ISO 15118 as the Enabler of Vehicle-to-Grid Applications

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***Abstract*—This work provides a comprehensible overview of the ISO 15118 standard to show the potential of this future-proof charging communication protocol used for integrating electric vehicles (EVs) into the smart grid. The various parts of the ISO 15118 document family as well as their functionality scope are introduced. An internationally agreed-upon mechanism to enable EVs to feed energy back to the grid without compromising the grid's stability is key to a successful market introduction of Vehicle-to-Grid-enabled EVs and charging infrastructure. Therfore, the mechanism specified in ISO 15118 to enable bidirectional power flow is introduced and discussed.**

***Index Terms*—ISO 15118, V2G, ancillary services, BPT**

I. Introduction

With the increasing popularity of electric vehicles (EVs) on one side and a rise of renewable energy sources in a decentralized electrical grid on the other side, more and more industry-oriented research projects around the globe address the question of how to efficiently integrate EVs into a smart grid. The best solution would be a standardized approach that would allow for a secure, future-proof, and user-convenient way of charging an EV in such a manner that both the driver's mobility demands and the grid's demand for a stable, energy-efficient, and safe operation are met at all times.

In 2010, the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) joined forces to create the ISO/IEC 15118 Joint Working Group. For the first time, experts from the automotive industry and the utility and energy provider industry worked together to develop an international communication standard for charging EVs. The Joint Working Group succeeded in creating a widely adopted standard that is now called ISO 15118. This standard enables the integration of EVs into the smart grid through information and communication technology.

This paper will give an overview of ISO 15118 [1] and guide the reader through the various parts of this standard, providing a roadmap of its diverse and feature-rich functionality. The information presented in section II is essential in understanding the rich potential of this future-proof communication standard, especially with regards to Vehicle-to-Grid (V2G) applications. Section III will then build upon this knowledge and explain how V2G applications can be realized with ISO 15118 [2]. Section IV summarizes and concludes the findings presented herein.

II. Overview On ISO 15118

ISO 15118 is titled "Road vehicles – Vehicle to grid communication interface" and consists of seven parts. Each part covers a different aspect of digital communication between electric vehicles and charging stations.

Fig. 1 illustrates the relationship between all seven parts of ISO 15118 and the seven communication layers as defined by the Open Systems Interconnection (OSI) model. This reference model defines how applications communicate across a network. The functionality of the ISO 15118 document parts can be mapped to the communication layers of this OSI model.

A. The Seven Document Parts of ISO 15118

Part 1 is called **"General information and use-case definition"** and is referred to as **ISO 15118-1**. It outlines the intention of the specification and explains the overall goals of the standard by defining terms and use cases.

ISO 15118-2 is titled **"Network and application protocol requirements"**. This is the core or the heart of the entire international standard because it defines the technical specifications of all application layer messages and their respective parameters exchanged between the EV and the charging station. Based on this second part, the use cases defined in ISO 15118-1 to establish a successful higher-level communication and charging session can be realized.

ISO 15118-3 is titled **"Physical and data link layer requirements"** and defines communication for wired charging on the two lowest layers – the data link layer and the physical layer. Powerline communication as defined in the HomePlug Green PHY specification is applied to encode digital signals onto the Control Pilot (CP) pin, which is part of the charging cable. These layers establish the higher-level communication outlined in ISO 15118-2. This third part also concerns the interaction with another standard called IEC 61851 – which specifies analogue signals that encode the available amperage at a charging station. ISO 15118 builds upon this analogue and mainly safety-related IEC standard and enhances the charging process with digital higher-level communication.

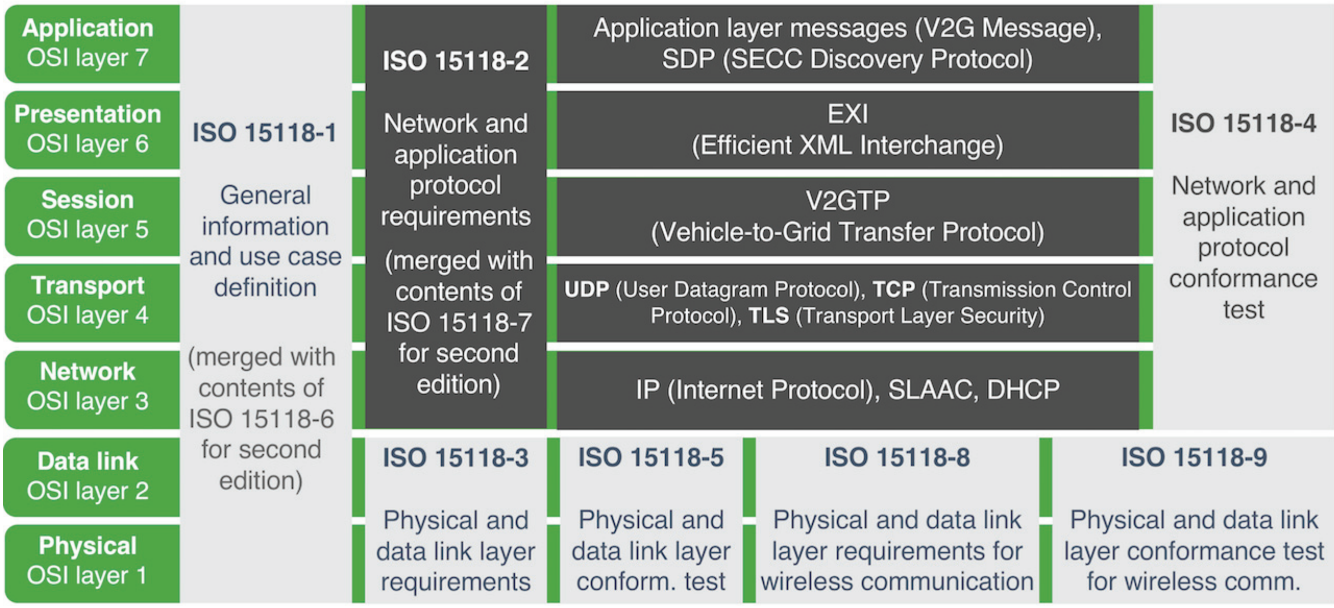

Fig. 1. ISO 15118 document parts and their relation to the Open Systems Interconnection (OSI) layers

Part four and five of this family of ISO documents relate to **conformance tests** for the requirements specified in ISO 15118-2 and -3, respectively. A conformance test is a set of rules that describes whether a certain input of data is valid with respect to both the data itself and the current state of the system that is being tested. In ISO 15118-4 and -5, the ”systems under test” (SUTs) are the EV and the charging station. There are hundreds of conformance tests defined to assess every single technical requirement specified in the ISO 15118-2 and -3 documents. To test an ISO 15118 product for conformance to the standard, one can either go to a provider of such a test system (e.g. VERISCO) or even attend at the biannual International ISO 15118 and CCS Testing Symposia that have been established for this purpose. Visit www.testing-symposium.net for more information.

ISO 15118-6 is called **”General information and use-case definition for wireless communication”** and is one of the parts that does not exist as a standalone document anymore. The ISO/IEC joint working group decided to add use cases for both wired and wireless communication and charging to the second edition of ISO 15118-1.

ISO 15118-7 is called **”Network and application protocol requirements for wireless communication”**. This part was originally devised to add the technical requirements of wireless communication to the wired specifications outlined in part two. However, the joint working group decided to merge part two and part seven. You can find requirements about both wired and wireless communication and charging in the second edition of ISO 15118-2.

In contrast to parts six and seven, **ISO 15118-8** remains as a separate document to specify the technical requirements for wireless charging communication on the lowest two communication layers. Part 8 is called **”Physical layer and data link layer requirements for wireless communication”**.

ISO 15118-9 is called **”Physical and data link layer conformance test for wireless communication”**. This specification is intended to provide conformance tests for part eight and completes the current list of required conformance tests for both wired and wireless communication. Part nine is the newest member of the ISO document family. In October 2017, the ISO/IEC joint working group introduced it as a ”New Work Item Proposal” – the first stage of a standardization project. It takes three to four years for new proposals to go through all necessary stages and balloting phases before reaching the final status of an officially recognized international standard.

B. Protocols Applied in ISO 15118-2

The operating principle behind the OSI model is this: communication between two endpoints in a telecommunication network is divided into seven distinct groups of related functions or layers. Take, for example, the scenario of an EV that needs to communicate with a charging station to charge its battery. Here, one endpoint is the electric vehicle communication controller (EVCC), and the other endpoint on the charging station side is the supply equipment communication controller (SECC). The EVCC’s message will be processed on the EV side by all functional layers, starting with the application layer and all the way down to the physical layer. Once the message has traversed to the bottom layer, the EV sends the data to the charging station using a physical medium like a charging cable or a WiFi connection. On the receiving end, the charging station will go through the same steps but in the opposite direction. The complete data packet traverses from the bottom physical layer up to layer seven – which is called the application layer.

ISO 15118 defines two types of application messages:
SDP messages and **V2G messages**.

SDP stands for SECC Discovery Protocol and consists of exactly one request and response message. The EV and the charging station use this message pair during the communication setup to mutually exchange their respective IP address and port. This ensures both EV and charging station know where to send the data packets during each communication session.

The V2G message type, short for Vehicle-to-Grid message, is used to transmit the other 18 messages that handle all other communication, from starting a session and entering a charging loop to terminating a session.

The **application layer**'s header for V2G messages always contains a session ID. For those messages whose data integrity and authenticity needs to be ensured, like metering data or a message used for certificate installation or certificate update, an additional digital signature must be applied.

Next, the application layer sends the data packet to the **presentation layer**. The presentation layer translates the application data into a specific format that both the sending and receiving side will understand. To speed up the transmission, the chosen format compresses the data to reduce the amount of bits and bytes to send. ISO 15118 uses Efficient XML Interchange (EXI) for V2G messages, a binary data representation of data structures that are in the Extensible Markup Language (XML) form. All V2G messages in ISO 15118 are defined in the XML format. An XML message coming from the EV's application layer is encoded into the EXI format on the presentation layer before being delivered to the session layer beneath. Upon receiving the message, the charging station will then decode EXI into XML again. EXI is not applied for SDP messages.

Layer five, the **session layer**, handles communication sessions between the EV and charging station. On this layer, a dedicated ISO 15118-protocol mechanism comes into place. This is called the Vehicle-to-Grid Transfer Protocol or V2GTP. The V2GTP header contains important information about the payload type, stating whether it is an EXI encoded V2G message type or an SDP message that is being transported. This information is necessary for both the EV and charging station to correctly process the incoming message.

Layer four is called the **transport layer**. Both the EV and the charging station need to establish a TCP/IP connection in order to reliably send data packets to each other via the communication link and guarantee error recovery and retransmissions, if needed. All V2G messages are transmitted using TCP. TLS, the Transport Layer Security protocol, must be selected any time data needs to be secured by encryption. On the other hand, SDP messages are transmitted using the User Datagram Protocol (UDP). UDP does not focus on reliability of data transmission. Instead, UDP is primarily used for applications that focus on very quick transmission of data packets from point A to point B in a communication network. The order in which point A sends the data is not necessarily the same order in which point B receives the data. The EV and charging station exchange their respective addresses within SDP messages. These messages can be sent numerous times; the order of the messages doesn't matter and some identical messages can be lost during transmission without affecting the outcome. The most important thing here is that at least one of the sent messages is successfully received and processed. With V2G messages, however, the order is very important for the respective state machines that control the information flow within a charging session. This is why a reliable transmission mechanism like TCP or TLS is needed here.

On layer three – **the network layer** – TCP makes use of Internet Protocol (IP) to assign unique IP addresses for the EVCC and SECC, needed to route data packets between both entities. Other protocol mechanisms applied on the network layer include Stateless Address Autoconfiguration (SLAAC) and Dynamic Host Configuration Protocol (DHCP).

The two lowest layers of the seven layers of communication are the **data link layer and the physical layer**. On the physical layer, data is transmitted using electric signals such as voltage or radio frequencies. During wired communication, the EV exchanges data with the directly connected charging station using digital signals modulated on a wire inside the charging cable, called the Control Pilot (CP) pin, when it is plugged into both the EV and charging station.

C. *Message Sequence for an ISO 15118 Charging Session*

Fig. 2 illustrates a sequence of messages being exchanged for an Alternating Current (AC) charging session carried out via ISO 15118. The entities that carry out certain actions, such as sending or receiving messages and opening or closing contactors, are illustrated in the boxes at the top. States A, B, and C relate to certain voltage levels measured by the charging station and are defined in IEC 61851. ISO 15118 builds and expands on IEC 61851 and enables digital communication between EVCC and SECC, which starts as soon as the duty-cycle of the pulse width modulation (PWM) signal is set to 5%, as defined in IEC 61851.

All the messages illustrated in Fig. 2 are sent as V2G messages, each consisting of a header and a body. The header carries information including the session ID and an optional digital signature, the body holds the actual message content. The sequence starts with the **supportedAppProtocolRequest**. The EV and charging station use this request-response

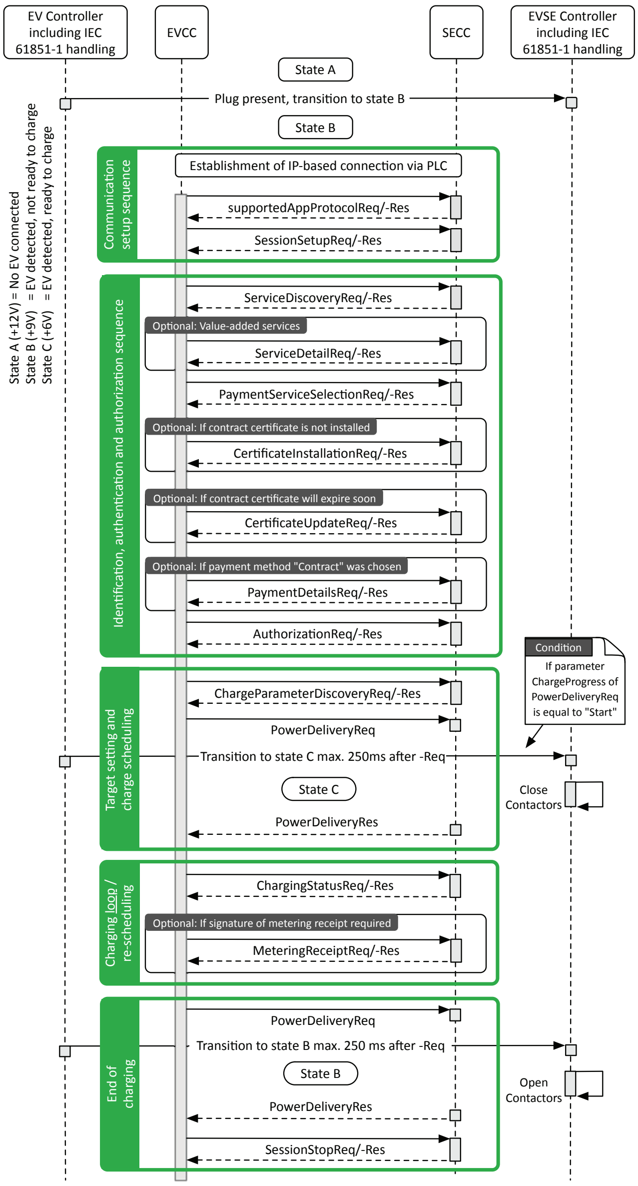

Fig. 2. Message sequence for an Alternating Current (AC) charging session

message pair to agree upon a protocol version. As shown in Fig. 1, ISO 15118-1 and -2 are in the process of being rewritten for the second edition. ISO is likely to publish this second edition in 2019 and it may be some time before EV and charging station vendors incorporate it into their products. During this transition phase, it's important that both the EV and charging station speak the same version of ISO 15118. If they are not compatible, it won't be possible to initiate an ISO 15118 charging session.

Next up is the **SessionSetupRequest** that is used to assign a unique session ID for a communication session. The session can be paused and resumed at a later time using the same session ID. In this case, the previously agreed upon charging parameters will be applied again to ensure charging continues as originally intended by the driver.

Next, the EV will use the **ServiceDiscoveryRequest** to ask the charging station about its offerings. These services include:

- AC single-phase charging or AC three-phase charging,
- Variations of Direct Current (DC) charging,
- The available identification mechanisms, namely External Identification Means (EIM) or Plug & Charge, and
- Optional value-added services such as Internet access to download additional data.

The EV can request more details for each service by using the optional **ServiceDetailRequest** message.

Once the identification mechanism, charging mode, and optional value-added services to use are clear, the EV then will inform the charging station with the **PaymentServiceSelectionRequest**. The term ”Payment” may be confusing here since this message has nothing to do with payment but with the authentication and authorization method.

ISO 15118 provides two ways of authenticating and authorizing a user for a charging session: External Identification Means (EIM) and Plug & Charge (PnC). EIM represents any user authentication method that requires additional action by the driver such as presenting an RFID card to the reader or scanning a QR code on a label at the charging station. Plug & Charge, on the other hand, is a more user-convenient way of charging that also enables security features and ensures data integrity and authenticity through digital certificates and digital signatures. In case the EV selects Plug & Charge as an identification method, a valid digital contract certificate must be installed in order for the charging station to automatically authenticate and authorize the driver. If the EV does not yet have this certificate installed or if its existing contract certificate has expired, the EV can use the **CertificateInstallation** message pair to install a new contract certificate from the charging station.

In cases where an EV has a soon-to-be expiring contract certificate installed for Plug & Charge, the EV can be programmed to initiate a **CertificateUpdate** message pair to receive a new contract certificate.

If the EV is programmed to select Plug & Charge as its identification method, the EV will need to present its contract certificate to the charging station in order for the driver to be authenticated and authorized for charging. This is done using the **PaymentDetailsRequest** message.

The **Authorization** message pair is used to avoid what is called a replay attack. This is a form of network attack in which a valid data transmission is maliciously or fraudulently repeated in order to gain access to a restricted resource.

With the **ChargeParameterDiscoveryRequest and -Response** messages, the EV and charging station mutually exchange their respective technical charging limits by communicating their maximum and minimal allowed voltage levels and amperage. The EV also informs the charging station of the amount of energy needed and the desired departure time provided by the driver. The SECC will then calculate a charge schedule to propose to the EV. The proposed schedule will include the maximum power with which the EV is allowed to charge while connected to the charging station as well as an optional **SalesTariff**. The SalesTariff includes schedules that provide information on cost over time, cost in relation to power demand and amount of energy, or a combination of these, aimed at incentivizing the EV to engage in a certain charging behavior.

Once the charging station sends the proposed charging schedule to the EV, the EVCC will calculate a charging schedule of its own. It does so by taking into account several factors like the technical restrictions imposed by the battery management system and financial incentives provided within the ChargeParameterDiscoveryResponse message. This EV charging schedule must not exceed the upper power limits provided by the charging station. The EVCC then sends its schedule to the SECC via the **PowerDeliveryRequest** message. The EVCC can decide to instantly start charging or to delay the charging process. It indicates this intent by setting the parameter ”ChargeProgress” to either ”Start” or ”Stop”, as shown in Fig. 2. If the parameter is set to ”Start”, the EV will trigger a switch to cause the voltage level to drop from 9 V to 6 V. According to IEC 61851, this will cause a state transition from state B to state C: ”EV detected and ready for charging”. The charging station will then close its contactor to initiate the flow of energy.

We are now in a charging loop. The **ChargingStatusRequest** message is empty. This message pair is used frequently to trigger a response message from the charging station during charging. Doing so enables the charging station to react to any unforeseen situations within the local electrical grid. One such circumstance would occur if several EVs were to suddenly begin charging at the same time and all request to be charged as quickly as possible. If the charging station's local transformer cannot handle this situation, then some EVs will need to be charged at a lower level of power. Depending on the individual circumstance, the charging station can ask the EV to **renegotiate its requested charging schedule** or even demand the EV instantly stop charging to prevent the grid from a potentially dangerous overload.

The charging station can also request a digital signature from the EV for the current meter values by using the **MeteringReceiptRequest** message. This triggers the EV to send a signature declaring that it has seen the meter values.

As soon as the EV intends to pause or end the charging session based on its calculated charging schedule, it will send another **PowerDeliveryRequest** message with its parameter ChargeProgress set to ”Stop”.

The communication concludes with the **SessionStopReq/-Res** message pair. The request message's ChargingSession parameter can be set to either ”Terminate” or ”Pause”. If the charging session is to be paused, certain parameters, like the agreed-upon charging schedule, are temporarily stored by the charging station so it can apply these values when the charging resumes.

The sequence for DC charging is very similar to the one shown in Fig. 1. Given the technical conditions behind DC charging, three additional messages are needed and the one sent during the charging loop is replaced by the **CurrentDemandReq/-Res** message pair for a more tightly controlled charging loop.

D. Publication Status of ISO 15118

The ISO/IEC joint working group has published ISO 15118-1 (April 2013), -2 (April 2014), -3 (May 2015), -4 (February 2018), -5 (February 2018), and -8 (March 2018) as international standards and plans to publish the second edition (see section III) of ISO 15118-1 and -2 in late 2019.

III. Enabling V2G Applications With ISO 15118

Although ISO 15118 is titled ”Road vehicles – Vehicle to grid communication interface”, the Vehicle-**to**-Grid feature has so far only been described as a use case in ISO 15118-1. ISO 15118-2 did not yet define any messages that would allow a bidirectional power transfer, enabling the EV to feed energy back to the grid.

In late summer 2015, the ISO/IEC joint working group initiated the work on edition two of ISO 15118-1 and -2 as new features needed to be properly specified. The major topics addressed in the second edition are:

- Charging busses via pantographs, also known as Automatic Connection Device (ACD) charging
- Wireless power transfer (WPT) in line with IEC 61980 and wireless communication via IEEE 801.11n
- Handling of multiple contract certificates for Plug & Charge to enable more use cases for contract-based charging, e.g. using different contracts for charging at home and charging at the employer's charging infrastructure
- Transport Layer Security (TLS) being mandatory in all charging scenarios, raising the overall data security level
- Multiplexed data streams to enable the parallelization of certain tasks, e.g. the renegotiation of a charging profile without stopping the (dis-)charging process
- Bidirectional power transfer (BPT) for both AC and DC charging to enable real V2G applications.

The remainder of this section will focus on bidirectional power transfer.

When it comes to feeding energy back to the grid, there are certain technical regulations that any generating device (producer) connected to the grid needs to comply with in order to guarantee a stable operation of the electrical grid. These regulations are written down in **grid codes**. A grid code is a technical specification which defines the parameters an electricity generating plant or a consumer connected to a public electric network has to comply with to ensure the safe and secure operation of the electrical grid. The behaviors specified by a grid code include voltage regulation, power factor limits, reactive power supply, and response to short-circuits or frequency changes on the grid. There are common aspects which are included in the national grid codes. However, there is no perfect match or clear international consensus on naming or features of a grid code. Thus, it is quite hard to design a mass market product against a set of highly complex and inconsistent rules.

In DC charging mode, the power converter is located "off-board" in the charging station which is always a stationary device. Therefore, the location-dependent grid codes can be programmed into the controller of the charging station that manages the power flow from and to the grid. This makes bidirectional energy transfer in DC charging mode an easy task to achieve from the point of view of ISO 15118 as no additional grid-related information like the necessary ratio between active and reactive power needs to be exchanged between the EV and the charging station.

In AC charging, however, technical requirements need to be defined that clearly specify which information needs to be exchanged between the EV and the charging station as the power converter that manages the power flow is located "on-board", i.e. inside the EV. In general, there are two possible approaches to guarantee that the EV will comply to the local grid codes of the country in which it is currently located:

1) The parameters of a certain set of national grid codes (e.g. inside Europe) are stored in the EVCC, associated with a unique grid code identifier. The SECC would then only need to communicate the grid code specific identifier to the EVCC to ensure a safe and secure operation of bidirectional power transfer.

2) The SECC needs to explicitly communicate a set of parameters to the EVCC to ensure that the reverse power flow from the EV to the grid does not violate local grid code constraints.

While the first option allows for a rather easy adaptation of the ISO 15118 communication protocol, it requires the EV manufacturers to make sure a multitude of grid code parameters are stored on their communication controllers. It turns out that at least some EV manufacturers are not too fond of this option, which is why the second option was introduced to the Draft International Standard (DIS) [2]. This DIS is the most up-to-date version of edition 2 of ISO 15118-2 at the point in time of writing this paper.

The current solution works as follows: the EV shall use the **ServiceDiscoveryReq/-Res** message pair to find out if only charging or both charging and discharging are offered as power transfer services by the charging station. The **ChargeParameterDiscoveryReq/-Res** message pair is then used to mutually exchange boundary parameters for bidirectional power flow. The **AC_EVBidirectionalParameter**, for example, contains among other nested parameters information about the maximum charge and discharge power as well as the maximum and minimum charge and discharge current. When entering an AC charging loop for bidirectional power flow, the EV and charging station exchange **AC_BidirectionalControlReq/-Res** message pairs. As pointed out before, we only need to communicate grid code-relevant parameters to the EV in case of AC bidirectional power flow because there the power converter is located in the EV. This is why we have the parameters **EVSETargetActivePower**, **EVSETargetReactivePower**, and **EVSETargetFrequency**, listed in the AC_BidirectionalControlRes message that the SECC sends to the EVCC. This way, the charging station can react upon the actual situation in the grid and demand the EV to provide potential ancillary services.

IV. Conclusion

This paper provided an overview of the features and functionality specified in ISO 15118. This future-proof communication protocol enables V2G applications that will be introduced with the second edition of ISO 15118-2 in 2019. Although the first generation of ISO 15118-enabled EVs that will enter the market in 2019 will not support reverse power flow yet, we can expect to see V2G support based on ISO 15118 with the following generation of EVs in three to five years. The future will show if bidirectional power flow will be more the case for AC or for DC charging stations. Based on the assumption that EV manufacturers tend to avoid any additional costs that are not absolutely needed in their point of view, it might be more likely that we will rather see DC charging stations that offer reverse power flow to the grid. With regards to the use cases, it can be assumed that reverse power flow will primarily be offered at locations where the EV will be connected to the charging station for a longer period of time, such as at home or at the employer's parking space. This leaves enough time to provide ancillary services if necessary and guarantee that the driver will have a sufficiently charged EV to reach his or her destination.

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References

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