Safety measures for electric vehicle charging

by Jean-François REY

Executive summary

Electric vehicle will represent up to 50% worldwide sales of vehicles in 2040. Even in 2019, the stock of electric vehicle reached 7.2 million units. Charging safely electric vehicle is made with Electric Vehicle Supply Equipments (EVSE) powered by a switchboard with the necessary protective measures.

Those safety measures are provided by circuit-breaker, residual current device of type B and surge protective devices, complying to their relevant product standards.

However, some EVSE claim for built-in protective devices or embedded protection. How safe are those solutions? How to select a safe charging solution?

This document summarizes the protective measures required by the International Standards, and explains how to identify if protection against electric shocks, protection against overcurrents or protection against overvoltages are correctly implemented.
According to International Energy Agency, the global stock of electric vehicle (EV) and plug-in hybrid electric vehicle (PHEV) reached 7.2 million units in 2019, with an annual average increase of 60% over the period 2014-2019. Bloomberg New Energy Finance estimates that the EV and PHEV could represent up to 50% of total worldwide sales of vehicle in 2040.

Increasing use of Electric Vehicle will require an intense growth of charging infrastructure. The vehicle charging needs connection to an electricity supply, the question of electrical safety when charging is central. The so-called EVSE (electric vehicle supply equipment) are intended to be installed in various environments: in the vicinity of private buildings (e.g. large charging stations for office building), in public area (e.g. car parking with charging stations) or in residential facilities; the vehicle and the charging station may be located outdoor, in a wet environment and in contact with children, or a person not aware of the risk of electricity.

For safe charging of electric vehicle, the International Electrotechnical Committee (IEC) defined a set of standards, covering devices for protection (short-circuit, electric shocks, overvoltages) and electrical installation standards.

This document intends to highlight, the safety measures for electric vehicle charging, and the applicable reference documents.
Safety measures for Electric Vehicle charging

Safety measures are required by IEC 60364 (Part 7-722)

International series of standard for Low Voltage Electrical Installations (IEC 60364 series) contains a new part dedicated to supply of electric vehicle. First edition was published in 2015 to define a set of safety measures for EV charging. The second edition was published in 2018 to address more specifically the various possible cases of EV charging.

The charging of electric vehicle requires specific measures to cover the various applications and environments, such as
- outdoor charging in presence of water, snow, salt, ice, dust;
- charging in public areas with presence of children, persons not aware of risks of electricity, risks of mechanical shocks on the EV supply equipment;
- charging in residential premises (private homes or multi-house dwellings), with no scheduled maintenance;
- charging of EV fleets for industrial or public actors, where the availability of vehicle is essential.

IEC 60364 part 7-722 requires electrical safety protective measures to address the above mentioned applications.

- Protection against short-circuits and overloads
- Protection against electric shocks and risks of electrocution
- Protection against overvoltages

Moreover, the Electric Vehicle Supply Equipment (wallbox or parking stations) shall be in accordance to the relevant part of IEC 61851 series.

Protection against short-circuits with circuit-breakers

Like for any final circuit supplying a load, IEC 60364 part 7-722 requires to provide, so-called overcurrent protection. In practice, this means protection against short-circuits or overload in the final circuit, which is really meaningful having in mind that some charger can be rated up to 22 kW or 50 kW, meaning permanent load current of 32 A or 63 A.

Protection shall be provided by circuit-breakers complying with their relevant standard, namely IEC 60898-1 or IEC 60947-2, installed in the distribution switchboard. Compliance to these standards provides safe behaviour during the entire life of the installation. This includes the case of high short-circuit (e.g. 6 kA, 10 kA or 20 kA), overload in the circuit, temperature rise behaviour when nominal current is passing, ageing, behaviour of terminals, insulation, electrical or mechanical endurance...
Protection against electric shocks with 30mA RCD

When considering that EV charger can be located in public areas, outdoor, with presence of water, presence of children; when also considering that an electric vehicle is a large conductive area, which could come in contact with human body, the question of protection against electric shocks shall be considered carefully.

Firstly, to cover an insulation fault, the most common safety measure is to connect all accessible metal parts to the earth (Protective Earth) and to disconnect the supply in case of fault. This is function is performed either with a circuit-breaker in TN earthing system or with a medium sensivity RCD for TT earthing systems.

Secondly, the effect of currents on human beings is covered in IEC 60479 series, and the threshold of ventricular fibrillation is defined (see Figure 1, curve c₁). For this reason, one of the most important requirement of IEC 60364 part 7-722 is to require that each connected point be protected by a 30 mA RCD.

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Each AC connecting point shall be individually protected by a residual current device (RCD) with a rated residual operating current not exceeding 30 mA.
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IEC 60364-7-722:2018 subclause 722.411.3.3

![Figure 1 - Time-current effect of AC current on human body (IEC 60479-1) – curve c₁ defines the threshold of ventricular fibrillation](image)

RCD shall preferably be of type B, or possibly of type A in case the EVSE contains a 6 mA DC detection

As the Electric Vehicle may reject DC residual current during charging, the selection of type of RCD shall be done carefully. The most advanced solution is to install a 30 mA type B RCD, complying to IEC 62423. Type B RCDs provide protection against residual AC, pulsating DC and smooth DC residual currents (see document "How to Choose Type B Earth Leakage Protection"). Such solution will provide also continuity of service in case of small DC residual currents, not dangerous for human beings.
Alternatively, IEC 60364-7-722 offers the possibility to use a type A RCD, complying to IEC 61008 or IEC 61009 series in conjunction with an EVSE equipped with a Residual Direct Current Detecting Device (RDC-DD), complying to IEC 62955, intended to detect 6 mA DC residual current and marked with $I_{\Delta \text{dc}} = 0.006\, \text{A}$. Such solution will be more sensitive in case of presence of DC residual currents, therefore continuity of service may be a challenge.

### Protection against overvoltages

The power surge generated by a lightning strike near an electricity network propagates into the network without undergoing any significant attenuation. As a result, the overvoltages likely to appear in a LV installation may exceed the acceptable levels for withstand voltage recommended by standards IEC 60664-1 and IEC 60364. The electric vehicle being designed with an overvoltage category II, according to IEC 17409, therefore, it should be protected against overvoltages that could exceed 2.5 kV.

As a consequence, IEC 60364-7-722 requires that EVSE installed in locations accessible to public be protected against transient overvoltages. This is provided by the use of a type 1 or type 2 surge protective device (SPD), complying to IEC 61643-11, installed in the switchboard supplying the electric vehicle, with a protection level $U_p \leq 2.5\, \text{kV}$.

### EVSE shall comply to IEC 61851 standard

The EVSE (Electric Vehicle Supply Equipment) is the system that manages the flow of electricity to the electric vehicle. It shall comply to the EVSE standard, IEC 61851.

This standard defines the fundamental aspects or EV charging such as the 4 charging modes.

- **Mode 1** is for AC charging up to 16 A on a regular domestic socket-outlet. This mode 1 is prohibited by several countries.
- **Mode 2** is for AC charging up to 32 A on a domestic or industrial socket-outlet, with a portable device intended to provide protection against electric shocks.
- **Mode 3** is for AC charging, with no limit in current, but with a control pilot function, embedded in the EVSE, intended to manage the charging process.
- **Mode 4** is for DC charging of the electric vehicle.

IEC 61851 contains all the safety requirements covering the EVSE, as an equipment. Therefore, it is essential that the EVSE complies to IEC 61851 series. However, the EVSE shall be supplied and protected according to IEC 60364-7-722.

Such overcurrent protective devices shall comply with IEC 60947-2, IEC 61009 series or IEC 60898 series. In some cases the overcurrent protection may be installed inside the EVSE (the case where the EVSE contains several connecting points intended to be used simultaneously), but in all cases the overcurrent protection shall comply to IEC 60947-2, IEC 60898-1 or IEC 61009-1.
Example of Electric Vehicle charging installation

The EVSE (Electric Vehicle Supply Equipment) shall be integrated in the electrical installation in order to comply to the safety measures of IEC 60364-7-722, and thus provide protection against short-circuits, electric shocks, and overvoltages.

Each EVSE shall be supplied by a switchboard with a dedicated circuit with circuit-breaker complying to IEC 60898-1, a 30 mA type B RCD complying to IEC 62423 and, where the connected point is accessible to public, by a surge protective device complying to IEC 61643 series, as shown in Figure 2.

![Figure 2 – Recommended single line diagram for charging electric vehicle](image-url)
Alternatively, IEC 60364-7-722 also considers the case where protection against electric shock is done by a 30 mA Type A RCD, complying to IEC 61008 or IEC 61009 series, in conjunction with a function of detection of 6 mA DC residual current, complying to IEC 62955, in the EVSE, as given in Figure 3. This alternative solution is usually applied for more simple application.

This 6 mA DC detection function is known as Residual Direct Current Detecting Device (RDC-DD). It should be mentioned that:

- The function monitors any DC residual current in the circuit;
- RDC-DD function is a detection function, it does not provide protection;
- RDC-DD shall comply to IEC 62955;
- RDC-DD shall be used in conjunction with a 30 mA Type A RCD, installed in the LV switchboard.

In case the DC residual current exceeds 6 mA the RDC-DD function included in the EVSE will immediately switch off the contactor of the EVSE thus stopping charging the electric vehicle, in order to be compatible with the use of a Type A RCD. However this value of DC residual current is not dangerous.

Figure 3 – Alternative single line diagram for charging electric vehicle
Situation on the market today and compliance to the safety requirements of IEC 60364-7-722

Sometimes, it may be difficult to clearly understand if a solution for electric vehicle charging truly complies to the safety requirements as mentioned above. In particular there are EV charging system claiming for built-in protection, or built-in type B RCD, or embedded type A RCD, or designed according to IEC 62955 and IEC 61009 for RCD protection. Such system claim that no additional protection is needed. This must be checked very carefully, because the standards for residual current devices or circuit-breakers contain numerous safety tests to verify the device safe operation in all cases. Those standards contain all the necessary requirements and test procedures to help guarantee the safety behaviour of the device, for example

- suitability for isolation
- behaviour in case of overload
- behaviour in case of short-circuit
- operating characteristics in case of residual current
- electrical and mechanical endurance
- ageing tests
- electromagnetic compatibility (EMC)

If those safety measures are not complied with, there is a risk that the user of the electric vehicle be exposed to overheating, fire or electric shock. The electric vehicle itself may be damaged.

In the case where the manufacturer of EVSE decides to integrate an RCD, a circuit-breaker or Surge Protection in the EVSE, those device must comply to their relevant standards, to avoid dangerous situation for the user.
Safety measures for electric vehicle charging

How to identify if protection against electric shocks is correctly implemented with type B RCD?

For protection against electric shocks, the residual current device (RCD) plays a key role. In the case the EVSE claims for built-in Type B RCD, the following items should be checked, as given in Table 1. If one of the items of table 1 is not ticked, the EVSE does not contain a type B residual current device. It may contain an RCD-like function, but this function does not provide safe behaviour in presence of AC and DC residual current, as required by IEC 62423.

Table 1
Criteria for checking that the safety requirements of IEC 62423 for Type B RCD are complied with

<table>
<thead>
<tr>
<th>Key item</th>
<th>Simplified check-list safety requirements for RCD Type B complying to IEC 62423</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Is there a symbol of type B visible when the EVSE is installed ?</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>Is the value of residual current marked (e.g. 30 mA) ?</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>Is there a Test Device, allowing periodic testing of the RCD, indicated by letter T ?</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>Is there an operating means (toggle) allowing to switch ON and OFF the RCD ?</td>
<td>✓</td>
</tr>
<tr>
<td>5</td>
<td>Are the markings “O” and “I” visible to indicate the position of the contacts ?</td>
<td>✓</td>
</tr>
<tr>
<td>6</td>
<td>Is there a symbol indicating suitability for isolation when the contacts are in the open position ?</td>
<td>✓</td>
</tr>
<tr>
<td>7</td>
<td>Is the rated current of the RCD marked (e.g. 40 A) ?</td>
<td>✓</td>
</tr>
<tr>
<td>8</td>
<td>Is the making and breaking capacity of the device ($I_m$) indicated in Amps ?</td>
<td>✓</td>
</tr>
</tbody>
</table>

Example of front face markings of type B RCCB, according to IEC 62423

Symbol of Type B RCD, according to
How to identify if protection against electric shocks is correctly implemented with type A RCD in conjunction with RDC-DD?

A said earlier, an alternative solution is to provide protection with an RCD of Type A, complying to IEC 61008 or 61009 series in conjunction with a function of detection of the DC residual current (RCD-DD, complying to IEC 62955, and marked $I_{\Delta dc} = 0.006$ A). In the case the EVSE claims for built-in Type A RCD, the following items should be checked, as given in Table 2. If one of the items of table 2 is not present, the EVSE does not contain a type A residual current device. It may contain an RCD-like function, but this function does not provide safe behaviour in presence of residual current, as required by IEC 61008 and 61009 series.

<table>
<thead>
<tr>
<th>Key item</th>
<th>Simplified check-list for the safety requirements for RCD Type A according to IEC 61008 and 61009 series</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Is there a symbol of type A visible when the EVSE is installed?</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>Is the value of residual current marked (e.g. 30 mA)?</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>Is there a Test Device, allowing periodic testing of the RCD, indicated by letter T?</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>Is there an operating means (toggle) allowing to switch ON and OFF the RCD?</td>
<td>✓</td>
</tr>
<tr>
<td>5</td>
<td>Are the markings “O” and “I” visible to indicate the position of the contacts?</td>
<td>✓</td>
</tr>
<tr>
<td>6</td>
<td>Is there a symbol indicating suitability for isolation when the contacts are in the open position?</td>
<td>✓</td>
</tr>
<tr>
<td>7</td>
<td>Is the rated current of the RCD marked (e.g. 20 A)?</td>
<td>✓</td>
</tr>
<tr>
<td>8</td>
<td>Is the breaking capacity of the device indicated in Amps?</td>
<td>✓</td>
</tr>
</tbody>
</table>
How to identify if protection against overcurrents is correctly implemented?

In order to provide protection against overcurrents (overload and short-circuits), a circuit-breaker is needed. In the case the EVSE claims for *built-in* circuit-breaker, the following items should be checked, as given in Table 3. If one of the items of table 3 is not present, the EVSE does not contain a circuit-breaker. It may contain a circuit-breaker-like function, but this function does not provide safe behaviour in case of short-circuit or overload.

<table>
<thead>
<tr>
<th>Key item</th>
<th>Simplified check-list for the safety requirements of circuit-breakers according to IEC 60898-1 or IEC 61009 series</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Is the rated voltage indicated and visible (e.g. 230 V)?</td>
<td>✔</td>
</tr>
<tr>
<td>2</td>
<td>Is the rated current indicated in conjunction with the tripping curve (e.g. C40)?</td>
<td>✔</td>
</tr>
<tr>
<td>3</td>
<td>Is the rated short-circuit capacity, in amperes, indicated (e.g. 6000 A)?</td>
<td>✔</td>
</tr>
<tr>
<td>4</td>
<td>Is there an operating means (toggle) allowing to switch ON and OFF the RCD?</td>
<td>✔</td>
</tr>
<tr>
<td>5</td>
<td>Are the markings “O” and “I” visible to indicate the position of the contacts?</td>
<td>✔</td>
</tr>
<tr>
<td>6</td>
<td>Is there a symbol indicating suitability for isolation when the contacts are in the open position?</td>
<td>✔</td>
</tr>
</tbody>
</table>
Charging Electric Vehicle requires connection to a powerful electricity supply, even though the vehicle is situated in an outdoor environment, during a rainy period, and moreover used by persons not aware of the risks of electricity. Electrical safety is of paramount importance to avoid short-circuits, overheating, or electric shocks.

The installation standard, IEC 60364 part 722 defines the safety measures to charge the electric vehicle namely: protection against electric shocks, protection against overcurrents and protection against overvoltages. This is provided by properly selected and installed circuit-breakers, residual current devices and surge protective devices. In particular, the use of Type B RCD in the switchboard supplying the EVSE provides optimal protection.

However, some EVSE on the market claim for built-in Type B RCD, or embedded Type A RCD, or designed according to IEC 62955 and IEC 61009 for RCD protection.

In such case the user is invited to check that the essential safety requirements as given in Table 1, Table 2 or Table 3 are fulfilled. If this is not the case, there are risks that the user be exposed to electric shocks, overheating of fires.

About the author

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