VEHICLE INTEROPERABILITY
TESTING SYMPOSIUM

VOLTS 2023
TESTING EVENT DATA REPORT

Outcomes, Challenges, and Next Steps

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Executive Summary

This report summarizes interoperability test data collected at the Vehicle Interoperability Testing Symposium (VOLTS) 2023 testing event held in Long Beach, California, on May 10 and 11, 2023. The event, funded by the California Energy Commission's Clean Transportation Program, was implemented by CharIN, innos Inc., and other partners, which have a long history of hosting CharIN Testivals.

VOLTS was designed to support product development and standards implementation in a collaborative, low-risk environment to move toward an interoperable charging ecosystem. VOLTS convened electric vehicle (EV) stakeholders to conduct interoperability tests, develop and finalize products, conduct implementation testing and test tool development for charging standards and protocols, and discuss means to overcome common technology barriers facing the industry. These stakeholders included, but were not limited to, electric vehicle supply equipment (EVSE) manufacturers, automotive original equipment manufacturers (OEMs), and EV software and network providers. By gathering all of these stakeholders together, VOLTS supported rapid protocol testing and validation of many combinations of products, and provided an invaluable resource for product development and standards implementation. [1] The VOLTS testing symposium was designed to troubleshoot products at any stage of development and help determine if the equipment is ready to move on to conformance testing and commercialization.

VOLTS participants were paired up to conduct pre-defined interoperability test scenarios. For every test session, participants submitted the outcome of the test scenario using a survey form. For every test session, the partners agreed on which party would be responsible for submitting the test survey. All data were anonymized and processed for this report. Because the process to protect the anonymity of testing results required validation to be completed by the paired testing submitter, quality assurance of post-submission aggregate testing data was limited.

All EVs and EVSE supported the CCS Type 1 connector for DC charging, the SAE J1772 connector for AC charging, or both. By design, the VOLTS Testing Symposium was scoped to focus on ISO 15118 intra-protocol testing to ensure interoperable implementations of ISO 15118 communication between EVSEs and EVs. This includes secure communication, such as certificate handling, to ensure secure and interoperable Public Key Infrastructure (PKI). A few key statistics and takeaways from the Testing Symposium include:

- Over the course of 2 days, across 7 test slots, 174 EV-EVSE pairings occurred, with each pairing lasting for two hours.
- Collectively, over 1,000 individual tests were performed and more than 50% of all tests used ISO 15118 communication.
- More than 80% of the attempted charging sessions resulted in successful charging. This is notable, as the event included production, prototype/pre-production systems for vehicles and charging systems.
- A relatively modest number of successful Plug and Charge (PnC) tests were reported due to time constraints or because the equipment was not prepared for the test scenario.

[1] California Energy Commission, "Request for Proposals Vehicle Interoperability Testing Symposium (VOLTS)," October 2021 https://www.energy.ca.gov/sites/default/files/2021-10/00_RFP-21-601_VOLTS_Solicitation_Manual_Addendum_01_ada_0.docx

- ISO 15118-2 smart charging capabilities are not yet widely implemented or used in EVs and EVSEs to date. This could be due to a number of factors including the lack of market signals or the use of alternate data routes beyond ISO 15118, such as telematics.

Three key next steps are recommended in this report:

1. **Consistently performing conformance testing and certification:** If conformance testing and certification is voluntarily (i.e., not mandated by regulators) and offers a standardized and scalable approach to ensure that EV and EVSE conform to protocol specifications, it could ensure that EV and EVSE interoperate. Other communication standards and industry associations, such as W-Fi and Bluetooth, have established best practices for conformance testing in certification. In both examples, third-party testing and certification schemes are used to qualify products and ensure a high level of interoperability.

2. **Making better use of smart charging capabilities of ISO 15118:** Future testing events could provide an improved platform to support testing of smart charging capabilities including crafted schedules, which may or may not include tariff information. These crafted schedules could be provided by a backend that is accessible to participants or are manually coded into EVSEs.

3. **Making improvements to future testing events:** Based on feedback from participants and observers, attendees recommended that CharIN:

    a. Continue to collect data to recognize the state of ISO 15118 implementation and interoperability gaps.

    b. Continue to implement a mandatory test plan or test script, but either reduce the number of testing scenarios or increase the length of the test sessions.

    c. Establish dedicated test slots/position for specific tests, such as manipulation of the EVs shift position, smart charging, PnC, etc.

    d. Improve the technical capability registration process to confirm that equipment can in fact support certain technical capabilities.

    e. Build out additional backend infrastructure for things like smart charge testing and PnC testing.

1. Introduction and Background

This report summarizes interoperability test data collected at the Vehicle Interoperability Testing Symposium (VOLTS) 2023 testing event held in Long Beach, California, on May 10 and May 11, 2023. The event, funded by the California Energy Commission's Clean Transportation Program, was implemented by CharIN, innos Inc., and supported by partners.

VOLTS was designed to support product development and standards implementation in a collaborative, low-risk environment to move toward an interoperable charging ecosystem. VOLTS convened key electric vehicle (EV) stakeholders to conduct interoperability tests, develop and finalize products, conduct implementation testing and test tool development for charging standards and protocols, and discuss means to overcome common technology barriers facing the industry. These stakeholders included but were not limited to: electric vehicle supply equipment (EVSE) manufacturers, automotive original equipment manufacturers (OEMs), and EV software and network providers. By gathering all of these stakeholders together, VOLTS supported rapid protocol testing and validation of many combinations of products and provided an invaluable resource for product development and standards implementation. [2]

1.1 Data Collection and Processing

VOLTS testing participants were paired up to conduct pre-defined interoperability test scenarios over the course of a test session (also referred to as "test slot"). For each test session, participants submitted the outcome of the test scenario using a survey form. For each test session, the testing partners agreed on which party would be responsible for submitting the test survey. All data were anonymized and processed for this report. Because the process to protect the anonymity of testing results required validation to be completed by the paired testing submitter, quality assurance of post-submission aggregate testing data was limited. No data elements were altered. In addition, certain data elements, such as the open text fields, were processed and grouped based on similar findings or observations reported by the participants. Any data that could be traced back to a particular participant were excluded from this report (such as freeform text responses).

In cases where submitted data appeared technically incorrect, a remark is provided. However, no data was altered.

Reported data for each test scenario is discussed in Section 4 Testing Scenarios. For a summary of findings based on the reported data, please refer to Section 5 Test Data Findings.

[2] California Energy Commission, "Request for Proposals Vehicle Interoperability Testing Symposium (VOLTS)," October 2021 https://www.energy.ca.gov/sites/default/files/2021-10/00_RFP-21-601_VOLTS_Solicitation_Manual_Addendum_01_ada_0.docx

1.2 Glossary and Acronyms

Words and acronyms that are frequently used in this document to describe the charging process or the outcome of testing are described here.

Basic charging (BC)	Charging controlled by IEC 61851-1 or SAE J1772 only. AC charging without high level communication.
BPT	Bidirectional Power Transfer.
Cable Check	Before charging the EVSE performs an isolation test. Once isolation has been established the EVSE will indicate “Valid” in the EVSEIsolationStatus Signal and set the EVSEProcessing Signal in the subsequent CableCheckRes message to “Finished”. The charging process will continue to Pre-charge.
CCS Type 1	Combined Charging System Type 1.
ChargeParameter	Maximum values to be used for charging. The EV and EVSE typically exchange its maximum values such as maximum voltage, current, power, state of charge available power. If there is no match between the exchanged parameters, the charging session may be terminated due lack of compatibility.
Charging session	For the purpose of this document, a charging session start at plug-in, successful charging for one minute or more, a session stops, and plug out.
DIN 70121:2014	Digital communication protocol between a direct current (DC) EVSE and an EV for control of DC charging with CCS.
EIM	External identification means – typically by using a Radio Frequency Identification (RFID) card or other form of external identification or payment terminal.
EVCC	EV communication controller.
Fail	The expected objective of the test has been achieved. It does not imply non-conformance with a standard.
ISO 15118-2:2014	Vehicle-to-Grid Communication Interface - Part 2: Network and application protocol requirements.
ISO 15118-20:2022	Vehicle-to-Grid Communication Interface — Part 20: 2nd generation network layer and application layer requirements.
ISO 15118-3:2015	Vehicle-to-Grid Communication Interface - Part 3: Physical and data link layer requirements.
Not applicable	The test or objective of the test cannot be executed. Reasons may include lack of support for the particular standard or function under test, lack of time, equipment not ready, or test partner not ready.

Pass	The expected objective of the test has been achieved. It does not imply conformance with a standard.
PKI	A public key infrastructure is a set of roles, policies, hardware, software, and procedures needed to create, manage, distribute, use, store and revoke digital certificates and manage public-key encryption.
PKI-1	Multiple root Certificate Authority
PKI-2	Single Vehicle-to-Grid (V2G) root Certificate Authority
PLC	Power Line Communication. Additional details are found in ISO 15118-3 or SAE J2934/4.
PnC	Plug (Park) and Charge. Authentication mechanism using certificates stored in the EV to automatically start a charging session upon plugging in the EV.
Pre Charge	After successfully completing cable check, the EV and EVSE process to the pre-charge sequence where the EVSE voltage will be adjusted within 20V of the battery voltage to reduce inrush current. The EV sends the requested target voltage to the EVSE. Once the EV deems the measured voltage at the terminals or inlet to be sufficiently close to the required value, the next sequence, Power Delivery, will be initiated by the EV.
SAE J1772-2017	SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler. Defines the type 1 connector.
SAE J2934/4-2014	Broadband PLC Communication for plug-in EVs.
SAEJ2847/2-2015	Communication Between Plug-In Vehicles and Off-Board DC Chargers.
SDP	SECC discovery protocol – The EVCC uses the SECC discovery protocol (SDP) to get the IP address and port number of the SECC. The SDP client (EV) sends out SECC discovery request messages to the local link (multicast) expecting any SDP server to answer its request with an SECC discovery response message containing this information.
SECC	Supply equipment communication controller.
SLAC	Signal level attenuation characterization, which is used to associate an EV to an EVSE.
TCP	Transmission Control Protocol. Additional details are found in RFC 9293.
TLS 1.2	Transport Layer Security version 1.2
TLS 1.3	Transport Layer Security version 1.3

2. Overview of Testing Event Participants

The testing event was open to EVSE (commonly called chargers, charging stations, or charging equipment), EVs, and dedicated test systems (used to test communication interoperability and conformance). Test systems may simulate an EV or EVSE.

EVSE may support AC charging, DC charging, or both. In addition, EVSE may support EV-EVSE communication using DIN 70121 (SAE J2931/4 2014-10 & SAE J2847-2), ISO 15118-2 & ISO 15118-3, ISO 15118-20 & ISO-15118-3, or a combination of these protocols. Typically, EVSE and EVs at VOLTS supported both ISO 15118-2/3 and the older DIN 70121 protocol (SAE J2931/4 2014-10 & SAE J2847-2).

EVSE and EVs at VOLTS supported either the CCS Type 1 connector for DC charging, the SAE J1772 connector for AC charging, or both.

DIN 70121 (SAE J2931/4 2014-10 & SAE J2847-2) is still the prevailing communication standard for DC charging on basis of external identification means (EIM). However, DIN 70121 only supports DC charging.

The VOLTS testing event was scoped to focus on ISO 15118 testing to ensure interoperable implementations of ISO 15118 communication between EVSE and EVs, including secure communication such as certificate handling using PKI.

The same physical and data link layer is used with DIN 70121, ISO 15118-2, ISO 15118-20, and is based on PLC as specified in ISO 15118-3.

2.1 Technical Capabilities of Participating EVSE

A total of 21 EVSE participated in the testing event. Of these, 6 of the EVSE supported AC charging and 15 EVSE supported DC charging.

All 21 registered EVSE supported external identification means (EIM), 18 registered EVSE supported ISO 15118-2, and 11 EVSE supported ISO 15118-2 with PnC.

In addition, 4 test systems participated acting as EVSE. All test systems supported AC and DC charging, ISO 15118-2/3, DIN 70121, EIM, and PnC. Two test systems additionally supported ISO 15118-20.

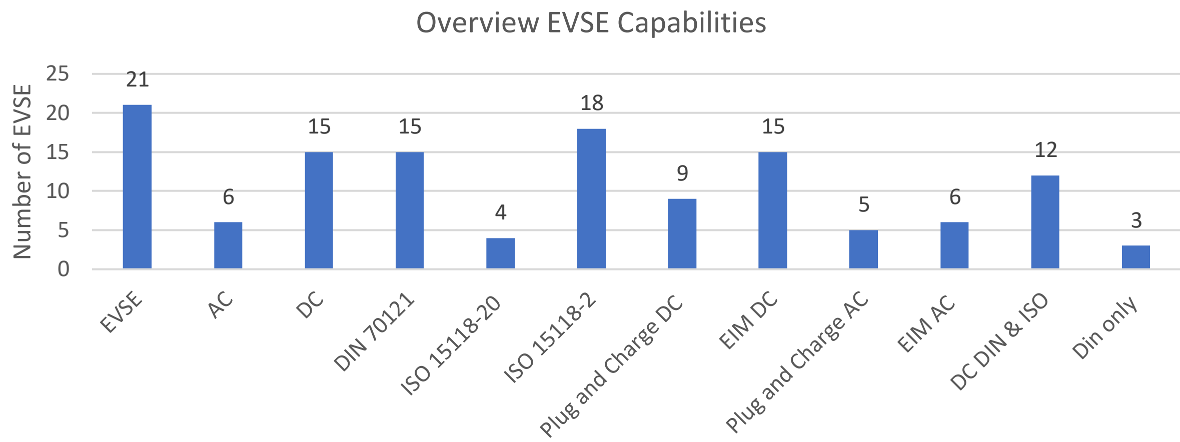

Figure 1 Overview EVSE Capabilities

2.1.1 DC EVSE Capabilities

15 DC EVSE models participated at VOLTS. Of these:

- 3 supported only DIN 70121.
- 12 supported ISO 15118-2 and DIN 70121.
- 9 featured PnC implementation using ISO 15118-2.
- 4 supported ISO 15118-20. This does not imply bi-directional charging capability.

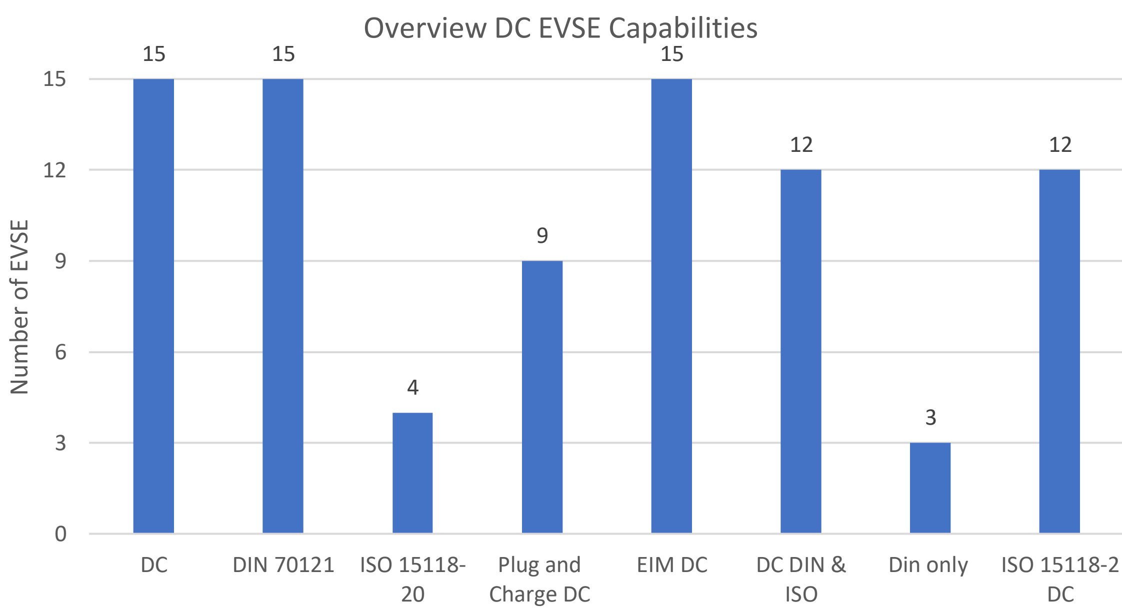

Figure 2 Overview DC EVSE Capabilities

2.1.2 AC EVSE Capabilities

6 AC EVSE models participated at VOLTS. Of these:

- All supported ISO 15118-2.
- 5 supported both EIM and PnC.
- 1 supported only EIM.

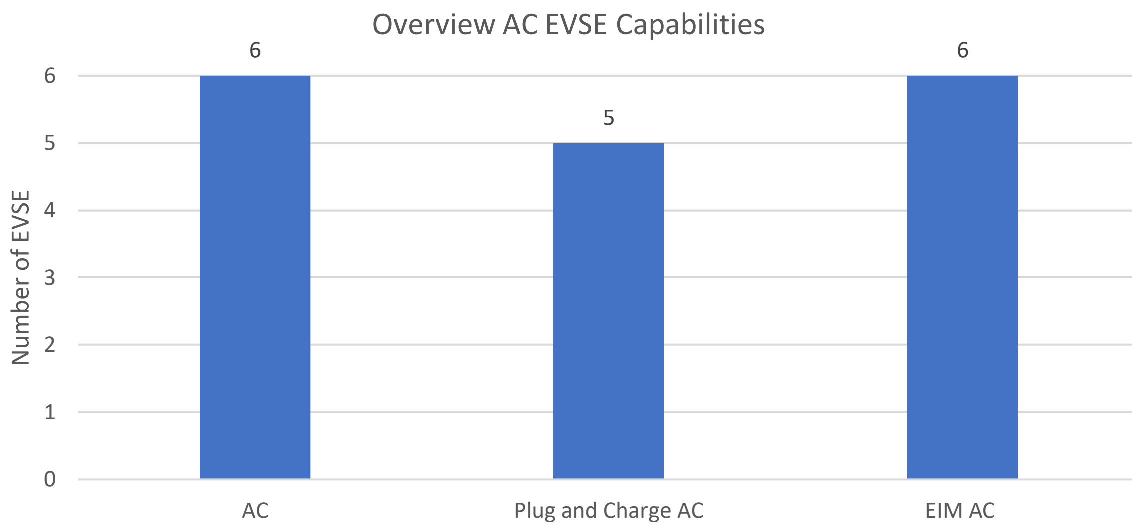

Figure 3 Overview AC EVSE Capabilities

2.1.3 EVSE Supporting ISO 15118-2

Out of 21 participating EVSE, 18 supported ISO 15118-2. All AC EVSE supported ISO 15118-2. While all EVSE supporting ISO 15118-2 supported at least EIM, 14 EVSE additionally supported PnC.

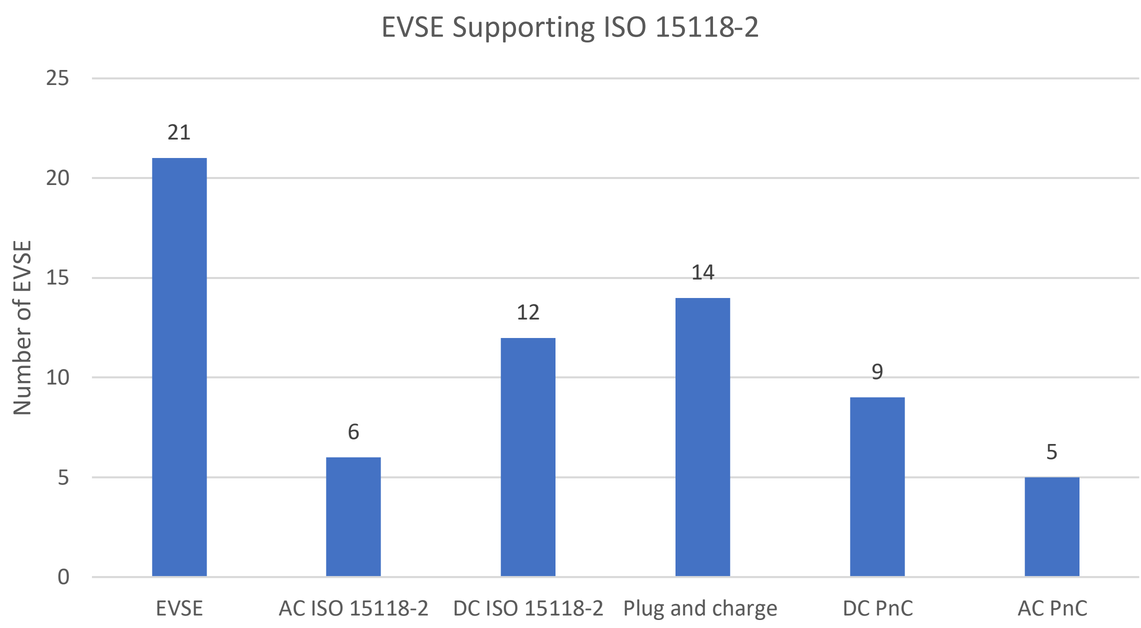

Figure 4 EVSE Supporting ISO 15118-2

2.1.4 EVSE Supporting ISO 15118-20

As shown in Figure 5, 4 EVSE registered support for ISO 15118-20. Of these, 2 were AC EVSE and 2 were DC EVSE.

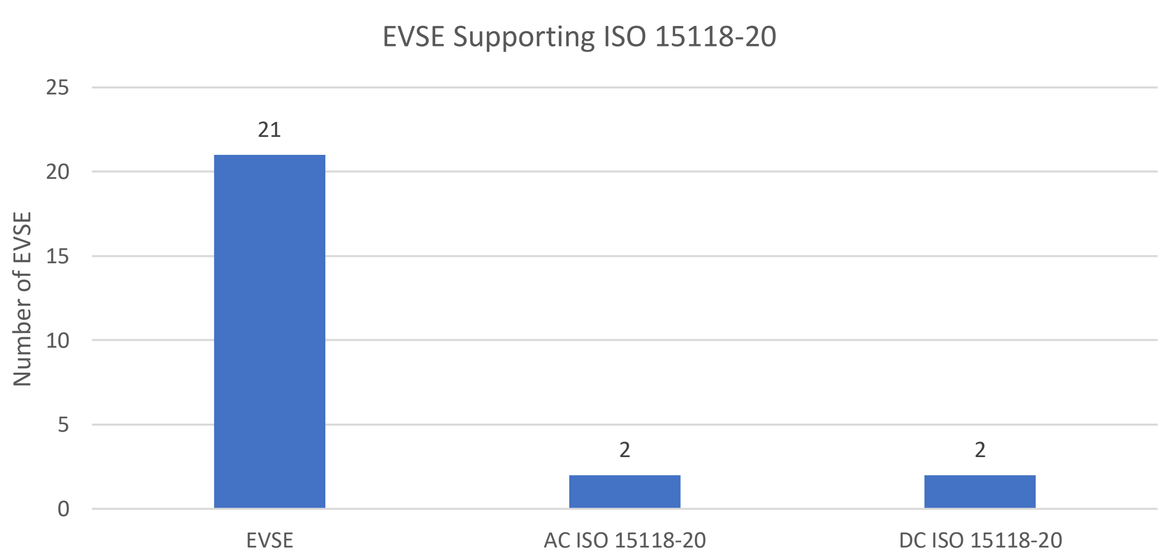

Figure 5 EVSE Supporting ISO 15118-20

2.2 Technical Capabilities of participating EVs

A total of 21 EVs participated in VOLTS. Of these:

- 20 supported DIN 70121 for DC charging.
- 17 supported ISO 15118-2.
- 1 supported only ISO 15118-2.
- 9 supported PnC for DC charging.
- 6 supported PnC for AC charging.

It is observed that, among participating EVs, school buses and other medium- and heavy-duty vehicles were more likely to have supported only DIN 70121.

AC testing with ISO 15118-2 had 10 participating EVs. All of these EVs participating in AC ISO 15118 testing supported EIM authentication and 5 EVs supported PnC for AC charging.

As shown in Figure 6, 2 EVs registered support for ISO 15118-20.

An additional 2 test systems participated in AC testing acting as the EV.

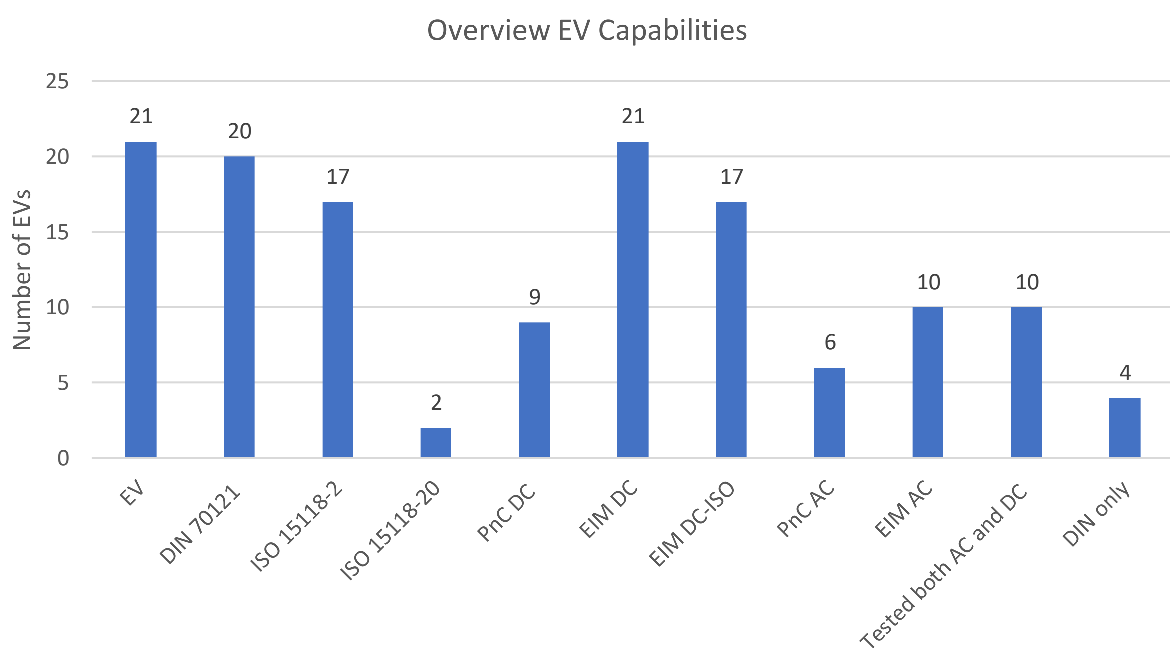

Figure 6 Overview EV Capabilities

2.2.1 EVs Supporting ISO 15118 -2

Of the 21 participating EVs, 17 supported ISO 15118-2. It is observed that, among participating EVs, school buses and medium- and heavy-duty vehicles were more likely to have supported only DIN 70121. Among those that supported ISO 15118-2, 9 of the EVs supported PnC for DC, and 6 supported PnC for AC. Note that, an EVSE supporting EIM does not necessarily support ISO 15118-2.

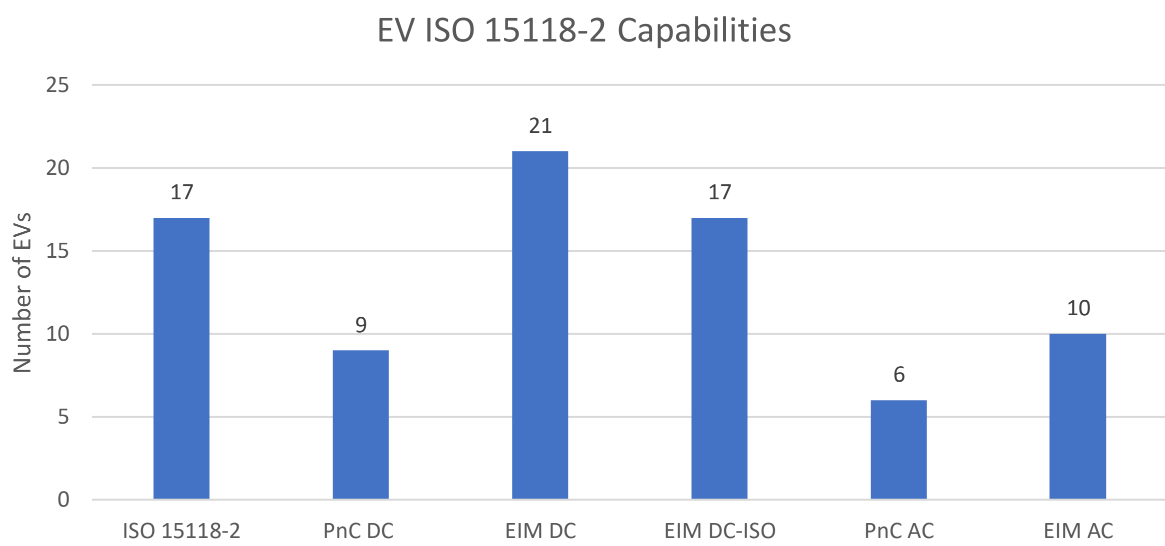

Figure 7 EV ISO 15118-2 Capabilities

2.2.2 EVs Supporting ISO 15118 -20

Out of 21 registered EVs, 2 EVs supported ISO 15118-20 including PnC.

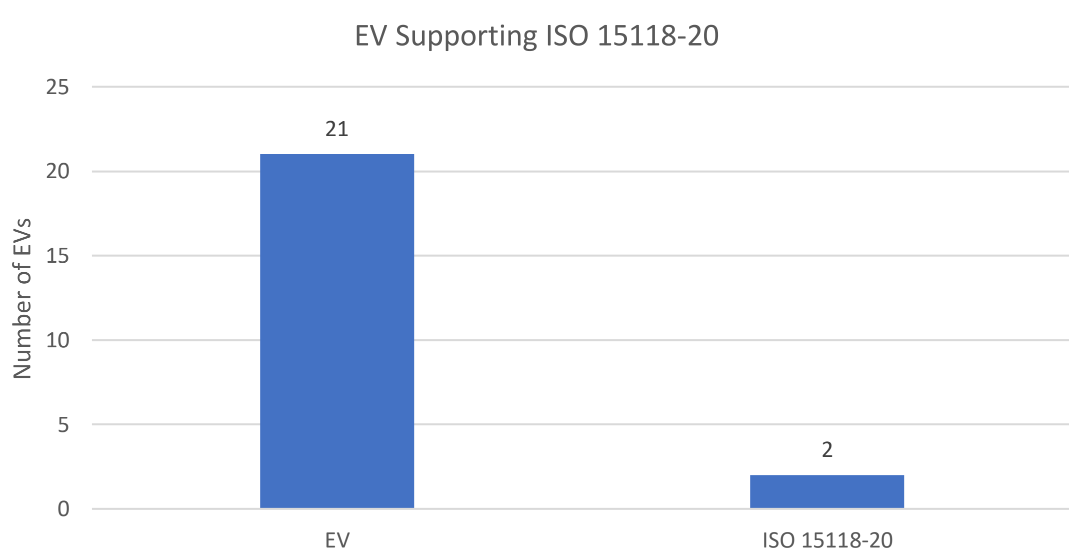

Figure 8 EV Supporting ISO 15118-20

2.3 Technical Capabilities of Participating Test Systems

Six test systems participated in the testing event simulating either an EV or EVSE. As shown in Figure 9, 2 test systems were registered as EV simulation (to serve as a test system for EVSE) and 4 test systems were registered as EVSE simulation (to serve as a test system for EVs). All test systems supported DIN 70121 and ISO 15118-2, including smart charging and PnC. Three test systems supported ISO 15118-20.

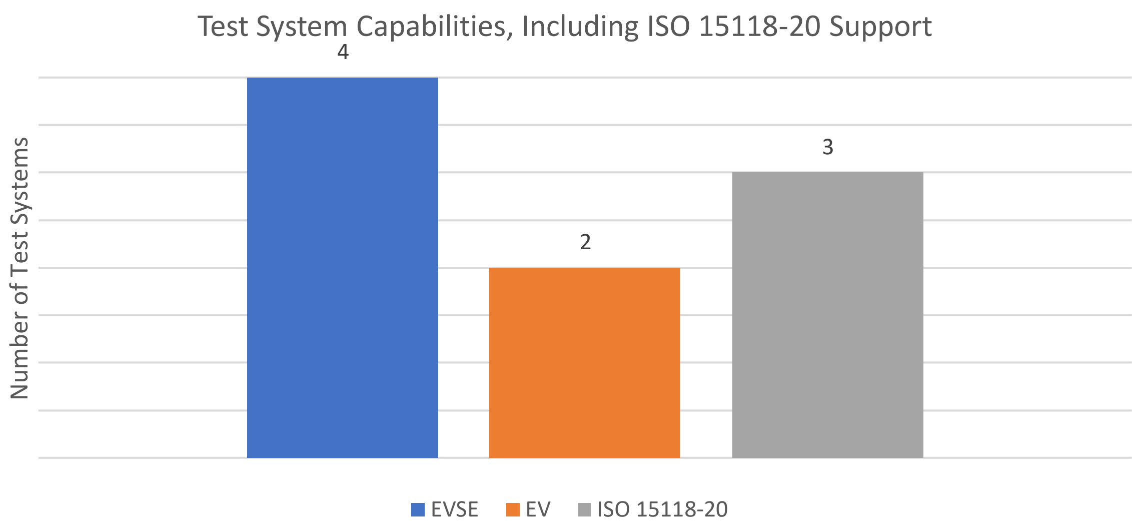

Figure 9 Test System Capabilities, Including ISO 15118-20 Support

3. Test Event Organization

The test event took place at the charging plaza of WattEV, 2406 Pier A Way, Long Beach, California. The charging plaza of WattEV is equipped with thirteen 350 kW chargers and 26 bays for high power charging of heavy-duty electric trucks.

3.1 Test Date

Testing activities occurred May 10 and 11, 2023. The first day was a public observation day where registered VOLTS non-testing attendees could watch the tests underway whereas the second day was a closed event with only participating, registered testers allowed on site.

3.2 Test Site

Each EVSE was stationed at a test bay, and EVs rotated across test bays according to the testing schedule.

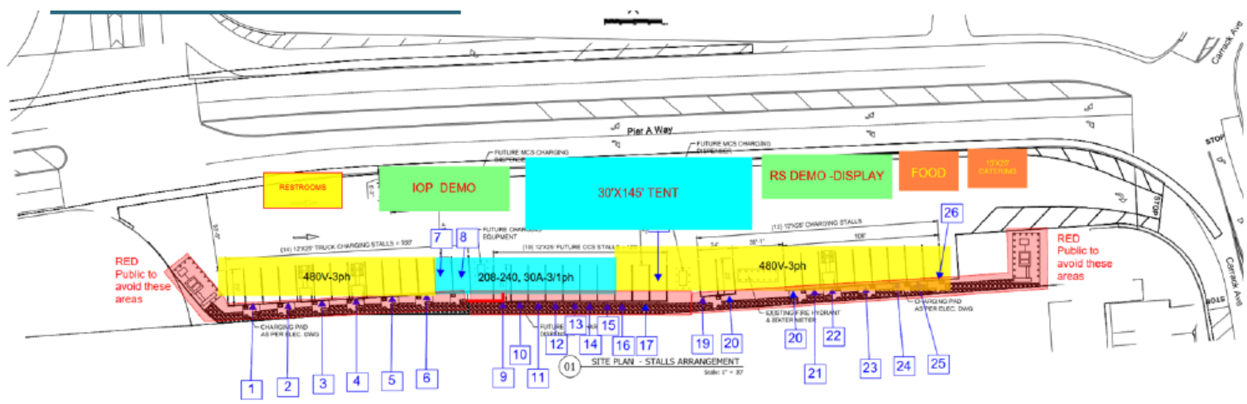

Figure 10 Diagram of the Test Site Configuration for VOLTS

In total, 174 individual tests over 7 test slots were conducted during the 2 days. Each test slot lasted for 2 hours. During each test slot, about 90 minutes were dedicated to mandatory and pre-selected baseline test scenarios, as well as conditional test scenarios. If the conditional test scenarios were feasible based on the capabilities of the products comprising the test couple, the test couple was directed to execute the conditional test scenarios during the test session. For the last 30 minutes of the test slot, free interoperability testing was allowed.

Each test pair was required to submit a test report at the end of each test slot using an online survey provided by the VOLTS organizing team.

Each test couple was required to coordinate which (EV or EVSE) participant was responsible for the writing and submitting the test survey at the end of the test slot. At the end of the test slot, EVs rotated to the next test bay according to the test pairing schedule.

Test pairings were randomly assigned after considering the particular capabilities of the EVSE, EV and test system, respectively.

3.3 Technical Registration Details

The following companies participated in testing at VOLTS.

3.3.1 AC EVSE Technical Registrations

Company
IoTecha
Switch Energy
Switch EV Ltd
Tesla
Zerova Technologies USA

Table 1 AC EVSE Technical Registrations

3.3.2 DC EVSE Technical Registrations

Company	Type
ABB	ABB Equipment 1
ABB	ABB Equipment 2
Autel Energy	
Borg Warner Inc	
BTC Power Inc	
dSPACE GmbH	
EcoG GmbH	
EVgo	
Freewire Technologies	
ideanomics	
InCharge Energy	
Keysight Technologies	
Rectifier Technologies Ltd	
Rivian	
SparkCharge	
TeraWatt Infrastructure	
Vector Informatik GmbH	Vector Equipment 1
Vector Informatik GmbH	Vector Equipment 2
Zerova Technologies USA	

Table 2 DC EVSE Technical Registrations

3.3.3 EV Technical Registrations

Company	Type
AMP	
Blue Bird Corporation	
BMW of North America	BMW Equipment 1
BMW of North America	BMW Equipment 2
Canoo Technologies Inc	
Ford Motor Company	Ford Equipment 1
Ford Motor Company	Ford Equipment 2
Green Power Motor Company	Green Power Motor Company Equipment 1
Green Power Motor Company	Green Power Motor Company Equipment 2
Hyundai Kia America Technical Center Inc (HATCI)	Hyundai Kia Equipment 1
Hyundai Kia America Technical Center Inc (HATCI)	Hyundai Kia Equipment 2

Lightning eMotors	
Mercedes Benz R&D North America	Mercedes Benz Equipment 1
Mercedes Benz R&D North America	Mercedes Benz Equipment 2
Navistar	Navistar Equipment 1
Navistar	Navistar Equipment 2
PACCAR	PACCAR Equipment 1
PACCAR	PACCAR Equipment 2
Rivian Automotive	Rivian Equipment 1
Rivian Automotive	Rivian Equipment 2
Volkswagen Group of America	
Volvo Cars Corporation	

Table 3 EV Technical Registrations

3.3.5 Test System Technical Registrations

Company
AIO Electric
DEKRA SE
Keysight
Rivian
ROCSYS
Vector Informatik

Table 4 Test System Technical Registrations

3.3.5 Pairing Based on Technical Registrations

A total of 38 AC test pairings across 7 test slots were scheduled over the 2 testing days. However, 42 report submissions were received. The extra report submissions may have been due to both test parties submitting reports for certain test slots or other user submission errors.

A total of 132 DC test pairing across 7 test slots were scheduled over the 2 testing days, and 132 report submissions were received.

4. Testing Scenarios

Unlike at prior CharIN Testivals, participants at VOLTS submitted data from test sessions to help identify and publicize potential interoperability challenges. At prior CharIN Testivals, issues discovered might be debugged on the spot, and such spot fixes do not typically facilitate in-depth analysis and debugging to thoroughly resolve interoperability issues. A key goal for VOLTS is to leverage the collected data to better identify and address root causes of interoperability challenges.

As mentioned above, testing scenarios were split into two main parts identified as “baseline tests” and “conditional tests”.

Baseline tests included scenarios simulating “normal” charging sessions as any consumer might experience during charging. These scenarios are summarized below:

1. The EV is connected with the EVSE, the EV initiates a charging session by establishing a communication link, including either a TCP or TLS connection, followed by selection of the communication protocol (DIN 70121, ISO 15118-2, and so on), selection of the payment method (EIM or PnC), and charging for 1 minute.
2. The EV shift position is manipulated while the connector is plugged in and charging.
3. The connector is inserted to produce a lock fault.
4. The connector latch is pressed while charging.
5. Emergency stop at the EVSE.

In addition to baseline tests, conditional tests validated scenarios involving ISO 15118-2 EIM and PnC, smart charging, and ISO 15118-20. Not all products or test pairs could execute conditional tests.

4.1 Section B: TS1: Test Scenario – Intentional Charging

This test scenario follows a normal charging process whereby the EV is connected to the EVSE and a charging session started. Charging will continue for about 1 minute, after which the charging session will be stopped either by the EV or EVSE. This test scenario is executed 6 times. The protocol used for the charging session is selected by the EV on the basis of supported protocols and indicated priority of the EVSE. Results may differ across each of the 6 iterations and results for each iteration are summarized below.

This baseline test includes:

- TS1-A1: Intentional Charging (Iteration 1)
- TS1-A2: Intentional Charging (Iteration 2)
- TS1-A3: Intentional Charging (Iteration 3)
- TS1-A4: Intentional Charging (Iteration 4)
- TS1-A5: Intentional Charging (Iteration 5)
- TS1-A6: Intentional Charging (Iteration 6)

The participants are required to report behaviors on the EVSE and EV as follows.

- Executed (pass) - Successful stop without any error after normal charging
- Executed (fail) - SLAC Issue
- Executed (fail) - SDP Issue
- Executed (fail) - TCP Issue
- Executed (fail) - TLS Issue
- Executed (fail) - Authentication Issue EIM
- Executed (fail) - Authentication Issue PnC
- Executed (fail) - Backend Issue
- Executed (fail) - Charge Parameter Issue
- Executed (fail) - Cable Check Issue
- Executed (fail) - Stop Ignored
- Not applicable – In this case the testers are required to justify

4.1.1 Overall results - Test Scenario - Intentional Charging (6 Iterations)

4.1.1.1 TS1-A1: Intentional Charging (Iteration 1)

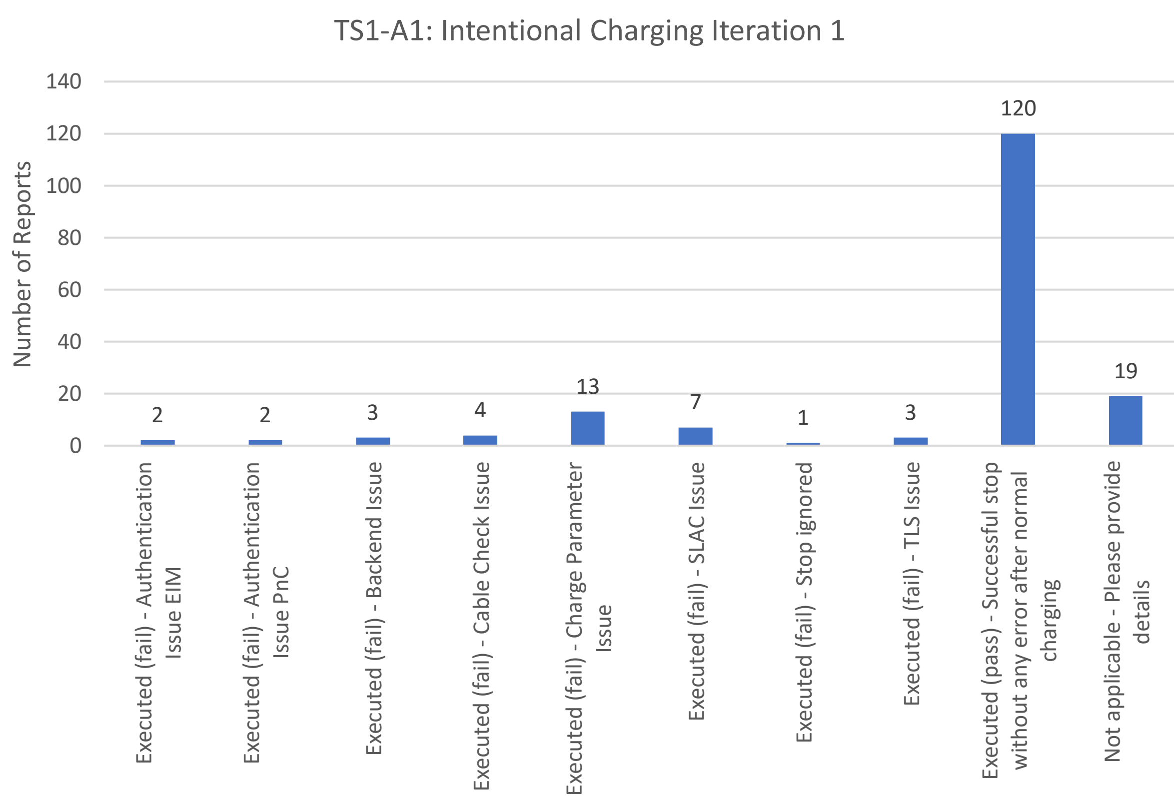

Figure 11 TS1-A1 – Intentional Charging Iteration 1

174 survey results were submitted. Of those, 120 reports indicated a successful charging session (69 percent), while 35 reports indicated a failed charging session. In addition, 19 reports indicated “Not Applicable”.

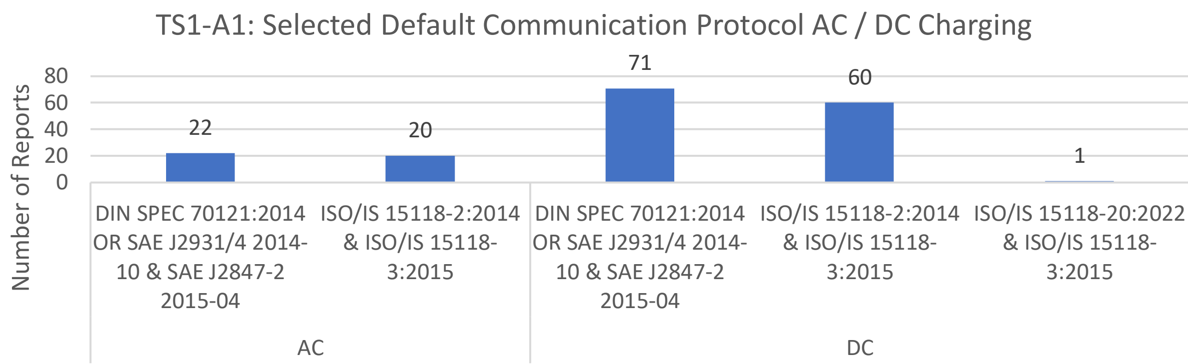

Figure 12 TS1-A1 – Selected Default Communication Protocol

It is noted that for AC testing, 22 of the participants indicated DIN 70121 as the default communication protocol in their survey. These may be user submission errors, as DIN 70121 does not support AC charging. It is fair to assume that all AC charging sessions were executed on the basis of the ISO 15118-2 standard.

For DC charging, 132 charging sessions were reported. In addition, 71 sessions indicated DIN 70121 as the selected default communication protocol, while 60 submissions indicated ISO 15118-2 as the selected default communication protocol. One DC charging session was reported to use ISO 15118-20.

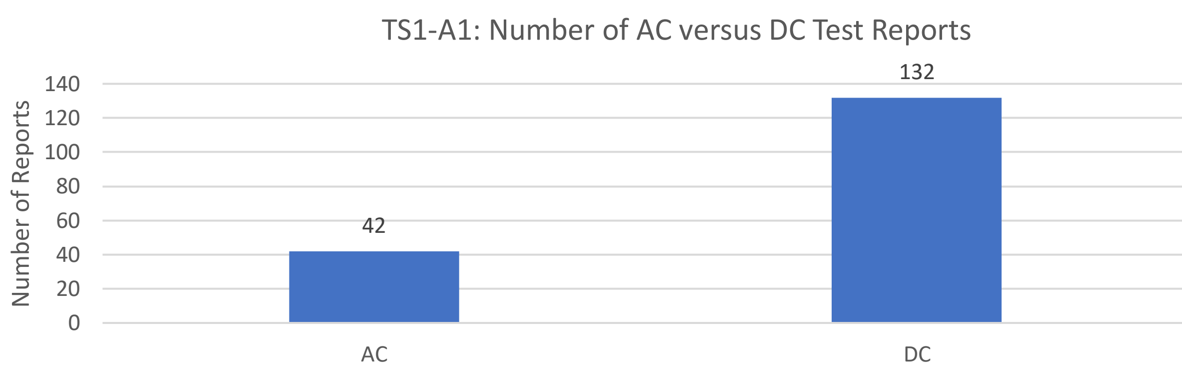

Figure 13 TS1-A1 – AC vs DC Test Reports

The survey results suggest that 42 AC charging sessions and 132 DC charging sessions were executed. There were 38 AC test pairings scheduled, which is 4 less than was reported based on the survey results. Since all test data has been anonymized, it is not possible to identify the likely cause of these submission errors.

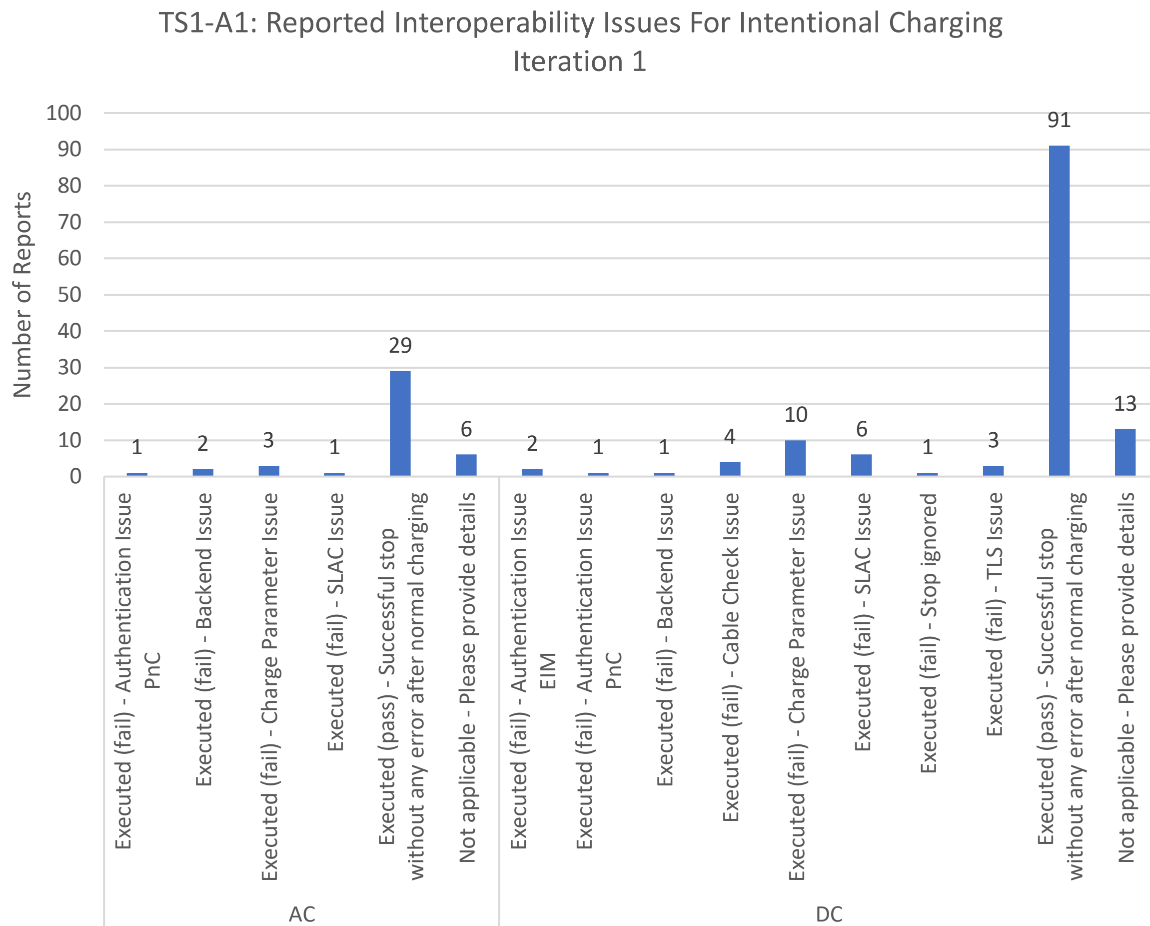

Figure 14 *TS1-1 – Reported Interoperability Issues For Intentional Charging Iteration 1*

Of the successful tests (i.e. excluding the not applicable test submissions), 91 (76 percent) DC charging sessions resulted in pass and 29 (80 percent) AC charging sessions resulted in pass. This is a great rate of success given that prototype and pre-production equipment were included in these results. Among unsuccessful charging sessions, several problems were reported during the charging preparation phase; these included establishing an EV-EVSE link (SLAC; 7 reports), establishing a connection (TLS or TCP; 3 reports), authentication (EIM or PnC; 4 reports), or other backend issues (3 reports). Another 13 reports of unsuccessful charging sessions were due to issues encountered during exchange of charge parameters (note that this occurs after successfully establishing communication and authentication).

4.1.1.2 TS1-A2: Intentional Charging (Iteration 2)

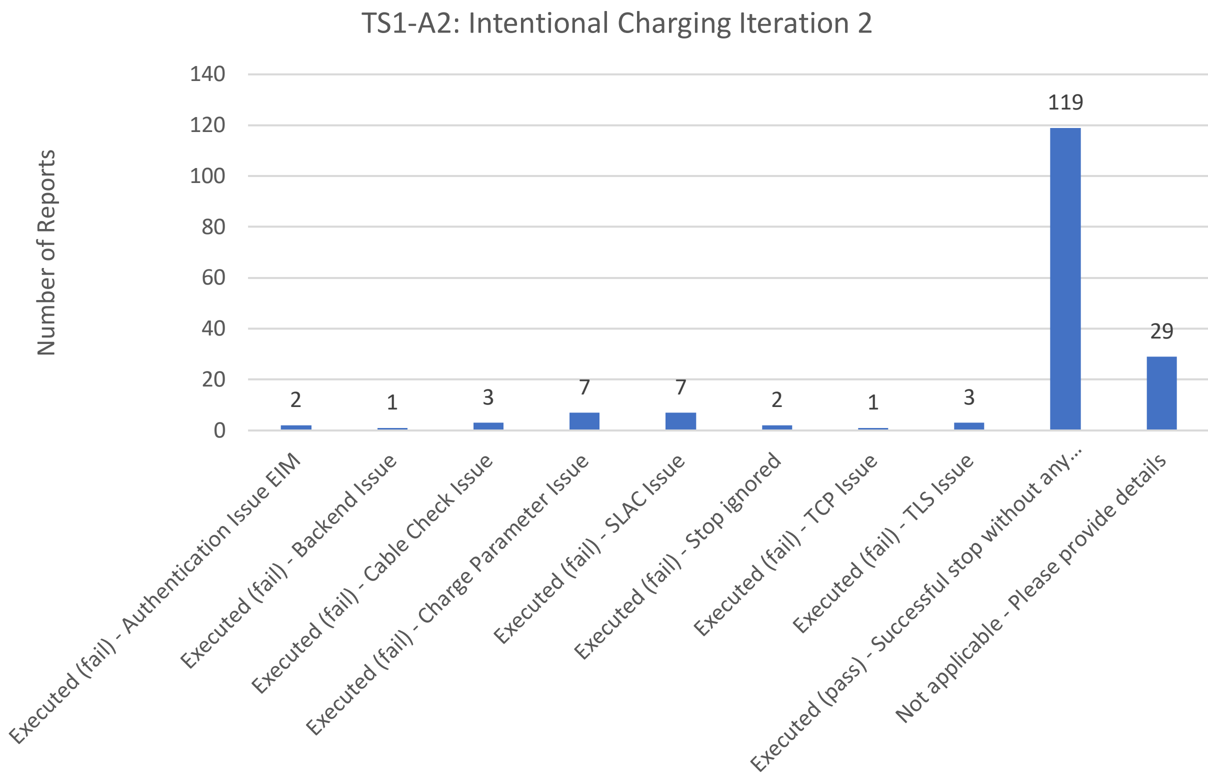

Figure 15 TS1-A2 – Intentional Charging Iteration 2

Depicted in Figure 15, 174 survey results were submitted and 119 reports indicated a successful charging session (68 percent) while 26 reports have reported a failed charging session. "Not Applicable" was indicated for 29 reports.

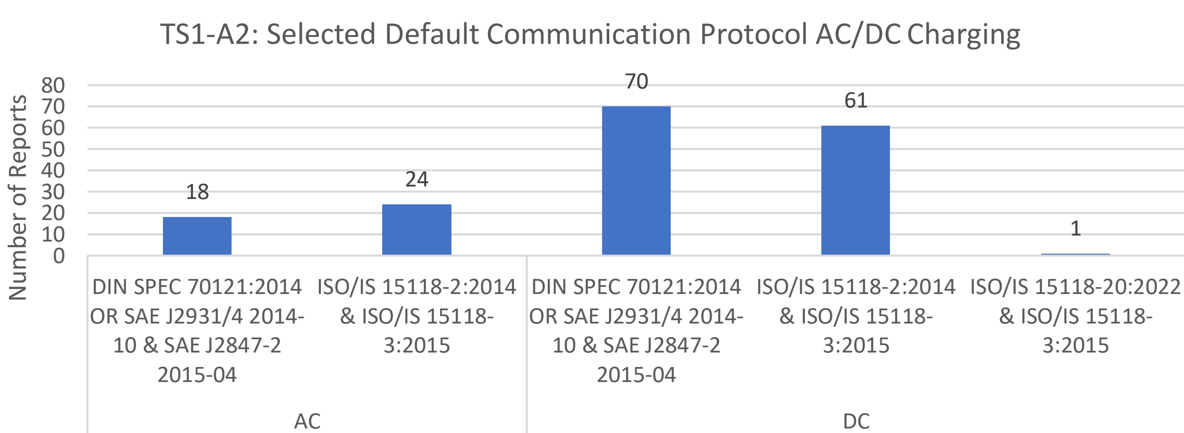

Figure 16 TS1-A2 – Selected Default Communication Protocol for Iteration 2

As seen in Figure 16, 18 AC participants indicated DIN 70121 as the default communication protocol in their survey, which is slightly lower than the number of AC participants that had indicated DIN 70121 for the first iteration. As before, these may be due to a user submission error, as DIN 70121 does not support AC charging. It is fair to assume that all AC charging sessions were executed on basis of the ISO 15118-2 standard.

For DC charging 132 charging sessions were reported. One DC charging session was reported to use ISO 15118-20.

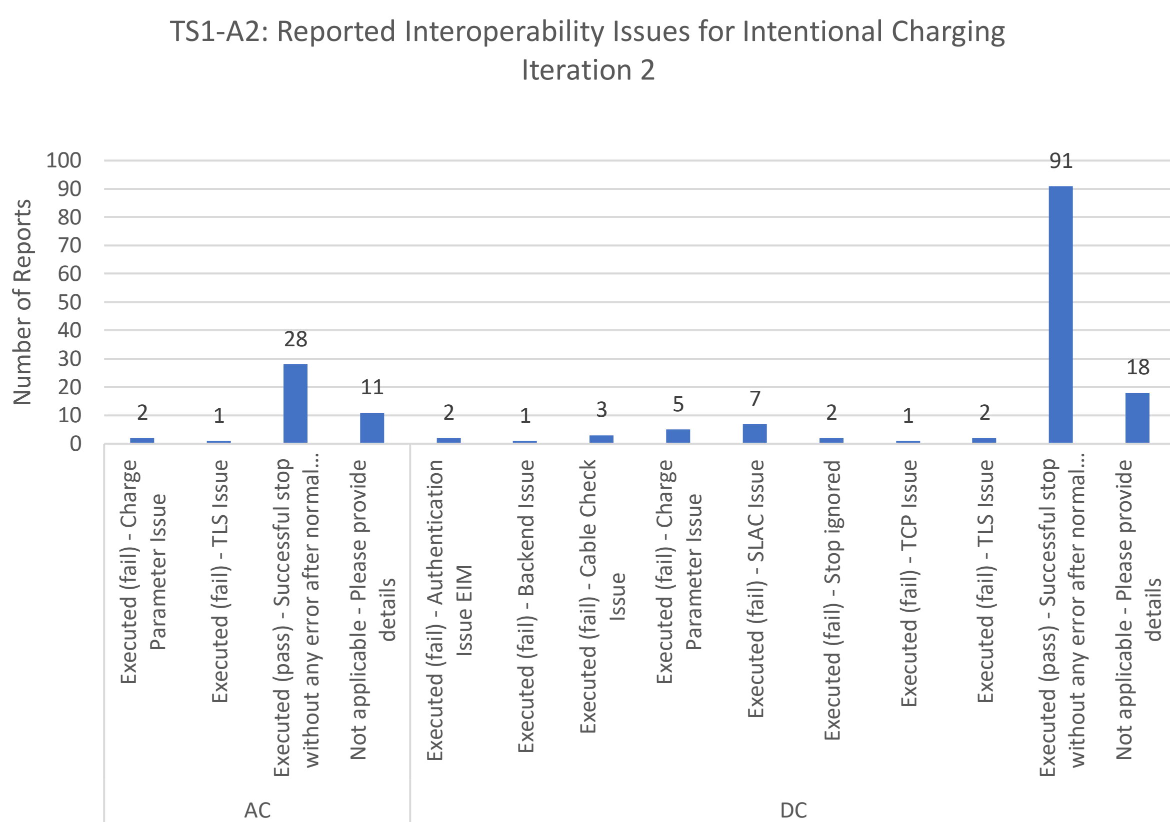

Figure 17 TS1-A2– Reported Interoperability Issues for Intentional Charging Iteration 2

Of the successful tests (i.e. excluding the not applicable test submissions), 91 (76 percent) DC charging sessions resulted in pass and 29 (80 percent) AC charging sessions resulted in pass.

As before, among unsuccessful charging sessions, several problems were reported during the charging preparation phase which included: establishing an EV-EVSE link (SLAC; 7 reports), establishing a connection (TLS or TCP; 4 reports), authentication (EIM or PnC; 2 reports), or other backend issues (1 report). Another 7 reports of unsuccessful charging sessions were due to issues encountered during exchange of charger parameters (note that this occurs after successfully establishing communication and authentication).

4.1.1.3 TS1-A3: Intentional Charging (Iteration 3)

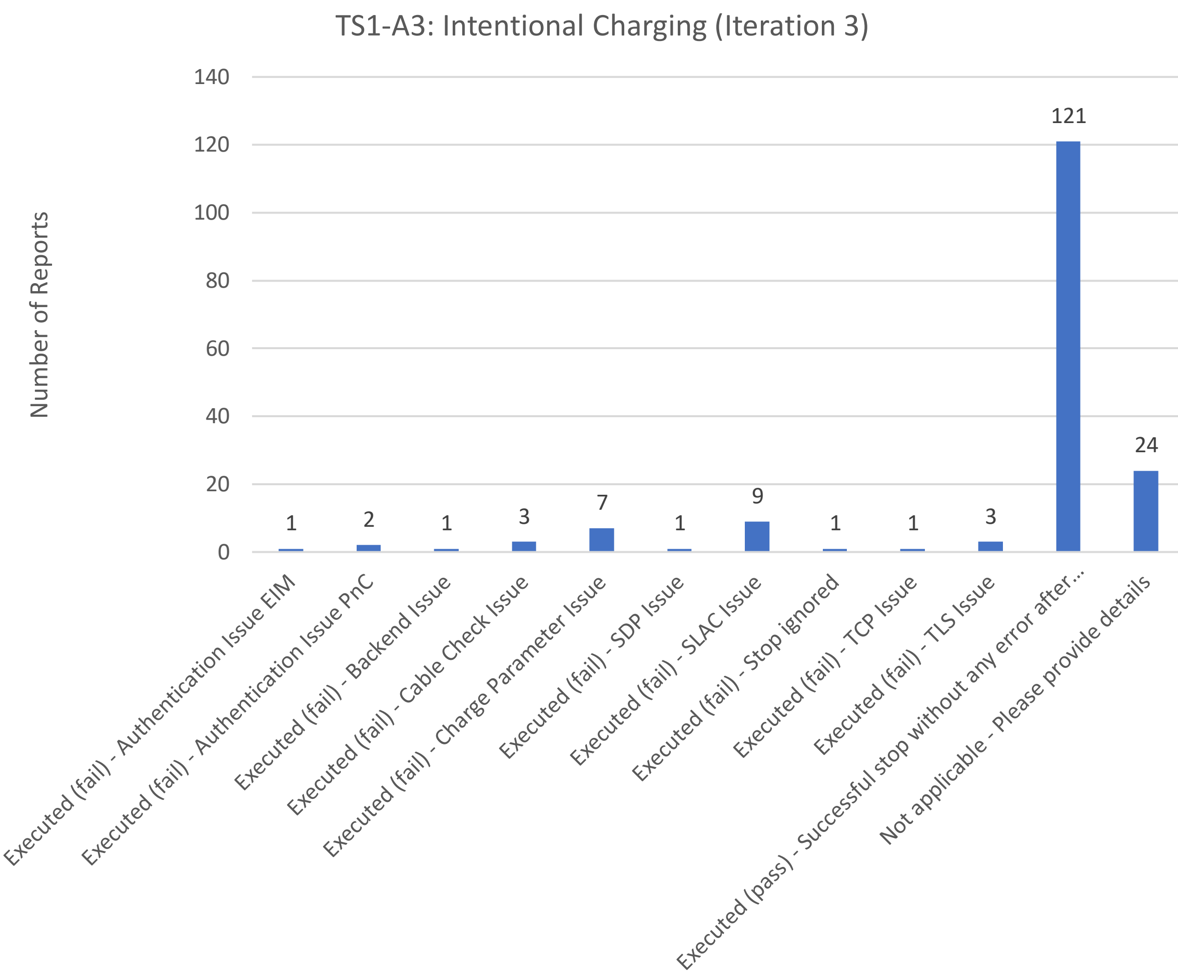

Figure 18 *TS1-A3 – Intentional Charging Iteration 3*

The 174 survey results, depicted in Figure 18, were submitted and 121 reports indicated a successful charging session (69 percent), while 29 reports indicated a failed charging session. "Not Applicable" was indicated for 29 reports.

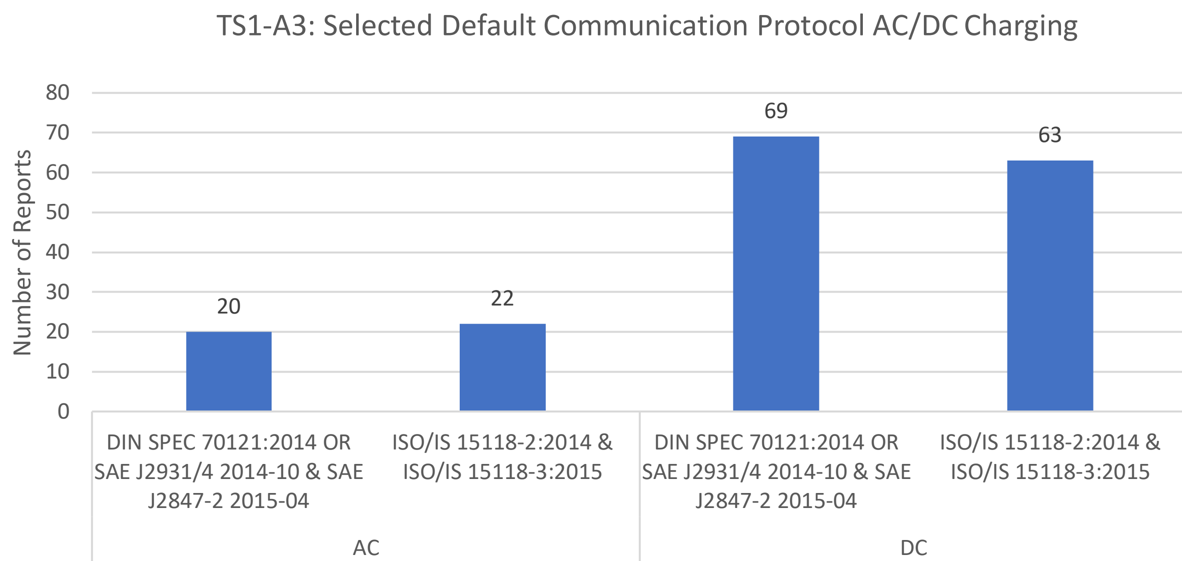

Figure 19 TS1-A3 – Selected Default Communication Iteration 3

Shown in Figure 19, 20 AC participants indicated DIN 70121 as the default communication protocol in their survey. These may be due to user submission errors, as DIN 70121 does not support AC charging. It is fair to assume that all AC charging sessions were executed on the basis of the ISO 15118-2 standard.

For DC charging, 132 charging sessions were reported. 69 indicated DIN 70121 as the selected default communication protocol, while 63 submissions indicated ISO 15118-2 as the select default communication protocol. It is also noted that unlike the first and second iteration, no ISO 15118-20 protocol use was reported.

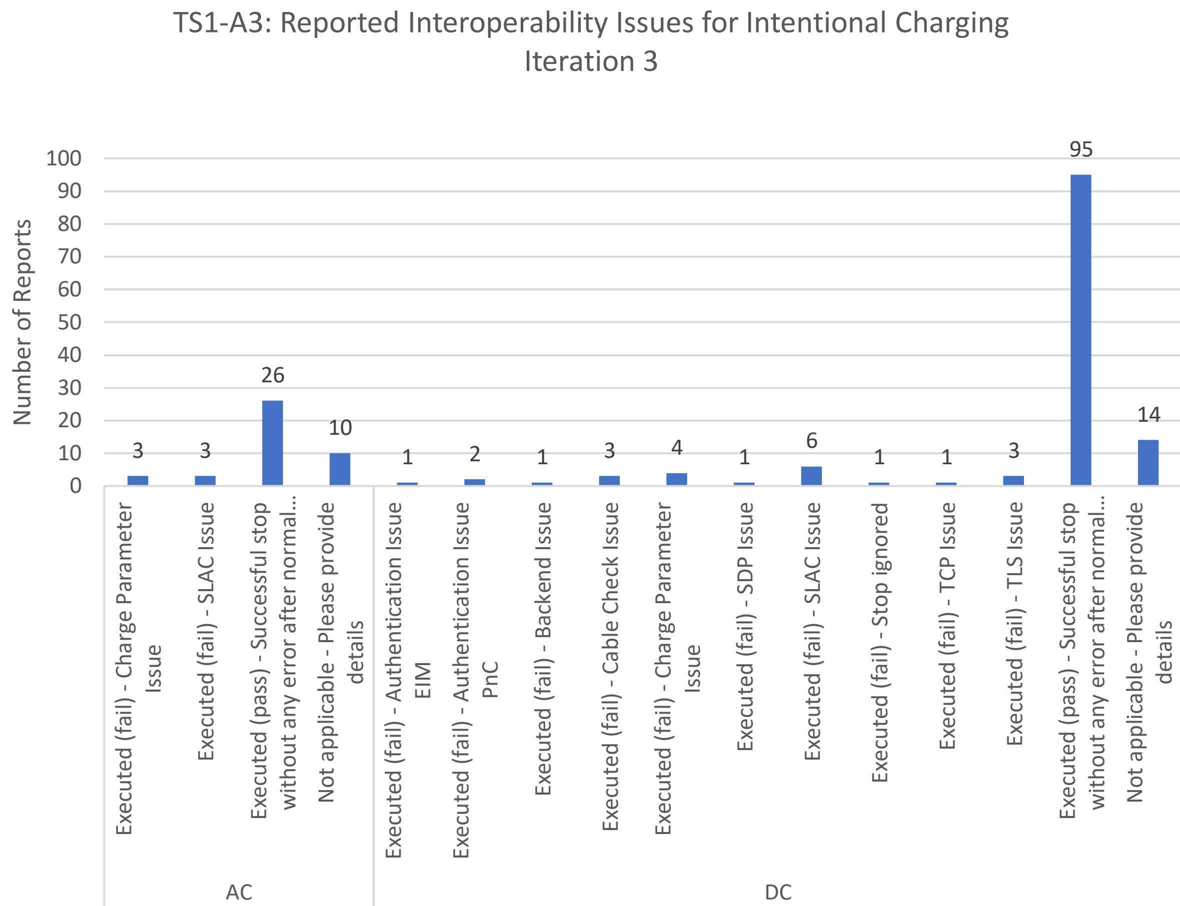

Figure 20 *TS1-A3 – Reported Interoperability Issues for Iteration 3*

Of the successful tests (i.e. excluding the not applicable test submissions), 95 (83 percent) DC charging sessions resulted in pass and 26 (81 percent) AC charging sessions resulted in pass.

As before, among unsuccessful charging sessions, several problems were reported during the charging preparation phase. These included establishing an EV-EVSE link (SLAC; 9 reports), establishing a connection (TLS or TCP; 4 reports), authentication (EIM or PnC; 3 reports), or other backend issues (1 reports). Another 7 reports of unsuccessful charging sessions were due to issues encountered during exchange of charge parameters (note that this occurs after successfully establishing communication and authentication).

4.1.1.4 TS1-A4: Intentional Charging (Iteration 4)

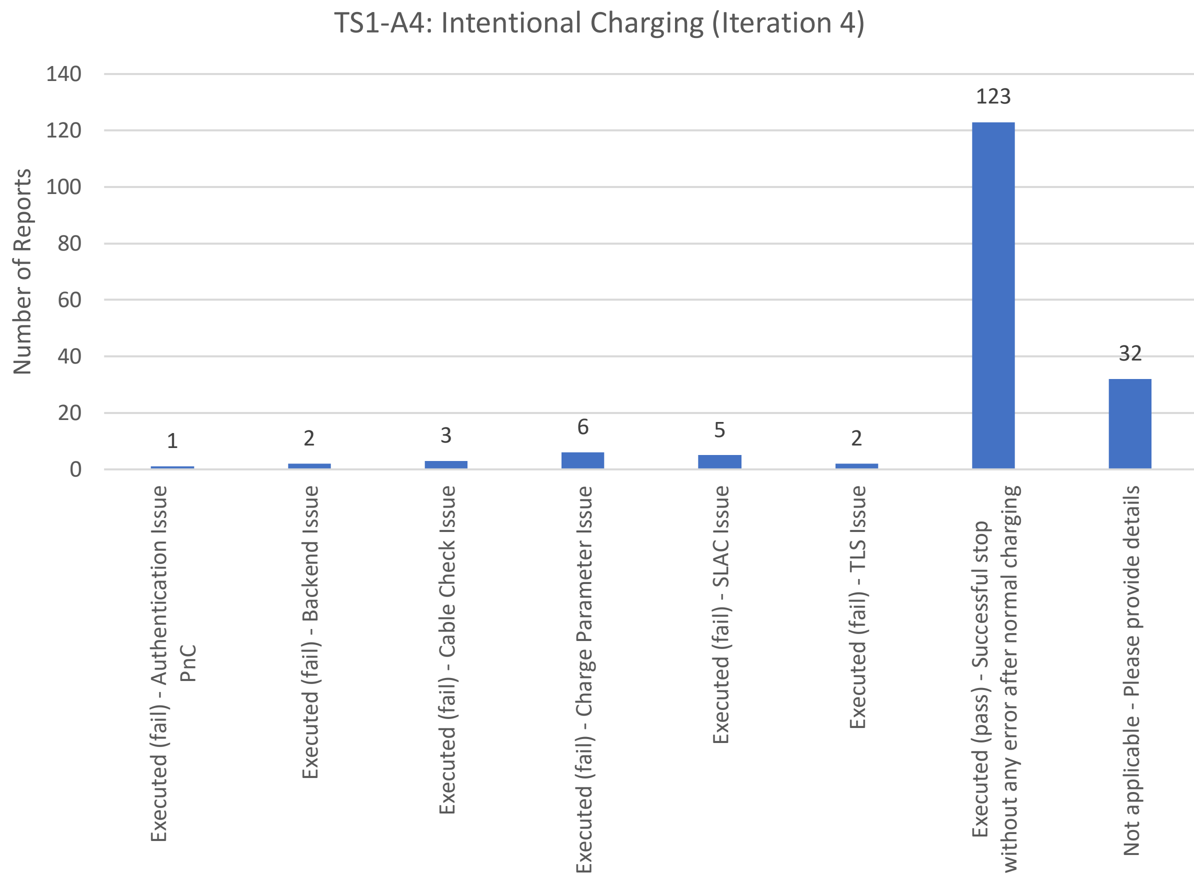

Figure 21 TS1-A4 – Intentional Charging Iteration 4

Seen in Figure 21, 174 survey results were submitted, and 123 reports indicated a successful charging session (70 percent) while 19 reports indicated a failed charging session. “Not Applicable” was indicated for 32 reports.

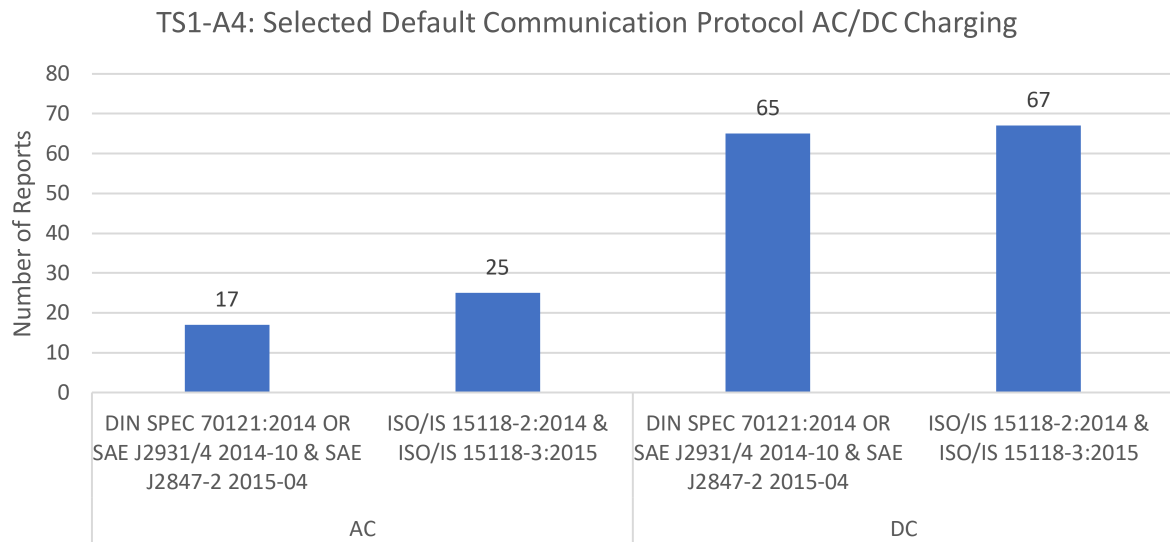

Figure 22 TS1-A4 – Selected Default Communication Iteration 4

For AC testing, 17 indicated DIN 70121 as the default communication protocol in their survey. These may be user submission errors, as DIN 70121 does not support AC charging. It is fair to assume that all AC charging sessions were executed on the basis of the ISO 15118-2 standard. The inconsistency might also be from submission errors misidentifying the type of charging (AC or DC) under test.

For DC charging, 132 charging sessions were reported. 65 indicated DIN 70121 as the selected default communication protocol while 67 submissions indicated ISO 15118-2 as the select default communication protocol. No ISO 15118-20 protocol use was reported.

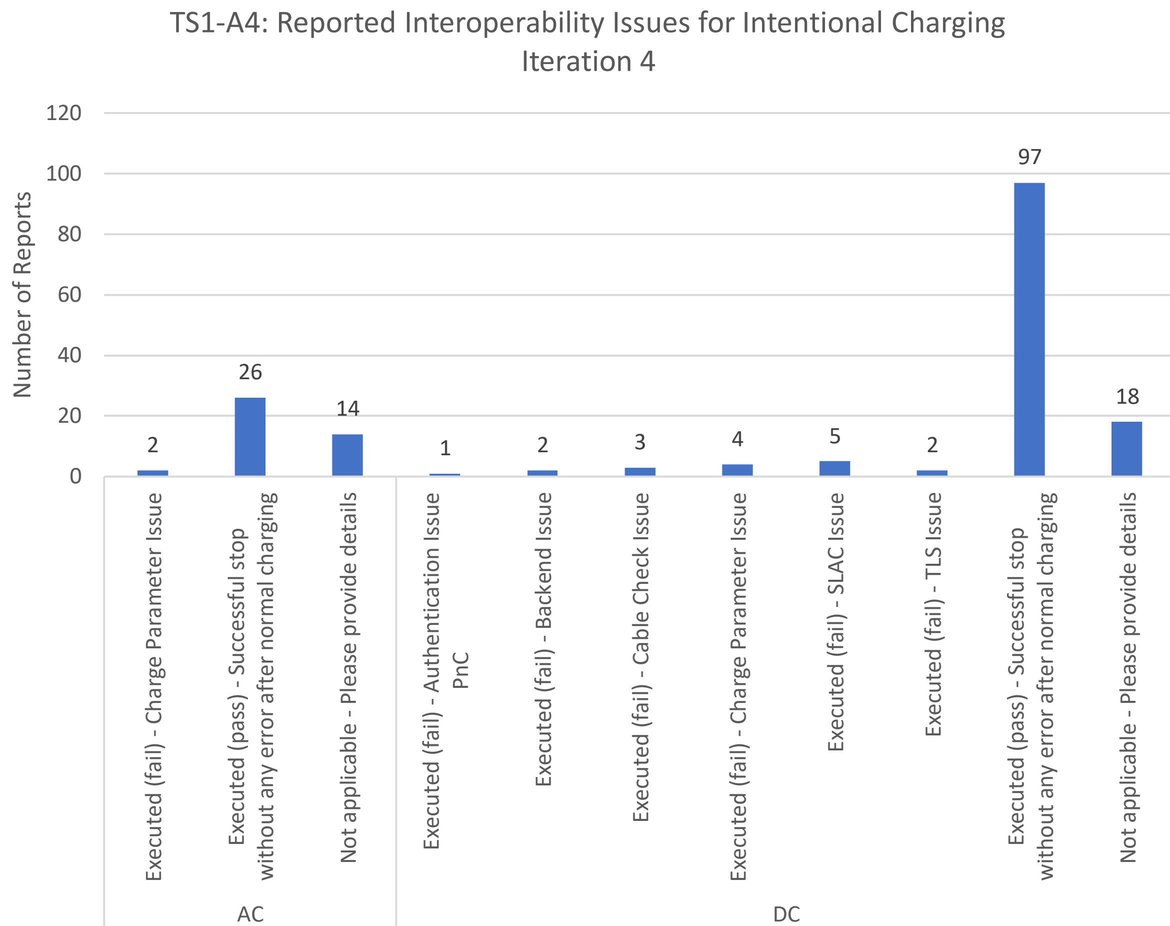

Figure 23 TS1-A4 – Reported Interoperability Issues for International Charging Iteration 4

Of the successful tests (i.e. excluding the not applicable test submissions), 97 (85 percent) DC charging sessions resulted in pass and 26 (92 percent) AC charging sessions resulted in pass. As before, among unsuccessful charging sessions, several problems were reported during the charging preparation phase. These included establishing an EV-EVSE link (SLAC; 5 reports), establishing a connection (TLS or TCP; 2 reports), authentication (EIM or PnC; 1 reports), or other backend issues (2 reports). Another 9 reports of unsuccessful charging sessions were due to issues encountered during exchange of charge parameters (note that this occurs after successfully establishing communication and authentication).

4.1.1.5 TS1-A5: Intentional Charging (Iteration 5)

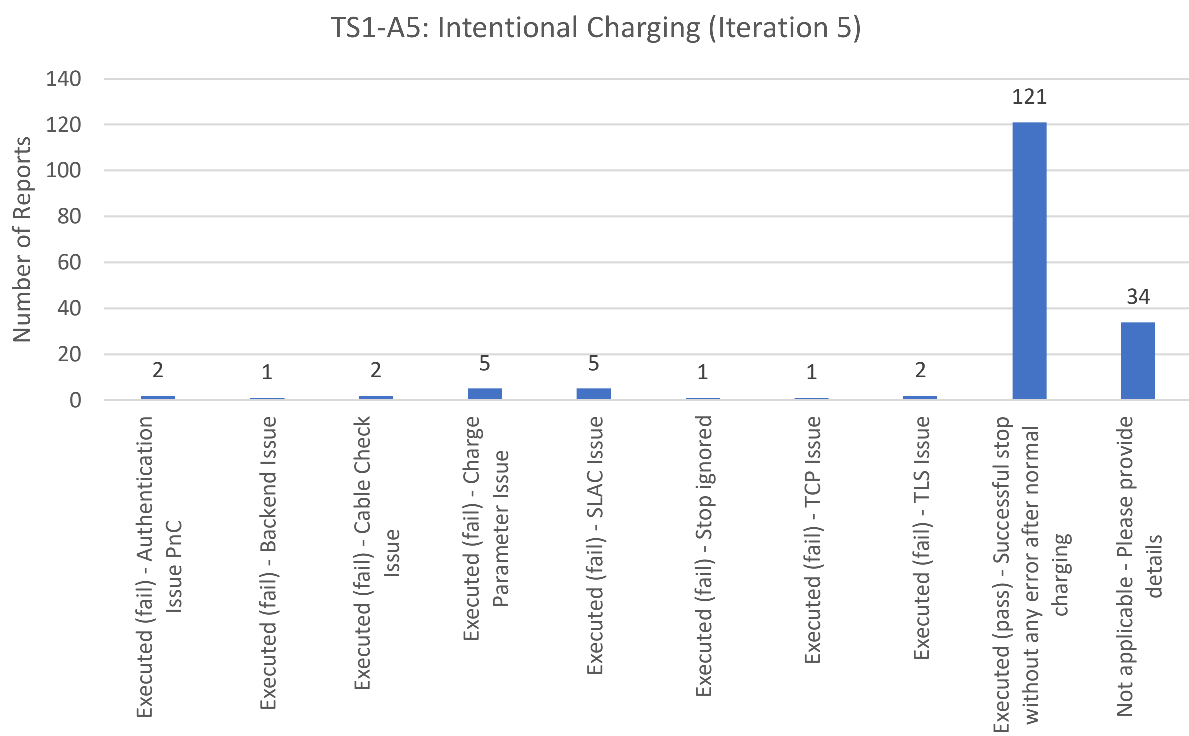

Figure 24 TS1-A5 – Overall Result Intentional Charging Iteration 5

In iteration 5, charted in Figure 25, 174 survey results were submitted and 121 reports indicated a successful charging session (69 percent) while 19 reports have reported a failed charging session. In addition, 34 reports indicated "Not Applicable".

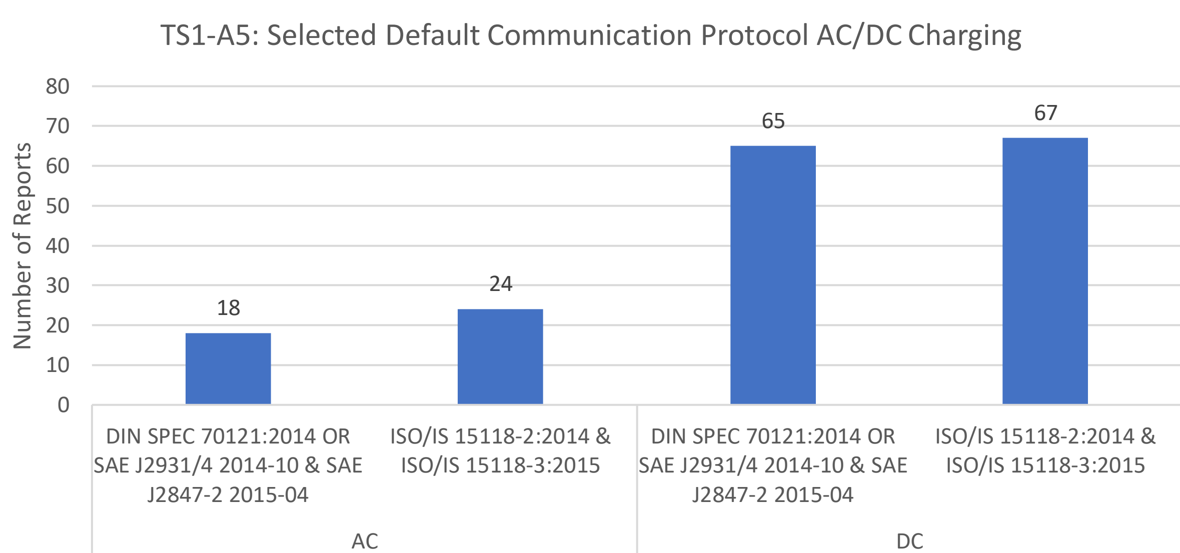

Figure 25 TS1-A5 – Selected Default Communication Iteration 5

For AC testing, 18 participants indicated DIN 70121 as the default communication protocol in their survey. These may be user submission errors, as DIN 70121 does not support AC charging. It is fair to assume that all AC charging sessions have been executed on the basis of the ISO 15118-2 standard. The inconsistency might also be from submission errors misidentifying the type of charging under test (AC or DC).

For DC charging, 132 charging sessions were reported. 65 indicated DIN 70121 as the selected default communication protocol while 67 submissions indicated ISO 15118-2 as the select default communication protocol. No ISO 15118-20 protocol use was reported.

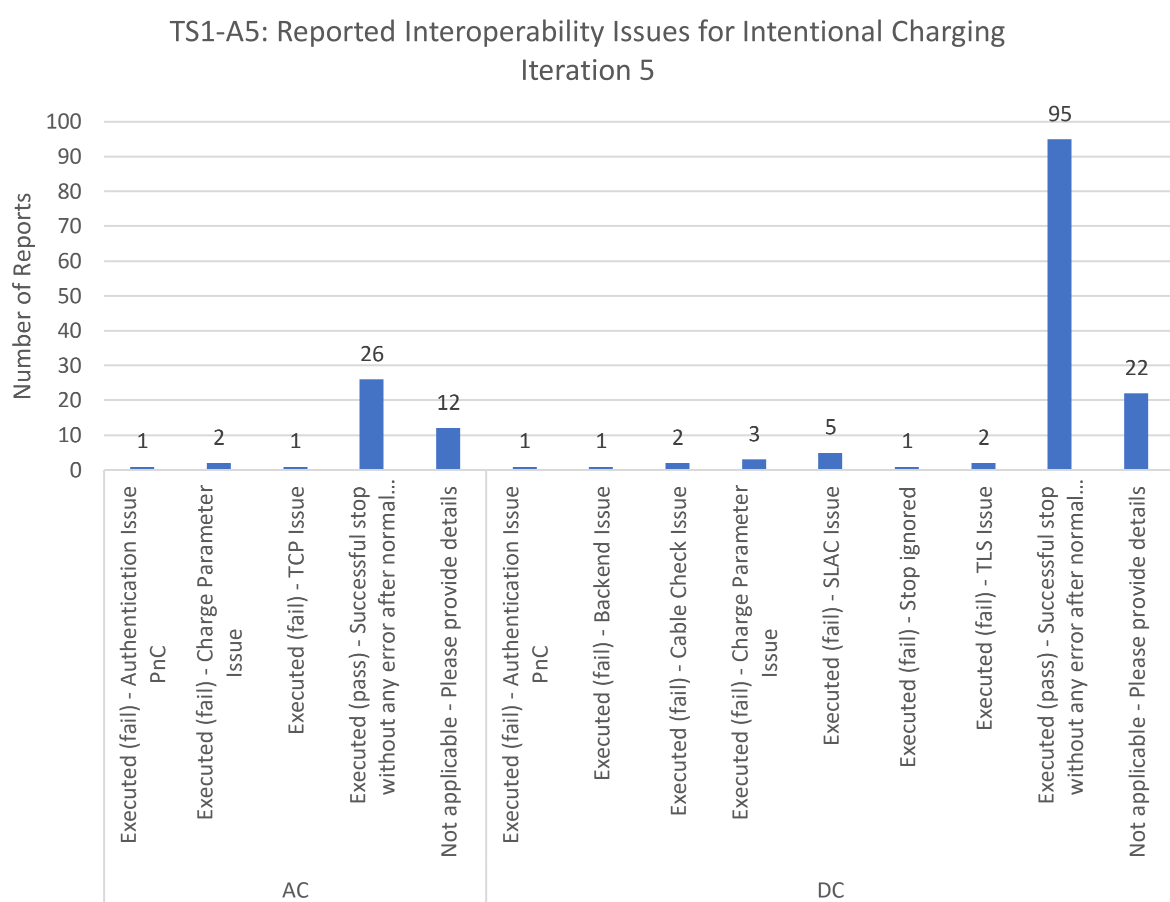

Figure 26 TS1-A5 – Reported Interoperability Issues for Intentional Charging Iteration 5

Of the successful tests (i.e. excluding the not applicable test submissions), 95 (86 percent) DC charging sessions resulted in pass and 26 (86 percent) AC charging sessions resulted in pass. As before, among unsuccessful charging sessions, several problems were reported during the charging preparation phase; these included establishing an EV-EVSE link (SLAC; 5 reports), establishing a connection (TLS or TCP; 3 reports), authentication (EIM or PnC; 2 reports), or other backend issues (1 reports). Another 5 reports of unsuccessful charging sessions were due to issues encountered during exchange of charge parameters (note that this occurs after successfully establishing communication and authentication).

4.1.1.6 TS1-A6: Intentional Charging (Iteration 6)

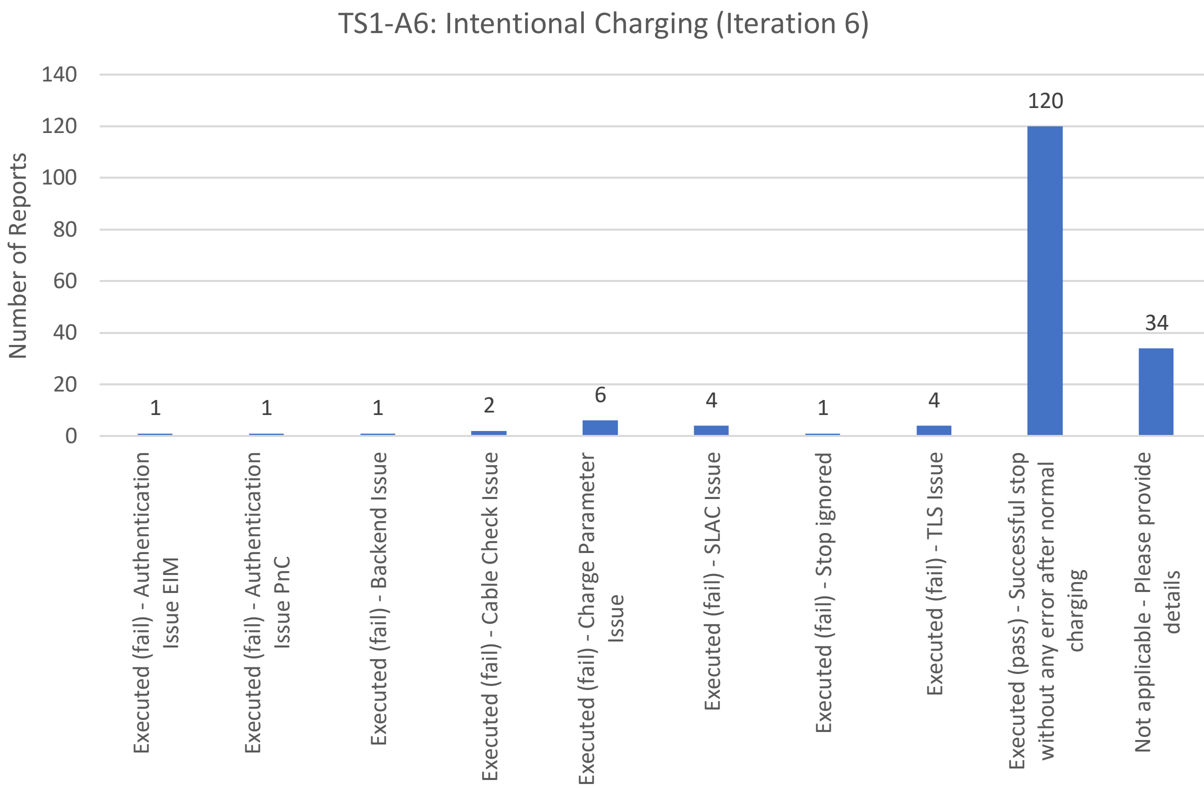

Figure 27 TS1-A6 – Overall Result Intentional Charging Iteration 6

In iteration 6, displayed in Figure 28, 174 survey results were submitted. 120 reports indicated a successful charging session (69 percent) while 20 reports have reported a failed charging session. "Not Applicable" was indicated for 34 reports.

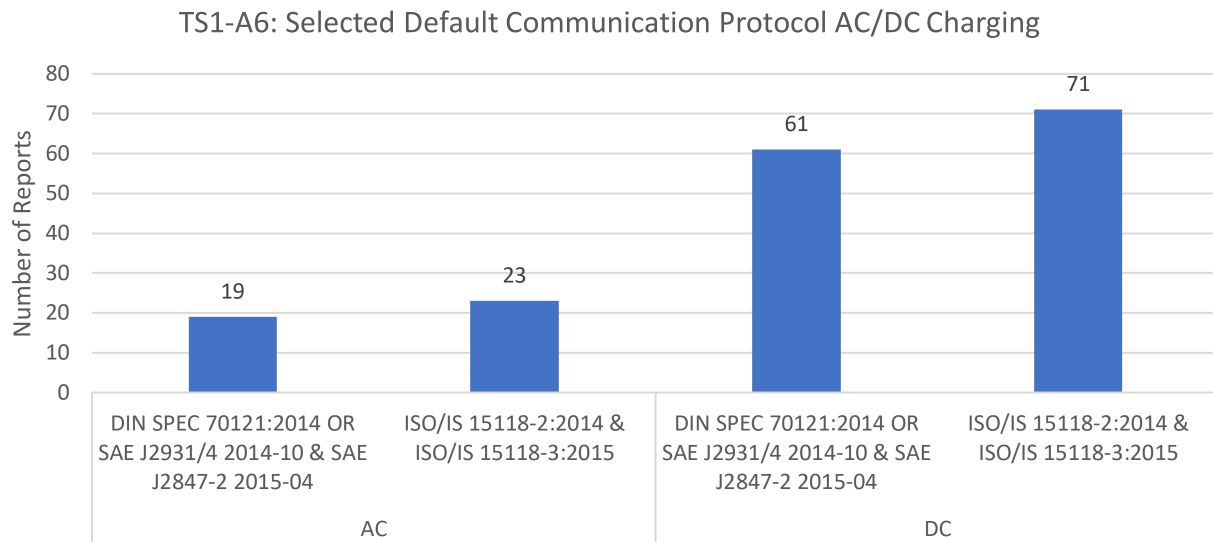

Figure 28 TS1-A6 – Selected Default Communication Iteration 6

For AC testing, 19 participants indicated DIN 70121 as the default communication protocol in their survey. These may be user submission errors, as DIN 70121 does not support AC charging. It is fair to assume that all AC charging sessions have been executed on the basis of the ISO 15118-2 standard. The inconsistency might also be from submission errors misidentifying the type of charging under test (AC or DC).

For DC charging, 132 charging sessions were reported. Of those, 61 indicated DIN 70121 as the selected default communication protocol while 71 submissions indicated ISO 15118-2 as the select default communication protocol. No ISO 15118-20 protocol use was reported.

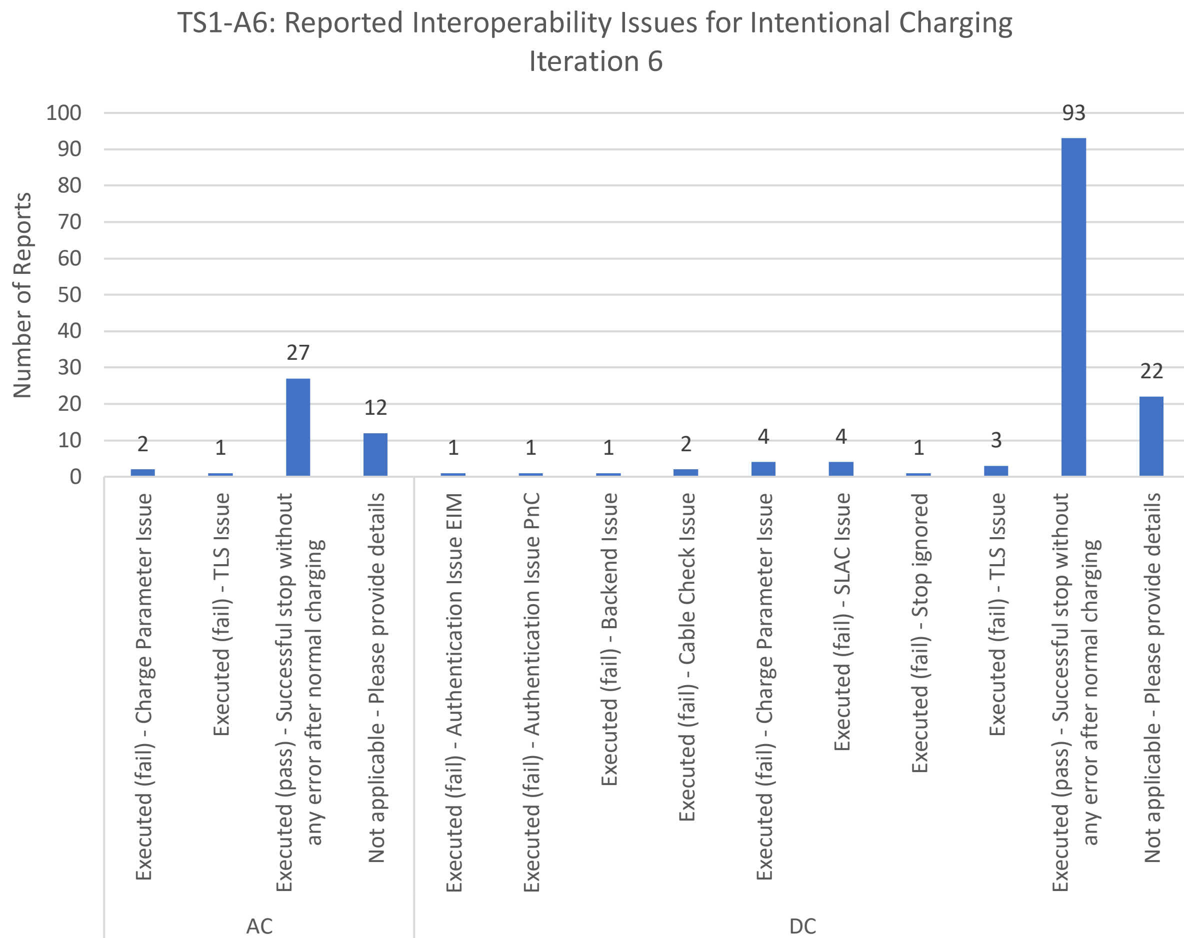

Figure 29 TS1-A6 – Reported Interoperability Issues for Intentional Charging Iteration 6

Of the successful tests (i.e. excluding the not applicable test submissions), 93 (84 percent) DC charging sessions resulted in pass and 27 (89 percent) AC charging sessions resulted in pass. As before, among unsuccessful charging sessions, several problems were reported during the charging preparation phase. These problems included establishing an EV-EVSE link (SLAC; 4 reports), establishing a connection (TLS or TCP; 4 reports), authentication (EIM or PnC; 2 reports), or other backend issues (1 reports). Another 6 reports of unsuccessful charging sessions were due to issues encountered during exchange of charge parameters (note that this occurs after successfully establishing communication and authentication).

4.1.2 Summary of TS1 Intentional Charging

The evaluation of the submitted results for TS1 intentional charging showed that approximately 86 percent of AC test sessions (resulting in pass or fail) and approximately 82 percent of DC test sessions (resulting in pass or fail) were successful. About half of the issues reported occurred during the charging preparation phase, which includes establishing a PLC link (SLAC), establishing a TCP or TLS connection, negotiating the communication protocol, and authorizing charging. Other issues reported are after authorization, including exchange of charge parameters (ChargeParameterDiscovery), cable check (CableCheck), and pre-charge (PowerDelivery and CurrentDemand). There were no issues reported when a charging session was active, and only one report encountered an issue while stopping a charging session.

As previously noted, for AC charging 42 reports were submitted despite there only being 38 scheduled test parings. This suggests that 4 of the AC charging submissions may have misidentified the charging type. It is also noted that for approximately half of the AC charging reports, DIN 70121 had been selected as the default communication protocol. These may have been user submission errors, as DIN 70121 does not support AC charging.

As the testing iterations progressed, one can observe a shift from DIN 70121 to ISO 15118 as the selected protocol. The data below captures both AC and DC reported charging sessions.

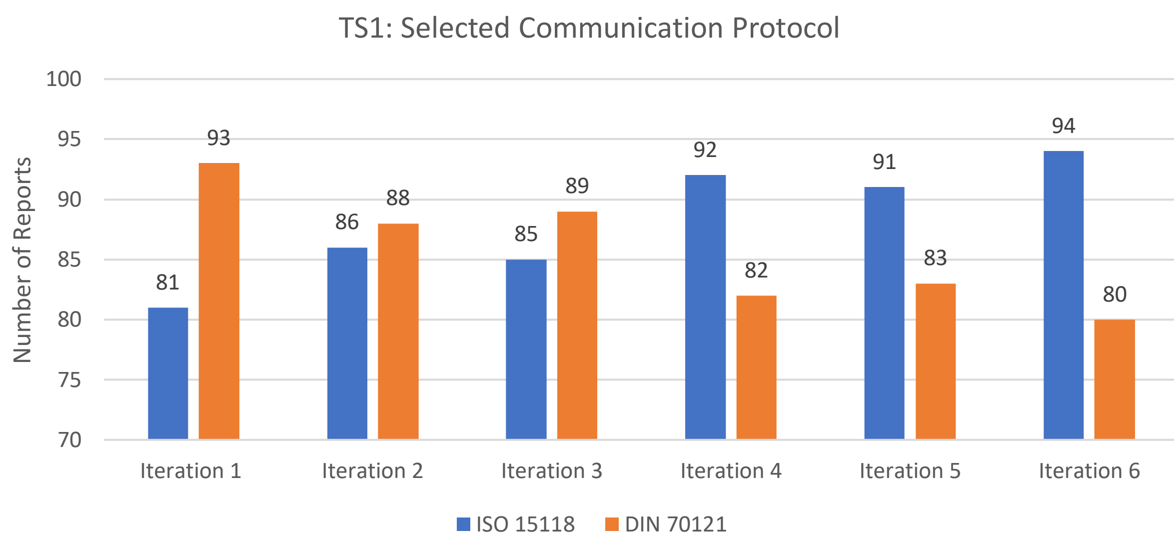

Figure 30 Selected Communication Protocol for TS1 Intentional Charging Iterations

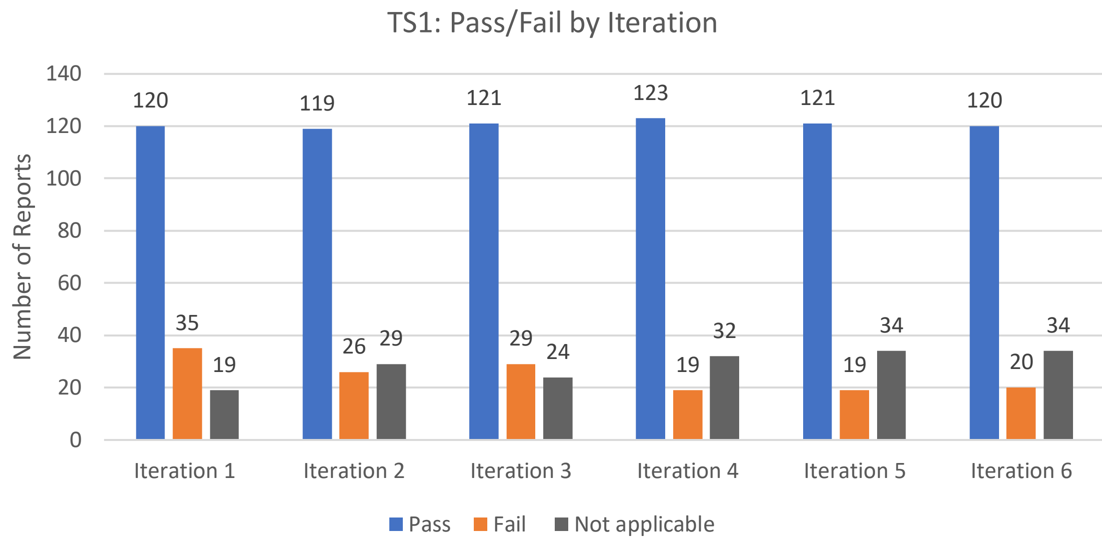

Figure 31 TS1 Pass / Fail Ratio by Iteration

The pass / fail ratio remained largely constant across iterations, which suggests that the selection of the ISO 15118 communication protocol did not result in more failed charging sessions.

It is worthwhile to note that beginning with iteration 4, participants increasingly reported a lack of time and reported issues under "Not applicable."

Of the 872 charging attempts resulting in reported pass or fail, 83% (724) were reported as successful while 148 (17%) were reported as unsuccessful or failed.

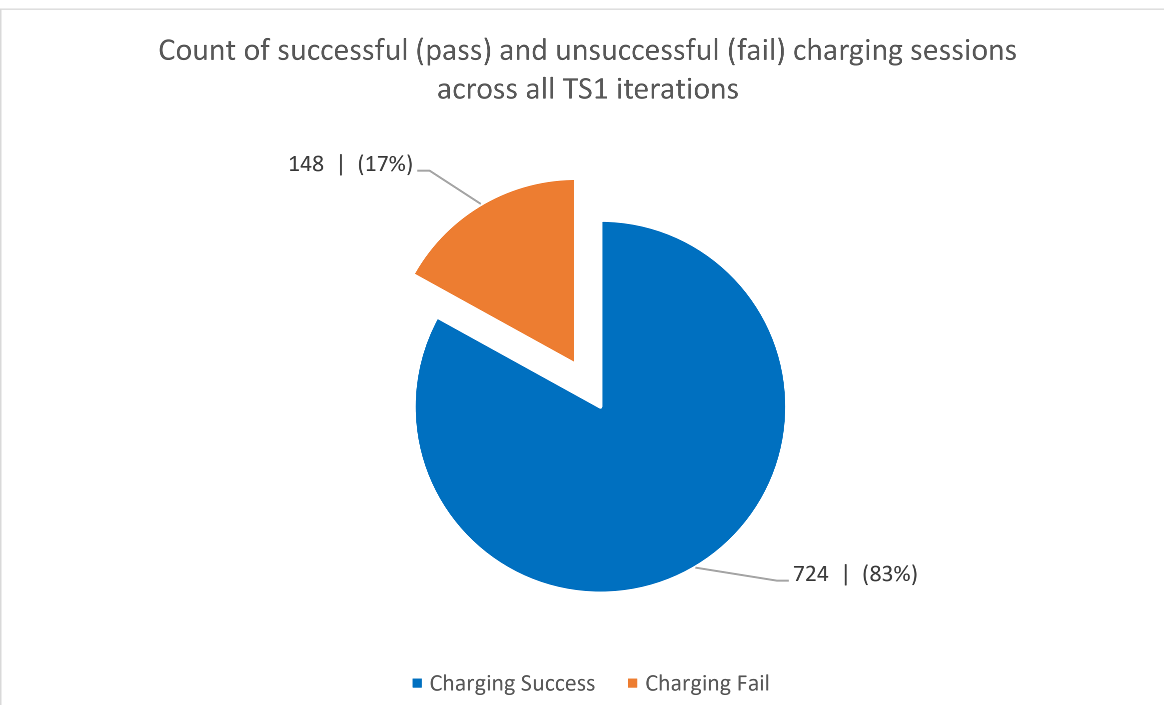

Figure 32 TS1 pass / fail ratio across all iterations

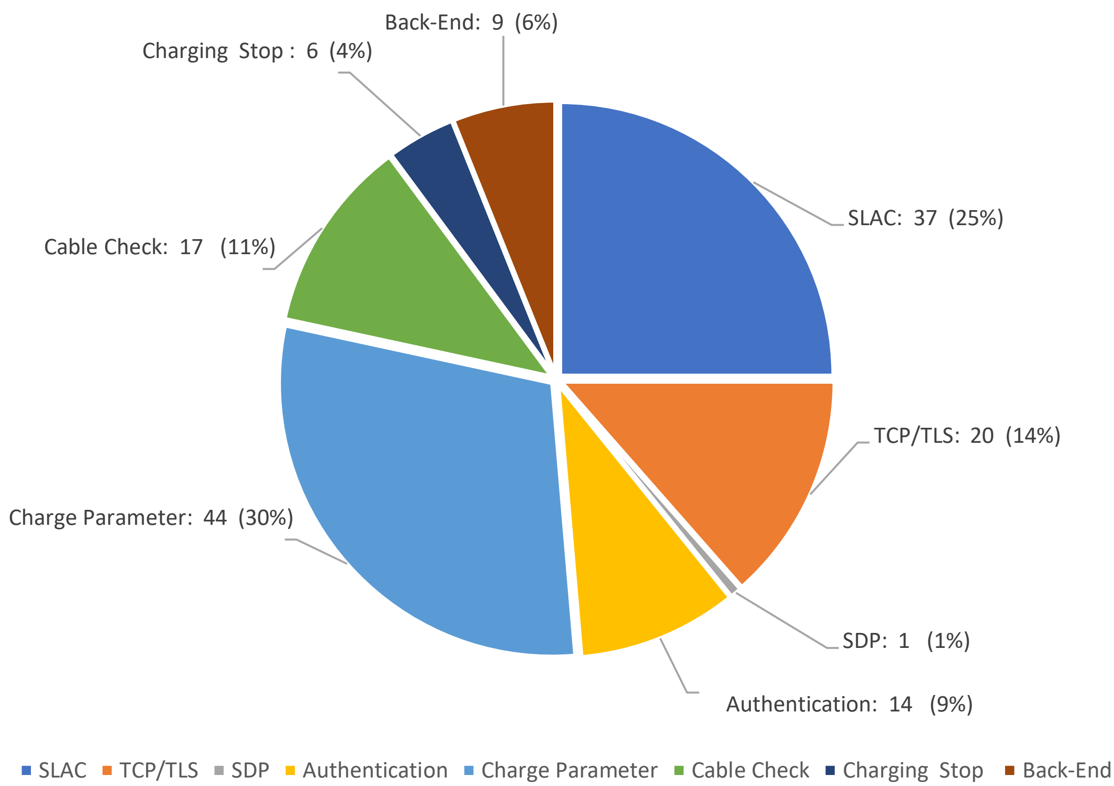

Figure 33 TS1: Reported reason for unsuccessful charging session

Of the 148 failed charging sessions, 25 percent reported a SLAC interoperability issues that means the EV and EVSE have not been able to establish a PLC data link. Another 14 percent reported a TCP/TLS interoperability issue, 1 percent reported a SECC discovery issue, and 9 percent reported issues during the authentication. These data suggest that, overall, 53 percent of the charging attempts did not complete the initial handshake and authentication.

In addition, 30 percent of unsuccessful sessions reported charge parameter issues, which means the EV and EVSE were not able to successfully exchange the parameters for a successful charging session. Similarly, 11 percent reported issues during the cable check process and the remaining interoperability issues were related to backend and charging termination issues.

4.2 Section C: TS2: Test Scenario – EV Shift Position

This baseline test includes manipulating the EV shift position while the connector is plugged in and charging. The following scenarios were tested:

- TS2-A: EV Shift Position - During charging
- TS2-B: EV Shift Position - EV is on, in neutral mode (N) and (hand) brake is on
- TS2-C: EV Shift Position - EV is on, in drive mode (D) and (hand) brake is on
- TS2-D: EV Shift Position - EV is off, in neutral mode (N) and (hand) brake is on
- TS2-E: EV Shift Position - After charging but NOT unplugged

These tests may not be executable where the EV is replaced by a test system and vice versa.

4.2.1 TS2-A: EV Shift Position - During charging

Procedure:

Pre-Condition: EV is off, in parking mode (P) and (hand) brake is on.
Attempt to initiate a charging session. During charging, attempt to move the EV (Turn EV on, Switch into drive mode (D), release the (hand) brake and then try to start driving).

The participants were required to report behaviors on the EVSE and EV as follows.

- Executed (pass) - EV cannot move before charging is stopped and connector is unplugged
- Executed (fail) - EV could be moved
- Executed (fail) - Please provide details
- Not applicable - Please provide details

4.2.1 TS2-A: EV Shift Position - During Charging

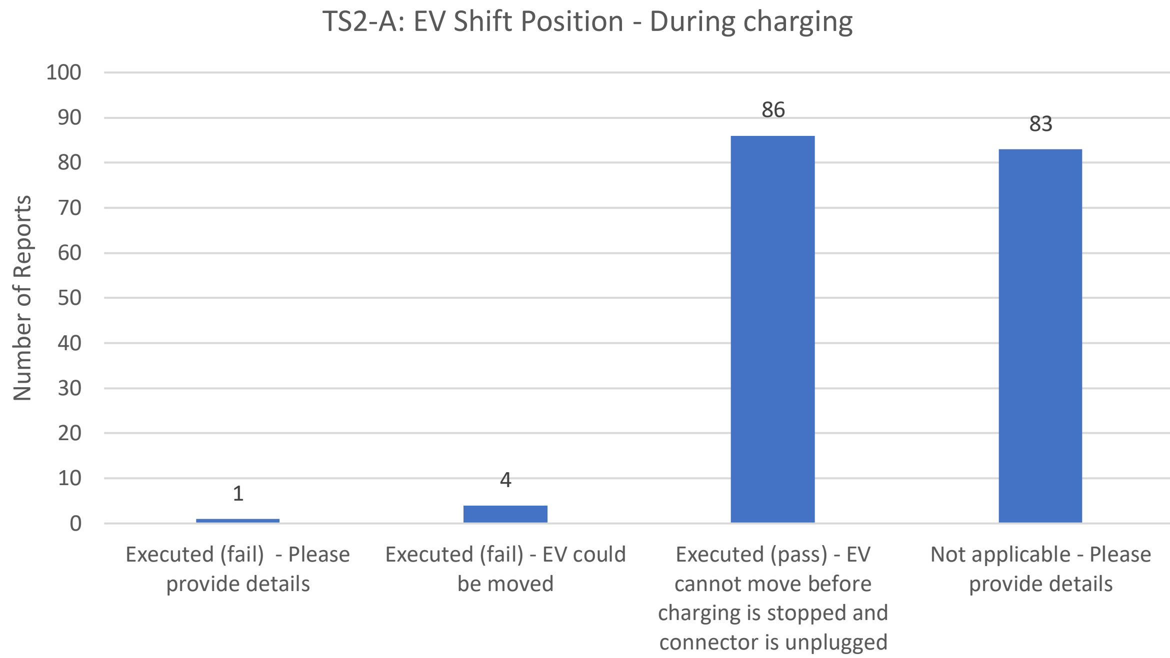

Figure 34 TS2-A – EV Shift Position - During Charging

As shown in Figure 35, 83 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario. In total, 91 test pairs executed this test scenario and 94 percent of these test were successful (EV was not able to move). In 4 cases, it was reported that the EV was able to move despite an active charging process.

4.2.2 TS2-B: EV Shift Position - EV is on, in neutral mode (N) and (hand) brake is on

Procedure:

Pre-Condition: EV is on, in neutral mode (N) and (hand) brake is on.
Attempt to initiate a charging session. If charging is possible, try to move the EV (Switch into drive mode (D) and release the (hand) brake, then try to start driving).

The participants were required to report behaviors on the EVSE and EV as follows.

- Executed (pass) - EV cannot move before charging is stopped and connector is unplugged
- Executed (pass) - Charging is not possible in neutral mode (N) and (hand) brake is on
- Executed (fail) - EV could be moved
- Executed (fail) - Please provide details
- Not applicable - Please provide details

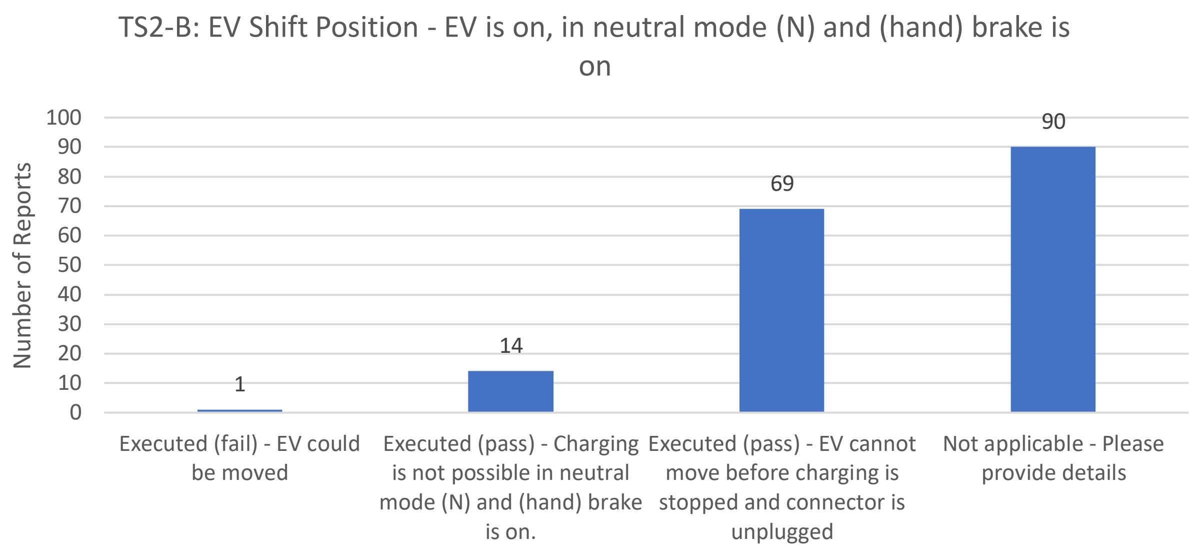

Figure 35 TS2-B – EV Shift Position - EV is on, in neutral mode (N) and (hand) brake is on

As seen in Figure 36, 90 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario. In total, 84 test pairs executed this test scenario and 99 percent of these were successful (the EV was not able to move). In 1 case, it was reported that the EV was able to move despite an active charging process.

4.2.3 TS2- C: EV Shift Position - EV is on, in drive mode (D) and (hand) brake is on

Procedure:

Pre-Condition: EV is on, in drive mode (D) and (hand) brake is on. Attempt to initiate a charging session (EV may switch to parking mode (P)).

If charging is possible, try to move the EV (Switch into drive mode (D) if not already, release the (hand) brake and then try to start driving).

During testing:
The participants are required to report behaviors on the EVSE and EV as follows.

- Executed (pass) - EV cannot move before charging is stopped and connector is unplugged
- Executed (pass) - Charging is not possible in drive mode (D) and (hand) brake is on
- Executed (fail) - EV could be moved
- Executed (fail) - Please provide details
- Not applicable - Please provide details

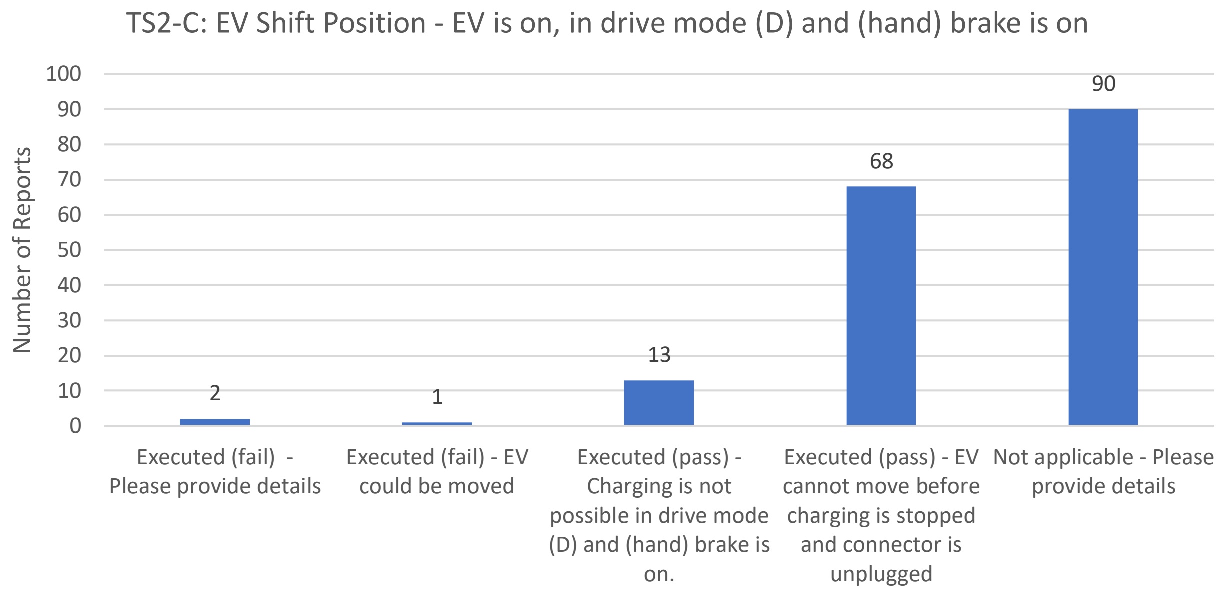

Figure 36 TS2-C – EV is on, in drive mode (D) and (hand) brake is on

In Figure 37, 90 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario. In total, 84 test pairs executed this test and 98 percent were successful (the EV was not able to move). In 3 cases, it was reported that the EV was able to move despite an active charging process.

4.2.4 TS2- D: EV Shift Position - EV is off, in neutral mode (N) and (hand) brake is on

Procedure:

Pre-Condition: EV is off, in neutral mode (N) and (hand) brake is on (EV may switch to parking mode (P)). Attempt to initiate a charging session.

If charging is possible, try to move the EV (Switch into neutral mode (D), if not already, and release the (hand) brake then try to move (push) EV if possible).

This shall simulate what happens if the EV is parked in a sloped position and the (hand) brake can be released during charging.

During testing:
The participants are required to report behaviors on the EVSE and EV as follows.

- Executed (pass) – EV cannot move before charging is stopped and connector is unplugged
- Executed (pass) – Charging is not possible in drive mode (D) and (hand) brake is on
- Executed (fail) – EV could be moved
- Executed (fail) – Please provide details
- Not applicable – Please provide details

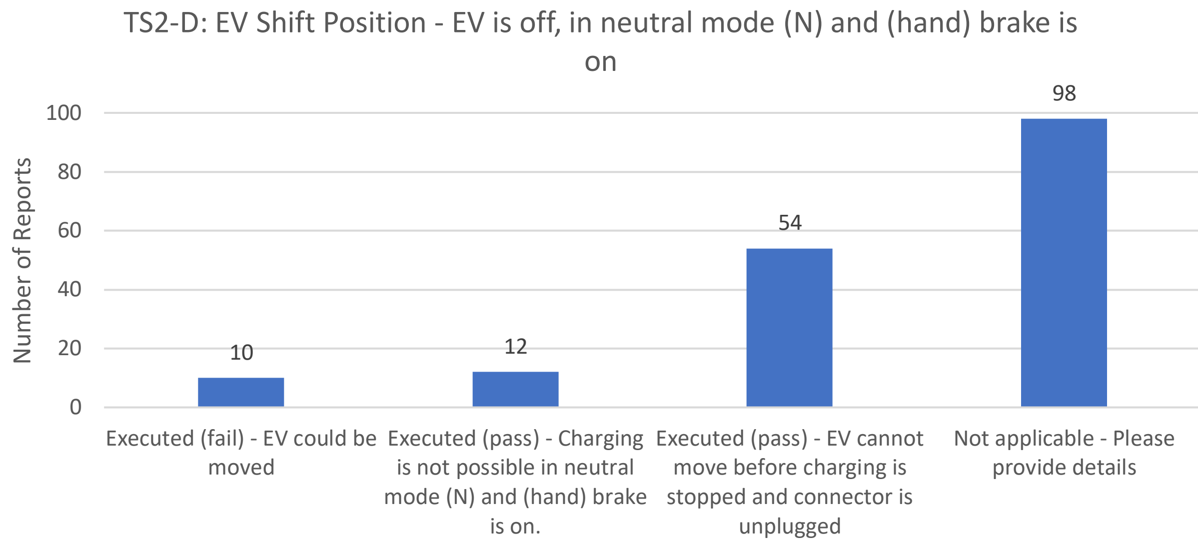

Figure 37 TS2-D – EV Shift Position – EV is off, in neutral mode (N) and (hand) brake is on

Depicted in Figure 38, 98 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario. In total, 76 test pairs executed this test. In 10 cases, it was reported that the EV may be able to move despite an active charging process (the hand brake can be released while shift is in N position). This scenario may be important for larger vehicles or for EVSE installed on a sloped road.

4.2.5 TS2- E: EV Shift Position – After charging but NOT unplugged

Procedure:

Pre-Condition: EV is in parking mode (P) and (hand) brake is on. Attempt to initiate a charging session. Charge for 1 min and then stop the charging process at the EVSE or test system.
After charging keep the connector plugged in and try to move the EV (Switch into drive mode (D) and release the (hand) brake, try to start driving).

During testing:
The participants are required to report behaviors on the EVSE and EV as follows.

- Executed (pass) – EV cannot move before connector is unplugged
- Executed (fail) – Please provide details
- Not applicable – Please provide details

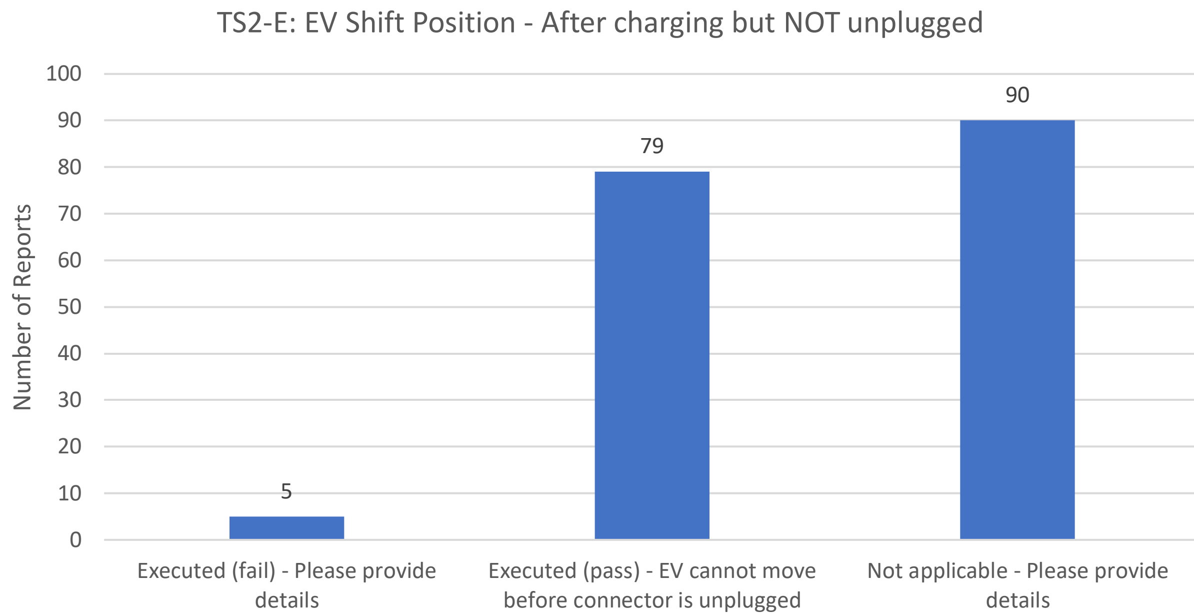

Figure 38 TS2-E – EV Shift Position – After charging but NOT unplugged

The histogram in Figure 39 shows that 90 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario. In total, 84 test pairs executed this test. In 5 cases, test pairs reported that the EV was able to move despite an active charging process.

4.2.6 Summary Section C: TS2: Test Scenario – EV Shift Position

The testing did indicate, based on the reporting, that under certain circumstances it might be possible that the EV can be moved while charging or plugged in. Test data indicate that this was particularly common among medium- and heavy-duty vehicles.

4.3 Section D: TS3: Test Scenario – Charger Connector Lock Fault

This baseline test includes testing and manipulating the charge connector to produce a lock fault. Lock faults may occur when twisting the cable, putting pressure on the cable, partly inserting the connector, and so on.

- TS3: Charger Connector Lock Fault

These tests may not be executable where the EV is replaced by a test system and vice versa.

4.3.1 TS3 Charger Lock Fault

Procedure:

Try to place the charger connector in a false position to produce a lock fault (twisting the cable, putting pressure on the cable, partly inserting the connector, and so on). Attempt to initiate a charging session.

During testing:
Check the behavior on the EVSE and EV and report the results as prompted below. If a lock fault could be produced, please provide details on how this could be achieved and if it is reproducible.

The participants are required to report behaviors on the EVSE and EV as follows.

- Executed (pass) – Charger Connector could not be placed in a false position to produce a Lock Fault
- Executed (pass) – Charger Connector could be placed in a false position to produce a Lock Fault but the EV detects the fault and reports it via EVErrorCode = “FAILED_ChargerConnectorLockFault”
- Executed (fail) – Charger Connector could be placed in a false position to produce a Lock Fault but this was not detected by the EV
- Executed (fail) – Please provide details
- Not applicable – Please provide details

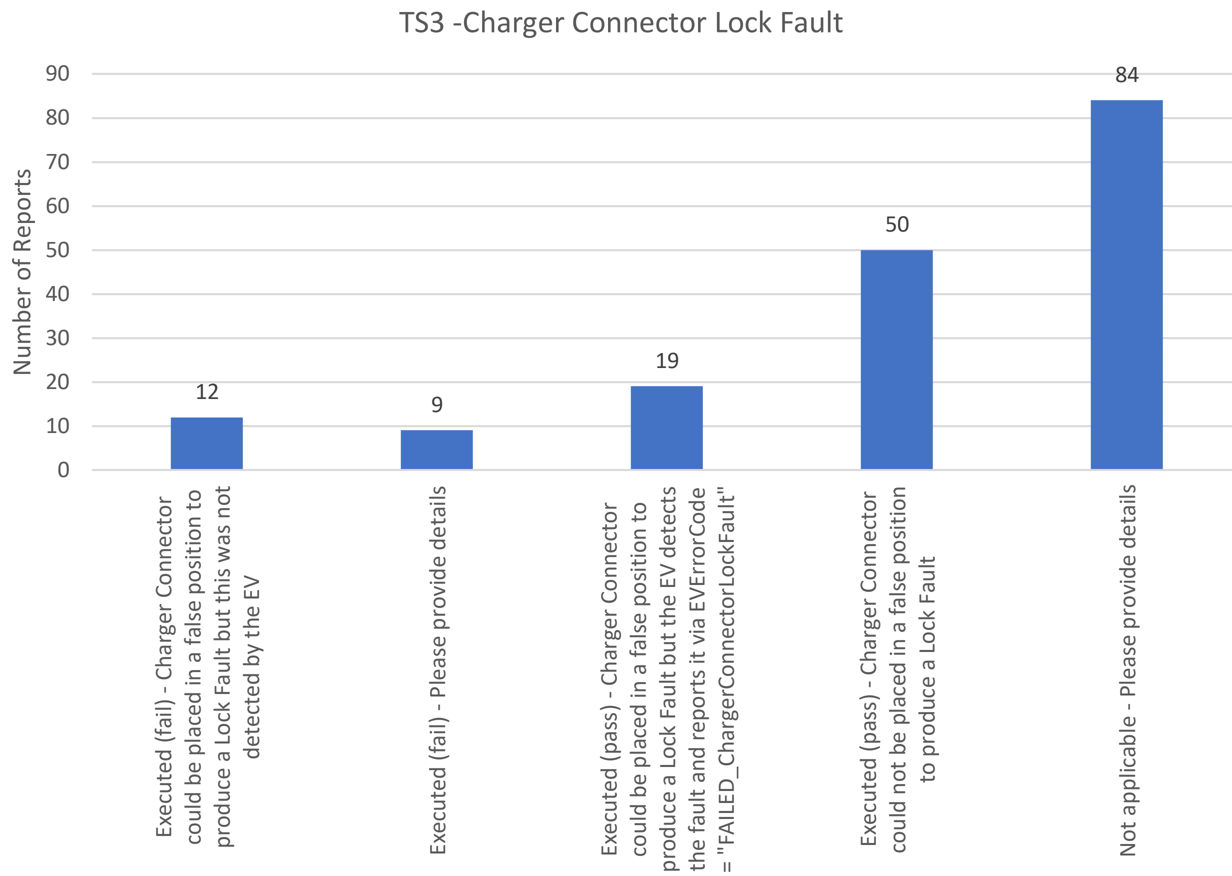

Figure 39 TS3 – Charger Connector Lock Fault

As seen in Figure 40, 84 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario. In total, 84 test pairs executed this test. In 21 instances, the test pair reported that a lock fault could be produced but the EV did not detect the fault or respond with an error message. In 2 instances, it was reported that it was possible to disconnect the connector while charging was ongoing (resulting in a “hot disconnect;” see also test scenario TS4 below).

4.4 Section E: TS4: Test Scenario – Charger Connector Latch Pressed

This baseline test includes manipulating the charger connector latch while charging. This scenario simulates a situation where someone tries to interrupt a charging session by removing the connector. In such instances, hot disconnects, where the connector is removed even while charging is in process, should be avoided.

- TS4: Charger Connector Latch pressed

These tests may not be executable where the real EV is replaced by a test system and vice versa.

4.4.1 TS4 Charger Connector Latch Pressed

Procedure:

Attempt to initiate a charging session (EV doors may need to be locked).

During charging, press the charger connector latch.

During testing:
Please check the behaviors on the EVSE and EV and report the results as answers below.

The participants are required to report behaviors on the EVSE and EV as follows:

- Executed (pass) - Latch cannot or (marginal) be pressed (S3 does NOT switch) and has no impact on charging (not stopped) and the connector cannot be removed
- Executed (pass) - Latch can be pressed (S3 switched), charging session ends and the connector be removed after current drops < 5A in 30 seconds
- Executed (fail) - Latch can be pressed (S3 switched), charging session ends and the and the connector cannot be removed
- Executed (fail) - Latch can be pressed (S3 switched) and has no impact on charging (not stopped) and connector cannot be removed
- Executed (fail) - Latch can be pressed (S3 switched) and has no impact on charging (not stopped) and the connector could be removed
- Executed (fail) - Please provide details
- Not applicable - Please provide details

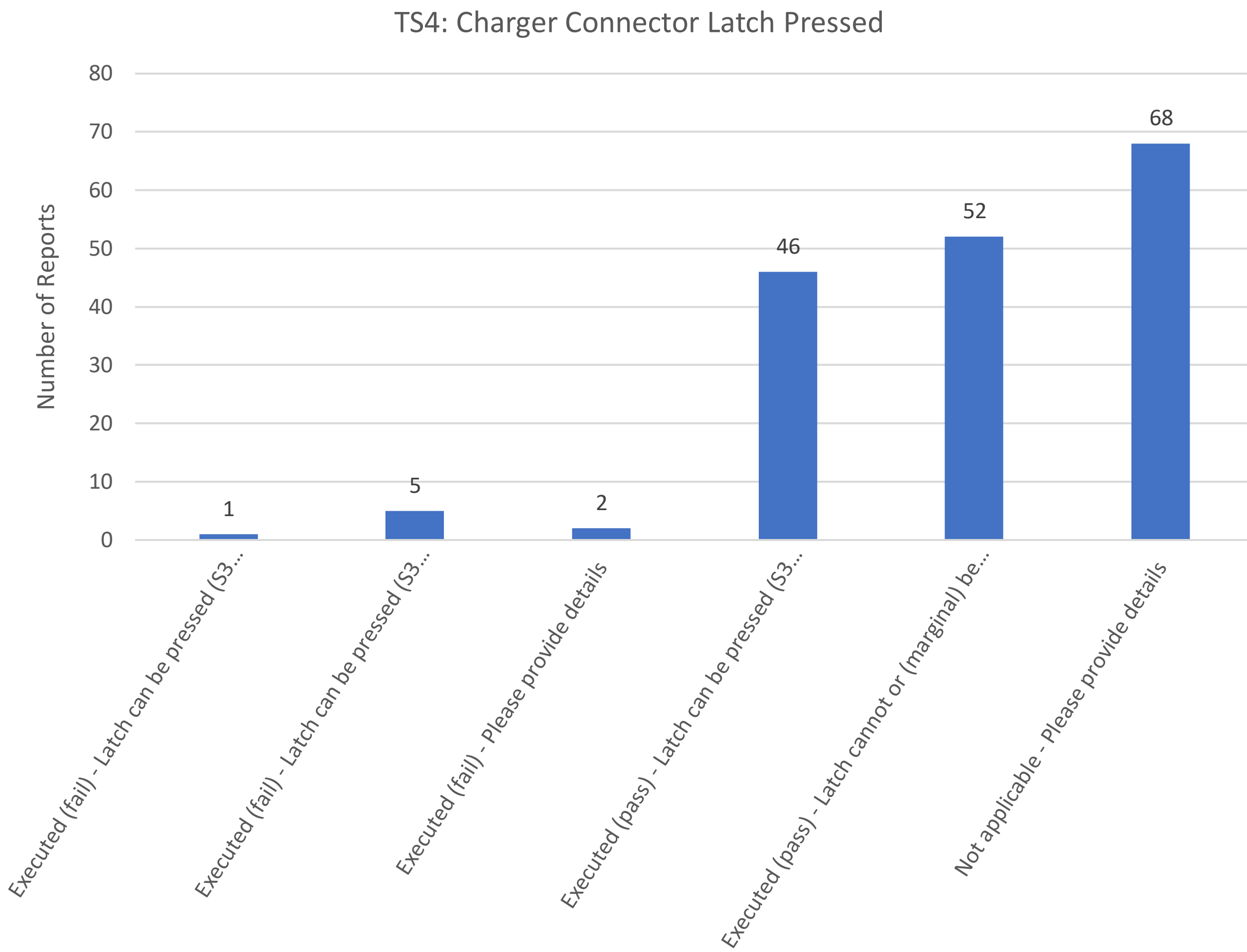

Figure 40 TS4– Charger Connector Latch Pressed

Figure 41 shows that 68 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario. In total, 106 test pairs executed this test and 8 test pairs reported a fault. In 2 instances, it was reported that after pressing the latch it was still possible to immediately remove the connector. No further details were provided on whether a hot disconnect occurred, but in these 2 instances, it is likely that the current reduction of the EVSE would not meet the 30 milliseconds requirement. This could constitute a potential safety hazard when removing the connector (hot disconnect).

Note: SAE J1772 states “EVSE shall detect the invalid Pilot or Proximity state and begin ramping down output current within 30 milliseconds (t31-t30). Current shall drop to less than 5 A at a minimum rate of -200 A/second or faster.”

4.5 Section F: TS5: Test Scenario – Emergency Stop by EVSE

This baseline test includes testing and manipulating the emergency stop button of the EVSE while charging.

- TS5-A: Behavior after pushing the emergency stop button during charging (before cable check)
- TS5-B: Behavior after pushing the emergency stop button during charging (while charging)

These tests may not be executable when the real EV is replaced by a test system and vice versa.

4.5.1 TS5-A: Behavior after pushing the emergency stop button during charging

Procedure:

Attempt to initiate a charging session. Push the emergency stop button before cable check (during authentication).

During testing:
Please check the behaviors on the EVSE and EV and report the results as answers below.

The participants are required to report behaviors on the EVSE and EV as follows:
- Executed (pass) – Successful stop / emergency stop
- Executed (fail) – Please provide details
- Not applicable – Please provide details

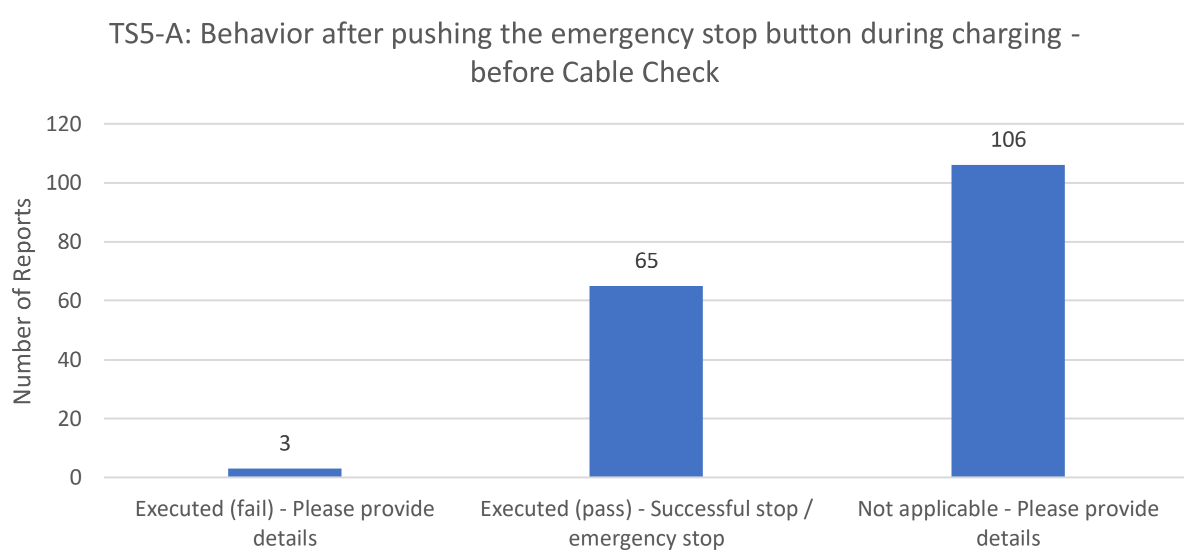

Figure 41 TS5-A – Behavior after pushing the emergency stop button during charging – before Cable Check

The chart in Figure 42 shows that 106 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario. In total, 68 test pairs executed this test. In 3 instances, test pairs reported a fault. 2 test pairs reported a stopping (shutdown) time longer than what is allowed by the standards (e.g. SAE J1772, IEC

61851-23). In addition, 1 test pair reported that the EV did not recognize that the pulse width modulation signal changed from 5 percent to 100 percent.

4.5.2 TS5-B: Behavior after pushing the emergency stop button during charging

Procedure:

Attempt to initiate a charging session. Push the emergency Stop button during CurrentDemand (charge cycle).

During testing:
Please check the behaviors on the EVSE and EV and report the results as answers below.

The participants are required to report behaviors on the EVSE and EV as follows:

- Executed (pass) - Successful stop / emergency stop
- Executed (fail) - Please provide details
- Not applicable - Please provide details

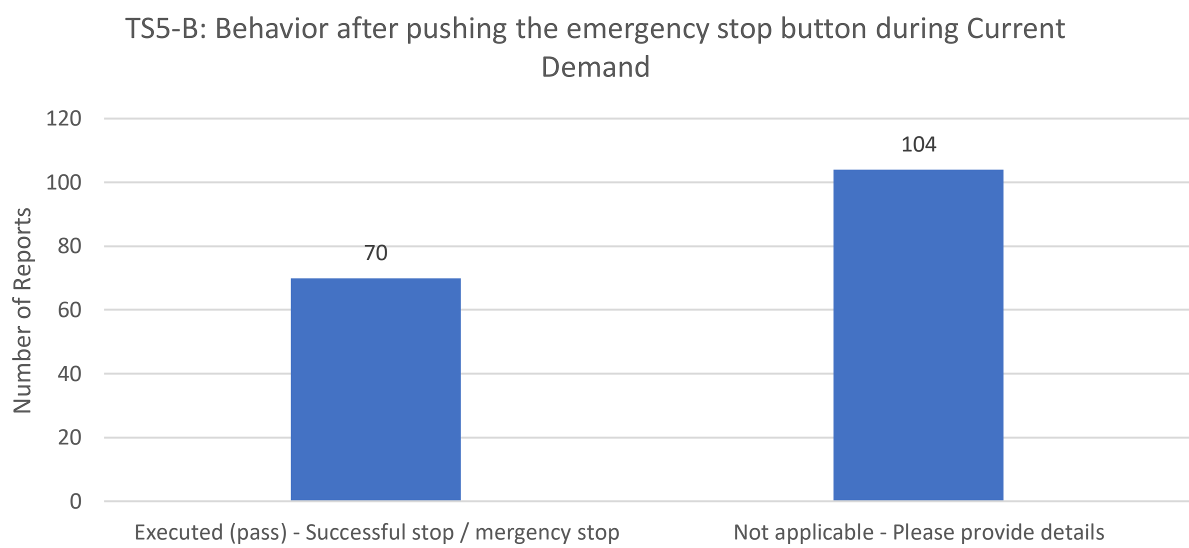

Figure 42 TS5-B – Behavior after pushing the emergency stop button during Current Demand

Some tests were not completed. That is, 104 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario. In total, 70 test pairs have been executing this test with a positive result. All test pairs reported successful emergency stops.

4.6 Section G: CTS1: Conditional Test Scenario - Charging EIM with ISO 15118-2

This conditional test includes testing ISO 15118-2 with external identification means such as RFID card (external identification means excludes PnC).

— CTS1: Intentional Charging EIM with ISO 15118-2

These tests may not be executable by EV, EVSE and test systems that do not provide ISO 15118 support.

4.6.1 CTS1: Conditional Test Scenario - Charging EIM with ISO 15118-2

Procedure:

Attempt to initiate a charging session. Charge for 1 minute and then stop the charging process using the EVSE, EV, or test system.

During testing:

The participants are required to report behaviors on the EVSE and EV as follows:

— Executed (pass) - Successful stop without any error after 1 minute of normal charging
— Executed (fail) - Please provide details
— Not applicable - Please provide details

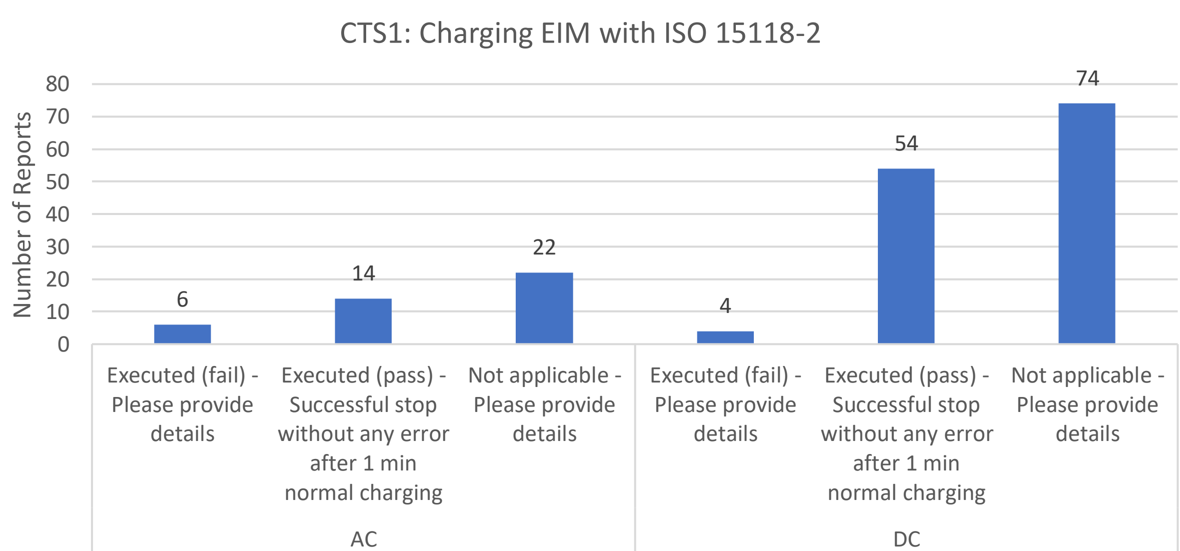

Figure 43 CTS1 – Charging EIM with ISO 15118-2

For this conditional test scenario, a total of 42 test reports for AC charging were submitted. 14 test pairs reported a successful ISO 15118 charging session while 6 pairs have reported problems with ISO 15118 charging. The remaining 22 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario.

Additionally, a total of 132 test reports For DC charging were submitted. 54 test pairs reported a successful ISO 15118 charging session while 4 pairs reported problems with ISO 15118 charging. The remaining 74 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario.

4.7 Section H: CTS2: Conditional Test Scenario - Charging using PnC with ISO 15118-2

This conditional test includes testing ISO 15118-2 using the PnC service.

All required V2G certificates to enable PnC were made available by Keysight Technologies and distributed to all participants via email prior to the event. Test participants were asked to provision these V2G certificates to the equipment where applicable. The certificates are provided in both PEM & DER format.

- Number of root certificates
    - Multiple root certificates are provided to test whether the leaf certificate is properly validated against the root certificate.
- Number of certificate chain and sub-certificates between Root-CA and Leaf
    - Two different certificates chains each with two sub-certificates are provided for testing
    - ISO 15118 parameters for Test PKI-1 (Multiple Root CA) is used as the default for the testing event
    - ISO 15118 parameters for Test PKI-2 (Single V2G Root CA) is optionally used if agreed upon by the test pair for this test scenario (CTS2-B)
- For testing the Certificate Update and Certificate Installation, the following certificates properties are provided:
    - One contract certificate will be valid for ~2 year
    - One contract certificate will expire before the Testival
    - One contract certificate will expire ~one week after the Testival

In addition, the following invalid certificates were provided to all PnC participants:

CRT_CONTRACT_LEAF_EXPIRED	Leaf Certificate has expired
CRT_CONTRACT_LEAF_EXPIRED_ISSUER_SUB1	Leaf Certificate was derived from expired SUB 1 Certificate
CRT_CONTRACT_LEAF_EXPIRED_ISSUER_SUB2	Leaf Certificate was derived from expired SUB 2 Certificate
CRT_CONTRACT_LEAF_EXPIRES	Leaf Certificate expires soon
CRT_CONTRACT_LEAF_INVALID_CONTENT	The Subject contains a Country Name (not allowed -> see Table F.4 in the standard)
CRT_CONTRACT_LEAF_INVALID_EMAID	EMAID has an invalid syntax
CRT_CONTRACT_LEAF_WRONG_EMAID	EMAID differs from the original version when the contract was concluded (Syntax is correct).
CRT_EVSE_LEAF_EXPIRED	Leaf Certificate has expired
CRT_EVSE_LEAF_EXPIRES	Leaf Certificate expires soon
CRT_MO_SUB1_EXPIRED	SUB 1 Certificate has expired
CRT_MO_SUB2_EXPIRED	SUB 2 Certificate has expired

CRT_MO_SUB2_EXPIRED_ISSUER_SUB1	SUB 2 Certificate was derived from expired SUB 1 Certificate
CRT_OEM_LEAF_EXPIRED	Leaf Certificate has expired
CRT_OEM_LEAF_EXPIRES	Leaf Certificate expires soon
CRT_OEM_LEAF_INVALID_CONTENT	The Domain Component is set to "INVALID" and not "OEM" (not allowed -> see Table F.4 in the standard)
CRT_PROV_LEAF_EXPIRED	Leaf Certificate has expired
CRT_PROV_LEAF_EXPIRES	Leaf Certificate expires soon

Table 5 Invalid Certificate used for Testing

The following test scenarios are used to test PnC:

- CTS2-A: Intentional charging using PnC with ISO 15118-2 (PKI1 vs. PKI1)
- CTS2-B: Charging using PnC with ISO 15118-2 and different PKI (PKI1 vs. PKI2)
- CTS2-C: Charging using PnC with ISO 15118-2 with an invalid certificate
- CTS2-D: Charging using PnC with ISO 15118-2 with an expired certificate
- CTS2-E: Intentional charging using PnC with ISO 15118-2 (PKI1 vs. PKI1) and Certificate Installation before charging

These tests may not be executable by EV, EVSE, and test systems that do not provide ISO 15118 support.

4.7.1 CTS2-A: Intentional charging using PnC with ISO 15118-2 (PKI1 vs. PKI1)

Procedure:

Attempt to initiate charging with PnC authentication. Both EV and EVSE shall be configured to use the provided test PKI1.

During testing:

The participants are required to report behaviors on the EVSE and EV as follows:

- Executed (pass) - Successful stop without any error after 1 minute of normal charging
- Executed (fail) - Authentication Issue PnC
- Executed (fail) - Please provide details
- Not applicable - Please provide details

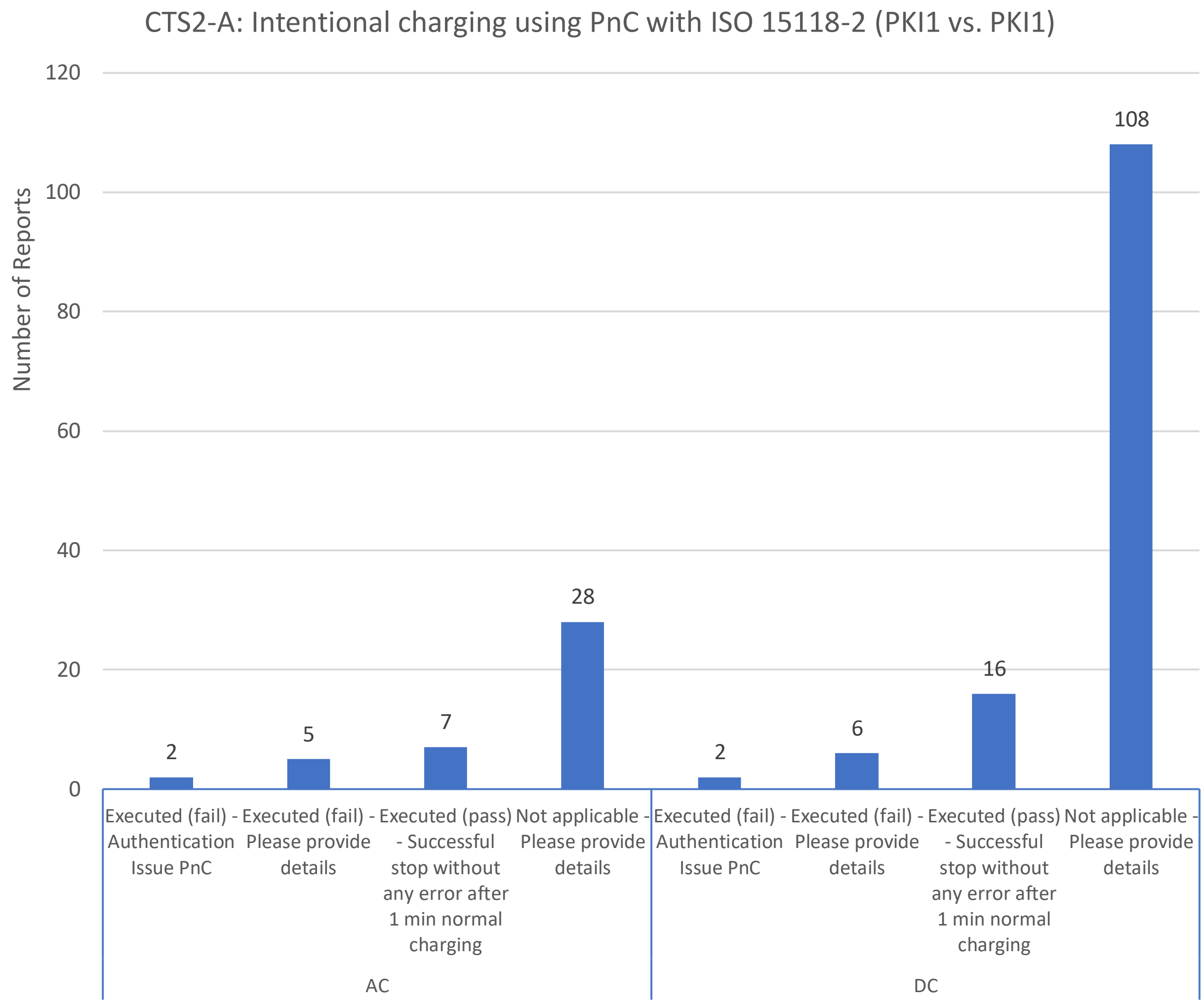

Figure 44 CTS2 -A – Intentional charging using PnC with ISO/ 15118-2 (PKI1 vs. PKI1)

For AC charging, 42 reports were submitted for this conditional test scenario. Of the test pairs, 7 reported a successful ISO 15118 PnC based charging session, while 7 pairs have reported problems with ISO 15118 PnC charging. The remaining 28 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario.

Additionally, for DC charging, 132 reports were submitted. 16 test pairs reported a successful ISO 15118 PnC based charging session, while 8 pairs have reported problems with ISO 15118 PnC charging. The remaining 108 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario.

4.7.2 CTS2-B: Charging using PnC with ISO 15118-2 and different PKI (PKI1 vs. PKI2)

Procedure:

Attempt to initiate charging with PnC authentication. The EV shall be configured to use the provided test PKI 1 and the EVSE shall be configured to use the provided test PKI 2. During testing:

The participants are required to report behaviors on the EVSE and EV as follows:

- Executed (pass) - TLS connection cannot be established
- Executed (pass) - Authentication Issue PnC
- Executed (fail) - Successful stop without any error after 1 min normal charging
- Executed (fail) - Please provide details
- Not applicable - Please provide details

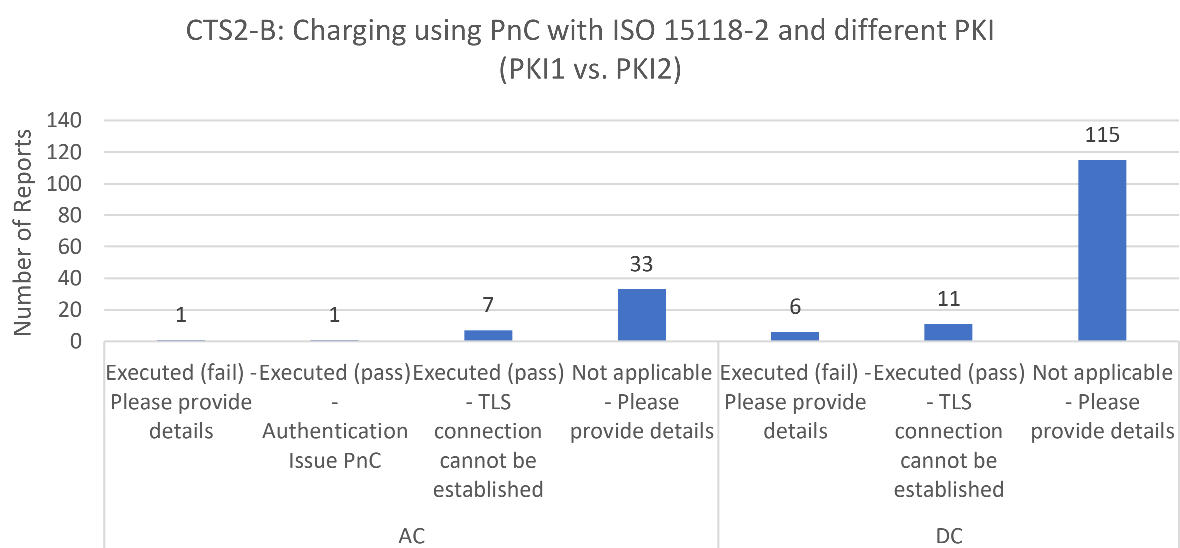

Figure 45 CTS2 -B – Charging using PnC with ISO 15118-2 and different PKI (PKI1 vs. PKI2)

For AC charging, 42 reports were submitted for this conditional test scenario. Of the test pairs, 7 reported a successful test – in this case no TLS connection was established. Also, 2 pairs reported failures. The remaining 33 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario.

Additionally, for DC charging, 132 reports were submitted. 11 test pairs reported a successful test – in this case no TLS connection was established. In addition, 6 pairs reported failures. The remaining 115 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario.

4.7.3 CTS2-C: Charging using PnC with ISO 15118-2 with an invalid certificate

Test steps:

Attempt to initiate charging with PnC authentication. Both EV and EVSE shall be configured to use the provided test PKI1.

The EV shall use the invalid contract certificate of PKI 1 for the PnC authentication process. Try to charge for 1 minute and then stop the charging process either by EVSE or EV.

The participants are required to report behaviors on the EVSE and EV as follows:

- Executed (pass) - Authentication Issue PnC
- Executed (fail) - Successful stop without any error after 1 minute of normal charging
- Executed (fail) - Please provide details
- Not applicable - Please provide details

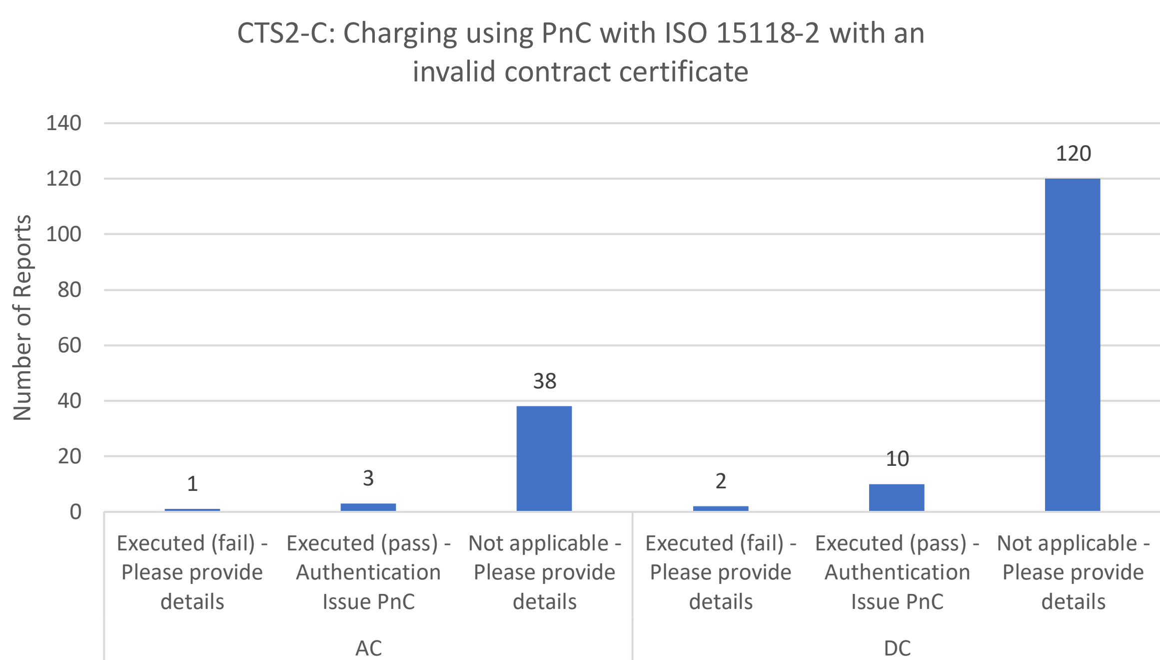

Figure 46 CTS2 -C – Charging using PnC with ISO 15118-2 with an invalid contract certificate

For AC charging, 42 reports were submitted for this conditional test scenario. Of the test pairs, 3 reported a successful test – in this case no charging was possible since the contract certificate is invalid. Also, 1 pair reported a failure. The remaining 38 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario.

Additionally, for DC charging, 132 reports were submitted. Of the test pairs, 10 reported a successful test – in this case no charging was possible since the contract certificate is invalid. Also, 2 pairs reported a failure. The remaining 115 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario.

4.7.4 CTS2-D: Charging using PnC with ISO 15118-2 with an expired certificate

Procedure:

Attempt to initiate charging with PnC authentication. Both EV and EVSE shall be configured to use the provided test PKI1.

The EV shall use the expired contract certificate of PKI 1 for the PnC authentication process. Try to charge for 1 minute and then stop the charging process either by EVSE or EV.

The participants are required to report behaviors on the EVSE and EV as follows:

- Executed (pass) - Authentication Issue PnC
- Executed (fail) - Successful stop without any error after 1 minute of normal charging
- Executed (fail) - Please provide details
- Not applicable - Please provide details

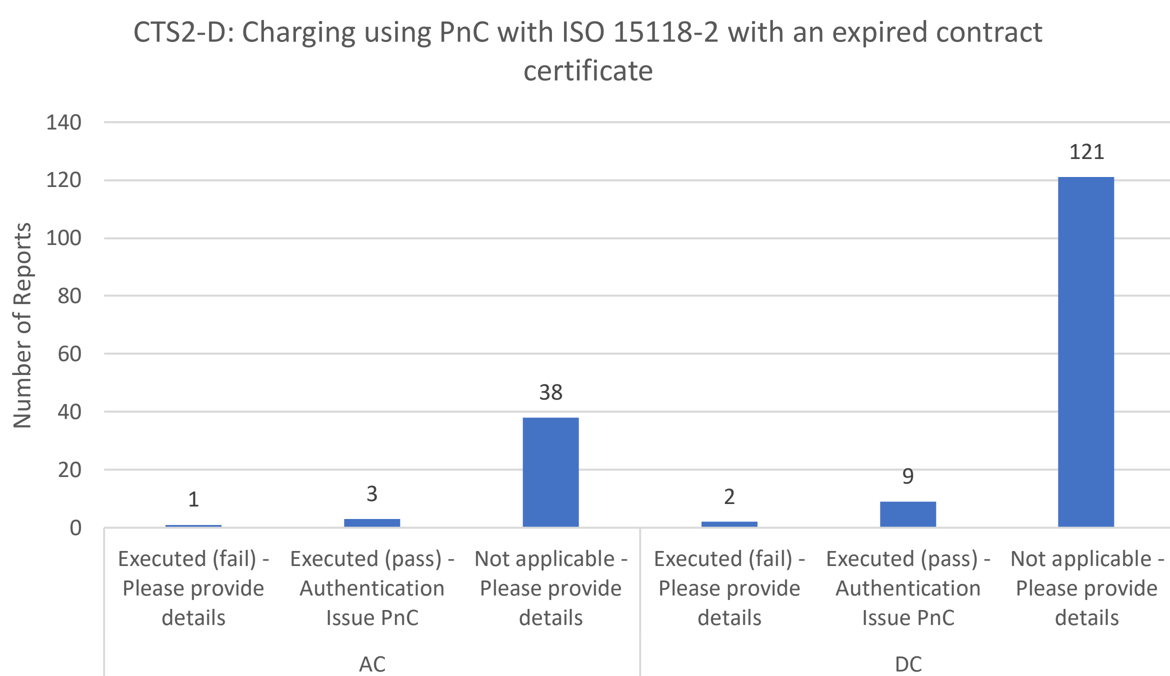

Figure 47 CTS2 -D – Charging using PnC with ISO 15118-2 with an expired contract certificate

For AC charging, 42 reports were submitted for this conditional test scenario. Of these test pairs, 3 reported a successful test – in this case no charging was possible since the contract certificate has expired. Also, 1 pair reported a failure. The remaining 38 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario.

Additionally, for DC charging, 132 reports were submitted. In this test, 9 pairs reported a successful test – in this case no charging was possible since the contract certificate has expired. For contrast, 2 pairs reported a failure. The remaining 121 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario.

4.7.5 CTS2-E: Intentional charging using PnC with ISO 15118-2 (PKI1 vs. PKI1) and Certificate Installation before charging

Procedure:

Attempt to initiate charging with PnC authentication. Both EV and EVSE shall be configured to use the provided test PKI1.

The EVSE shall be configured to provide the Certificate Installation service. The EV shall be configured such that it triggers a Certificate Installation process before charging.

The participants are required to report behaviors on the EVSE and EV as follows:

- Executed (pass) - Successful stop without any error after 1 minute of normal charging
- Executed (fail) - EVSE does not provide Certificate Installation service
- Executed (fail) - EV does not start Certificate Installation process
- Executed (fail) - Authentication Issue PnC (Certificate cannot be used)
- Executed (fail) - Please provide details
- Not applicable - Please provide details

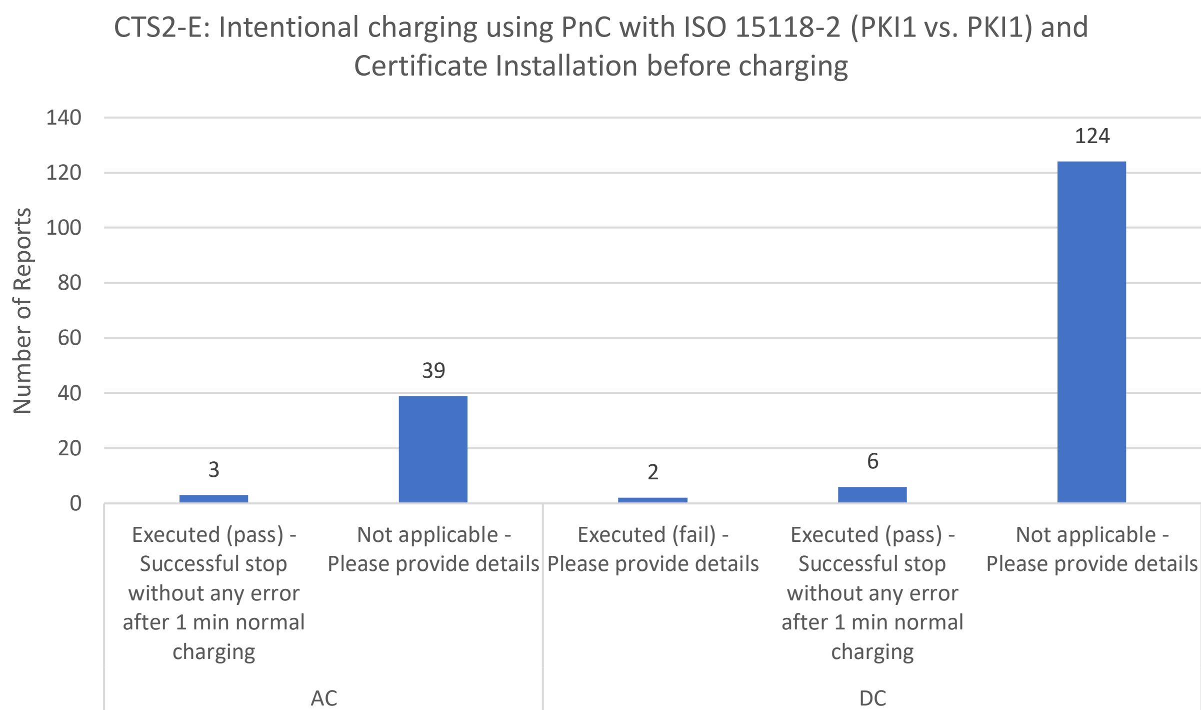

Figure 48 CTS2 -E – Intentional charging using PnC with ISO 15118-2 (PKI1 vs. PKI1) and Certificate Installation before charging

Note: Per ISO 15118-2 the EVSE is required to support certificate installation / update service.
This test scenario cannot be applied to EVs that do not support certificate installation / certificate update using ISO 15118-2 communication.

For AC charging, 42 reports were submitted. In this test group, 3 pairs reported a successful test – in this case the contract certificate was successfully installed in the EV and the charging process started. The remaining 39 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario.

Here, 2 test pairs reported that the EV does not support Certificate Installation and Certificate Update but rather certificates must be installed via OEM telematics.

Additionally, for DC charging, 132 reports were submitted, and 6 test pairs reported a successful test – in this case the contract certificate was successfully installed in the EV and the charging process started. The remaining 124 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario.

4.8 Section I: CTS3: Conditional Test Scenario - Charging using Schedules (Smart Charging) with ISO 15118-2

This conditional test includes testing ISO 15118 using schedules. Schedules allow charging to take into account grid conditions over time and facilitate what is commonly called smart or managed charging. Schedules are provided by the EVSE during the Charge Parameter Discovery and may include Pmax =0 entries forcing the EV to pause the charging session during those time intervals. The execution of testing may be dependent on the ability to support scheduling by the EVSE and EV. Typically grid schedules are communicated by secondary actors such as utilities. Grid schedules may be communicated via OCPP, OpenADR, and/or the Market Informed Demand Automation Server (MIDAS) hosted by the California Energy Commission.

No specific schedule is provided for this test scenario. The EVSE participants are free to code a schedule that meets the requirements below or use an appropriate backend that supplies a schedule meeting the requirement below.

The following test scenarios are used to test smart charging capabilities:

- CTS3-A: Intentional charging using Schedules (Smart Charging) with ISO 15118-2 containing a charging schedule with 3-5 non-zero entries
- CTS3-B: Intentional charging using Schedules (Smart Charging) with ISO 15118-2 containing a charging schedule with 3-5 entries in the operating range of both EV and EVSE where one of the entries (other than the first one) is explicitly forcing 0 Amps.
- CTS3-C: Intentional charging using Schedules (Smart Charging) with ISO 15118-2 containing a charging schedule with 3-5 entries in the operating range of both EV and EVSE where the first entry is explicitly forcing 0 Amps.

4.8.1 CTS3-A: Intentional charging using Schedules (Smart Charging) with ISO 15118-2 with charging schedule with 3-5 non-zero entries

Procedure:

Attempt to initiate charging. Both EV and EVSE shall be configured to use schedules. The EVSE shall send a charging schedule with 3-5 non-zero entries in the operating range of both the EV and EVSE. Charge for 1 minute and then stop the charging process either by EVSE or EV.

The participants are required to report behaviors on the EVSE and EV as follows:

- Executed (pass) - Successful stop without any error after 1 minute of normal charging
- Executed (fail) - Charge Parameter Issue
- Executed (fail) - Backend Issue
- Executed (fail) - Please provide details
- Not applicable - Please provide details

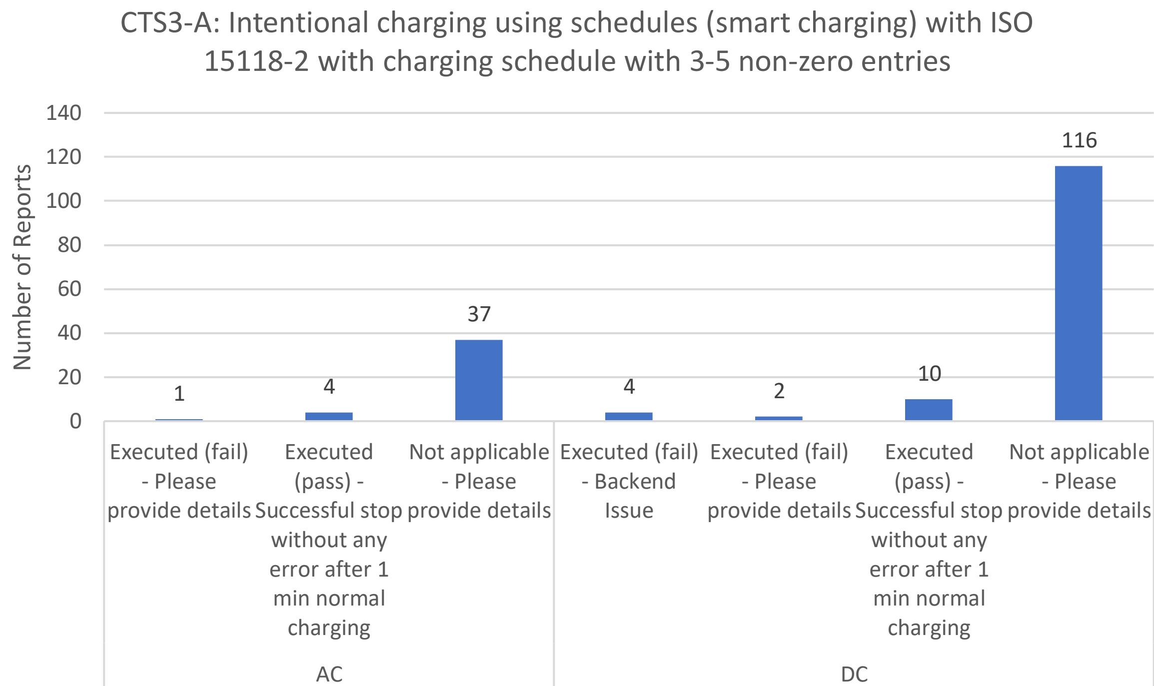

Figure 49 CTS3 -A – Intentional charging using Schedules (Smart Charging) with ISO 15118-2 with charging schedule with 3-5 non-zero entries

For AC charging, 42 reports were submitted. Here, 37 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario or the EV/EVSE does not support smart charging.

In addition, 4 test pairs reported a successful test – in this case the EV was able to process the schedule and the charging process has started. 1 test pair reported a failure where the EV did not follow the submitted schedule.

Additionally, for DC charging, 132 reports were submitted, and 116 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario or the EV/EVSE does not support smart charging. In this submission, 10 test pairs reported a successful test.

In 4 instances, it was reported that the OCPP backend was not configured for scheduled charging. It should be noted that VOLTS did not require participants to use OCPP to communicate schedules to the EVSE.

Based on reporting, at least one EV does not appear to support schedules with multiple entries.

4.8.2 CTS3-B: Intentional charging using Schedules (Smart Charging) with ISO 15118-2 with charging schedule with 3-5 entries – one entry forcing 0 Amps

Procedure:

Attempt to initiate charging. Both EV and EVSE shall be configured to use schedules.

The EVSE shall send a charging schedule with 3-5 entries in the operating range of both the EV and EVSE where one of the entries (other than the first one) is explicitly forcing 0 Amps.

Charge for 1 minute and then stop the charging process either by EVSE or EV.

The participants are required to report behaviors on the EVSE and EV as follows:

- Executed (pass) - Successful stop without any error after 1 minute of normal charging
- Executed (fail) - Charge Parameter Issue
- Executed (fail) - Backend Issue
- Executed (fail) - Please provide details
- Not applicable - Please provide details

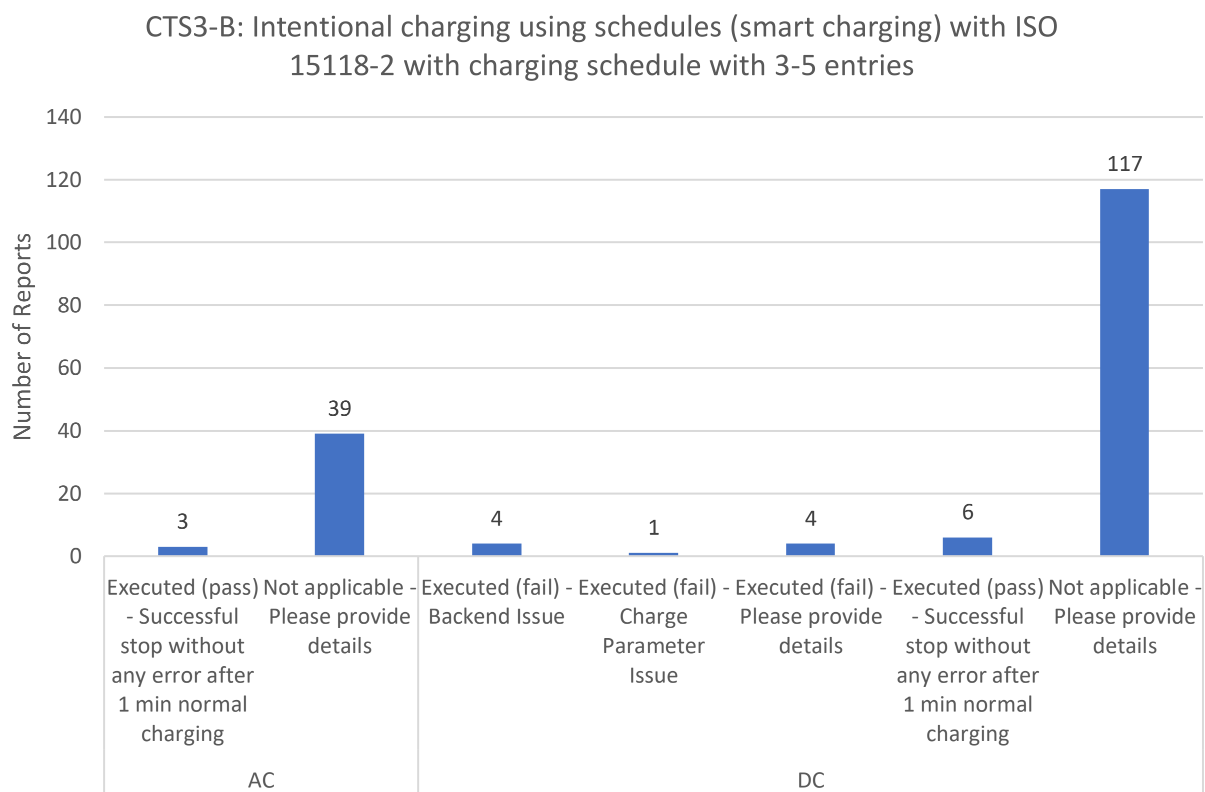

Figure 50 CTS3 -B – Intentional charging using Schedules (Smart Charging) with ISO 15118-2 with charging schedule with 3-5 entries

For AC charging 42 reports were submitted. Of this submission, 39 test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario or the EV/EVSE does not support smart charging. Also, 3 test pairs have reported a successful test.

For DC charging, 132 reports were submitted. In this test, 116 pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario or the EV/EVSE does not support smart charging. For comparison, 6 test pairs reported a successful test.

Based on reporting, at least one EV does not appear to support schedules with multiple entries.

Moreover, 4 test pairs reported that OCPP backend was not configured for smart charging. It should be noted that VOLTS did not require participants to use OCPP to communicate schedules to the EVSE.

4.8.3 CTS3-C: Intentional charging using Schedules (Smart Charging) with ISO 15118-2 with charging schedule with 3-5 entries – one entry forcing 0 Amps

Procedure:

Attempt to initiate charging. Both the EV and EVSE shall be configured to use schedules.

The EVSE shall send a charging schedule with 3-5 entries in the operating range of both EV and EVSE where the first entry is explicitly forcing 0 Amps for approximately 1 minute.

Charge for 3 minutes and then stop the charging process either by the EVSE or EV.

The participants are required to report behaviors on the EVSE and EV as follows:

- Executed (pass) – Successful stop without any error after 3 minutes of normal charging and first minute was 0 Amps
- Executed (fail) – Charge Parameter Issue
- Executed (fail) – Backend Issue
- Executed (fail) – Please provide details
- Not applicable – Please provide details

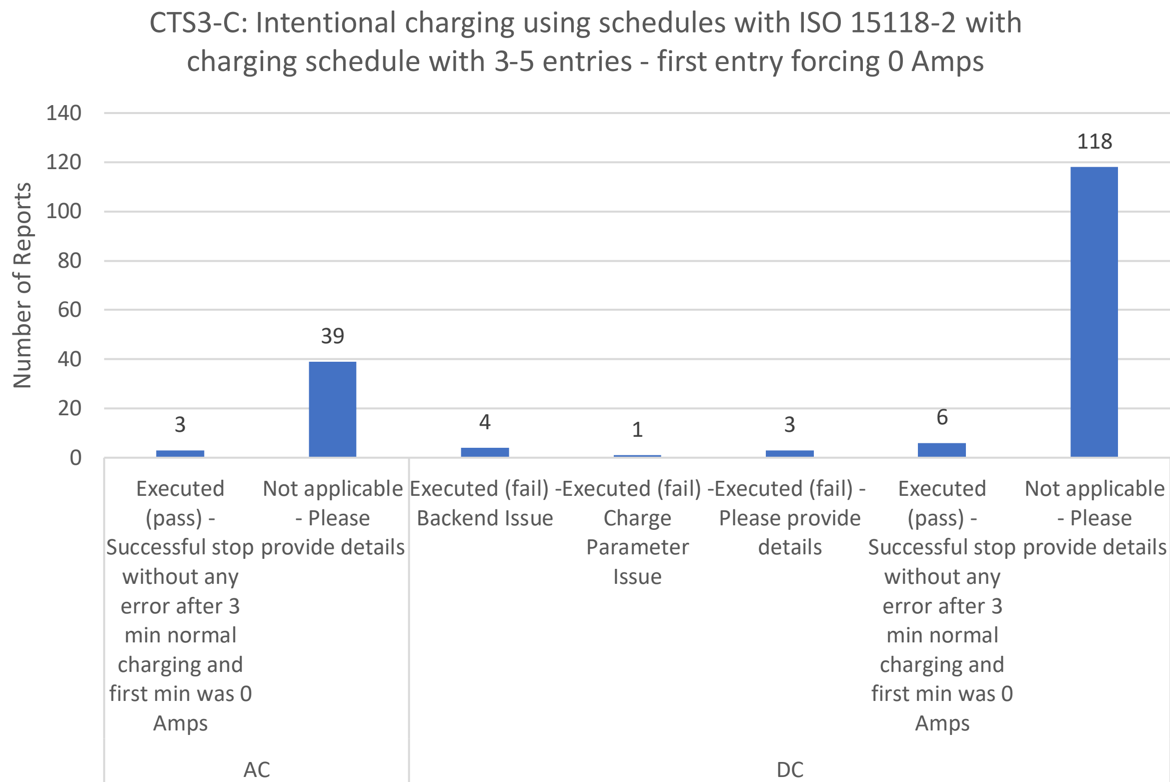

Figure 51 CTS3 -C – Intentional charging using Schedules (Smart Charging) with ISO 15118-2 with charging schedule with 3-5 entries – first entry forcing 0 Amps

For AC charging, 42 reports were submitted. The remaining 39 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario or the EV/EVSE does not support smart charging. Here, 3 test pairs have reported a successful test – in this case the EV was able to process the schedule and the charging process started with the first minute reporting zero power flow.

For DC charging, 132 reports were submitted. The remaining 118 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario or the EV/EVSE does not support smart charging. For reference, 6 test pairs have reported a successful test – in this case the EV was able to process the schedule and the charging process started with the first minute reporting zero power flow.

Based on reporting, at least one EV does not appear to support schedules with multiple entries.

Moreover, 4 test pairs reported that OCPP backend was not configured for smart charging. It should be noted that VOLTS did not require participants to use OCPP to communicate schedules to the EVSE.

4.9 Section J: CTS4: Conditional Test Scenario - Intentional Charging EIM with ISO 15118-20

This conditional test includes testing implementation using the new ISO 15118-20:2022 standard in combination with ISO 15118-3:2015. ISO 15118-20 mandates Transport Layer Security (TLS) 1.3 for all charging services. Alternatively, this test scenario allows for testing ISO 15118-20 implementation with TLS 1.2 or using TCP with no security, though this does not strictly conform with ISO 15118-20 security requirements.

The following test scenarios was used:

- CTS4-A: Intentional Charging EIM with ISO 15118-20:2022 & ISO 15118-3:2015

Procedure:

Execute good case procedure for charging. Charge for 1 minute and then stop the charging process either by the EVSE or EV.

During testing

The participants are required to report behaviors on the EVSE and EV as follows:

- Executed (pass) – Successful stop without any error after 1 minute of normal charging (using TCP)
- Executed (pass) - Successful stop without any error after 1 minute of normal charging (using TLS 1.2)
- Executed (pass) - Successful stop without any error after 1 minute of normal charging (using TLS 1.3)
- Executed (fail) - Please provide details
- Not applicable - Please provide details

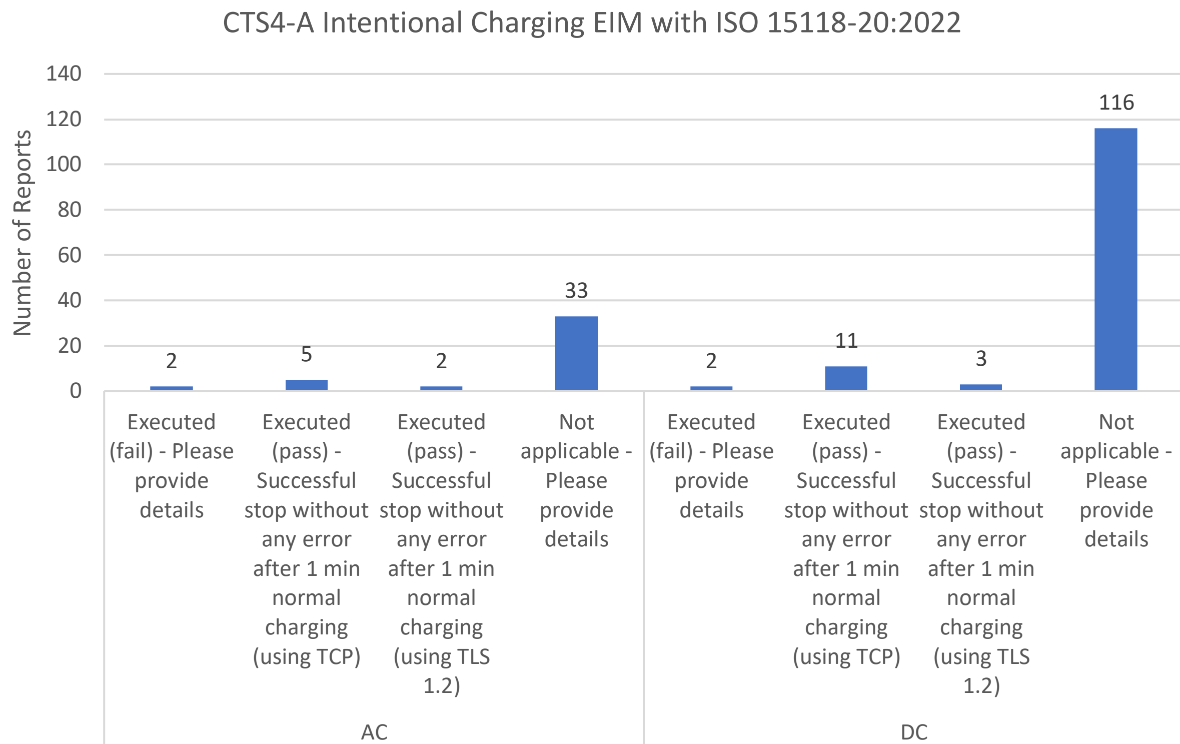

Figure 52 CTS4 -A – Intentional Charging EIM with ISO 15118-20:2022

For AC charging, 42 reports were submitted. In this submission, 33 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario.

Here, 5 test pairs reported a successful charging session using ISO 15118-20 but without TLS.

And, 2 test pairs reported a successful charging session using TLS 1.2.

There were no reports of a successful charging session using TLS 1.3 (which is the mandated security requirement in ISO 15118-20).

For DC charging, 132 reports have been submitted. In this group, 116 of the test pairs were not able to execute this test scenario either due to time constraints or because the EV, EVSE, or test equipment was not prepared for the test scenario.

Here, 11 test pairs reported a successful charging session using ISO 15118-20 but without TLS.

While, 3 test pairs reported a successful charging session using TLS 1.2.

There were no reports of a successful charging session using TLS 1.3 (which is the mandated security requirement in ISO 15118-20).

5. Test Data Findings

Over 170 test sessions were executed at VOLTS, totaling more than 1000 individual tests across the 2 days. Findings based on submitted test data are summarized below.

5.1 State of ISO 15118 Implementation

One of the goals of VOLTS was to evaluate industry readiness for ISO 15118-2, which is required under the final rules for the National Electric Vehicle Infrastructure Formula Program. The event demonstrated that industry has begun implementing ISO 15118-2, including advanced features like PnC and smart charging.

On the EVSE side, 18 of the 21 participating models supported ISO 15118. All participating AC chargers supported ISO 15118-2 and every participating AC charger except one supported PnC. Three DC EVSE only supported DIN 70121.

On the EV side, 17 models participated at VOLTS. Of these, 4 EVs supported DIN 70121 only. It is observed that medium- and heavy-duty vehicles at VOLTS were more likely to support DIN 70121 only.

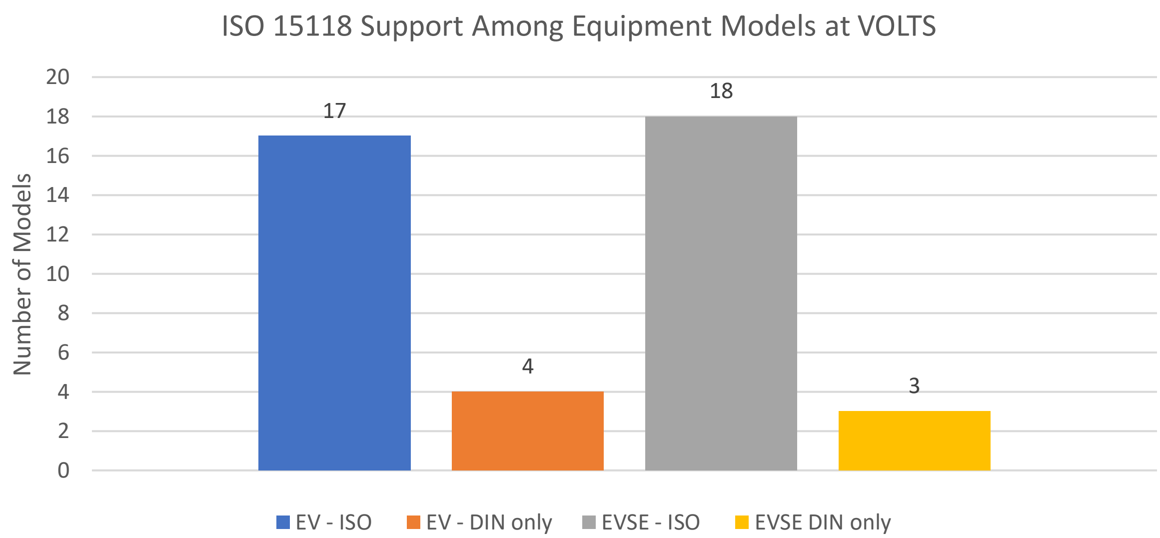

Figure 53 ISO 15118 Support Participating EV/EVSE

In 50 percent of all testing performed (resulting in either pass or fail) at VOLTS (within the Testing Schedule TS1-1 to TS1 -6, Intentional Charging), the selected default protocol was ISO 15118-2.

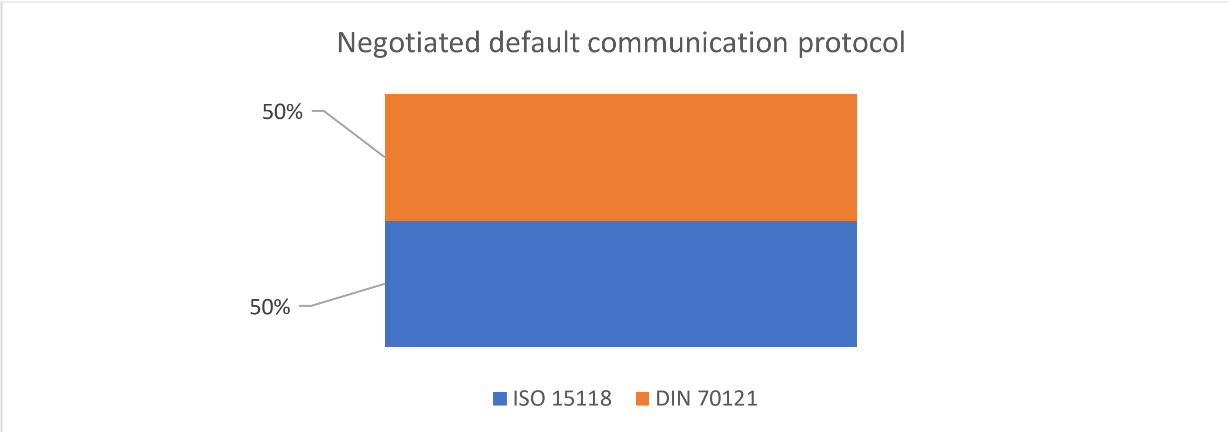

Figure 54 Default Negotiated Communication Protocol – Intentional Charging

(Note: That percentage was likely higher taking to account the erroneously reported DIN 70121 for AC charging – see figure 12, 16, 19, 23, 26 and 29 selected default communication protocol TS1-A1-A6.

Not all ISO 15118-2 charging attempts were successful. In fact, 83 percent of attempted charging sessions using the ISO 15118-2 communication protocol were successful and resulted in charging session of one minute or more. Around 17 percent of attempted charging sessions resulted in recorded interoperability issues. For comparison, among charging sessions using the older DIN 70121 for charging, 12 percent of attempted charging sessions resulted in interoperability issues and 88 percent resulted in a successful charging session of one minute or more. DIN 70121 implementations are expected to be more mature since the standard has been deployed for 10 years and is the current prevailing standard for DC charging.

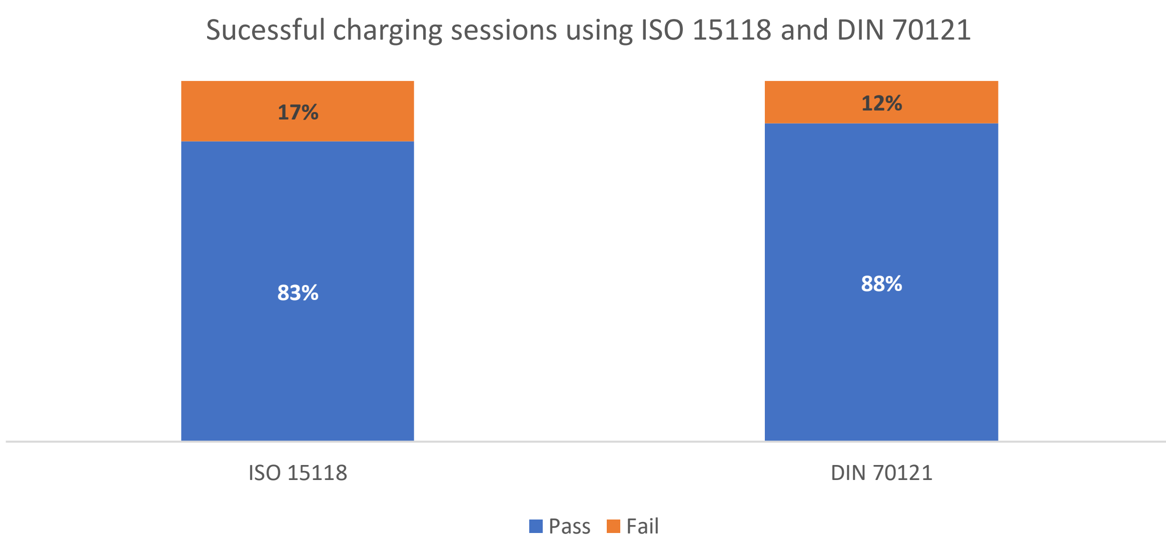

Figure 55 Successful Charging Session ISO vs DIN

Interoperability issues (i.e. unsuccessful charging sessions within Testing Schedule TS1) were reported in 17 percent of ISO 15118 charging attempts at VOLTS. Of these failed attempts, 27 percent were due to problems during SLAC, which is the initial process to establish a PLC data link. Another 27 percent were due to problems with Charge Parameter. During the ChargeParameter exchange, the EV and EVSE exchange their maximum charge parameters, expected energy demand, and possible constraints from the grid side, and then perform a general compatibility check. If this check detects an incompatibility between the EV and EVSE, the charging session would be terminated. Another 22% of the reported interoperability issues were related to TCP setup (EIM) or TLS setup (PnC). For TCP problems, no potential root cause was identified. For TLS problems, the V2G root certificate on either the EV or EVSE side may have been incorrect or did not match.

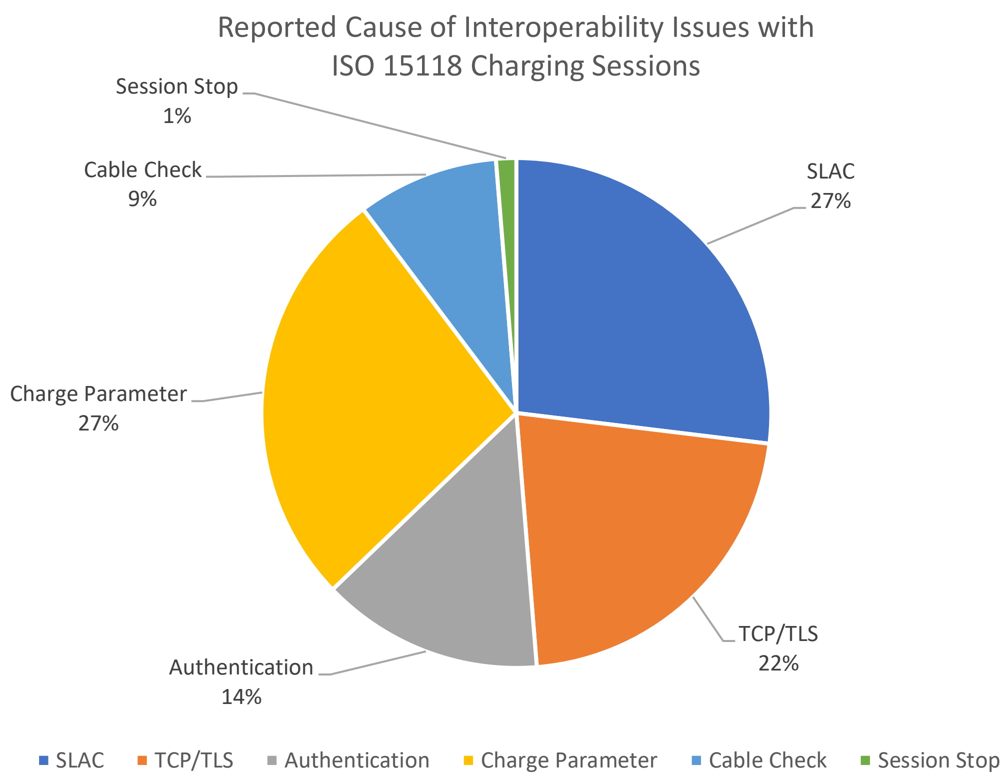

Figure 56 Reported Cause of Interoperability Issues with ISO 15118 Charging Sessions

PnC using ISO 15118-2 was tested in conditional test scenario CTS2-A. The submitted reports indicated that 38 PnC charging attempts were made and 23 of them resulted a in a successful charging session of one minute or more. The remaining 15 attempts failed to establish a charging session.

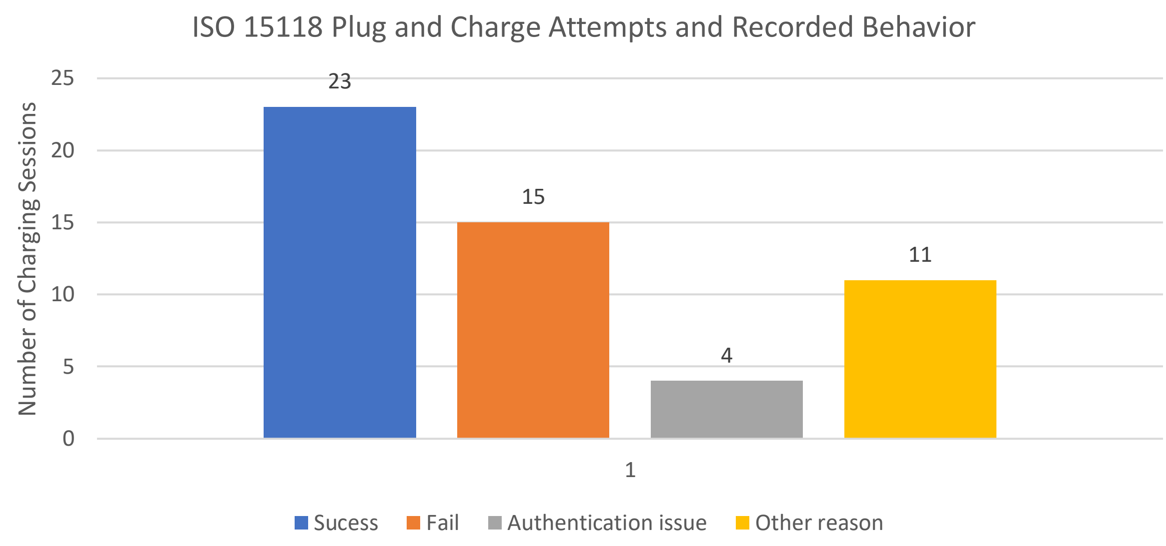

Figure 57 CTS2-A ISO 15118 Plug and Charge Attempts and Recorded Behavior

5.2 EV Shift Position Manipulation

The test scenarios involving manipulating the EV shift position revealed a potential issue. This report encourages industry to further investigate the issue and review any safety implications of test failures.

At VOLTS, participants tested EV shift position manipulation as part of several test scenarios:

- TS2-A: EV Shift Position - During charging
- TS2-B: EV Shift Position - EV is on, in neutral mode (N) and (hand) brake is on
- TS2-C: EV Shift Position - EV is on, in drive mode (D) and (hand) brake is on
- TS2-D: EV Shift Position - EV is off, in neutral mode (N) and (hand) brake is on
- TS2-E: EV Shift Position - After charging but NOT unplugged

Data from VOLTS test reports indicate that in 4 percent of the cases, the EV may have been able to move while charging or plugged in. This was more likely to occur in medium- and heavy-duty vehicles. While the collected data should be interpreted with caution, the data may indicate a potential safety issue.

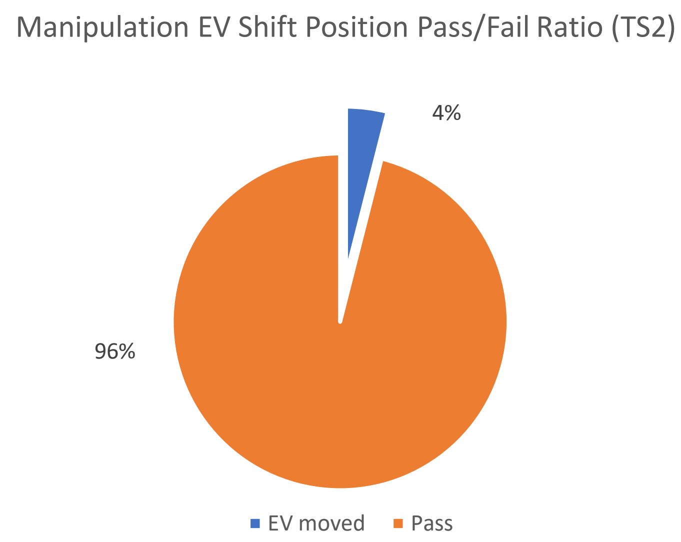

Figure 58 Manipulation EV Shift Position Pass/Fail Ratio ("EV moved" indicates fail) TS2

5.3 Charge Connector Manipulation

The charge connector is a critical part of the charging experience. Observations from past testing events and field reports were the main motivator in including the TS3 and TS4 test scenarios:

- TS3: Charger Connector Lock Fault
- TS4: Charger Connector Latch pressed

Data indicate that there is a potential safety issue that should be investigated by the industry and potentially addressed in a revision of SAE J1772 or other relevant standards. Of the 24 percent of the test reports resulted in failure, at least one test pair indicated that a hot disconnect would have been possible.

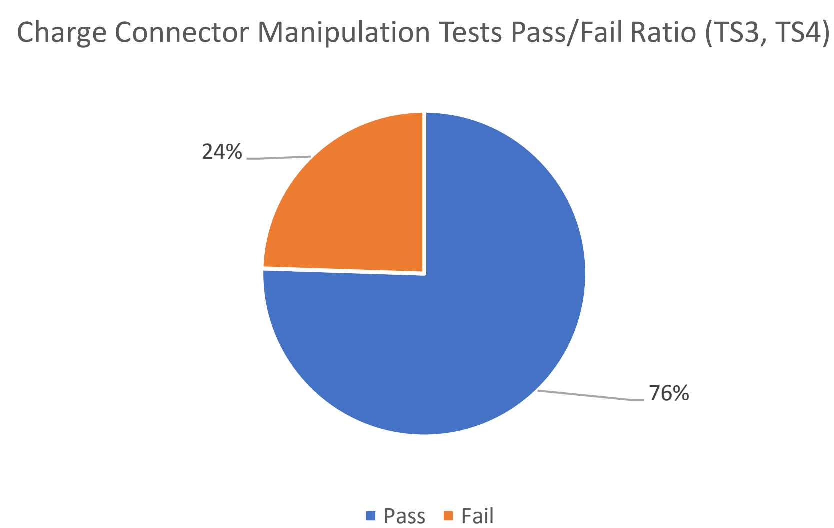

Figure 59 Charge Connector Manipulation Tests Pass/Fail Ratio (TS3, TS4)

This report encourages industry to further investigate and review the safety implications of these failures.

SAE J1772 may be ambiguous with regards to the two test scenarios above. Industry is encouraged to potentially address these issues in a voluntary conformance specification.

5.4 Time constraints

Participants were tasked with performing 15 individual baseline tests and up to 10 more conditional tests within each 120-minute test slot. This translates to an average of 8 available minutes to execute and report each test scenario if all baseline tests were run, or only 4.8 available minutes for each test scenario if all baseline and conditional tests were run. The submitted data suggests that participants may not have had sufficient time to run all requested test scenarios.

The number of submitted “Not applicable” entries may be used as an indicator of available time to run the test scenario. “Not applicable” may indicate insufficient time, and/or the EV or EVSE not being capable of running that particular test scenario. It is observed that for the first baseline tests, most of the submitted reports had usable data (that is, reports other than “Not applicable”). However, an increasing number of test participants marked “Not applicable” as the test scenarios progressed.

Future testing events may consider limiting the number of test scenarios or extending each test slot duration.

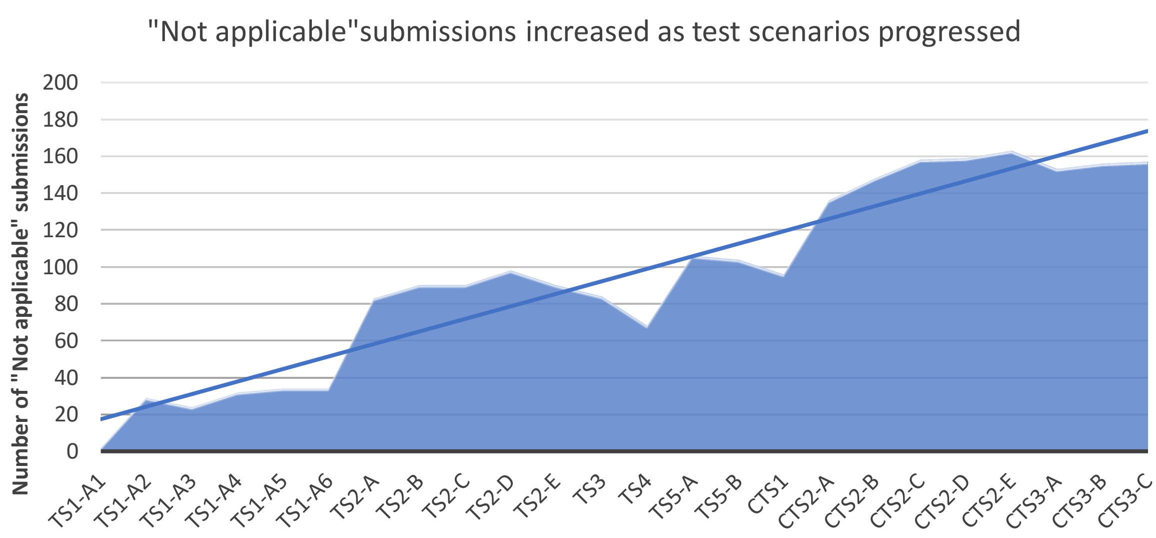

Figure 60 “Not applicable” submissions may indicate tester time constraints

6. Challenges and Next Steps

The entire e-mobility industry is under great pressure to keep up with the growing market demand for EVs and charging infrastructure while at the same time ensuring that EV drivers enjoy a seamless charging experience with any EV at any EVSE. This report makes the following recommendations based on reported data points from VOLTS.

6.1 Conformance Testing

The testing event revealed that interoperability problems still exist with the older DIN 70121 standard, even though that standard has been in use for 10 or so years. One way to address shortcomings and also offer new entrants a platform for product validation is to consistently perform conformance testing and certification. Conformance testing and certification is voluntarily (if not mandated by regulators) and offers a standardized and scalable approach to ensure that EV and EVSE conform to protocol specifications. This in turn helps ensure that EV and EVSE interoperate. Best practices for conformance and certification testing are already available from other communication standards and industries, such as Wi-Fi[3] and Bluetooth.[4] In both examples, third party testing and certification schemes are used to qualify products and ensure a high level of interoperability. Within the e-mobility sector, the Open Charge Alliance operates a third-party testing and certification scheme[5] for both charging stations and the backend systems that manage charging stations. It is important that conformance tests are also conducted for EV-EVSE communication, which is the centerpiece for a seamless charging experience for any EV driver.

CharIN has established a testing and certification scheme for DC EVSE that verifies conformance with the DIN 70121 communication standard.[6] The industry should be encouraged to voluntarily adopt this existing scheme as a benchmark for DC EVSE and actively participate in the further advancement of future testing and certification programs, in particular for the ISO 15118-2 standard. The VOLTS test data indicate that interoperability issues are not always on the EVSE side but can be found on the EV side as well, suggesting that having appropriate conformance program for both EVs and EVSE could help reduce interoperability issues for both DIN 70121 and ISO 15118 implementations.

The industry is also encouraged to work on harmonized error codes that could be displayed to the consumer on, for example, the EVSE. The industry is also encouraged to make consistent use of the error codes that are built into DIN 70121 and ISO 15118.

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[3] https://www.wi-fi.org/downloads-public/Wi-Fi_Alliance_Certification_Process_Overview_v3.6.pdf/32754
[4] https://www.bluetooth.com/develop-with-bluetooth/qualification-listing/
[5] https://www.openchargealliance.org/certification/ocpp-16-certification/
[6] https://www.charin.global/technology/charin-conformance-testing/

6.2 Smart Charging

Smart charging offers various benefits including grid balancing, load management, cost optimization, and a better user experience. In particular, dynamic power adjustments taking into account current or forecasted grid loads, renewable energy generation, electricity prices, and user demands could reduce the environmental and grid impacts of EV charging. Notably, a report published by the California Energy Commission under California Assembly Bill 2127[7] confirms the clear need for and benefits of smart charging.

The VOLTS testing data suggests that the ISO 15118-2 smart charging capabilities are not yet widely implemented in EVs and EVSE. Only 9 test pairs successfully conducted smart (scheduled) charging testing at VOLTS, while the majority did not test smart charging due to time constraints or because the equipment did not support smart charging using ISO 15118-2.

The lack of smart charging implementation may be due to the industry's current focus on immediate on-demand charging, lack of appropriate market signals, and/or smart charging implementations relying on EV telematics rather than ISO 15118. The upcoming OCPP 2.0.1 protocol fully supports smart charging, including processing of ISO 15118 data such as required amount of energy by the EV, expected departure time, and grid and tariff related information.

Industry is encouraged to make better use of smart charging capabilities of ISO 15118. Future testing events should better support testing of smart charging capabilities, such as by distributing pre-designed schedules for tester use. Such pre-designed schedules could be provided by a backend that is accessible to participants or are manually coded into EVSE.

6.3 Recommendations for Future Testing Events

Based on the collected feedback (see Appendix) and data submissions from tester participants, this report makes the following recommendations for future testing events.

- **Continue data collection at testing events**
  Data collection at VOLTS provided insight on the state of ISO 15118 implementation and interoperability gaps that should be addressed by the industry. Participant feedback greatly supported continued data collection at future events.

- **Continue providing testing structure with a mandatory test plan**
  For comparable and consistent data collection, a mandatory test plan is required. However, the test plan used at VOLTS may have been too extensive or test slots were too short to complete and report all test scenarios. Future events may consider longer test sessions or reducing the number of mandatory test scenarios.

- **Consider dedicated test slots for specific tests or use cases**
  The collected test data suggests that certain test scenarios may have been particularly useful for

[7] https://efiling.energy.ca.gov/getdocument.aspx?tn=236237

selected equipment models. For example, selected EV models yielded the most valuable data for test scenarios involving manipulation of the EV's shift position. It may be more efficient to facilitate such testing at a dedicated test slot to improve testing efficiency and improve data collection quality. The same applies for testing of certain use cases that may not yet be implemented by all testing participants, such as smart charging and or PnC. Dedicated test slots may provide test pairs with the opportunity for more efficient, in-depth, and targeted testing.

- **Ensure accuracy of equipment technical capabilities submitted during registration**
  Participant feedback requested that future events improve the process for specifying equipment technical capability during registration. For example, approximately half of the registered EVSE and EVs indicated PnC capability during registration. However, test data show that much fewer actually tested PnC during VOLTS test sessions, and this may be due to insufficient time or because the EV or EVSE did not actually support PnC. In other words, technical capabilities provided during registration did not always match the actual technical capabilities of the equipment brought to VOLTS. Improved accuracy of these technical capability specifications could improve testing efficiency. Another participant comment suggested collecting nameplate information of all participating equipment such maximum voltage, current, and power.

- **Consider including backend support to facilitate testing**
  Test reports frequently cited backend issues, for example during testing for smart charging and PnC. While EVSE to backend communication was not in scope for VOLTS, future events may consider providing a dedicated and consistent backend infrastructure for tester use. Such a backend should likely be compliant with OCPP 2.0.1.

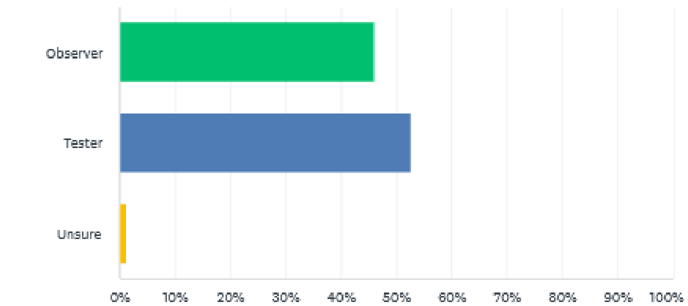
Based on the results of the post-event survey, see Appendix, testers appreciated having two-hour test slots, the test plan provided at the VOLTS was too long and the amount of time provided was not sufficient. The test plan could be modified to limit the number of times that a test is performed. This could also help to decrease the occurrences of Not Applicable, which may have been related to the amount of time for testing.

Appendix

VOLTS post-event quantitative testing event survey feedback.

Were you an observer or a tester during the VOLTS Testing Symposium?

Answered: 78 Skipped: 13

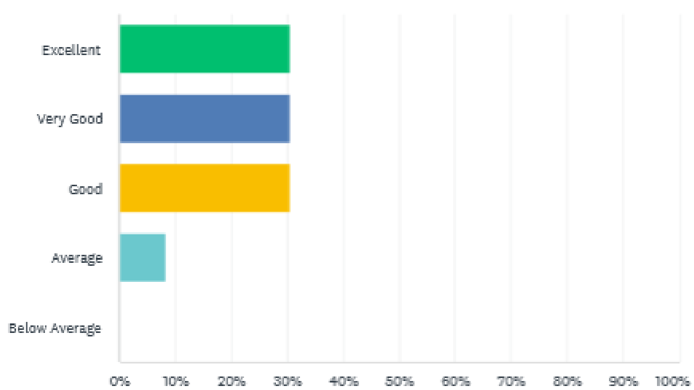


ANSWER CHOICES	RESPONSES	
Observer	46.15%	36
Tester	52.56%	41
Unsure	1.28%	1
TOTAL		78

1.

How would you rate the Testing Symposium overall?

Answered: 36 Skipped: 55

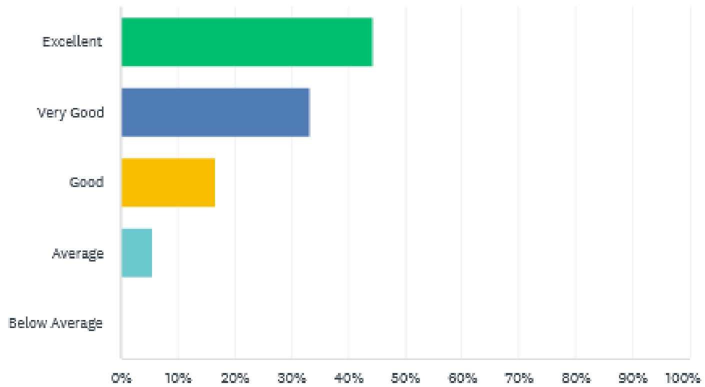


ANSWER CHOICES	RESPONSES	
Excellent	30.56%	11
Very Good	30.56%	11
Good	30.56%	11
Average	8.33%	3
Below Average	0.00%	0
TOTAL		36

2.

How useful was the VOLTS Testing Symposium to your line of work?

Answered: 36 Skipped: 55

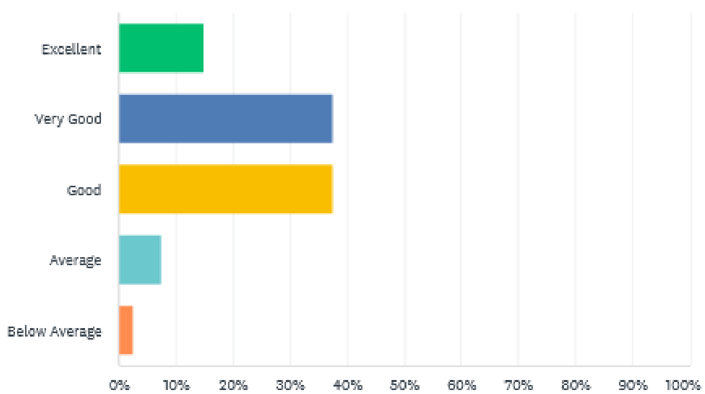


ANSWER CHOICES	RESPONSES	
Excellent	44.44%	16
Very Good	33.33%	12
Good	16.67%	6
Average	5.56%	2
Below Average	0.00%	0
TOTAL		36

3.

Please rate the length of time you received for each test pairing at the event (2 hours).

Answered: 40 Skipped: 51

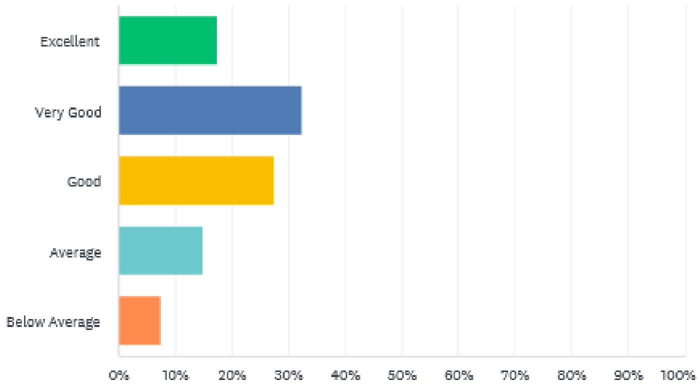


ANSWER CHOICES	RESPONSES	
Excellent	15.00%	6
Very Good	37.50%	15
Good	37.50%	15
Average	7.50%	3
Below Average	2.50%	1
TOTAL		40

4.

Please rate the length of time overall for testing at the event (2 full days).

Answered: 40 Skipped: 51

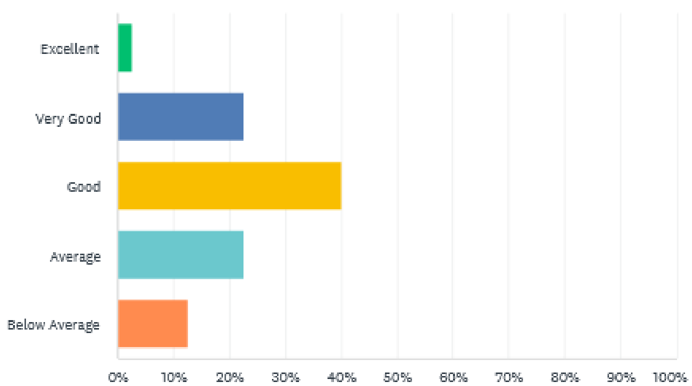


ANSWER CHOICES	RESPONSES	
Excellent	17.50%	7
Very Good	32.50%	13
Good	27.50%	11
Average	15.00%	6
Below Average	7.50%	3
TOTAL		40

5.

Please rate your experience using the prescribed test plan.

Answered: 40 Skipped: 51

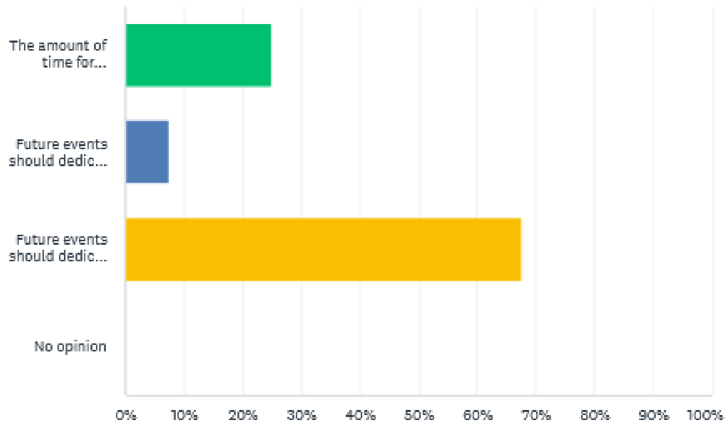


ANSWER CHOICES	RESPONSES	
Excellent	2.50%	1
Very Good	22.50%	9
Good	40.00%	16
Average	22.50%	9
Below Average	12.50%	5
TOTAL		40

6.

For future testing, would you want more or less time allotted to prescribed testing compared to self-directed testing?

Answered: 40   Skipped: 51

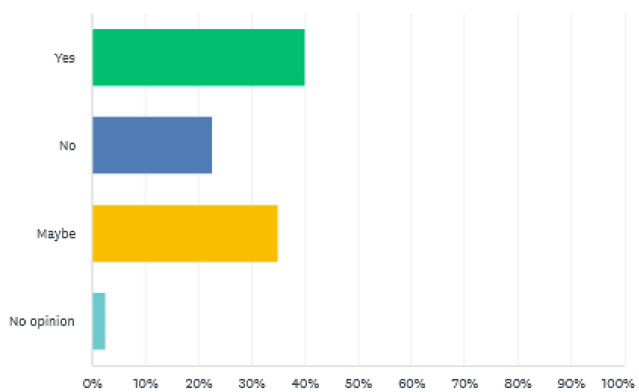


ANSWER CHOICES	RESPONSES	
The amount of time for prescribed testing compared to self-directed testing at VOLTS was ideal	25.00%	10
Future events should dedicate more time to prescribed testing	7.50%	3
Future events should dedicate more time to self-directed testing	67.50%	27
No opinion	0.00%	0
TOTAL		40

7.

Would you recommend using a prescribed test plan at future events?

Answered: 40   Skipped: 51

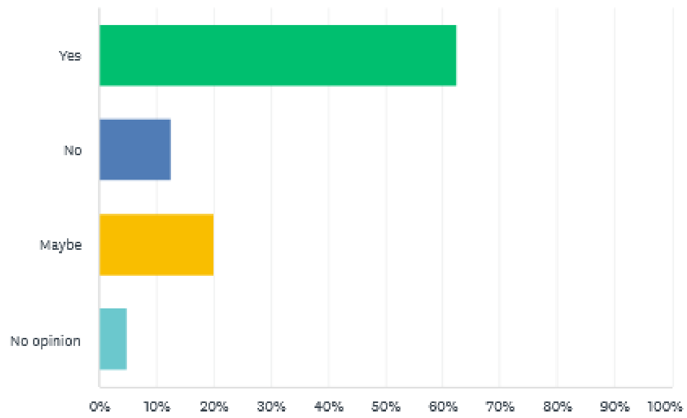


ANSWER CHOICES	RESPONSES	
Yes	40.00%	16
No	22.50%	9
Maybe	35.00%	14
No opinion	2.50%	1
TOTAL		40

8.

VOLTS required testers to submit test data from paired testing. CharIN will compile and anonymize the data in a report to CEC. Should future events include similar data collection activities?

Answered: 40   Skipped: 51



ANSWER CHOICES	RESPONSES	
Yes	62.50%	25
No	12.50%	5
Maybe	20.00%	8
No opinion	5.00%	2
TOTAL		40

9.