Smart Grid-Ready Communication Protocols And Services For A Customer-Friendly Electromobility Experience

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Abstract: A worldwide increasing interest in technologies which are aiming towards an electrical grid which is able to integrate and control intelligent producers of (renewable) energy, energy storage devices, consumer loads, and network operating equipment through the use of information and communication technology (ICT), a so-called "smart grid", can be observed worldwide. At the same time, the renaissance of the electric vehicle (EV) as an enabler technology for a more sustainable and a resource-saving means of transport is very much linked to the smart grid discussion. The breakthrough of electromobility can however only be achieved if the technology and communication flow related to the charging process of an EV is going to be standardised. Little attention has been paid so far in academia to the concrete ICT-based mechanisms and protocols which realize all workflows needed to charge an EV, such as the reservation of charging stations, means for realizing provider-independent charging, charge scheduling, and demand side management. This paper introduces what we consider to be the most promising and currently wide-spread protocols dealing with energy-relevant data of EVs, namely the evolving V2G communication interface standard ISO/IEC 15118, the Open Charge Point Protocol by the E-laad initiative, and Hubject's Open intercharge Protocol. With a special focus on ISO/IEC 15118, a formal model is developed, mapping the key parameters of ISO/IEC 15118 to account for the relevant hard restrictions imposed by the communicating parties within which a charge scheduling optimization can take place.

1 Introduction

Intensive efforts can be observed worldwide to modernize the electrical grid as well as the energy market, which both developed over the decades, towards a system which is able to cope with the upcoming structural changes induced by a movement to a more sustainable energy generation in the medium and long term. Those efforts are targeted to flow into a system widely called the "smart grid". The smartness of this envisioned grid is to be understood as the cost-effective integration and control of intelligent energy producers, energy storage devices, consumer loads and network operating equipment in the energy transmission and distribution network facilitated by information and communication technology (ICT) and automation technologies [VDE13]. Furthermore, research funding programs regarding electromobility and incentives for buying electric vehicles (EVs) are increasing on a global scale. The German Federal Government, for instance, passed the National Electromobility Development Plan in August 2009 [Ger09] which constituted the framework for future technology developments supporting an aspired market launch of EVs in Germany. Those EVs need to be integrated into the energy system in such a way that they do not overload the grid with their additional charging demand, but rather stabilize it and facilitate the shift to an evolving smart grid with a progressively growing number of dispersed wind and solar-based power plants. We face the demand to transform the grid from a consumption-oriented production system to a production-oriented consumption system with the help of additional decentralized energy storage devices. EVs can store surplus renewable energy and – if equipped with a power inverter – even *feed this energy back to the grid when needed.* Exploiting the *flexibility of the charging demand* is a necessary prerequisite for this paradigm "demand follows supply". Thinking a step further, EVs could play an active role when it comes to voltage stabilization in the distribution grid through the provision of reactive power. In general, the following three exemplary use cases demonstrate the high potential of a profitable application of EVs in a smart grid:

Integration 1 – Decoupling the availability of volatile excessive renewable energy from its consumption and providing it when needed in peak-load times. The objective is to minimize the deviation from desired load profiles, having as a special case the reduction of load peaks. Furthermore, Germany's Renewable Energy Sources Act (EEG) encourages an increased self-consumption of dispersed generation.

Integration 2 – Using the EV to sustain a stand-alone electrical network, supporting the household with energy until a power failure has been resolved. In our setup, an H-bridge connected to the Energy Smart Home Lab (ESHL) allows for emulating any network state and virtually placing the ESHL into a critical network segment.

Integration 3 – Using the EV for ancillary services such as provision of reactive power. Similar to the higher voltage levels, power generation systems in Germany supplying low-voltage networks have to contribute to the voltage stability in the low-voltage network according to [VDE12]. With the EV as well acting as a power generation system with up to 22 kWp AC, this duty can be complied with through the provision of reactive power.

In order to realize an ICT-based integration postulated by the above mentioned definition of a smart grid and these three scenarios, we need communication interfaces suitable to exchange and process the essential energy-related information. As there are many newly established and traditional entities in this evolving energy market, such as the customer driving the electric vehicle, a charge point operator, a distribution system operator (DSO) and transmission system operator (TSO), a clearing house, and any kind of e-mobility provider (e. g. local utility, car manufacturer), to name just a few, it is easily conceivable that the communication between these emerging entities will not be dealt with by one single communication interface, but rather a multitude of ICT-based protocols, each of them reflecting several layers of the communication flow.

Hence, the specific contribution of this paper consists of

(i) an introduction of what we consider to be the most promising and currently wide-spread protocols dealing with energy-relevant data of EVs, namely the evolving V2G communication interface standard ISO/IEC 15118, the Open Charge Point Protocol (OCPP) by the

E-laad initiative, and Hubject's Open intercharge Protocol (OICP) (section 3), and
(ii) a formal model mapping the key parameters of ISO/IEC 15118 to account for the relevant hard restrictions imposed by the communicating parties within which a charge scheduling optimization can take place (section 4).
The major part of this work deals with the evolving ISO/IEC 15118 standard, since we believe that it will be part of nearly every new EV in the next decade. According to the distribution network survey [Den12] of the German Energy-Agency which depicts the grid expansion and the resulting investment needs in Germany until 2030, the majority of the regenerative generation capacity will be connected to the low-voltage distribution grid. This implies that the deployment of bi-directionally charging EVs promises a high potential for balancing energy demand and supply as well as lowering the required investments, a suitable communication interface which facilitates load flexiblity provided.

2 Related Work

The required communication interface for the realization of beneficial charging strategies is usually either taken for granted or a specific protocol is discussed on its own. Ruthe et al. [RSRW11] compared e. g. a high-level protocol initiated by the German utility RWE and Daimler [RWE10] (implemented and investigated in a prior work of Mültin et al. [MAS12]) and a first committee draft of ISO/IEC 15118 regarding protocol stack and real-time response capability in case of short-term bottlenecks in the low voltage grid. Their timing assumptions, however, do not hold anymore since the evolution of this communication interface now facilitates e.g. voltage stabilization, as opposed to their conclusion. Schmutzler et al. [SW10] [SWJV11] investigated a similar version of ISO/IEC 15118. They looked at the mapping of several smart grid use cases on the message schema in the protocol and evaluated the coding efficiency of the exchanged data since this protocol is used in embedded systems. A scenario similar to the KIT approach is currently under investigation by Toyota [Toy12] as well as Honda [Hon13], however, scientific data has not yet been published. The communication protocol used there is a proprietary solution.
Until now, little attention has been paid to the protocols OCPP and OICP in academic literature, which is understandable given that e. g. OICP has just been released in April 2013. Michel [Mic12] poses the research question on what aspects influenced the standardization process of the Dutch EV charging infrastructure and what implications can be identified for innovation, in this context analyzing the OCPP to some extend.

3 Communication Interfaces in a Smart Grid

In this section we show how the various communication interfaces handle different aspects of the necessary workflows for electromobility in a smart grid and how these protocols, situated on several "layers", have the potential to seamlessly integrate to one another.

3.1 ISO/IEC 15118

In Europe, three IEC standardizations mainly define the interface between an EV and a charging station (henceforth called EVSE for Electric Vehicle Supply Equipment).
IEC 62196 [IEC11] is a standard for a set of electrical connectors for EVs and guarantees the *physical interoperability*. It consists currently of three types, of which the type 2 connector (IEC 62196-2), originated by the company Mennekes, has been declared as a standard for Europe by the European commission in January 2013.
The IEC 62196 standard is based on IEC 61851 [IEC10] which defines four different charging modes, from slow charging using a household-type socket-outlet to fast charging using an external charger. A so-called Control Pilot (CP) line integrated into the IEC 62196 plugs allows to distinguish four EV connection states (as indicated in Fig. 1) and maps the maximum charging currents allowed by the EVSE via an analog PWM-signal (Pulse Width Modulation). Its mechanism ensures that power flow is only activated if connected to a stationary vehicle. Thus, IEC 61851 is an *analog safety-related low-level protocol*. A simple load control can indeed be realized, yet, essential parameters discussed in section 4.2 cannot be communicated, the (dis-)charging flexibility is not exploited.
The need for such a digital communication protocol leads to the third standardization effort: ISO/IEC 15118, entitled *Road vehicles – Vehicle-to-Grid Communication Interface*. It should be noted that the term "Vehicle-to-Grid" in this title is a bit misleading, since it is in fact only an "EV-to-EVSE" communication. This work focuses on the "network and application protocol requirements" of this standard (ISO/IEC 15118-2) [ISO12], currently in the state of a draft for international standard (DIS). It shall be noted that ISO/IEC 15118 is not the only existing digital V2G communication protocol under development, in fact, the US American SAE (Society of Automotive Engineers) started a task force in 2008 to develop the SAE J2847, a series of recommended practices documents which amongst others define the communication between plug-in vehicles and the utility grid (SAE J2847/1-3). Those SAE documents focus rather on the direct communication between an EV and the "utility" – a placeholder for a grouping of entities responsible for providing services to the premises, such as the utility itself, transmission operator, aggregator or energy services companies – as required by the US utilities (the EVSE is merely a bridging device), with demand response mechanisms as defined in the Smart Energy Profile (SEP) 2.0. ISO/IEC 15118 strictly defines the communication between an EV and an EVSE, the communication from EVSE to an external entity is not defined which reflects the differing philosophy between USA and Europe. There is some common understanding between SAE J2847 and ISO/IEC 15118, however, the latter – being an international standard – seems to have a broader scope and is more clearly defined with regards to the active charge control, renegotiation mechanisms, the handling of the payment process, as well as value-added services such as a HTTP connection for media streaming. The protocol strictly follows a client/server scheme, thus the EV (or Electric Vehicle Communication Controller – EVCC – to be precise) may send requests whereas the EVSE (or Supply Equipment Communication Controller – SECC) may send responses only. However, the SECC is able to send within its response messages (during the charging loop) a certain notification which triggers the EVCC to *stop* the charging process or *renegotiate* the charging schedule. This way the charging process can dynamically adapt to changing grid situations.

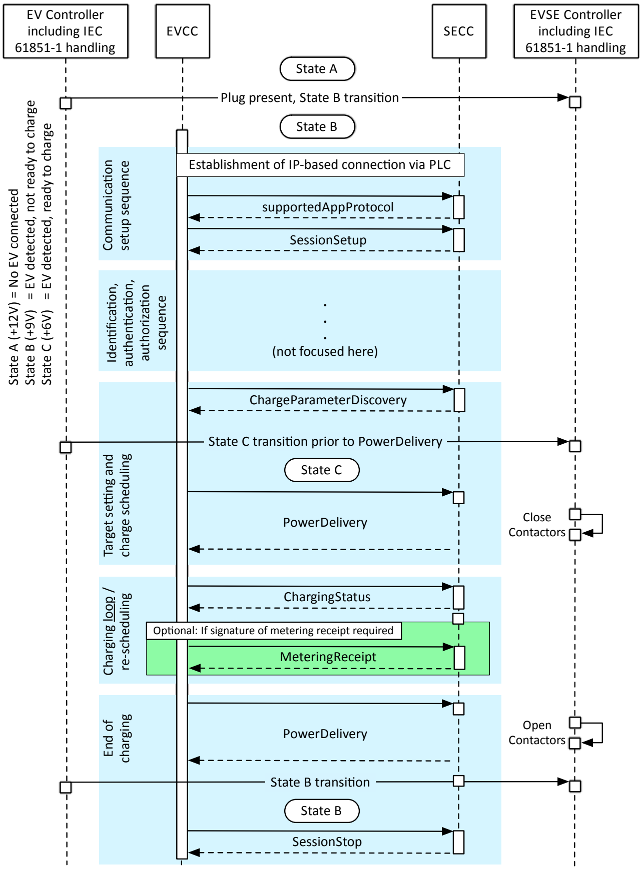

Figure 1: AC request-response message sequence with PnC

Fig. 1 depicts the request-response message sequence as proposed by the current ISO/IEC DIS 15118-2 for AC charging using PnC (Plug-And-Charge) identification mode. PnC is a scenario where the customer just has to plug his vehicle into the EVSE and all aspects of charging are automatically taken care of with no further intervention from the driver, including load control, authentication, authorization, and billing, based on a contract between customer and e-mobility provider which is stored inside the EV. DC charging varies only in minor changes of the message set, the part of the protocol handling the relevant parameters listed in section 4.2 remains the same.

Security aspects are addressed in this protocol to guarantee confidentiality and integrity of the exchanged data as well as the authentication of the communicating parties. Cryptographic procedures both on the presentation layer – with XML signatures for meter readings and encryption based on certificates for contract-based authentication – and on the transport layer with TLS using X.509 certificates and a public-key infrastructure to secure the communication are specified.

Being a communication standard used in embedded (automotive) systems, an important factor is the data size of the exchanged V2G messages. They are defined using XML which facilitates a very efficient encoding format according to definitions in W3C EXI 1.0. The Efficient XML Interchange (EXI) format allows to use and process XML-based messages on a binary level which increases the processing speed of this data as well as reduces the memory usage. EXI messages can be up to 100 times smaller than equivalent XML documents.

The implementation of EXI allows for relatively small timeout values defined in [ISO12]. A timeout occurs (leading to a stop of the communication session) if the time span between sending a request and receiving the respective response exceeds 2s. No more than 60s may elapse between two consecutive requests (except after the last Session Stop Request).

As already stated, ISO/IEC 15118 does not define the communication beyond the EVSE to an external entity. This communication flow is explicitly handled by the OCPP.

3.2 Open Charge Point Protocol

The OCPP is a de facto open standard initiated by the E-laad foundation, a consortium of the Dutch grid operators, in 2009. It describes a method enabling EVSEs to communicate with managing central systems from different vendors (not necessarily a system of the charge point manufacturer) via web service communication (SOAP). Initially developped for the 10,000 E-Laad charging stations in the Netherlands, OCPP has evolved into a European initiative and has already been adopted by several similar initiatives in different countries worldwide [Mic12]. Several operations are described herein of which some are initiated by the charge point, such as messages related to authorization, synchronization, meter values and transactions, and some are initiated by the managing central system, such as the ones for reservation, firmware updates, transactions, or diagnostics as well as remote power systems management actions (e. g. unlocking the charge plug, rebooting the EVSE) [El13]. In case no connection to the central system is possible, so-called authorization lists can be stored in the EVSEs and updated by the central system as soon as they are online again. The technical specification states that those authorization lists can contain specific RFID card IDs. It is however conceivable that contract IDs as well as public keys can be communicated between the charging stations and the backend system such that the energy contract-related data specified in ISO/IEC 15118 can be exchanged. Although not explicitly stated in the technical description of version 1.5, it is imaginable that as well a load limitation signal (refer to PMaxSchedule in section 4.2) reflecting a critical grid situation can be communicated via OCPP. A new version 2.0 of OCPP is currently under development and could contain additional information to permit such EVSE load management.

In summary, OCPP can take energy-related as well as authorization and billing information exchanged between the EV and the EVSE to the next layer, the managing central backend system. As already mentioned, a customer can authenticate himself via external identification means such as an RFID card, or via the more customer-friendly PnC alternative described above in the ISO/IEC 15118 subchapter. Albeit the chosen identification method, the usual case is that a customer has a contract with his energy provider (or more generally spoken his e-mobility provider) which allows him to charge his EV at those charging stations belonging to this provider. Yet, those EVSEs might not be installed all along the route of the EV driver, especially when it comes to international road trips. This is where the Hubject consortium comes into play with its OICP.

3.3 Open intercharge Protocol

The German joint venture Hubject is a B2B service platform providing a simple information and transactional gateway for the automation of contract-based business relationships between power suppliers, car manufacturers, infrastructure service providers as well as further mobility business parties. Its vision is amongst others to provide customers a simple and provider-independent access to public and semi-public charging infrastructures, thereby linking regional and national (European) e-mobility markets. The information exchange between Hubject and e-mobility provider (EMP) systems or charge point operator (CPO) systems is based on SOAP messages, as stated in the Open intercharge Protocol released in April 2013 [Hub13]. The following exemplary offered services shall illustrate the potentials of this protocol:
HubjectAuthorizeStart – In case a customer wants to authenticate himself at an EVSE which does not recognize the customer's authentication data, the CPO's system can send a HubjectAuthorizeStart request to Hubject which must contain the authentication data (e. g. contract ID provided via the PnC scenario). Several options are then tried out: (i) Offline authentication by checking authentication data previously uploaded by EMPs, (ii) deriving the EMP from the provided identification data and directly forwarding the HubjectAuthorizeStart request to the respective EMP which then checks for validity, or, if both fail, (iii) broadcasting the HubjectAuthorizeStart request to all registered EMPs.
HubjectAuthorizeRemoteStart/Stop – A customer can inform his EMP of his intention to charge a vehicle at an EVSE of an CPO e.g. via a mobile phone or smart phone application. The EMP's provider system can then initiate a charging process at the CPO's station by sending a HubjectAuthorizeRemoteStart request to Hubject. The same procedure can of course be carried out for the termination of the charging process through the HubjectAuthorizeRemoteStop request. This feature thus supports a user-triggered remote control in case the anticipated departure time changed.
HubjectEvseSearch – The customer of an EMP can perform an EVSE search e. g. by using a graphical user interface of the EMP's provider system which then sends a HubjectEvseSearch request to Hubject with mandatory parameters (provider ID, range, geocoordinates) and optional parameters (for example to include EVSEs of other operators into the search result).
There are many more requests defined in OICP, such as the HubjectChargeDetailRecord which is imporant for the billing process and can even be used as a value-added service to the customer. Safekeeping of sensitive data is assured through the uncoupling of personal data and anonymous user data.

In a nutshell, the communication interfaces presented here have the potential to seamlessly integrate into each other and assure a customer-friendly electromobility experience by providing an easy to use and interoperable access to the charging infrastructure and offering value-added services. The largest potential for facilitating a grid-friendly operation and managing the inherent crucial energy-related information is, in our opinion, awarded to the upcoming standard ISO/IEC 15118 with a broad support of leading companies, which is the focus of section 4.

4 Approach for An Optimized Charging Schedule

We make some assumptions about tariff-based signals coming from an external entity such as the energy provider, any kind of EMP, or a fleet or system operator. We refer to this entity henceforth as “secondary actor” (SA).

4.1 Pricing schemes as incentives

There are several pricing incentives discussed in literature [KPS$^+$11] [Eur11] as well as by utilities world-wide, some of which are more or less promising with regards to the resulting effect. A common understanding is that the spread between the highest and lowest price needs to be big enough and/or the load shifting should be done automatically by a (home) energy management system rather than manually by the resident to get a response and reduce a limitation in customer comfort. We incorporate the following pricing schemes into our setup:
Time-of-Use Pricing (TOUP) – The residents pay different fixed and predefined prices based on season, day of week, and time of day reflecting the longterm wholesale price. On a broader scope, when looking at several households of an urban district, these prices could be customer-specific to avoid avalanche effects. A $C_{TOUP}(t)$ signal communicates the costs of each given time interval.
Critical Peak Pricing (CPP) – Based on temporarily occurring critical peaks, either unanticipated or anticipated (e.g. event days), those additional real-time prices can be several times as much as TOU prices. The goal is to dramatically reduce load in relatively few critical peak hours. A $C_{CPP}(t)$ signal communicates the costs and the load limits for each given time interval. We conceive this load limit not to be a hard limit whose violation yields a de-energization, but a soft limit with high penalty costs.
There are also concepts such as a peak time rebates (PTR), where customers get credits for load reduction but no penalty if load increases. However, we think that the psychological effect of losing money (CPP) is more substantial than getting a (maybe small) credit. Both pricing schemes are representable by using the contract-based pricing of ISO/IEC 15118.

There are other promising incentive mechanisms such as gamification which try to engage the customers to use energy in off-peak times or consume energy more efficient. The idea behind gamification is to use game techniques and game design elements (badges, leaderbords, highscores, virtual goods, etc.) and apply them in non-game contexts in order to motivate and engage users to work towards a common goal. Prominent examples are Nike+ and Foursquare. In the energy efficiency and energy saving context, the ideas can reach from applying smileys on the energy bill and comparing one's use of energy to their neighborhood [New09], or comparing the energy-efficient style of driving an EV to a surrounding community [Sla10] and thus establishing an eco-competition. These gamification aspects are, however, not adapted in our approach yet.

4.2 Mapping between communication parameters and the formal model

In order to evaluate the integration scenarios mentioned in section 1, an intelligent energy-efficient home equipped with observable as well as controllable thermal and electrical loads and renewable energy sources has been built which has already been thoroughly introduced in [AS11] and [BAR$^+$10]. Together with a sophisticated energy management system, a bi-directionally charging EV and an H-brige able to emulate any (critical) grid situation, this environment provides for a variety of energy-related parameters which are essential for a mature charging strategy of an EV. Tab. 1 summarizes those parameters as defined in ISO/IEC 15118-2, referred to as param 1 to 14, and maps them to variables which are used to establish a formal model for charge scheduling optimization. Although the testing environment presented is a private scenario, these parameters can as well be applied for the semi-public or even public scenario.

Some parameters in Tab. 1 are underlined, such as the ones for *power feedback* as well as *power factor adjustment* for voltage stabilization, which means that they are not yet part of the official message specification of ISO/IEC 15118-2 but reflect the advanced implementation used in our research project *iZEUS*. Nominal voltage parameters are omitted since there is no direct formal mapping, instead the derived power variables are calculated based on the law of physics $P = V \cdot I$.

In its *Charge Parameter Discovery Request* (refer to Fig. 1), the EVCC communicates the user-defined departure time (param 1), the needed energy amount (param 2), the energy amount available for discharge (param 3) as well as the currents supported by the EV per phase (param 4 to 7).

The SECC's *Charge Parameter Discovery Response* communicates, amongst others, EVSE restrictions given by param 8 to 11. Furthermore, it comprises a so-called *PMaxSchedule* (param 12) which represents a *hard load limit curve which is not to be exceeded at any time by the EV*, possibly provided by a SA through the OCPP, otherwise the EV will be de-energized. This PMaxSchedule is given as a function over time with tuples consisting of times t_i and their respective upper bounds of power p_i. Each t_i, given in seconds as an offset time from sending this message, denotes the start of the respective time interval which lasts until the subsequent offset time t_{i+1} of the next tuple is reached. The length of the last time interval is indicated by the duration value d. The value of n can be increased to facilitate a schedule with very fine-grained time slots. With a PMaxSchedule a SA can incorporate into the protocol an identified present or anticipated future need for a grid-based hard limitation in the network load, as opposed to the soft limitation in the CPP

Table 1: Mapping of V2G CI parameters to formal model

Param	V2G CI parameter [unit]	Formal mapping
1	DepartureTime [s]	$t_d \geq 0$
2	EAmount [Wh]	$E_{EV}^{+}(t) > 0$
3	EAmountDischarge [Wh]	$E_{EV}^{-}(t) \in \mathbb{R}$
4	EVMaxCurrent [A]	$p_{EV,max}^{+} > 0$
5	EVMinCurrent [A]	$p_{EV,min}^{+} > 0$
6	EVMaxCurrentDischarge [A]	$p_{EV,max}^{-} < 0$
7	EVMinCurrentDischarge [A]	$p_{EV,min}^{-} < 0$
8	EVSEMaxCurrent [A]	$p_{EVSE,max}^{+} > 0$
9	EVSEMinCurrent [A]	$p_{EVSE,min}^{+} > 0$
10	EVSEMaxCurrentDischarge [A]	$p_{EVSE,max}^{-} < 0$
11	EVSEMinCurrentDischarge [A]	$p_{EVSE,min}^{-} < 0$
12	PMaxSchedule [(s, W)]	$\{(t_i, p_{EVi}) \mid i \in [n]\}$
13	Duration of last time slot [s]	$d > 0$
14	PowerFactor	$powFac(t)$

signal. If no grid schedule is provided by a SA then the PMaxSchedule is solely based upon the limits of the local installation (EVSE and charge cord).

An optional *SalesTariff* can be sent in this response message as well which provides means for optimizing the charging schedule in the EVCC based upon cost information (TOUP or CPP), where "cost" refers to any given kind of cost (monetary, CO_2 emission, etc.) and is provided as a relative cost tier. Although *our primary focus* is to assess the potential of a *direct control* of the EV such that the *PMaxSchedule reflects amongst others the residential load situation as well as the availability of local renewable energy*, we as well investigate the sales tariff driven charge incentive. In the latter case, the PMaxSchedule only reflects critical situations in the grid and/or the limits of the local installation, the resulting envelope below PMaxSchedule is then primarily based on TOUP and CPP signals forwared to the EVCC. It is conceivable that a SA might price the charging of EVs differently from the price for residential load (see e. g. German utility RWE's approach [RWE13]). The contract primarily concluded with the SA and later on installed in the EV via the *Certificate Install Request/Response* and *Certificate Update Request/Response* messages in ISO/IEC 15118-2 allows for such use cases.

Let $T_{EV} = [t_p, t_d]$ be the time between plugging the EV into the EVSE t_p and a user-provided departure time t_d, where $t_p \leq t_1$ ((dis-)charging process may be temporally delayed) and $t_n + d \leq t_d$ (HV battery might be fully charged before departure time). Time span Δt_i of offset time t_i for all $t_i \in T_{EV}$, $i \in [n]$ is then defined as

$$\Delta t_i = \begin{cases} (t_{i+1} - t_i) & \text{if } 1 \leq i < n, \\ d & \text{if } i = n. \end{cases} \tag{1}$$

An external SA-based PMaxSchedule with limits for charging ($p^{+}_{GRID,max}(t)$) and discharging ($p^{-}_{GRID,max}(t)$) can be incorporated into our charging schedule $P_{EV}(t)$ which equals $p_{EV,i}$ for each timeslot i. To avoid any confusion, it is important to remember that we primarily focus on a direct control of the (dis-)charging schedule which reflects the current local load situation at the ESHL and the availability of local renewable energy. Thus, PMaxSchedule (param 12) equates to $P_{EV}(t)$, in which we already integrate possible SA-based grid limits instead of just forwarding those limits to the EV. Our $P_{EV}(t)$ for the EV might be even more restrictive depending on the residential situation. For all $i \in [n]$ and $t \in T_{EV}$, it holds that

$$p_{EV,i} \in [p^{-}_{max}(t), p^{-}_{min}] \cup \{0\} \cup [p^{+}_{min}, p^{+}_{max}(t)], \tag{2}$$

with $p_{EV,i}$ denoting the power value (W) in the i-th timeslot, where

$$\begin{aligned} p^{-}_{min} &= \max(p^{-}_{EV,max}, p^{-}_{EVSE,max}), & (3)\\ p^{-}_{max}(t) &= \min(p^{-}_{EV,max}, p^{-}_{EVSE,max}, p^{-}_{GRID,max}(t)), & (4)\\ p^{+}_{min} &= \max(p^{+}_{EV,min}, p^{+}_{EVSE,min}), and & (5)\\ p^{+}_{max}(t) &= \min(p^{+}_{EV,max}, p^{+}_{EVSE,max}, p^{+}_{GRID,max}(t)). & (6) \end{aligned}$$

$p^{-}_{EV,max}$ and $p^{-}_{EVSE,max}$ are to be seen as the negative of the absolute value of the maximum possible discharge power as opposed to the $\max$ function used in (4) and (5). The values for $p^{-}_{EV,min}$ and $p^{-}_{EVSE,min}$ are to be handled accordingly.

After having received the proposed $P_{EV}(t)$, the EV's battery management system will conduct a feasibility check, whereupon the EVCC will send a calculated $P_{EV}(t)$ in the *Power Delivery Request* to the SECC. This schedule will finally be followed by the EV during the charging session until the HV battery is fully charged, a renegotiation is triggered by the SECC, or a session stop is induced e. g. by the user.

Let $Capa_T$ be the total usable capacity of the HV battery and $Capa_U$ the user-defined desired minimum capacity (which directly influences param 3). The *initial* values for the needed energy amount $E^{+}_{EV}(t_p)$ and the energy amount available for discharge $E^{-}_{EV}(t_p)$ vary over time as given by (7) and (8). The energy amount values are computed by the EV and are determined based on several parameters including charger efficiency, energy required for battery maintenance or conditioning, other vehicle systems – altogether summarized with the term $\alpha \in \mathbb{R}$ in (10) –, and current battery SOC. Let k be the largest index such that $t_p \leq t_k \leq t \leq t_d$, then:

$$\begin{aligned} E^{+}_{EV}(t) = E^{+}_{EV}(t_p) - \Sigma_{i=1}^{k-1}(p_{EV,i} \cdot \Delta t_i) \\ - p_{EV,k} \cdot (t - t_k), \end{aligned} \tag{7}$$

$$E_{EV}^{-}(t) = E_{EV}^{-}(t_p) - \Sigma_{i=1}^{k-1}(p_{EV,i} \cdot \Delta t_i) \\ - p_{EV,k} \cdot (t - t_k). \tag{8}$$

The constraints are given by (9) through (12). Constraint (9) states that the HV battery must not be overcharged. A negative value of $E_{EV}^{-}(t_p)$ indicates the energy amount available for discharge, whereas a positive value denotes an instant need for recharge until the minimum SOC provided by the driver has been reached, therefore leaving no possibility to delay the charging process or to use the EV for V2G purposes, as stated in (10). Above all, the capacity values may not be negative.

$$0 \leq E_{EV}^{+}(t) \leq Capa_T + \alpha, \tag{9}$$

$$-(Capa_T - Capa_U)) \leq E_{EV}^{-}(t) \leq Capa_U, \tag{10}$$

$$Capa_T > 0, \tag{11}$$

$$Capa_U \geq 0. \tag{12}$$

Up to this point, we defined the *hard restrictions* within which a charging schedule optimization can take place, such as:
Renewables-oriented – Minimize the difference between the total load and the available power from renewable sources.
Consumption- and cost-oriented – If the overall difference is positive, minimize the costs for retrieving energy from the grid and for violating $C_{CPP}(t)$. Furthermore, assess the best times when to use the renewable energy for charging and when to feed it back to the grid which is refunded by law.
A request for reactive power – which will lower the percentage of active power and thus slightly increase the charging demand – can be sent during the charging loop with the *Charging Status Request/Response* pair. This can be integrated into the model by multiplying $p_{EV}(t)$ with $powFac(t)$.
A first formal model of the domestic load management has been presented in Allerding et al. [APSS12]. The formulation of a holistic optimization problem integrating the components user, EV, grid signals TOU and CPP, residential loads, and renewable generation is, due to the page limit, not presented here. We want to emphasize that, beyond cost or renewables driven optimization approaches, the specific stress on the HV components, especially the expensive battery, which is caused by a certain charging strategy, should be accounted for as well. There are certain analyses [Her10] which point out that the four stress factors which accelerate the ageing process and reduce the HV battery's capacity the most are – in that order – high current rate, depth of discharge, temperature of the battery as well as keeping the battery on a high SOC for a long time period. The task of finding an optimal charging schedule which combines the interests imposed by e. g. integration scenario 1 on the one hand and accounts for battery health degradation issues on the other hand is a very challenging one. While the former might yield frequent changes between charging and discharging cycles throughout the complete connection time, the latter would e. g. aim at charging the EV as late as possible. A single optimal solution might not exist, instead an optimal Pareto front could be obtained [BMF10].

5 Discussion And Future Work

The presentation of the evolving communication interfaces has shown that there are currently very intensive efforts to standardize the ICT-based processes of integrating EVs into the electrical grid and to facilitate the evolution towards a so-called smart grid. We have also illustrated that, induced by the liberalization of the energy market, the elevation, processing and exchange of energy-related information in the charging-an-EV context is distributed across several layers and entities of the energy market. As long as these protocols are defined and built on an open basis – as opposed to proprietary protocols – and are able to work on top of each other so as to guarantee the customer an electromobility-friendly experience, they can provide the necessary boost in the electromobility market.
Our primary focus lies on the investigation of the evolving ISO/IEC 15118 standard – with the first author of this paper being an active member of the standardization body – and its potential to serve as the communication interface which is able to integrate an EV into the smart grid both as a flexible energy storage device especially for renewable energy and a device for the provision of ancillary services to stablize the grid if needed.
Future work – A holistic investigation of the interplay between a real residential smart home equipped with observable as well as controllable thermal and electrical loads and renewable energy sources, a sophisticated energy management system, a bi-directionally charging EV and an H-brige able to emulate any (critical) grid situation is carried out the framework of the *iZEUS* research project. Reliable data will be gathered over a period of several weeks during an evaluation phase in our living lab with real residents in an everyday life situation at the beginning of October 2013. We will be able to log the energy-relevant data and test the three integration scenarios presented in section 1 with authentic data, answering questions as to which degree the EV can satisfy the envisioned goals postulated in our integration scenarios. Moreover, we are able to not only evaluate a single network segment with the use of the H-bridge, but a multitude of (e. g. unstable) grid situations which helps to strengthen the significance of our results. As soon as the integration scenarios 1-3 are evaluated during the residential times, we can consider other use cases, such as an urban district consisting of several smart homes. The formal model focused primarily on the constraints imposed by the user, the EV and the grid, and less on the situation arising from scheduling each appliance inside the smart home, since this issue has already been addressed [APSS12]. Nevertheless, these ideas will be integrated into this model in more detail and presented in future work. Residential battery storage systems are planned to be integrated in the ESHL as well which will offer new exciting optimization possibilities.

6 Conclusion

The evolving market of electromobility can play a major role in a smart grid with a growing share of dispersed renewable energy sources, but only if the designed communication interfaces are enabled to deal with requirements from different stakeholders. We introduced the currently most promising and wide-spread communication interfaces dealing with energy-relevant data of EVs, namely the evolving V2G communication interface standard ISO/IEC 15118, the Open Charge Point Protocol of the E-laad initiative, and Hubject's Open intercharge Protocol. In this context, we showed how those protocols can on the one side offer an enjoyable experience for customers of electromobility through easy access and value-added services, and on the other hand serve as an enabling technology towards the vision of a smart grid.

Based on three scenarios for integrating an EV into the grid using the setup of a residential energy-efficient smart home and an evolving V2G communication standard, we offered an in-depth understanding of the mechanics of ISO/IEC 15118-2. This communication interface has been adapted and crucial parameters have been additionally introduced to meet the requirements of a smart grid, especially the EV's ability to serve as a flexible energy storage device and to provide ancillary services. The mathematical model introduced captures the key parameters of this adapted standard and accounts for all hard restrictions imposed by the demands of each associated party. With this formal model as a basis, we are able to harvest the full integration potential of EVs and derive charging schedules which optimally reconcile the differing objectives.

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