

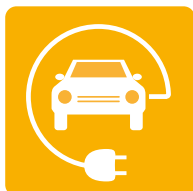
# Electrical safety for emobility



# Intelligent electrical safety for the mobile future

In nearly 70 years, we have learned to think ahead in a strategic, future-oriented manner and to deal today with what the customer will need tomorrow. Innovative solutions and services, unique know-how and global

expertise when it comes to electrical safety provide a response to the mobile challenges of the future - from electrical installation to the range of different charging stations and into the vehicle.



**Electric vehicles**



**Charging stations**



**Energy log**

# The challenge of emobility

## Electrical safety from the charging socket to the electric vehicle

Electrical safety both in the electric vehicle itself and in the charging infrastructure is of key importance in the use of electric vehicles (EV). As in all areas of everyday life, protecting people from the hazards caused by electrical current is top priority here too.

### In the electric vehicle (EV)

In the vehicle, there are various voltages which require careful coordination of protective measures to control them. Insulation faults in the Class B voltage system (on-board network) caused by, for example, contamination, humidity, faulty connections, etc. must be avoided or detected and remedied.

### At the charging station

The basic aim is to be able to charge electric vehicles from virtually any socket. This means different networks and protective measures can come together during the charging process. This requires careful coordination and implementation of all measures in order to guarantee comprehensive electrical safety for the user here too.

### In building installations

The requirements for electrical safety in buildings are defined in detail in the DIN VDE 0100 series of standards. To make sure that electric vehicles (EV) can be charged safely and reliably, both the necessary protective measures required for the building and those required for new installations must be complied with and the system set up in accordance with the normative requirements for the charging process.



# Electrical safety for the on-board network for electric vehicles - insulation monitoring

The power supply system in an electrical vehicle, known as the "Voltage Class B On-Board Network" can be seen as an isolated power supply system while the vehicle is running. One of the major challenges lies in detecting insulation faults early. Causes for insulation faults in normal operation can be, for example: contamination, salt, humidity, faulty connectors, mechanical influences, etc.

## What are the requirements of the standard?

- *ISO6469-3:2011*  
*Electrically propelled road vehicles – Safety specifications – Part 3: Protection of persons against electric shock*  
"the minimum insulation resistance of the on-board network must be maintained throughout the service life and under all operating conditions".

## The perfect solution:

- Permanent monitoring of insulation resistance with ISOMETER® series IR155 or iso165C

## Major characteristics:

- Universal for Voltage Class B systems  
AC/DC 0...1000 V IR155  
AC/DC 0...600 V iso165C
- Patented measurement method for preventative detection of insulation faults 0...10 MΩ
- Additional safety via automatic self-test
- Permanent monitoring of earth connection to electrical chassis
- Detection of symmetrical insulation faults
- Short-circuit-proof outputs for
  - Fault messaging
  - Measured value (PWM signal)
- Conformal coating (SL1301EO-FLZ) on IR155
- Available for DC 12 V and 24 V supply voltage
- Automotive approval e1 according to 72/245/EWG/EEC 2009/19/EG/EC
- CAN interface on iso165C



ISOMETER® iso165C

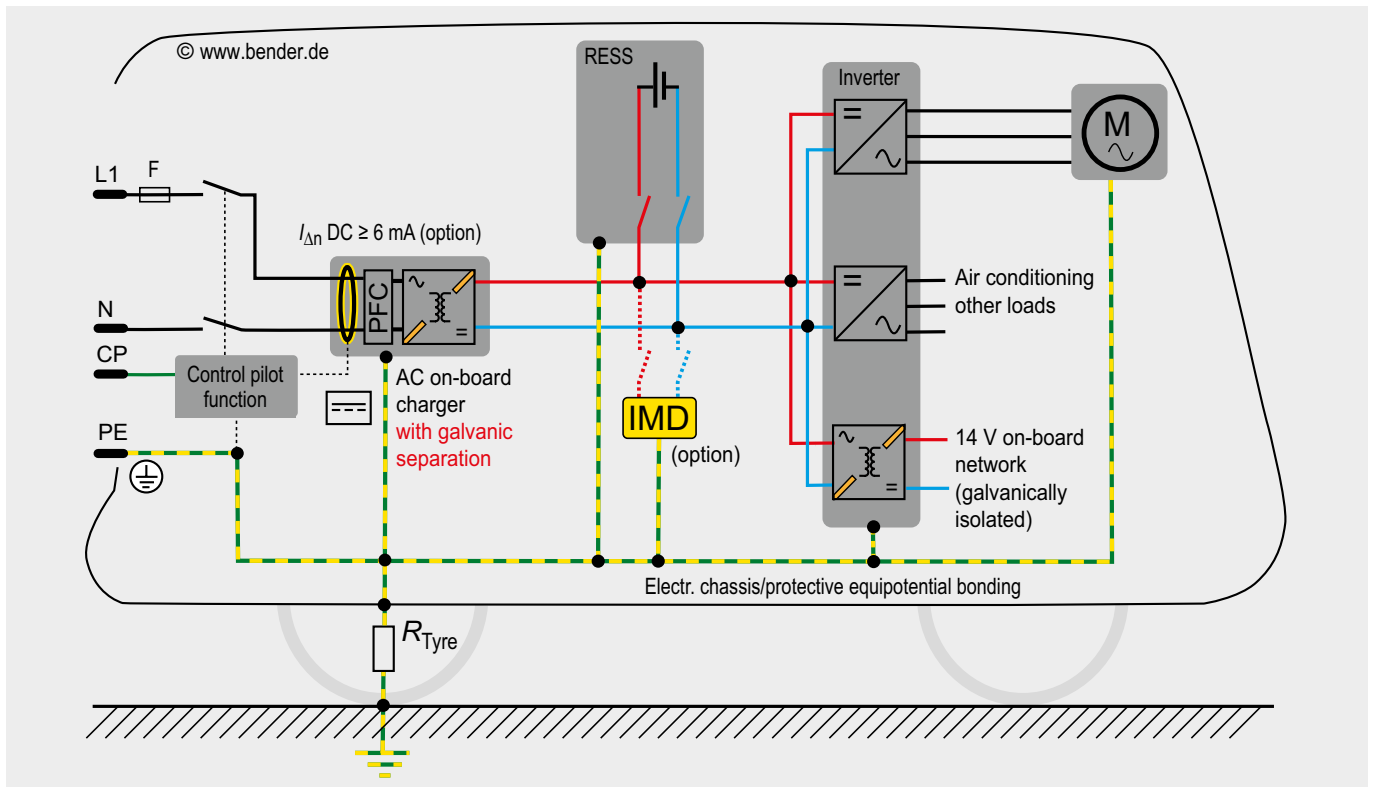


ISOMETER® IR155

## Overview of important standards:

- *ISO 6469-3:2011-12*  
Electric propelled road vehicles – Safety inspections – Part 3: Protection of persons against electric shock
- *ISO 23273-3:2006-11*  
Fuel cell road vehicles – Safety inspections – Part 3 – Protection of persons against electric shock
- *UL 2231-1:2002-05*  
Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits: General requirements
- *IEC 61557-8:2007-01*  
Electrical safety in low voltage distribution systems up to 1000 V a.c. and 1500 V d.c. – Equipment for testing measuring or monitoring protective measures – Part 8: Insulation monitoring devices for IT systems

## Application examples



Insulation monitoring in an electric vehicle (EV) with an AC on-board charger with galvanic separation

IMD = Insulation Monitoring Device

PFC = Power Factor Correction

# Electrical safety for DC charging stations

## - Insulation monitoring

DC charging stations are the means of choice for charging electrical vehicles quickly. In order to guarantee the electrical safety of the charging circuit, it is set up as an unearthed DC power supply system (IT system) with insulation monitoring. During the charging process, the insulation monitoring device monitors the entire charging circuit in the charging station as far as the electric vehicle. This requires coordination with the insulation monitoring device in the vehicle. The IMD in the vehicle is switched off.



ISOMETER® isoEV425 with AGH-EV coupling device

### What are the requirements of the standard?

- IEC 61851-23 (2014-03):2014-11

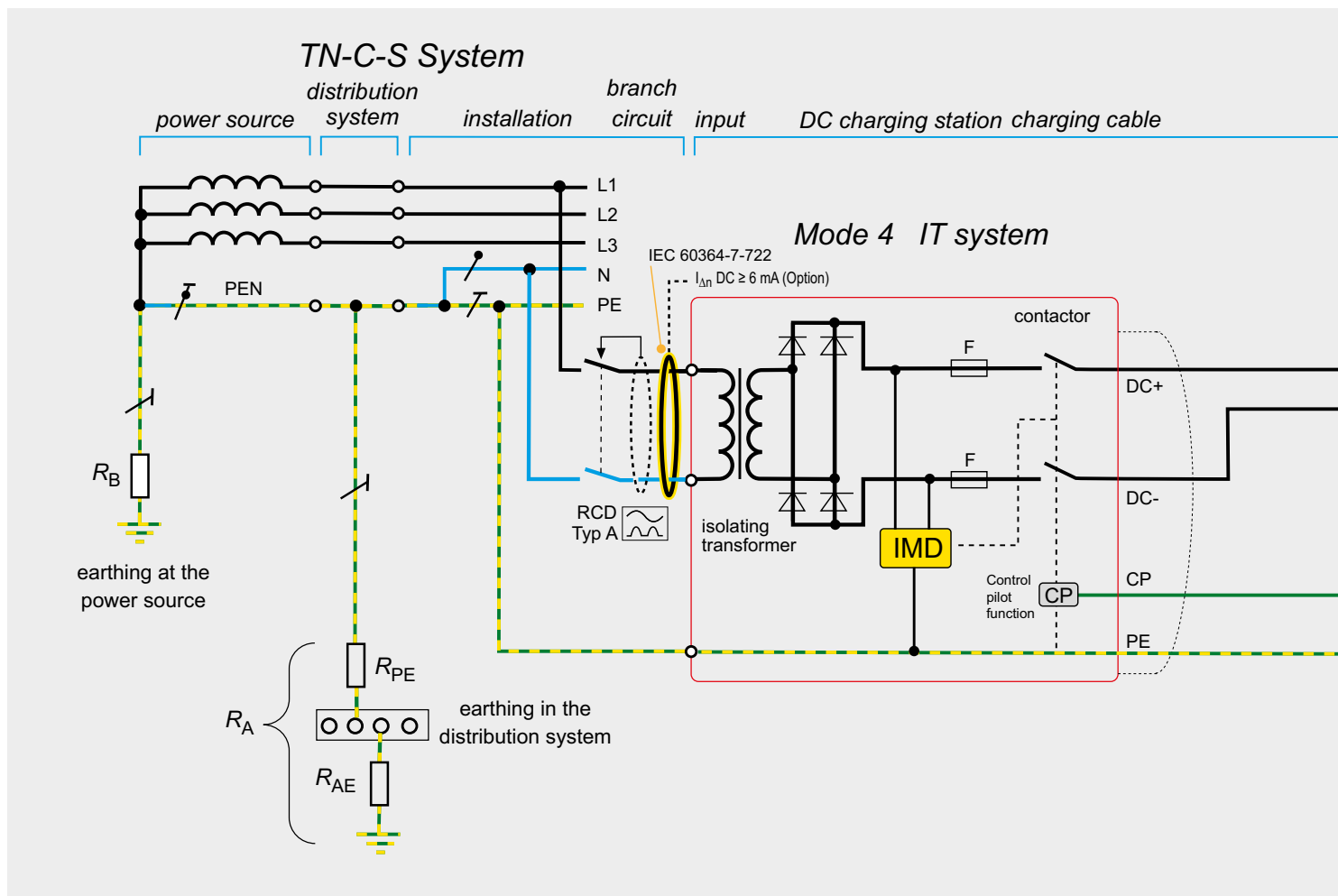
7.5.101: Monitoring of insulation resistance of the secondary circuit.

Par. CC.5.1: The secondary circuit shall be designed as an IT system and protection measures in accordance with Par. 411 of IEC 60364-4-41 shall be applied. 411.

### The perfect solution:

- Monitoring of the DC charging circuit using ISOMETER® isoEV425 and AGH-EV coupling device (for voltages of up to DC 1000 V).

### Application examples





### Overview of important standards:

- *DIN EN 61851-23 (VDE 0122-2-3):2014-11*  
Electric vehicle conductive charging system  
Part 23: d.c. electric vehicle charging station  
(IEC 69/206/CD:2011)
- *IEC 61557-8:2014-01*  
Electrical safety in low voltage distribution systems up to 1000 V a.c. and 1500 V d.c. – Equipment for testing measuring or monitoring protective measures – Part 8: Insulation monitoring devices for IT systems

### Major characteristics:

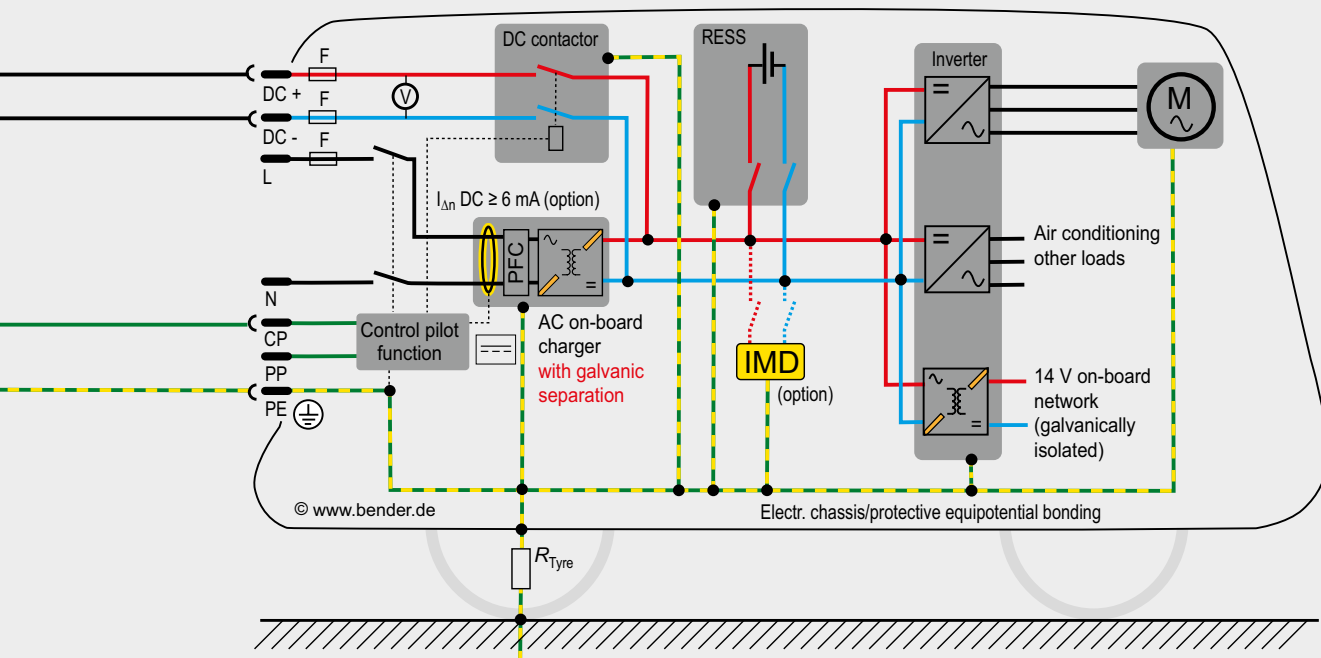
- Insulation monitoring for unearthed charging stations AC 0...793 V/DC 0...1000 V (IT systems)
- Two response values that can be set separately
- Basic parameterisation 100/500 k $\Omega$
- Network/earth connection monitoring
- LEDs for operation, Alarm 1, Alarm 2
- Internal/external test/reset button
- Two separate alarm relays with single pole (one N/O contact each)
- N/O operation, N/C operation, selectable
- Fault memory selectable
- Self-monitoring with automatic alarm
- Multifunctional LC display



*LINETRAXX® GM420*  
For monitoring of the protective conductor continuity in DC charging stations.

vehicle inlet connector

battery electric vehicle (BEV)



# Electrical safety for AC charging

## Monitoring of direct fault currents $I_{\Delta n} DC \geq 6 \text{ mA}$

If the electric vehicle is connected to a conventional socket (Mode 2) or a charging station (Mode 3) to charge the battery, the protective measures set out in the DIN VDE 0100 and DIN VDE 61851 series of standards must be complied with. A major element of the infrastructure is the use of type A residual current devices (RCD). A separate current circuit must be set up for each charging socket. In Mode 2, a mobile protective device (IC-CPD) is used to fulfil the safety requirements in the standards. Both the type A residual current device (RCD) and the mobile protective device switch off if an alternating or pulsating error current  $\geq 30 \text{ mA}$  occurs.

In the event of an insulation fault, if a direct fault current greater than  $I_{\Delta n} DC \geq 6 \text{ mA}$  occurs in the charging current circuit, a type B residual current device (RCD) is required or other suitable measures must be taken. The background to this is the fact that the function of a type A residual current device (RCD) can be negatively impacted by direct fault currents greater than  $I_{\Delta n} DC \geq 6 \text{ mA}$ .

The RCMB420EC residual current monitor provides a solution which enables direct fault currents  $I_{\Delta n} DC \geq 6 \text{ mA}$  to be detected and evaluated. Disconnection measures prevent malfunction of the type A residual current device.

### What are the requirements of the standard?

- *DIN EN 61851-1 (VDE 0122-1):2012-01*  
*Electrical equipment of electric vehicles – Electric vehicle conductive charging system –*  
*Part 1: General requirements; section 7.6*  
"The charging system must limit the introduction of **direct currents** and non-sinusoidal currents which could affect the functionality of residual current devices (RCD)..." (Translation: Bender GmbH & Co KG)
- *IEC 60364-7-722:2015 (Power supply of electric vehicles*  
*722.531.2.101*  
"Residual current protective devices (RCD)
  - A separate type A residual current device (RCD)  $I_{\Delta n} \leq 30 \text{ mA}$ , min. for each connection point
  - Suitable measures must be taken for direct fault currents  $I_{\Delta n} DC \geq 6 \text{ mA}$ ."  
(Translation: Bender GmbH & Co KG)



*RCMB420EC Residual current monitoring module (model example)*

### The perfect solution:

- The RCMB420EC residual current monitor detects direct fault currents and can initiate disconnection via a switching element.

### Major characteristics:

- Residual current monitoring  $I_{\Delta n} DC \geq 6 \text{ mA}$
- 2TE DIN rail unit for connection of an external measuring current transformer
- For 1ph/3ph systems up to 32 A
- Permanent connection monitoring of measuring current transformer
- LEDs for operation and alarm
- Internal test button
- Alarm relay with 1 N/C contact
- Precise measurement by means of digital measurement method
- Insensitive to load currents thanks to full magnetic shielding
- With optional analogue measurement output
- Cost-oriented solution in connection with fault current protective device (RCD type A)

### Other device functions:

- 2-channel residual current measurement  $I_{\Delta n} DC \geq 6 \text{ mA}$



**Application example:**

The RCMB420EC residual current monitor provides various options for integration into the power supply system for electric vehicles.

In an AC EV charging station, this means that, for example, the charging switch can be connected, plus the relays for the fault current circuit in the IC-CPD. It can also be used in an electric vehicle (EV).

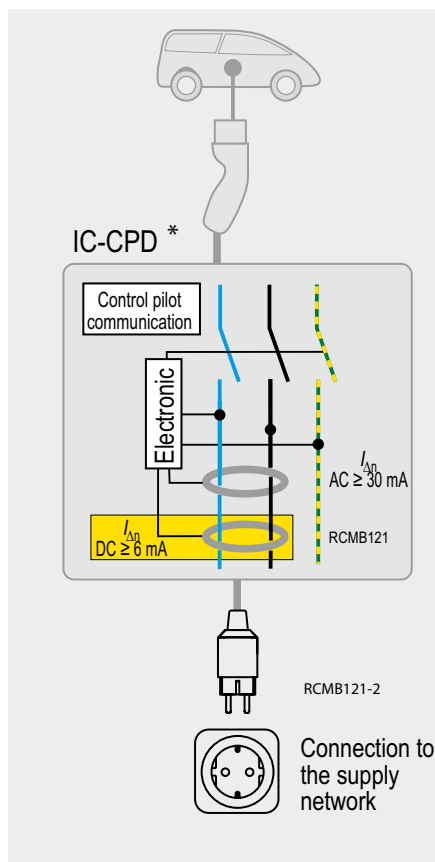
**Compact and future-proof:**

The RCMB121 residual current monitor already fulfils the requirements of the new draft of the standard IEC 62752 (IC-CPD). Due to the compact structure, in addition to its use in a IC-CPD (charging mode 2) it is suitable for use in wall boxes (charging mode 3). The RCMB121 complies with the requirements of IEC 60364-7-722:2015.



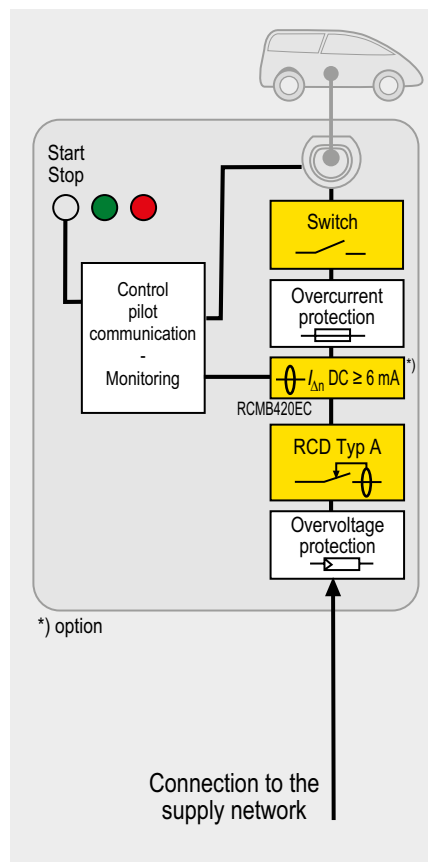
Residual current monitoring module RCMB104

**Charging mode 2  
Charging from sockets**

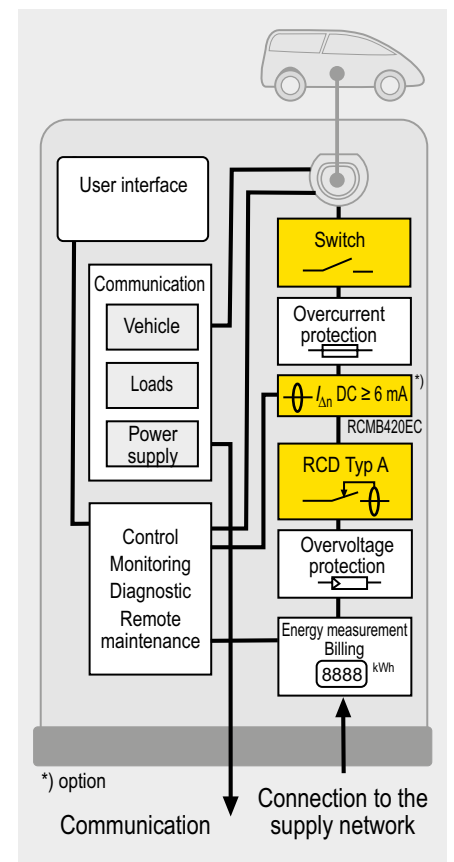


\* IC-CPD = In-Cable Control and Protective Device  
Customer-specific RCMB solution on request

**Charging mode 3  
e.g. private charging station**



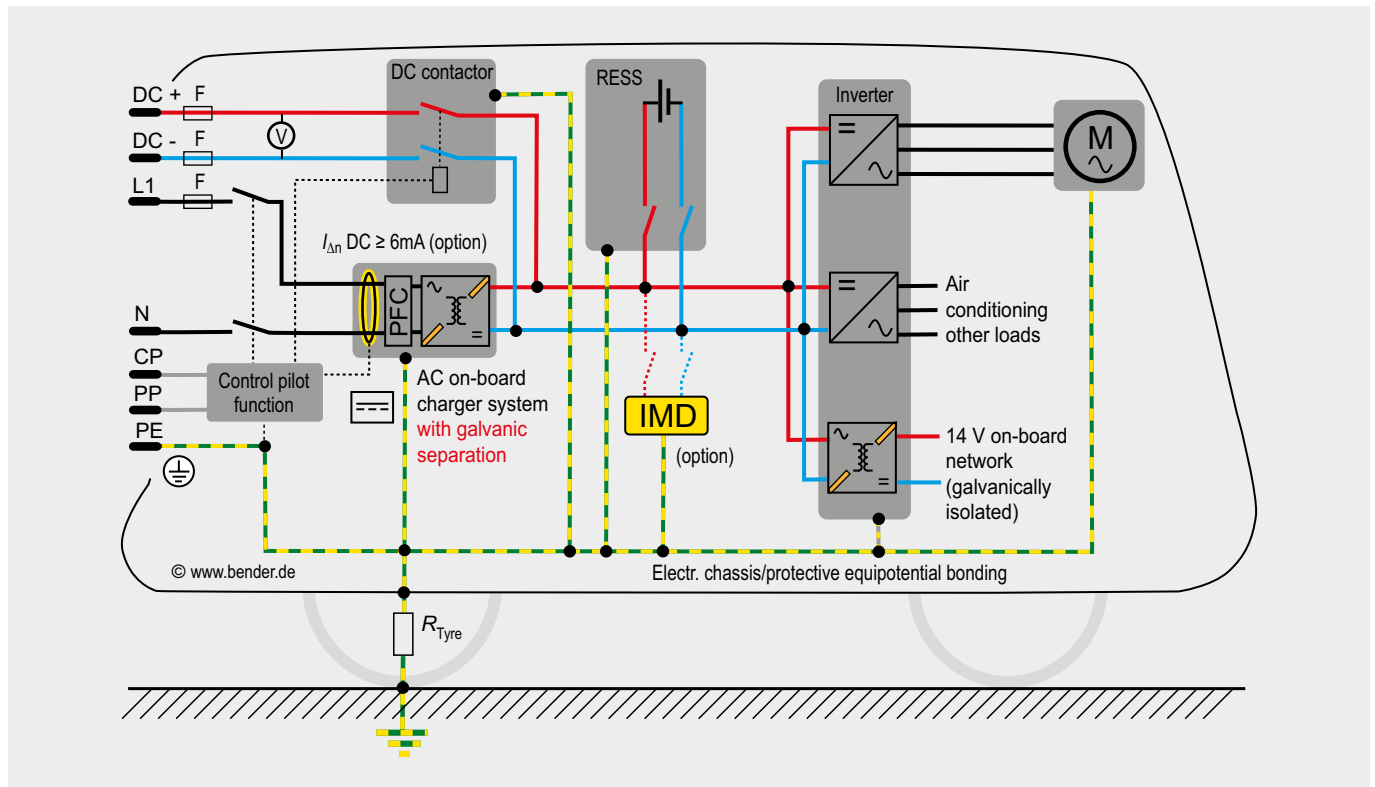
**Charging mode 3  
e.g. public charging station**



# Electrical safety for AC charging

## Monitoring of direct fault currents $I_{\Delta n} \text{ DC} \geq 6 \text{ mA}$

### Use in an electric vehicle (EV)



#### Overview of important standards:

- *DIN EN 61851-1 (VDE 0122-1):2012-01*  
Electrical equipment of electric vehicles – conductive charging systems for electric vehicles – Part 1: General requirements
- *DIN VDE 0100-722:2012-10*  
Low-voltage electrical installations – Part 7-722: Requirements for special installations or locations - Supply of electric vehicles;
- *IEC 62020:2003-11*  
Electrical accessories – Residual current monitors for household and similar uses (RCMs)

# AC charging considering the electrical safety requirements

The Charge Controller CC612 combines the electrical safety requirements of AC charging points with the vehicle charging requirements.

It is optionally available with an AC/DC sensitive residual current monitoring device. Monitoring is done via an externally connected shielded current transformer which is connected to the CC612. Thereby, the requirements of the standards series DIN VDE 0100 or rather DIN VDE 61851 regarding protective measures directly in the Charge Controller are complied with. A residual current device (RCD) type A can be used in the infrastructure. The measured values are available to the backend system via the integrated modem.

Due to its compact structure and size (114.5 mm x 22.5 mm x 99 mm), the Charge Controller makes intelligent, small and cost-effective charging stations possible. To communicate with the Charge Controller, a backend system together with a well-known and reliable communication protocol is required. Since most of the backend device manufacturers use the OCPP communication protocol, the Charge Controller is compatible with OCPP-1.5 and with all electric vehicles currently present on the market.

Integration tests with the backend implementations of providers such as Vattenfall, Bosch, NTT and DRIIVZ have been successfully carried out. The Charge Controller can be operated in an "Always-on system", which is always connected to a mobile network. The controller supports 2.5G Edge and 3G UMTS mobile networks. For connection to online operation, a SIM card is required. User interaction is facilitated using an optional RFID module, which consists of an RFID card reader and LEDs.



Charge Controller CC612

Charging is initiated by either holding a valid RFID card close to the reader or remotely by the backend system via OCPP. In offline operation, the charge controller can optionally allow charging without authorisation or it can authorise users based on RFID and a local white list of authorised RFID cards.



# Electrical safety begins with the electrical installation

The safe, reliable charging of electric vehicles (EV) is directly linked to electrical safety in building installations. In earthed systems (TN/TT systems) the focus is on the use of residual current devices (RCD) and in unearthed power supply systems (IT systems) it is on the use of insulation monitoring devices (IMD) or insulation fault location systems (IFLS).

## Basis for a safe electrical installation

- Correct selection of earthing system and conductors
- Correct selection of protective measures (basic protection/fault protection)
- Correct insulation of exposed, conductive parts
- Correct sizing of cables and wires
- Correct selection of overcurrent protection
- Correct selection of overvoltage protection

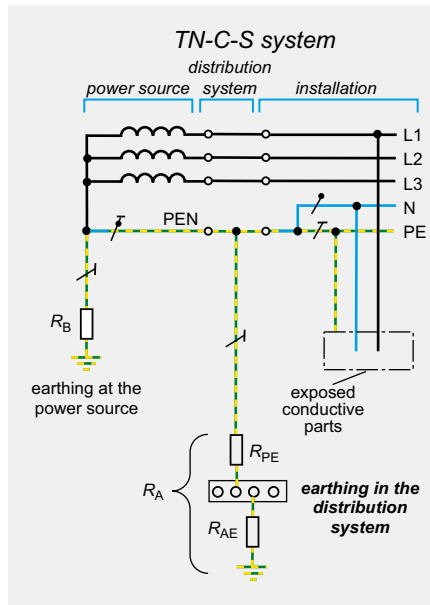
## Operating a safe electrical installation

- Standard-compliant planning and installation
- Use of standard-compliant equipment and components
- Standard-compliant initial inspection and commissioning
- Correct operation
- Periodic inspections
- Regular maintenance and repairs with, for example, replacement of worn components

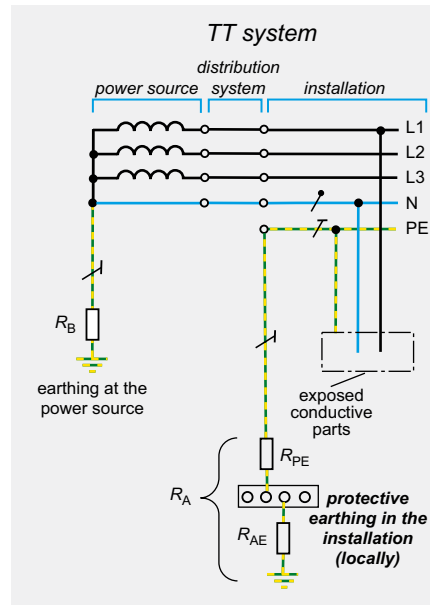
## Overview of important standards:

- *DIN VDE 0100-100 VDE 0100-100:2009-06*  
*Low-voltage electrical installations*  
Part 1: Fundamental principles, assessment of general characteristics, definitions (IEC 60364-1:2005, modified); German adoption HD 60364-1:2008
- *DIN EN 61140 VDE 0140-1:2007-03*  
*Protection against electric shock*  
Common aspects for installation and equipment (IEC 61140:2001 + A1:2004, modified); German version EN 61140:2002 + A1:2006
- *DIN VDE 0100-410 VDE 0100-410:2007-06*  
*Low-voltage electrical installations*  
Part 4-41: Protective measures – Protection against electric shock (IEC 60364-4-41:2005, modified); German adoption HD 60364-4-41:2007
- *DIN VDE 0100-722 VDE 0100-722:2012-10*  
*Low-voltage electrical installations*  
Part 7-722: Requirements for special installations or locations – Power supply of electric vehicles; IEC 60364-7-722:2015

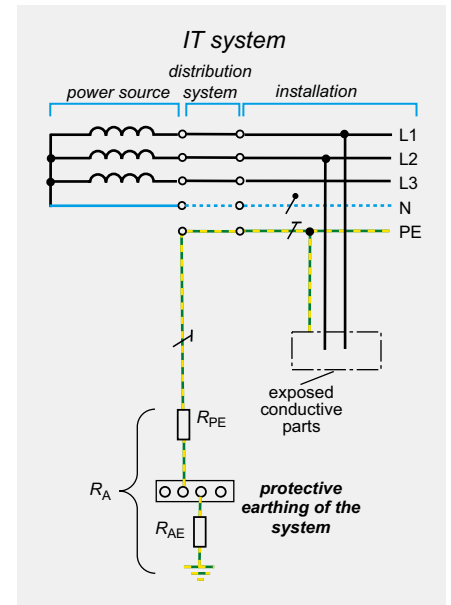
## Possible network designs based on DIN VDE 0100-100 (VDE 0100-100): 2009-06 for charging



*TN-C-S system 3-phase, 4 conductors, PEN conductor at the point of supply divided into PE and N conductors*



*TT system with earthed protective conductors and N conductors throughout the whole system*



*IT system where the exposed conductive parts (of electrical equipment) have separate connections to earth*

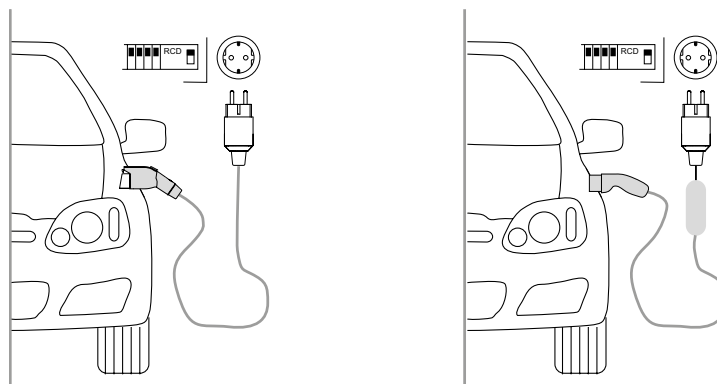
In all three systems, an earthing system must be installed which complies with DIN VDE 0100-410 (VDE 0100-410): 2007-06, Chapter 411.3.1 Protective earthing and equipotential bonding.

### Example checklist for safe building installation

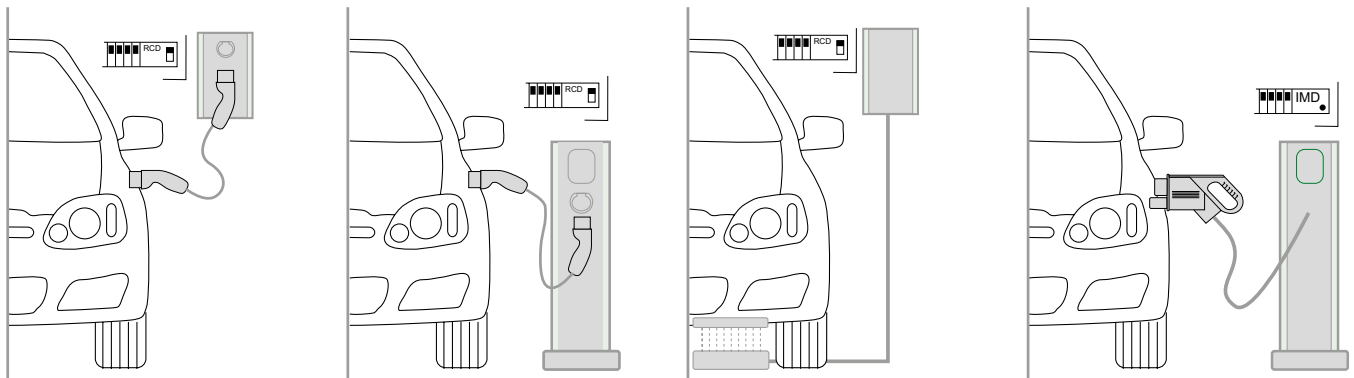
- Where should charging take place?
- Is the connected power in the building sufficient or does it need to be increased?
- Can an existing line be used or does a new one need to be laid?
- Is a residual current device (RCD) installed in the charging current circuit distributor?
- Which residual current device (RCD) is fitted, type A or type B?
- Are other measures required (e.g. RCMB420EC)?
- How are the lines protected?
- What connecting device/type is required?



# Overview of charging methods



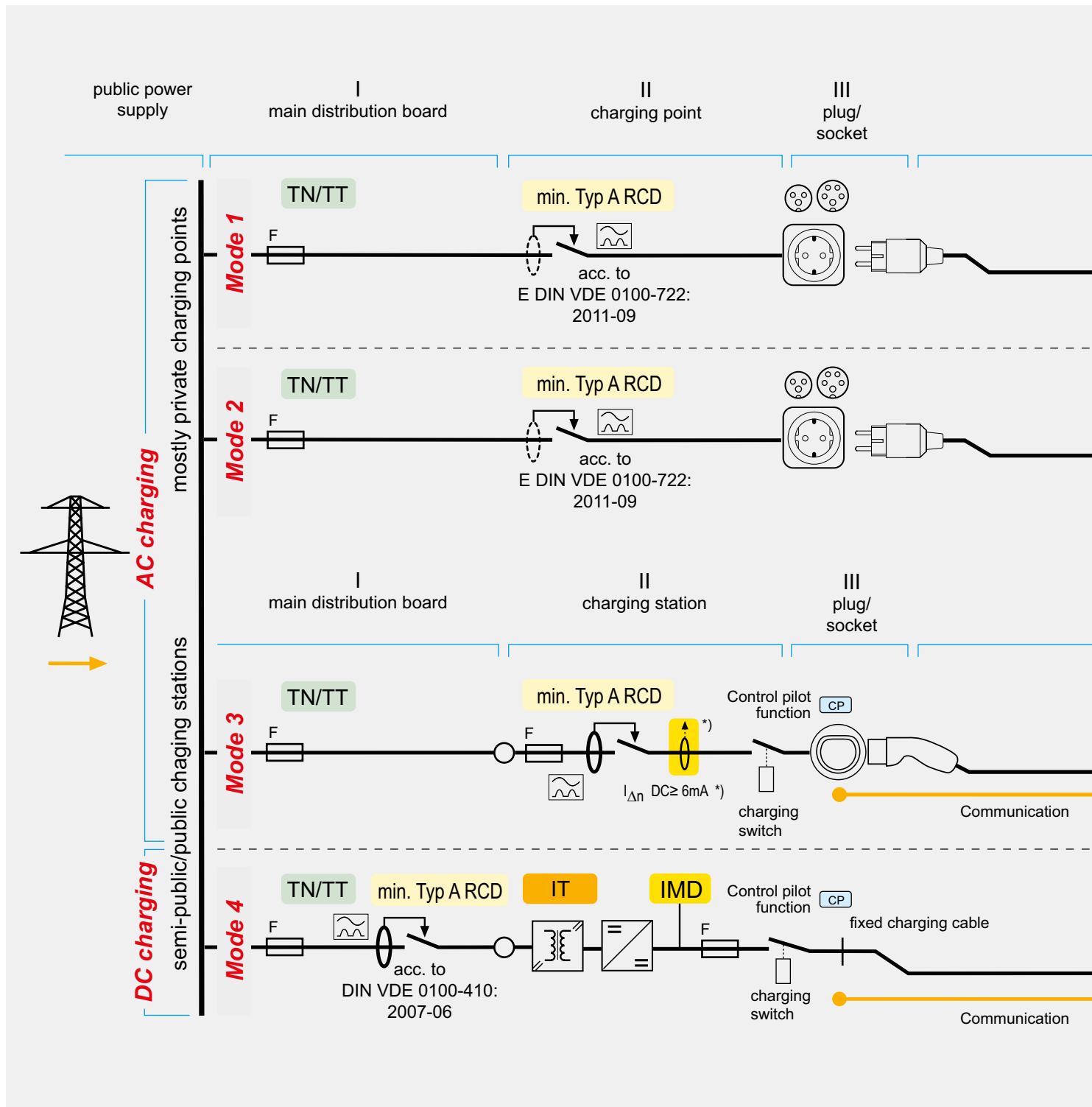
	AC charging Schuko/CEE	AC charging Schuko/CEE
Charging mode	1	2 (SAE level 2)
Billing method	No	
Power	max. 1ph 16 A (3.7kW) max. 3ph 16 A (11 kW) / 3ph 32 A (22kW) SAE 2ph 80A	
Charging time	A few hours, depending on capacity of the HV store in the vehicle	
Charging current circuit	Charging cable is "part of the vehicle"	charging cable included IC-CPD & "low-level" Control Pilot function
Communication	–	Control Pilot
<b>Value range</b>	<b>Building installation</b>	
Protection and monitoring device	min. RCD type A $I_{\Delta n} \leq 30 \text{ mA}$ , if $I_{\Delta n} \text{ DC} \geq 6 \text{ mA}$ RCD type B or type A plus suitable measures in charging point	
Standards	DIN VDE 0100-410 (VDE 0100-410):2007-06 DIN VDE 0100-722 (VDE 0100-722):2012-10 DIN EN 61851-1 (VDE 0122-1):2012-01	
<b>Value range</b>	<b>Charging cable</b>	
Protection and monitoring device	–	$I_{\Delta n} \text{ AC} \leq 30 \text{ mA}$ (if $I_{\Delta n} \text{ DC} \geq 6 \text{ mA}$ shutdown)
Standard	–	IEC 62752 (IC-CPD)
<b>Value range</b>	<b>Charging point/Charging station</b>	
Protection and monitoring device	min. RCD type A $I_{\Delta n} \leq 30 \text{ mA}$ – if $I_{\Delta n} \text{ DC} \geq 6 \text{ mA}$ RCD type B or RCD type A plus suitable measures (sensor, e.g. RCMB103 or RCMB121-1)	
Standards	DIN EN 61851-21:2011-05 (VDE 0122-1:2011-05) E DIN EN 61851-22 (VDE 0122-2-2):2011-04 (IEC 69/184/CD:2010)	

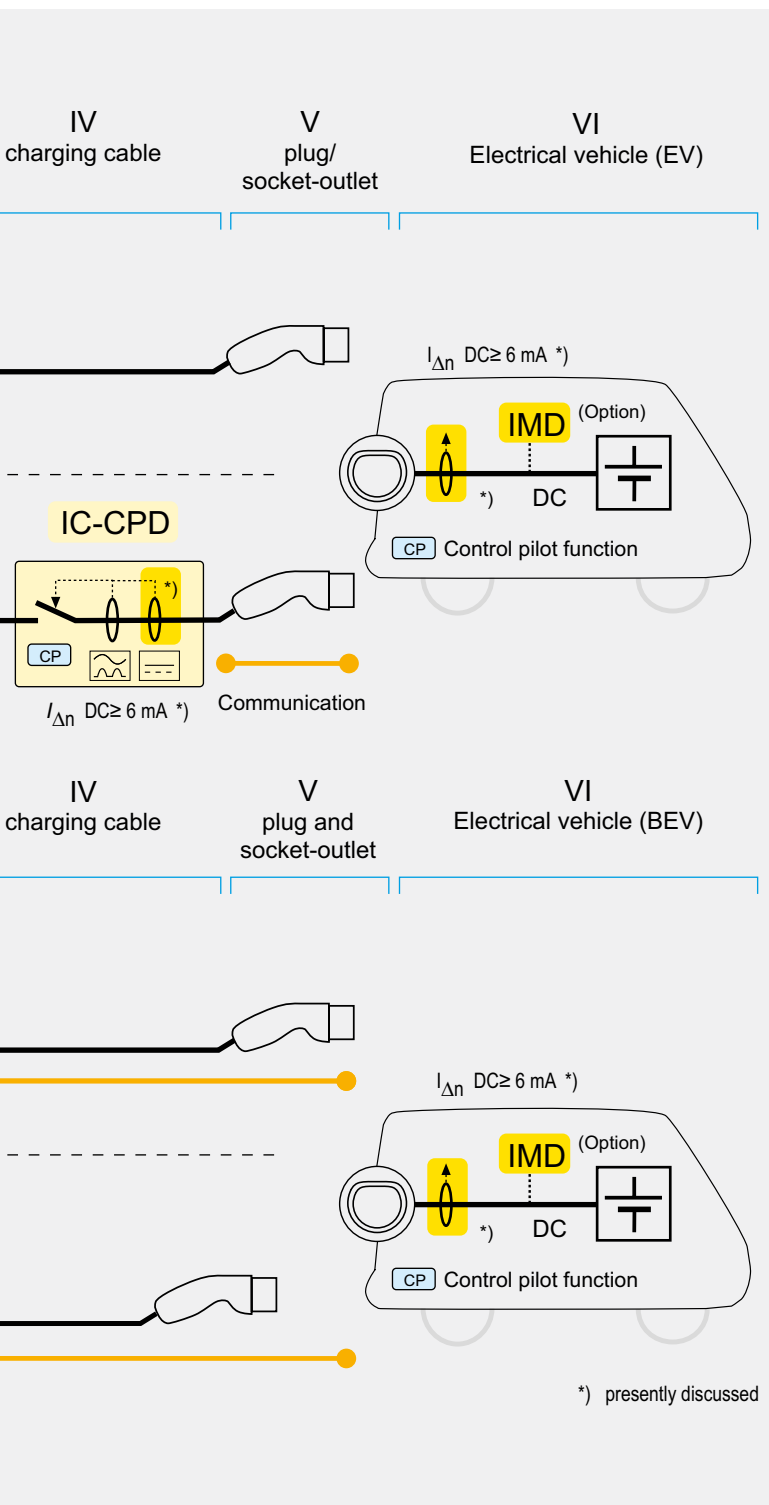


AC charging wall box (home & public)	AC charging "Intelligent" charging station	Inductive charging	DC fast charging
3 (SAE level 3)		-	4 (SAE level 3)
No	Yes	Yes	Yes
max. 1ph 16 A (3.7kW) max. 3ph 63 A (43.5 kW) SAE 2ph 80A		2..5 kW	DC low ≤ 38 kW DC high ≤ 170 kW
A few hours, depending on capacity of the HV store in the vehicle			≤ 30 min.
Wall box with "low-level" Control Pilot Function	Charging station with "high-level" PLC communication/network access	Communication Wireless	Charging station with "high-level" PLC communication/network access
Control Pilot	Power Line Communication, Control Pilot (PWM), RFID, GSM, 3G/4G	Wireless	Power Line Communication
<b>Building installation</b>			
min. RCD type A $I_{\Delta n} \leq 30 \text{ mA}$ , if $I_{\Delta n} \text{ DC} \geq 6 \text{ mA}$ RCD type B or type A plus suitable measures in charging point			
DIN VDE 0100-410 (VDE 0100-410):2007-06 DIN VDE 0100-722 (VDE 0100-722):2012-10 DIN EN 61851-1 (VDE 0122-1):2012-01			
<b>Charging cable</b>			
-	-	-	-
-	-	-	-
<b>Charging point/Charging station</b>			
min. RCD type A $I_{\Delta n} \leq 30 \text{ mA}$ – if $I_{\Delta n} \text{ DC} \geq 6 \text{ mA}$ RCD type B or other measure (e.g. RCMB420EC)			IMD
DIN EN 61851-21:2011-05 (VDE 0122-1:2011-05) E DIN EN 61851-22 (VDE 0122-2-2):2011-04 (IEC 69/184/CD:2010)			DIN EN 61851-23:2014 (VDE 0122-2-3:2014-11) DIN EN 61557-8:2013-08 (VDE 0413-8:2013-08)

# Overview of charging modes and protective measures

Electric vehicles (EV) are normally loaded at different times, in different places or different feed points, requiring different energy input. In order to provide the necessary safety and charging energy to match the demand, four different charging modes are defined in IEC 61851-1:2010-12.





#### ■ Mode 1: Uncontrolled charging

- AC charging at a socket 1ph/3ph (Schuko, CEE)
- Max. charging current: 16 A/11 kW
- Charger built into the vehicle
- No communication with the vehicle
- Locking mechanism of the plug and socket-outlet in the vehicle
- This is not recommended, as it is not guaranteed that a residual current device (RCD) is included in the building installation.

#### ■ Mode 2: Uncontrolled charging

- AC charging at a socket 1ph/3ph (Schuko, CEE)
- Max. charging current: 32 A/22 kW
- Charger built into the vehicle
- Protective device/pilot function in the cable (IC-CPD)
- Locking mechanism of the plug and socket-outlet in the vehicle

#### ■ Mode 3: Controlled charging

- AC charging on type-tested supply units for electric vehicles
- Max. charging current: 63 A/43.5 kW
- Charger built into the vehicle
- Protective device/pilot function integrated into charging station
- Locking mechanism on both sides of the plug and socket-outlet

#### ■ Mode 4: Controlled charging

- DC charging on type-tested DC charging stations for electric vehicles
- Max. charging power: DC low max. 38 kW/DC high 170 kW (charging voltage and current depend on system)
- Monitoring and protective device/pilot function integrated into charging station
- Locking mechanism of the plug and socket-outlet in the vehicle
- Charging cable built into the charging station

# Monitoring of direct fault currents $I_{\Delta n} DC \geq 6 \text{ mA}$

Type A residual current device (RCD) are provided in accordance with IEC 61008-1/IEC 61009-1 to trigger for the following fault currents  $I_{\Delta n}$ :

- for sinusoidal alternating fault currents
- for pulsating direct fault currents

If direct fault currents  $I_{\Delta n} DC \geq 6 \text{ mA}$  occur, e.g. during charging, then both the response time and the response level of residual current devices (RCD) can be negatively affected. In the worst case, a type A residual current device will no longer respond to a high level of direct fault current. In order to prevent this, either type B residual current devices (RCD) can be used or other suitable measures taken.

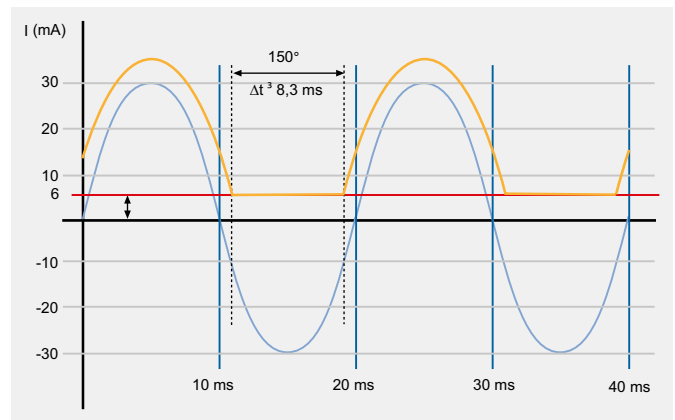
Suitable measures could be: Detection of  $I_{\Delta n} DC \geq 6 \text{ mA}$  using RCMB420EC and therefore

- Controlling the charging switch in a charging station (Mode 3)
- Controlling the relay in an IC-CPD
- Controlling the vehicle electronics

One of these measures can be used to guarantee that there is no negative impact on the function of (any) type A residual current device (RCD) in the building installation.

## Note

The use of a detection system for  $I_{\Delta n} DC \geq 6 \text{ mA}$  with RCMB420EC also makes a residual current device (RCD) necessary in accordance with DIN VDE 0100. It protects the type A residual current device (RCD) against malfunction.



## Quote from:

- *DIN EN 61851-1 (VDE 0122-1):2012-01 Electrical equipment of electric vehicles – Electric vehicle conductive charging system – Part 1: General requirements; section 7.6*

"The charging system must limit the introduction of **direct currents** and non-sinusoidal currents which could affect the functionality of residual current device (RCD)..." (Translation: Bender GmbH & Co KG).

## Quote from:

- *DIN VDE 0100-722 (VDE 0100-722):2012-10 Low-voltage electrical installations*

"722.531.2.101 Residual current devices (RCD)

- A separate type A residual current device (RCD)  $I_{\Delta n} \leq 30 \text{ mA}$ , min. for each connection
- When direct fault currents  $I_{\Delta n} DC \geq 6 \text{ mA}$  occur, suitable measures must be taken."



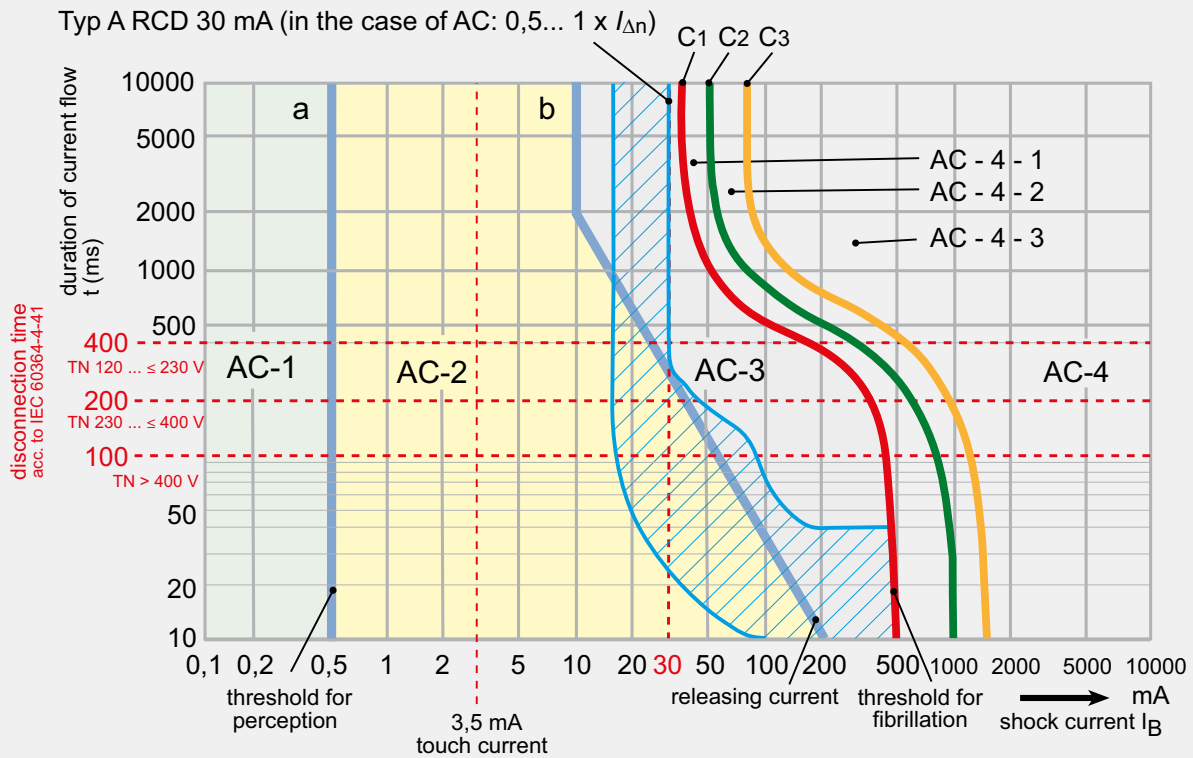


Diagram: Time/current zones of effects of AC currents (15 to 100 Hz) on persons for a current path corresponding from left hand to feet in accordance with IEC and with disconnection times as defined in DIN VDE 0100-410:2007 and the normal response curves for a residual current device (RCD).

Areas	Area boundaries	Physiological effects
AC-1	Up to 0,5 mA curve a	Perception possible, but usually no startle reaction.
AC-2	Beyond 0,5 mA curve b	Perception and involuntary muscle contractions likely but usually no harmful physiological effects.
AC-3	Curve b to curve C1	Strong involuntary muscle contractions. Difficulty in breathing. Reversible disturbances of heart functions. Immobilisation (muscle cramps) may occur. Effects increasing with current magnitude and time. Usually, no organic damage to be expected.
AC-4	Beyond curve C1	Patho-physiological effects may occur, such as cardiac arrest, breathing arrest and burns or other cellular damage. Probability of ventricular fibrillation increasing with current magnitude and time.
	C1 – C2	AC-4.1 Probability of ventricular fibrillation increasing to around 5 %
	C2 – C3	AC-4.2 Probability of ventricular fibrillation increasing to around 50 %
	Beyond curve C3	AC-4.3 Probability of ventricular fibrillation above 50 %



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**eMobility**

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