Importance of Interoperability Testing in Smart and Bidirectional Charging Systems

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Abstract: Interoperability is crucial for integrating EVs and EVSEs into the energy ecosystem, ensuring seamless communication among energy management and grid requirements. In a smart and bidirectional charging context, where EVs not only consume electricity but also have the capability to feed power back into the grid, interoperability becomes even more crucial. Standardized protocols like ISO15118 and OCPP enable efficient charging communication and energy exchange. Interoperability enhances consumer convenience, and grid stability by facilitating dynamic power flow management and supporting distributed energy resources. Prioritizing interoperability, P3's cutting-edge “Energy.Lab” offers automated testing solutions to unlock the full potential of smart and bidirectional charging technologies throughout energy innovations. Core purpose of this paper is to share methodologies and best practices for testing and validation of smart and bidirectional charging functionalities - ranging from application of automated test tools over use-case specific test concepts to standards in configuration and error codes.

1 Introduction

Interoperability is a cornerstone in the integration of electric vehicles (EVs) and electric vehicle supply equipment (EVSE) into the wider energy ecosystem. This concept refers to the ability of different systems and devices to communicate and function with each other without restrictions, regardless of the manufacturer or technology used. As electric vehicles become more widespread around the world, the need for a seamless and connected charging infrastructure is becoming increasingly important.

At the heart of interoperability is facilitating communication between EVs, EVSEs and energy management systems. In a world where there are multiple EV models from different manufacturers and different charging station providers, interoperability ensures that an EV can be charged at any compatible station. This is important not only for the convenience of consumers, but also for the efficiency and reliability of the entire energy system. Without interoperability, the charging experience could become fragmented, with compatibility issues leading to user frustration and potential barriers to wider EV adoption.

Beyond consumer convenience, interoperability is essential for optimizing energy management within smart grids. Smart grids rely on the dynamic flow of information to manage electricity demand and supply effectively. Interoperable systems enable real-time data exchange between EVs, charging stations, and grid operators, allowing for intelligent scheduling of charging sessions, load balancing, and demand response. This is particularly crucial during peak demand periods when the grid is under stress, as well as during times when renewable energy generation, such as solar or wind power, fluctuates.

Moreover, interoperability is a key enabler of advanced technologies like Vehicle-to-Grid (V2G). V2G technology allows EVs to not only draw power from the grid but also to return electricity back to it, acting as mobile energy storage units. This bidirectional flow of energy is instrumental in stabilizing the grid, especially as the penetration of renewable energy sources increases. For V2G to function effectively, a high degree of interoperability is required, ensuring that vehicles, charging infrastructure, and grid systems can all communicate seamlessly.

The importance of interoperability is further underscored by the development of standardized protocols such as ISO 15118, OCPP (Open Charge Point Protocol), and EEBUS. These standards have been designed to promote uniformity across the EV ecosystem, ensuring that different systems can operate together smoothly. ISO 15118, for example, facilitates communication between EVs and charging stations, enabling functionalities like Plug & Charge, which allows for automatic identification and billing of the vehicle without the need for user interaction. OCPP, on the other hand, is widely adopted for managing communications between charging stations and central systems, providing a standardized interface for interoperability across different manufacturers. EEBUS is focused on ensuring interoperability within the broader energy management context, allowing various energy devices, including EVs, to communicate with each other effectively.

Regulators and industry organizations recognize the importance of interoperability in achieving a scalable and efficient EV infrastructure. By adhering to these standards, manufacturers, energy providers, and other stakeholders can ensure that the systems they develop are compatible with each other, reducing the risk of fragmentation in the market. This alignment not only supports the current integration of EVs into the energy ecosystem but also lays the groundwork for future advancements in smart grid technologies and the broader energy transition.

2 Smart and Bidirectional Charging

Smart and bidirectional charging are transformative developments in the field of electric mobility, fundamentally altering how Electric Vehicles (EVs) interact with the energy grid. Traditional EV charging involves a one-way flow of electricity, where power is drawn from the grid to charge the vehicle’s battery. However, bidirectional charging introduces a new dynamic, allowing EVs not only to consume electricity but also to discharge stored energy back into the grid. This bidirectional flow of energy is particularly valuable in the context of modern energy systems, where the integration of renewable energy sources, such as solar and wind, introduces variability and complexity into grid management.

In a bidirectional charging system, EVs can function as mobile energy storage units, contributing to the grid's stability and resilience. During periods of high renewable energy generation, such as midday when solar power is abundant, EVs can be charged using excess renewable energy. Conversely, during peak demand periods or when renewable generation is low, these vehicles can return stored energy to the grid, helping to balance supply and demand. This capability supports the broader adoption of renewable energy by mitigating some of the challenges associated with its variability.

Smart charging complements bidirectional charging by adding layers of intelligence and automation to the charging process. Smart charging systems are designed to optimize charging schedules based on various factors, such as electricity prices, grid demand, and the availability of renewable energy. These systems can prioritize charging during off-peak hours when electricity is cheaper and the grid is under less strain, or they can delay charging to align with periods of high renewable energy production. This not only reduces the cost of charging for consumers but also helps to flatten demand peaks, easing the burden on the grid.

Moreover, smart charging systems can communicate with grid operators to provide demand response services, where charging is adjusted in real-time to respond to grid conditions. For example, if the grid is experiencing high demand, smart charging systems can temporarily reduce or pause charging to alleviate pressure on the system. In return, EV owners may be compensated for their participation in these demand response programs, creating an incentive for them to contribute to grid stability.

The effective implementation of smart and bidirectional charging hinges on the interoperability of the systems involved. Interoperability ensures that EVs, charging stations, energy management systems, and grid operators can communicate and coordinate seamlessly, regardless of the manufacturer or technology used. Standardized communication protocols, such as ISO 15118, OCPP and EEBUS, are essential in this context, as they provide the necessary framework for these interactions.

Furthermore, the potential of bidirectional charging extends beyond supporting the grid. It can also play a role in home energy management systems, where EVs can be used to power homes during outages or peak pricing periods, reducing reliance on the grid and lowering energy costs. This capability, known as Vehicle-to-Home (V2H) or Vehicle-to-Building (V2B), highlights the versatility of bidirectional charging technologies and their potential to transform not only transportation but also energy consumption patterns.

In conclusion, smart and bidirectional charging represent a paradigm shift in how electric vehicles interact with the energy grid, offering benefits for grid stability, renewable energy integration, and consumer cost savings. Their success, however, is contingent on the development and widespread adoption of interoperable systems and standardized protocols, which are crucial for enabling the seamless operation of these advanced charging technologies.

3 Standardized Protocols for Interoperability

There are many protocols and standards for smart charging and grid integration of electric vehicles that are already in use or under development. Figure 1 shows the most important standards and how they relate to each other. The following subsections take a closer look at the standards presented and explain the special features of each. [FfE23]

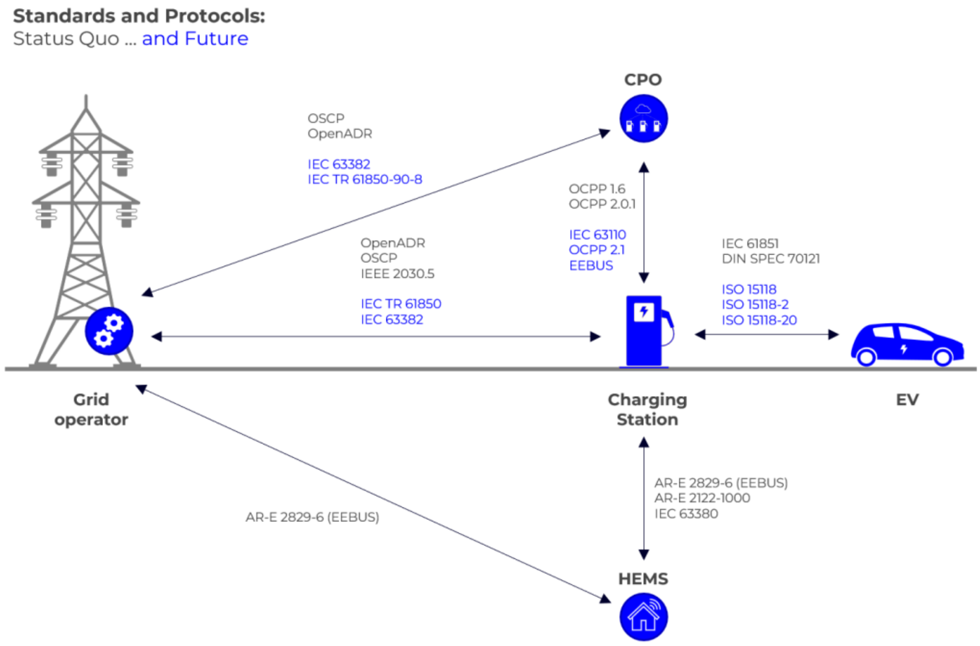

Figure 1: Overview of the relevant communication interfaces and charging infrastructure standards for electromobility.

3.1 Communication between EV and Charging Station

The IEC 61851 standard is currently supported by all electric vehicles in Europe. In this low-level communication standard, signals are transmitted via pulse width modulation. It only offers basic charging functions and does not enable any advanced authentication and authorization functions. IEC 61851 does not enable digital data transmission that goes beyond simple control signals. It is expected in the industry that IEC 61851 will only remain relevant as a fallback solution in the future. [FfE23]

ISO 15118 is a high-level communication standard for the communication interface between electric vehicles (EVs) and charging infrastructure. This protocol encompasses several key features that enhance the user experience and operational efficiency. One of the most notable features is Plug & Charge, which automates the authentication and billing process by allowing the EV to automatically identify itself and initiate charging upon connection to a compatible charging station. This eliminates the need for manual intervention, making the charging process seamless and user-friendly. Additionally, in 2022, the responsible committees released the successor to ISO 15118-2, ISO 15118-20. The standard supplements the existing standard with additional functionalities that will be essential for electromobility in the future. These include bidirectional power transfer (BPT), which enables the feeding of energy back into the power grid. This capability allows EVs to not only draw power from the grid but also return excess stored energy back to it, thus contributing to grid stability and facilitating the integration of renewable energy sources. By enabling these advanced functionalities, ISO 15118 plays a crucial role in promoting interoperability, enhancing the efficiency of energy use, and supporting the development of smart grids. At present, market acceptance is still very low, but as ISO 15118 is supported by several major car manufacturers, this will change in the future. [ISOa] [ISOb]

3.2 Communication between Charging Station and CPO

The Open Charge Point Protocol (OCPP) from the Open Charge Alliance is currently the de facto standard for communication between charging stations and CPOs. It offers compatibility with some other charging infrastructure protocols, such as OpenADR. OCPP is mainly used for authentication and authorization and offers application possibilities for smart charging and demand response. The latest OCPP version 2.0.1, which was released in 2020, supports ISO 15118-2 and thus enables functionalities such as Plug & Charge. Version 2.0.1 also offers increased safety requirements that go beyond version 1.6, which currently prevails on the European market. Bidirectional charging is not yet supported in version 2.0.1. A successor version currently under development will make OCPP compatible with ISO 15118-20 and support bidirectional charging. [OCPP]

OCPP is currently widely used and accepted internationally. However, there are also manufacturers of home energy management systems (HEMS) that rely on the EEBUS communication interface for communication between electric vehicles and charging devices. EEBUS is a communication protocol designed to ensure interoperability within the broader energy management landscape. It focuses on enabling seamless data exchange and coordination between various energy-consuming and energy-generating devices, including EVs, home energy management systems, and the electrical grid. EEBUS facilitates the integration of EVs into smart grids by allowing these vehicles to interact with other energy devices and systems, optimizing energy usage and supporting demand response initiatives. For instance, an EV connected to a home energy management system via EEBUS can adjust its charging times based on the availability of renewable energy, such as solar power, or according to the overall energy consumption patterns of the household. This level of integration and coordination helps in balancing energy loads, reducing peak demand, and enhancing the efficiency and sustainability of energy use. Currently EEBUS is not widespread on the market, but it offers great potential for bidirectional charging. [EEBUS22]

IEC 63110 is a standard published in 2023 that was developed as an alternative to OCPP. It covers the definitions, use cases and architecture for the management of charging and discharging infrastructures for electric vehicles. IEC 63110 addresses the general requirements for building an electric mobility ecosystem and therefore covers the communication flows between different electric mobility stakeholders as well as the data flow with the power grid. It offers some advantages over the OCPP, but market penetration is still very low. In addition, the OCA and the IEC recently entered into a cooperation agreement under which OCPP version 2.0.1 is to be published as IEC 63584. It is therefore unlikely that IEC 63110 will continue to prevail. [IECa] [IECb]

3.3 Communication with a Home Energy Management System (HEMS)

The VDE application rule AR-E 2122-1000 has been in place since 2021 for communication between electric vehicles and the local energy management system downstream of a grid connection point, taking grid-side requirements into account. This application rule serves as the basis for the IEC 63380 standard, which was published in January 2024. [IECc]

Application rule AR-E 2829-6 is a communication protocol for the interface to the electrical low-voltage distribution grid at the subscriber's property boundary. It is compatible with AR-E 2122-1000 for communication between the local energy management system and the charging infrastructure. AR-E 2829-6-1 to 2829-6-4 were published in 2021/2022. AR-E 2122-1000 and AR-E 2829-6 are based on the specifications of the EEBUS communication interface. Compatibility of AR-E 2829-6 with OpenADR is being sought.

3.4 Communication with the electricity grid

The OSCP protocol from the Open Charge Alliance has been used for communication between CPOs and the power grid for several years. Version 1.0 was released in 2015 and version 2.0 in 2020. OSCP is not yet widely used. It is used by the distribution system operator to transmit the physical grid capacity to the CPO. [OSCP]

There is also the OpenADR protocol for communication with the electricity grid, which is used for communication for demand response (DR) and distributed energy resources (DER) applications. It is currently used primarily for peak load management, and other DR and DER applications are being tested. OpenADR has been officially accredited as IEC 62746-10-1 ED1 since 2018. [IECd]

Another protocol for grid communication is IEEE 2030.5, also known as Smart Energy Profile 2.0 (SEP 2.0), it is a communication protocol that was developed for interoperability in smart energy grids. It enables communication between different devices in the smart grid, such as energy meters, electric vehicles, chargers and household appliances. IEEE 2030.5 supports bidirectional communication and makes it possible to exchange data on energy consumption, load control, pricing and other relevant information in real time. [IEEE]

Legislation on communication between charging stations and the power grid is still under development and standardization efforts are still in the early stages. The industry expects that the IEC 61850 series of standards, whose application for station automation is established in energy and telecontrol technology, will play a role. IEC 61850-7-420 describes communication for DR and DER applications. The IEC TR 61850-90-8 technical report builds on this and presents an object model for electromobility. The IEC 61850 series is a widely used standard that is constantly being further developed. [IECf]

Over the next few years, the IEC 63382 standard for the grid integration of electric vehicles is to be developed at international level. The JWG15 working group was founded for this purpose in 2021 and publication is planned for 2025. [IECg]

3.5 Key findings

As the previous chapters illustrate, there is a wide range of protocols and standards for the interoperability of components within the overall system of electromobility. However, these standards are only helpful for interoperability if they reflect a broad consensus among the involved stakeholders and, therefore, gain widespread acceptance. Furthermore, the existence of numerous different and competing standards makes it more difficult to achieve and maintain broad interoperability across all manufacturers and system levels.

Particularly in the field of bidirectional charging, the standards currently relevant, according to P3 expertise, are those depicted in Figure 2. At the forefront is OCPP, as this protocol has already gained wide acceptance in the industry and has become the de facto standard. Furthermore, its scope is continuously expanding through ongoing development. IEC 63110, developed to replace OCPP, fundamentally offers all the functions needed for the future. However, this standard has so far seen little adoption in the industry. Additionally, the OCA and IEC are currently working together on a new standard, IEC 63584. From P3's perspective, IEC 63110 will therefore not become established in the future.

For communication with the electrical grid, the relevant standards are primarily OpenADR, IEEE 2030.5, and EEBus, which will compete in the future. It is currently unclear which of these standards will prevail or whether they will coexist. This underscores the importance of extensive interoperability testing, as the coexistence of different standards in particular makes development especially complex.

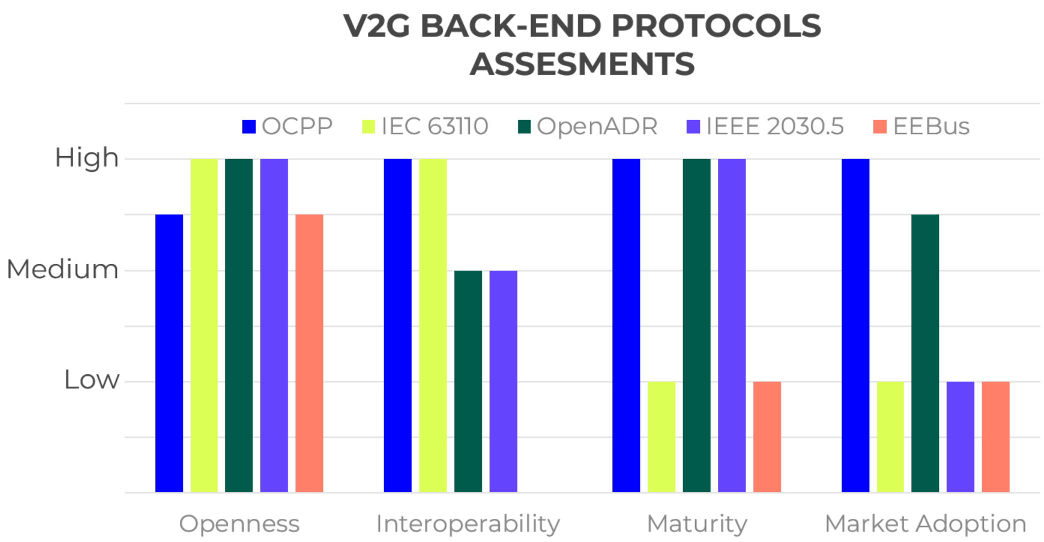

Figure 2: An assessment of the main EV back-end protocols for V2G.

4 Benefits of Interoperability

Interoperability in the electric vehicle (EV) ecosystem offers a range of significant benefits that extend across consumer experience, grid stability, and the integration of renewable energy sources. By ensuring seamless communication and compatibility between various EVs, charging stations, and energy management systems, interoperability enhances the overall convenience and reliability of EV charging. For consumers, this means the ability to charge their vehicles at any compatible station without worrying about compatibility issues, thereby simplifying the user experience and encouraging the adoption of electric mobility.

From an energy management perspective, interoperability plays a critical role in optimizing grid operations. It facilitates dynamic load balancing, allowing the grid to manage energy demand more efficiently, especially during peak usage times. This capability is essential for maintaining grid stability, as it helps prevent overloading and ensures a consistent supply of electricity. Furthermore, interoperability supports advanced functionalities such as Vehicle-to-Grid (V2G) technology, where EVs can return stored energy to the grid during high demand periods, thus acting as mobile energy storage units and enhancing grid resilience.

Interoperability also promotes the integration of renewable energy sources into the grid. By enabling EVs to communicate effectively with renewable energy systems, it allows for the synchronization of charging activities with periods of high renewable energy production. This not only maximizes the use of clean energy but also helps in balancing the intermittency of sources like solar and wind power. Through these capabilities, interoperability contributes to a more sustainable and efficient energy ecosystem, supporting the transition to greener energy solutions.

Additionally, standardized protocols that ensure interoperability, such as ISO 15118, OCPP, and EEBUS, provide a foundation for innovation and scalability within the EV industry. These standards enable different manufacturers and service providers to develop compatible products and services, fostering a competitive and diverse market. This, in turn, drives technological advancements and reduces costs, making electric mobility more accessible and appealing to a broader audience.

Overall, the benefits of interoperability are multifaceted, encompassing enhanced consumer convenience, improved grid stability, effective integration of renewable energy, and a supportive environment for innovation and market growth. By prioritizing interoperability, stakeholders in the EV ecosystem can create a more robust, efficient, and sustainable future for electric mobility and energy management.

5 P3 Energy.Lab

P3's Energy Lab is at the forefront of ensuring the reliability and effectiveness of smart and bi-directional charging technologies through its state-of-the-art testing solutions. The Energy Lab is dedicated to unlocking the full potential of these advanced charging systems through rigorous testing and validation of their functionalities in various scenarios. This includes the application of test tools that simulate real-world conditions to evaluate the performance and interoperability of electric vehicles (EVs) and electric vehicle supply equipment (EVSE).

The Energy Lab employs a comprehensive set of test methods that cover a wide range of use cases. These methods are tailored to validate the compatibility of EVs and charging stations with standardized protocols such as ISO 15118, OCPP and EEBUS. By ensuring compliance with these standards, P3 helps manufacturers and service providers to develop products that integrate seamlessly into the wider energy ecosystem.

In the future, it will also be possible to test and validate the development and use of vehicle-to-grid (V2G) technologies in the P3 Energy Lab. This not only contributes to grid stability, but also improves the efficiency and sustainability of energy use by facilitating the integration of renewable energy sources.

In addition, the Energy Lab focuses on the validation of intelligent charging functions, such as dynamic load balancing and demand response. By testing these functions, P3 ensures that charging systems can adapt to grid conditions in real time to optimize energy distribution and minimize the risk of grid overload. This capability is critical to maintaining a stable and resilient energy infrastructure, especially with the increasing uptake of EVs.

The Energy Lab also addresses the practical aspects of EV and EVSE deployment, such as configuration and fault code standards. By providing detailed insights into these areas, P3 helps players in the EV ecosystem to develop robust and reliable products that meet regulatory requirements and user expectations.

6 Conclusion

In conclusion, the integration of Electric Vehicles (EVs) and Electric Vehicle Supply Equipment (EVSE) into the energy ecosystem hinges on the interoperability of these systems. The adoption of standardized protocols such as ISO 15118, OCPP, and EEBUS is crucial for ensuring seamless communication and operation across diverse platforms. Interoperability enhances consumer convenience by allowing EVs to charge at any compatible station without issues, and it is instrumental in optimizing grid stability and efficiency through smart and bidirectional charging technologies.

P3's Energy.Lab plays a vital role in this landscape by offering comprehensive testing solutions that validate the performance and compatibility of EVs and charging infrastructure. Through rigorous testing, the Energy.Lab ensures that these systems meet the necessary standards and can operate reliably in real-world conditions. This not only supports the deployment of advanced technologies like Vehicle-to-Grid (V2G) but also facilitates the integration of renewable energy sources, contributing to a more sustainable and resilient energy grid.

The benefits of interoperability extend beyond immediate operational efficiencies, fostering innovation and market growth by creating a competitive and diverse environment. As the EV market continues to expand, prioritizing interoperability will be essential for scaling infrastructure and meeting the increasing demand for electric mobility. By adhering to standardized protocols and leveraging advanced testing solutions, stakeholders can ensure a robust, efficient, and user-friendly EV ecosystem, paving the way for a cleaner and more sustainable energy future.

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