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Beyond the Plug and Socket: Towards Safe Standardized Charging Infrastructures

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Abstract

This paper will present the current evolution in the field of charging infrastructure standardization, highlighting the main development areas of safety, compatibility and performance, also giving special interest to ongoing European developments in the field as well as to the residential charging field.

Keywords: standardization, infrastructure, conductive charging, European union

1 Background

1.1 Generalities

In urban traffic, due to their beneficial effect on environment, electrically propelled vehicles are an important factor for improvement of traffic and more particularly for a healthier living environment.
The operation of the electrically propelled vehicle is dependent on the availability of efficient electric energy storage devices: the traction batteries. To allow the use of cheap and clean electric energy from the grid, recharging infrastructures shall be available to transfer electric energy from the distribution grid to the battery. Although wireless systems are being considered and standardization work is ongoing, this paper will focus on conductive charging, presenting the current evolution in the field of charging infrastructure standardization and giving special interest to ongoing European developments in the field.

1.2 Global standardization bodies

Standardization, on a global level, is mainly dealt with by two institutions: the *International Electrotechnical Commission* (IEC), founded in 1904, deals with all things electrical, whileas the *International Organization for Standardization* (ISO), founded in 1948, deals with all other technologies. With standardization of the electric road vehicle becoming a key issue, the question arises which standardization body would have the main responsibility for electric vehicle standards. This problem is less straightforward then it looks: the electric vehicle, which introduces electric traction technology in a road vehicle environment, represents in fact a mixed technology, being both a ”road vehicle” and an ”electrical device”.

Collaboration between ISO and IEC in the field of electric vehicles has been established since the foundation of the respective working groups, ISO TC22 SC21 and IEC TC 69, in the early 1970s. During the years however, there have been considerable discussions between the two groups as to the division of the work; a consensus was agreed defining the specific compentences of the respective committees, as shown in Table 1.

Table 1: Basic division of work IEC/ISO

ISO	IEC
Work related to the electric vehicle as a whole	Work related to electric components and electric supply infrastructure

1.3 European standardization: EV activities of CENELEC and CEN

Within Europe, CENELEC and CEN operate as the pendants of IEC and ISO. Both have been active in electric vehicle standardization in the 1990s, through their technical committees CENELEC TC69X and CEN TC301. However, much of this work was parallel to the global standardization work, with the European standards created superseded by international standards when these were available (such as prEN50275 vs. IEC61851 and EN1987 vs. ISO6469).
Both committees went dormant around the turn of the century. TC301 however was reactivated as a general CEN technical committee dealing with road vehicles. TC69X was reactivated in 2011 following the activities of the Focus Group (see 1.5), with the aim of expediting the European adoption of IEC TC69 documents.

1.4 The EU mandate M/468

On 29 June 2010 the DG Enterprise & Industry of the European commission issued Mandate M468 concerning the charging of electric vehicles [1]. Its scope was to develop or review existing standards in order to:

- Ensure interoperability and connectivity between the electricity supply point and the charger of electric vehicles, including the charger of their removable batteries, so that this charger can be connected and be interoperable in all EU States1.
- Ensure interoperability and connectivity between the charger of electric vehicle- if the charger is not on board- and the electric vehicle and its removable battery, so that a charger can be connected, can be interoperable and re-charge all types of electric vehicles and their batteries.
- Appropriately consider any smart-charging issue with respect to the charging of electric vehicles.
- Appropriately consider safety risks and electromagnetic compatibility of the charger of electric vehicles in the field of LVD Directive 2006/95/EC [2] and EMC Directive 2004/108/EC [3].

The mandate was addressed not only to CEN and CENELEC, but also to the telecommunications standards body ETSI. The standards bodies were requested to develop European standards or to review existing standards in order to:

- Ensure interoperability and connectivity between the electricity supply point and the charger of electric vehicles, including the charger of their removable batteries, so that this charger can be connected and be interoperable in all EU States.
- Ensure interoperability and connectivity between the charger of electric vehicle- if the charger is not on board- and the electric vehicle and its removable battery, so that a charger can be connected, can be interoperable and re-charge all types of electric vehicles and their batteries.
- Appropriately consider any smart-charging issue with respect to the charging of electric vehicles.
- Appropriately consider safety risks and electromagnetic compatibility of the charger of electric vehicles in the field the low voltage and EMC directives.

1.5 CEN/CENELEC actions

To respond to the demands of the mandate, CEN and CENELEC constituted the *Focus Group on European Electro-Mobility - standardization for road vehicles and associated infrastructure* as an (informal) joint working group, reporting to the CEN and CENELEC Technical Boards.
This Focus Group had a very wide participation, including representatives of the CEN and CENELEC national members often from local industry or Governments - and of all major European associations of stakeholders in the field. Its final report [4] formulated a number of recommendations affecting the development of electric vehicle standardization issues in Europe. It is aimed at the relevant international standards committees, as well as the corresponding European technical committees in the framework of CENELEC.
Also, interaction with regulatory bodies shall be established, on one hand concerning vehicle type approval which are dealt with by UNECE regulations [5], on the other hand with electric wiring regulations which may differ strongly between different countries. Electrical safety is a vital requirement and protection against electric shocks remains the key driver of electric equipment standardization.
As a follow-up to the Focus Group, and following one of its recommendations, an Electro-Mobility Co-ordination Group has been constituted by CEN and CENELEC with the aim to support coordination of standardization activities during the critical phase of writing new standards or updating existing standards on Electro-Mobility, and make recommendations accordingly.

1.6 The proposed European Directive

A proposal for European directive on the deployment of alternative fuels infrastructure [6] was circulated in January 2013. This document is framed within the "EU Clean Fuel Strategy" and announces an ambitious package of measures to ensure the build-up of alternative fuel stations across Europe with common standards for their design and use. Regarding electric mobility, the target is very ambitious concerning the number of charging points to be deployed in Europe: 7900000 charging points by 2020, with at least 10% of these charging points being publicly accessible. The proposed directive also states technical specifications to which member states will have to comply.

2 Conductive charging standardization

2.1 Generalities

The main reference documents for conductive charging are the IEC61851 family of standards. The first part, dealing with general requirements, was first published in 2001 [7]. Revision was started with the reactivation of IEC TC69 WG4 in 2005, leading to the publication of the second edition in 2010 [8].
The parts 21, dealing with electric vehicle requirements, and 22, dealing with the requirements for a.c. charging stations, were also published in 2001 [9, 10]. The revision work on these parts created the need however for a new version of part 1, which is now being drafted and circulated as CD in 2012 [11] and 2013 [12].
Part 21 was reoriented for the new edition: the vehicle requirements proper were transferred to ISO (as vehicle-related issues are ISO's province) into a new document ISO17409 which was circulated as CDV in 2013 [13], with Part 21 focusing on EMC issues for charging (see also 2.4).
The requirements for the a.c. vehicle charging station will be treated in the new edition of Part 1, so that Part 22 will be withdrawn.
Parts 23 and 24, dealing with d.c. charging, were circulated as CDV in 2012 [14, 15] and will be FDIS by the end of 2013.
To cover the specific needs of light electric vehicles, a new work item proposal was adopted in 2012 [16].

2.2 Charging modes for conductive charging

A key concept in conductive charging are the so-called *charging modes*, introduced in the international standard IEC61851-1 [8].

2.2.1 Mode 1 charging

Mode 1 charging refers to the connection of the EV to the a.c. supply network (mains) utilizing standardized socket-outlets (i.e. meeting the requirements of any national or international standard), with currents up to 16A. This corresponds to non-dedicated infrastructures, such as domestic socket-outlets, to which electric vehicles are connected for charging.
These socket-outlets can easily and cheaply deliver the desired power, and due to their availability, Mode 1 charging is the most common option for charging electric vehicles, particularly when existing infrastructures are to be used.
There are however a number of safety concerns to be taken into account. The safe operation of a Mode 1 charging point depends on the presence of suitable protections on the supply side: a fuse or circuit-breaker to protect against overcurrent, a proper earthing connection, and a residual current device (RCD) switching off the supply if a leakage current greater than a certain value (e.g. 30mA) is detected.
In most countries, RCDs are now prescribed for all new electric installations. There are however still a lot of older installations without RCD present, and it is often difficult for the EV user to know, when plugging in, the vehicle, whether or not a RCD is present. Whileas some countries leave this responsibility to the user, Mode 1 has therefore been outlawed in a number of countries such as the United States.
Furthermore, some countries like Italy do not allow Mode 1 charging for charging places accessible to the public and limit its use to private premises, out of concern that live standard socket-outlets in public places may be exposed ito the elements, vandalism or unauthorized access.
In countries where the use of Mode 1 charging is allowed, it will remain a preferred mode for private premises (including residential garages as well as corporate parking lots) due to its simplicity and low investment cost. With a proper electrical installation including RCD, Mode 1 allows charging in full safety.
However, the uncertainty faced by the user about the presence of an RCD when plugging in the electric vehicle in an arbitrary standard outlet makes that a potential hazard may be present. For this reason, Mode 1 charging is being abandoned in favor of Mode 3, with Mode 2 as a transitory solution.
Mode 1 charging is now only considered as the main mode for small vehicles such as two-wheelers. [4]

2.2.2 Mode 2 charging

Mode 2 charging connection of the EV to the a.c. supply network (mains) also makes use of standardized socket-outlets. It provides however additional protection by adding an *in-cable control box* (ICCB) with a control pilot function (cf. 2.2.5) between the EV and the control box.
The introduction of Mode 2 charging was initially mainly aimed at the United States, as a transitional solution. It is now however receiving global interest to replace Mode 1 for charging at non-dedicated outlets.
The main disadvantage of Mode 2 is that the control box protects the downstream cable and the vehicle, but not the plug itself, whereas the plug is one of the components more liable to be damaged in use.
This is particularly the case when considering the typical load profile of an electric vehicle charging which involves drawing a relatively high current during several hours. Standard domestic accessories are designed to draw their nominal 16A

current for one hour and will overheat and degrade faster. For this reason, most Mode 2 cables fitted with domestic plugs have their current limited to 10A (see also 3.1.1). If industrial style accessories such as IEC60309-2 [17] are used, the full 16A current can be drawn in permanence without problems.
Furthermore, the use of the ICCB is not elegant and not always very practical, e.g. in public environments.
The ICCB for Mode 2 will be described in the standard IEC 62752 [18].
The CEN-CENELEC Focus Group recommended that occasional charging on private premises should preferably be done using mode 2 to ensure RCD protection. [4].

2.2.3 Mode 3 charging

2.2.4 Definition

Mode 3 charging: involves the direct connection of the EV to the a.c. supply network utilizing dedicated electric vehicle supply equipment. This refers to private or public charging stations. The standard IEC61851-1 [8] mandates control pilot protection between equipment permanently connected to the a.c. supply network and the electric vehicle.

2.2.5 Control pilot

For Mode 3 charging, the IEC 61851-1 standard foresees additional protection measures to be provided by the so-called *control pilot*, a device which has the following functions mandated by the standard:

- verification that the vehicle is properly connected
- continuous verification of the protective earth conductor integrity
- energization and de-energization of the system
- selection of the charging rate (ampacity)

This function is typically performed through an extra conductor in the charging cable assembly, in addition to the phase(s), neutral and earth conductor. Annex A of IEC61851-1 specifies the control pilot circuit given in Fig. 1, showing the operation of the system. A control signal (1 kHz PWM) is sent through the control pilot conductor. The switch on the vehicle allows to control the charging, whileas the duty cycle of the PWM signal controls the current absorbed by the charger, thus allowing dynamic ampacity control. When no vehicle is connected to the socket-outlet, the socket is dead. This provides a key safety advantage particularly for publicly accessible charging points. Power is delivered only when the plug is correctly inserted and the earth circuit is proved to be sound.

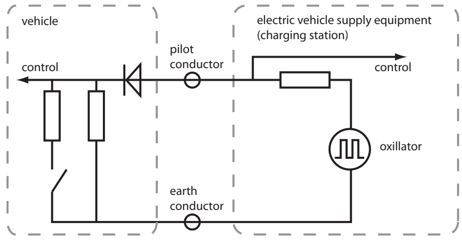

Figure 1: Control pilot conductor

The connection process shall be such that the earth connection is made first and the pilot connection is made last. During deconnection, the pilot connection shall be broken first and the earth connection shall be broken last. This sequence also ensures that the current is interrupted at the contactor and not at the power contact pins of the plug, thus eliminating arcing and prolonging the service life of the accessories.
The use of a control pilot function with fourth wire is also included in the SAE standard J1772 [19].

2.2.6 Control pilot alternatives

The use of a dedicated conductor for the control pilot necessitates an extra conductor and thus the use of special cables and accessories.

2.2.7 Implementation of Mode 3

The inherent safety features, as well as the potential for smart grid integration, make Mode 3 a preferred solution, it was thus recommended by the Focus Group for public charging stations as well as for home charging using dedicated outlet. [4].

2.2.8 Mode 4 charging

Mode 4 charging is defined as the indirect connection of the EV to the a.c. supply network (mains) utilizing an off-board charger where the control pilot conductor extends to equipment permanently connected to the a.c. supply.
This pertains to d.c. charging stations, which are mostly used for fast charging. As the charger is located off-board, a communication link is necessary for regulated d.c. charging stations to allow the charger to be informed about the type and state of charge of the battery as to provide it with the right voltage and current.

2.3 Standardization for fixed charging infrastructure

The emergence of fixed charging infrastructure for electric vehicles has also prompted other committees to work on the subject.
Concerning the requirements for charging posts in the public domain, IEC SC17D has prepared

IEC61439-7 ”Low-voltage switchgear and controlgear assemblies — Part 7: Assemblies for specific applications such as marinas, camping sites, market squares, electric vehicles charging stations”, which was circulated as FDIS early 2013 [20]; this FDIS was rejected however. This document is to be used with the general standard IEC61439-1 [21].
The subject of charging infrastructure was also taken up by IEC TC64, the committee in charge of ”electrical installations and protection against electric shock”. TC64 is a very powerful committee since its standards have a strong influence on wiring regulations. The general standard IEC60364 ”Low voltage electrical installations” saw the drafting of a special part dealing with supply of electric vehicles: IEC60364-7-722. This document was circulated as CDV in 2012 [22], but was rejected for passing to FDIS stage, having received more than 25% negative votes, and is thus sent back to the working group for revision.

2.4 EMC issues for charging

The influence of the extended use of power electronic converters as used in battery chargers will have to be closely followed up in order to avoid potential problems regarding electromagnetic interference either in the form of radiated electromagnetic waves or as conducted interference on the interconnecting cables. EMC is defined as the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.
EMC is heavily regulated, on one hand by the EMC directive 2004/108/EC [3] which pertains to electric and electronic equipment, and on the other hand by the vehicle EMC directive 2004/104/EC [23] which pertains to road vehicles.
Furthermore there are numerous international standards published by IEC, ISO and CISPR dealing with the matter.
The EMC constraints for road vehicle have been traditionally focused on radiated EMC, more particularly radio disturbances caused by spark-ignition engines, which were at the base of the creation of CISPR (Special international committee on radio interference) in 1934. Grid connection of electric vehicles however brought however the problem of conducted EMC and hence the need for new standards. The various part of standards concerning charging standards covered most of the EMC problems for low frequency phenomena, except in the frequency range between 2 kHz and 150 kHz, a frequency band which contains the typical operating frequencies of power electronic converters as used in electric vehicle traction systems and battery chargers. It will thus be necessary that this frequency range is addressed by standardization.
The low frequency range below 2 kHz is mostly relevant for conductive emissions (power quality and harmonics), for which limits are give by international standards such as IEC61000-3-2 [24] and 61000-3-12 [25].

New standardization work on EMC for electric vehicle charging were undertaken with the revision of IEC61851, where the Part 21 will focus on EMC issues, bringing together all relevant requirements. This document will have two parts, focusing respectively on on-board and off-board charging systems. Both were circulated as CD in 2012 [26, 27].

2.5 Regulatory issues of charging

The difference in national electric regulations and wiring codes constitutes a major challenge for the specification of a pan-European charging system.
Some nations require shutters for socket-outlets in domestic environments, while others do not.
Furthermore, the extension of the scope of the Low Voltage directive [2] has to be defined. Domestic socket-outlets are not subject to LVD, whileas industrial ones (60309-2) do, this type of plug being harmonized. Dedicated charging equipment will be clearly within the scope of the LVD. The vehicle does not, the applicability of LVD on the vehicle inlet (which is coupled with a connector according to the same standard) is still a matter of discussion however.

3 Accessories for charging

3.1 Connection to the a.c. network: plug and socket-outlet

3.1.1 Standard domestic plugs

For Mode 1 and Mode 2 charging, (also for Mode 3 charging with power-line communication), standard plugs and sockets can be used encompassing only phase, neutral, and earth contacts. In most areas, this will usually be the standard domestic plugs as described in various national standards, and typically rated 10 to 16A [28].
One has to recognize however that these domestic plugs, particularly not the low-cost versions mostly used on consumer grade equipment, are not really suited for the heavy-duty operation of electric vehicle charging, characterized by

- long time operation at near rated current
- frequent operation, including disconnection under rated load
- exposure to outdoor conditions.

This leads to a shorter lifetime of the accessories and to contact problems which may cause hazardous situations. It is thus recommended to limit the rating of the charging equipment using such plugs to a lower value, up to 10A, their use being confined to small vehicles such as scooters (for which this current level is largely sufficient), as well as for occasional charging of larger vehicles (the ”grandma” solution).

3.1.2 Standard industrial plugs

A better alternative is to use industrial plugs and sockets as defined by the international standard IEC60309-2 [17]. These plugs (in standard blue colour for 230V, red for 400V) are widely used, particularly in Europe, for industrial equipment but also for outdoor uses like camping sites, marinas, etc., where they function in an operation mode comparable to an electric vehicle charging station. Both plugs/sockets and connector/inlets are available in the IEC60309-2 family. The relatively high insertion force, particularly for higher current versions, has been cited as an issue affecting user-friendliness for electric vehicle deployment.
These accessories are widely spread on the market and are relatively inexpensive, making them the preferable solution for Mode 1 or Mode 2 charging. The Focus Group [4] proposed them as interim solution pending development of dedicated accessories.

3.1.3 Dedicated plugs

The use of a physical control pilot conductor necessitates the introduction of specific accessories for electric vehicle use. Such plugs and sockets are described in the international standard IEC62196 ”Plugs, socket-outlets, vehicle couplers and vehicle inlets - Conductive charging of electric vehicles”.
Part 1 of this standard [29] gives general functional requirements; it integrates general requirements from the industrial plug standard IEC60309-1 [30] with the electric vehicle requirements of IEC61851-1 [8].
Physical dimensions for a.c. accessories are treated in part 2, was published in 2011 [31]. It does present standard sheets for several types of plugs and socket-outlets:

- Type 2
  Type 2 is a three-phase plug rated for currents up to 63A, and has two auxiliary contacts. It is illustrated in Fig. 2 and based on a realisation by the German company Mennekes. The need for three-phase accessories was expressed by European car manufacturers and utilities, recognizing the potential benefits of three phase charging and the availability of three phase supply in most European countries.

Figure 2: Type2 plug

- Type 3
  Type 3 is also a three-phase type, it is illustrated in Fig. 3 and based on a design by Italian company SCAME further adopted by the ”EV Plug Alliance”. Its design is derived from a single phase plug adopted as national standard in Italy [32] where it is in widespread use particularly for light electric vehicles such as two-wheelers.

  One main difference between Type 2 and Type 3 accessories is the presence of ”shutters” on the latter, providing IPXXD protection.

Figure 3: Type3 plug and socket-outlet

The CEN-CENELEC Focus Group recommended to define one unique footprint for the a.c. plug and socket outlet, encompassing five power contacts (three phases, neutral, earth) and two auxiliary contacts to allow Mode 3 charging. Both Type 2 and Type 3 fit this definition, the choice however will be influenced by external factors such as national wiring regulations which in some countries require shutters for all socket outlets in domestic environments.
The proposed European directive on the deployment of alternative fuels infrastructure [6] however prescribed the use of Type 2 accessories as the standard solution for Europe. Charging points shall comply with this standard by the end of 2015.

3.2 Connection to the vehicle: vehicle inlet and connector

3.2.1 IEC 62196-2 connectors

IEC62196-2 [31] also describes accessories for the vehicle side. Connectors can be made according to the Type 2 and Type 3 geometries described in 3.1.3; one should note however that the plug-side accessories are not intermateable with the vehicle-side accessories.
The standard also describes the Type 1 single phase coupler rated for 250V and 32A (30A in the United States and Japan). It is fitted with two extra contacts: one for the control pilot (CP) and one for an auxiliary coupler contact (CS) which can be used to indicate the presence of the connector to the vehicle and to signal the correct insertion of the vehicle connector into the vehicle inlet. With a diameter of 44mm, this connector is made in a compact way. (Fig. 4) This solution is featured in SAE-J1772 [19] and based on a proposal made by the Japanese company Yazaki. It is intended to be used as vehicle connector only, there is no corresponding plug as US charging stations typically work with a Case ”C” connection.

Figure 4: Type 1 connector

The automobile industry is presently mounting both Type 1 and Type 2 inlets on cars and light trucks, depending of the original market of the vehicle. In Europe, both types can thus be found.

3.2.2 IEC 62196-3 connectors

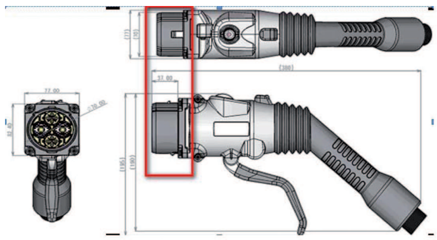

Figure 5: CHAdeMO connector

Accessories for d.c. charging are treated in IEC62196-3 which is presently at CDV level [33]. This will only pertain to connectors and vehicle inlets, as d.c. charging stations will typically use a Case "C" connection.

The standard presents three families of connector, corresponding to the three charging protocols described in parts 23 and 24 of IEC61851 [14, 15]:

- the d.c. connector/inlet proposed by the CHAdeMO association (Fig. 5)
- the d.c. connector/inlet proposed by the Chinese NC (Fig. 6)
- the "Combo" connector/inlet, encompassing both a.c. (Type 1 or 2) and d.c. connections in one unit (Fig. 7). The inlet can be used for a.c. with a Type 1 or 2 a.c. connector, or for d.c. with the combo connector.

In order to further reduce the amount of vehicle real estate used for the inlet, and taking into account the 63A rating of the Type 2 a.c. accessories, it has been proposed to use this system with commutable a.c./d.c. pins. Typical use scenarios of the pins are illustrated in Fig. 8. The combined use of a.c. and d.c. on the same pins has however given rise to safety concerns particularly from the electrotechnical industry where such practices are not common. The injection

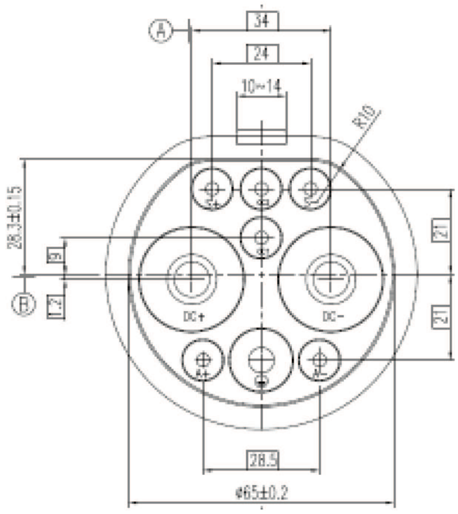

Figure 6: Chinese connector interface

Figure 7: Combo connector example

of d.c. fault currents into the a.c. grid must in fact be impeded in all cases, as the a.c. circuit breakers will not be able to interrupt these d.c. currents. The issue is now under consideration in the standards committees.

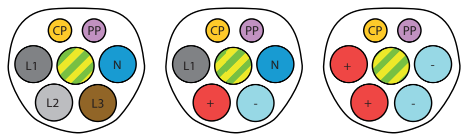

Figure 8: Combined use of Type 2 connector: three phase a.c., single phase a.c. with d.c., d.c.

The distinct parts of IEC62196-2 and IEC62196-3 can be considered "catalogue standards", presenting standard sheets for various solutions without however making a distinct choice for one particular solution.
The proposed European directive [6] prescribes the use of "Combo type 2" connectors for d.c. charging stations. Fast charging points shall comply with this standard by the end of 2017.

4 Residential charging

A large part of the charging operations for electric vehicles will occur in the private sphere (either residentially or commercially), particuoaroy where the vehicles are parked during the night. There is plenty of time to provide a full charge;

in addition, electricity rates are considerably cheaper at night. This means that the vehicle will make use of existing electrical installations in order to charge. The properties of such systems vary widely, and the problem arises if the charge of the vehicle can be carried out in total safety. The electrical installations shall meet certain standards of performance and safety. Moreover, one must consider future developments towards the ”Smart Grid”. Integration of EV infrastructure in the ”Smart Grid” requires, among other things, dynamic control of the charging current. The ”Mode 3” charging described in IEC 61851 has this feature, but requires a special infrastructure and special accessories. The first versions of these home charging infrastructure are proposed already today by various energy companies and car manufacturers. There may be however a considerable business opportunity for specialist companies and SMEs in the field.

Furthermore, the electricians, who will install and maintain the equipment with individual customers, will need specialist formation in order to safely integrate charging infrastructure. The electric vehicle user, both for personal or professional use, will need the assurance that the vehicle can be charged safely, and thereto may have to make appropriate adjustments to the electric installation. To do this, the user needs the necessary expertise. The first point of contact for the user in terms of the electrical installation is and remains the electrician , for whom the infrastructure for electric vehicles defines an expansion of the knowledge domain . For the electrician installing Mode 3 charging infrastructure is a new application with new components (EV socket-outlet, charge controller, pilot wires, ...) and new concepts (charging modes, charge speed, trickle charge, ...) causing the need for specific knowledge. The bearer of this knowledge is the pre-eminent expert on the subject as electrician.

This residential charging is the main subject of the THEO project supported by the Flemish region, aiming to create knowledge instruments for electricians to help them install charging infrastructure for electric vehicles. It will focus on new installations as well as the expansion or renovation of existing infrastructures in the private sector, which consists of residential and commercial environments.

5 Conclusions

The charging of electrically propelled vehicles remains a key issue for future standardization work. As with all standardization matters, charging standards pertain to the three main pillars of the house of standardization: safety, compatibility and performance.

Safety standards ensure protection against electric shock and other related hazards, as well as controlling electromagnetic compatibility issues, allowing the charging infrastructure to be used safely in all its potential environments.

Compatibility standards obviously refer to the definition of suitable plugs and sockets for electric vehicle charging, but also cover the communication needs of charging and allow the electric vehicle to be deployed in an extended area and the infrastructure to be universally usable.

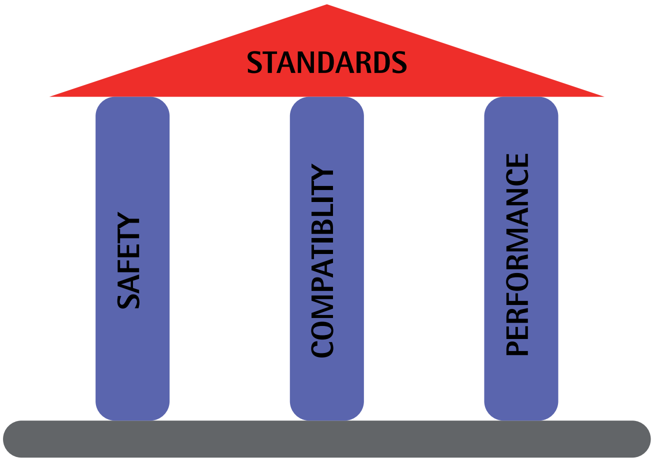

Figure 9: The House of Standardization [34]

Performance measurement standards, in the framework of this study, pertain to the management of energy measurement for billing as well as battery state of charge and state of health.

Intensive work is now being performed by international standardization committees in order to realize unified solutions which will be a key factor in allowing the deployment of electrically propelled vehicles on a global level, highlighting the technical and societal relevance of standardization.

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