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Electrical safety as key issue in EV charging infrastructure

Peter Van den Bossche[1,2], Arjen Mentens[1,2], Guillaume Dotreppe[1,2]
[1]*Vrije Universiteit Brussel, Belgium, pvdbos@vub.be*
[2]*Flander's Make, Heverlee, Belgium*

Executive Summary

The use of electricity for electric vehicle conductive charging creates the need to mitigate the risks associated with it. This has been extensively addressed in both standardization and regulation. The paper will focus on the principles followed in different documents, as well as some regulatory issues.

Keywords: safety, standardization, regulation, charging, infrastructure

1 Introduction

In urban traffic, due to their beneficial effect on the environment, electric vehicles are an important factor for improvement of traffic and more particularly for a healthier living environment. The electric vehicle gets its energy from the electricity grid, through a conductive or a wireless connection. The vehicle, whilst charging, and its EV supply equipment thus become an electric appliance connected to the grid, which shall behave in a safe way, as any other appliance, eliminating the risk of electric shock to the user.

To this effect, a key role has to be played by international standardization defining safety requirements for global deployment in a sector which is highly regulated on the national level.

2 Hazards

The electricity used in electric vehicles is both DC of the battery and AC for the charging connection and also for the drive system). The voltages used, considered class "B" in the relevant standard for electric vehicle electrical safety ISO6469-3 [1] exceed the "extra low voltage" bands defined in IEC61140 [2] and thus create the need for additional protection measures.

Protection has to be provided both against direct contact (with live parts – fig. 1) and indirect contact (with parts becoming live as result of a fault – fig. 2).

According to IEC60364-4-41 [3] several protective measures can be implemented for protection against electric shock. The concepts used are defined in IEC61140 [2]. These are reflected in the various standards for conductive charging.

3 Protection by automatic disconnection of supply

For this protective measure, protection against direct contact (basic protection) is provided by basic insulation of live parts or by barriers or enclosures, and protection against indirect contact (fault protection) is provided by earthing and equipotential bonding with automatic disconnection in case of a fault. [3]

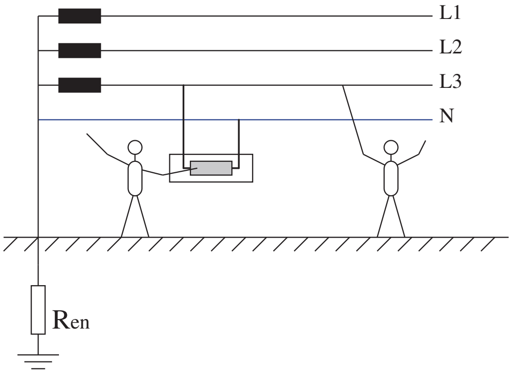

Figure 1: *Direct contact*

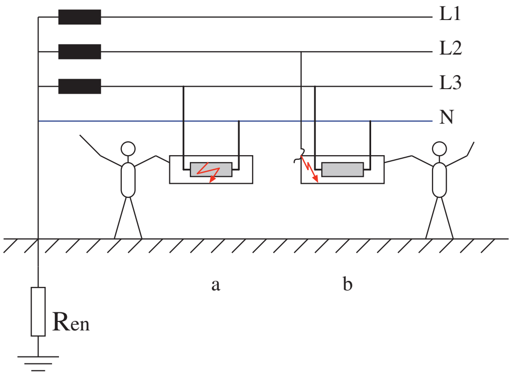

Figure 2: *Indirect contact*

This is the approach followed in the main international standard governing electric vehicle charging, the IEC61851-1 [4], the third edition of which was published in 2017 with a revision under preparation.

The protective device providing this disconnection depends on the earthing system used, as defined in IEC60364-1 [5]. Whileas in a TN system the fault current going through the protective conductor (for the protection against indirect contact) has the magnitude of a short-circuit current and will be interrupted by the existing overcurrent protection, the fault current in a TT system will be much lower and the use of a RCD is needed (figs. 3 and 4).

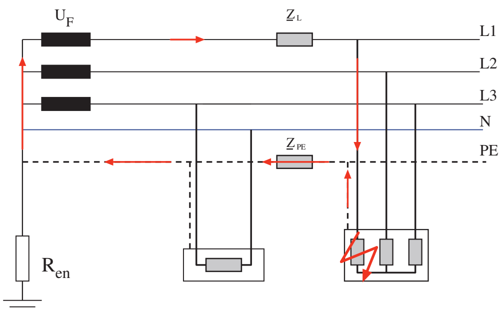

Figure 3: *Fault current in TN-net*

The standard [4] requires one RCD per connection point. Since battery chargers are rectifiers which may cause a direct fault current, this has to be catered with. The RCD shall be type B, or a type A with appropriate equipment ensuring the disconnection of the supply in case of DC fault current above 6 mA DC. Such special ”Type A+EV” RCDs are now available and are described by the standard IEC62955 [6].
The reason for the 6mA DC limit is because DC fault currents exceeding 6mA may ”blind” (through magnetic saturation of the measuring magnetic circuit) type A RCD which may not work appropriately

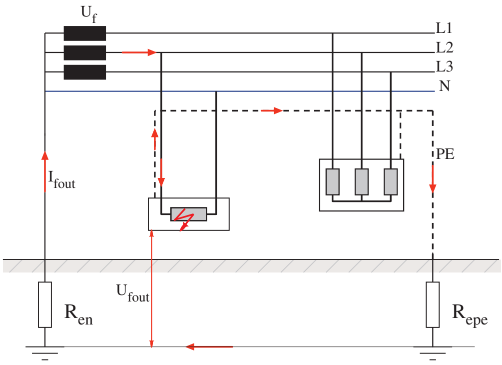

Figure 4: *Fault current in TT-net*

in this case. To this effect, RCDs mounted upstream of a type B shall also be type B (fig. 5) according to wiring regulations [15].

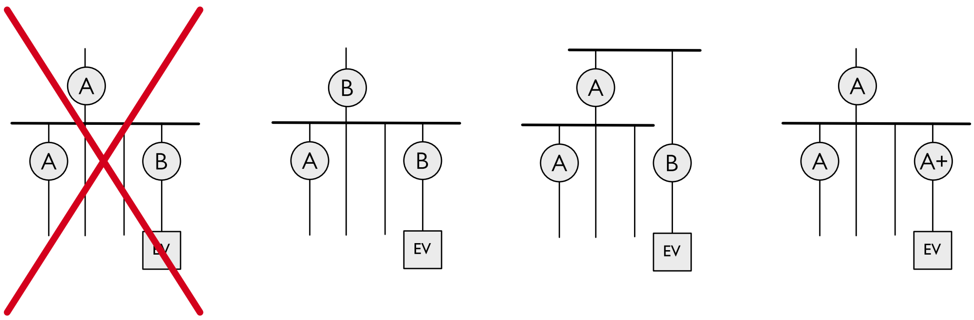

Figure 5: *Permissible mounting of RCD*

The continuity of the protective conductor which is essential for the safety is continuously monitored in the ”Mode 3” charging mode through the control pilot conductor. This has given rise to the creation of new style accessories as described in IEC62196-2 [7].

These developments have allowed the creation of a safe EV charging ecosystem, which is now deployed worldwide (with however some regional preferences on the type of accessories used, e.g. Type 1 in US and Type 2 in Europe.

However, electric installations have to comply to national wiring rules, and there are a few subjects where confusion may arise.

A first point related to the socket-outlets, which in a number of countries have to be provided with shutters (child protection), particularly if used in a residential environment. The Type 2 socket-outlet has no such shutters — which are in fact not strictly needed for a Mode 3 accessory as the socket-outlet is always dead when no EV is properly connected —, and for this reason the Type 3 plugs and sockets have been proposed and were adopted in France and Italy.

With the EU directive on alternative fuels infrastructure [8], prescribing Type 2 accessories, has led to the demise of Type 3. This has created a good Europe-wide standardization landscape for AC conductive charging (hardware-side at least).

4 Protection by double or reinforced insulation

For this protective measure, protection against direct contact is provided by basic insulation, and protection against indirect contact is provided by supplementary insulation. [3] Dangerous voltage on the accessible parts of electrical equipment through a fault in the basic insulation is thus prevented.

Equipment with this protective measure is identified by two concentric squares (fig. 6). It shall NOT be connected to the protective earth conductor, as to avoid dangerous voltages coming from elsewhere due

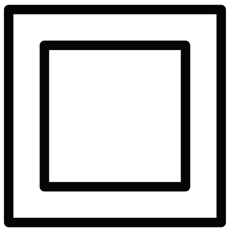

Figure 6: *Symbol for double or reinforced insulation*

to another fault.

The situation of double or reinforced insulation is however difficult to enforce given the external factors of a vehicle environment. It is however widely used for the charging equipment in ”light” electric vehicles such as e-bikes, mopeds and scooters.

Such vehicles were initially the scope of the 61851-3 series. The term of ”Light” vehicles creates some problems however, as it refers to an administrative classification of vehicles relating to vehicle mass, number of wheels, maximum speed,. . . which may be relevant for type approval, traffic regulations, driving licences,. . . but which are in no way related to electrical safety whilst charging and protection against electric shock.

To this effect, the scope of IEC61851-3 series was adapted to cover the equipment for the conductive transfer of electric power between the supply network and an electric road vehicle, or a removable RESS or traction-battery of an electric road vehicle when the equipment is connected to the supply network, having a supply voltage up to 480 V AC or up to 400 V DC and a rated output voltage up to 120 V DC, where the protection against electric shock relies on double or reinforced insulation, and with double or reinforced insulation between all AC and DC inputs and outputs. This double or reinforced insulation does apply to the charging equipment and not to the vehicle itself (which is anyway out of scope of the IEC standard, being the province of ISO).

The IEC61851-3 series was intended to be published as technical specification (TS) in a first phase, and as full-fledged international standard (IS) later. It was initially divided in seven parts, parts 1 and 2 dealing with general requirements for stationary and mobile equipment, part 3 with battery swap (which was subsequently transferred to IEC62840 series where it was published as a publicly available specification [9]), and parts 4 to 7 dealing with communication issues.
The document takes into account various connection configurations: onboard or offboard chargers, removable batteries,. . . (fig. 7)

These documents have known a chequered history, with parts 1 and 2 rejected at the DTS stage in 2019 [10, 11],with subsequent delays. The publication is now in a final phase however and will be by the end of 2022.

5 Protection by electrical separation

For this protective measure, protection against direct contact is provided by insulation of live parts or by barriers and enclosures, and protection against indirect contact is provided by simple separation of the separated circuit from other circuits and from earth. [3]

This is the approach followed by IEC61851-25 [12] (fig. 8) which provides requirements for the DC EV supply equipment where the secondary circuit is protected from primary circuit by electrical separation, with a rated supply voltage up to 480V AC or up to 600 V DC with output voltages up to 120 V DC and output currents up to 100 A DC. With these limits, the document clearly also addresses the ”light” vehicle category which is also the scope of IEC61851-3 series. The discrepancies between the safety approach in the two documents have given rise to substantial discussions in the standards committees leading to delays in the publication of the documents.

6 Installation rules

Whileas the abovementioned standards approach electrical safety in their own manner, they relate directly to the charging posts (electric vehicle supply equipment) and its functioning.

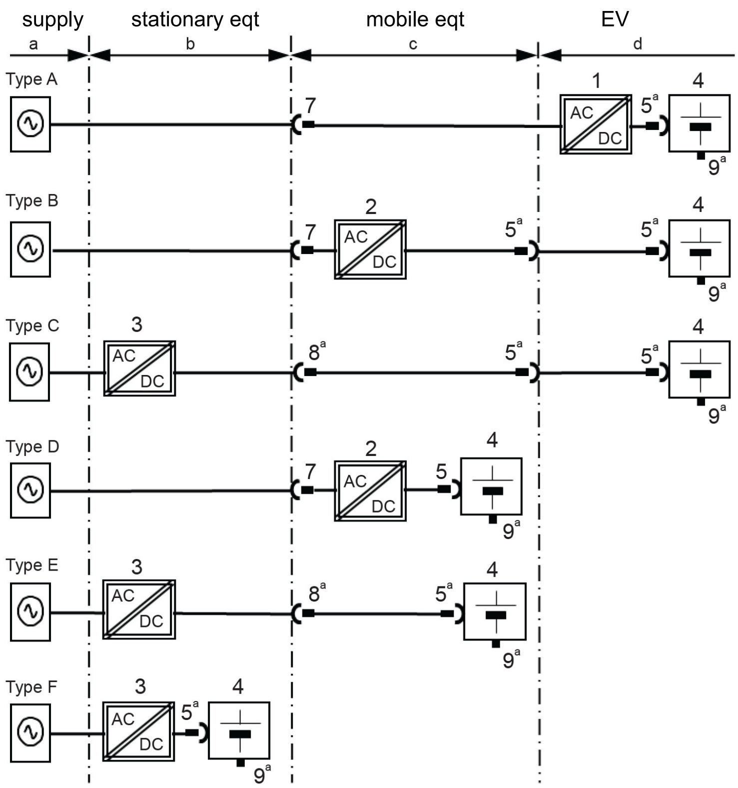

Figure 7: *Configurations for charging (IEC61851-3-1)*

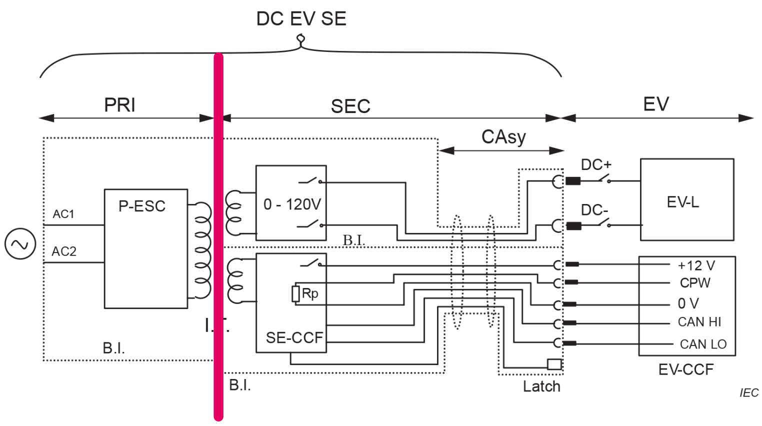

Figure 8: *Charging with electrical separation (IEC61851-25)*

The charging post is however connected to the building's electrical installation. Such installations are in most countries strictly regulated, where two approaches can be chosen: some countries require explicit compliance to standards, like France with the NF C 15-100 [13], other ones rely on regulations like the American National Electrical Code [14], whileas some countries like Belgium enshrine wiring regulations straight in the law, with the "General Regulation for Electrical Installations" [15].

The GREI saw a new revised edition in 2019. A new chapter was prepared early 2021 to deal with EV charging stations [16]. As of spring 2022, this chapter is not yet published and thus not in vigour; standardization may be known as a slow process, but the administrative legal mills are even slower.
The number of this chapter, 722, reflects the international standard that inspired it: the IEC 60364-7-722 [17].

The main protection measures imposed by this new document can be summarized as follows:

- Mode 3 charging posts are considered part of the fixed installation and shall not be connected via plug and socket
- Every connecting point shall have its dedicated current path
- Protection against indirect contact can be provided passively (through separation transformer) or actively (switching off supply via RCD)
- Every current path shall have its proper 30mA RCD, with protection against DC faults either in the RCD (switchboard) or within the charging post
- Overcurrent protection is to be foreseen in either the switchboard or the charging post
- The installations shall take into account the foreseen external influences
- Charging posts inside a building shall be provided with a emergency cutoff switch, except in residential installations
- Charging posts which are able to supply energy back (V2G) shall comply to the rules for decentral production units

7 Conclusions

Whileas it is clear that international standardization remains a key factor in making safe and efficient electromobility — or any other technology — possible, there is the interaction with regulation as well as the internal dynamics of standardization to be taken into account.

Acknowledgments

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Presenter Biography

Peter Van den Bossche, civil mechanical-electrotechnical engineer, promoted in Engineering Sciences from the Vrije Universiteit Brussel on the PhD thesis "The Electric vehicle, raising the standards". He is currently lecturer at the Vrije Universiteit Brussel. Since more than 15 years he is active in several international standardization committees, currently acting as Secretary of IEC TC69.