Conductive Charging Standardisation Issues

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Abstract

Among different battery charging techniques that are in vogue for electric vehicles, the conductive technology remains up to now the most favoured, mostly because it allows connection of electric vehicles to existing electric power supplies without the necessity for extra infrastructure. However, the advent of electric vehicles in different countries has led to the development of different approaches concerning conductive charging, taking into account specific safety and security issues. To this effect, several conductive charging modes have been defined by standardisation committees. All these modes are fitted to specific applications. The choice of a preferred solution remains a complex one, based on issues both technology, regulations and local ‘’culture’. As the successful introduction of electric vehicles is greatly dependent on the availability of a suitable charging infrastructure, the comparative assessment of conductive charging technologies standardisation is of paramount significance for the promotion of the electric vehicle as a vital factor for improvement of traffic and more particularly for a healthier living environment.

Introduction - Generalities

Electric vehicles are dependent on an external supply of electricity to charge their batteries when needed. At first, most vehicles were charged used fixed, off-board chargers; this is still the case for electric vehicles which operate in a controlled environment such as industrial vehicles.

A number of manufacturer-standardised battery connectors have been developed and are used throughout industry; however, these solutions are typically geared to be used by trained personnel on one hand, and their design takes into account the low voltage levels typical for such vehicles on the other hand.

Roadgoing vehicles are now most often fitted with on-board chargers. The advent of power electronics has made lightweight chargers possible, dispensing with the need of a heavy mains-frequency transformer. Furthermore, the presence of an on-board charger significantly enhances the operational flexibility of the vehicle.

For the connection of the electric vehicle to the network, the conductive technology remains up to now the most favoured, mostly because it allows connection of electric vehicles to existing electric power supplies apparently without the necessity for extra infrastructure. However, the advent of electric vehicles in different countries has led to the development of different approaches concerning conductive charging, taking into account specific safety and security issues. To this effect, several conductive charging modes have been defined by standardisation committees. These mode correspond to certain technologies being used, focused on specific applications and on the availability of infrastructure according to local traditions.

The choice of a preferred solution remains a complex one, based on issues both technology, regulations and local ‘culture’. As the successful introduction of electric vehicles is greatly dependent on the availability of a suitable charging infrastructure, the comparative assessment of conductive charging technologies standardisation is of paramount significance for the promotion of the electric vehicle as a vital factor for improvement of traffic and more particularly for a healthier living environment.

Charging Modes

The different charging modes have been defined by the IEC (Document IEC 61851-1). In the following paragraphs, wording quoted from the IEC document is italicised.

This list of charging modes may seem arbitrary and mundane; it represents however the outcome of a considerable effort by the members of the relevant standardisation committees in order to represent the different and often diametrically opposed approaches followed in several countries.

Mode 1 charging:

“Mode 1 charging” stands for *the connection of the EV to the a.c. supply network utilizing standardized socket-outlets at the supply side, single-phase or three-phase, and utilizing phase(s), neutral and protective earth conductors.*
This means that the electric vehicle is directly connected to a standard socket-outlet. This is currently the most frequent way of electric vehicle charging in Europe. The standard European socket-outlet provides up to 16A at 230V. This power level corresponds with normal charging for small and medium sized vehicles. An outlet of this power level can be installed at extremely low cost The standard American outlet however gives only 15A at 120V, a bit puny output to charge a automobile-sized vehicle. This output power is referred to as “Level 1” charging in the USA, and stands for “cord and plug connected portable EV supply equipment (EVSE) that can be transported with the EV and is intended for emergency use”. Most EVs introduced in America are not designed for this type of charging, using instead “Level 2” charging, which is a dedicated 240 V 40 A charging circuit.

However, Mode 1 charging has raised a number of safety concerns: its safe use depends on the presence of a residual current device (RCD) on the supply side. The installation of such device is now enforced by national codes in most countries; however, many older installations continue to exist without RCD, or even without protective earth conductor connection. In such cases, hazardous conditions may occur after a fault. Thus, without RCD, mode 1 charging is not permissible. Whileas some countries leave this responsibility to the user, mode 1 is prohibited in a number of countries, or limited to private environments (closed garages) with controlled access.
Where the presence of an RCD on the supply side can not be ensured by national codes, mode 1 charging is not permissible. In some countries, mode 1 charging may be prohibited by national codes, or limited to private environments with controlled access.

Although Mode 1 charging is considered by many a transitional solution, pending the development of dedicated electric vehicle charging infrastructure, it is sure that Mode 1 will be with us, at least in the countries where it is not prohibited, for a long time, particularly for private home charging and fleet vehicle charging in controlled-access environments.

In some countries (Switzerland) Mode 1 charging is used for public charging stations; additional protection is provided by the RCD and by mechanical means (key-locked flap preventing unauthorised access to plugs and socket-outlets). For greater safety and reliability, the use of industrial plugs and sockets-outlets according to IEC 309-2 becomes increasingly popular. These are of a heavier build then standard “domestic” plugs and more suitable for harsh environments, repeated disconnection under load and prolonged operation at high current rates.

Mode 2 charging:

The safety concerns with Mode 1 charging in certain countries (particularly the USA) has lead to the definition of Mode 2: *the connection of the EV to the a.c. supply network utilizing standardized socket-outlets, single-phase or three-phase, and utilizing phase(s), neutral, and protective earth conductors together with a control pilot conductor between the EV and the plug or in-cable control box.*

Mode 2 allows additional protection of the cable and the vehicle, whilst using standard, non-dedicated socket outlets. It uses a special plug (or an in-cable device) holding an RCD and additional protection devices (control pilot conductor; see below). In Europe, it is used very rarely. This solution can be considered as transitional.

The introduction of Mode 2 charging in the USA reflects the American infrastructure process which developed electrical standards and code language that was adopted by the National Electrical Code (NEC 625), this ensured that personnel protection and other safety considerations were implemented in all charging systems utilised (inductive or conductive).

Mode 3 charging:

Mode 3 charging refers to specific electric vehicle charging stations, with the *direct connection of the EV to the a.c. supply network utilizing dedicated EV supply equipment where the control pilot conductor extends to equipment permanently connected to the a.c. supply*. It concerns dedicated infrastructure: equipment specially designed and reserved for EV use, whether intended for public access or not.

The control pilot is a device which controls the integrity of the protective (earth) conductor (by adding a control pilot conductor which forms a loop with the protective earth conductor), and which is able to perform additional safety functions, such as ensuring the socket outlet is dead when no vehicle is present, as well as basic communication functions. This is particularly interesting for charging stations located in public locations.

Mode 3 charging stations come in different power levels:

- 16A, 230V: corresponding to standard socket-outlet but with enhanced safety features. This configuration will be typical for on-street charging stations, and is being deployed in several European countries.

  For the socket-outlet and plug combination, several options are being considered:

  - A Mode 3 socket outlet with fourth pin for the control pilot, with a matching plug which is compatible with a standard (Mode 1) socket outlet, enabling vehicles to charge both at a private garage (albeit in Mode 1, without control pilot protection) and at public charging stations (in Mode 3). This system is under operation in France (over 200 public charging stations in Paris alone). However, the special plugs used are very expensive, leading to a number of charging stations being fitted with mechanical safety devices (locking trap door) instead, allowing the use of “domestic” plugs. The control pilot function is then lost however.
  - A new type of plug and socket-outlet specially reserved for EV use. Such a solution is being proposed for the Italian market, as a lightweight 4-prong plug (including control pilot) which may be feasible for lightweight vehicles such as scooters and electric bicycles

- 32 A, 230V: this represents a higher power level (7kW) for semi-fast charging. This power level is readily available at most places. This option has been developed into an multifunctional charging solution, with a common plug design, compatible with existing IEC 309-2 plugs, but fitted with additional contacts for control pilot and “power indicator”. This implies an “intelligent charger” however, which can adjust its input current according to its needs. This equipment, already being deployed in Switzerland, can be used in different ways:

  - Connected to a public charging station. The charger detects the presence of the charging station (through the control pilot) and sets its input current to 32 A. High power level is chosen. Control pilot provides additional protection: when no vehicle is present, the socket outlets are dead.
  - Connected to a private charging station, i.e. a wall box with suitable socket-outlet and control pilot circuitry. The charger operates at 32 A and control pilot

protection is provided. This solution is aimed at corporate vehicle depots which need a higher rate of charge, as well as to discerning private vehicle owners.

- Connected to a private socket-outlet (standard IEC 309-2 16 A outlet, i.e. Mode 1). The charger does not detect the control pilot and defaults to 16 A.
- Connected to a standard “domestic” socket-outlet (Mode 1) using a suitable adapter cord set. The power-indicator function (a resistive circuit) can be used to adjust the charging current to a level lower than 16 A when desired (e.g. rated outlets of 10 A or 13 A in some countries)

The different modes of operation of this equipment are illustrated in Figure 1.

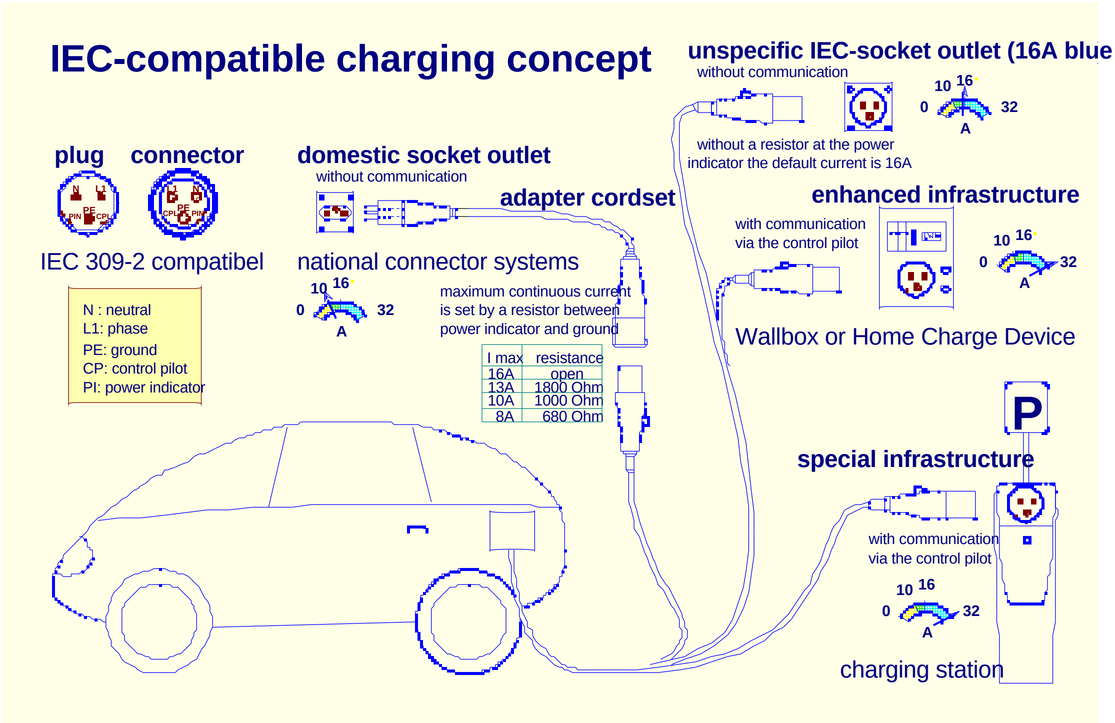

Figure 1
Charging modes

- High power Mode 3 charging stations. The development of three-phase drives on electric vehicles has opened the opportunity of using these devices for charging the batteries through direct connection to a three-phase distribution network. Such a network can be made available quite easily, and attainable power levels are very high, up to several dozens of kilowatts. This way, really fast charging becomes possible without the necessity of heavy and expensive fixed chargers like in Mode 4. It has even been proposed to use the batteries of vehicles such connected to the grid for peak-shaving purposes.
  The development of such an infrastructure however raises specific standardisation issues: since the three-phase inverters used on the vehicle may not have a galvanic separation in their circuits. This means that the vehicle traction circuits, including the battery, will become connected to the grid, and part of an electric appliance, which may rise the need for specific protection measures. Thus, standardisation of these issues may become the competence of IEC, while as the vehicle and its traction equipment have traditionally being covered by ISO.

Mode 4 charging:
In Mode 4 *(the indirect connection of the EV to the a.c. supply network utilising an off-board charger where the control pilot conductor extends to equipment permanently connected to the a.c. supply),* the vehicle is charged with a d.c. current provided by an off-board charger.

Vehicles in captive areas like industrial vehicles are mostly charged with off-board chargers; for road-going vehicles, this solution is most often used for fast charging stations which require a very heavy infrastructure. This infrastructure being very expensive, its usage has been largely limited to public charging stations for “emergency” charging.

The development of a common interface

The components of a conductive charging connection can be summed up as follows:

- On the vehicle: the “vehicle inlet”, were the cable is connected.
- On the cable:
  - The “connector” mating with the vehicle inlet
  - The “plug” mating with the socket outlet
- On the wall or charging station: the “socket outlet”

Not all of these have to be present, as shown in the different “cases” for connection:

- Case A: a fixed cable with plug attached to the vehicle. No connector or vehicle inlet
  This solution has been popular with early electric vehicles, particularly smaller ones, but is now not used so frequently.

- Case B: a detachable cable with both plug and connector. A flexible solution, offering the opportunity to access Mode 3 or 4 charging stations with a fixed Case C cable, while still having an on-board cable available for use at (EV-dedicated or not) socket outlets.

- Case C: a fixed cable attached to the charging station. No plug or socket outlet.
  This case will be preferred for high-power connections due to the heavy cable needed.

Standardisation committees (IEC TC69 WG4 and IEC SC23H WG6; draft document IEC 61XXX-1, which is based on the connector standard IEC 60309-1) have covered the issue of the development of a common interface (vehicle inlet and connector) to be used for different charging modes. Such a common interface can largely add to the flexibility of electric vehicles and to the intermateability of infrastructures.

In order to allow cost-effective solutions for each application, two designs for the interface are considered:

- A “universal” interface for all modes of charging, which provides *either*:
  - High power a.c. and 32 A a.c.   or
  - High power d.c. and 32 A a.c.

- A “basic” interface which provides for 32 A a.c. The basic interface is aimed to offer a low-cost solution for vehicles which do not have the need for high power charging, while it still offers Mode 3 compatibility and control pilot protection.

This means that there will be three types of vehicle inlets:

- universal a.c. (U_A) for a vehicle which can accept high-power AC charging
- universal d.c. (U_D) for a vehicle which can accept high-power DC charging
- basic (B)

and four types of connectors:

- universal a.c. (U_A)
- universal d.c. (U_D)
- universal 32 A (U_{32})
- basic (B)

These devices intermate as shown in Table A:

Table A
Connector Intermatability

Inlet	Connector			
	U_A	U_D	U_{32}	B
U_A	Yes	No	Yes	No
U_D	No	Yes	Yes	No
B	No	No	No	Yes

The contact positions in use on these interfaces are shown in Table B.

Table B
Vehicle interface positions

Pos	U_A	U_D	U_{32}	B	function
1	•	•			High power connection a.c. or d.c.
2	•	•			High power connection a.c. or d.c.
3	•	•			High power connection a.c.
4	•	•	•	•	32 A phase 1
5	•	•	•	•	32 A phase 2
6	•	•	•	•	32 A phase 3
7	•	•	•	•	32 A neutral
8	•	•	•	•	Ground/earth
9	•	•	•	•	Control pilot
10	•	•	•		Communication
11	•	•	•		Communication
12	•	•	•		Clean data earth
13				•	Power indicator
14				•	Power indicator

The configuration of contact positions is fixed for all “universal” configurations, with contact positions which may be used or not, according to the application. So will the third high-power contact for three phase a.c. not be used in d.c.; measures shall of course be taken to prevent intermating of U_A and U_D devices: the universal vehicle inlet shall be intermateable with *either* the high power a.c. connector or the high power d.c. connector. The 32A connector shall be intermateable with both vehicle inlets.

The basic interface can be either single-phase or three-phase, with the connector intermateable with either the single-phase or three-phase vehicle inlet. It may include additional contacts for control pilot and power indicator.

Practical issues

Conductive charging infrastructure will remain a solution of choice due to its simplicity and its compatibility with existing distribution outlets non dedicated to EV use (at least in Mode 1 and Mode 2). To understand the developments which have taken place in the field, it is interesting to summarise the issues which are in the field here:

Safety

It shall be the first and paramount aim of any standardisation or equipment design to ensure safe operation and protection of personnel. The use of mains electricity connected to vehicles may indeed create potential hazardous situations, particularly when taking into account specific issues like operation by non-specialist users, frequent disconnection under load, operation in wet atmospheric conditions and harsh treatment of cables and connectors.

Adequate protection can in most cases be provided by RCDs. For privately-owned installations, it is the responsibility of the owner to ensure that his electrical installation is safe for Mode 1 charging. In some countries, Mode 2 is obligatory to enforce this safety.

For public infrastructure, additional safety features are necessary because of the increased risks to the equipment (accidents, vandalism,…) which may create hazardous conditions for personnel. The control pilot circuit, typical for the dedicated EV infrastructure of Mode 3, takes this on, removing the voltage when potential hazardous conditions occur.

Flexibility

The electric vehicle, in order to have a chance to achieve a significant penetration of the market, particularly the private vehicle market, must be able to charge at different locations away from its home base, as to allow its operation in a wider area. Plugs and sockets must be intermateable. This highlights the problem of creating a “universal” infrastructure, taking into account on one hand the specific needs of different applications and on the other hand the existing differences in electrical infrastructure in different countries. This aspect is particularly striking in Europe, where nearly every country has its own type of plug and socket-outlet, with different ratings, and where international trips with electric vehicles are a quite realistic option due to the intense trans-border traffic in a number of populated regions. A common interface will be relatively easy to realise for the vehicle inlet/connector interface. For the plug/socket outlet side, dedicated EV infrastructures (i.e. charging stations) can be fitted with a common interface. Connection of electric vehicles to existing infrastructure (i.e. Mode 1 or Mode 2 charging) can be done with material compatible with IEC 309-2 plugs, or by using suitable adapter cord sets, which may allow charging at the correct rating. These adapter cord sets however shall be of a design which does not compromise safety.

Cost

The cost of charging infrastructure is a paramount issue. As electric vehicles now come at a premium cost compared to thermal vehicles (mainly due to the small series production), vehicle owners will be less inclined to make a significant additional investment in infrastructure. This implies that Mode 1 (or 2) charging will remain in use, as it allows connection to standard non-dedicated outlets.
Mode 3 equipment should be designed as to ensure compatibility with existing outlets (albeit in Mode 1), while not being too costly or over-engineered. Hence the proposed division between high power (U_A or U_D) and normal power (U_{32}) interfaces, these being intermateable to enhance flexibility. Furthermore, for certain applications, the “basic” interface offers a low cost solution. This may be particularly interesting for smaller vehicles (e.g. electric two-wheelers), where it is more critical to limit the extra cost for infrastructure, and where heavy or large-sized connectors are undesireable.

Conclusions

The standardisation work being performed on conductive charging technology is aiming to realise a world-wide (or at least continent-wide) unified infrastructure which will allow actual deployment of electric vehicles on a large scale. The progress made in this field clearly show the benefits of international standardisation work; the activities of the committees active in the field are considered a very good example of fruitful collaboration. A number of issues remain to be resolved however, based mainly on specific properties and traditions of each operating theatre.

Acknowledgments

The data in this paper (Tables A and B, Figure 1) are derived from the activities of the working groups IEC TC69 WG4, IEC SC23H WG6 and CENELEC TC69X WG3.

Disclaimer

This paper reflects standardisation work in progress, and the opinions of the author on the matter; it should not be considered as presenting definitive standards or regulations on the issues concerned.