STANDARDIZATION OF CONDUCTIVE AC CHARGING INFRASTRUCTURE FOR ELECTRIC VEHICLES

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ABSTRACT

This paper presents a review and discussion on the subtle role of the standardization of conductive AC charging infrastructure for the rollout of electric vehicles. The current status of the standardization and the resulting (in)compatibility of different standards is discussed. It is concluded that standardization is already sufficient, resulting in a limited number of systems that are mostly compatible.

LIST OF ABBREVIATIONS

BEV	Battery electric vehicle
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
ICEV	Internal combustion engine vehicle
IEC	International Electrotechnical Commission
SOC	State of Charge

INTRODUCTION

Interest in electric vehicle (EV) technology and its standardization is increasing, due to multiple reasons. First, there are the volatile and increasing fuel prices [1]. Second, there are environmental and health concerns which can be reduced by EVs [2]. The European 20-20-20 targets are to be met in 2020 [3], and EVs could help to achieve them. Other reasons are technological advantages, e.g. a higher well-to-wheel efficiency than internal combustion engine vehicles (ICEVs) [4].

Obstacles for electric vehicles

There are four obstacles that inhibit or slow down the rollout of EVs. The first one is range anxiety. 80 % of the daily driven distances are typically less than 80 km per weekday [5]. A battery electric vehicle (BEV) can typically cover this range [6]. However, a psychological effect remains due to the smaller range of BEVs relative to the range of ICEVs [7].
This range anxiety is exacerbated by another obstacle: the relative long charging time of EVs. The charging time can be reduced by increasing the charging power, but it is closely related to another obstacle: the impact on the power system. Charging EV batteries constitutes an extra load on the power system. This could create problems, e.g. peak power increase and undervoltage [8].
The last obstacle is the high cost price of BEVs, which is due to the price of batteries. It is possible to reduce range anxiety by increasing the battery capacity, but then the obstacle of the high cost is increased. The energy cost for EVs is lower than for ICEVs, but as long as the total cost of EVs is higher than for ICEVs, this obstacle will remain. However, it is difficult to put a price on the health and environmental benefits of EVs. Also, it should be noted that BEVs have never been produced in full-scale mass production, which could lower the price.

The role of standardization

The standardization is an amplification factor in the rollout of charging infrastructure, also known as the electric vehicle supply equipment (EVSE). Through the rollout of standardized charging infrastructure, the obstacles can be tackled more effectively. Range anxiety will diminish faster when rolling out standardized EVSE, because it creates more charging opportunities for the EV users.
Furthermore, the standardization of the interaction between the EV and the EVSE allows to use the available grid connection more effectively. This allows the EV to charge as fast as possible, given the constraints of the battery charger and the grid connection. By using a compatible interaction mechanism for DC fast charging, that makes use of an off board charger, it can be implemented more easily. Both aspects contribute to reduce range anxiety.
Standardization of the interface between the EVSE and the power system allows to better mitigate the impact. E.g. the charging of EVs can be coordinated, as discussed in [8].
Finally, the standardization of charging infrastructure benefits from the economies of scale, which could lower the EVSE cost. Also, if more parts are standardized, more competition is enabled, which results in lower prices [9].

Scope

The standardization of EVs and charging infrastructure of previous generations is discussed in [1]. A general approach of standards conflicts with historic examples, e.g. CD vs. cassette players, is discussed in [9]. There are publications

that express the viewpoint on EV charging infrastructure of one geographical area [10], [11], or one particular industry [12].
This paper presents a review and discussion on the subtle role of the standardization of conductive AC charging infrastructure. The goal is to determine whether standardization is sufficient for the rollout of EVs. DC conductive fast charging, wireless inductive charging and battery swapping are not discussed in this paper.

AC CHARGING INFRASTRUCTURE

The International Electrotechnical Commission (IEC) created an international standard for conductive charging systems for EV charging, IEC 61851-1 [1]. The connection between the EV and the EVSE can be realized in different manners, as summarized in Table 1. According to the standard, there are three connection cases:

- **Case A:** The charging cable is attached to the EV. The cable plug connects to the EVSE socket.
- **Case B:** A loose cable is used, with a connector at the EV side and a plug at the EVSE side. This allows to create a high degree of compatibility between different vehicle inlets and EVSE sockets.
- **Case C:** The cable is attached to the EVSE. The cable connector must be compatible with the EV inlet.

The IEC 61851-1 standard also defines four different charging modes:

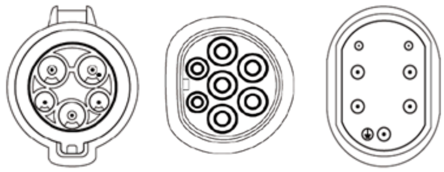
- **Mode 1:** Charging current up to 16 A, both single-phase and three-phase are allowed. The grid connection occurs through a standard socket. A resistor between the power indicator and the ground provides the resistive coding, which is required to inform the EV on the available grid connection power rating.
- **Mode 2:** Charging current up to 32 A, both single-phase and three-phase are allowed. The grid connection occurs through a standard socket with an in-cable protection device. This also provides the control pilot signal, required to inform the EV on the available grid connection power rating.
- **Mode 3:** Dedicated charging infrastructure, currents up to 32 A for Case B and 63 A for Case C. The control pilot signal is provided by the EVSE.
- **Mode 4:** DC-fast charging up to 400 A. This mode uses a high-power off board charger. This charging mode is not further discussed here.

The resistive coding for Mode 1, and the control pilot signal for Mode 2 and 3, set the maximum current that the EV may draw. The implementation aspects of the resistive coding and the control pilot signal are discussed in [13]. However, the effective instantaneous current the EV will draw is controlled by the charge, which is located inside the EV. Thus, if the EV charger power rating is lower than the available power rating, the EV will only draw the power it can handle. Furthermore, the charging power will be reduced when the battery reaches its maximum State of Charge (SOC) [14].
Different types of plugs/sockets and inlet/connector types are used for the connection between EV and EVSE:

- **Domestic type plug/socket:** It is used for Case A and B, so the vehicle can charge at a domestic non-dedicated socket. However, the electric installation must be able to deliver the required charging power. The connection allows Mode 1 and 2 charging.
- **IEC 62196-2 Type 1:** This inlet/connector is also known as SAE J1772, and is used for Case B and C. This connection allows for Mode 1, 2 and 3 charging. It is the standard inlet/connector in the USA and Japan. Also in Europe, several vehicles are equipped with this inlet type, e.g. Nissan Leaf and Chevrolet Volt.
- **IEC 62196-2 Type 2:** This is used as inlet/connector for Case B and C, but also as plug/socket for Case A and B. This connection allows for Mode 1, 2 and 3 charging. It is used in Europe and some European vehicles are equipped with this inlet type, e.g. Smart Fortwo electric drive.
- **IEC 62196-2 Type 3:** This plug/socket type is used for Case A and B. This allows for Mode 3 charging. This plug/socket type is used in Europe, just as Type 2

Table 1: overview of the plug/socket and inlet/connector types.

IEC 62196-2	Type 1	Type 2	Type 3
Single/three-phase	Single	Single/three	Single/three
Maximal current [A]			
Mode 1	16	16	/
Mode 2	32	32	/
Mode 3	80	63	32
Vehicle inlet/ connector	Yes	Yes	No
Plug/socket	No	Yes	Yes



DISCUSSION

The EVSE setup has a significant influence on the accessibility and compatibility by EVs. Both functional and hardware aspects are discussed in the following subsections, to evaluate the effectiveness of current standardization on the rollout of EVs.

Charging modes

Most EVs are Case B and C compatible, having a dedicated EV inlet. They are typically delivered with an adapter cable that has an inlet-compatible connector on the one side, and a domestic socket on the other side. The cable and its functionalities determine whether it is Mode 1 or Mode 2 charging compatible. As a result, every domestic socket could be considered as charging infrastructure. The extensive availability of these sockets creates a lot of charging opportunities. Thus, these charging modes are very effective to reduce range anxiety.

However, Mode 1 and 2 have some drawbacks. The charging current is typically limited to less than 16 A. 10 A appears to be commonly used in Europe [15]. This is to avoid tripping of the fuse of the electric installation, taking into account that other appliances may be connected to the same power circuit in a typical household installation. Therefore, the charging time is relatively long with these charging modes. Even if a specific circuit could deliver more current, this is not possible, because the socket cannot adapt the resistive coding or the control pilot signal.

Mode 3 charging has the advantage that the available power supply can be used more effectively, because the EVSE provides the control pilot signal. This results in a shorter charging time, because typically more than 10 A of charging current is available on the dedicated circuit that the Mode 3 EVSE is connected to. Furthermore, Mode 3 charging offers the possibility to continuously adapt the charging current of each EV through variations in the control pilot signal. This provides a higher degree of flexibility for controlled charging strategies compared to on-off switching. E.g. the allowable charging current could be adapted to anticipate on fluctuating local photovoltaic power production.

However, Mode 3 charging also has some disadvantages. A dedicated infrastructure is required. This results in lower charging opportunities compared to Mode 1 and Mode 2 charging, which negatively impacts the range anxiety. Therefore, it must be considered whether the advantages of Mode 3 charging infrastructure outweigh the disadvantages. E.g. for charging at home, the investments in Mode 3 charging infrastructure, allowing to charge at 3.3 kW, might be unnecessary if the vehicle is parked at home for sufficiently long times to charge the battery with Mode 1 or Mode 2. Furthermore, resistive charging losses and battery aging are lower with lower charging currents [16]. From this point of view, it is better to charge at a lower current for a longer amount of time.

Controlled charging strategies also could be implemented in the battery charger, regardless of the charging mode. Then, if the charging strategy relies on knowledge that is available within the EV, it does not depend on communication. E.g. each vehicle could implement an individual peak shaving algorithm. Thus, if a vehicle has 10 hours to charge 10 kWh, it will charge at 1 kW instead of charging at the maximal allowable power rating. For voltage-dependent charging, as discussed in [17], it also makes more sense to implement this in the charger, because the voltage is already measured in the charger. Also, the required relatively high time resolution would otherwise require high-bandwidth communication between EV and EVSE.

Plug/socket and inlet/connector types

In the USA and Japan, EVs are only equipped with Type 1 inlets. This allows the EVs to perform Mode 1 or 2 charging with a charging cable that has a Type 1 connector on the EV side. Mode 1 is prohibited in the USA, because not all domestic installations have the required grounding. For Mode 3 charging, only Case C occurs. As a result, the EV user can charge at all Mode 3 charging infrastructure, because they are all equipped with a cable that has a Type 1 connector. Thus, in the USA and Japan, the EV user only needs to carry a cable for Mode 1 or Mode 2 charging.

In Europe on the other hand, both Type 1 and Type 2 EV inlets occur. Therefore, two types of Mode 1 and Mode 2 charging cables exist. For Mode 3 charging, both Case B and Case C charging are used. The advantage of Case B charging is that all different combinations of EVSE sockets and vehicle inlets are compatible, by making use of the appropriate charging cable. Therefore, Case B is typically used for public charging with currents up to the allowable limit of 32 A. are used occur for Case B charging infrastructure, but in most geographic areas there is a preferred socket type [18].

Thus, despite the two types of vehicle inlets and the two types of EVSE sockets that occur in Europe, a specific vehicle only needs one cable for Mode 3 charging within a geographic area [18]. The EV user needs to carry a cable for Mode 1 or Mode 2, and a cable for Mode 3 charging. In areas without a preferred EVSE socket type, e.g. Belgium, an EV user needs two cables to be able to use all Case B Mode 3 charging infrastructure. This is a significant disadvantage for the rollout of EVs.

For Mode 3 Case C charging, the infrastructure needs to be compatible with two different types of EV inlets. Therefore, Case C charging is typically only used for public charging with currents higher than 32 A, because two types of connectors are required to supply all types of EVs. At private locations, where the inlet type of the EV is known, e.g. at home or at the workplace, Case C charging could be implemented as easy as Case B.

A commonly occurring configuration for public charging infrastructure in Europe is supplied with both a standard domestic socket and Type 1 or Type 2 socket. This guarantees that all EVs can be charged due to the presence of the domestic socket, and that Mode 3 charging is possible with the appropriate charging cable.

CONCLUSIONS

There are many different compatible EV charging options, of which several occur at locations where vehicles are typically parked for a relatively long time anyway. This positively impacts the rollout of EVs, and it is an advantage

compared to ICEVs, which always need to visit a petrol station for refuelling.
Even though the power rating for Mode 1 and 2 charging is relatively low, the widespread availability of domestic sockets creates many charging opportunities. Therefore, these charging modes should remain to be valid options in the future. In addition, dedicated Mode 3 charging infrastructure allows charging at a higher power rating, which reduces the charging time.
Contrary to the USA and Japan, different types of EV inlets and EVSE sockets occur in Europe. However, there is no significant negative impact on the rollout of EVs in areas with a preferred EVSE socket type, when opting for Case B charging. Then, the EV user only needs one cable type to connect the EV to the EVSE infrastructure within the area. In areas without a preferred EVSE socket type, it is recommended that a choice is made as soon as possible.

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