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CharIN e.V. – Maximizing Interoperability with certified Conformance Tests

Michael Keller [1], Jesús Gallego1[1]

[1]*CharIN Academy GmbH, EUREF-Campus 10-11, 10829 Berlin, Germany, coordination@charin.global*

Executive Summary

This paper outlines a structured framework for minimum conformance and interoperability testing for Electric Vehicles (EVs) supporting AC and DC charging. Aligned with standards like DIN 70121, ISO 15118-2/-3, SAE J1772, IEC 61851-x, and ISO 17409, the framework ensures fundamental requirements and seamless interoperability. Key areas include basic signaling, high-level communication, and connectors Combined Charging System (CCS) Type 1 and CCS Type 2. The testing protocol involves five stages: identifying test cases, developing specifications, defining new test cases, test cases validation, and defining certification specification.

CharIN has long championed EV interoperability through initiatives such as the Testivals, where cross-industry collaboration ensures systems work harmoniously. The Test Conformance represents the next major global step—transforming collaborative learnings into a standardized certification process. With a clear prioritization between interoperability assurance and full standard conformance, this program positions CharIN at the forefront of enabling a consistent, reliable, and scalable EV charging ecosystem worldwide.

Keywords: Electric Vehicles, Standardization, AC & DC Charging technology, V2I (Infrastructure) Communication, International Networking

1 Introduction

The Charging Interface Initiative e.V. - abbreviated to CharIN e. V. - is a registered non-profit association founded in 2015 to promote Combined Charging System (CCS) as a standard worldwide, to define requirements for the evolution of CCS related standards and for the certification of CCS based products, besides the development of the Megawatt Charging System (MCS). Since then, the association has grown to more than 300 international members along the whole e-mobility value chain.

Under the CharIN umbrella, cross-industry stakeholders like automakers, charging station manufacturers, component suppliers, energy providers, grid operators, and many others continue moving towards

interoperable charging, where vehicles, chargers, and software systems work together and to make the user experience reliable, easy and smooth.

Through years of hosting global Interoperability Testivals, CharIN has played a critical role in validating the interaction between EVs and EVSEs in real-world scenarios. Based on that, the next major step is the introduction of a globally recognized EV Conformance and Interoperability Program. This program formalizes lessons learned from Testivals into a structured testing and certification framework—ensuring not just interoperability, but also conformance to standards, closing existing gaps, and strengthening the reliability and consistency of EV charging worldwide.

2 Main Goals

Within this environment, where EV market diversifies, and with it, potential interoperability incidents increase, CharIN focus its efforts in developing and certifying Conformance test cases for EVs and EVSEs, supporting AC and DC charging. These tests are aligned with, and in addition to, the specifications outlined in the DIN 70121 [1] and ISO 15118-2/-3 standards [2] [3], alongside associated standards such as SAE J1772 [4], SAE J3400 [5], IEC 61851-x [6], IEC 62196-x [7], ISO 17409 [8], and ISO 5474-x [9]. The proposed framework aims to ensure that fundamental interoperability requirements are met, providing a foundation for seamless integration across diverse systems.

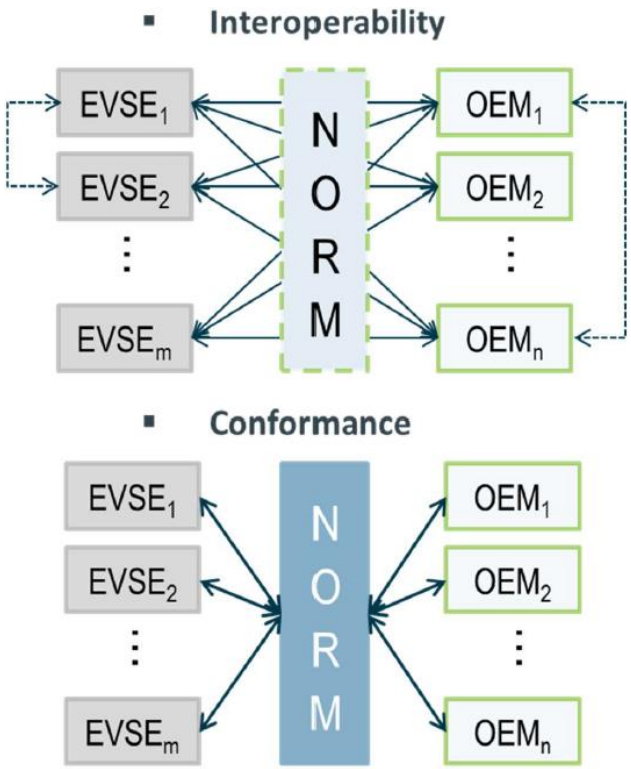

Figure 1: Testing scenarios (interoperability vs. conformance)

The primary objectives of the proposed Conformance and Interoperability Program include the following areas: Basic Signaling covering Basic CP, Emergency Shutdown, Proximity Pilot (PP) Interruption and Restart Process; and Charging Hight Level Communication (ISO15118) covering Secure Layered Architecture Communication (SLAC), Service Discovery Protocol (SDP), and Vehicle-to-Grid (V2G) communications.

With these goals in mind, CharIN has developed the EV Conformance and Interoperability Program to provide a structured, standardized approach for testing and certifying interoperability across various EVs and EVSEs. This framework will ensure that the defined goals are systematically addressed through a series of phases, each focusing on specific aspects of EV conformance.

The conformance program also lays the foundation for the next major milestone in CharIN's mission: product certification. Once the conformance test cases are fully defined and validated, products such as EVs and EVSEs will be eligible to undergo certification testing. Successful completion of this process will grant manufacturers the CharIN Conformance Label—a trusted mark of verified interoperability and quality. This label will not only support clearer product differentiation in the market but also reinforce end-user confidence and help drive widespread adoption of reliable, standardized charging solutions worldwide.

3 EV Conformance and Interoperability Program Framework

The EV Conformance and Interoperability Program is designed to establish a standardized and certified approach that ensures robustness, repeatability, and reliability in EV charging technology. This structured framework fosters a comprehensive ecosystem where EVs and EVSEs achieve seamless communication and operation. While the test cases are aligned with key international standards, they also go beyond to address gaps, clarify grey areas, and ensure that interoperability is not just theoretical—but proven and certifiable in practice. This approach elevates the program from standard compliance to a true interoperability conformance test. The program is composed of five key phases.

3.1 Identifying Appropriate Tests

The foundation of the program begins with identifying and selecting the necessary conformance and interoperability tests that mostly go beyond existing standards. While key industry standards such as ISO 15118-4/-5 [10] [11] and IEC 61851-23 serve as essential references for interoperability and safety requirements, the program also considers Basic Signaling. Since fundamental signaling protocols are already well-defined, distinct conformance tests may not be required for basic functionalities. Relevant protocols include SAE J1772 (North American AC and DC charging communication), SAE J3400 (North American Megawatt Charging System - MCS), IEC 61851-1 (General Requirements for conductive charging systems), IEC 62196-x (EV connector and plug standards), IEC 61851-21-1 (Electromagnetic Compatibility Requirements) and ISO 5474 & ISO 17409 (Safety requirements for in-vehicle charging systems).

These standards serve as benchmarks to ensure consistency and interoperability across various EV and EVSE manufacturers. The program will also identify additional areas where specific testing requirements are needed beyond the scope of current regulations to address evolving technological advancements.

3.2 Specification Development

Once the necessary tests have been identified, the next crucial step is the development of detailed specifications that outline the required interactions, signals, and response mechanisms. These specifications provide the clear guidelines needed to ensure uniformity and reliability in testing across all stakeholders.

To promote a unified approach, CharIN will publish an EV Extended Conformance and Interoperability Specification. This document will outline agreed-upon test cases that guarantee high-level Conformance and Interoperability for all stakeholders in the EV charging ecosystem.

The specification will define key elements such as:

- Expected Interactions: Standardized messages and commands between EVs and charging stations.

- Communication Signals: Defining acceptable ranges, timing constraints, and error handling.
- Fault Response Mechanisms: Ensuring the system responds appropriately to critical errors or unexpected conditions.

By clearly defining these parameters, manufacturers, developers, and certification bodies will have a precise reference to ensure compliance with interoperability requirements.

3.3 Developing New Test Cases

While the specifications provide a foundation for testing, there are areas where existing standards do not fully address the complexities of emerging EV technologies. To close these gaps, CharIN is developing new, comprehensive test cases that account for advanced functionalities and new charging systems: the CharIN EV Extended Conformance and Interoperability Test Cases. These cases will specifically address:

- Error Handling Mechanisms: Ensuring EVSEs and EVs properly respond to disruptions such as power fluctuations, communication errors, and hardware failures.
- Advanced Operational Modes: Verifying compatibility with features like vehicle-to-grid (V2G), bidirectional charging, and high-power charging scenarios.
- New Connector and Protocol Configurations: Developing tests for emerging standards, such as Megawatt Charging Systems (MCS) and other evolving DC fast charging architectures.

The development of test cases, particularly for emerging functionalities, is essential to keep pace with rapidly evolving EV technology. As technology advances, these test cases will be continuously refined to reflect the latest industry needs and innovations.

3.4 Test Validation

After developing these new test cases, it is crucial to validate them through real-world testing to ensure they accurately reflect the conditions under which EVs and EVSEs operate. The Test Validation phase is designed to assess the reproducibility, performance, and fault tolerance of the proposed test scenarios. The validation process will focus on:

- Reproducibility: Ensuring that test results remain consistent across different testing environments and hardware implementations.
- Best-Case Performance Testing: Verifying that systems operate optimally under normal conditions.
- Fault Tolerance Assessments: Simulating challenging conditions (e.g., sudden disconnections, high electrical loads, degraded communication links) to test system resilience.

Validation processes will be conducted in collaboration with industry partners, testing laboratories, and manufacturers to provide an industry-wide standard for conformance testing.

3.5 Certification Specifications

To facilitate industry-wide adoption and recognition, CharIN will develop and publish Certification Specifications that enable independent third-party testing and certification services. These specifications will allow manufacturers, regulators, and other stakeholders to:

- Streamline Testing Activities: Provide clear guidelines for laboratories and test houses to conduct standardized assessments.
- Ensure Quality and Safety Compliance: Maintain a rigorous and reliable certification process that aligns with international safety and performance benchmarks.
- Support Regulatory Acceptance: Enable easier adoption of standardized certification processes within national and regional regulatory frameworks.

By implementing a structured certification approach, the program will enhance the confidence of consumers, businesses, and policymakers in the reliability and compatibility of EV charging systems.

4 Standard Prioritization and Testing Criteria

To maintain a focus on the most impactful aspects of interoperability, CharIN has categorized test cases into different priority levels. This prioritization ensures that the most critical scenarios are addressed first, enabling manufacturers to concentrate on the areas that will most significantly impact real-world interoperability.

After review and analysis by the experts in testing and real field testing, Test Cases are divided into two levels based on safety, operational relevance, and real-world application. to align with the program's objectives:

- Priority 1 (Best Interoperability): tests in this category are vital for robust interoperability and are focused on cases with high safety implications or high likelihood of occurrence in the field. Scenarios in this category include robustness testing for expected operational cases, which carry more weight than error cases, and critical error handling tests that prioritize user safety. Tests of this priority aim to guarantee seamless interaction across varied EV charging infrastructure setups.
- Priority 2 (Full Standard Conformance): these tests complement Priority 1 by addressing less likely field scenarios and repetitious error cases that may affect device certification but have minimal impact on interoperability. Priority 2 encompasses error scenarios unlikely to occur under standard conditions and repetitive failure injections for response consistency. This prioritization helps manage resource allocation, focusing on the most impactful cases for interoperability while still addressing full standard conformance.

5 Interoperability Test Cases

Building upon the prioritization criteria outlined in the previous section, CharIN focuses its efforts on testing the scenarios that are most critical for ensuring interoperability. To maximize interoperability, only Priority 1 Test Cases must be considered. The primary objective is to define the minimum number of test cases that ensure the highest level of interoperability in real-world scenarios, with a target success rate of at least 95%. To achieve this, CharIN experts have analyzed all current standards, and selected test cases that align with these goals. In cases where the standards' test cases demonstrated gaps—manifested as interoperability failures in the field—these were evaluated, and new specifications (CharIN Test Cases) were defined. CharIN experts span across vehicle manufacturers, EVSE manufacturers, and testing systems (vendors and testing entities). These experts are involved not only in standardization bodies but also in the development, testing, and certification of vehicles.

When gaps are identified and new specifications are defined in CharIN Test Cases, these are presented to the relevant standardization bodies (such as ISO, DIN, SAE, etc.) for discussion and incorporation in future revisions of the standards

5.1 High Level Communication Test Cases

The following CharIN implementation guides cover high-level communication protocols and are based on key standardization documents:

- Implementation Guide to DIN SPEC 70121:2014 [12]
- DC CCS Power Classes [13]

These guides cover the following topics:

- Secure Layered Architecture Communication (SLAC)
- Service Discovery Protocol (SDP)
- Vehicle-to-Grid (V2G) communications
- Plug & Charge (PnC)
- External Identification Mean (EIM)

The test cases have been developed based on the following standardization documents:

- DIN SPEC 70122 Ed1:2018 Communication Test Cases
- ISO 15118-4:2018
- ISO 15118-5:2018
- IEC 61851-1 Ed.3, Annex A.4
- IEC 61851-23 Ed.2
- SAE J1772:2024

Additionally, CharIN has drafted the following Test Case documents to cover existing gaps:

- Test Cases for DIN SPEC 70121:2014 Implementation Guide [14]
- Test Case Modification Guide [15]

Based on the information above, Table 1 summarizes the areas covered by Priority 1 Test Cases, ensuring maximum interoperability in the High-Level Communication area.

Table 1: Interoperability Test Cases- High Level Communication

Test Case ID
SLAC process (common for both DIN and ISO - based on 15118-5 and DIN 70122-2018)
SDP process (common for both DIN and ISO)
DIN 70121 V2G (DIN 70122 and CharIN DIN V2G)
ISO V2G - EIM (ISO 15118-4)
ISO V2G – PnC (ISO 15118-4)

5.2 Basic Signaling Test Cases

The guideline CharIN EV Conformance Test Specification for Basic Signaling [16], covers the following topics:

- CP Basic Test Cases
- Communication Pause initiated by SECC within different phases of charging
- TCP closing within different phases of charging
- EVSE initiated restart of sleeping EV
- Emergency Shutdown initiated by EVSE within different phases of charging
- Proximity Pilot Interruption initiated by EVSE within different phases of charging

This guideline has been developed based on the following standardization documents:

- SAE J1772:2024
- IEC 61851-1 Ed. 3
- IEC 61851-23 Ed. 2

- ISO 15118-2 Ed.1
- ISO 15118-3 Ed.1
- DIN SPEC 70121:2014

Based on this, Table 2 summarizes the areas covered by Priority 1 Test Cases, ensuring maximum interoperability in the Basic Signaling area.

Table 2: Interoperability Test Cases- Basic Signaling

	Test Case ID
Emergency Shutdown	During Cable Check
	During Pre-Charge
	During Energy Transfer Stage
	Special Emergency Shutdown Test Case
Restart Process	Using just one restart method (B1 -> B2, B1 -> E -> B1 -> B2 or B1 -> F -> B1 -> B2)
	Using restart method loop one time
	Using restart method loop a multiple time
Basic CP Test Cases	Stability of normal charging process during variation of values
	Consider high OP and low OP
Pause Methode	Before Cable Check
	Before Energy Transfer
	During Energy Transfer

Once the interoperability of EVs and EVSEs is rigorously tested, the final step in the process is product certification. This phase ensures that products meet the required standards and are recognized for their high level of interoperability.

6 Product Certification

Once the analysis of the Priority 2 Test Cases is completed and integrated into the previous lists of test cases, validated for consistency, the EV Conformance and Interoperability Program will be ready to move on to its final phase: product certification.

For product certification to be granted (for both EVs and EVSEs), a system of certified test laboratories is necessary. To this end, a cross-certification process for test labs, which must utilize certified test equipment, is established.

Cross-certified test labs will be able to conduct the certification tests based on the conformance test specifications, utilizing certified test equipment. If products (EVs and EVSEs) successfully pass the certification tests, the Conformance Certification Label can be applied to the product.

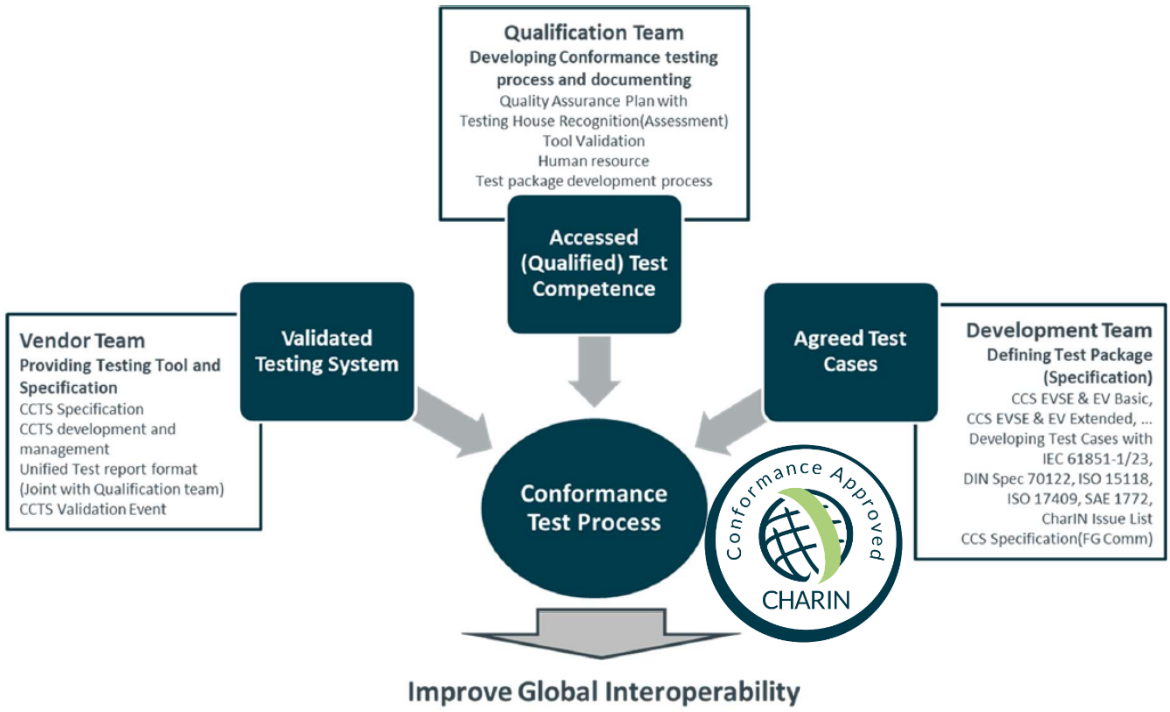

Figure 2: Building blocks of the Conformance Test process of CharIN and its Conformance Certification Label

With this label, the products can be clearly identified at being on the highest level of interoperability and the label can be used for example in RFQs for improving the quality and customer satisfaction in the field.

7 Conclusions

The rapid advancement of electric vehicle technology and the growing demand for reliable and interoperable charging systems have underscored the importance of standardized conformance and interoperability testing. The EV Conformance and Interoperability Program, spearheaded by CharIN, plays a critical role in addressing these challenges by developing a structured framework for ensuring seamless communication and compatibility between EVs, EVSE and related infrastructure.

Through the CharIN Conformance Testing Program, we are identifying relevant test cases, developing new specifications to address emerging gaps, and validating these test cases in real-world conditions. This approach drives innovation while ensuring that EVs and charging stations from different manufacturers can seamlessly interact. The program is focused on delivering a certification that can be placed on each EV and EVSE that has passed the Conformance Testing process, signaling to customers where they can charge easily and reliably according to the highest Conformance Testing standards. By setting clear priorities for testing—especially focusing on high-impact scenarios that affect user safety and operational reliability—the program aims to achieve a high success rate in real-world deployments, benefiting both consumers and industry stakeholders.

Moreover, the certification of products with CharIN's Conformance Certification Label will help foster greater trust in the EV charging ecosystem. This certification not only guarantees a high level of interoperability but also aids in streamlining the certification process for manufacturers, regulators, and other stakeholders. As the EV market continues to evolve, CharIN's commitment to advancing standardization, testing, and certification ensures that the global electric mobility ecosystem remains connected, efficient, and ready for the challenges of the future.

In conclusion, CharIN's Conformance and Interoperability Program represents a crucial step toward a more integrated, robust, and sustainable electric mobility infrastructure. By aligning stakeholders across industries and promoting best practices, CharIN is helping to shape a future where EVs and charging systems are fully interoperable, driving the global transition toward clean, sustainable transportation.

Acknowledgments

We extend our gratitude to the members of CharIN's Focus Group Test Conformance & Interoperability for their contributions to the EV Conformance and Interoperability Program. Their collaborative efforts have been essential.

Nomenclature

AC - DC: Alternating current - Direct Current

CCS: Combined Charging System

CP: Control Pilot

EIM: External Identification Mean

EVSE: Electric Vehicle Supply Equipment

EV: Electric Vehicle

MCS: Megawatt Charging System

PnC: Plug & Charge

SECC: Supply Equipment Communication Controller

SLAC: Secure Layered Architecture Communication

SPD: Service Discovery Protocol

SUT: System-under-test

TCP: Transmission Control Protocol

V2G: Vehicle-to-Grid

References

[1] DIN/TS 70121:2024-11 *Electromobility - Digital communication between a d.c. EV charging station and an electric vehicle for control of d.c. charging in the Combined Charging System.*

[2] ISO 15118-2:2014 *Road vehicles — Vehicle-to-Grid Communication Interface. Part 2: Network and application protocol requirements.*

[3] ISO 15118-3:2014 *Road vehicles — Vehicle to grid communication interface. Part 3: Physical and data link layer requirements.*

[4] SAE J1772 *SAE Electric Vehicle and Plug-in Hybrid Electric Vehicle Conductive Charge Coupler*

[5] SAE J3400 *North American Charging System (NACS) for Electric Vehicles*

[6] IEC 61851-x *Electric vehicle conductive charging system (Parts 1, 3, 21, 23, 24 and 25)*

[7] IEC 62196-x *Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles (Parts 1 to 6).*

[8] ISO 17409:2020 *Electrically propelled road vehicles — Conductive power transfer — Safety requirements*

[9] ISO 5474-x *Electrically propelled road vehicles — Functional and safety requirements for power transfer between vehicle and external electric circuit (Part 1 to 6).*

[10] ISO 15118-4:2018 *Road vehicles — Vehicle to grid communication interface. Part 4: Network and application protocol conformance test*

[11] ISO15118-5 :2018 *Road vehicles — Vehicle to grid communication interface. Part 5: Physical layer and data link layer conformance test*

[12] *CharIN Implementation Guide to DIN SPEC 70121:2014*

[13] *CharIN DC CCS Power Classes, Version 6, 2018-06-24*

[14] CharIN Test Cases for DIN SPEC 70121:2014 Implementation Guide, *Version 1.1.3 2021*

[15] CharIN Test Case Modification Guide, *Version v0.1.0*

[16] CharIN EV Conformance Test Specification for Basic Signaling, *Version 0.1.0*

CharIN e.V., www.charin.global, accessed on 2025-04-11

CharIN e.V., https://www.charin.global/technology/charin-conformance-testing/, accessed on 2025-04-11

Presenter Biography

Michael Keller is Chief Technology Officer (CTO) of the Charging Interface Initiative (CharIN) e. V. and CEO of the CharIN Academy GmbH.
Michael Keller brings over 20 years of experience in leadership roles, including 14 years in the Volkswagen Group. As a co-founder of CharIN e. V. and long-time Executive Board member and treasurer, Michael has played an instrumental role in shaping the association's direction.
Michael Keller received his engineer degree for electric in Karlsruhe and was awarded with the "Professor Ferdinand Porsche Preis" of the Technical University in Vienna in 2009 for the "first automotive application of a lithium-ion hybrid battery".

Jesús Gallego is Technical Project Manager of the CharIN Academy GmbH, where he leads the initiatives related to Conformance Testing and Interoperability in the e-mobility sector. With extensive experience in project management across automotive manufacturing, IT solutions and cybersecurity, he has successfully driven technical developments and global collaborations.
Jesús Gallego earned a PhD in Mechanical Engineering from the University of Zaragoza in 2012, with a doctoral dissertation titled: *'Development of Design Optimization Criteria for Efficient Infrastructures for Electric and Hydrogen Vehicles.*