SIEMENS

Totally Integrated Power

Technical Series Edition 9

Electrical infrastructure for e-car charging stations

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Energy and electric mobility program

Increased promotion of regenerative energy sources seems to have led to the situation that Germany has become one of the bigger exporters of electricity within Europe. The move from combustion engines using fossil fuels towards electricity in the traffic sector might cushion this effect. Thanks to the energy-saving options offered by the vehicles' drive batteries, a buffer could be created for the varying energy yield of wind and sun. This would help achieve the goal of a 38 % share of renewables in electric power generation by 2020 [1] in Germany – as outlined in the energy concept and the National Action Plan. A prerequisite for this is the tight control of energy flows, as to be put into practice by smart grids. This is outlined in the "Government Program for Electric Mobility" of the Federal Republic of Germany [2].

According to this program, a minimum of one million electric vehicles are to be used in Germany by the year 2020, by 2030 this figure should rise to six million. However, it is left open which vehicle types are to be electrified. An estimate of the German Bike Association [3] for 2012 already assumes 1.3 million electric bicycles in Germany so that the figure of one million electric vehicles given in the "Government Program for Electric Mobility" will be referred to cars.

Boundary conditions for electrified car traffic

Starting from the notion that diesel cars will more frequently be used for longer distances, the mean daily driving route of 30 km as for Otto cars [4] will be transferred to e-cars in inner city traffic. Considering a mean energy consumption of 20 kWh per 100 km of vehicle mileage [5], there is an average power demand of 6 kWh per day and vehicle. The annual energy consumption of one million e-cars would be 2.2 TWh, corresponding to 0.4% of the net electricity consumption in Germany (541 TWh). To precisely understand these figures, it must be mentioned that for the year 2010, a mileage of 360 billion kilometers was recorded for motor vehicles in Germany [5]. If this vehicle mileage would have to be performed by utilizing electrical energy, this would correspond to a power demand of 72 TWh.

Since users desire short charging times, the statements on the electricity demand only allow for a conditional prediction of the power demand and hence of the load of the electric power distribution grids.

In 2020, statistics expect 0.95 charging points per vehicle to "fill up" e-cars [6]. Roundabout 150,000 of a total of 950,000 charging points shall provide for normal charging in the public and approximately 7,000 fast charging stations are expected. The remaining charging points shall serve for normal charging in the private sector.

The charging stations must comply with applicable standards and technical supply conditions (see "Summary" section on page 14f.). The number of charging stations of course depends on the quantity and product features of the vehicles, the mobility and charging behavior of the users as well as on the grid infrastructure which is available. Integrating the charging infrastructure into existing medium and low-voltage grids will result in **four typical charging situations**:

- Plug charging stations in the home, garage or underground car park (home charging with rather small output)
- Public AC charging stations with several, more powerful charging points (for example at multi-storey car parks, company parking lots, large parking facilities)
- Fast charging stations using direct current similar to petrol stations
- Battery exchange stations

Only the first three charging situations are relevant for planning electric power distribution. Although a strong predominance of home charging is expected for 2020 [6] based on the above figures, an analysis of the dwelling structure leads to a different breakdown of figures regarding a sustainable use of e-cars.

According to the German Federal Statistical Office, there are more than 40 million dwellings in Germany, distributed as follows:

- about 11.5 million detached houses
- about 3.6 million semi-detached houses, comprising about 7.2 million dwellings accordingly
- about 3.08 multiple dwellings, comprising certainly more than 20 million flats

Considering the large number of multiple dwellings and the diversity in mobility, we may assume that far less than half of the charging processes will be performed at home charging stations. To a much greater extent, charging stations with a high power demand and a connection to the medium-voltage grid will be required. By controlling the charging processes, a lower simultaneity factor may then perhaps be assumed. Before we will describe an example for the power demand estimate of a charging station, we will explain the charging modes and the associated charging units.

Charging modes for electric vehicles

Based on IEC 61851-1 (VDE 0122-1), conductive charging of electric vehicles can be distinguished according to four modes. A residual current operated circuit breaker (RCCB) of at least type A according to IEC 61008-1 (VDE 0664-10) in conjunction with an overcurrent protection device or a residual current circuit breaker with overcurrent protection (RCBO) (at least fault current type A) in accordance with IEC 61009-1 (VDE 0664-20) is required for all types of charging processes. Charging modes 1 to 3 describe charging an electric vehicle with a charger situated inside the vehicle (on-board charger), whereas with charging mode 4, the charging device is not installed inside the vehicle (off-board charger). Please note that owing to the different grid voltages, there are special requirements for the USA.

Charging mode 1

In charging mode 1, the electric vehicle is connected to single- or three-phase AC grids using a standardized socket (standard interface in accordance with IEC 60309-1, -2 – corresponding to VDE 0623-1, -2 – and IEC 60884-1). The charging current must not exceed 16 A, the voltage must not exceed 250 V (in case of single-phase AC current) or 480 V in case of three-phase AC current. It is not permitted that the electric vehicle back-feeds current into the stationary electric installation.

We recommend the use of a surge arrester. In Sweden and Japan, the use of a residual current operated circuit breaker, type AC, is permitted in connection with domestic installations. Charging mode 1 is prohibited in the USA.

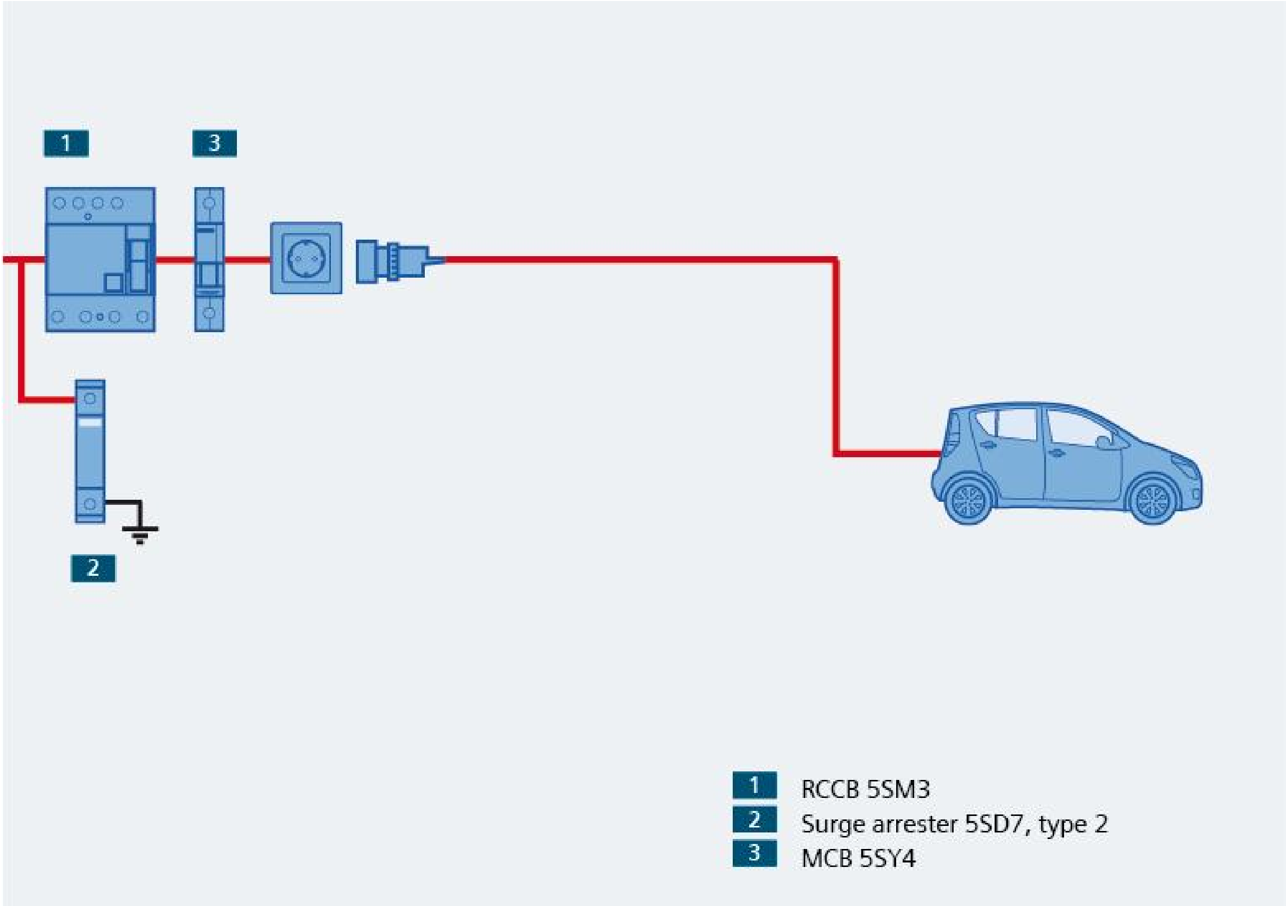

Fig. 1: Charging infrastructure for charging mode 1

Charging mode 2

In charging mode 2, the electric vehicle is connected to single-phase or three-phase AC grids using a pilot function of the charging control unit (pilot function using an in-line module in the charge lead). The control box must be placed in the plug or 0.3 m (in Germany: 2 meters) away from the plug or power supply facility of the electric vehicle at maximum. If the in-cable control box (ICCB) has run-over capability in accordance with IEC 62196-1 (VDE 0623-5-1), the distance must be no greater than 0.3 m. To increase the protective level, the in-line module contains a residual current operated circuit breaker.

The charging current must not exceed 32 A, the voltage must not exceed 250 V (in case of single-phase AC current) or 480 V in case of three-phase AC current. The control pilot for implementing the pilot function allows for communication between the ICCB and the vehicle.

It is not permitted that the electric vehicle back-feeds current into the stationary electric installation.

Using this charging mode requires a line-side residual current operated circuit breaker and an overcurrent protection device. We recommend the use of a surge arrester.

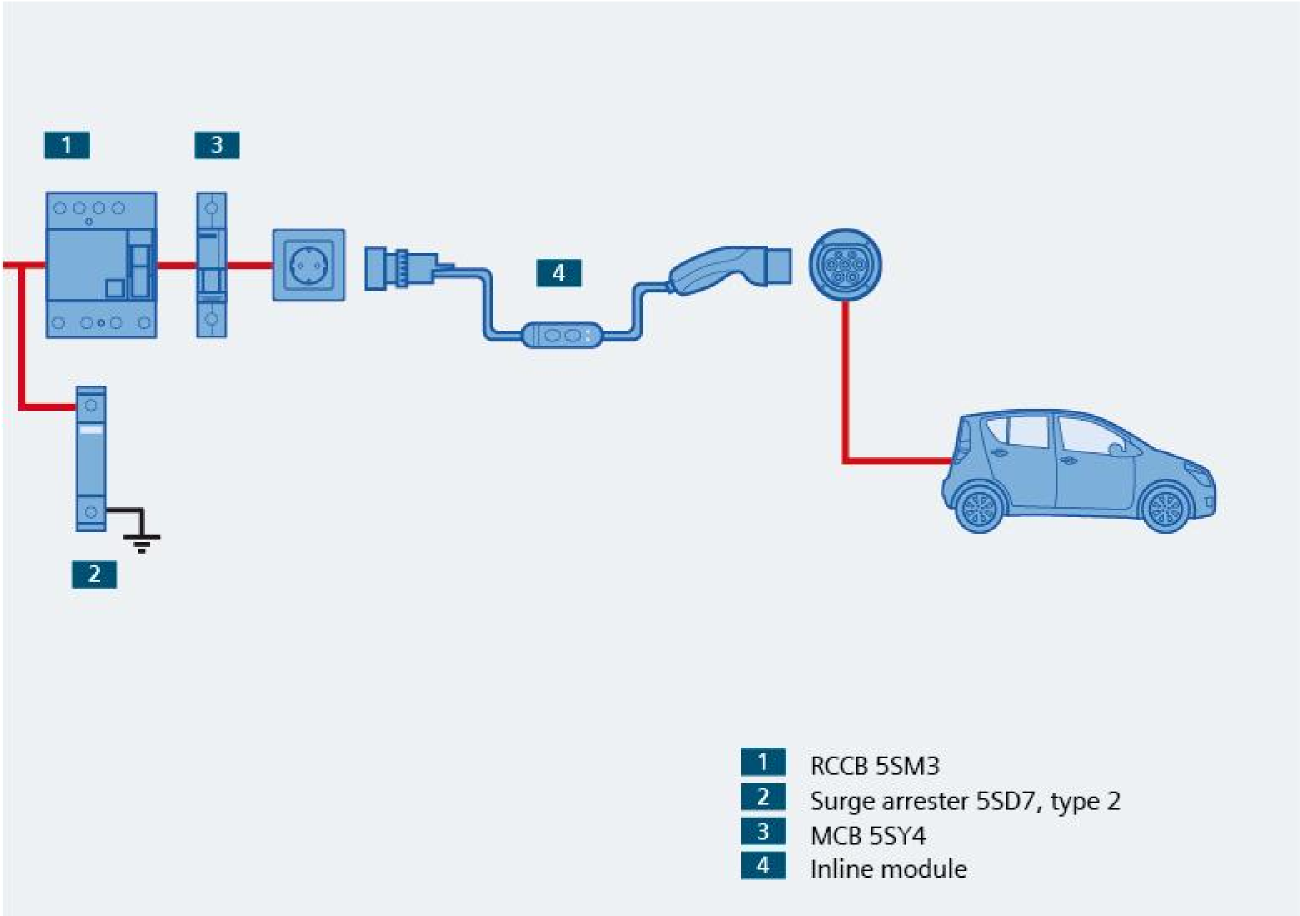

Fig. 2: Charging infrastructure for charging mode 2

Charging mode 3

In contrast to charging mode 2, IEC 61851-1 (VDE 0122-1) does not impose any restrictions regarding the current and voltage of AC supply for charging mode 3. The electric vehicle is connected to single-phase or three-phase AC grids, using a pilot function of the charge control box, via an on-board charger and a charge controller in the charging station.

Using this charging mode requires a line-side residual current operated circuit breaker and an overcurrent protection device. We recommend the use of a surge arrester.

A mechanical or electrical system must be present that ensures that plugging or unplugging is only possible if the supply of the socket or the vehicle plug is switched off. In contrast to charging modes 1 and 2, back-feeding could be considered, because communication and control between vehicle and charging unit can be operated in both directions and a suitable plug interlock is available. However, provisions must be made against a vehicle's inadvertent feeding into the stationary electrical installation.

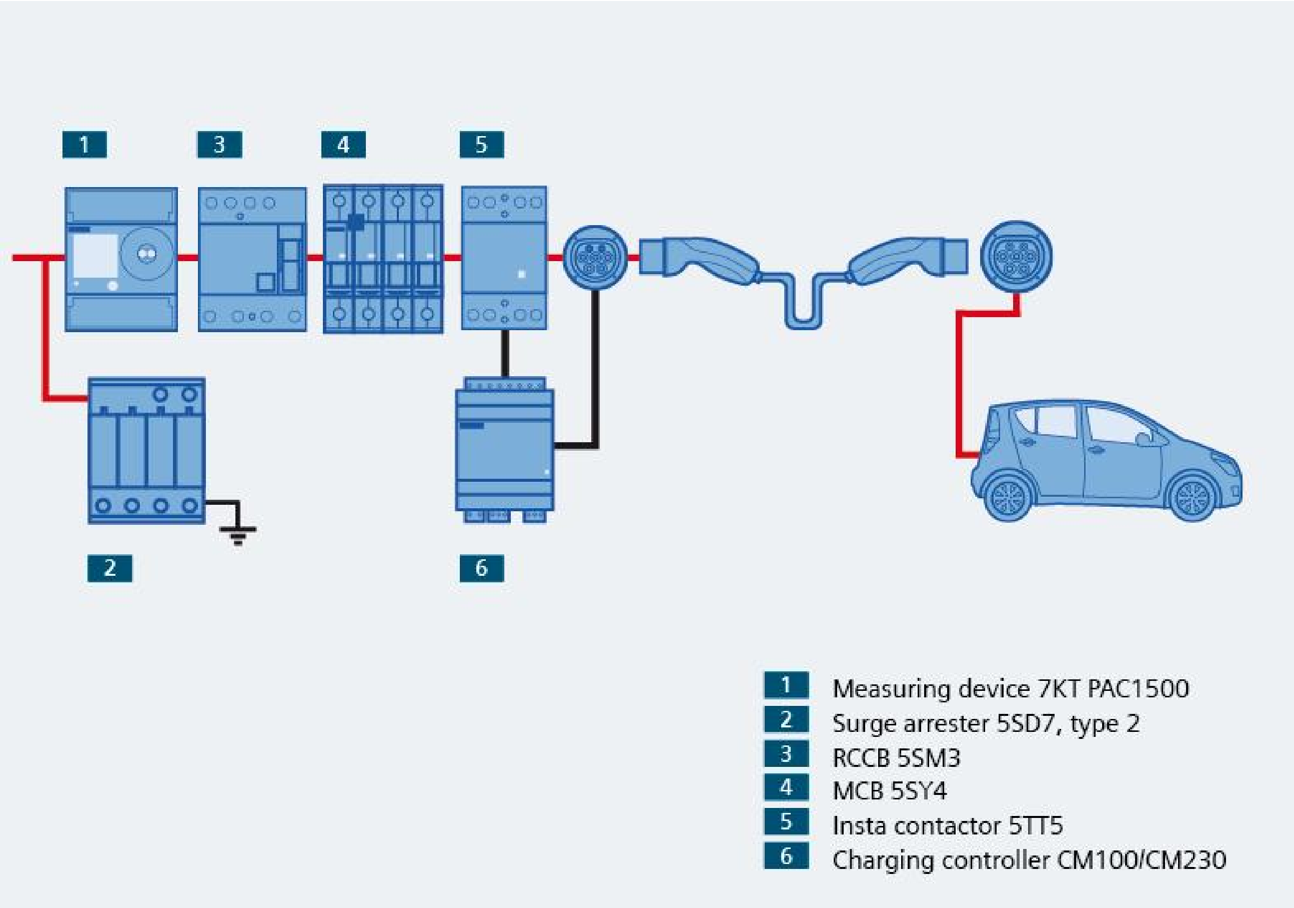

Fig. 3: Charging infrastructure for charging mode 3

Charging mode 4

The IEC 61851-1 (VDE 0122-1) standard suggests further options for implementing charging mode 4 using an AC supply. The connection between an electric vehicle and an external charging device shall be equipped with a pilot function from the vehicle to the unit which is continually connected to the AC grid. However, the connection according to case "C" in accordance with IEC 61851-1 (VDE 0122-1) is specified. Here, the supply line including vehicle coupler for the charging process must be permanently connected to the charging station.

Applying this charging mode requires a line-side AC/DC-sensitive residual current operated circuit breaker and overcurrent protection devices for alternating and direct current. We recommend the use of surge arresters.

The draft standard IEC 69/206/CDV:2011 (IEC61851-23; Draft VDE 0122-2-3) calls for a number of functions to be observed for DC charging stations. Among other functions, a mechanical or electrical system must be present that ensures that plugging or unplugging is only possible if the supply of the vehicle coupler is switched off. Moreover, provisions must be made against a vehicle's inadvertent feeding into the stationary electrical installation.

- Check for proper vehicle connection in accordance with stipulations
- Continuous equipotential bonding and/or protective earth conductor continuity checking
- System on-/off-switching
- Measurements of current and voltage
- Blocking, locking and releasing the vehicle coupler
- Protection of the charging station against overvoltage and overcurrent
- Insulation check prior to charging
- Protection of the battery against overvoltage and/or overcurrent
- Voltage check of the charge lead prior to unlocking the vehicle coupler
- Integrity of the pilot circuit supply
- Short-circuit check between plus and minus of the DDC circuit output prior to charging
- User-triggered off-switching of the charging current
- Overload protection for parallel conductors
- Requirements of fault protection

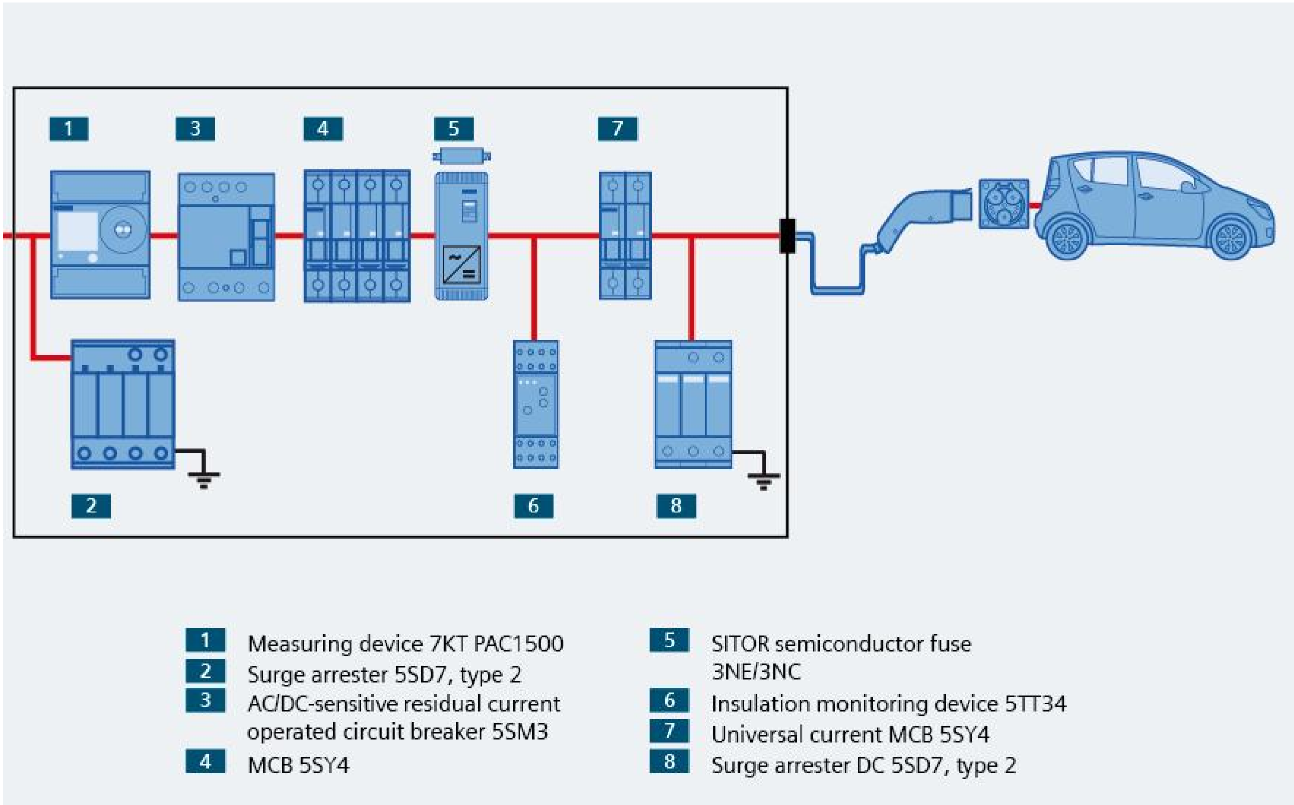

Fig. 4: Charging infrastructure for charging mode 4

Charging units for different charging situations

In line with the above described charging situations, complete charging units are offered. However, when integrating those into existing electric power distribution structures, the current load must be kept in mind. If home charging was performed using a conventional socket, the charging times would either be several hours, or high charging currents could result in a fire risk for the domestic power distribution system.

Here, we must recommend laying a separate circuit using halogen-free cables. In view of the integration into a smart grid, at least the option of back-feeding electricity from the electric vehicle into the grid should be offered. Therefore, even for home charging, the charging units to be chosen should feature charging mode 3.

Charging unit Siemens WB100A (wall box)

The system-tested, CE conforming WB100A charging unit can charge vehicles in charging mode 3 in accordance with IEC 61851-1 (VDE 0122-1) using a charging cable and plug that correspond to the standards group IEC 62196 (VDE 0623) and are suitable for indoor and outdoor use. Pre-wired SENTRON protective, switching and monitoring devices mounted inside the charging unit ensure maximum safety during charging. Any confusion with undersized charging cables is excluded, since the current carrying capacity is rated to the rated current of the charging unit and the miniature circuit breaker.

Fig. 5: Siemens WB100A wall boxes

To suit all needs, either 16 A or 32 A can be chosen in combination with single- or three-phase current and plug type 1 or 2 (see Fig. 6) in accordance with IEC 62196-2 (VDE 0623-5-2).

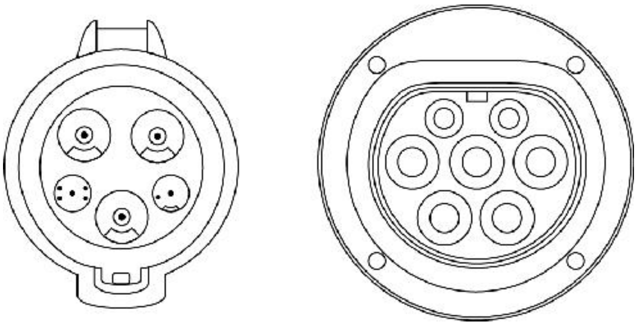

Fig. 6: Schematic top view for plug type 1 (left) and 2 (right) acc. to IEC 62196-2 (VDE 0623-5-2)

Technical data:

Rated input voltage/frequency: 230/400 V AC, 50/60 Hz

Rated input current: 16 or 32 A, single- or three-phase

Maximum permissible conductor cross section 16 mm²

Fault current protection:
residual current operated circuit-breaker, 30 mA, type A or B

Rated breaking capacity (I_{cn}): 10 kA

Safety class: II

Environmental conditions:

Ambient temperature: -25 °C .... +40 °C

Degree of protection: IP 54 acc. to IEC 60529 (VDE 0470-1)

Site of installation: Suitable for indoor and outdoor use

Charging station for three-phase charging

A compact charging station allows to implement charging mode 3 for three-phase charging or charging modes 1 and 2 using an optional single-phase socket. One charging station can charge two vehicles simultaneously, which saves installation and maintenance cost. There is the option to equip the charging connectors with calibrated (MID conforming) meters for exact invoicing of the energy charged and/or a feed-in meter to offset the total energy consumption between electricity supplier and operator precisely.

The Ethernet interface or an integrated GSM/GPRS modem allows to link up the charging station to the control centre and thus to smart grid control. In combination with a charging control software, a number of customer-friendly applications can be implemented:

- If the demanded power exceeds the quantity offered, the charging process is halted and continued automatically as soon as the appropriate output is available.
- The output available is evenly distributed to the vehicles connected.
- Testing of the integrated residual current operated circuit breaker can be performed by remote maintenance from the control center.
- Options to book a charging terminal
- Differentiated invoicing options as a customer service

As user identification at the charging station, users hold their RFID cards against the marked area of the built-in LCD display. After successful user identification, the covers of the charge connectors are opened (on the left, or respectively on the right), so that a charging plug can be plugged in. The charging station automatically checks for electrical compatibility of charging station, cable and vehicle and starts the charging process after a successful check.

To connect the charging station to the low-voltage grid of the supplier, a service entrance box is integrated matching the specific charging station type, or a suitable house connection box can be mounted (DIN 43627). If the connection grid has a high short-circuit power, an appropriate LV HRC fuse can be built in as back-up protection inside the house connection box, this implements short-circuit protection for the charging station. Integrated temperature monitoring of sockets and the interior of the charging station together with off-switching, or respectively interruption of the charging process in case of excessive temperatures serves as additional overload protection.

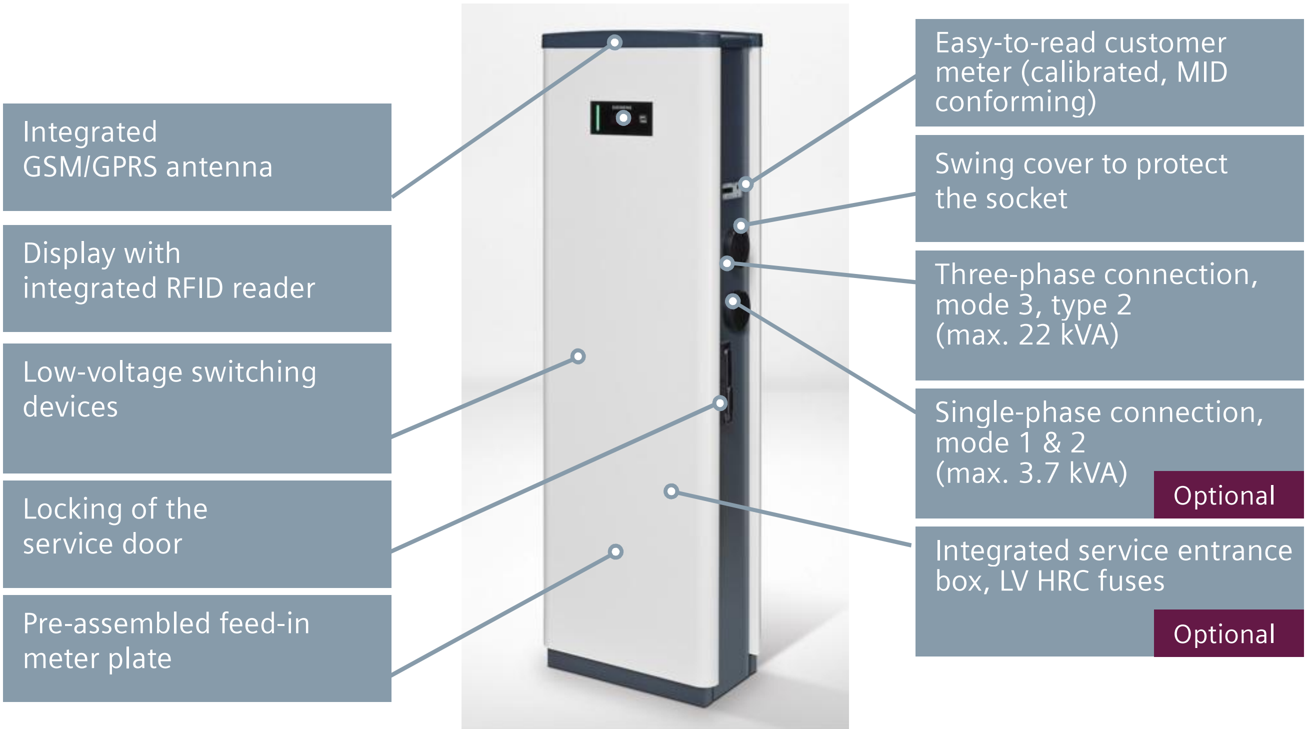

Fig. 7: Example of an AC charging station

Technical data:

Rated input voltage/frequency: 400 V AC, 50 Hz

Rated input current:
2 x 32 A (integrated service entrance box)

Connected load: 44 kVA

Maximum permissible conductor cross section: 5 x 50 mm²

Fault current protection:
2 x RCCB, 30 mA, type A (optionally type B)

Rated breaking capacity (I_{cn}): 10 kA

Dimensions W x H x D: Approx. 500 x 1,650 x 290 mm

Weight: Approx. 100 kg

Environmental conditions:

Ambient temperature: -25 °C .... +40 °C

Degree of protection: IP44 in accordance with IEC 60529 (VDE 0470 -1)

Mechanical strength:
IK 08 in accordance with IEC 62262 (VDE 0470-100)

Relative humidity (non-condensing): 95 %

Maximum altitude of the site of installation: 2,000 m

Fast charging station for direct current charging

The most important field of application for a DC fast charging station are combined outdoor parking and charging spaces with an average parking time of less than an hour. This may include restaurant or department store parking lots and the parking lots for official cars and service cars of companies and the public administration with frequent service and field deployments. Thanks to the extremely short charging times of typically 15 to 30 minutes, new service concepts might be developed for coffee and fitness breaks during charging "on the road".

The fast charging station works in charging mode 4 with a connection case "C" in accordance with IEC 61851-1 (VDE0122-1). This means a cable and vehicle plug is fixed-mounted at the charging station. The charging station meets the CHAdeMO specification and also is in compliance with CE.

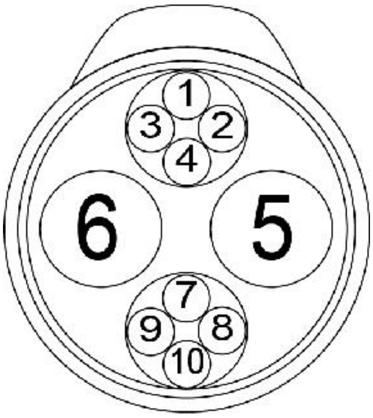

Fig. 8: Pin arrangement for DC fast charging acc. to CHAdeMO (Pin 5 and Pin 6 are used for direct current supply, otherwise they are communication terminals, Pin 3 is not assigned)

The core element of a fast charging station is the DC charging unit with modern power electronics where the charging voltage can be set. The IGBTs (Insulated Gate Bipolar Transistor) clocked at 20 kHz work nearly without noise, since their working frequency is outside the range most people are able to hear. High-quality filters at the input side make sure that the already low perturbations are dampened further. Electrical isolation ensures safe isolation between feeding grid and DC charging voltage. In addition, the DC charging circuit is equipped with an insulation monitoring device.

Technically seen, a smoothing choke and a DC filter circuit provide for a reduction of interference voltages that stress the vehicle batteries and may result in unnecessary battery ageing.

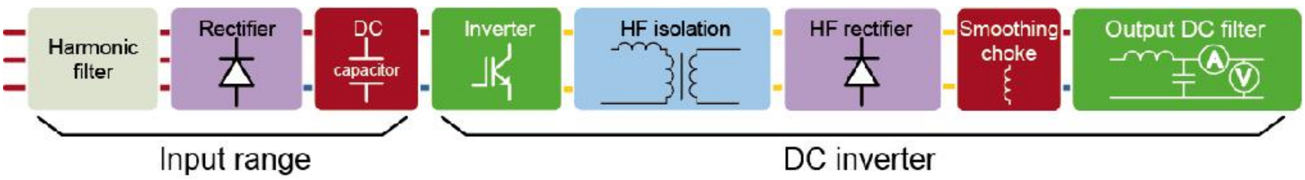

Fig. 9: Schematic structure of a DC charging circuit

An Ethernet interface is built in to network the charging stations, a GSM/GPRS modem can optionally be integrated. Similar to an AC charging station, connectivity with a charging control software is thus possible. In addition to the RFID reader, a color display is built in to help the user communicate with the station.

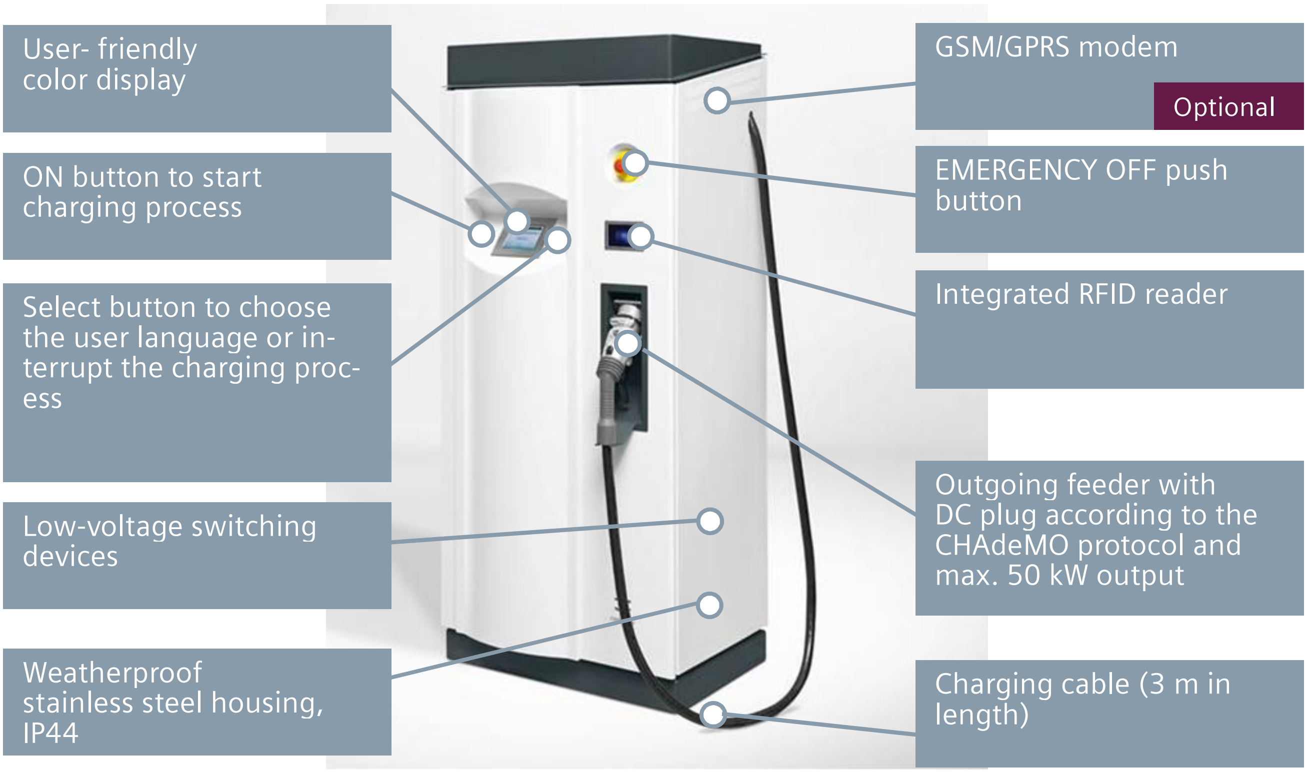

Fig. 10: Example of a DC fast charging station

Technical data:

Rated input voltage/frequency:
3-ph 400 V AC/ 50 Hz to 60 Hz

Rated input current/power: 80 A / 55.4 kVA

Efficiency > 94% at rated power (417 V/120 A)

Power factor > 0.95 at maximum power

Residual current operated circuit breaker:
One each (input-side) at the control circuit and the upstream rectifier:

Short-circuit protection: Yes

Temperature monitoring: Yes

Rated output voltage: 50 to 500 V DC

Charging current / output power: Max. 120 A/ max. 50 kW

Plug type in accordance with CHAdeMO specification:
JEVS G105-1993

Charging mode in accordance with IEC 61851-1 (VDE0122-1): 4

Connection type in accordance with IEC 61851-1 (VDE0122-1): Case "C"

Output-side line protection: Fuse 160 A / 30 kA

Maximum conductor cross section: 4 x 50 mm²

Dimensions W x H x D: Approx. 800 x 1,900 x 660 mm

Weight: Approx. 420 kg

Required short-circuit power ratio at the connection point:
$R_{sce} \geq 220$

Environmental conditions:

Ambient temperature: -10 °C .... +40 °C

Ambient temperature (heated): -30 °C .... +40 °C

Degree of protection: IP 44 in accordance with EN 60529

Relative humidity: max. 90% without condensation

Maximum altitude of the site of installation: 2,000 m

Qualitative description of the electric power distribution for charging stations

This edition of the Technical Series is essentially focused on the planning of charging stations outside the home charging sector. Therefore we must assume a larger number of charging stations and a correspondingly high power demand. This will be quantified in the section "Empirical determination of the power demand for a model charging station" (page 14). This section will first describe the **basic structure of the power supply infrastructure**. Important criteria of power supply to charging stations for electric vehicles are:

- Low transmission losses
- High voltage quality
- High energy efficiency
- Few grid perturbations
- Low maintenance and repair cost
- Safety against vandalism

Owing to the high power demand for the supply of a charging station and the transmission losses involved, a distribution transformer is usually installed close to the load centre, which is supplied from the medium-voltage grid. This kind of installation also ensures that a high short-circuit level has a favorable effect on grid perturbations. Extensive low-voltage networks for power distribution to the individual charging stations, for lighting equipment and – if applicable – for measurement and control systems and safety systems at the parking lots should not be planned either, but it should be made sure that the distribution transformers be located close to the low-voltage main distribution systems (LVMD).

When determining location and space requirements, a controlled reactive power compensation and measures for the prevention of grid perturbations must be provided, for example choking or the integration of harmonics filters. To control and monitor the power and voltage quality, respectively for grid analysis and to meet requirements regarding supply quality in accordance with the EN 50160 standard, a monitoring device such as the SICAM Q80 power quality recorder should be used.

Fig. 11: SICAM Q80 power quality recorder

Transformer and LVMD are accommodated in suitable locations indoors with no access from the public. The planning must consider the relevant regulations for transformer substations in buildings with multiple use. In Germany, for instance the following regulations are relevant: for safety lighting equipment this is EN 50172 (VDE 0108-100), for electromagnetic compatibility (EMC) this is EMVG (Act on the Electromagnetic Compatibility of Equipment) and BImSchV (Federal Ordinance on the Protection against Immissions), for the construction of operating areas this is the respective EltBauV ordinance
(Ordinance on the construction of electrical operating areas) and there are more regulations concerning environmental compatibility, heat, sound and fire protection.

Busbar trunking systems and cables for current transmission from the LVMD to the charging stations will be compared in the sections below. To do so, both technologies will be briefly presented and their advantages and disadvantages will be demonstrated.

Connecting the charging stations using SIVACON 8PS busbar trunking system

Considering the power demand of the charging stations, a busbar trunking system that is hung from the ceiling, or the stress-bearing structure of the building, is the system of choice. In the LVMD, the busbar trunking system is directly connected at the outgoing feeder of a circuit breaker and installed above a row of charging stations. The busbars should be fitted at a height where they can only be reached with ladders or scaffolds.

The individual charging stations are connected to a switching device via system-specific tap-off units.

The method of connection is either circuit-breaker-protected (molded-case circuit breaker, MCCB) or fuse-protected (fuse switch disconnector). The switching device in the tap-off units can be configured as back-up protection for the charging station. A cable is laid from the tap-off unit to the charging station whose protection (short-circuit protection) is ensured by the switching device in the tap-off unit (overload protection in the charging station is the prerequisite).

Advantages:

- Easier maintenance, since disconnection of the entire charging station is possible on-site
- Low fire load, since the busbar trunking systems are free from PVC and halogens.
- High flexibility, for example using pluggable tap-off units and easy extendibility in case of later change and retrofitting
- Very good assignment of the switching devices to the individual charging stations
- High voltage quality owing to a lower voltage drop
- High short-circuit level at the connection point of the charging station (positive effect in terms of grid perturbations)
- Less work involved for fault identification due to the spatial assignment of the protective devices
- Less space required in the LVMD, since the protective devices are located in the tap-off units at the charging stations

Disadvantages:

- Initially higher cost of investment, which, however, will pay for itself in the course of time due to lower maintenance cost and a greater flexibility in retrofitting.

Connection of charging stations using cables or wires

Von From the LVMD, cables are laid in cable trays or the floor area (sub-floor installation) to connect the indvidual charging stations.

The switching and protective devices (circuit-breaker-protected, fuse-protected) pertaining to the charging stations are placed in the LVMD. Each charging station has its own feeder cable.

Advantages:

- Lower cost of investment
- Back-up protection of the charging station cannot be reduced, since cables cause an additional short-circuit current attenuation
- Cables can be easily laid in the floor and connected to the charging station from the bottom

Disadvantages:

- Higher fire load
- Rigid cable laying in case of changes or retrofitting
- A higher voltage drop and thus a lower short-circuit power affect the voltage quality and grid perturbations
- Increased space requirements in the LVMD cabinet, which consequently grows (more panels)
- Higher maintenance expense, since switching and protective devices for the individual stations are not in the same location (spatial assignment)

Grid perturbations when charging electric vehicles

Unfortunately, the power demand is often taken as the only criterion for the grid design of charging stations. Since power-electronic systems are used for transforming the AC grid current into DC battery current, the perturbations on the grid are an essential design factor. In particular the impact of the different charging converter circuits owing to harmonics is to be observed in the planning [7]:

- The level of short-circuit power at the connection point of the charging station is decisive for the voltage distortion from harmonics.
- When integrating a large number of charging units (for example at public parking lots) or fast charging stations into the grid, a sufficiently high short-circuit power must be available at the connection point. Therefore, charging units should be integrated at the medium-voltage level and – if possible – suitable grid concepts for improving grid stability should be drawn up.
- A stable medium-voltage grid, respectively a high short-circuit power reduces the effects of harmonic currents.
- Integration into the medium-voltage grid reduces the impact on other sensitive power consumers in the low-voltage grid
- Feed-in of high-frequency current components into the medium-voltage grid by the power converters connected in the low-voltage grid can be significantly reduced by high-frequency filters and the dampening properties of transformers and cables.

AC charging uses the rectifier of the electric vehicle, so that it is therefore normally impossible to make any predictions about the grid perturbations resulting from the power converters. With DC fast charging stations, specifying the short-circuit power ratio R_{sce} (see the technical data in the section "Fast charging station for direct current charging") defines the required short-circuit power at the linking point. How to determine R_{sce} is described in the section "Integration into the low-voltage grid of the supplier".

Typical electronic components for implementing power converter circuits are diodes, thyristors and transistors. In the following, we will distinguish between line-commutated power converters using thyristors and self-commutated power converters using transistors to demonstrate, how different the impact can be these can have on the harmonic oscillation range. But this can only be a theoretical approximation.

Power converter based on thyristor technology

The characteristic harmonic currents of this converter type with either six-pulse or twelve-pulse thyristor bridges theoretically appear only in the range of the following harmonic orders:

6-pulse	5th/7th,	11th/13th,	17th/19th,
	23rd/25th,	... harmonic component,	
12-pulse		11th/13th,	
	23rd/25th,	... harmonic component,	

Ordinal $h = n \times k \pm 1$

k: Pulse figure of the power converter, here 6 or 12
n: Integer greater than zero
h: Harmonic wave of the ordinal h

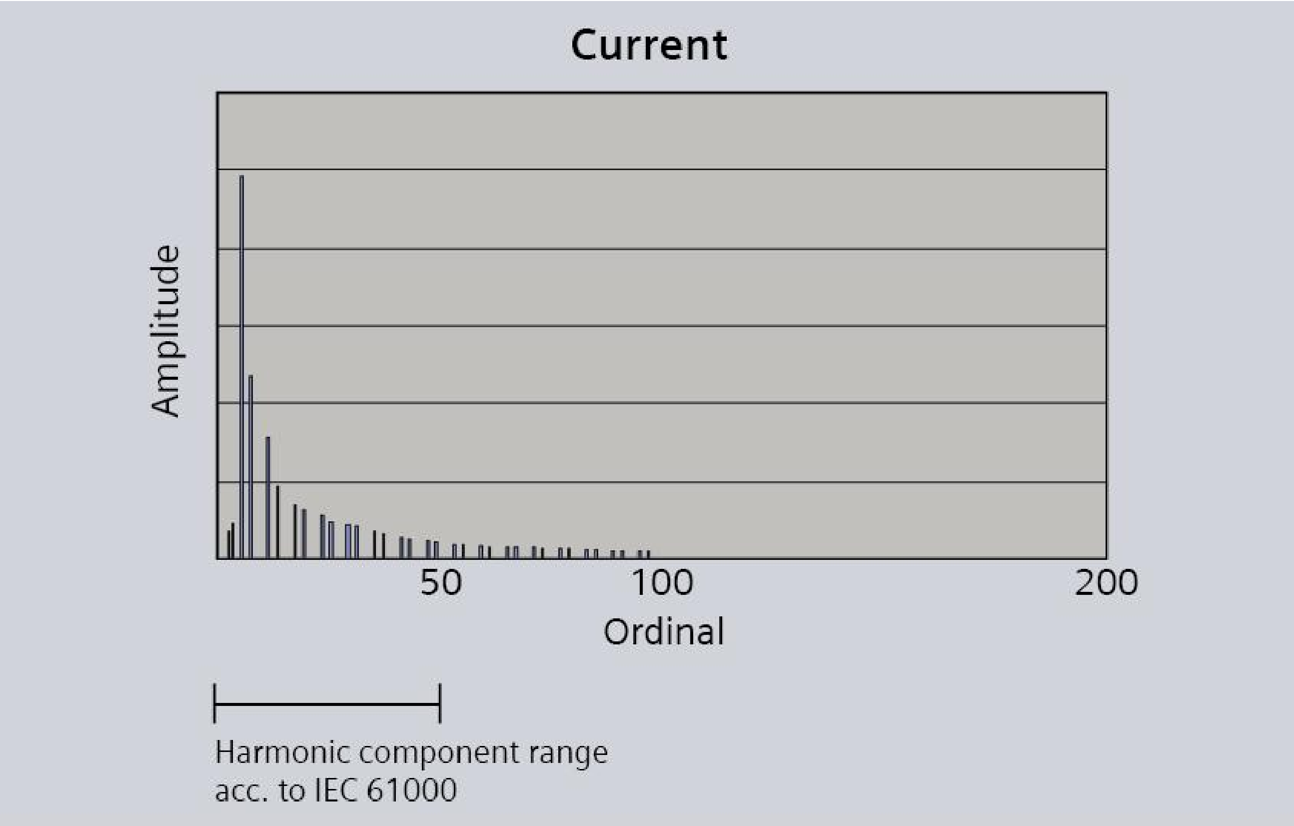

Fig. 12: Frequency analysis for the harmonic components of a thyristor rectifier [6]

Power converter based on transistor technology and pulse width modulation (PWM)

Due to the switching frequencies of power transistors in the kilohertz range, PWM converters also generate harmonic components in frequencies above the range which is typical for power converters based on the thyristors, for example above the 49th order with about 2.5 kHz and more. With the increasing use of PWM converters, as applied in the charging stations of electric vehicles, it becomes more and more important to take harmonics into account.

The advantage of frequencies in the kHz range is their spatially limited propagation around the source. Frequencies with a disturbing impact above the range discussed in the standards (in EN 50160 the ordinal h = 40 was agreed) can typically only be found in that grid range where they were generated. The reason is, they can hardly overcome transformers and are nearly shorted by the capacities of longer cables. In Fig. 13, a PWM transistor converter is considered with a switching frequency of approx. 2.5 kHz (ordinal h = 50; frequency = h x 50 Hz).

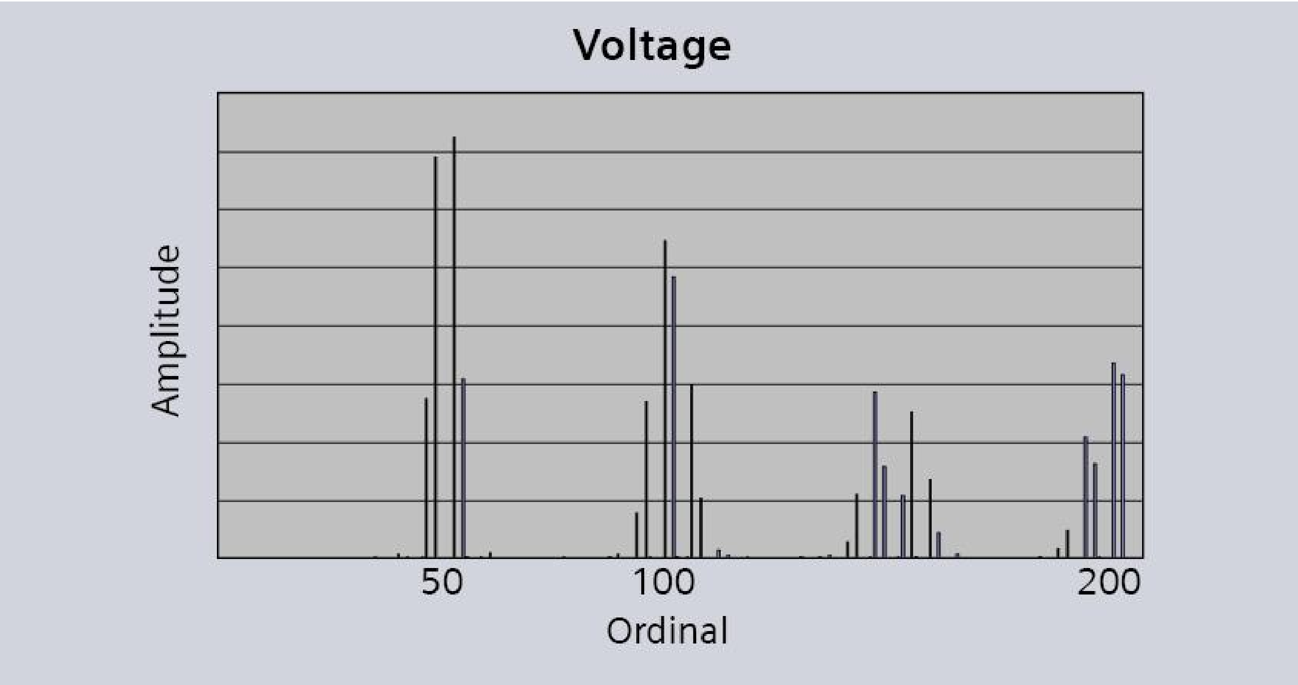

Fig. 13: Frequency analysis for the harmonic components of a PWM transistor converter [6]

Voltage characteristics of electricity supplied by public grids

Sections 4.2.5 and 5.2.5 of the EN 50160 standard define the requirements with regard to the harmonic voltage for the low and medium voltage range. In Tab. 1 the mean 10-minute values of the voltage r.m.s. value of each individual harmonic component given in EN 50160 is listed which must be adhered to by 95% during any weekly interval.

Uneven harmonic				Even harmonic	
No multiples of 3		Multiples of 3			
Order h	Relative voltage amplitude U_h	Order h	Relative voltage amplitude U_h	Order h	Relative voltage amplitude U_h
5	6.0 %	3	5.0%	2	2.0 %
7	5.0%	9	1.5%	4	1.0%
11	3.5 %	15	0.5%	6 to 24	0.5%
13	3.0%	21	0.5%		
17	2.0%				
19	1.5%				
23	1.5%				
25	1.5%				

Tab.1: Electromagnetic compatibility level of the individual harmonic voltages in relation to the fundamental voltage U_1 in accordance with EN 50160

Resonances which may cause higher voltages for a single harmonic component are pointed out. In addition, it is demanded that the *THD (Total Harmonic Distortion)* of the supply voltage (sum of all harmonic components up to the ordinal 40) be less or equal to 8 %.

$$THD_U = \sqrt{\sum_{h=2}^{40} (U_h)^2} \leq 8\%$$

Note:

No values are given for harmonic components above the 25th order, since they usually low, but cannot be predicted owing to resonance effects. IEC 61000 specifies the value 0.2% for each frequency above the 50th harmonic. This, however, does not constitute a normative limit, but is a recommended, non-binding value. The reason is that a widespread application of transistor-based power converters using PWM technology has only boosted in recent years.

Integration into the low-voltage grid of the supplier

If the power drawn is less than approx. 100 kVA, it is directly drawn from the low-voltage grid of the supplier. In accordance with EN 50160, the charging stations are connected to the low-voltage grid with a single-phase voltage of 230 V and a three-phase voltage of 400 V.

The charging infrastructure is built up in the home and business environment of the user on the one hand, and at public charging points along street parking areas on the other. In these situations, there are different network topologies:

a) In rural areas, these are radial networks. Several spur lines, branching further if need be, are connected to a transformer substation. Branching from there, domestic connection lines supply the customers.
b) In urban environments, low-voltage grids are often designed as closed ring-main or meshed networks which are fed from two ends (by two transformer substations) or even from multiple points.

Charging units with less than or equal to 16 A which meet the requirements of IEC 61000-3-2 (VDE0838-2) may be connected to any connection point in the public grid without further tests. For equipment featuring a rated current of more than 16 A but less than or equal to 75 A, it is the short-circuit power ratio R_{sce} in accordance with IEC 61000-3-12 (VDE 0838-12) which is decisive. According to [8], the factor R_{sce} represents the ratio of the 3-pole short-circuit power $S_{K,VP}$ at the linking point (VP) to the equipment output $S_{r,G}$ or respectively to the system output S_A:

$$R_{sce} = \frac{S_{K,VP}}{S_{r,G}} = \frac{S_{K,VP}}{S_A}$$

For single-phase equipment there is $R_{sce} = \dfrac{S_{K,VP}}{3S_{r,G}}$

For three-phase equipment there is $R_{sce} = \dfrac{S_{K,VP}}{2S_{r,G}}$

The short-circuit power $S_{K,VP}$ outlined in [8] is not the **subtransient initial symmetrical short-circuit AC power** S_K'', as described in IEC 60909-0 (VDE 0102), but it is a **measure for the line impedance**.

The determination of $S_{K,VP}$ essentially differs from that of S_K'' by the following aspects:

- No voltage factor c
  (c= 0.95 for I_{kmin}; c= 1.1 for I_{kmax})
- Lower conductor temperatures (70 °C instead of 80 °C for I_{kmin}; 20 °C for I_{kmax}) for resistance determination
- Passive consumers (capacitors and reactor in compensation systems or filters) are factored in

The short-circuit power ratios at the connection point can be determined with SIMARIS design. To do so, the 3-pole short-circuit current I_{k3min} at the linking point (VP) is related to the equipment current $I_{r,G}$, drawn or respectively to the system current I_A.

$$R_{sce} = \frac{I_{K3min;VP}}{Ir,G} = \frac{I_{K3min:VP}}{I_A}$$

Verteiler: NSVS 1.1A.1.1.1
max. zulässige Abschaltzeit = 5s

gf	=	1	cos(φ)	=	0,9 ind.
Igw	=	31,754 A	Ibw	=	31,754 A
Igb	=	-15,379 A	Ibb	=	-15,379 A
Igs	=	35,283 A	Ibs	=	35,283 A
Ik3max	=	39,602 kA	φ3	=	-78,94 °
Ipk	=	87,66 kA			
Ik1maxph_n	=	37,217 kA	φ1ph_n	=	-75,298 °
Ik1maxph_pe	=	35,867 kA	φ1ph_pe	=	-75,665 °
Ik3min	=	34,091 kA	φ3	=	-78,032 °
Ik2min	=	29,524 kA	φ2	=	-78,032 °
Ik1minph_n	=	31,862 kA	φ1ph_n	=	-73,499 °
Ik1minph_pe	=	30,716 kA	φ1ph_pe	=	-73,893 °

Fig. 14: Minimum 3-pole short-circuit current from a calculation with SIMARIS design

If you perform this check, you will be on the safe side, since a calculation of the 3-pole minimum short-circuit current in SIMARIS design makes determinations as in IEC 60909-0 (VDE 0102) (voltage factor 0.95 for calculating I_{kmin} and resistance values for cables and wires as well as busbar trunking systems at 80 °C).

According to [8], no evaluation of the harmonic components must be performed, if the following condition is satisfied:

$S_{k,VP} / S_A \geq 150$ for the low-voltage grid

$S_{k,VP} / S_A \geq 300$ for the medium-voltage grid

If either of the two conditions is not satisfied, more precise analyses must be made, as described in [9].

To connect a fast charging station for DC charging, a factor $R_{sce} \geq 220$ at least requires a short-circuit power $S_{k,VP}$ of approx.12 MVA, which is usually not the case in public low-voltage distribution grids.

Empirical determination of the power demand for a model charging station

As a model for the calculation of the power demand for charging stations at a company car park or a public car park, we will assume 100 parking lots for a mix of e-cars using different charging systems must be supplied with electricity:

- Charging times vary between half an hour and eight hours
- 8 % of the parking lots are suitable for DC fast charging within 30 minutes
- 92 % of the parking lots are equipped with AC charging stations whose capacity is used for charging within one to eight hours

Consequentially, the layout of the car park is as follows:

- 8 DC fast charging stations for one parking lot each
- 46 AC charging stations for 2 parking lots each

We must assume that all fast charging stations are used simultaneously. Therefore, the DC fast charging stations must be supplied with a total current of
8 x 80 A = 640 A.

For the AC charging stations, we assume the following power distribution for charging the individual vehicles:

20% of the AC charging stations are run at full load; 9 charging stations are loaded with 2 x 32 A	=	576 A
28% of the AC charging stations are run at half load; 13 charging stations are loaded with 2 x16 A	=	416 A
52 % of the AC charging stations are run at 25% of the total load; 24 charging stations are loaded with 2 x 8 A	=	384 A
Total:		**1,376 A**

This utilization corresponds to a simultaneity factor of approx. 0.47 for the AC charging stations.

The total current load for these 100 parking lots featuring both AC and DC charging is then

640 A + 1,376 A = 2,016 A.

This results in a power demand of about 1,390 kVA which is to be supplied by the feeding transformer. The matching standard transformer (TUMETIC, GEAFOL) with 1,600 kVA nominal power and u_k = 6% can supply a maximum initial short-circuit alternating current I_k'' of approx. 42 kA. It can thus help create short-circuit conditions at the charging stations which are above their specifications. Back-up protection must therefore be observed generally.

The assumption of a simultaneity factor only makes sense if the load distribution is controlled by a charging control software. Without control, the power demand shall be determined as having a simultaneity factor 1, i.e. in our model a maximum current of 3,538 A corresponding to a power demand of approx. 2,450 kVA. A suitable standard transformer with a power rating of 2,500 kVA would therefore be capable of supplying a maximum initial short-circuit alternating current of approx. 66 kA.

The electrical components built into the charging units only dispose of a limited short-circuit strength. For short-circuit protection in compliance with IEC 60364-4-43 (VDE 0100-430), it is normally indispensable, that appropriate back-up protection is configured for the connection of the charging units to the supply grid With the DC fast charging station and the WB100A wall box, this must be implemented outside the charging unit upstream of the connecting cable in the circuit. With a three-phase charging station, back-up protection can be achieved using an LV HRC fuse (size 00), optionally located in the integrated house connection box.

With back-up protection, an upstream protective device supports the downstream protective device in handling the maximum short-circuit current. A fuse or a short-circuit-current-limiting circuit breaker (for example a molded-case circuit breaker, MCCB, of type 3VA or 3VL) could be used.

Manufacturer-specific back-up protection tables help determine the short-circuit strength. In a network configured with SIMARIS design, short-circuit strengths and back-up protection are tested, and if problems have arisen, an error message will be output.

Summary

The implementation of relevant standards and guidelines for the safe provision of electrical energy to electric vehicles is still in its initial stage. Electrical designers must therefore compile specifications from the material available (see Fig. 15) and are additionally confronted with the problems of harmonic components induced by power electronics contained in the charging devices for the vehicle batteries.

The wide range of charging devices in terms of their technical implementation does not permit a forecast on grid perturbations, so that a general problem solution featuring passive filtering of the generated harmonic components is out of the question. In addition, there are no statements about high-frequency interferences fed into the grid by the PWM transistor converter. These interferences are supposedly not reduced by active filters. In the contrary, active filters can be the source of more HF power feedback into the grid.

Owing to the high requirements placed on the short-circuit level of the feeding grid, grid perturbations may be favorably influenced. For this reason, charging stations with fast charging stations and correspondingly high charging currents should be directly connected to the medium-voltage grid in most cases. Fast charging in the domestic sector must therefore be viewed with a critical eye

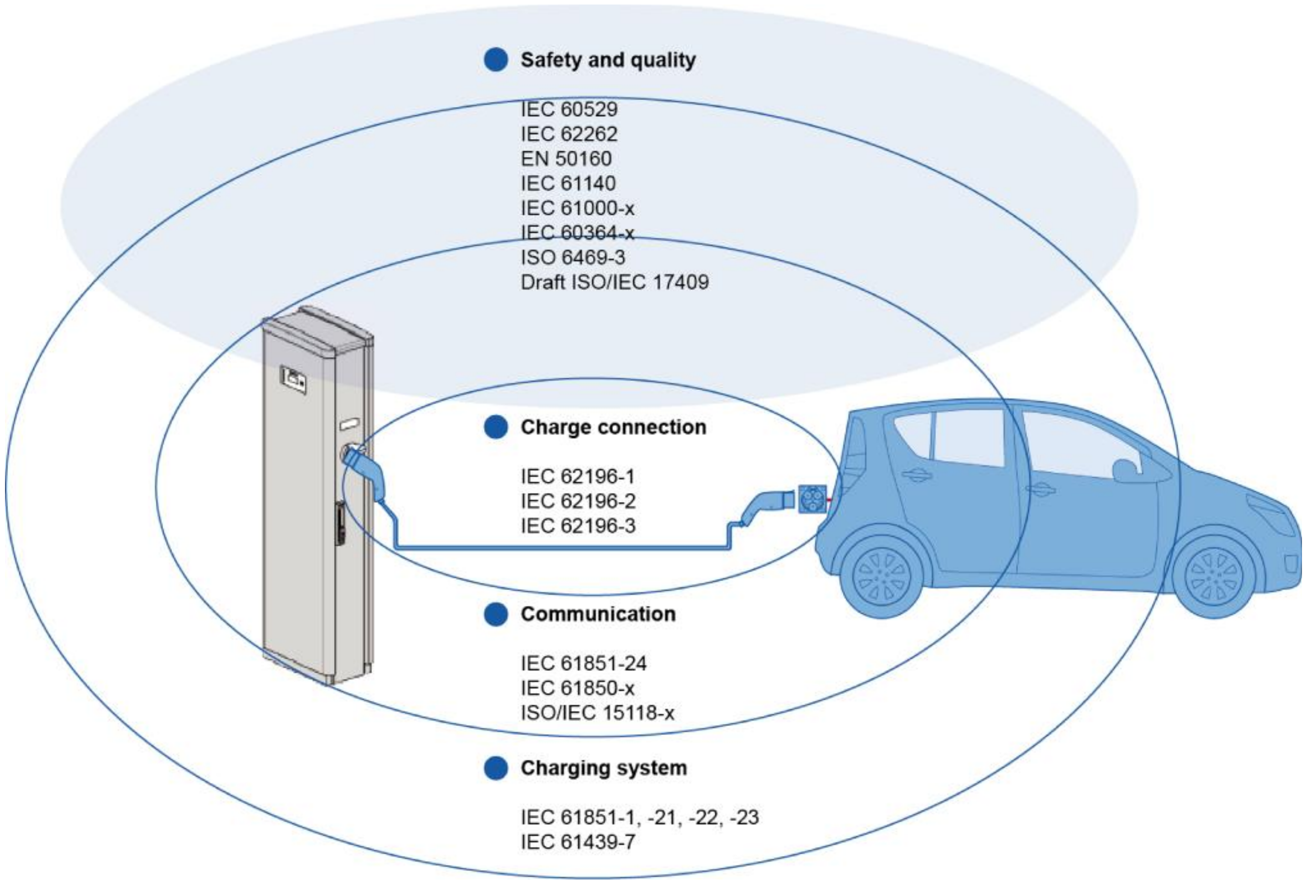

Fig. 15: Important standards on and around electric power supply in the electric mobility sector

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