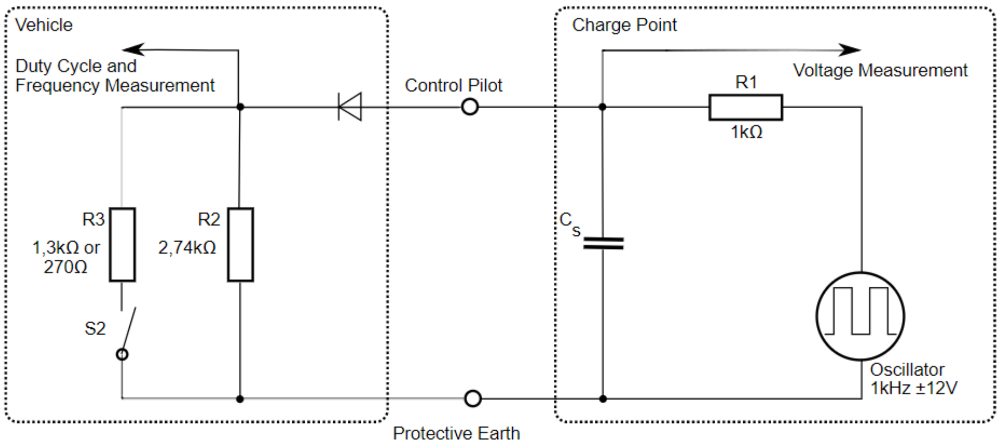

Figure 5: Simplified Circuit Diagram according to IEC 61851-1 Figure A.1 [17]

For AC charging, this so-called basic communication as shown in Fig. *5* is sufficient, wherein the charging point sends a pulse-width modulation (PWM) signal with $1\ kHz$ and $+/-\ 12\ V$ amplitude. The duty-cycle of the PWM encodes the maximum current that is currently available at this charging point. If the duty-cycle is 100% (so a constant $+12\ V$ on CP) the EVSE is not ready to charge.

On the vehicle side, a resistor network connects the CP pin to PE. This circuit (Fig. *5*, left side noted "Vehicle"), in series with the 1kΩ output impedance of the source, allows the vehicle to influence the amplitude of the PWM signal by setting various defined resistance values (S2 and R3).

The resulting voltage level represents the vehicle state. These states are: No vehicle connected ($12V$), vehicle connected ($9\ V$), vehicle ready for charging ($6\ V$) and ready for vehicle charging but requires ventilation of the environment ($3\ V$; e.g. for Lead-Acid-Batteries). Two more states are defined: the charging station is shut down ($0\ V$) and an error occurred ($-12\ V$). By measuring the positive half wave voltage amplitude, the charging point determines the vehicle state. Therefore, it is imperative that the equivalent source resistance of 1kΩ of the EVSE is within the specified 3% tolerances including the in line inductance of the ISO 15118 RL-Filter [18].

IEC 61851-1 Table A.1 delivers a set of parameters to be measured by the MV in order to determine the conformance of the EVSE. The tolerances specified are to be maintained over the full useful life and under environmental conditions as specified by the manufacturer.

Notable measurements of the basic signalling are the edge steepness of the PWM signal, which has to attain 10% to 90% and 90% to 10% in $2\mu s$, the PWM frequency at $1000\ Hz$ (+-0,5%), the output voltage level of $\pm\ 12\ V$ $(\pm 0.6\ V)$, the PWM pulse width of $\pm 25\mu s$, as well as the PWM duty cycle according to IEC 61851-1 Table A.6 of 8-97% from $6\ A$ to $80\ A$ in case of AC charging and 5% $(\pm 2\%)$ in case of DC charging. Also the total cable capacity, including the recommended electromagnetic interference (EMI) supressor capacitance C_S according to Fig. *5* and the coupling capacitors according to ISO 15118-3, has to be within $3.1\ \mu F$, but ideally lower than $2\ \mu F$.

Other possible measurements entail as aforementioned the crosstalk from the power lines onto CP in case of AC and DC charging

3.4 HLC and HF-PSD on CP

With the basic signalling as detailed in chapter 3.3, the vehicle can only send limited information to the charging station, it is not sufficient for DC charging. When charging with DC, the target current and voltage must be transferred from the vehicles BMS, most likely via an intermediate Electric Vehicle Communication Controller (EVCC), to the charging point. In the case of the connector according to IEC 62196 [16], the basic signalling according to IEC 61851 is still used as a safety level in addition to the high-level communication. In conjunction with the IEC 62196 [16] connectors and DC charging, ISO 15118 [18] has to be used. Because of the necessity to send the current set-point of the charge control in the high-level communication HLC for DC charging, the ISO 15118 [18] HLC must be used. Additionally, it can be used in AC charging as well.

An example of another useful application of ISO 15118 [18] is the integration of the charging vehicle into a smart grid. The open systems interconnection (OSI) layers of ISO 15118 [18] that are closest to the physical layer are based on the HomePlug Green PHY (HPGP) specification [19]. The signal of this orthogonal frequency-division multiplexing (OFDM) powerline communication is also sent via the CP.

Since the HLC of the ISO 15118 [18] uses an OFDM signal with a frequency spectrum of $1.8 - 30\ MHz$ crosstalk from other DC-EVSEs nearby can be a major contributor to EMI present on any individual CP line. Other spurious EMI emitters, crosstalk from the powerlines and multi DC charge point operation with HLC can be a major source of unexpected charge disruption as detailed in chapter 2.2 but at the same time can be a challenge to measure in the field with existing techniques. It is important to note that the measurement goal of displaying sporadic spurious immissions do not contradict the expected measurement optimisation techniques from the MiM prototype detailed in chapter 2.1, but only increase the duration of the $0\ kW$ measurement phase.

With the two PSD measurements of the noisefloor present on the CP line between MV and EVSE within the $0\ kW$ and the $150\ kW$ measurement phases as detailed in chapter 2.2, complementary to a PSD of the EVSEs HLC OFDM spectrum, a sufficiently accurate view on the signal to noise ratio (SNR) for the HLC can be acquired. If the noisefloor increases or the PSD of the OFDM signal received at the MV decreases, then the SNR will decrease. If the SNR falls below a threshold even the extensive error correction mechanisms of the HPGP, like the ROBO Interleaver or the $^1/_2$ Turbo Convolutional Coding, can not recover the original signal and an unexpected charge disruption occurs. The determination of exact thresholds is under investigation.

Other than EMI in the frequency domain, OFDM signals can be affected by inter symbol interference (ISI) as well. As the CP line has no determined cable impedance and no matching termination, ISI or the ringing of this point-to-point connection can be a significant source of disturbance. In the HPGP Specification used in the HLC of the ISO 15118 ISI can be mitigated by using an extended Cyclic Prefix duration t_{prefix}, which consists of the mandatory Rolloff Interval R_I and the for HPGP optional Guard Interval G_I, as per HomePlug GREEN PHY Specification [19] (Table 3-2). With this optional G_I the C_I can be increased for example from $4.96\ \mu s$ to $4.96\ \mu s + 7.56\ \mu s = 12{,}52\ \mu s$ with the MINI-ROBO-Mode. This is an ongoing subject of investigation at the FKFS. Expected is that shorter lengths of the cyclic prefix on degraded charging cables can contribute significantly to the SNR seen by the receiver. This can necessitate higher ROBO-Modes of HPGP with increased lengths of the cyclic prefix and reduced maximum data rates.

3.5 Authorization methods

When it comes to the authorization of the EV at the charging station, mainly two methods are distinguished: Plug and Charge (PnC) and external identification means (EIM) [18].

PnC allows the vehicle to start the charging process without any further activation of the vehicle user, see Fig. *6*. In scenario D1 a contract certificate is used for the authorization at the charging station. Opposite to that is the authorization by a secondary actor (SA) in scenario D2 [18].

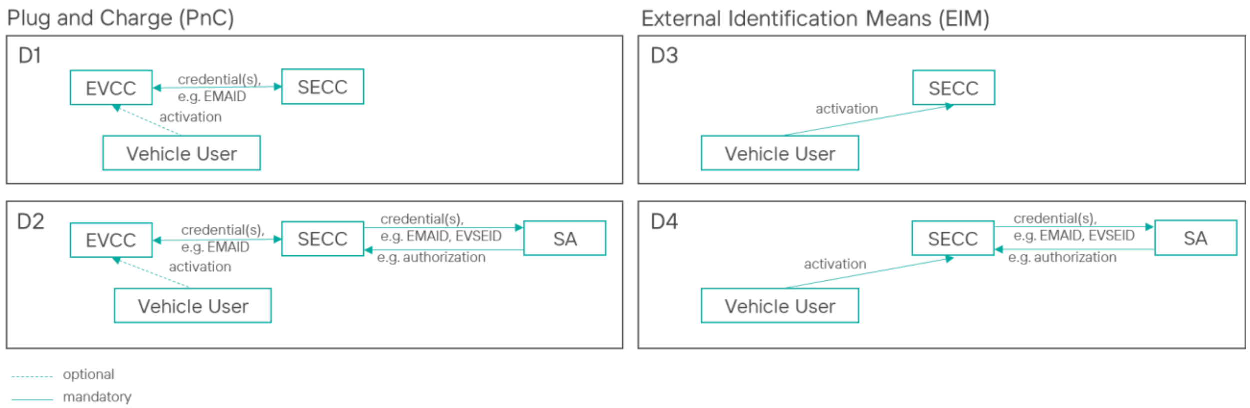

Figure 6: Graphical overview of scenarios for Identification [18]

Authorization with a radio-frequency identification (RFID) card or chip, as part of the EIMs, is described in scenario D3. A credential is therefore needed at the charging station. In scenario D4 a credential is needed also, but the authorization is carried out with the help of a secondary actor. An example therefor is the Credit Card [18].

In addition to the test with access data from the CPO, behavior with access data from competitors also have to be checked. Here it needs to be differentiated, whether these are rejected or whether roaming works.

In the roaming tests, preference should be given to access data from smaller providers, since errors with large providers would quickly be noticed in the field (in day-to-day business) due to the number of customers. In addition to the purchase of electricity and the price, the correct billing also has to be checked afterwards.

4 Conclusion

This paper introduces a novel concept for a high-power mobile test vehicle that contains the necessary measurement technology and energy system as a solution for the aforementioned challenges and requirements. This solution would support and reliability test the security of the charging networks on European level by ensuring independent certification and validation including interoperability and seamless charging experience. The main advantage of this concept is that the most important measurements can be set up intelligently so that many measurements can take place at the same time and the number of manipulations is minimized. This gives charge point operators (CPO) the chance to collect a precise overview of the existing EVSE fleet. These could be used for detecting the degradation in different components of the charging station. Another advantage is the modular setup of the test system. The separation of the measurement and the energy sink unit allow a quick adjustment of the system for higher charging capacities.

Furthermore, the tests are near fully automated and repeatable with minimal physical handling by the operators. The challenge is that the different measurement targets or measuring devices do not influence each other. Due to the holistic approach of the measurements and the analysis, early indicators of failures might be found.

A further complication with the charging parks is that the charging points are used in parallel, which may also influence the reliability of the charging process. This can be investigated by further extensions to the test system. The use of satellites allow a detection of at least the charging communication of different charging stations under load.

When the handling is assessed, particular attention should be paid to the needs of people with disabilities. Limitations due to mobility impairments are also taken into account, due to visual impairments. Even people without impairments will benefit from it. Even an RFID card reader that is mounted too high or a display that reflects only in sunlight can also have a negative effect on the handling of a charging. The FKFS is currently working on checklists to provide a neural basis for the evaluation of accessibility of charging stations. It is also important from the charging park operator point of view to check further aspects; such as a functionality of the load management system.

Acknowledgments

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