Easee Safety Summary

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Introduction

This document demonstrates how Easee's products, Home and Charge, are safe to use and in line with applicable essential requirements. The document provides a summary of key safety features in the Easee Charge and Home charging robots, and addresses concerns as raised by the Swedish Elsäkerhetsverket.

There are numerous standards for assessing the different parts of the charger, none of which comprise a complete test for all the safety features that are utilized in advanced EV chargers. As the additional safety measures that are intrinsic to the Easee chargers may not be applicable or suited for the different parts of test standards, this document gives a broader view of the complete safety measures that are in place. This is backed up by field data from over 700 000 chargers, in service for years.

Safety Summary

Summary

The charger in conjunction with the upstream breaker provides a high level of safety with a minimum of mechanical components that wear out over time. Innovative technologies enable an enhanced level of online and internal monitoring, switching, fault detection and self-testing, beyond requirements in the standards. In addition to heightened safety this allows for chargers with low heat dissipation, energy efficiency and reduces the failure rate of the product itself, resulting in a safe and sustainable charging solution in line with essential product requirements.

This report demonstrates that the Easee chargers' intrinsic safety offer adequate electrical safety and is actively detecting and mitigating risk to the health and safety of persons, animals or damage to property. For instance, the charger's ability to identify temperature rises and respond to potential fires is beyond any ordinary installation products or user appliance's ability to mitigate hazardous situations.

For the worst-case electrical fault scenarios, safe disconnection and a safe state at the initial fault is always provided (by charger and/or upstream SCPD). Active misuse and disregard for alarms and warnings, while also experiencing yet another fault is what is required to be exposed to any potential risk. It is only after a welded relay error that a consecutive fault may become hazardous.

A great deal of determination for bypassing safety features must be displayed to be able to produce such a chain of events, and this does not align with foreseeable use.

The very low fault ratio for welding of 0.062% itself shows how unlikely the key factor is for any consecutive hazardous fault. Adding consecutive faults, disregarding instructions, and misuse through adapters (that passes the IEC 61851-1 standard) and overlooking visual faults, the likelihood of this is deemed to be far lower than what is an acceptable risk in everyday consumer products. The fault rate for welding and RCD faults is also far lower than the standard RCD malfunction rate (which is often between 3-15%. See chapter Standard RCD reliability).

Removing installed chargers may lead to users reverting to charging by ordinary sockets or simple chargers without additional safety. This seems to directly contribute to achieving the opposite of the intended goals and intentions of the regulatory framework and relevant standards.

Abbreviations and definitions

List of all used acronyms.

A / kA / mA	Ampére (kilo-, milli-)
AC	Alternating current
CPLD	Complex Programmable Logic Device
CP	Control Pin Contact
DC	Direct Current
ESV	Elsäkerhetsverket
EV	Electric Vehicle
HW	Hardware
IEC	International Electrotechnical Committee
IP	Ingress Protection
IT	Insulated Terra grid system
kWh	kilo Watt hours
LED	Light Emitting Diode
LVD	Low Voltage Directive
MCU	Master Control Unit
MTBF	Mean Time Between Failure (Calculated by: Number of faults/Time of operation)
OTA	Over The Air
PE	Protective Earth
RCD	Residual Current Device
RDC-DD	Residual Direct Current-Detecting Device
RED	Radio Equipment Directive
RMA	Return Merchandise Authorization
SPCD	Short Circuit Protection Device / Overcurrent protection / Breaker
TN	Terra Neutral grid system
TT	Terra Terra grid system
V / kV	Volt (kilo-)

Regulatory Background

Products sold on the European market must comply with essential requirements as set out in the legislation, including safety requirements. In the case of EV chargers, key regulatory requirements are set out in the EU Radio Equipment Directive (RED) and the EU Low Voltage Directive (LVD) (See *Figure 1* below). The legislation is supplemented by a range of standards, including harmonized standards, providing detailed technical guidelines and specifications. These standards, developed and maintained by organizations such as the European Committee for Electrotechnical Standardization (CENELEC), establish comprehensive criteria for electrical product safety, performance, and interoperability. For products manufactured in accordance with harmonized standards there is a presumption of conformity with the corresponding essential requirements in the legislation.

But the use of standards is not mandatory. Manufacturers are generally free to apply other technical specifications to demonstrate that their products satisfy the essential requirements in the legislation.

The core standard for EV chargers is IEC 61851. The Home and Charge products were originally released to market aimed to fulfill the EV charging standard EN IEC 61851-1:2017. This standard does not contain exhaustive specifications for all the safety features that are utilized in advanced EV chargers but are supplemented by several other standards. For example, it implies that one of the following standards shall be fulfilled for RCDs: IEC 61008-1; IEC 61009-1; IEC 60947-2, IEC 62423. Specifically, IEC 61008-1 was used for Easee's chargers, with IEC 62955 for RDC-DD. Over time Easee's chargers may turn out to be better suited to fulfill standards other than IEC 61008-1.

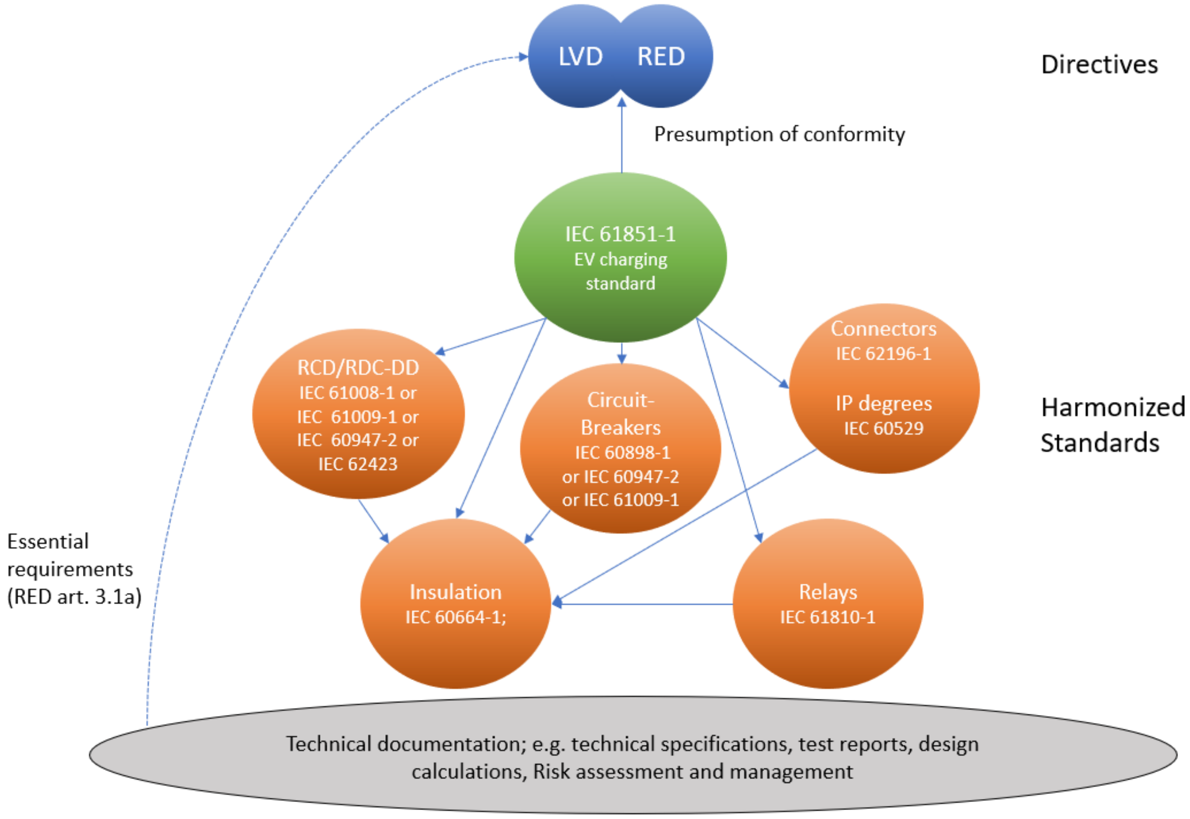


Figure 1 Typical hierarchy for ensuring a safe EV charger (examples, not exhaustive).

However, if Easee's Home and Charge products do not satisfy all the detailed criteria under the associated standards of IEC 61851 to formally qualify for a presumption of conformity – what makes the EV chargers still electrically safe to use?

The main goal of IEC 61851 and the essential requirements in RED and LVD is to develop safe, functional products with adequately low error rate, ensuring they do not pose a risk to people, animals, or property. Electrocution and fires are the most critical hazards caused by electrical products and are therefore key hazards to mitigate.

Easee's chargers contain several features and solutions providing enhanced safety compared to the specifications in the standards. To allow for both safe use as well as be a sustainable product with long operation and low electrical loss, Easee has engineered a complex charger.

Non-compliance with certain small parts of the aforementioned standards does not mean that Easee's products are hazardous or non-compliant with essential requirements. Standards are written based on technology available at the time of writing, not the capabilities of technologies developed after the regulations are codified. The EV charger sector is still subject to rapid technological developments. To emphasize how important Easee takes its role as a developer of such products, the key features of the products and key concerns raised by Elsäkerhetsverket are addressed.

Safety features

By handling risk either in accordance with standards and requirement or in line with traditional risk assessment and reduction (ISO 12100) appropriate safety measures and functionality is selected. The following sections show key principles utilized in the Easee chargers.

Fail-safe and detection of errors

Fail-safe

The fail-safe principle ensures that if something fails, it fails in or to a safe state. In general, this means that it stops working in a state without any residual risk. It typically shuts off entirely or cuts the power.

The internals of the charger are based on redundant signals, with monitoring through both hardware and software. Any malfunction in either will automatically stop and disconnect any charging session.

To maintain a closed relay the charger relies on its own control voltage, and will shut down if energy is lost, instead of relying on the detected fault energy to disconnect the power, like traditional switchgear.

If the internal power supply breaks down, the charger will not supply any of the outgoing socket pins, automatically leaving the system in a safe state.

Detection

Easee chargers work proactively to detect errors and avoid hazards, instead of merely reacting to a fault that has occurred. When anomalies are detected by the charger or the EV the charger enters an error state and alerts the user.

The charger monitors its internal safety functions, in addition to the input voltage, and the voltage present at the connection terminals. This enables the charger to detect and give warnings of internal errors as well as installation errors outside the charger itself (for example: faulty wiring, grid type, voltage). If any deviance is detected the charger will restrict charging, avoiding the fault entirely if possible. Other equipment such as heaters, AC units, water heaters, lights, switches, socket outlets, and so forth in an electric installation will not detect, warn, or inhibit use, as they rely only on the protection devices in the circuit to disconnect any fault. No control is given to avoid connecting to a fault.

Detection is further described in the section Surveillance and analysis.

By shutting down the charging session, or the charger itself, the charger enters a safe state until the fault is rectified or the criteria for safe performance are reestablished.

Examples of tests carried out by the chargers compared to different standard requirements:

Control criteria (automatic by appliance)	Easee	IEC 61851-1	IEC 61008-1	IEC 61009-1	IEC 60947-2	IEC 62955
Power supply configuration	Yes	No	No	No	No	
Residual current device	Yes	Yes	Yes	Yes	Yes	Yes
Type 2 socket monitoring	Yes	Yes	-	-	-	-
EV charging	Yes	Yes	-	-	-	-
Welded Relay Detection	Yes	Optional	No	No	No	No
Control closing of relays	Yes	No	No	No	No	No
Control Opening of relays	Yes	No	No	No	No	
Relay wear and tear detection	Yes	No	No	No	No	
High temperature detection	Yes, Terminals + socket	No	No	No	No	No
Overcurrent detection	Yes	Yes	Earth fault	Yes	Yes / upstream	Earth fault
Voltage control	Yes	No	No	No	No	No
Supplying (Grid) voltage control (detection of earth fault or missing PEN)	Yes	No	No	No	No	No
RCD Testing	Automatic (<1 day + between charge)	-	Manual	Manual	Manual	Manual or Automatic (<1 day)
Real-time analysis of fault	Yes	No	No	No	No	No
Over the air update	Yes	No	No	No	No	No
Impossible to use if RCD-test fails	Yes	Yes	No	No	No	Yes, if automatic
Communication (remote)	Yes	No	No	No	No	No
Sound	Yes		No	No	No	Yes
Lights	Yes	Yes	No	No	No	No
Position of flag/switch (mechanical)	No	-	Yes	Yes	Yes	Yes

Table 1 Functionality and control matrix

If any of the required tests listed above fails, the charger enters an error state and will not allow power to the socket outlet.

Error warnings

When a fault occurs, the user is warned (visually and audibly) by the charger and in the user app. If the charger is not suited for further use, then the charger is blocked from use by entering a persistent error state. A persistent error must be unlocked via Easee support and cannot be unlocked by the customer.

- In the event of a critical error the user is warned through the app:
  "We have detected a critical fault on your charger. Your charger is permanently locked and can not be reset. If the charging cable is attached, disconnect power to the charger and carefully remove the charging cable."

If a cable is connected the audible warning will continue to warn the user. The red LED will warn whether or not the cable is connected as long as the fault is present.

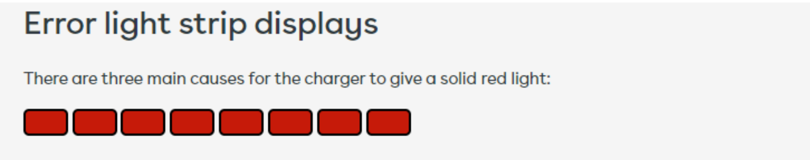


Figure 2 Critical error warnings [1]

Compared to ordinary socket outlets, the charger's LEDs, audible signals, app warnings and preventing use provide a detailed and customizable interface for warning and guiding the user through the necessary precautions and actions to be taken. This reduces the risk of misuse in addition to the other mitigated risks.

To further mitigate the possibility of injury or misuse the app warning gives the following information:

- Warning of loss of power/offline charger:
  "If the circuit breaker has tripped, you should always disconnect the charging cable before attempting to restore power." (Detailed instructions are available directly by link in the app.)

By following the instructions and warnings it is ensured that there are no exposed wires, for example in a damaged charging cable, that can lead to a secondary earth fault causing damage or injury.

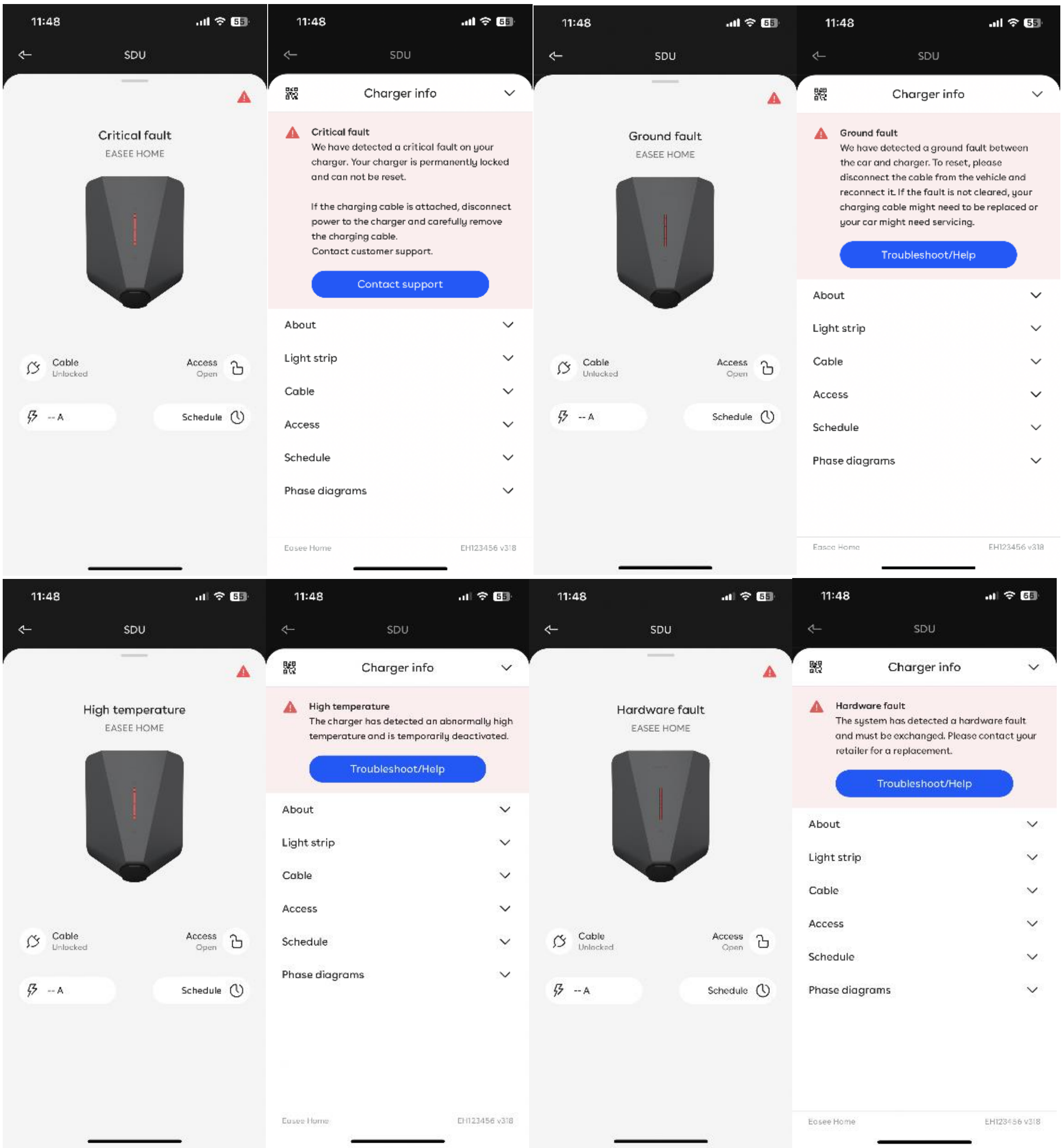


Figure 3 Error Warnings and corresponding explanations- Examples from app

Surveillance and analysis

The chargers allow for continuous testing of safety features which gives a reliable and frequent report of the product's performance. Analysis of data also enables Easee to monitor and improve detection throughout the product's lifetime via software updates. This also allows dedicated push notifications to be sent to users experiencing recurring non-critical faults. This can be done proactively, before a critical error occurs, and is under current development for existing chargers. This is another method of extended safety measures for the user.

Self-testing RCD

Compared to manual testing (which is required periodically for manual RCDs), the Home and Charge products allow for an enhanced safety feature whereby testing can be demanded instead of expected. (See section below regarding Standard RCD Reliability). The frequency of the automatically performed tests is thus greatly increased, which in turn provides a safer product for the end user. The RCD function in an Easee charger is verified by a self-test that runs:

- after power on,
- after disconnecting an EV, or
- at least every 24 hours.

Comparing to requirements from standards the IEC 62752/ed.2 (type 2 portable charging) Easee chargers perform in accordance with the stricter requirements, while testing more frequently than required by IEC 62955 8.11 (<1 day + power on) and the IEC 61008-1 (manual, 3-12months.)

Easee's failure rate (2023) for its internal RCD unit is 0,05% (376 out of 704 676 in 2023) [2], which is far lower than the mechanical manually tested RCD units (See section below).

When an RCD error has been detected (which is done automatically and at least once a day), no power is fed to the socket or to the car, rendering the situation completely safe. The user is also warned both by app and by the charger.

Standard RCD reliability

Mechanical standard RCDs require manual testing, in accordance with standards and producer requirements. This test requires active input from the end user and is far less likely to be carried out at the specified intervals. When testing is not performed the RCD's ability to disconnect is taken for granted, leaving the user with a false sense of security.

Research based on testing manual RCDs in Denmark [3], Scotland [4], Australia [5], and test results presented by Eaton [6] show that between 3-15% of the RCDs are failing to release *when* tested with the manual test-button. Intervals for testing range from 1-12 months. In addition to this, a large number is most likely not tested as often as required by the manufacturer, thus leaving the user to rely on false security.

Temperature

In addition to monitoring currents and voltage, Easee chargers actively monitor internal temperatures as well as relay states and wear. Temperature is proving to be a key point when assessing data from all chargers. As data from all charging sessions are being synced to the cloud, RMA-cases where the product has suffered damage can be analyzed using stored or real time data for the specific charger. Compared to chargers without intrinsic risk mitigation in both hardware and software, an Easee charger provides safe disconnection of the vehicle being charged, while also offering detailed measurements of internal and terminal temperatures. These measurements can in turn be used to improve algorithms to detect similar faults at an even earlier stage, since software and threshold values can be updated over the air (OTA) to the charger throughout its lifetime.

Temperature sensors at terminals will derate or stop charging if there is potential overheating at the terminals. This function prevents severe overheating or fire to occur inside the charger or at its terminals. This is a heightened level of safety that is far beyond the protection capabilities of an analogue protective device (like a normal RCD or circuit breaker) located in the distribution board. What Easee is doing is comparable to having a thermography assessment being carried out continuously during charging rather than months or years apart. If an overheating is detected by any of the sensors, it also clears any fault by shutting down and warning the user.

Temperature rise at terminals is one of the more frequent causes of electrical fires [7]. Often due to faulty installation (wrong torque, reduced cross section, debris at the terminals etc.) the resistance at the terminals can increase with the result of terminals overheating and possibly leading to a fire. This applies both to the terminals connecting to the backplate and on the outgoing socket to the charging cable.

When comparing this functionality to simpler chargers, normal socket outlets or other similar appliances the risk of a fire is much higher, as neither of these products can detect nor act based on temperature.

In the event of a temperature rise, the charging current is first derated. If this does not stop or bring the temperature down, the charging session is stopped. The corresponding warning for high temperature is given by the charger and in the app. (See figure below).

Red – pulsating light	The Charging Robot has measured an abnormal temperature and has entered in safe mode. Please go to our knowledge base[2] for further information.

Figure 4 Fault warning high temperature - From user manual [8]

In 2023 the number of occurrences were distributed as follows [2]:

- Output Current was reduced = 76 086
  due to high temperature being detected by the charger (> 89°C detected.)
- Fatal Temperature Error = 1739
  Limit reached either after a derating of current or by directly detection.
- Actual faults in need of correction (RMA) = 770
- *Instances of fire developing = 0*

In all events of a detected fatal temperature a potential fire was avoided, and the charger was disabled from further use. This error can be caused by installation fault shown below, or by faults in the socket outlet/plug. When the critical temperature value is reached the charging session is stopped before any temperatures that would potentially cause a fire are reached. This leaves a critical temperature error rate of 0,25%, which all resulted in a mitigated fire. Some faults caused by faulty cable etc. may be temporary, as shown by the lower number of RMA (770 chargers replaced) compared with the number of reported critical temp errors (1739).

Avoiding tampering with installed charger settings

For simpler chargers, adjusting dipswitches or position switches inside the charger to allow a higher charging current is frequently mentioned in online forums. This is a low-effort manipulation that enables the user to overload the supplying cable after the initial installation by supplier. These kinds of chargers are also not likely to have temperature monitoring of terminals, further allowing potential overload.

For Easee chargers, the maximum current allowed for the charger can only be set by the installer app used when installing and is not available to the end user. The end user is only allowed to reduce the current limit to the charger.

Data and statistics

Chargers in use per 31 Dec 2023

The quoted number is retrieved from in-production chargers installed at commercial & domestic sites in 2023 [2]. Energy and power average data is based on the period from Nov ’23 to Feb ’24 [9].

- Number of installed chargers = 704 676
- Total years of service during 2023 = 643 169 years (= 5 634 160 000 hours)
- Number of Charge Sessions during 2023 => 82 352,675
- Idle chargers not in use, 0 charge sessions = 10 638 (1,5%)
- Chargers with less than 10 charge sessions = 45 427 (6,4%)
- Avg. number of charge session (non-idle chargers) = 116
- Average charge energy per session: 18,48kWh
- Average charging power per session: 6,39kW
- Avg. annual energy per. Top 100 chargers: ca. 25 000kWh
- Avg. annual energy per charger in 2023: ca. 20 00kWh
- Accumulated total energy delivered by chargers: 1 522 112 MWh

However, many newly installed chargers did not see immediate use. Specifically, 111,181 chargers exhibited a significant delay, ranging from 4 to 9 months, between installation and their first utilization. This delay often corresponds with the customers' anticipation of receiving an EV, resulting in chargers being installed far in advance of acquiring the vehicle. [9]

Aging and reliability

Overall numbers of critical failures include the increased expectancy of early failures one can expect from new products, and in the early life of a product. Continuous learning allows Easee to improve this both by hardware and software upgrades when a weakness is detected. This can prolong the expected lifetime as shown in the figure below.

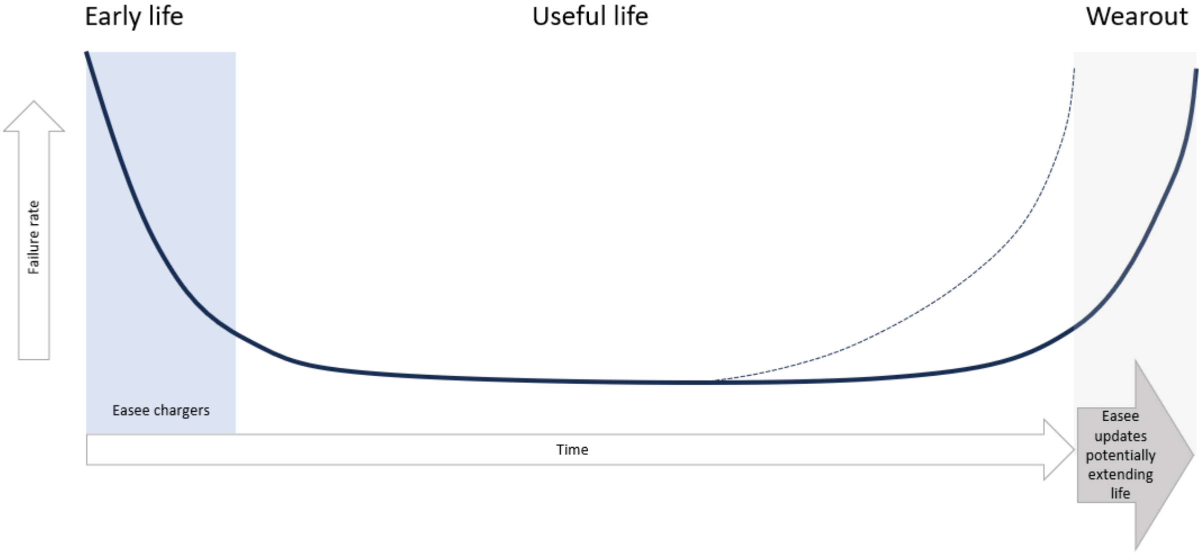


Figure 5 Reliability and typical distribution of faults throughout service life. Easee chargers’ current location is shown in blue. Green shows potential extended useful life enabled by over-the-air updates.

By looking at the different reported critical faults that occurred during 2023 it shows a low failure rate. The mean time between failures (MTBF) can be monitored, and failure rates will typically be higher in the early life after installing a product. Even though all Easee chargers are within the early life stage, its failure rate is already very low. This shows that the reliability of the product is very good, even at a time when it is expected to have an overrepresentation of malfunctions.

Hardware faults detected by the chargers in the first versions of chargers have already been improved upon and rectified either by software improvements, hardware improvements, or both. By learning from all the accumulated data Easee are continuously improving the product and extending its life expectancy for both coming product generations, as well as for the already installed chargers. This is indicated by the green arrow in the above figure.

At the (extended) end of life all chargers failing any of the required self-diagnostic tests will shut down and attain a safe state.

Overall charger data from 2023:

- Number of installed chargers = 704 676
- Total years of service during 2023 = 643 169 years (= 5 634 160 000 hours)
- Mean Time Between Failure for critical fault = 643 169 years/3075 faults = 209 years
- Overall number of critical failures = 3075
- Overall reported critical fault rate = 0,44%

The different critical faults were distributed as follows (may include temporary faults):

- Fatal Temperature = 1739 = 0,25%
- Welded relay = 440 = 0,062%
- RCD test fail = 376 = 0,053%
- Other (Dead, CPLD, etc.) = 520 = 0,074%

The charger's overall tolerance for aging and endurance also is shown by passing relevant tests in IEC 61008-1 part 9.23 for electronic aging and part 8.6 and test 9.10 for mechanical and electrical endurance. An adaptation to test in line with clause 9.8 of IEC 62752 was made to test electronically, instead of manually, as this better represents actual operating conditions for the chargers. [10] Verification of reliability is shown through relevant tests in 9.22.1 and 9.22.2 tests for RCD according to 61008-1. [11]

Reliability is also shown in accordance with IEC 62855 clause 9.19. [12] IEC 61851-1 does not specify any durability tests and requires only test of functionality after different stresses.

Usage and incident reporting to authorities

All data from the chargers can be extracted from the cloud and made available in various ways for reporting to authorities, such as analyzing specific faults of interest, energy use or trends in usage or fault frequencies and duration.

All, or selected, types of usage data can be extracted and reported to relevant authorities upon request to give insight in user habits, fault occurrences and typical disturbances experienced both in the installation, product and from the supplying grid.

The reports can be generated and shared at a quarterly rate of reporting.

Components and safe operation

The following sections give a summary of the combined safety functions that are in place, and how they work together in the event of a fault, regardless of their ability to fulfill the initial test criteria in the standard. It also shows how different types of faults do not occur simultaneously, and that each hazard is mitigated to reduce risk and probability.

Simplified control arrangements and internal dependencies are shown in the figure below.

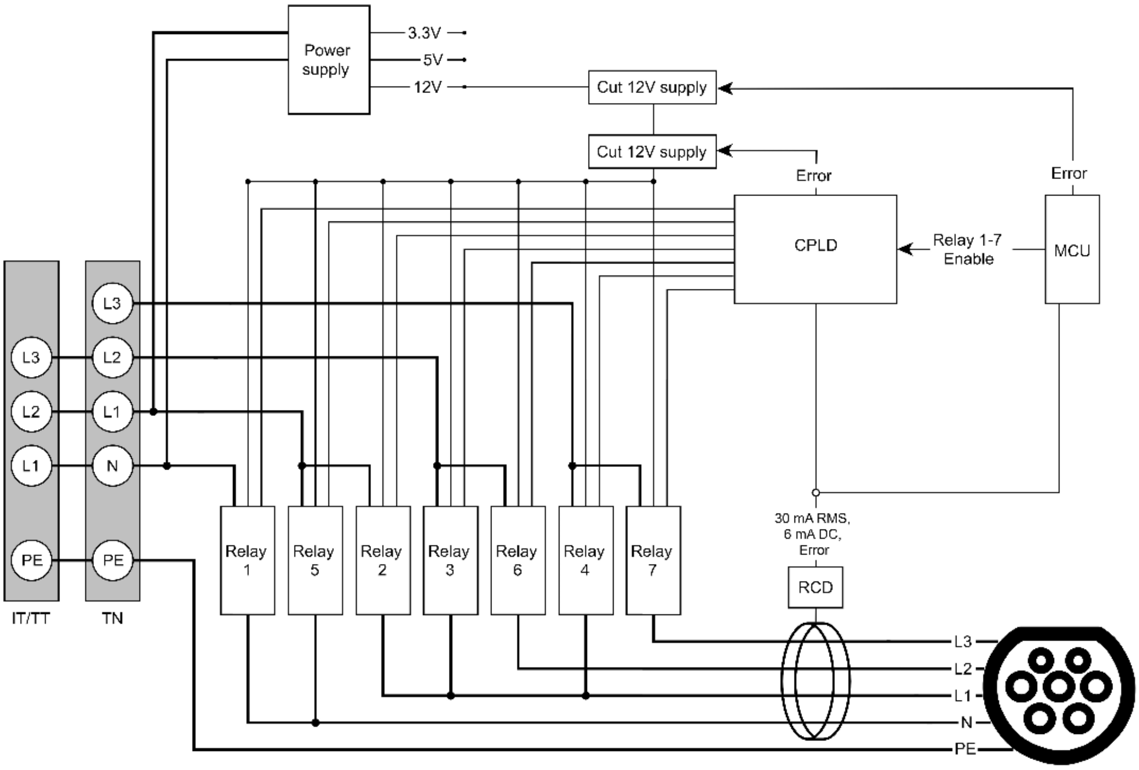


Figure 6 System overview, Internal relay and control arrangement

Welded contacts

When a direct earth fault or short circuit occurs in the cable or in the vehicle, the internal relays carry large currents until disconnected. If the relay itself is not able to break the current, the upstream SCPD will disconnect the fault. This is in line with the requirements in IEC 61851-1 section 13. According to 13.1 Note 5 and 13.3 Note 2, overcurrent protection of the charger and connected cable can be achieved in the charger, in the fixed installation or in both.

A large current (10kA>500A) may lead to the welding of one or more relay contacts. During 2023 a total of 440 chargers (0,062% out of ca. 704 000) [2] suffered from welded contacts. The overall number shows that this is an occurrence of low frequency. When used according to the manual and the requirements in IEC 61851-1, the risk is eliminated.

The MCU detects that relays open when relays are disengaged. If confirmation of open relay is not given, the charger will go into fault mode with visual and audible warning. No power will be given to the socket pins that are not welded (welded relay can be warned by nuisance warnings from supplying grid or elsewhere in the private installations).

A relay or relays stuck in the closed position are detected and signaled to the user. The system is also put in a non-operating state (acc. error mode F, IEC 61851-1). In this event the charger will enter a persistent error state. If welding is detected after re-setting from another error the charger will immediately enter persistent error state.

Once again comparing a damaged charger (with a welded relay) to larger socket outlets of >32A the charger still has many safety features in place, and there should not be a difference in the risk associated with using them. There is a very significant decrease in risk when using a smart charger that will continue to give error warnings.

RCD and RDC-DD

The AC RCD tests according to EN 61008-1 are failing to fulfill the test criteria being used for disconnecting. The reason is mainly the potential welding of contacts when disconnecting high currents. However, this does not cause a safety concern, as a high current cannot flow through a person or animal due to its internal resistance, resulting in a disconnection of any. Different earth fault scenarios are explained in the following sections.

The charger performs DC detection and disconnection (RDC-DD) >6mA according to the requirements in IEC 62955 and IEC EN 61851-1 section 8.5.

Disconnection of all currents <=5A is done within the time limits for both EN 61008-1 and IEC 62955.

The RCD-sensor data sheet specifies applicable for both AC and DC use; IEC 62955:2018 applies for DC (Direct Current) Differential Current Sensors, IEC 62752:2016 applies to both AC (Alternating Current) and DC Differential Current Sensors.

RDC-DD functionality and hardware are described in the RDC-DD Funksjonsbeskrivelse. [13]

See extract for RCD performance in the figure below.

Parameter	RCCB	RDC-DD	Easee
Standard	EN 61008-1	IEC 62955	EN 61008-1 + IEC 62955
Classification	Type A	RDC-MD (4.11.3)	Type A + RDC-DD
AC trigger level	15-30 mA	30-60 mA	15-30 mA
DC trigger level	N/A	3-6 mA	3-6 mA
Rated current	10-125 A	16-125 A	32 A
Rated voltage	400 V	400 V	400 V
Rated impulse voltage	4 kV	4 kV	4 kV
Break time 30 mA AC	300 ms	N/A	<200 ms
Break time 60 mA AC	150 ms	300 ms	<100 ms
Break time 150 mA AC	40 ms	80 ms	<30 ms
Break time 5 A DC	40 ms	80 ms	<30 ms
Break time 6 mA DC	N/A	10 s	<500 ms
Break time 60mA DC	N/A	300 ms	<100 ms
Break time 200mA DC	N/A	100 ms	< 30 ms

Figure 7 RCD performance, key disconnection times and values

Possible worst case fault scenarios

In the below sections, different cases explain events in different fault scenarios.

All first faults will be as described in scenarios 1 or 2. It is important to keep in mind that scenarios 3-4 require wrongful use, a consecutive fault to occur and can *only* occur *after* an initial fault causing welded relays (0,062%). Scenario 5 explains how an addition of an external RCD will impact the functionality of the charger.

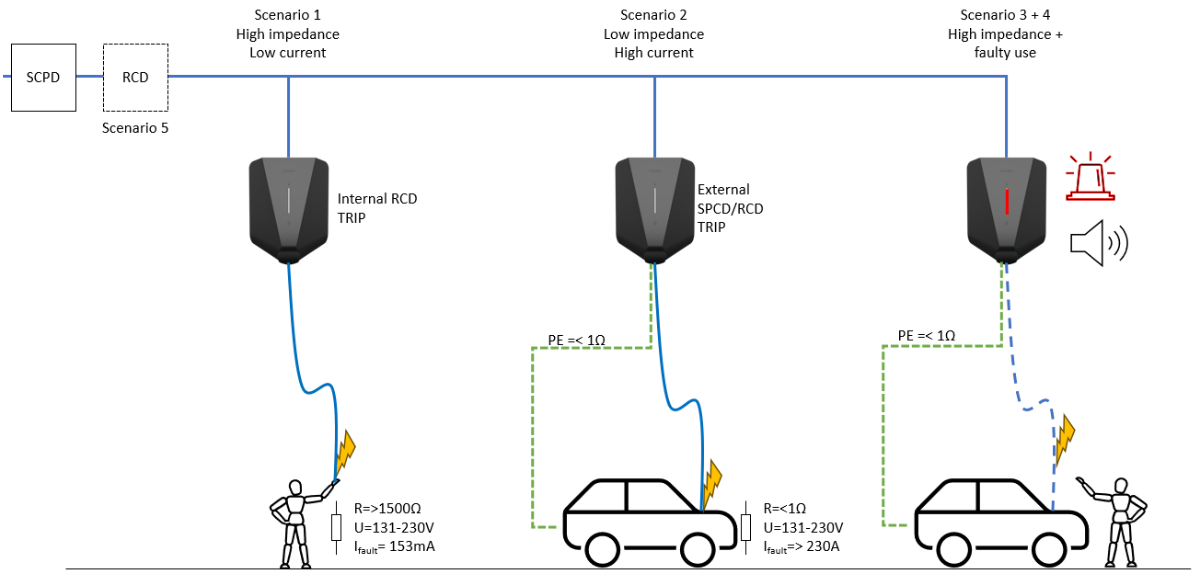


Figure 8 Illustration of possible fault scenarios

Scenario 1 – Low currents with successful disconnection by charger

- Low current faults are caused by high impedance (such as person, animal, or poor connections).
- Can be caused by exposed wire in a damaged cable.
- Prospective fault current is in the mA-range.
- Typical current through a person <150mA or an animal <500mA.
- Make/break current for relays is 500A (capable of disconnecting overload and high impedance faults)
- In an IT-grid the first earth fault to occur downstream of the supplying transformer will be in the range 50-1000mA and will disconnect without welding. (This also applies to low impedance faults.)
- (A secondary earth fault in an IT-grid will be high current – see Scenario 2.)
- ***Result: Above scenarios will be disconnected by the RCD or RDC-DD within required time limits. No possible risk.***

Scenario 2 – High currents with potential welding of contacts

- High current faults with potential welding of contact(s) are caused by low impedance.
- Impossible through human body (persons >1500ohm).
- Current path through phases or PE conductor.
- Typical fault current in the kA-range.
- High current faults will be disconnected by upstream breaker acc. to IEC 61851-1 section 13. Overcurrent protection can acc. To 13.1 Note 5 and 13.3 Note 2 be achieved in the charger, in the fixed installation or both.

- This also applies if the charger is not able to disconnect due to welded contacts in TT, TN and secondary earth fault in IT grids.
- Back-up protection provided by the upstream SCPD ensures instant disconnection. (The function provided by an upstream RCD in such an event is equal to that of an SCPD.)
- If welding occurs in the charger it will flash red light while giving a push notification in the charger app explaining the course of action to be taken.
- The chassis of a car is connected to PE, thus leaving it impossible to have an active earth fault connected to it.
- The insulation provided by the tires makes no difference, as the PE-conductor in the charging cable is directly connected to the car chassis.
- Guidance for disconnecting cable is given in the app.
- ***Result: Instant disconnection by SCPD due to short circuit.***

Scenario 3 – Earth fault in car *after* welding of relays.

Requires a combination of multiple faults.

- first Scenario 2 for welding of relays (0.062%),
- followed by not following described steps in a fault event,
- then re-connecting the circuit (if able to) while not responding to active critical alarm,
- followed by a separate fault involving a person/animal.

If welding of contacts is detected (or an earth fault has occurred) the user is guided by the app (and user manual) to remove the charging cable before re-energizing. This eliminates the risk of being electrocuted due to a faulty cable (after reenergizing). Guidance for removal of cable is also given if the upstream breaker has tripped (loss of power/communication).

By following guidance given in the app and the manual the following scenarios are excluded, but the possible faults are described in the following sections as illustration of possible events if someone disregarded the described procedures.

TN or TT grid (or secondary earth fault in IT-grid), after welding

- A high current fault (Scenario 2) will have to be the cause to enable welding. (This excludes the case of a low mA fault for first fault in IT grid.)
- When re-connecting power, the warnings will sound immediately, and will sound as long as a cable is attached.
- If the cable is left plugged in in the charger and an earth fault is present in car/chassis the current will go directly through the PE in the charging cable.
- PE is directly connected to chassis resulting in a direct ground fault, the RCD/SCPD is not able to close.
- This causes instant short circuit in TN/TT grid, or when the fault is secondary in the transformer circuit (IT-grid).
- ***Result: Instant disconnection as in Scenario 2 by upstream SCPD (or RCD if installed).***

IT-grid (first earth fault), after welding

- Can only happen if procedures for re-connection have not been followed and welding has occurred after a different fault (different from the first earth fault) have occurred.
- Warning sound is active if a cable is attached.
- Requires fault to be the first earth fault in IT-grid to be able to be permanent (Second fault will be instantly disconnected, Scenario 2)

- If the chassis of the car is connected to a phase, the PE conductor will carry most of a fault current.
- If a person (>1500Ω) touches the car the fault currents path will divide by using both PE (1Ω) and person (>1500Ω) possible paths to return to the transformer.
- This is the reason why copper piping, faucets and showers are bonded in IT-grids (Touch voltage <50V)
- ***Result: Touching the car is equally dangerous as e.g. touching a kitchen faucet.***

Scenario 4 – Cable faults after welding of relays

If a cable is damaged so that live conductors may be touched, the cable will display clear visible signs of damage. As in the above cases for grid-types, all require severe disregard for routines and warnings, and in addition the very low probability of several faults occurring consecutively.

- Comparing to larger socket outlets of >32A the charger has an array of safety features in place.
- There is no requirement for using an RCD for large socket outlets (over 32A, up to 125A) but these are allowed without restriction in both domestic and professional installations.
- Both types of **sockets rely** on flexible cables, and there should not be a difference in the risk associated with using them.
- The charger will still warn of a potential hazard as this is currently in a critical error state, where any socket outlet will be without any sound or other warning.
- ***Result: Improved protection compared larger socket outlet circuits, but with local and app warnings of current fault, even after an initial fault with low probability (0.062%).***

Scenario 5 - Possible addition of RCD Type A (or Type B)

An addition of an upstream RCD type A may be included to mitigate the failed test criteria for the RCD short circuit test to ensure function in accordance with IEC61008-1 (or other RCD standards). This will pass the test criteria, but will not have any significant impact on safety, as the function is very similar to what the Easee chargers already provide.

Low currents:

- If the earth fault is of a high impedance (Scenario 1, possible person, or animal, current <5A) no welding will occur, as this leads to a fault current in the mA-range.
- ***Result: Any such fault will be disconnected by either the charger or the upstream RCD, within the requirements for RCD and RDC-DD.***

High currents:

- If the fault has low impedance (Scenario 2), the current will be high.
- ***Result: disconnection will be achieved either by the RCD or SCPD (as there is no requirement for discrimination at higher currents).***

High current and welding:

- Should a welding of internal relays occur during an earth fault (Scenario 2) the upstream RCD type A or SCPD will trip.
- If the fault is of low impedance the protection devices will lack coordination at high currents, and thus providing no selectivity.
- The charger will no longer be able to communicate after an upstream disconnection. When power is re-instated in the supplying circuit, the charger will alert the user via sound, flashing red lights and an app warning.
- This scenario always include resetting one or more upstream protection devices.

- ***Result: The Easee charger functionality and warnings are identical regardless of whether there is a tripped upstream RCD type A/B or an SCPD.***
- ***Result: The Easee charger relies on the upstream SCPD for high currents and takes care of all lower currents itself. This does not fulfill the test criteria for EN61008-1 but is still achieving safe disconnection of high currents in a near identical manner.***

Overvoltage test to pilot circuit (Control Pin)

The charger is constructed of non-conductive plastic materials. These materials pass overvoltage testing for insulation tests. All conductive exposed materials shall be tested with an overvoltage test, to ensure proper earth connection or impulse voltage withstand capabilities.

As the socket outlet is designed according to IPXXB, where a test probe of 12mm/80mm is not able to touch the control circuit contacts, these are therefore not considered to be an exposed conductive part to be tested with overvoltage. The testing of a PELV circuit with no exposed conductive parts is not relevant to fulfill 61851-1 section 12.7.

Relays life expectancy

Since relays are switched without current in normal operating conditions the relays can expect an elongated electrical lifetime, upwards towards the mechanical expected lifetime of 100k switches. The relays are switched before and after the charger in the EV is activated, leaving the relays unloaded during opening and closing actions in normal operation. This eliminates potential arcing during making/breaking at nominal current, thus increasing electrical life expectancy.

The requirements of a minimum of 50k switching under normal conditions in IEC 61851-1 section 12.2.5 is comfortably met. See extracts from manual below. [14]

Life Expectancy	(minimum operations)
mechanical	
standard version	3×10^5 (1.8 mm contact gap version)
option (200) version	1×10^5 (2.3 mm contact gap version)
electrical	see UL/cUR/TÜV/CQC ratings

Figure 9 AZSR131-1AE-12DGW(200) Mechanical life expectancy

Rated Loads	
UL/cUR	26 A at 277 VAC, resistive, 85°C, 50k cycles 35 A at 277 VAC, resistive, 85°C, 30k cycles
TÜV/CQC	22 A at 277 VAC, resistive, 70°C, 100k cycles 26 A at 277 VAC, resistive, 85°C, 50k cycles 33 A at 277 VAC, cos phi 0.8, 85°C, 50k cycles 35 A at 277 VAC, cos phi 0.8, 85°C, 30k cycles

Figure 10 AZSR131-1AE-12DGW(200) Electrical life expectancy @<22A --> 100k

Relay contact spacing

The internal relay contact distance requirement is a function of the required voltage that is required. Different standards differ in the sufficient kV tolerance for isolation. The different standards EN61008-1, IEC 62955, IEC 60947-2 and 61851-1 part 8.1 points directly or indirectly (via testing) to IEC 60664-1 to establish sufficient spacing at different external factors such as pollution degrees, height relative to sea level and the geometric shape of the contacts. The required gap is therefore not static but may be higher or lower than the *implied* 3mm in IEC 61851-1 section 8.1 (which in most cases is sufficient, regardless of design). Of the above standards 61008-1 has the strictest requirement.

The goal is not to have distance, but sufficient insulating tolerances [kV]. *The requirement is overvoltage category 3. This corresponds to 4kV, (not 3mm, which is only implied).*

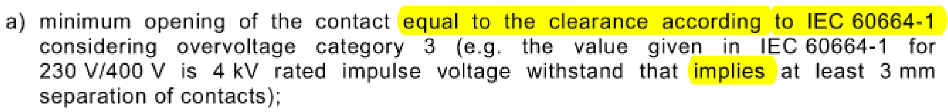
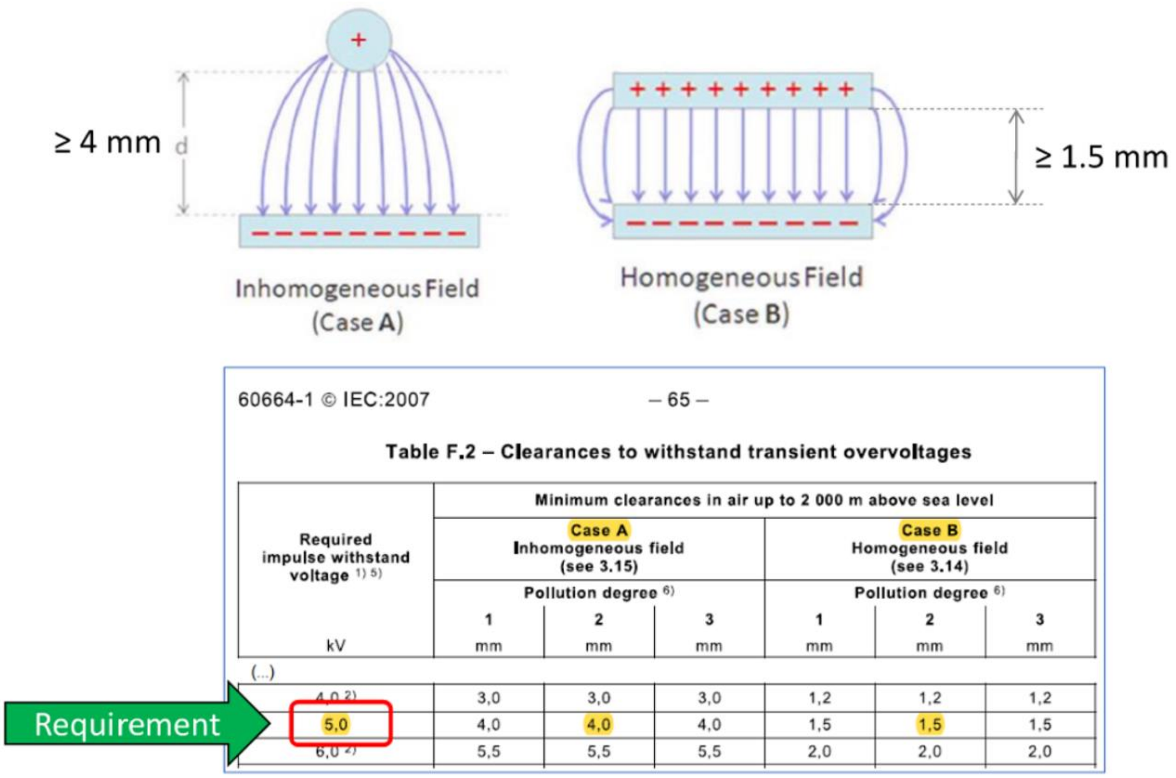

a) minimum opening of the contact equal to the clearance according to IEC 60664-1 considering overvoltage category 3 (e.g. the value given in IEC 60664-1 for 230 V/400 V is 4 kV rated impulse voltage withstand that implies at least 3 mm separation of contacts);

Figure 11 Extract from 61851-1 section 8.1



60664-1 © IEC:2007 – 65 –

Table F.2 – Clearances to withstand transient overvoltages

Required impulse withstand voltage [1) 5)]	Minimum clearances in air up to 2 000 m above sea level					
	Case A Inhomogeneous field (see 3.15)			Case B Homogeneous field (see 3.14)		
	Pollution degree [6)]			Pollution degree [6)]		
	1	2	3	1	2	3
kV	mm	mm	mm	mm	mm	mm
(...)						
4,0 [2)]	3,0	3,0	3,0	1,2	1,2	1,2
5,0	4,0	4,0	4,0	1,5	1,5	1,5
6,0 [2)]	5,5	5,5	5,5	2,0	2,0	2,0

Figure 12 Arrangement of contact surfaces and the distance requirements in EN60664-1

Different standards (Figure 1) and their requirements:

- The suggested requirement in EN61008-1 (4mm) allows for all geometric shapes, without need for testing. This corresponds to Case A shown in the figure above, with 5kV withstand voltage.
- According to IEC 62955:2018 clause 8.1.3 a, an implied gap of 3mm regardless of geometric shape.
- The distance may be reduced provided that the distances are not less than the minimum allowed in IEC 60664-1 for a homogenous field condition (1,5mm @5kV). See Case B above.

- The strictest of the requirements for impulse voltage testing are found in IEC61008-1 (For type A RCDs), with a required impulse test voltage of 6,2kV to be verified as suitable for insulation.
- Fulfilling IEC61851 Ed.3 part 8.1 for mode 3 charging requires in addition to outlet IPXXB an opening of contacts equal to IEC 60664-1 section 8.1 a).
  3mm is implied, see Figure 11. When using contacts with a homogenous field the distance required is reduced to 1,2mm for 4kV. When derating for the test environment the test requirement is 5kV, with a corresponding distance of 1,5mm. The homogenous field with 2,3mm gap used in the Easee chargers is therefore sufficient.

While it does not meet the implied spacing distance (without testing) it meets all other requirements for isolation and voltage withstand capabilities. The relay Easee uses withstands 6,2kV impulse voltage test, and fulfills the requirement for insulation resistance for all the above standards [10].

Electrical coupling of the contacts, intended for Edition 2 of IEC 62955

Extract from Electro Suisse Report [15]:

“The IEC 61008-1 standard, referred to in the corresponding paragraph of IEC 61851-1, mentions the mechanical coupling of the relays - however, Easee solves this electrically. There is no evidence that the electrical coupling of the relays does not offer the same level of safety as mechanical coupling. The fact that electric coupling is not (yet) mentioned is because standards often lag market innovations.

At present, WG 8 of TC 23 SC 23E working on Edition 2 of IEC 62955 "Residual direct current detecting device (RDC-DD) to be used for mode 3 charging of electric vehicles". According to the status as of February 2023, for the next stage Committee Draft for Voting (CDV) paragraph 8.1.2 provides that the coupling of the poles can be performed either mechanically or electrically. This also shows that electrically coupled relays can, in terms of safety, be equated with mechanically coupled contacts and that this deviation from the IEC 61008-1 standard can be accepted.”

(Working Group 8 of Technical Committee 23 Sub Committee 23E Circuit-breakers and similar equipment for household use)

Misuse through use of adaptors

The possible misuse through use of an adaptor should be disregarded as relevant. This is mentioned in the manual and is passing the criteria in accordance with IEC 61851-1 (See figures below).

10	REQUIREMENTS FOR ADAPTORS		P
	Vehicle adaptors shall not be used to connect a vehicle connector to a vehicle inlet.	No adaptors permitted in manual; certified vehicle connector used.	P

Figure 13 Extract from TUV test report [16] for IEC 61851-1 compliance, Showing pass verdict for no use of adaptors.

16.2 User manual for EV supply equipment

User information shall be provided by the manufacturer on the EV supply equipment or in a user's manual.

Such information shall state:

- which adaptors or conversion adapters are allowed to be used, or
- which adaptors or conversion adapters are not allowed to be used, or
- that adaptors or conversion adapters are not allowed to be used,

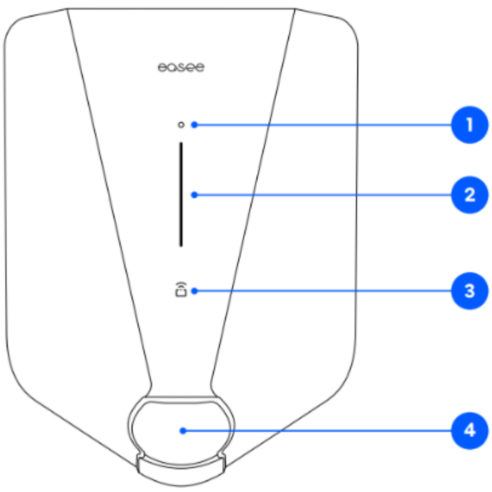
and

- that cord extension sets are not allowed to be used.

The user manual shall include information about national usage restrictions.

Figure 14 Extract from IEC 61851-1 specifying user manual requirements for no use of adaptors, and also specifying that extension cords are not allowed by the standard regardless of use of any adaptors.

Features



1. **Touch button:** The touch button is used to activate the local interface. The local interface is intended for local operations of the charger when no internet is available. Read more about the local interface at: easee.com/support/localinterface
2. **Light stripe:** The light stripe communicates the status of the Charging Robot at all times. (See Charging Robot interface).
3. **RFID area:** The integrated RFID reader enables access control of the Charging Robot and identification of different users. You can use it to unlock the charger with an Easee Key. Check our knowledge base at easee.support for more details on how to add and manage your Easee Keys.
4. **Type 2 socket:** The Type 2 socket is completely universal and allows you to charge any type of electric vehicle using the appropriate charging cable. Furthermore, it is possible to permanently lock the charging cable, so you do not have to worry about it being stolen.

NOTE: Adaptors should not be used on the charger or the charging cable. The charging cable must have appropriate sockets on each end.

Figure 15 Note from user manual stating no adaptors shall be used. [8]

The possible misuse through using an adaptor directly violates both the product's user instructions and intended use. As such, misuse through an adaptor is not considered to be foreseeable use nor appropriate, as all consumer appliances can be misused with a certain degree of determination. A key difference for the chargers is that it offers a warning of any fault directly at the charger, which differs from typical circuits with numerous appliances connected to different outlets that are being controlled by a common RCD at another location (typically a distribution board).

Through use of an adaptor that bypasses communication and simplifies the charger, the charger ends up more like a traditional socket outlet, but with the intrinsic functions and warnings still in place. Only the communication to the connected EV is disabled. The only hazardous use can only occur *after* an initial fault, as described in previous chapters.

If the possibility of misuse is still there after a fault (only possible *after* a welded relay failure (2023 rate of <0.062%), the user must once again display gross negligence by both tampering with the equipment and also not adhering to the active warnings both locally and in the app. This would still leave the charger comparable to a socket outlet of >32A without any required RCD. For all other faults the charger will disconnect power, disabling further use.

The charging of vehicles is the only allowed use, even with an adaptor if one was permitted for use. IEC61851-1 section 16.2 also specifically points out that extension cords are not to be used, under any circumstance.

Comparison to other consumer appliances

Other consumer appliances and parts of an electrical installation are a large contributor to fires, and if broken, damaged or misused can potentially also cause electrical hazards. This is, however, generally a risk that is at a sufficiently low level to being accepted for everyday use. Comparing the Easee chargers to everyday appliances and risks like using an extension cord, water heater, AC-unit etc., or driving a car, or cooking; it poses no greater risk than any of these. In fact, using the Easee charger provides the opposite — it mitigates the root causes for several of the relatable hazards, as described in previous chapters.

Tabell 3: Andel av händelser orsakade av fasta elinstallationer som resulterat i brand

Orsak	Andel som lett till brand	Antal bränder
Övrigt	100%	2
Elcentral	78%	231
Elkabel	77%	115
Kopplingsdosa	76%	82
Serviskabel/neutralledarfel	68%	13
Eluttag	67%	255
Strömställare	59%	16
Dimmer	40%	8
Totalt	**72%**	**724**

Figure 16 Extract from ESV report [7] showing events leading to a fire in fixed installations.

The statistics above show faults in permanent electrical installations that led to a fire in residential properties. Highlighted rows are showing the two types of relatable potential faults an EV charger may be a part of. The Easee charger's temperature sensors can mitigate *both* potential hazards, and thus greatly reducing the risk for person or property damage.

Through the entire year of 2023 no fires occurred in Easee chargers, even though the chargers measured an increased temperature in either the Type 2 socket or the terminals/backplate 76 086 times. [2] These were all mitigated by decreasing charging current (derating).

Removing installed chargers may lead to users reverting to charging by ordinary sockets or simple chargers without additional safety. This seems to directly contribute to achieving the opposite of the intended goals and intentions of the regulatory framework and relevant standards.

Misuse that causes fires

Misuse of home appliances is always an uncontrollable factor. The ESV report [7] shows misuse that led to fires being dominated by one type of equipment. The number of faults due to wrongful use of a stovetop eclipses the faults caused by all other appliances combined (by a factor of almost five).

When comparing a charger and the connected cable to other similar home appliances such as "Elledning", "Eluttag och kontakt", "Motor och kupévärmare" the numbers are relatively low, one can assume that similar probabilities apply to a charger. As the charger has intrinsic safety functions that these products have not, the probability is even lower.

Compared to fires caused by stovetops, a charger with additional safety features will pose a significantly lower risk, even lower than the comparable other passive appliances.

3.6 Felanvändning

Felanvändning definieras som oavsiktlig följd av mänsklig handling. Under 2022 orsakade felanvändning av elprodukter 1 530 händelser. Under samma år orsakade elrelaterade fel i utrustning 641 händelser.

Felanvändning av spis/häll är fullständigt dominerande och står ensamt för nästan dubbelt så många händelser än alla händelser orsakade av elrelaterade fel i utrustning. Det är också denna som orsakar flest elrelaterade dödsbränder.[26]

Tabell 12: Antal händelser som orsakats av felanvändning per startobjekt

Orsak	Antal händelser
Spis/häll	1267
Ugn	79
Mikrovågsugn	65
Annan el	21
Brödrost	19
Belysningsarmatur	17
Elledning eller elkabel	10
Bastuaggregat	10
Fritös	10
Varmluftspistol	8
Elelement	6
Elcentral	3
Batteri	2
Elmotor	2
Grilltändare	2
Kaffebryggare eller kaffemaskin	2
Eluttag eller kontakt	2
Fläkt eller annan ventilationsanläggning	2
Motor- eller kupévärmare	1
Torktumlare	1
Totalsumma	**1 530**

Figure 17 Extract from ESV report [7] showing occurrences of wrongful use that led to fires. Stovetop shown in yellow.

The only possible hazardous misuse of a charger through an adaptor occurs when the adaptor actively bypasses any communication circuit *and* there has been a previous situation that has welded the relays. This also requires the circuit breaker to be re-engaged after a short circuit without correcting the circuit, while overlooking the chargers alarm (optical and audible), as this is in a critical fault state that must be reset through Easee support. The charger in this case actively discourages any misuse if in an error state. The previous chapter Misuse through use of adaptors also explains why such misuse should be disregarded for a charger.

Trends

The ESV report "Elrelaterade bostandsbrander orsaker och trender 2018 – 2022" [7] Shows trends in faults leading to fires that generally decline for consumer equipment. This can be explained by the fact that newer products with more electronics and monitoring mostly stop working or are stopped by the equipment even when a fault occurs. The report also points out overload of sockets and cords as a high contributor to fires.

This is a parallel that should be drawn to Easee's analytical way of both monitoring products and designing them. Actively monitoring and disconnecting overload and temperature in/at the appliance also mitigates the most dominant cause of fire in appliances.

This shows how Easee is leading the way for future products, with clever solutions providing a functionally safe product, going far beyond what the standards require.

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