



Ground Fault Current Protection in AC Level 2 Charging

Bender's mA-CCID Circuits for U.S. and EU Markets

Summary

As AC Level 2 electric vehicle charging infrastructure expands globally, ground-fault protection has become a critical design and certification challenge for EVSE manufacturers. Design decisions made early in the platform architecture directly affect personnel safety, regulatory approval, liability exposure, and long-term product viability. Note: In the IEC world, these currents are referred to as residual currents.

The United States and Europe have adopted different regulatory frameworks to address ground-fault protection in EVSE. In the U.S., Charge Circuit Interrupting Devices (CCIDs) evaluated under UL 2231 and UL 2594 are mandatory. In the EU, personnel protection relies on a coordinated system of ground fault current devices (RCDs) and ground fault direct current detecting devices (RDC-DDs) governed by IEC 61851, IEC 62955, and associated installation codes.

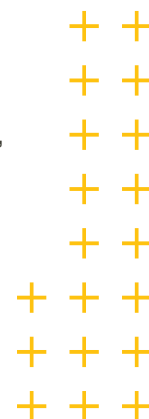
Despite differing terminology and certification paths, both regions confront the same technical reality: smooth DC ground-fault currents at or above 6 mA can magnetically saturate conventional Type A ground fault current sensors, delaying or preventing tripping of upstream protection devices. This phenomenon—commonly referred to as DC blinding—represents a credible safety risk in modern EV charging systems that incorporate rectifiers, power factor correction stages, and high-frequency power electronics.

This paper explains the origin of DC blinding, reviews the applicable U.S. and EU standards, and describes how Bender's mA-CCID circuit technology enables EVSE manufacturers to achieve compliant, future-ready ground-fault current protection using a common hardware platform adaptable to both regulatory environments.

Introduction

Electric vehicle supply equipment operates at the intersection of high current, power electronics, and direct human interaction. Insulation failures, wiring faults, moisture ingress, or improper installation can all lead to ground-fault currents flowing through unintended paths, potentially exposing users to electric shock or causing thermal damage and fire.

Historically, ground-fault and ground-fault current protection devices were designed to detect sinusoidal 50/60 Hz ground fault currents. Modern EV chargers, however, incorporate rectifiers, power factor correction circuits, EMI filters, and switch-mode converters that can generate non-sinusoidal and smooth DC ground fault currents. These current waveforms present significant challenges for traditional detection techniques.





Bender has been a pioneer in ground-fault current measurement and insulation monitoring technology for decades. Its mA-CCID circuits and ground-fault current monitoring modules are specifically engineered to address the evolving protection requirements of EVSE while supporting compliance in both North American and European markets.

In U.S. terminology, AC Level 2 charging refers to 208–240 V single-phase charging as defined in SAE J1772 and NEC Article 625. In Europe, the equivalent functionality is provided by Mode 3 charging under IEC 61851-1, typically operating at 230 V single-phase or 400 V three-phase. While the nomenclature differs, the underlying safety challenges are identical.

Standards and Regulatory Landscape

Ground-fault current protection in EVSE exists within a broader ecosystem of electrical, installation, and functional safety standards. Understanding how these standards interact is essential for compliant product design.

U.S. Regulatory Model

In the United States, UL 2231-1 and UL 2231-2 define the performance requirements for CCIDs used in EV supply circuits. UL 2594 mandates the integration of CCIDs in AC Level 2 charging stations. Two common trip classifications are permitted: CCID6 devices that trip at approximately 6 mA AC, and CCID20 devices that trip at approximately 20 mA AC when ground continuity monitoring is implemented.

While UL CCID requirements focus primarily on AC ground-fault currents, modern EVSE designs increasingly incorporate DC-aware detection techniques to address real-world fault conditions not explicitly described in the legacy standard language. These real-world fault conditions include potential “DC blinding”.

EU Regulatory Model

In Europe, IEC 61851-1 defines charging modes and mandates ground-fault current protection for Mode 3 charging. Installation standards such as IEC 60364-7-722 and DIN VDE 0100-722 require a 30 mA Type A RCD upstream of the EVSE. IEC 62955 further requires protection against smooth DC ground-fault currents by means of either a dedicated RDC-DD with a 6 mA DC threshold or the use of a Type B RCD that inherently detects AC and DC leakage.

Functional Safety Considerations

When ground-fault current detection circuits perform safety functions that influence contactor operation, additional functional safety standards apply. UL 991 governs safety-related solid-state controls, while UL 1998 applies to programmable software components. Together, these standards ensure that both hardware and software safety mechanisms operate reliably under fault conditions. CCIDs fall under safety-related controls and need to be evaluated to UL 991 & 1998.





Table 1: Comparison of U.S. and EU Ground-Fault Current Protection Requirements for AC Level 2 / Mode 3 EVSE

Aspect	U.S. (Level 2, UL/NEC)	EU (Mode 3, IEC/DIN VDE)	Notes
Primary Standard	UL 2231-1/-2, UL 2594, NEC 625	IEC 61851-1, IEC 60364-7-722, IEC 62955	Different frameworks, same safety intent
Device Type	CCID (integrated into EVSE)	Type A RCD + RDC-DD, or Type B RCD	RDC-DD mandated if only Type A used
AC Trip Threshold	CCID6 (~6 mA AC), CCID20 (~20 mA AC with ground monitoring)	30 mA Type A RCD (AC + pulsating DC)	Both focus on AC protection
DC Trip Threshold	Not explicit in UL CCID; modern CCIDs can integrate DC detection	RDC-DD trips ≥6 mA smooth DC; Type B covers AC + DC	EU explicitly addresses DC blinding
Response Time	≤25 ms (UL 2231-2)	≤300 ms depending on RCD type, <40 ms at 5x	UL faster trip requirement
Ground Continuity	Mandatory monitoring for CCID20	Not a separate RDC-DD function; ensured by installation	Different emphasis
Connector Standard	SAE J1772 (Type 1)	IEC 62196-2 (Type 2)	Different plug standards
Installation Rule	NEC Article 625	IEC 60364-7-722 / VDE 0100-722	Covers wiring & protective devices

The 6 mA DC Blinding Problem

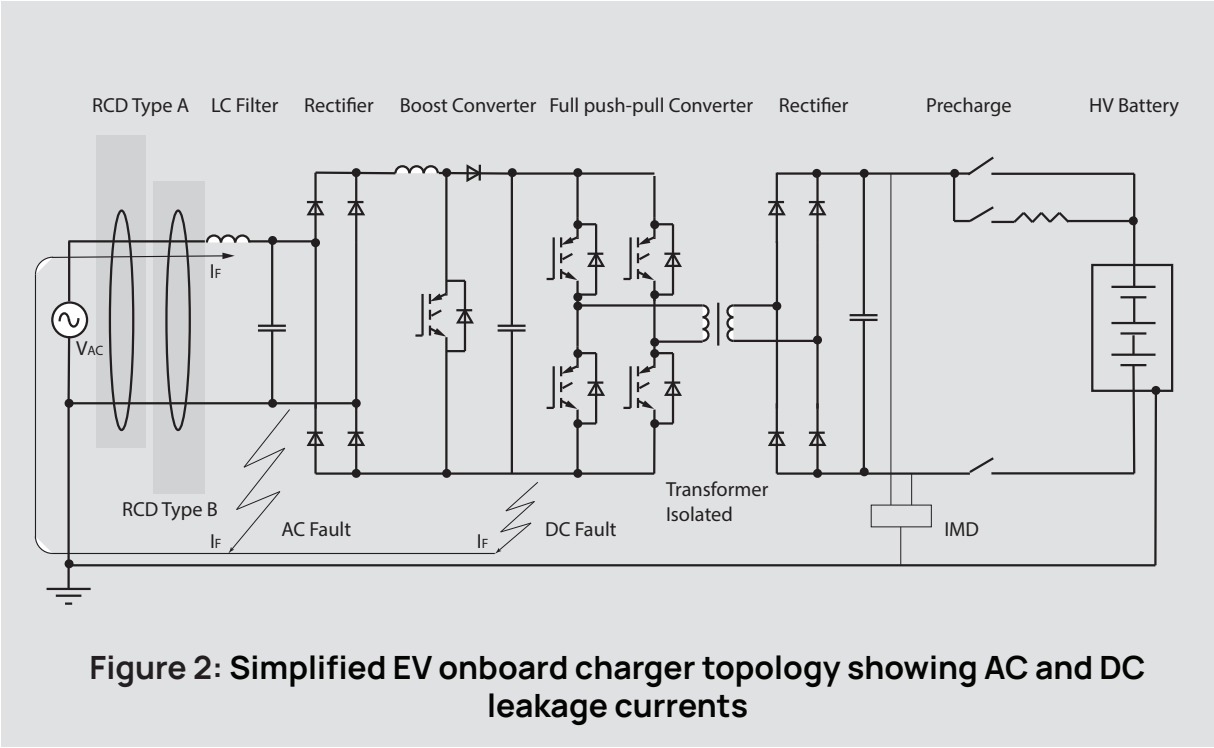
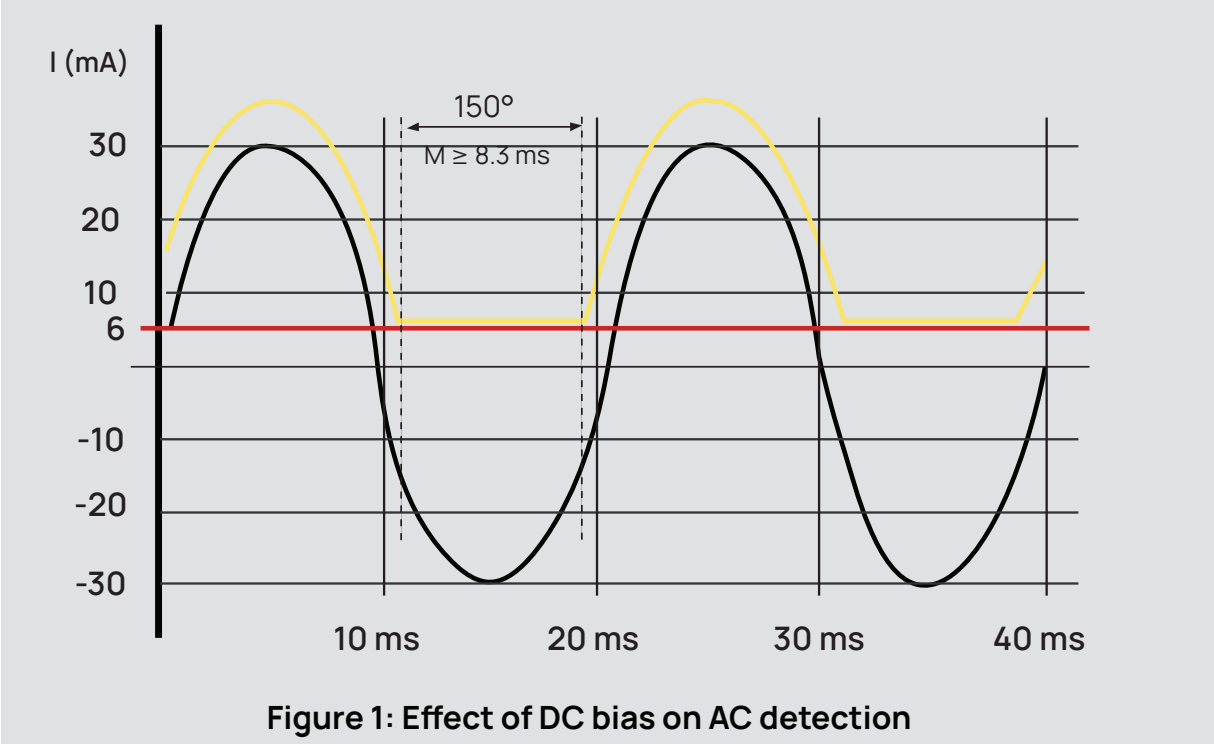
Type A ground-fault current devices and conventional GFCIs rely on magnetic current transformers to detect differential AC currents between phase conductors. Smooth DC ground-fault currents introduce a steady magnetizing force that drives the transformer core into saturation. Once saturated, the sensor’s ability to accurately detect superimposed AC leakage is significantly degraded.

At DC leakage levels of approximately 6 mA and above, several adverse effects can occur: trip thresholds increase, response times are extended, and in severe cases the protective device may fail to trip entirely in the presence of a dangerous AC fault.

Sources of smooth DC leakage in EV systems include insulation degradation in onboard charger PFC stages, rectifier leakage paths, and EMI suppression networks. When these currents are injected into the protective earth conductor, they can compromise not only the EVSE’s internal protection but also upstream installation-level RCDs.

Note: IEC 62955 defines a 6 mA smooth DC threshold to prevent blinding of upstream type A RCD.







Technology Approaches to DC Leakage Protection

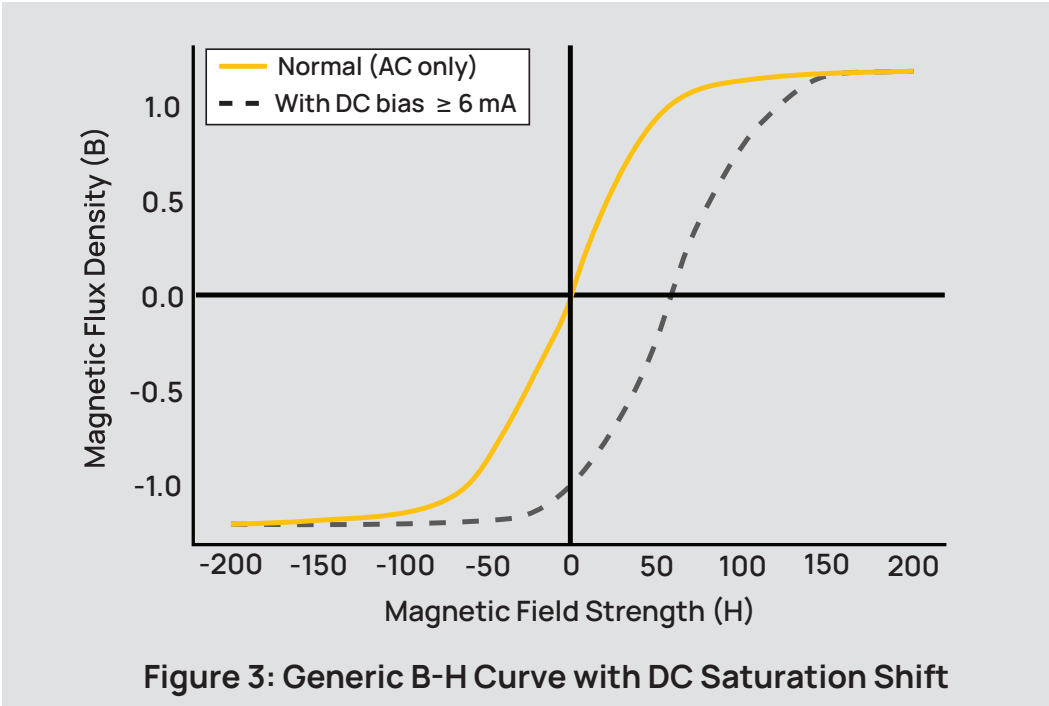
Two primary strategies are employed to mitigate the effects of DC leakage in EV charging systems.

Type A RCD with RDC-DD:

This approach retains a conventional 30 mA Type A RCD and supplements it with a dedicated RDC-DD that monitors for smooth DC leakage at a threshold of 6 mA. Upon detection, the EVSE controller disconnects the supply using contactors, thereby preventing DC blinding of upstream protection devices. This method offers cost efficiency and flexibility while meeting IEC 62955 requirements.

Type B RCD:

A Type B RCD integrates full AC and DC sensitivity using active electronic sensing and dual-core measurement techniques. It provides comprehensive protection across a wide frequency spectrum but at increased cost and reduced design flexibility compared to modular solutions.



Bender mA-CCID Circuit Technology

Bender's mA-CCID circuits and RCMB modules provide high-resolution detection of both AC and DC ground-fault currents. Key features include milliamperes-level sensitivity, integrated self-test functions, fail-safe outputs that default to a safe state on fault, and robust EMC immunity suitable for the electrically noisy EVSE environment.

In U.S. applications, Bender mA-CCID circuits can be integrated into CCID20 architectures with ground continuity monitoring to meet UL requirements while extending protection to DC leakage conditions. In EU applications, the same modules function as RDC-DDs in Type A + RDC-DD configurations or as part of functionally equivalent AC/DC protection solutions. This enables OEMs to deploy a single hardware platform across multiple regions.





Application Scenarios

Residential EVSE in the U.S. typically employ CCID20 protection combined with ground continuity monitoring. Incorporating DC-sensitive detection improves robustness without altering the UL certification pathway.

Commercial EVSE installations in Europe commonly use a 30 mA Type A RCD coordinated with an RDC-DD. Bender RCMB modules provide compliant DC detection while allowing the EVSE to control disconnection.

Premium or global installations may adopt Type B protection strategies to simplify installation at higher upfront cost.

Conclusion

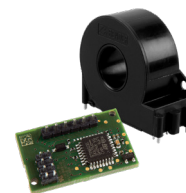
Ground-fault current protection in EV charging systems has evolved beyond simple detection of 50/60 Hz leakage. Smooth DC ground-fault currents pose a real and measurable risk to conventional protection devices.

Although the U.S. and EU regulatory frameworks differ in structure, both ultimately require reliable detection and disconnection at sensitive milliamperes levels. Bender's mA-CCID circuit technology enables EVSE manufacturers to address this challenge with a unified, future-proof design approach that reduces certification risk and enhances user safety.





	Dimensions	Supply voltage	Standards	Switching threshold		Bender Article Number
Variant 4-N4641-				X6	X30	Bender article
X900 RCMB121-1	49.45 mm (Length) 34.3 mm (Width) 13.95 mm (Height)	DC 5 V +/- 0.1	V IEC62752	6mADC+30mArms	30m Arms (info)	B94042490
X901 RCMB121-2			UL2231	5mArms (CCID5)	20mArms (CCID20)	B94042491
X903 RCMB121-3			EC62752 or UL2231	6mADC+30mArms	20mArms	B94042492
X904 RDC121-4			IEC62955	6mADC	6mADC (Info)	B94042493
X920 RCMB123-1			IEC62752	6mADC+30mArms	30m Arms (info)	B94042470
X922 RDC123-4			IEC62955	6mADC	6mADC (Info)	B94042473
Variante 4-N4641-				IEC	UL	Bender article description
X803 RCMB121-3S	49.45 mm (Length) 34.3 mm (Width) 13.95 mm (Height)	DC 5 V +/- 0.1	IEC62752 UL2231	6mADC+30mArms	20mArms (CCID20)	B94042449
X804 RDC121-5S			IEC62955 UL2231	6mADC	20mArms	B94042448
X836 RDC125-5S	Not finalized	DC 5 V +/- 0.1*	IEC62955 UL2231*	6mADC*	20mArms (CCID20)	B94042450 *Preliminary
X825 RDC123-5S	49.45 mm (Length) 34.3 mm (Width) 13.95 mm (Height)	DC 5 V +/- 0.1	IEC62955 UL2231	6mArms	20mArms (CCID20)	B94042478
X820 RCMB123-1S			IEC62752	6mADC+30mArms	30mArms (Info)	B94042475
PCB Solution				Switch 2	Switch 1	
RCMB104-1	PCB 28.00 mm (Length) 17.41 mm (Width) 6.5 mm (Height) CT 52.7 (Length) 20.8 mm (Width) 43.5 mm (Height)	DC 5 V +/- 5 %	IEC62752	6mADC+30mArms	30mArms (Info)	B94042480
RCMB104-2			UL2231	5mArms (CCID5)	20mArms (CCID20)	B94042481
RDC104-4			IEC62955	6mADC	6mADC (Info)	B94042483
RCMB104-3M			IEC62752 UL2231-2	6mADC+30mArms	20mArms (CCID20)	B94042484
RDC104-5M			IEC62955 UL2231-2	6mADC	20mArms (CCID20)	B94042487



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