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Vehicle-to-Grid AC Charging Station: An Approach for Smart Charging Development ⋆

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Abstract:
The use of electric powered vehicles is increasing steadily. This also leads to new challenges for the power grid. An electric powered vehicle provides heavy stress for the grid, especially when many vehicles are loading their accumulators simultaneously. To counteract these negative effects, smart charging is developed. With intelligent vehicle-to-grid communication, the stress for the grid, during the charging process, can be reduced. This is especially important when renewable energy sources are utilized. Using new software protocols and suiting hardware applications, smart charging can harmonize the needs of renewable energy sources and electro mobility. In this paper a smart charging capable AC charging station for hardware and software evaluation is proposed. This system is based on OCPP 2.0 and the ISO 15118 standard.

Keywords: V2G, OCPP, EVSE, EVCC, SECC, charging station, smart charging

1. INTRODUCTION

1.1 Smart Charging

Almost everything has to be smart today. Smart phones, smart watches, smart TVs, smart homes and last but not least smart grids are state of the art. In this context smart means increasing (one or more of the following attributes) by adding additional intelligence to existing devices or technologies:

- functionality
- efficiency
- safety
- security
- quality

The same approach can be utilized for the charging process of electric vehicles (EVs). This shall be referred to as smart charging. The main goal, drawing power from the grid to charge a vehicle's battery remains unchanged. However, by adding intelligence to this process it becomes possible to balance the grid, as well as to improve the driver's experience. For smart charging, improved communication between the vehicle and the charging station has to be implemented. This enables time scheduled and electric rate dependent charging and discharging of vehicles. By doing so the vehicle may be charged in the most convenient way for the driver. On top of that, each EV can also contribute to balancing the power grid. Smart charging allows to use the vehicles as temporary energy storages to buffer spikes in the energy production. Especially when renewable energy sources, such as photovoltaics or wind power, are utilized balancing the power grid is a non-trivial task. This topic becomes even more pressing when considering the steady increase of these energy sources. For example in Germany the share of renewable energy sources has already reached 23.4 % by end of 2013, which is an increase of approximately 15 % in a period of only ten years (German Federal Government, 2013). The feasibility of using electric vehicles for stabilizing the a power grid, which relies on renewable energy sources, has already been shown (Ferreira et al., 2011; Bauer et al., 2010).

Besides these aspects, smart charging allows initiating and stopping the charge process with a high level of controllability. It also supports authentication mechanisms between the user or the vehicle and the charging station, as well as the exchange of contract data. This may be used for payment systems in public charging stations (Open Charge Alliance, 2014).

However, actual smart charging implementations are not yet available. The improved communication, as well as the demand for interoperability between EVs and the infrastructure requires standardized solutions (Ruthe et al., 2011). This process has already begun, but it hasn't been completed as of yet. The most common standards for smart charging in Europe are International Organization for Standardization (ISO) 15118 for the interface between EV and charging station and Open Charge Point Protocol (OCPP) for the interface between a charging station and

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a central system. The American Society of Automotive Engineers (SAE) also defines the standards SAE J2847/1-3 for smart charging (Mültin et al., 2013).

1.2 State of the Art

Figure 1 shows an overview of the standards and protocols used for smart charging stations. The communication between the charging station and the EV is defined in International Electrotechnical Commission (IEC) 61851 and ISO 15118. OCPP is used for the interface between the central system and the Electrical Vehicle Supply Equipment (EVSE).

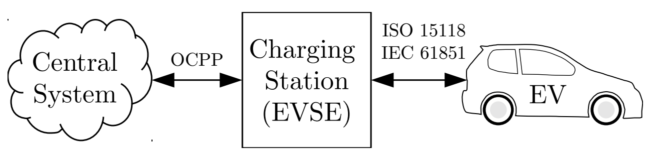

Fig. 1. Smart charging communication protocols

The IEC 61851-1 standard specifies the lowest communication layer between the EV and the charging station (IEC, 2014). For the communication, the control pilot (CP) and proximity pin (PP) are utilized. The control pilot enables a bidirectional communication and is generated by the EVSE. It is a Pulse Width Modulation (PWM) signal with a frequency of 1 kHz. It has a variable duty cycle, which corresponds to the maximum available current of the charging station. The charger in the vehicle must not exceed this maximum charge current. The EV is able to alternate the control pilot's voltage level, in order to signalize the vehicle's charging state. The proximity pin detects, if a cable is attached to the charging station. A standardized resistor in the plug represents the nominal current of the charging cable.

Smart charging according ISO 15118 enables active charge control, demand and response management, plug and charge, payment process and other services (ISO, 2013). Unfortunately, most charging stations don't provide the required hard- or software to allow smart charging.

Currently most charging stations use OCPP 1.5 for transferring data between the charging station and a central system. OCPP 1.5 is based on Simple Object Access Protocol (SOAP). It doesn't provide the features necessary for smart charging. To enable smart charging, the new OCPP 2.0 standard is required. Its extended message set can cover the demands for smart charging. The new message set allows to communicate with the vehicle using the ISO 15118 (vehicle-to-grid (V2G)) protocol. OCPP 2.0 messages use a JavaScript Object Notation (JSON) based notation. They are much smaller in size and faster in processing than SOAP messages. Therefore OCPP 2.0 is already implemented in some charging stations. Currently the reason is mainly its efficient JSON notation and not its smart charging capability.

Since some parts of the ISO 15118 are still under development, car manufacturers are hesitant to implement smart charging features into their vehicles. For this reason, there's no smart charging capable vehicle available at the current time.

1.3 Challenges

Smart charging requires a set of standardized protocols, which enable communication between EVs and charging stations, as well as V2G communication. The standardization process has already started and first V2G ready standards are available. However, there's still a number of open issues, as other standards are still in draft. The OCPP 2.0 standard is an example for this. It is still under development (currently Release Candidate 2), as are six of the eight parts of the ISO 15118.

Due to the unfinished state of these protocols, they are barely implemented in currently available vehicles and charging stations. Current charge points (especially those working with AC) provide only limited communication. Only the maximum possible (technically limited) charging current can be communicated to the vehicle. Load balancing, scheduling of the charging process or reserving specific amounts of energy isn't possible yet. As the number of electric vehicles and charging stations is expected to rise continually, V2G features like scheduling will become increasingly important for stabilizing the electric grid. The communication standard used by the power grid, which is Power Line Communication (PLC), may hereby also be a possible solution for vehicle-to-grid communication.

When implementing a smart AC charging station, the following challenges are presented:

(1) Charging shall be controllable depending on electricity price or grid load.
(2) The IEC 61851 standard allows only limited communication from the charging station to the EV. However, smart charging or smart grid applications shall provide extended communication.
(3) OCPP 2.0 and ISO 15118 shall be implemented.
(4) EVs shall implement the ISO 15118 interface.
(5) Users shall be supported through software and smart technologies.

In the following one possible implementation of an AC-capable smart charging station, using OCPP 2.0 and ISO 15118, is proposed. This system shall later serve as development and evaluation platform.

2. HARDWARE

The basic communication concepts are specified in the standards IEC 61851-1 and ISO 15118-1. Market available charging stations prohibit changes to their hardware and software, thus they can't be modified to enable smart charging. For this reason, an individual concept for a smart charging compatible station is developed. This platform allows to get full software and hardware access, in order to implement OCPP 2.0 and V2G protocols. The charging point is constructed with market available modules. The proposed concept shows one possible solution to build such a charging station.

Due to the fact, that there is no smart charging compatible vehicle on the market, an EV-Simulator has to be built, in order to test the developed system.

2.1 Charging Station

The developed charging station offers one charge point, thus one car can be charged at a given time. Figure 2 shows the hardware concept of the proposed charging station.

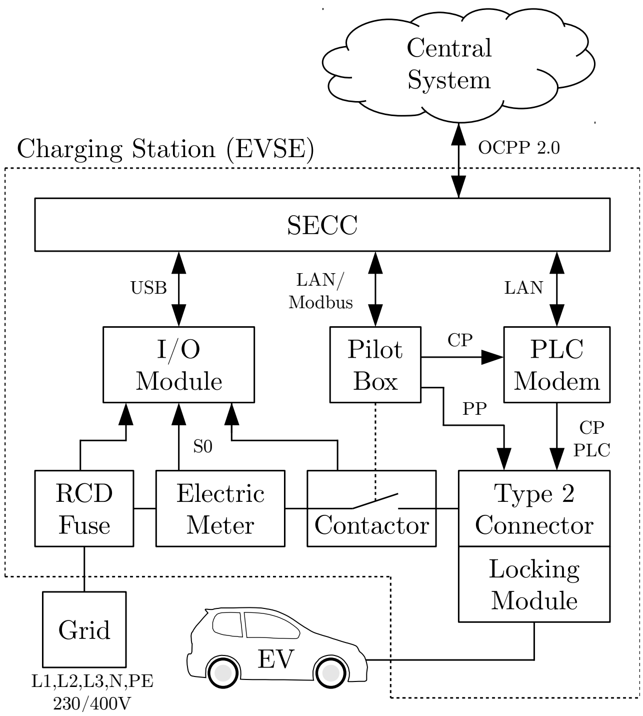

Fig. 2. Hardware concept of the developed charging station

The power circuitry of the charging station consists of a Residual Current protective Device (RCD), a circuit breaker for line protection, a contactor and a type 2 connector. This plug is designed for a maximum charge current of 63 A. It has seven pins, five are for power transmission, the remaining two pins are used for communication (CP, PP). The used plug is compliant with the IEC 62196-2 standard for plugs of AC and DC charging stations in europe. The development platform is a three phase AC charging station, which is designed to charge with currents up to 32 A. This corresponds to a maximum charge power of approximately 22 kW.

The Supply Equipment Communication Controller (SECC) is an ARM based embedded computer, which controls the charging process. Its software implements the V2G-protocol and the OCPP 2.0 communication. The electric meter records the energy consumption during the charging process. The Input/Output (I/O) module interprets the S0-pulses of the electric meter. An USB-interface allows the communication controller to access this information. Furthermore, the I/O module monitors the status of the RCD, the circuit breaker and the contactor in order to inform the operator about the charging station's state.

The pilot box generates the control pilot signal in accordance with IEC 61851-1. A Modbus/Ethernet interface connects the pilot box with the communication controller. The Modbus enables the SECC to retrieve the status of the pilot box and to start the charging process. It can only be started if a car is connected and the SECC signalizes the pilot box, that the process is permitted to start. The proximity pin detects a connected charging cable and its nominal current. Furthermore, the pilot box controls the contactor and the locking module for the charging plug. Once the charging cable is connected to the car, the cable must be locked at the charge point. This provides safety against electric sparks, due to an unintentional disconnection during the charging process.

A PLC modem extends the functionality of the charge point to smart charging compatibility. It supports the HomePlug Green PHY power line standard proposed in ISO 15118-3, which is still in draft (ISO, 2014b). The data stream is modulated onto the control pilot line. Tests by Lewandowski et al. (2011) show the suitability of this modulation for the connection between vehicle and charging station. The modem also supports Signal Level Attenuation Characterisation (SLAC) according to ISO 15118-3. SLAC provides safety by establishing a connection to the nearest PLC communication partner. This mechanism is required in case that multiple vehicles are charged at the same charging station.

2.2 EV-Simulator

Since there is no AC smart charging compatible vehicle on the market, an EV-Simulator is developed, in order to test the smart charging capabilities of the charging station. The simulator is able to communicate with the charging station according the protocols specified in ISO 15118 and IEC 61851. Furthermore, it contains configurable electronic loads to simulate a typical charging process of an actual vehicle. Figure 3 shows the hardware concept of the developed simulator.

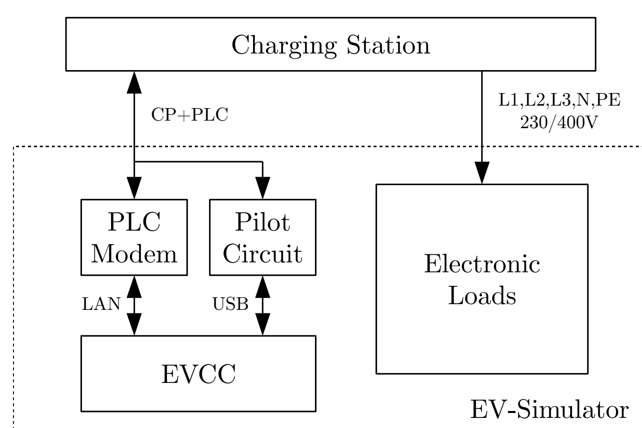

Fig. 3. Hardware concept of the developed EV-Simulator

The pilot circuit is the counterpart to the pilot box (IEC, 2014). The vehicle modulates the voltage level of the control pilot line, using changeable resistors. An USB-interface enables the Electrical Vehicle Communication Controller (EVCC) to change the value of these resistors and communicate the state of the simulated vehicle to the charging station.

The PLC modem enables the EVCC to communicate with the charging station. The V2G protocol is transferred by the PLC modem and modulated onto the control pilot line. The simulator automatically registers at the charge point using the SLAC protocol.

3. SOFTWARE

In this chapter the protocols necessary for smart charging are explained in more detail. Moreover, a modular approach for implementing these protocols into a charging infrastructure is shown. When it comes to authentication of users or billing for consumed energy, the charging station needs to communicate with a local grid operator. This operator is referred as central system. It manages all operations of an user or vehicle. For smart charging, communication also has to take place between vehicle and central system. Therefore special protocols are required.

3.1 OCPP 2.0

The Open Charge Point Protocol (OCPP) is a communication protocol between a charging station and a central management system. Although the protocol is used for the communication between charging station and central system, in some situations the protocol is also used to pass information of the system to devices and systems besides the charging point or central system, such as a web server (Open Charge Alliance, 2014).

Currently most public charging stations are using the protocol version 1.5. This version is based on SOAP and will transfer data via Hyper Text Transfer Protocol (HTTP). Basically this protocol is like an Extensible Markup Language (XML) message with some overhead.

With the introduction of protocol version 2.0 there is another way to send messages. Besides the SOAP based implementations, there is the possibility to use the much more compact JSON notation.

```
[3, "19223201",
{
        "status":"Accepted",
        "currentTime":"20:53:32.486Z",
        "heartbeatInterval":300
}]
```

Listing 1. OCPP 2.0 bootNotification JSON

Listing 1 shows an example message using this notation. The size of this JSON message is approximately 15 percent smaller, than an equivalent XML message, providing the same information. Depending on the message content the savings may be even higher. Particularly with regard to multitasking and limited hardware resources, the performance and respectively size of messages are important.

The advantage of OCPP 2.0 is not only the way how data is transferred, but the smart charging implementation. Version 2.0 of the protocol has a larger set of messages than 1.5. Some of the new messages are designed to enable smart charging. In the OCPP protocol, smart charging is defined as a controlled charging process where a charging point or a central system can set constraints to the amount of power, that is delivered during the course of a charge transaction. It can be used at a local level to limit the total amount of power, that may be drawn by a group of charging points, for example in a parking garage. It can also be used on a global level to adjust the power consumption of charging points to match the power generation capability of the grid or the availability of renewable energy sources.

In order to control the amount of power, an electrical vehicle may draw from a charging point, communication between them is necessary. The version 2.0 of OCPP has been designed to support the ISO 15118 for communication between vehicle and charging point (Open Charge Alliance, 2014).

3.2 ISO 15118

"ISO 15118: Road vehicles - Vehicle-to-Grid Communication Interface" is a protocol for an electric powered vehicle and a charging station. The standard is divided into eight separate parts, of which only the first two have been finalized so far.

(1) Use-cases
(2) Network and application protocol requirements
(3) Physical and data link layer
(4) Network and application protocol conformance test
(5) Physical and data link layer conformance test
(6) Use-cases for wireless communication
(7) Network and application protocol requirements for wireless communication
(8) Physical layer and data link layer requirements for wireless communication

The most important parts are 1, 2 and 3. Part 1 defines scenarios where smart charging can be used and how a workflow should be processed.

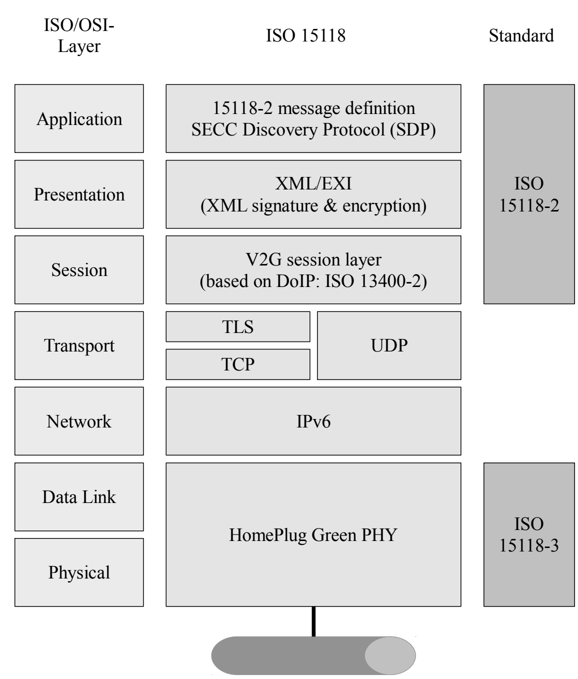

Fig. 4. Stack of ISO 15118, adapted from Ruthe et al. (2011) and ISO (2014a)

Part 2 specifies the software structure of the protocol. It is used to define the messages which should be sent over TCP/IP. A typical message for smart charging would be the user information of travel behaviour. The user can enter the time and date when he needs his vehicle charged at the front-end. A central system can use this information to alternate the schedule of charging to match the power generation capability of the grid or the availability of renewable energy sources. Figure 4 shows the stack of the ISO 15118 corresponding to the Open System Interconnection (OSI) model.

ISO 15118-2 describes how to send very size efficient byte streams from a charging station to a vehicle over TCP/IP. In the application layer the message can be seen in clear text. The format of this message may vary: The protocol can handle XML messages, document object models or a simple C data structure.

As already mentioned, XML messages produce a lot of overhead for the processed data. This is why the message is compressed by the presentation layer. The Efficient XML Interchange (EXI) format allows to use and process XML based messages on a binary level. Thus, the EXI format reduces the memory usage and increases the processing speed. The format uses a relatively simple grammar driven approach, that achieves very efficient encodings for a broad range of use cases. It is not uncommon for these messages to be up to 100 times smaller than equivalent XML documents (ISO, 2014a).

After the compression, a header, which is also known as Vehicle to Grid Transport Protocol (V2GTP) header, will be added in the session layer. Figure 5 shows such a data unit consisting of the header and payload.

Header (8 Bytes)	Payload (0- 4294967295 Bytes)

Fig. 5. Protocol Data Unit (ISO, 2014a)

The payload contains the application data (V2G message). The header is used to separate different messages within a byte stream and gives information for the payload processing.

3.3 Proposed Architecture

One major disadvantage of the currently available charging stations is their front-end. All manufacturers of charging stations create their own software. The user always is confronted with a new interface, and the energy supplier has to create a new interface for each charging station.

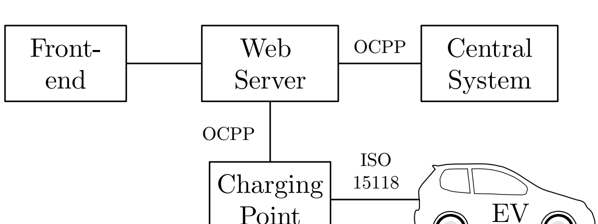

Fig. 6. Modular software architecture

The proposed software architecture presents a new approach for this: The software is divided into logical modules as illustrated in figure 6.

With this approach a energy supplier can use one or more modules as a template. All those modules can be customized by the operator, but in general they keep their interface and usability. If one component of the system is changed, only one module has to be customized, instead of the whole system. The consistent usage of the software infrastructure also enables communication with many different types and brands of charging stations, because of the infrastructure's independence to hardware. Every module itself has a defined interface to other modules, the user or the operator of the public stations. The interaction between the user and the charging station is handled by the front-end. Therefore, the implementation of the user interface has to fit specific needs as usability and standardization are crucial for wide-spread user acceptance. This interface can be accessed by various devices like a smart phone or an ordinary display mounted at the charging station. The variety of the human device interfaces requires a platform independent front-end. Hyper Text Markup Language (HTML) Version 5 is one approach to achieve this. One of the main objectives is the implementation of an unified user interface to make using the charging stations more comfortable.

The web server is the central point for the communication between all modules. The server has to handle all requests and responses from front-end, central system and charging point simultaneously.

The central system module represents the operator of the charging stations and is mainly responsible for authentication and workflow control.

The charging point is able to communicate with the vehicle and therefore has the ability to enable smart charging. Communication is achieved by Power Line Communication directly over the charging cable. The set of messages, which can be transferred is standardized in the ISO 15118-2 (ISO, 2014a). The communication over power line itself also has restrictions which are stated in ISO 15118-3. For the software module, the modulation is seen as a black box: From its point of view, the charging cable is like a common ethernet connection. The metering of the transferred energy is done by a special I/O module which can be accessed via a serial interface or USB. The connection from charging point to web server is also based on TCP/IP. All modules have to handle different connections at the same time. This parallelism has influenced the choice of programming language. While multitasking in C can be complicated, due to process intercommunication, it is easier by using Node.js.

All those modules communicate via TCP/IP, so basically they can be installed at different locations in the system. If there is only one charging station, all modules can be installed at the charging station directly.

Especially the consistent usability of this software architecture is a big advantage for the user, as different charging stations would still have a fairly similar front-end.

3.4 Node.js

One of the main tasks of the charging point module is to handle multiple connections and protocols simultaneously. With traditional programming languages like C/C++ every connection has to be handled by a separate thread. Creating and coordinating all those threads with interprocess communication requires extra effort.

Node.js is a new approach here. It is a software-platform which allows to run JavaScript with the “Google V8 Engine”on the server side. It is a single threaded implementation which is working with non-blocking I/Os. This non-blocking architecture doesn't put the process into a wait state if a single function is waiting for information to proceed.

Node.js uses asynchronous programming. Instead of blocking the process, when a function demands information, the next function, which is waiting in the process line is executed. Every function is combined with a callback which is enqueued and executed, once the data for the function is available. Because of this methodology, Node.js is often referred to as event-driven programming (Springer, 2013).

Node.js' open source concept is reflected by the node package manager (npm) - a marketplace where different packages and modules for many purposes can be down- and uploaded. However, some of these modules lack stability or quality and have to be customized.

If a standard npm library is not sufficient, a simple C library can be implemented. This library can then be accessed using libuv. With this mechanism the high level programming language Node.js also can fit the needs of a low level communication.

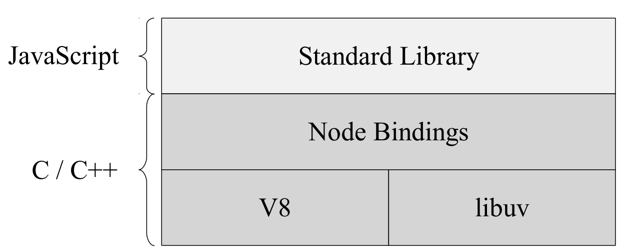

Fig. 7. Node.js architecture (Springer, 2013)

Figure 7 shows the architecture of Node.js. When using the packet manager, only standard libraries will be added. Node.js is implemented in C/C++, thus it is easy to access programs written in C.

4. CONCLUSION

With OCPP 2.0 and the ISO 15118 the basis for smart charging is already established, even though not all standards have been finalized yet. However, since the standardization isn't complete there are no commercial implementations available yet.

To allow the evaluation and further development of smart charging approaches a modular test system is proposed. A possible concept for a smart AC charging station is presented. Additionally an EV-Simulator is developed to allow the interaction with the test system.

Since the ISO 15118 standard is still in development, the necessary software for smart charging isn't implemented completely yet. However, the modular approach for the software architecture allows for easy modifications. Thus it's possible to implement the current state of the draft and react to changes in the standard, once they're published.

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