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Unification Requirements of Electric Vehicle Charging Infrastructure

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ABSTRACT

By increasingelectric vehicles in numbers and getting the public attention, availability, safety and accessibility of its charging infrastructure are key factorsto users' satisfaction. Charging infrastructure in electric vehicle industry can have a role as an interface for exchanging information among other components as well. Currently, lack of universality in electric vehicle industry has caused anisolation in networks of electric vehicles. This isolationwill cause difficulty in having an aggregated set of information about electric vehicles and their consumption pattern. The paper reviews current charging infrastructure and the possibility of providing universality based on candidate protocols and technologies.

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1. INTRODUCTION

Charging infrastructure (CI) is an important entity of power grid. Availability of this infrastructure is a key factor in general acceptance of Electric Vehicles (EV) [1]–[3]. In addition to the physical charging facilities, CI is a central communication interface among EV, Electric Vehicle Supply Equipment (EVSE), Power Grid, and energy suppliers [4], [5]. The data returning from EV through charge point (CP) can be used for monitoring, scheduling, energy distribution controlling during peak hours, and managing the energy consumption during off-peak hours. Currently, the lack of a universal communication interface in CI is a major issue in EV industry. Standard Development Organizations (SDOs) prepared a few terminologies and methodologies which have been used by EV manufacturers, EVSE manufacturers and EVSE service providers (SP) [3]. A successful deployment of EV requires a unified charging platform which is reliable and available in both public and private spots [1], [6], [7]. The importance of unification in charging platforms can be highlighted while discussing Smart Grid and Vehicle-to-Grid (V2G). Smart Grid and V2G are future technologies which will have a wide array of advantages and opportunities for Electric Vehicle Owners (EVO) and energy suppliers [8]–[10].

A smart grid is an electricity grid which uses different digital communications and other advanced technologies to monitor and manage the transport of electricity. Smart grid is able to carry out remote maintenance, predictive and detective functionalities for maintaining and repairing grid as well as pricing facilities for end users [11]–[13]. V2G is a part of smart grid which uses the information collected from EVs for power management and provides the facilities to send the energy from EV back to the grid [8]–[10]. Smart grid and V2G require a unified communication interface able to send and receive information with a bidirectional energy flow. In smart grid, EVs are integrated into the energy system and they turn the grid from a consumption-oriented production system to a production-oriented consumption system. As illustrated in Figure 1, between every energy consumer, power plants, and the power distribution control center, in addition to the power lines, there is a communication line for sending and receiving data and messages.

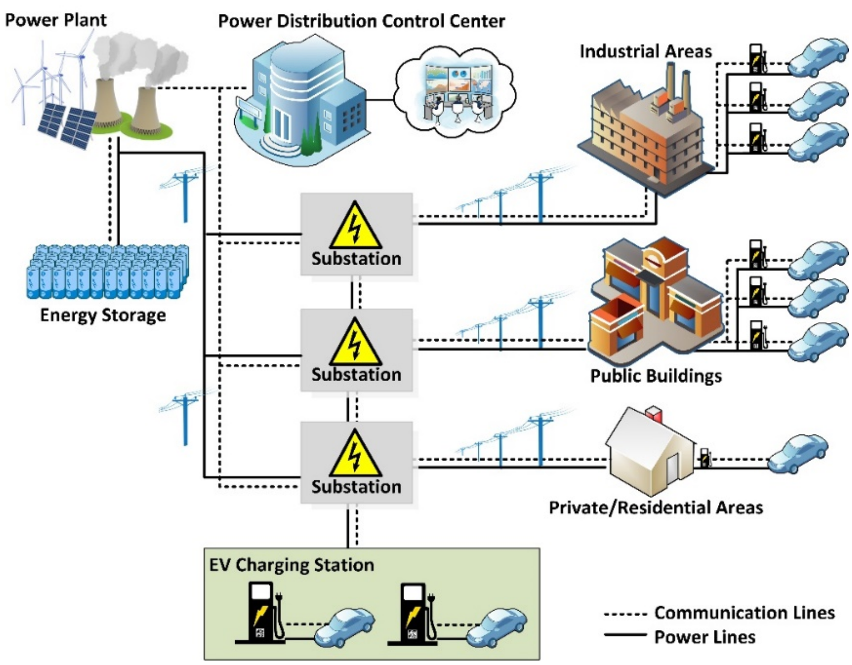

Figure 1. Power and Communication Lines in Future Smart Grids

In this paper, current CI is reviewed and the candidate components and technologies which are able to provide a universal CI are introduced. The paper is organized as follows: in section 2 the components of CI are reviewed. Section 3 discusses on the suitable entities and communication methods able to provide universality. Finally, some conclusions are presented in section 4.

2. CHARGING INFRASTRUCTURE

CI consists of different components, but the term generally refers to EVSE and the charging stations provided to recharge the EV battery. EVSE is basically the conductor, EV connector, attachment plugs and all other devices which are being used for the purpose of delivering energy to the EV. Although the charging process mostly happens during the night at home or in parking lots during the day, availability of a public charging station is an important factor in penetration of EVs [1], [6], [7]. Moreover, the universality in CI can address range anxiety. Range anxiety is the fear of being left on the road with an empty battery where there is no charging station [6], [14] or lack of any CI in which the EVO has registered. Range anxiety can be considered as another impact on market acceptance of EVs [14], [15].

There are three different types of EVs on the road: battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV), and hybrid electric vehicle (HEV). In HEV, the source of energy is gasoline. In order to recharge the battery in BEV and PHEV, the vehicle needs to be plugged into an external source of energy using the proper EVSE and charger [16].

2.1. Chargers

EV Battery chargers are important entities of CI. An EV battery charger must be efficient and reliable, with high power density, low cost, and low volume and weight [17]. These chargers can be categorized into on-board, off-board, unidirectional, bidirectional, conductive, and inductive chargers with support for different charging levels and charging modes.

2.1.1. On-board and Off-board Chargers

Depending on the location of the charger, EV chargers are classified into two groups of off-board and on-board chargers. An on-board charger is located inside the EV and allows the EVO to plug in the vehicle to any suitable power source. Because of weight, space, and cost of a charger, on-board chargers limit the power which means the charging period will be long [17]–[21]. On the other hand, an off-board charger does not have this limitation since it is installed on an external CI. The off-board charger is used for high-power direct current (DC) fast charging. The on-board charger is used together with alternating current (AC) EVSE [18], [19]. In off-board chargers, the communication between EVSE and the battery is a digital communication line such as power line carrier (PLC) or controller area network (CAN) [19]. Extra cost of redundant power electronics, risk of vandalism, and added clutter in an urban environment are considered as disadvantages of off-board chargers [17], [22]. Nevertheless, they are fast and the availabilityof off-board chargers are important in general acceptance of EVs [1], [6], [7], [14], [15].

2.1.2. Unidirectional and Bidirectional Chargers

The EV charger can be unidirectional or bidirectional power flow. Unidirectional is the traditional method of charging which is simple and needs less hardware [23]. Its simplicity makes it relatively easy for a utility to manage heavily loaded feeders due to multiple EVs [17], [23]. Unidirectional chargers can only charge the EV and unlike bidirectional chargers, they are not able to inject energy back to the grid [17]. However, additional hardware and equipment is necessary for bidirectional charging to provide the ability to injectthe energy back from EV to the grid [7], [24]. In order to satisfy V2G requirements, the charger needs to be able to transmit bidirectional power flow [4], [25]–[30].

2.1.3. Inductive and Conductive Chargers

In conductive charging, there is a physical hard-wired direct connection between the EV and the charger. This kind of charging uses a metal to metal contact the same as most of other electric devices [17], [18], [31]–[33]. In conductive charging, based on the charging level or charging mode, proper cable and charging type must be used [18]. The main disadvantage of these chargers is that the EVO must plug in the cable [17].

Inductive charging of EVs is based on magnetic contactless power transfer [17], [31], [32]. The first publication of SAE J1773 in 1995 provides a development practice for inductive charging. The document is stabilized in 2014which states that in inductive charging the same charger can be used for any vehicle [34]. In these kind of chargers, there is no wired connection between EV and the charger [18] and it transfers the power magnetically. The main advantage of these chargers is their convenience [17], [35] but low efficiency, complexity, size, and cost are considered as their disadvantages [17], [36]–[38].

2.2. Electric Vehicle Standards

Reliability, availability, safety, efficiency, and time are important factors in charging an EV and the widespread acceptance of EV depends on these factors [39]. Currently, different EV-related standards are provided byInternational Organization for Standardization (ISO), International Electrotechnical Commission (IEC), Society of Automotive Engineers (SAE), and other SDOs to address the connectors, safety, communication, charging topology, and interoperability. Table 1 summarizes these standards.

Table 1. Standards of Electric Drive

Measure	Standards
Connector	SAE J1772, IEC 62196-1, IEC 62196-2, IEC 62196-3, GBT20234-2, GBT20234-3
Safety	IEC 60529, IEC 60364-7-722, ISO 6469-3, ISO 17409, SAE J1766, SAE J2344, SAE J2929, SAE J2578, SAE J2464, SAE J2380
Communication	SAE J2931/1, SAE J2931/2, SAE J2931/3, SAE J2931/4, SAE J2931/5, SAE J2931/6, SAE J2931/7, SAE J2847/1, SAE J2847/2, SAE J2847/3, SAE J2847/4, SAE J2847/5, SAE J2847/6, ISO/IEC 15118, IEC 61851-24, IEC 61850, IEEE 80211P, GBT 27930
Charging Topology	SAE J2836/1, SAE J2836/2, SAE J2836/3, SAE J2836/4, SAE J2836/5, SAE J2836/6, IEC 61851-1, IEC 61851-21, IEC 61851-22, IEC 61851-23, GBT20234-1, IEEE P2030.1, IEEE P2030.2, IEEE P2030.3, IEEE P1547/1, IEEE P1547/2, IEEE P1547/3, IEE P1901.2
Interoperability	SAE J2953/1, SAE J2953/2

SAE and ISO are principal SDOs in developing EV standards. As stated by SAE, SAE J1772 was the first standard which was publicly accepted and used by industry [40], [41]. SAE J1772 is a standard for electrical connectors of EVs which defines a common EVSE for conductive charging together with functional and dimensional requirements [33]. On the other hand, the European Commission issued a standardization mandate to the European standardization bodies in 2000 concerning the charging of EVs. As a result, IEC 61851 was founded which contains the standards available at European level, dealing with the charging system, plugs and sockets [42]. However, SAE is the only SDO defining standards on interoperability (SAE J2953/1, SAE J2953/2) and its goal is to create a charging station and a charger and all systems have to be compatible with them [43].

Currently, basic standards exist to support the transition to EVs [44], but still some standards are required to control data communication between components of an EV network. Thesestandards must address the communication between CP and Central System (CS), EVO and CP, EV and CP, and also the communication between CS of different networks. By having unified networks of EVs and interoperable interfaces we can ensure a market that is strong, safe, worldwide, and sustainable.

2.3. Charge Point as a Communication Interface

CP in an off-board charger located in charging station plays an important role in CI and in the future power grids. In addition to providing physical charging facilities, CP can also be considered as a communication interface for exchanging data between different entities of a supply network and network of EVs [4], [5]. Currently, there is a set of standard communication protocols between EV and CP, in terms of hardware, power flow and data transactions which are being controlled by major SDOs [40], [42], [44]. But there is no standardized way of communication between CP and CS. Although Open Charge Point Protocol (OCPP) is introduced to address this issue, it has not been officially announced as a standard yet [45]–[47]. However, it is accepted and it is being followed by EV industry.

OCPP is an open protocol that provides a uniform communication between CP and CS. The goal of OCPP is to provide a uniform communication between any CP regardless of the manufacturer and CS [48]. By using OCCP as the communication protocol between CP and CS, SPs are free to change or upgrade the CPs without changing their CSs' application. They also will be able to use different types of CPs from different manufacturers based on geographical and climate situation of CPs' installation spots.

By having standards to control communication methods between all entities of a CI in a dynamic and grid-responsive bidirectional manner, we can integrate EVs into the energy system with the capability of demand response [4], [5], [44], [49]–[51].

2.4. Charging Modes and Levels

Although there are a few different terminologies and plugs, SDOs has a major role in acceptance and use of each. The success of EVs depends on standardization of infrastructure, efficient and smart chargers, and enhanced battery technologies [17]. Currently, there are 2 different terms about charging: Mode and Level [52]. "*Level*" is mostly used in North America, introduced by SAE and "*Mode*"is used by the European-based SDOs. But referring to those standards, "charging level" concentrates on the power level of a charging outlet and "charging mode" addresses the safety between EV and charging station.

Each mode has different capacities and provides different communication methods between EV and EVSE. Safety parameters increase from mode 1 to mode 3. Therefore, mode 3 is recommended for public EVSEs and mode 2 is recommended for charging at home or private parking lots [53]. Mode 1 is the simplest mode without any safety measures. Charging at this mode is not allowed in some countries, such as UK [54], [55]. Mode 4 is a DC fast charging using an external charger normally in public places. In this mode, the charger is part of the charging station (off-board charging) [54].

SAE J1772 defines EV charging system architecture in which the physical and electrical requirements of EV charging system are defined. Based on this standard three levels of charging are defined and being used in North America [42]. Charging speed increases from level 1 to level 3. Level 1 which is considered as the slowest charging level uses single-phase AC outlet and it is suitable for private areas. Level 2 which can be single-phase or three-phase is suitable for public and private areas with 13A to 32A power level. Level 3 is a commercial fast DC charging level suitable for public areas. This level is rarely used in private areas [23], [56].

2.5. Charging Types

For each charging mode or charging level, a specific charging type is required. The charging type describes the physical connection between vehicle and charging station. Currently, the widely accepted charging types are based on SAE and IEC standards. Table 2 summarizes these types and other plugs being used in EV industry.

Table 2. Charging Types and Plugs

Type	Description
IEC 62196-2 Type 1	Single-phase vehicle couplers not exceeding 250 V, 32 A.
IEC 62196-2 Type 2	Single-phase or three-phase vehicle couplers not exceeding 480 V, 63 A (three-phase) or 70 A (single-phase).
IEC 62196-2 Type 3	Three-phase vehicle couplers not exceeding 480 V, 63 A with 2 pilots.
[42], [55]	Single-phase vehicle couplers not exceeding 250 V, 16 A single-phase (with 1 pilot) or 32 A (with 2 pilots).
SAE J1772	Standard connector for EVs in the USA, developed by the SAE and accepted by IEC. It can be used for AC Level 1 (120V) or AC Level 2 (240V) charging. This connector is connector is considered as IEC 62196-2 Type 1 [42]
SAECombo	Integrates single-phase AC charging (Type 1), fast three-phase AC charging (Type 2), and DC quick charging into one vehicle inlet with PLC as data communication interface.
CHAdeMO	Quick charging plug developed by the CHAdeMO Association, Japan. Used in level 3 chargers capable of delivering up to 62.5 kWh of DC with CAN Bus as data communication interface.

The combination of AC and DC into one coupler was introduced by SAE in SAE J1772 in 2012 [33], [57]. The coupler which combines DC level 2 with AC is called SAE Combo. Inlet and plug in SAE Combo is depicted in Figure 2. This coupler is a combined charging system capable of low-level signaling and high-level communication using PLC interface. Details of messaging standards can be found in SAE J2874/2 [33], [58].

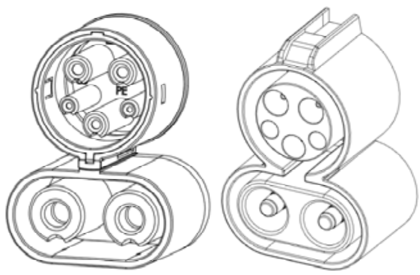

Figure 2. SAE Combo Inlet and Plug [33]

A variation of the combo connector is also adopted in Europe. In 2013, the European automakers agreed to have a universal charge type which combines AC and DC charging into one plug. This charging system which is called Combined Charging System (CCS) [53] is going through IEC standardization, and it will be used for AC and DC charging with the capability of delivering up to 100 kW power [42]. Currently, CHAdeMo is the standard quick charging plug for DC. In a report published in 2013 the European Committee on Transport and Tourism decided to terminate using CHAdeMO technology, but because at the moment CCS is not ready to be used, termination of CHAdeMO is postponed to a deadline at which the CSS can be deployed [59].

3. DISCUSSION

Standardization and unification in any industry are vital and lack of standardization will lead to fragmentation in the industry. Therefore, standardization in EV industry needs more attention, since the confusion and dissatisfaction of consumers will lead to failure of the technology. That is why as their major role, SDOs are addressing every aspect of this technology; connectors, safety, communication, charging topology, and interoperability. However, cooperation between SDOs is also important in order to be able to achieve a unified EV industry. Currently, the most suitable charging type which is suggested by SAE, SAE Combo, seems to satisfy different needs of EVs. This charging type supports different levels and modes of charging and uses PLC as the communication method between EV and CP [33], [60], [61]. Therefore, the proper plug and inlet needs to be installed on CPs and EVs during manufacturing. The general acceptance of SAE Combo as a universal charging type can be considered as a major step towards unification of EVSEs, but the network of EVs still needs more considerations.

SP is the one who invests in installing CPs, establishing charging stations and forming EV networks. In addition to charging stations, SP will also provide back-end software for EVOs to track their bills, review their charging schedules, and evenlocatethe charging stations. A group of EVOs registered under the same SP in order to use charging equipment (CPs) specified by the SPis considered as a network. Figure 3 illustrates an EV network of public and private CPs.

By having standards supporting unified technologies, we can achieve a network of EVs with the ability of having universal communications and interactions among its components. A standard communication method between CP and CS will make it possible for SP to install CPs regardless of the manufacturer. Moreover, a direct communication between CSs of different SPs, together with universal CIs accelerates achieving a network of EVs in which EVOs can charge their EVs without considering the CP manufacturer, SP, charging type, and charging mode. As a result, a universal network of EVs not only facilitates the EVOs, also it will provide a set of information usable in Business-to-Business (B2B) applications, future Smart Grid, and V2G.

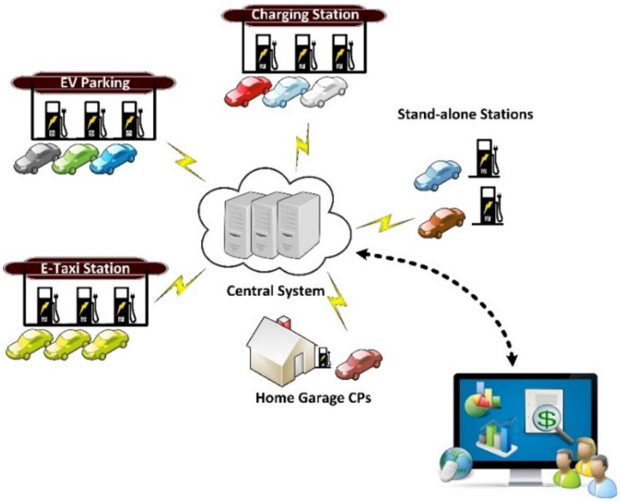

Figure 3. A Network of Electric Vehicles

4. CONCLUSION

This paper reviewed current EV CI and the possibility of its universality. CI as an important part of EV industry, needs to be universally standardized in order to be able to collect required information for B2B applications and being used as an interface for the future smart grid and V2G. A universally accepted CI, together with unified communication protocols between its components, can provide ease of use, ease of access and a database of valuable information for all stakeholders.

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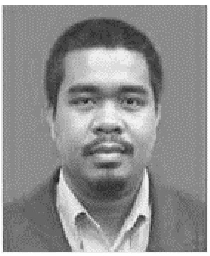

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