Study on V2G Protocols against the Background of Demand Side Management

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Abstract: This work provides an overview on current efforts for communication between interconnected electric vehicles and supply equipments also known as Vehicle-to-Grid (V2G) communication. Such efforts are core enablers for electric vehicles being used for demand side management. Hence this work investigates the ability to adapt the EV charging process in near real-time in case of grid violations through V2G communication by rescheduling or demand-limit renegotiations. The overall benchmark scenario is defined by the identified V2G rescheduling processes in case of unpredicted critical exceedance of operational grid constraints.

Introduction

Rapid increase of decentralised renewable energy generation along with the decrease of generation of conventional power plants leads to a change in the way how future power systems will be managed. In addition to adjust the overall power generation in order to match the actual demand situation of the grid, future power systems may also enforce adjustments of the demand through *Demand Side Management (DSM)* systems [1].

Within this context V2G communication enabled electric vehicles (EVs) may serve as ideal actors for DSM because of their high battery capacities, high charging powers, comprehensive availability with increasing market penetration and their capability to quickly adapt charging currents to given demand boundaries [2]. The latter point is of high importance since the interaction between unpredictable power generation and uncontrollable loads can lead to violations of local grid restrictions such as line/ grid-component overloads or voltage band violations. In general, the faster the coordination mechanism can react to changes in the supply configuration, the more efficient use is made of the installed grid capacity leading to a better overall cost efficiency.

The following section provides a system overview and introduces currently proposed principles along with ongoing standardisation efforts for V2G communication. The paper then reviews their functional scope particularly focusing on means for enabling near real-time DSM. Currently apparent integration issues of the proposed standards are addressed and an approach for optimising DSM mechanism for V2G is proposed before concluding the work.

Vehicle-to-Grid System Overview

This section provides an overview on the electric mobility system model and current standardisation efforts. Figure 3 highlights major entities being directly involved in the V2G interaction model for DSM: *Electric Vehicle (EV)*, *Electric Vehicle Supply Equipment (EVSE)* and various Back-End entities for *Accounting*, *Asset Management* and *Grid Integration (DSM)*.

The *V2G Front-End* as depicted in Figure 3 relates to communication between *Electric Vehicle Communication Controllers (EVCC)* and *Supply Equipment Communication Controllers (SECC)*. The scope of the *V2G Back-End* on the other side relates to communication between SECCs and various back-end systems for authentication, accounting and grid compatibility.

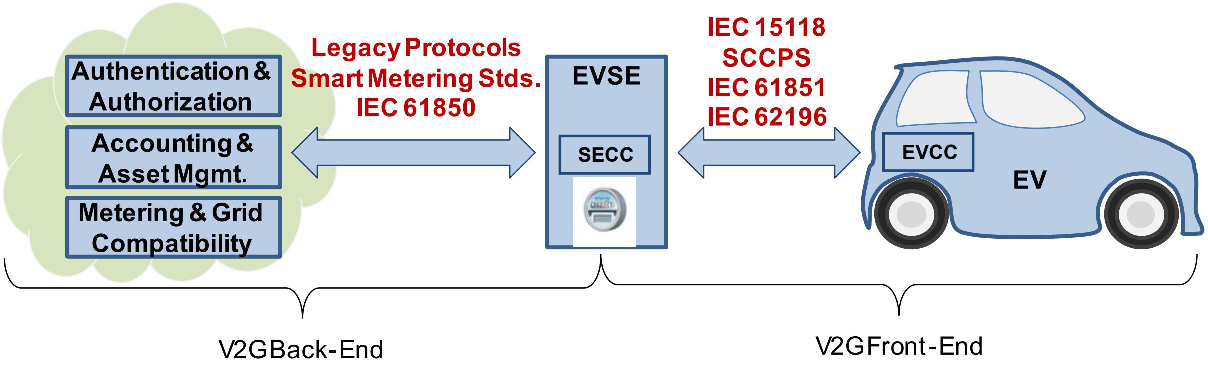


Figure 3: V2G-related Standards Overview

Concurrent V2G research and development efforts are consolidated in V2G standardisation groups. Hence, Figure 3 also provides an overview on relevant standards and pilot implementations:

- *IEC 62196* [3] is currently work in progress and defines plugs, socket outlets, vehicle connectors and vehicle inlets. The relevance of IEC 62196 with regards to the V2G communication interface is limited to physical interoperability in terms of signalling pins and connector compatibility.
- *IEC 61851* [4] standardises EV conductive charging systems based on either AC or DC and defines general EV- & EVSE-side requirements and different modes for charging.
- The *Smart Charge Communication Protocol Suite (SCCPS)* [5], [6] is part of a pilot project initiated by Daimler and RWE in 2008 in order to fill the gap of standardisation for PLC- and IP-based communication between EVs and EVSEs at that time. SCCPS was one of the core drivers in Germany leading towards establishment of the *ISO/IEC 15118 Joint Working Group (JWG)*.
- *ISO/IEC JWG 15118* [7] was formed in 2009 in order to define an international standard for more sophisticated V2G negotiations like DSM with

> plug & charge user comfort. The 15118 working group is divided in five project teams working on a three part standard covering the following aspects: general terms and use case definitions (part 1), data types, message exchange patterns and intermediate layer considerations (part 2), physical and data link layer requirements (part 3) and cross layer security aspects. At the time of this writing the group published committee drafts for part 1 and 2 of the envisioned V2G standard.

The V2G Back-End focuses on integration aspects like asset and grid management. With respect to authentication/authorisation, accounting and asset management B2M legacy protocols are current state of the art. In case of grid compatibility the situation is different; particularly with regards to smart metering protocols. Interoperability between heterogeneous metering devices and DSM entities is of major importance for seamless and grid compatible integration of EVSEs into existing substation networks [8]. However, this work focuses on the evaluation of the V2G Front-End against the background of the previously described DSM use case.

V2G Communication Aspects for Demand Side Management

In this section we will detail those V2G Front-End related standards being relevant for DSM. In this regard the following three standards are reviewed: IEC 61851-1 [9], SCCPS [5], [6] and committee drafts of ISO/IEC 15118 [7].

IEC 61851-1 Low Level Communication Protocol

IEC 61851-1 [9] describes four different charging modes and defines minimal requirements to ensure safety of charging systems. All currently respected modes are listed in Tab. 1.

Charging Mode	Charging Setup
1	1 Phase 250 VAC, 3 Phase 480 VAC, 16A
2	1 Phase 205 VAC, 3 Phase 480 VAC, 32A
3	Charging with dedicated EVSE equipment
4	Charging with an external charger

Tab. 1: Charging Modes in IEC 61851

Mode 2, 3 and 4 require a dedicated - safety-related - signal that must be provided by a dedicated circuit over a dedicated Control Pilot (CP) line in the charging cable. The primary purpose of this signal is to establish a time critical *Low Level Communication (LLC)* protocol to react on safety critical system state changes like connection losses or state changes of the charger. The signal is based on a 12V *Pulse Width Modulation (PWM)* signal of 1 kHz frequency. The EV lowers the positive amplitude of the signal to encode its current connection and charger status as shown in Tab. 2.

GND-CP Voltage	State	Description
+12V (const)	A	System idle – No EV connected
+9V (1kHz PWM)	B	EV detected – Not ready to charge
+6V (1kHz PWM)	C	EV detected - Ready to charge
+3V (1kHz PWM)	D	EV detected – Ready to charge (with external air condition)

Tab. 2: EV Connection States in IEC 61851-1 without Failure States

The EVSE monitors the state of the pilot signal in order to detect whether an EV is plugged in. In this case the EVSE encodes the supported charging current using the duty cycle of the control pilot. In case the PWM duty cycle changes, the EV shall adapt to the new charging current limit within a time period of 5000ms.

PWM Duty Cycle	Description
5%	Indicates an additional high level communication
10% <= duty cycle <= 85%	Current from 6A to 51A (%x) = current[A] / 0,6
85% < duty cycle < 96%	Current from 51A to 80A (%x) = (current[A] / 2,5) + 64

Tab. 3: PWM Duty Cycle and Charge Current Mapping

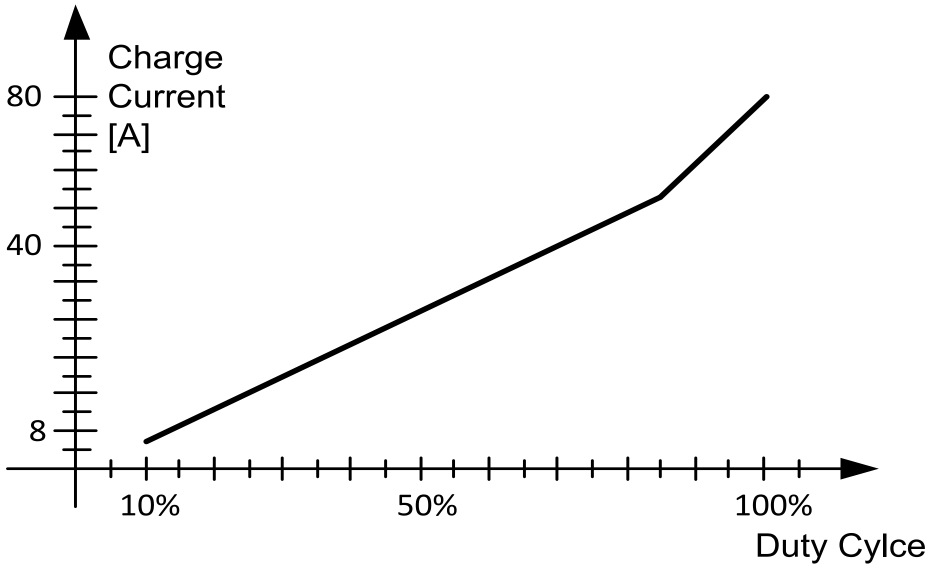


Figure 4: Current as a Function of PWM

High Level Communication Protocols

Next to the IEC 61851 LLC protocol the previously introduced *High Level Communication (HLC)* protocols - SCCPS [5], [6] and ISO/IEC 15118 [7] - provide means for advanced data exchange which is not possible with IEC 61851. Hence, they enable exchange of e.g. meter readings, tariff information and other relevant parameters for grid compatible integration of EVs into Smart Grids [10]. As opposed to IEC 61851 the HLC protocols provide smart charging means for less time critical parameters, e.g. non-individual-safety related aspects. Since SCCPS is tailored towards AC charging, this work also only considers AC charging in case of ISO/IEC 15118.

TCP/IP Stack Comparison between SCCPS and ISO/IEC 15118

Resulting from the idea to provide advanced means for data exchange between EVs and EVSEs, Figure 5 depicts the currently proposed TCP/IP stacks for both HLC protocols. At the time of this writing SCCPS is already deployed in field tests, whereas the ISO/IEC 15118 protocol definition is still work in progress. Hence both protocols and especially the ISO/IEC 15118 draft specifications are still subject to change.

SCCPS and ISO/IEC 15118 are both based upon Powerline Communications (PLC) on layer 1 and 2. Due to the wired connection between the EV and EVSE such an approach stands to reason. However, it must be considered that PLC uses the wire as a shared media and is subject to cross-talk issues similar to wireless technologies. Therefore association between two endpoints needs to be verified in scenarios where other PLC signal sources are exposed to the wire e.g. in cases where multiple EVSEs are deployed in immediate proximity. Most PLC standards cannot guarantee a valid association by the wired end-to-end interconnection. Therefore, in SCCPS an application layer resolution of this problem is enforced with a so called *Charge Point Discovery (CPD)* and *Silent Neighbourhood Broadcast (SNB)*. They influence the DHCP address assignment in a way that it can only be performed by *one* EVSE at a time and is directly linked to IEC 61851 state transitions. However, this mechanism is prone to DoS attacks. Hence, ISO/IEC 15118 favours resolving association issues on layer 1/2. In this regard Homeplug Green PHY provides a *Signal Level Attenuation Characterisation (SLAC)* mechanism [11] which ensures correct association by evaluating signal levels on-the-wire.

On the intermediate layers 3 and 4 both approaches build upon a common TCP/IP stack. Hence, besides utilisation of IPv4 in case of SCCPS and IPv6 in ISO/IEC 15118 there is no major difference between both approaches. In order to provide backward compatibility in IPv4-based network architectures, ISO/IEC 15118 also defines IPv4 support in Annex A of 15118-2. *Transport Layer Security (TLS)* is used in both cases to secure the EV-to-EVSE end-to-end connection.

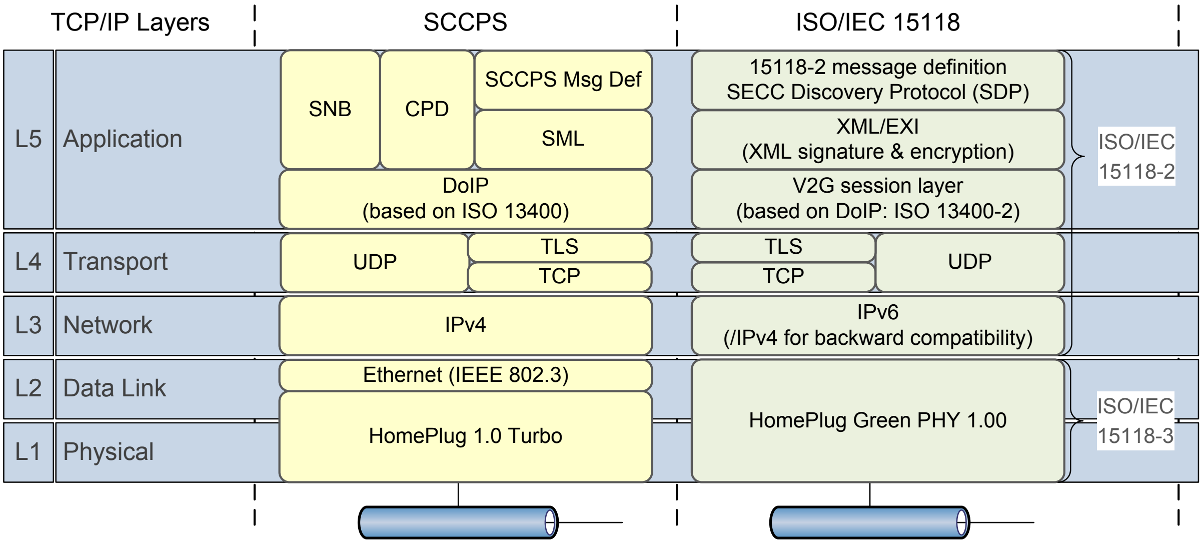


Figure 5: Overview of SCCPS and current status of ISO/IEC 15118 TCP/IP stacks

According to the current working draft of ISO/IEC15118 both protocols adopt parts of *Diagnostics over IP (DoIP)* defined in ISO 13400 for the application layer but some implementation details differ between both approaches. However, the most prominent differences appear on top of DoIP in the respective TCP/IP stacks.

SCCPS defines its message semantics based upon *ASN.1* and presents the application data through the *Smart Message Language (SML)* [12]. SCCPS defines a message structure with mandatory use of a pre-amble (*SML.Open.Response*) and post-amble (*SML.Close.Response*). The information carried in the pre- and post-amble are generic message contents not related to a specific context. The actual message context is provided with a *SML.Attention.Response*. SCCPS always combines the pre-amble, payload and post-amble into one logical entity, called *SML File*.

ISO/IEC15118 on the other side defines messages in *XML Schema* and most probably presents the application data in binary form through *Efficient XML Interchange (EXI)* which just became a W3C recommendation [13]. Each ISO/IEC 15118 message starts with a namespace declaration - due to the XML Schema based approach - followed by a message header and a message body. The header carries generic message contents necessary in every message exchange (e.g. session information, error indicators etc.). Whereas the body carries the payload of the message, which depends on the context of the message.

Application Layer Review

Both protocols share some common assumptions, requirements and basic design decisions:

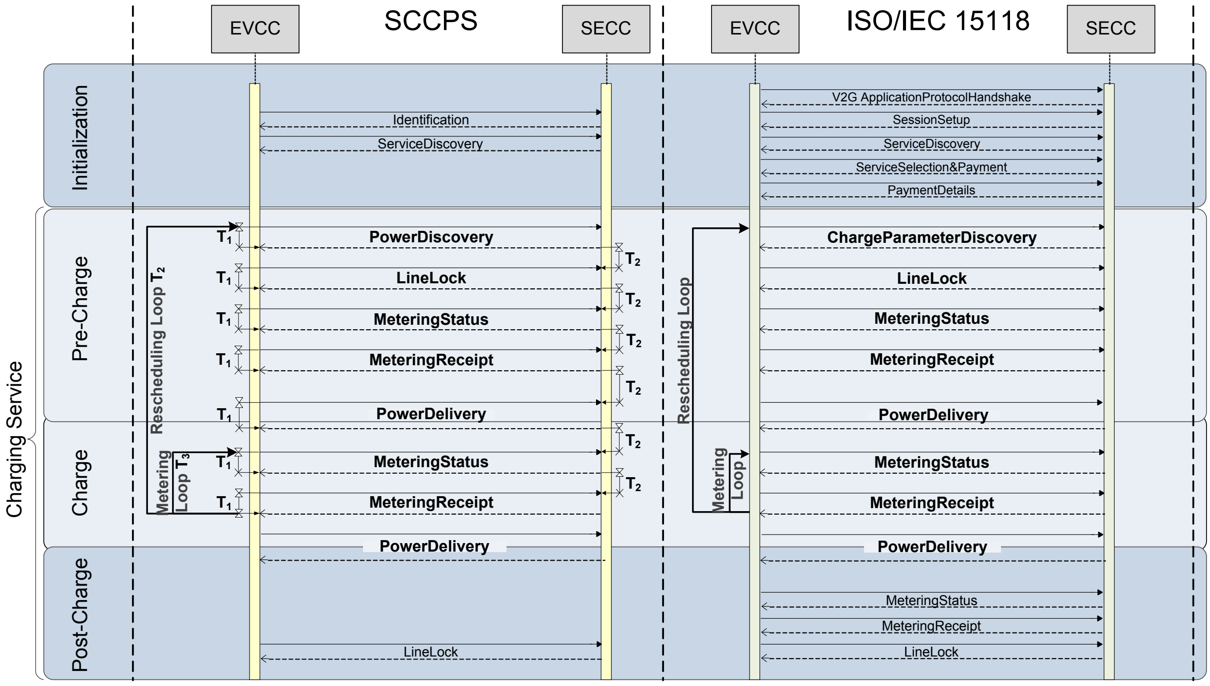
- The protocols enable plug & charge user comfort and at the same time shall allow sustainable grid integration.
- The protocols assume initial parametrisation of the charging process (e.g. end-of-charge, estimated amount of energy etc.). However, they do not make any assumption on how this parameterisation is applied.

- Both protocols follow a strict client-server model for the EVCC and SECC. The EVCC represents the client whereas the SECC the server. All message exchanges are synchronous and triggered by the EVCC in order to minimise protocol complexity for the EVCC.
- A contract based relationship between a mobility provider and customer is considered but not explicitly enforced. Also incorporation of enablers for value-added services is considered.

In general, the communication process for charging is divided into two phases:

1. Service Initialisation
2. Service Handling (Default: Charging Service)

According to their relevance for DSM the messages of the protocols are briefly described and illustrated in Figure 6. For the discussion in this work security related aspects are *not* considered.



Timer Definitions: T_1 = 30s T_2 = 15s T_3 = 10s

Figure 6: Comparison of Messages defined on Layer 7 for SCCPS and ISO/IEC 15118

The ISO/IEC 15118 starts communication with a handshake message identifying the exact application layer protocol (e.g. protocol version) followed by *SessionSetup*. In SCCPS these messages are combined to the *Identification* message which includes the protocol version, an unique ID and a public key. Next, the EV selects an available service from the EVSE. Besides the default *Charging Service*, the *ServiceDiscovery* may include further value added services like internet access. The main differences here are that ISO/IEC 15118 includes additional messages for the exchange of payment credentials for the selected service. For the sake of illustrating both protocols in this work, we split the *Charging Service* into three phases: *Pre-Charge*, *Charge* and *Post-Charge*.

The *pre-charge* phase starts with the exchange of general charging parameters including information on the EV-charger, estimated required energy amount and the point in time for the end of charge. The SECC response contains the name of the appropriate energy provider, applicable grid limits being derived from static EVSE limits and dynamic grid limits, as well as a list of available tariffs. A tariff is represented by a list of points in time each being associated with a cost. The EV may schedule its energy consumption according to the schedule of grid limits and costs. Following the sequence of messages the next message *LineLock* forces the EVSE to lock the charge cable in the EVSE. Locking the cable during the charge process provides additional safety as well as security means. The next step consists of the *MeteringStatus* and the *MeteringReceipt* messages. The exchange of both messages is processed as one atomic operation, where the *MeteringStatus* is used to receive the meter reading, meter-ID, and max. output power from the EVSE. The *MeteringReceipt* is used as a legal basis for billing since the EV acknowledges and digitally signs these values along with this message. After the initial meter reading exchange the EV notifies the EVSE about the selected tariff and the estimated charging plan. The EVSE responds by switching on the power if the state of the pilot signal is either *C* or *D*.

Now the *charging* phase starts, where the EV and EVSE continuously exchange *Metering Status/Receipt* messages in order to secure the billing process in case of any unexpected error conditions (see *Metering Loop* in Figure 6). Due to the adoption of the client-server architecture, the SECC cannot send a request to the EVCC in order to trigger a reschedule. Hence, if the EVSE wants to reschedule the charging plan due to changes in the current supply situation, the EVSE can indicate that by setting a flag in the *Metering Status Response* message. The EV may now continue the communication at the start of the pre-charge phase and negotiate a new charging plan (see *Rescheduling Loop* in Figure 6).

The *post-charge* phase starts with the request of the EV to switch off the power indicated by the *PowerDelivery* message. In contrast to SCCPS, ISO/IEC 15118 now requires an additional meter exchange in order to bill the exact energy amount. The communication finishes with the exchange of the *LineLock* message to unlock the charging cable.

Looking at the timing constraints for DSM, both proposed architectures depend on the application layer timers being illustrated for SCCPS in Figure 6. At the time of this writing ISO/IEC 15118 does not yet define any timers for the application layer. However, the same principles apply for application handling in the current working draft. In case of SCCPS a complete metering loop iteration can take up to:

$2T_1 + T_2 + T_3 = 85s$ (considering *worst case delays without errors*).

The same *worst case delay* for renegotiating a new set of tariffs or a new set of power demand limits takes up to:

$6T_1 + 6T_2 = 270s$.

In case the EV charger does not align to the proposed power demand limits of the EVSE, SCCPS defines a timeout of 300s for opening the contactors of the EVSE. Looking at these definitions, it becomes obvious that both approaches for AC charging do not propose mechanisms for enabling near real-time DSM. Hence, we investigate the concurrent handling of LLC and HLC in the next section in order to allow for near real-time DSM.

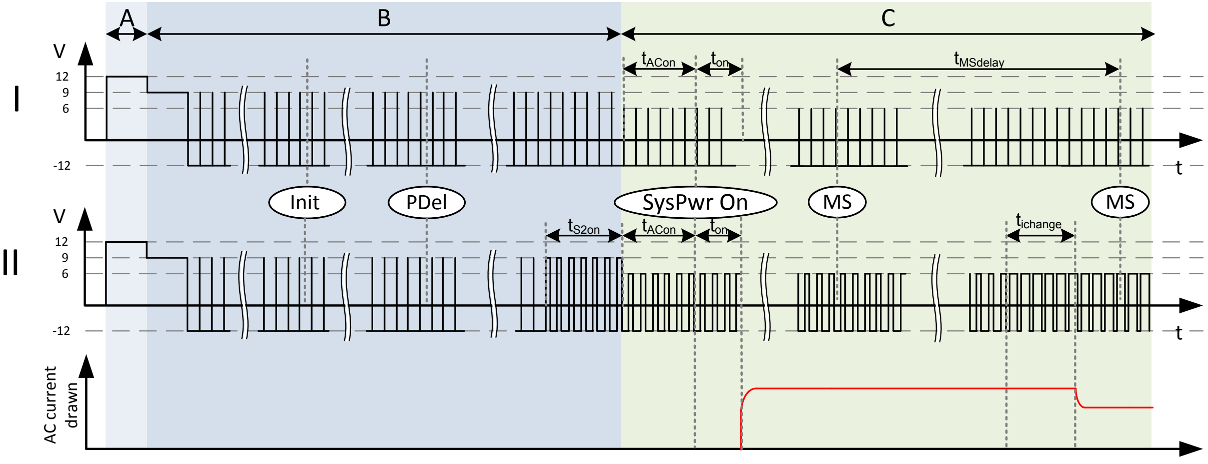
V2G Communication Approach enabling near Real-Time Demand Side Management

The integration of LLC and HLC is not yet finally standardized. With regards to our observation in the previous section, we suggest two different approaches for concurrent handling of LLC and HLC. Both approaches are discussed and integration issues are identified with regards to DSM. One of the introduced approaches supports long term charge schedules as proposed by ISO 15118 as well as real-time intervention. The real-time intervention may be used by the Distribution System Operator to limit the charging current in case of a local grid violation.

Part I of Figure 7 shows the first integration approach illustrating how LLC and HLC sequences are concurrently processed. After detecting an EV, signalled by pilot status B, the EVSE sets a 5% PWM duty cycle indicating support of HLC. The EV may then start the HLC by sending the initial message (see Figure 4). After sending the *PowerDelivery* message the EV may change the pilot status to C/D. The EVSE responds by switching on the power after a maximum delay of 3000ms. The PWM duty cycle remains at 5% duty cycle during the entire charging service. The pilot-signal is only used to monitor charge state transitions from C/D to B, which in turn forces the EVSE to switch off the power. The resulting delay for renegotiation of power demand limits would solely depend on the HLC protocol. According the previous section this would lead to a response time of up to 270s using the *Rescheduling Loop* (see Figure 6). Alternatively, provisioning of new grid limits can become part of the *Metering Loop* reducing the response delay to 85s. In this case however the rescheduling mechanism of the charge plan becomes an open issue since the *ChargeParameterDiscovery*/*PowerDiscovery* is bypassed.

The major difference of the second integration approach (part II in Figure 7) is that it uses the PWM duty cycle concurrently to the HLC Protocol in order to limit the charging current. This is done to achieve a near real-time response mechanism limiting the charging current in case of a decrease in supply capacity of the EVSE. Two aspects of the HLC have to be altered in response to the new handling of the pilot signal: First, the charge current limits negotiated during the *PowerDiscovery*/ *ChargeParameterDiscovery* have to be treated by the EV as non-committal, approximated values that can be overwritten during the charge process in case of unexpected grid constraints. However, these values are still used for deriving a charge schedule and allow for approximation of demands for grid operators. Second, the "maximum permissible" output power of the EVSE could be excluded from the *MeteringStatus* message, because it is now encoded in the duty cycle of the pilot signal. Parallel provisioning of this value through LLC *and* HLC would increase testing and error handling complexity. Part II of Figure 7 shows the resulting communication sequence. After the EVSE receives the *PowerDelivery* message it sets the duty cycle to the corresponding charging current. The

MeteringStatus message is still used to bill the charging process. Furthermore both sides can still force a renegotiation of the charge schedule and selected tariffs either if the supply situation changes or the user changes the overall charge preferences (e.g. end of charge or energy amount needed for next trip).



EV-Timings		EVSE-Timings		HLC-Timings	
t_{ACon}:	3s	$t_{ichange}$:	5s	$t_{MSdelay}$:	85s
t_{on}:	no maximum	t_{S2on}:	no maximum		

Figure 7: Timing Diagram for Integration of Low and High Level Communication

Following the second approach the latency for limiting the charging current due to an unexpected exceedance of operational grid constraints can be reduced to the response time of the charger on a PWM duty cycle change. IEC 61851 defines a maximum response delay of 5s for this process.

Conclusions & Outlook

This work analyses currently proposed standards for LLC and HLC of the V2G communication interface with regards to DSM. LLC is defined in IEC 61851 providing real-time safety mechanisms which can also be used for enabling near real-time DSM. Both investigated HLC protocols (SCCPS and ISO/IEC 15118) define advanced data exchange capabilities and share similar *principles* for application handling. However, as we showed in this work, the current status of both HLC protocol specifications does not allow for near real-time DSM.

Our analysis indicates that further standardisation efforts are required in order to integrate IEC 61851 into both HLC protocol approaches. Moreover, it was shown that the integration approach of IEC 61581 has a crucial impact on overall system response time for DSM. Furthermore the integration of IEC 61851 and any future HLC protocol has to be chosen wisely with respect to legacy support for already deployed EVs.

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All references to the *ISO/IEC 15118 V2G Communication Interface* represent current work in progress and might change for the official version of the standard.

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