Connection system on the recharging spot – a key element for electric vehicles

By Claude Ricaud and Philippe Vollet

> Abstract

At the heart of the energy and environmental challenges, the electric vehicle offers an effective and concrete solution to reduce the ecological footprint of transport.

As the global specialist in energy management, we intend to play a major role in the imminent adoption of electric vehicles and we are concentrating all of our expertise to offer charging solutions that are safe, easy to use, economical and energy-efficient.

The associated equipment must meet all safety requirements for installations and must integrate into the future smart grid. This will guarantee the availability of electric vehicles, an optimised energy bill and a minimum carbon footprint.

Schneider Electric

Introduction

For the last two centuries, the emissions of certain polluting gases caused by human activity have intensified the natural phenomenon known as the greenhouse effect. This phenomenon can have far-reaching consequences on the planet's climate and ecosystems. The international community has therefore mobilized to limit the concentrations of greenhouse gases in the atmosphere, with the goal of reducing emissions by half global by the year 2050.

With no gas emission, no discharge of particles and a silent operation, the electric vehicle offers an effective and concrete solution to reduce the ecological footprint of transport. It forms the last missing link in the panorama of sustainable urban mobility (train, tramway, bus, bicycle) and perfectly matches the needs of drivers travelling short distances of a few tens of kilometres essentially within urban areas. This is the case of private individuals who use their vehicle to commute to work and back and also of numerous corporate fleets.

Using an electric vehicle on a regular basis requires safe and easy-to-use charging installations. Moreover these charging infrastructures should moreover allow the user to charge his vehicle whenever he/ she makes a stop (home, workplace, malls, car parks, etc.) and should not require him /her to stop just to charge: the concept of electric vehicle charging is charging when we stop and not stopping to charge, unlike thermal vehicles! Different types of recharging infrastructures are therefore necessary to strike a balance between the complete charging of the vehicle and the user's habits related to the places where he/ she stops:

- For long stops (overnight at home, daytime in the workplace), complete charging in 6 to 8 hours can be done with a household or specific installation.
- For shorter stops of 1 to 2 hours (car park, mall, parking on a public road, lunch break, etc.), quick-charging with a specific terminal is necessary.
- There are still cases where the user has to stop to recharge (during a long trip or after intensive professional use, like taxis or certain vehicle fleets): here, very quick-charging in 15 to 20 minutes is necessary.

In all cases, the safety of the charging operation for people, for the vehicle and for the installation to which it is connected, is essential. It is this factor, for example, that limits the performance and use of existing electrical sockets during home charging. The different charging modes that have been defined by international standards offer solutions to solve this situation.

Charging modes

The arrival of electric vehicles into the everyday life of users should not change their habits, nor should it expose them to new situations that might be potentially hazardous when they charge their vehicles.

The battery capacity of a fully electric vehicle is about 20 kWh, providing it with an electrical autonomy of about 150 kilometres; rechargeable hybrid vehicles have capacity of roughly 3 to 5 KWh capacity, for an electrical autonomy of 20 to 40 kilometres (the heat engine ensures the autonomy of a conventional vehicle).

As this autonomy is still limited, the vehicle has to be charged every 2 or 3 days on average. In practice, the driver will probably recharge his /her vehicle as soon as he /she finds an occasion to do so.

For normal charging (3 kW), car manufacturers have built a battery charger into the car. A charging cable is used to connect it to the electrical network to supply 230 volt AC current. For quicker charging (22 kW, even 43 kW and more), manufacturers have chosen two solutions:

- use the vehicle's built-in charger, designed to charge from 3 to 43 kW at 230V single-phase or 400 V three-phase.
- use an external charger, which converts AC current into DC current and charges the vehicle at 50 kW

Charging time	Power supply	Voltage	Max current
6 – 8 hours	Single phase – 3.3 kW	230 VAC	16 A
2 – 3 hours	Three phase – 10 kW	400 VAC	16 A
3 – 4 hours	Single phase – 7kW	230 VAC	32 A
20 – 30 minutes	Three phase – 43 kW	400 VAC	63 A
20 – 30 minutes	Continue – 50 kW	400 – 500 VDC	100- 125 A
1 – 2 hours	Three phase – 24 kW	400 VAC	32 A

The user finds charging an electric vehicle as simple as connecting a normal electrical appliance; however to ensure that this operation takes place in complete safety, the charging system must perform several safety functions and dialogue with the vehicle during connection and charging.

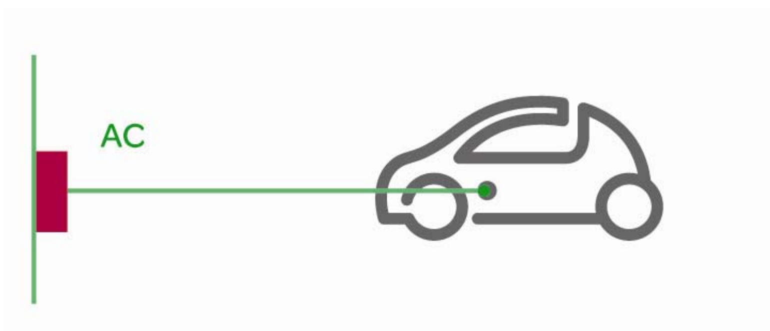
The IEC 61851-1 standard (work in progress) "ELECTRIC VEHICLE CONDUCTIVE CHARGING SYSTEM" defines the different charging modes. four types of charging modes have been defined:

Mode 1: Household socket and extension cord

The vehicle is connected to the power grid through standard socket-outlets (standard current: 10 A) present in residences. To use mode 1, the electrical installation must comply with the safety regulations and must have an earthing system, a circuit breaker to protect against overload and a earth leakage protection. The sockets have blanking devices to prevent accidental contacts.

Figure 1

"Mode 1" type connection



This solution is the simplest and the most direct to implement. It offers the driver the option of recharging his /her vehicle almost everywhere, which guarantees the peace of mind for the first-time buyers of electric vehicles.
Why then can't we be satisfied with this solution? As a matter of fact, it has several serious limitations and may pose risks if used incorrectly. These limitations have led to the definition of other more efficient charging modes.

The first limitation is the available power, to avoid risks of

- heating of the socket and cables following intensive use for several hours if we exceed the maximum power (which varies from 8 to 16 A depending on the countries in Europe)
- fire or electric injuries in case the electrical installation is obsolete or if certain protective devices are absent.

The second limitation is related to the installation's power management

- as the charging socket shares a feeder from the switchboard with other sockets (no dedicated circuit) if the sum of consumptions exceeds the protection limit (in general 16A), the circuit-breaker will trip, stopping the charging.

All these factors impose a limit on the power in mode 1, for safety and service quality reasons. This limit is currently being defined, and the value of 10A appears to be the best compromise. It must be noted that at this power, it will take nearly 10 hours to fully charge a vehicle.

No dedicated circuit

For instance, in France, the local standard NF-C-15100 standard on installation allows the connection of several household socket-outlets into the same protective element of the dwelling's electrical switchboard:

- Up to 5 socket-outlets with a cable with a cross-section 1.5 mm^2.

  Protection by a 16A circuit-breaker.
- Up to 8 socket-outlets with a cable with a cross-section 2.5 mm^2.

  Protection by a 20A circuit-breaker.

It is therefore highly probable that the household socket used for recharging an electric vehicle is on the same circuit as another electrical appliance, which is also in operation during the recharging.

In this case, the thermal protective device will open for safety reasons, as the cumulated currents of the electric vehicle and the household appliance will be higher than its setting threshold. Only the installation of a dedicated circuit for electric vehicle charging can prevent this type of unwanted tripping.

Temperature derating and intensive use

We have seen above that fully electric vehicles have charging powers varying from 3 to 24 kW. These powers correspond to charging currents from 16A single-phase up to 32A three-phase.

Moreover, recharging the vehicle may take up to 8 hours, and this has to be done regularly, even on a daily basis.

The NF-C-15100 standard imposes cable cross-sections of 1.5 mm^2 or 2.5 mm^2. Their maximum permissible power is 3.7 kW for a 1.5 mm^2 cable and up to 5.7 kW for a 2.5 mm^2 cable.

Household sockets are designed to be used at full load only for a limited period (typically 1 hour at maximum power, which is the case when we use household appliances). When charging an electric vehicle, the charging time exceeds this limit and can last up to 6 or 8 hours. Household sockets must therefore be classified as derating systems for this use case: their permissible current must be lower than 16A or 32 A in order to limit abnormal temperature increases in components and to prevent fire hazards.

Obsoleteness and non-compliance

In France, electrical installation professionals believe that there are about 7 million hazardous electrical installations (obsolete, non-compliant, etc.), accounting for a little less than half of the old residential building stock.

For instance in France, from 1972 onwards, new electrical installations are subject to an inspection and an attestation of compliance. This measure instituted by public authorities was extended in 2001 to the electrical installations of fully renovated dwellings.

However, the electrical installations of the 16 million dwellings built before 1972 are not covered by any regulatory control measure.

There are also misgivings about the condition of electrical installations in the dwellings built after 1972: according to electrical safety experts, an installation in which no change has been made for the last 30 years can be considered as obsolete. They further believe that, after thirty years, even in normal usage conditions, an electrical installation may most likely pose hazards due to wear and tear if no maintenance operation has been carried out since it was set up.

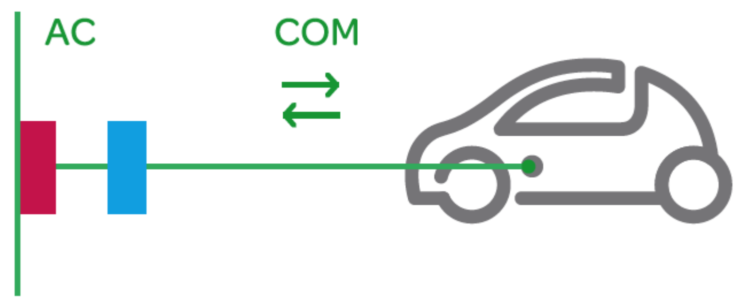
Connecting an electric vehicle without any precaution to this type of installation can therefore be dangerous for people and property when appropriate protective devices are absent.

Mode 2: Domestic socket and cable with a protection device

The vehicle is connected to the main power grid via household socket-outlets. Recharging is done via a single-phase or three-phase network and installation of an earthing cable. A protection device is built into the cable.

Figure 2

"Mode 2" type connection



(Protection device built into the cable)

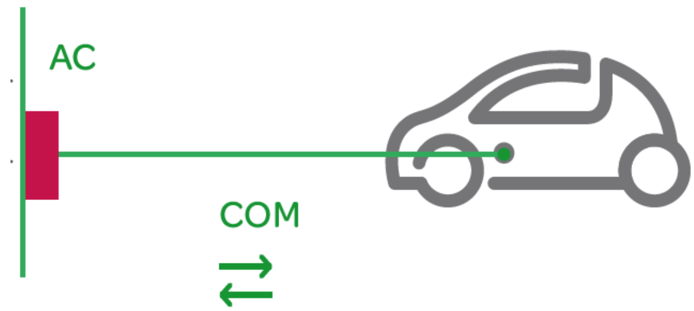
This solution is particularly expensive due to the specificity of the cable.

Mode 3: Specific socket on a dedicated circuit

The vehicle is connected directly to the electrical network via specific socket and plug and a dedicated circuit. A control and protection function is also installed permanently in the installation.

Figure 3

"Mode 3" type connection



(Protection device in the installation, specific recharging station)

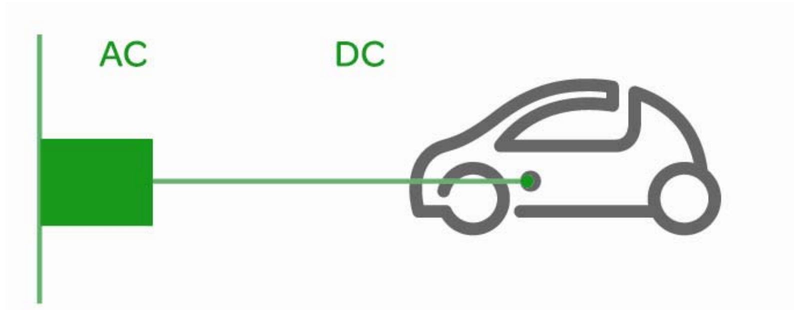
This is the only charging mode that meets the applicable standards regulating electrical installations. It also allows load-shedding so that electrical household appliances can be operated during vehicle charging or on the contrary optimise the electric vehicle charging time.

Mode 4: Direct current (DC) connection for fast recharging

The electric vehicle is connected to the main power grid through an external charger. Control and protection functions and the vehicle charging cable are installed permanently in the installation.

Figure 4

"Mode 4" type connection



(AC/DC external to the vehicle)

Solution recommended by Schneider Electric

Given the safety requirements and constraints of use, the electric vehicle charging system must be designed according to a specific electric vehicle standard in order to fully guarantee the safety of people and property.

The dedicated charging circuit imposed in "Mode 3" (see Figure 3) and defined in the draft IEC 61851-1 standard "ELECTRIC VEHICLE CONDUCTIVE CHARGING SYSTEM" guarantees maximum safety to users while charging their electric vehicle.

Furthermore, it also makes it possible to determine the charging power as accurately as possible if this is required by the energy provider (smart grid / demand-response) and imposes the addition of a specific and dedicated charging circuit.

A charging controller, on the infrastructure side, checks the following before starting the charging process:

- Check that the vehicle is connected correctly to the system.
- Check that the earthing system of the vehicle is connected correctly to the installation's protection circuit.
- Check that the power in the cable, the vehicle and the charging circuit are consistent.
- Determine the maximum charging power that will be allocated to the vehicle.

All these checks are carried out and communicated through a specific wire, called "PILOT WIRE".

It is essential for plugs and socket outlets on the infrastructure side to have two additional wires/pins, called pilot wires.
However, domestic outlets do not have these two additional wires/pins necessary for the charging controller to operate.

The IEC 62196-2 standard under development "Plugs, socket-outlets, vehicle couplers and vehicle inlets - Conductive charging of electric vehicles" defines a panel of sockets that can be used for charging via Mode 3. They contain the two pilot wires/pins in their standard version.

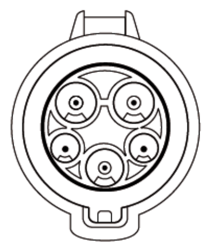
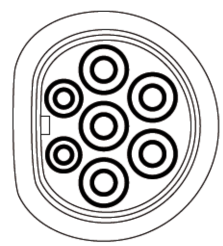
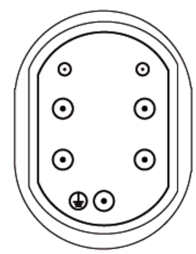
Charging sockets

Dedicated charging sockets

Three types of so-called "electric vehicle" sockets with connectors for the pilot wire can be used for charging electric vehicles.

Table 1

Types of socket

Characteristics	Type 1	Type 2	Type 3
Phase	Single-phase	Single-phase / 3-phase	Single-phase / 3-phase
Current	32 A	70 A (single-phase) 63 A	32 A
Voltage	250 V	500 V	500 V
No. of prongs	5	7	5 or 7
Blanking device	No	No	Yes
Diagram			

Schneider Electric recommends type 3 socket for the charging infrastructure, for two main reasons:

- Among the 3 models proposed (type 1, type 2 and type 3), only type 3 sockets and socket-outlets have blanking devices.

  These shutters are mandatory in France and in several European countries on household socket-outlets to avoid objects from being inserted into the socket, especially by children.

- Type 3 solutions also include blanking devices on sockets (male plugs) to anticipate the arrival of "Vehicles to Grid".

  In this case, the vehicle will act as a "power generator". The presence of blanking devices on plugs will therefore provide the same safety level for people as socket-outlets.

"Vehicle to grid" is a concept that makes it possible to use the energy stored in electric vehicles in order to support electrical networks during peak consumption periods or in the event of an emergency (storm, severed cable, etc.) …). The energy stored in the vehicle battery can also meet the electrical requirements of the residence. This technology implies that the charger on-board the vehicle as well as the interface between the vehicle and the electrical network is bidirectional (energy flows in both directions)

Conclusion

Optimising the transport sector, the largest consumer of fossil energy and producer of carbon dioxide, is vital for meeting tomorrow's climate challenge and for satisfying ever-increasing energy demands.

The electric vehicle, the missing link in the chain of sustainable urban mobility, represents a major step forward in reducing the ecological footprint of transport. Its development, and the success of this system, depends on the availability of suitable charging infrastructures.

The combination of mode 3 charging and type 3 connectors for the electrical installation offers the best solution for electric vehicle charging:

Simple

- Specific type 3 connectors are user-friendly and completely safe for the user.
- The control function manages the vehicle charging time and optimises power consumption based on needs.

Safe

- Using a dedicated and independent electrical circuit prevents any risk of unintentional connection with a non-compliant installation, and thereby guarantees the safety of people and property.
- Designed specifically for this application, the installation is easy-to-use and withstands conditions of intensive use.
- Type 3 connectors equipped with blanking devices on male and female plugs on the electrical installation side help to prevent any risk of electric shock for users and guarantees the integrity of the batteries installed in the vehicle.

Smart

Adding a pilot wire to the charging cable makes it possible to implement control functions and dialogue between the vehicle and the charging infrastructure.

- It ensures the optimal charging of batteries and preserves their service life.
- It makes it possible to communicate with vehicles of all types using standard protocols.

Flexible

Using a connection cable, fitted with a type 3 socket on the electrical installation side and with a connector matching the one provided by the manufacturer, means that only one cable per vehicle is required. Moreover, it can be adapted to the wide range of connectors chosen by the manufacturers (type 1 and type 2, even other specific solutions). This solution is also highly future-proof as far as the vehicle is concerned, allowing for the evolution of connectors in the future.

About the authors

Claude Ricaud is Innovation Director of the Power Business Unit at Schneider Electric. He also manages the Charging Infrastructure Task Force in the company.

Philippe Vollet is the Electric Vehicle Marketing Director of the Power Business Unit at Schneider Electric.

Sources

Schneider Electric benefit plan
www.schneider-electric.fr

IEC (International Electrotechnical Commission)
www.iec.ch

IEC 61851-1 « Electric Vehicle conductive charging system »

IEC 62196-2 « Plugs, socket-outlets, vehicle couplers and vehicle inlets - Conductive charging of electric vehicles »

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See www.schneider-electric.com/electric-vehicle

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