# 8 Assuring Interoperability between Conductive EV and EVSE Charging Systems

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## Abstract

The development and deployment rate of electric vehicles (EV) and plug-in electric vehicles (PEV) substantially depends on the corresponding EV supply equipment (EVSE). The facts that vehicles are intrinsically mobile and hence require interoperability between manufacturers, countries and charging points, implies that the components of the charging systems should extensively be tested, in order to allow access of the companies to the global market.

The two most common automotive charging communication standards are the pulse-width modulation (PWM) based IEC 61851-1 [1] and the CAN based CHAdeMO [2]. The third and latest approach is a power line communication (PLC) using V2G-protocol specified by the ISO 15118 [3]. The norm has been published in 2014 and will become the standard in Europe and North America for DC- and AC-Charging within the next years, since all major OEMs have decided to apply it. In order to implement the new standard in a way, that supports all specified use cases (e.g. private or public charging, plug & charge or external identification/payment) and simultaneously assure operation between all EV/EVSE communication controllers of different origins, dedicated verification techniques and routines are required.

This paper introduces the ISO 15118 norm and suggests independent and reproducible test methods that allow developers and quality managers to achieve a high degree of interoperability.

## 1. Introduction

The global breakthrough of electric mobility depends considerably on the availability of high-capacity batteries and a well-functioning charging infrastructure. The latter is only achievable, if all stakeholders agree on suitable standards and ensure a high product quality. In order to eliminate range anxiety, a dense network of standardized quick charging stations is required, that allows EV (term is used in this paper for both - Battery Electric Vehicles and Plug-In Hybrid Electric Vehicles) drivers to cover longer distances by recharging along the main motorways within an acceptable time. In order to gain interest in e-mobility, vehicle manufacturers, charging station operators and certification organizations are forced to only release well working, safe and reliable products onto the market.

With this purpose, the German Federal Ministry for Economic Affairs and Energy supports the SLAM project [4] with a total amount of 8.7 million Euros. The SLAM consortium (with BMW, Volkswagen, Porsche and Daimler as project partners, to name a few) aims to install six hundred CCS (Combined Charging System) charging stations in geographically beneficial locations. Another goal is to develop a reference test device for EV and EVSE (Electric Vehicle Supply Equipment) charging interfaces that helps to ensure the interoperability amongst all brands and models.

The normative standard for DC charging is given through the ISO 15118 norm (for an overview of the relevant international charging technology standards, see e.g. [5]). Because this standard is fairly recent (public release in 2014), it presents a challenge to the development and deployment of charging devices and charging station. This paper introduces in chapter 2 to the ISO15118 standard. In section 3, first an overview of the system architecture is given, before a Power Hardware-in-the-Loop (HiL) test environment for EVSE verification is presented. Chapter 4 describes the methodology of interoperability tests in the context of charging technology and finally, chapter 5 concludes the paper.

## 2. Vehicle to grid communication according to ISO 15118

The ISO 15118 standard covers all safety and functional requirements for charging an EV, but furthermore directly supports additional services that enable smarter applications. One example is automatic identification and payment when using public charging stations. This type of payment method is called Plug and Charge (PnC) and shall simplify and accelerate the process up to a point, where it becomes more convenient than refueling a conventional combustion engine vehicle at a gas station. In this case a backend communication is used to exchange metering information with secondary actors, such as energy providers or fleet operators.

Another example is scheduled charging. Real-time grid data (such as forecast of electricity rate and power grid utilization) can be combined with the personal driver profile (including average parking time during night and working time), so that smarter algorithms can be applied. Facilitating a Smart Grid (see e.g. [6]) is desirable for energy provider and consumer at the same time, because it potentially reduces the maximum total power demand of the grid which again leads to improved cost efficiency; either by throttling the charging power or delaying the charging process during peak loads, or by actually discharging the battery in order to deliver (and sell) electricity to the grid. Those strategies are going to become increasingly effective with more EVs (and therefore battery storages) being sold and charged. Hence, it is important that an international charging communication standard provides inherent support for these services. This is the case for the ISO 15118 norm.

### 2.1 Use Cases

The above mentioned examples are options that do not necessarily apply for every driver, place or time. Up to now, payment is handled most of the time through external identification means (EIM, e.g. RFID tag or credit card) or can be omitted at all (e.g. in case of private charging). Other more obvious distinctions must be considered between conductive (AC or DC) and inductive charging.

The ISO15118 addresses those distinct scenarios by describing any charging process as a sequence of nine function groups, that each may be handled differently depending on the use case. The function groups are defined as follows: Start of charging process (A), communication setup (B), certificate handling (C), identification, authentication and authorization (D), target setting and charge scheduling (E), charge controlling and re-scheduling (F), value-added services (G) and end of charging process (H). For instance, certificate handling (B) may require installing a new certificate, updating a known certificate or instead being skipped entirely (e.g. in case of private charging).

Thus, the process of establishing a legitimate charging connection between an EVSE and EV may be done within few or many steps. While an EVSE will (in most cases) support just one or two scenarios, an EV is expected to work with any compatible EVSE and hence, must provide full support for all charging scenarios.

## 2.2 Protocol Stack

The value added services and coverage of numerous use cases within one single standard, results in a high protocol complexity. In order to enable the previously mentioned features, the standard must provide the required performance, flexibility and security. Figure 1 illustrates the structure of the protocol as ISO OSI model.

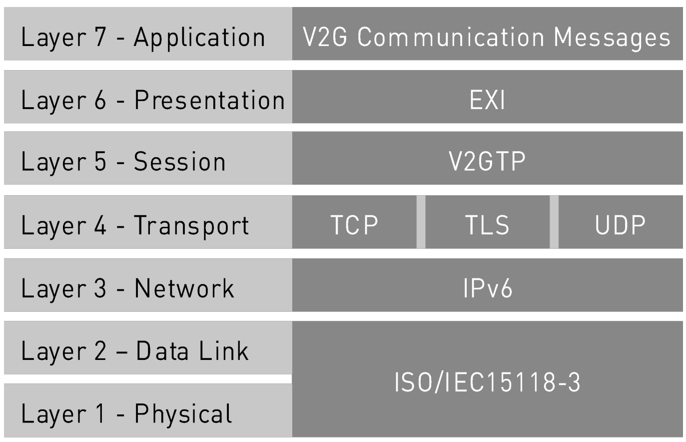


***Figure 1:*** *ISO 15118 Stack*

Implementation of OSI layer 1 and 2 is specified by ISO 15118 part 3. As physical and data link layers are handled by a standardized hardware module (QCA 7000 PLC modem), they are not further discussed in this paper.

Layer 3 to 7 are implemented partially as the following established internet protocols: IPv6 (Internet Protocol Version 6), UDP (User Datagram Protocol), TCP (Transmission Control Protocol) and TLS (Transport Layer Security); which are complemented by two specific protocols, V2GTP (Vehicle to Grid Transfer Protocol) and V2G-EXI (V2G – Efficient XML Interchange). The latter is carrying the required application data, that SECC (Supply Equipment Communication Controller) and EVCC (Electric Vehicle Communication Controller) must exchange before charging (e.g. to ensure the compatibility of EVSE and EV in terms of communication protocol and battery parameters) as well as during the charging process (e.g. periodic current demand request of EV).

# 3. Test Requirements

## 3.1 Architecture of Charging Systems

The charging interface of an EVSE or EV involves not just two communication controllers, a battery and AC/DC converter, but several other internal components, that must interact with each other in a determined way and sequence. Figure 2 shows a simplified illustration of the most relevant charging components and sub-systems inside an EVSE and EV.

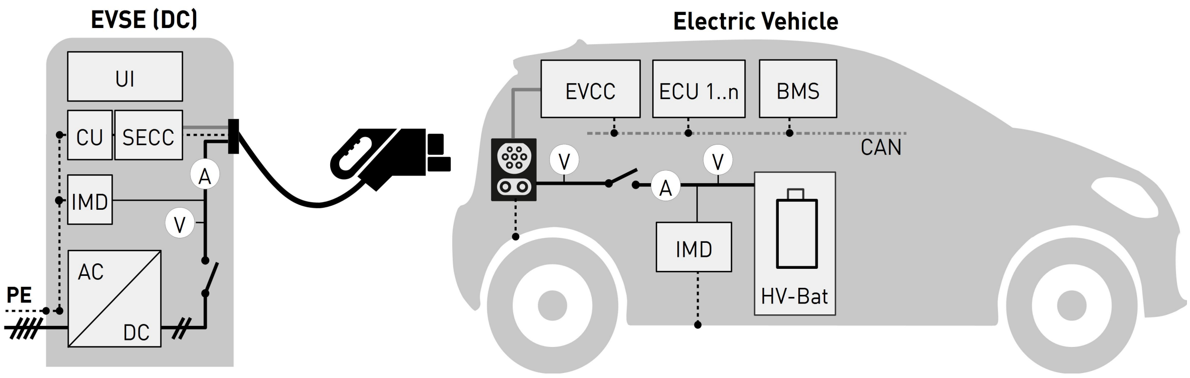


***Figure 2:** Charging System of EVSE and EV*

One can group those components into the following categories:

1. *High Voltage components*: AC/DC-converter, battery, contactors
2. *Controllers*: EVSE communication controller (SECC), EVSE Control Unit (CU), EV Communication controller (EVCC), battery management system (BMS) and other electronic control unit (ECU)
3. *Sensors & actuators*: current/voltage measurement, temperature sensors, inlet lock actuator
4. *Safety components*: insulation monitoring device (IMD), residual current operated device (RCD, not part of EVSE in case of mode 4 charging)

This distributed system imposes a complexity that needs to be addressed, particularly in early development and integration phases. The scope of this paper shall be the test of the system, rather than the isolated test of an EV or EVSE communication controller and its implementation of the V2G protocol. The latter is being one of the main objectives in the ENTEROP project [7]. A good introduction into the safety requirements of electric vehicles and EVSE is given in [8].

### 3.2 Environment for Interoperability Tests

For functional and compliance tests of charging systems, a Power HiL test environment is required. A suitable topology as well as the required interfaces and electrical specifications are discussed in [5]. For better understanding, two assumptions are used from now on: First, only charging mode 4 according to ISO 15118 using PLC based high level communication is of interest. Second, the test object shall be a charging station. With these restrictions, the corresponding test environment may be composed as follows:

- *EV Emulation*: Electrical emulation (signal and power level) of EV charging interface, including a configurable EVCC module and a bidirectional DC power source (DCE)
- *Power HiL Control*: Test control with user interface and models of EV & grid
- *Grid Emulation*: AC power source for emulation of world-wide mains

Figure 3 illustrates the required Power HiL setup:

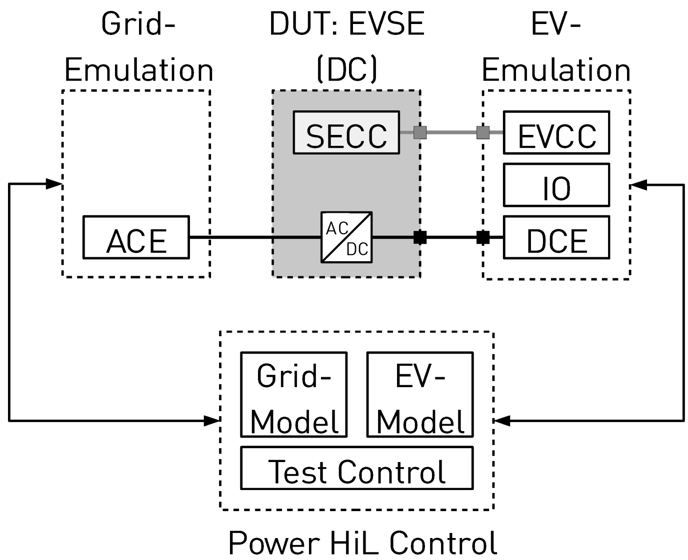


***Figure 3:*** *Power HiL Test Environment (for DC EVSE)*

The test possibilities in terms of test depth and significance strongly correlate with the EV model and emulation quality. Both must be accurate enough to reproduce the charging interface of a particular EV, but at the same time be exceedingly flexible in order to emulate stationary points and situations that are not supposed to occur under regular circumstances. The only way to achieve that is by implementing an EV model (in particular EVCC model), that uses an ISO 15118 compliant state machine which can be manipulated by varying parameters.

# 4. Methodology of Interoperability Tests

In order to obtain the maximum level of interoperability between the regarding product (in this case a DC charging station) and any other compatible product (all ISO 15118 compatible EVs), systematical verification steps ought to be performed. One can group those into the following four categories: Sample, functional/extended compliance and EMC test. Please note that order and title of the following categories have been chosen freely.

## 4.1 Sample Test

Obviously, before the specimen can be verified in terms of interoperability, it should have reached a certain minimum level of maturity. In case of the charging station, this level might be for instance a flawless charging operation with one specific reference EV. In addition, the charging station should react fault-free to typical events, such as end of charging or manual charging interruption, triggered by the user. A general functional test like this can be easily performed, as long as a compatible EV is available.

Passing the described sample test does not reveal any sort of information regarding the overall interoperability yet. In fact, it only states that one particular charging station operates with one particular EV. Performing a sample test with each produced piece will not even rule out potential fabrication faults, because those often are not (directly) visible within a single examination.

## 4.2 Functional Compliance Test

Since the manufacturer of EVSE and the manufacturer of EV are not the same in most cases, they will not have detailed information about how the other side implemented its controller and whether or not it complies with the written standard. For this reason, a true compliance test requires a synthetic environment which demonstrably operates within the given specification and provides appropriate analysis means. This dedicated test environment provides further advantages: It does not occupy an electric vehicle while testing. Charging duration is not restricted, as an electronic load is used instead of a battery that implies a limited capacity. Moreover, tests can be fully automated, which is particularly of interest in case of recurring test sequences and large numbers of units; such as in the case of End-of-Line (EOL) testing.

In the context of ISO 15118, the discussed test environment must provide at least the following features:

- IEC 61851-1 conform emulation of control pilot (CP) resistance values
- Analysis of control pilot signal (in particular PWM amplitude, frequency and duty cycle) and IEC 61851-1 conform interpretation
- IEC 61851-1 conform emulation of proximity pilot detection (when considering the charging cable as part of the EVSE)
- ISO 15118-2 conform emulation of Layer 3 to 7 communication stack, including step by step verification of SLAC process and V2G messages (data integrity and plausibility)

- ISO 15118-3 conform emulation of power line communication (GreenPHY and IEEE 802.3 MAC layer)
- Suitable high voltage sink for emulation of the EV battery storage
- Suitable BMS/battery model
- Measurement of DC voltage and charging current

If the test environment features the above mentioned requirements, a charging station can be operated as closed system under realistic conditions. Unlike in the previous sample test, the test sequence now becomes transparent because deviations to the norm are visible.

## 4.3 Extended Compliance Test

If two products are each following the right standard in just one particular scenario, they are not necessarily interoperable with each other. However, if both products are verified consistently in every (theoretically) valid case of application, and there is at least a single mutual one, the chance for interoperability is strongly increased. As presented in chapter 2.1, the ISO 15118 does support several use cases that sometimes are applicable and sometimes not. In this example, the charging station to be tested must operate well with all different types of EV batteries (which vary in voltage range, maximum charging current and capacity) and may also need to support both means of identification (EIM and PnC). Furthermore, IEC 61851 and ISO 15118 define for most electrical values a valid tolerance range, the response timeouts for all time critical events as well as the according reaction in case of a limit violation. For instance, the IEC 61851 specifies that an EVSE must disable its voltage output within 100ms after the EV revokes its power release, while the ISO 15118 specifies a maximum *message timeout* between *CurrentDemandRequest* and *-Response* of 250ms, and a *performance time* of just 25ms (for details see chapter 8.7 V2G communication timing in ISO 15118-2).

As a result, a suitable compliance test must cover all relevant use cases and allow selective control of all system parameters within and beyond the normative ranges. Then, limits can be approached systematically at runtime and causal effects become traceable. This way, the test coverage regarding the normative requirements becomes literally an area, instead of a one or N dimensional line. Figure 4 illustrates the difference in a figurative way.

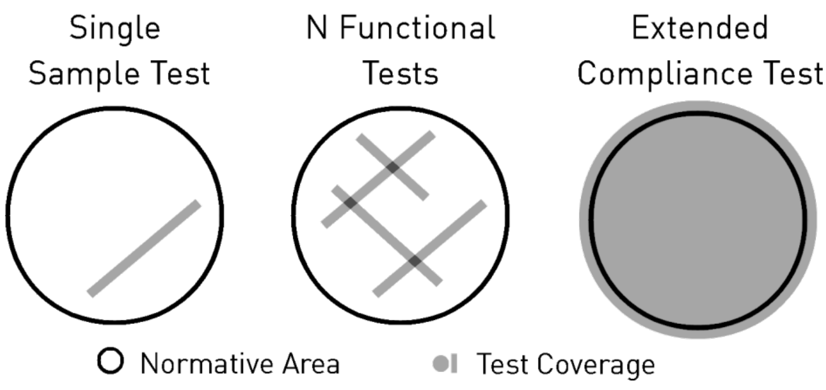


***Figure 4:*** *Test Coverage of Functional and Extended Compliance Test*

Moving freely within the normative limits also allows to safely trigger all error and emergency situations, that must be detected and eased by the safety systems of EVSE and EV (such as an insulation fault).

### 4.4 EMC Test

Charging at public power grids involves automotive (e.g. ISO 7637, ISO 11451/11452) and industrial EMC regulations (e.g. IEC 61000-3/4) that must be addressed equally. Since mains EMC quality may differ from region to region, functionality and interoperability of a product also depends on a sufficient EMC immunity of the product. The here discussed test environment is well suited for those tests, as it provides a convenient way for independent operation of unmodified series-production charging systems. It may of course require additional filtering of the test means to reduce undesired external EMC emission to a minimum.

## 5. Conclusion

Compared to the standard low level communication interface according to IEC 61851-1, the recently released ISO 15118 (part 2) is more comprehensive and therefore more costly in implementation. The technological barrier, missing experience and numerous covered use cases render possible deviant implementations, that will inevitably cause interoperability issues in the first generations of ISO 15118 products.

In order to avoid that to happen, systematically testing of all EV and EVSE is advised. This paper revised a methodology based on a previously presented test environment [5]. First Power HiL test benches for holistic interoperability tests of automotive charging systems have already been successfully implemented.

## Literatur


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