CHARGEX consortium

Recommended
ACTIONS TO IMPROVE ADAPTER SAFETY

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Argonne NATIONAL LABORATORY
INL Idaho National Laboratory
NREL Transforming ENERGY

Authors

Andrew Meintz, Marco Gaxiola, Vivek Singh, Isaac Tolbert, Saroj Shinde, and Kristi Moriarty

Contributors

ABB, Amphenol, Electrify America, Eaton, Electric Power Research Institute, EVgo, General Motors, Tesla, and UL Solutions.

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List of Acronyms

AC	alternating current
CCS	Combined Charging System
ChargeX Consortium	National Charging Experience Consortium
DC	direct current
DCFC	direct-current fast charger
EV	electric vehicle
EVSE	electric vehicle supply equipment
FMEA	failure mode and effects analysis
V2H	Vehicle to Home
V2L	Vehicle to Load
RPN	risk priority number

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1 Introduction

With the rapid advancement and acceleration in the electric vehicle (EV) industry within the United States, major automakers and EV charging companies are increasingly adopting the North American Charging Standard (NACS) connector style, now officially known as J3400. This shift is expected to enhance charging infrastructure, providing a better customer experience by making it easier for all EV drivers to access a wider network of direct-current (DC) fast chargers (DCFCs).

However, the adoption of the J3400 standard presents challenges for many EVs already on the roads and some currently coming off production lines that are equipped with the Combined Charging System (CCS) connector, which this report will refer to as the North American standard, CCS1. These vehicles will need adapters to use new or existing J3400 infrastructure.

During this transition, several issues have emerged. Firstly, there is a need to standardize the new connector type to ensure it is interoperable, safe, and reliable. Second, existing CCS EV drivers need a way to access the J3400 network, which will require electric vehicle supply equipment (EVSE) or sites with both connector types, driver-provided adapters to physically convert from CCS to J3400, or EVSE with retained adapters designed for use with the EVSE. Third, adapter standards will need to be written to specify how they will be designed and what evaluations will be needed to ensure safe and reliable performance.

To address these challenges, adapters that support different types of charging connectors will be essential. These adapters will play a crucial role in supporting the transition and ensuring continued service for legacy EVs with CCS inlets as the J3400 standard becomes the predominant one in the United States. Consequently, the National Charging Experience (ChargeX) Consortium has investigated and performed a teardown analysis on the different adapter versions on the market. The aim is to create a failure mode and effects analysis (FMEA) on what are expected to be the most common adapter types used in this transition.

In order to support this work, we executed an FMEA exercise with the main goal of identifying gaps in the existing adapters' performance and conformance to the most common safety requirements of high-power and high-voltage devices. This effort focused on adapters provided by the driver, as these may present the highest safety and reliability risks. The recommendations made here apply to both retained and driver-provided adapters.

1.1 What Is an Adapter, and What Role Does It Play in the EV Charging Industry?

In the EV charging industry, an adapter is a device that allows different types of charging connectors to interface with one another, enabling EVs to charge at stations with incompatible connectors. These adapters are crucial for ensuring compatibility across various standards, providing convenience and flexibility for EV owners. They enhance the utilization of existing charging infrastructure, support interoperability across different regions and technologies, and facilitate the transition to new charging standards, ensuring both older and newer vehicles can access charging facilities.

Similar to travel adapters used for household devices when moving between countries with different power outlet designs, EV charging adapters address compatibility issues arising from different connector designs used by various manufacturers, despite similar underlying electrical protocols. However, due to the higher voltages and currents involved in EV charging, especially in fast or ultra-fast DCFC stations, these adapters must be robust and reliable to prevent risks such as fires, short circuits, or electric shock. Thus, EV charging adapters are essential for maintaining safety and efficiency in charging infrastructure.

1.2 AC and DC Adapters

DC adapters are designed to handle much higher voltages and currents relative to alternating-current (AC) charging, making them suitable for high-power charging sessions. A typical existing CCS-to-J3400 adapter should be designed to carry up to 350 kW during a DCFC session. The focus of this report is primarily on DC adapters because they handle the highest voltages and currents, posing significant risks. Identifying the failure modes and effects of these adapters is critical to prevent potential catastrophic failures such as fires and electrical incidents.

AC adapters typically operate at lower power levels compared to their DC counterparts, with capacities up to 80 amps at 240 volts AC. While they are important for everyday charging, the risks associated with AC adapters are generally lower compared to DC adapters. However, we include one variant of AC adapters in our FMEA due to the high risk and probability of being misused as a DC adapter, which could lead to dangerous situations if an attempt is made to use them for DCFC.

1.3 UL 2252 Outline of Investigation

The UL 2252 "Outline of Investigation for Adapters for use with Electric Vehicle Couplers" was developed to ensure the safety of EVSE, including adapters used to connect EVSE to vehicles. This outline is the first step in developing a standard to address various safety criteria necessary to protect users and maintain the reliability of the EV charging infrastructure. The safety requirements encompass electrical safety, ensuring the equipment can handle specified voltage and current without risk; mechanical integrity, verifying that the adapter can withstand plugging, unplugging, and impacts; thermal management, ensuring the equipment manages heat generation to prevent overheating; and environmental durability, testing for resistance to moisture, dust, and temperature variations. Additionally, the outline ensures compatibility, by identifying the requirements for acceptable configurations to convert from different EVSE connectors to EV inlets.

The process of developing the UL 2252 outline into a standard involves several stages. It begins with initial research and stakeholder consultation to identify potential risks and necessary safety measures, followed by drafting the safety requirements and testing protocols. The draft is then shared with the public and industry stakeholders for feedback. Extensive testing is conducted to validate the requirements, and based on the outcomes and feedback, the standard is finalized and published for industry adoption.

This report supports this comprehensive process by identifying certain gaps that should be addressed to improve the requirements. While the UL 2252 outline of investigation addressed several issues for adapters, some specific issues have been identified and require updates in several standards as will be detailed in this document.

2 Adapter Evaluation

2.1 Teardown Analysis and Adapter Review

To deepen our understanding of how these adapters work and explore potential design strategies, we took apart several models currently on the market. This practical approach was incredibly helpful for developing a generalized functional diagram for these adapters and to identify possible failure modes. Through these teardowns (shown in Figure 1 and Figure 2), we gained firsthand insights into the materials used, the build quality, isolation techniques, and the assembly and durability methods employed.

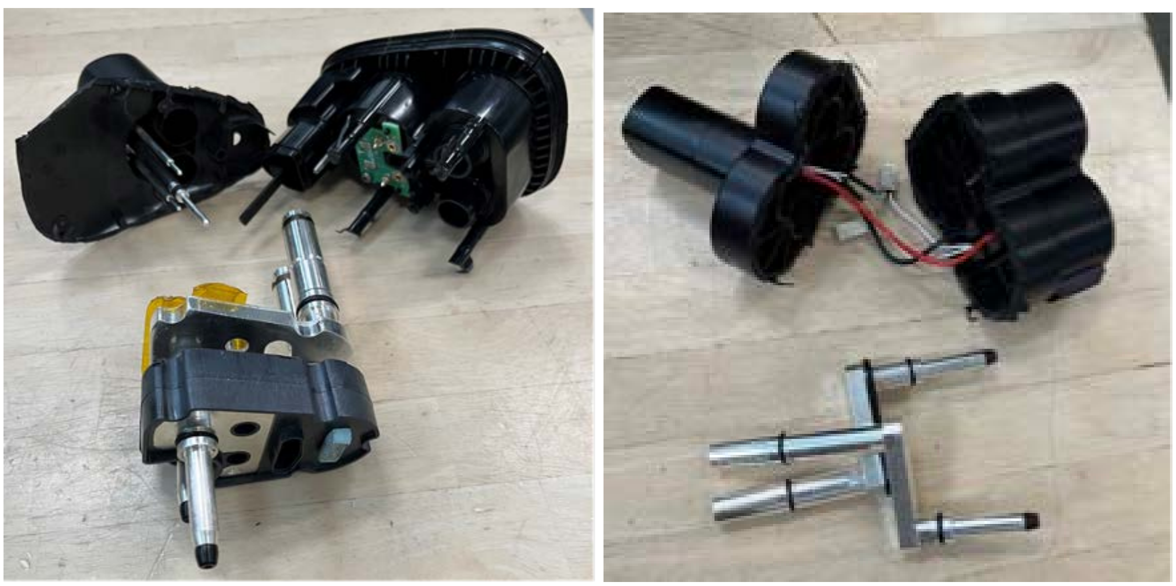

Figure 1. Two different disassembled CCS-to-J3400 adapters

Figure 2. A disassembled J3400-to-CCS adapter

2.2 Functional Diagrams

Creating functional diagrams allowed us to identify the most likely design case scenarios, along with the corresponding failure modes and their potential root causes. This enabled us to conduct a comprehensive FMEA study in which four cases for adapters were analyzed, and the naming convention for these cases follows conventional power flow (e.g., CCS to J3400 would be used in a situation where CCS EVSE charges a J3400 EV).

2.3 Case 1: CCS to J3400, Rigid Body Adapter

The functional diagram in Figure 4 illustrates the interaction between a CCS EVSE connector and a J3400 vehicle's inlet using an adapter shown in Figure 3. This adapter facilitates the connection and ensures compatibility between the differing connector interfaces. The diagram highlights various components such as the connector body, latch mechanism, proximity and pilot line sockets and pins, and several safety features like touch safety covers and thermistors for temperature monitoring.

The physical connections, material exchanges, energy transfers, and data exchanges between the connector, adapter, and vehicle inlet are clearly marked using different colored lines, providing a comprehensive view of how the system operates and interfaces with the user and environment.

Figure 3. CCS-to-J3400 adapter

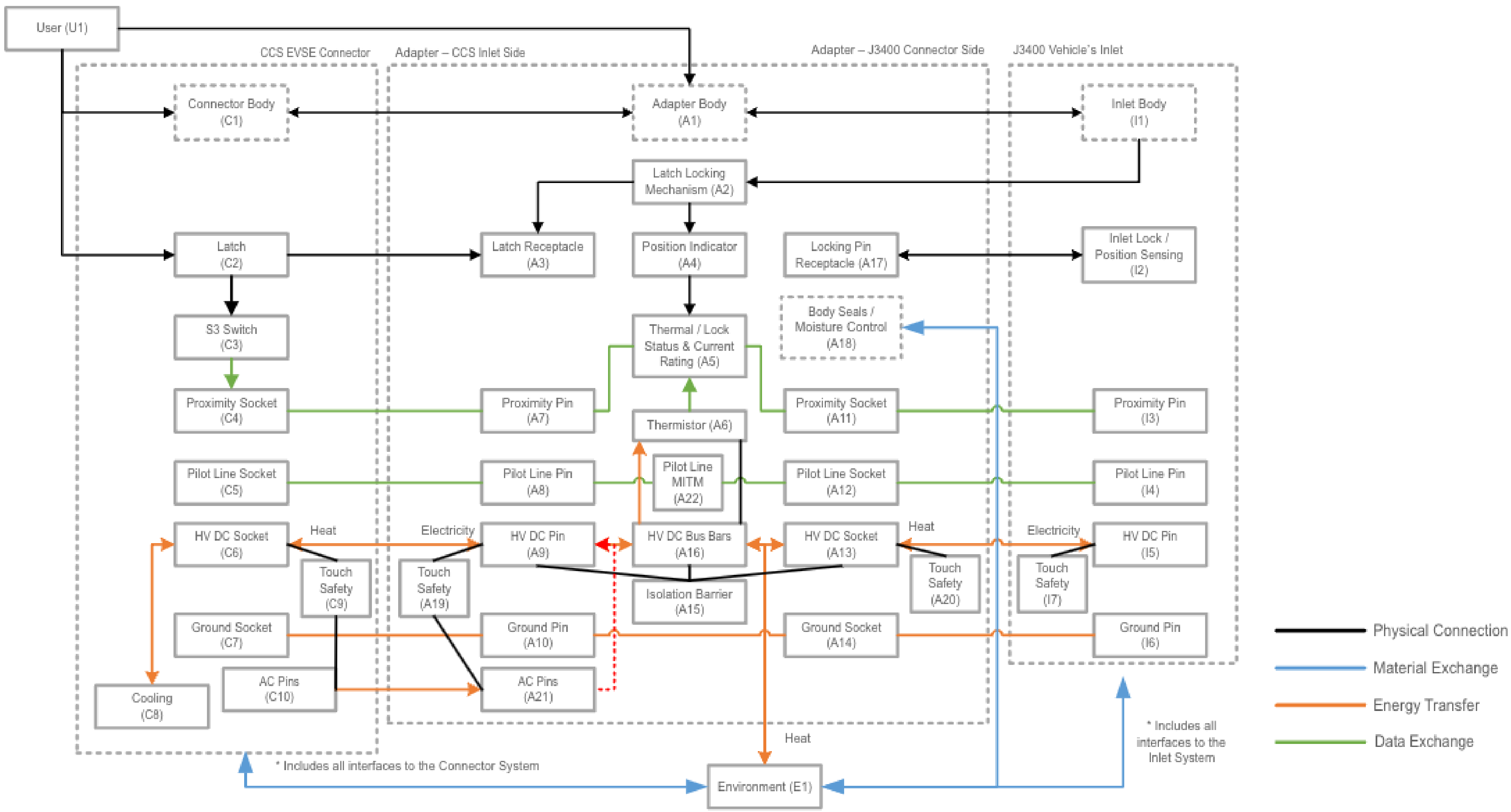

Figure 4. CCS-to-J3400 adapter functional diagram, rigid body adapter

2.4 Case 2: J3400 to CCS, DCFC Version, Rigid Body Adapter

The functional diagram in Figure 6 demonstrates how a J3400 EVSE connector is adapted to interface with a CCS vehicle inlet through the use of an adapter, shown in Figure 5. The diagram details the adapter's role in bridging the connector to the vehicle's inlet, allowing for efficient energy transfer, material exchange, and data communication. The diagram includes multiple components such as the connector body, locking pin receptacle, proximity sockets, pilot line sockets, high-voltage DC sockets, and various safety features, including touch safety covers and thermistors for monitoring temperature.

The diagram clearly outlines the flow of electricity and heat, as well as the interactions between physical connections, material exchanges, and data transfers across the system, highlighting the comprehensive interfacing between the vehicle, connector, and environment.

The red dotted line illustrates an unsafe configuration in which the AC and DC socket pins on the CCS side are internally interconnected. This configuration has been noted in several adapters of this type that we have evaluated.

Figure 5. J3400-to-CCS adapter

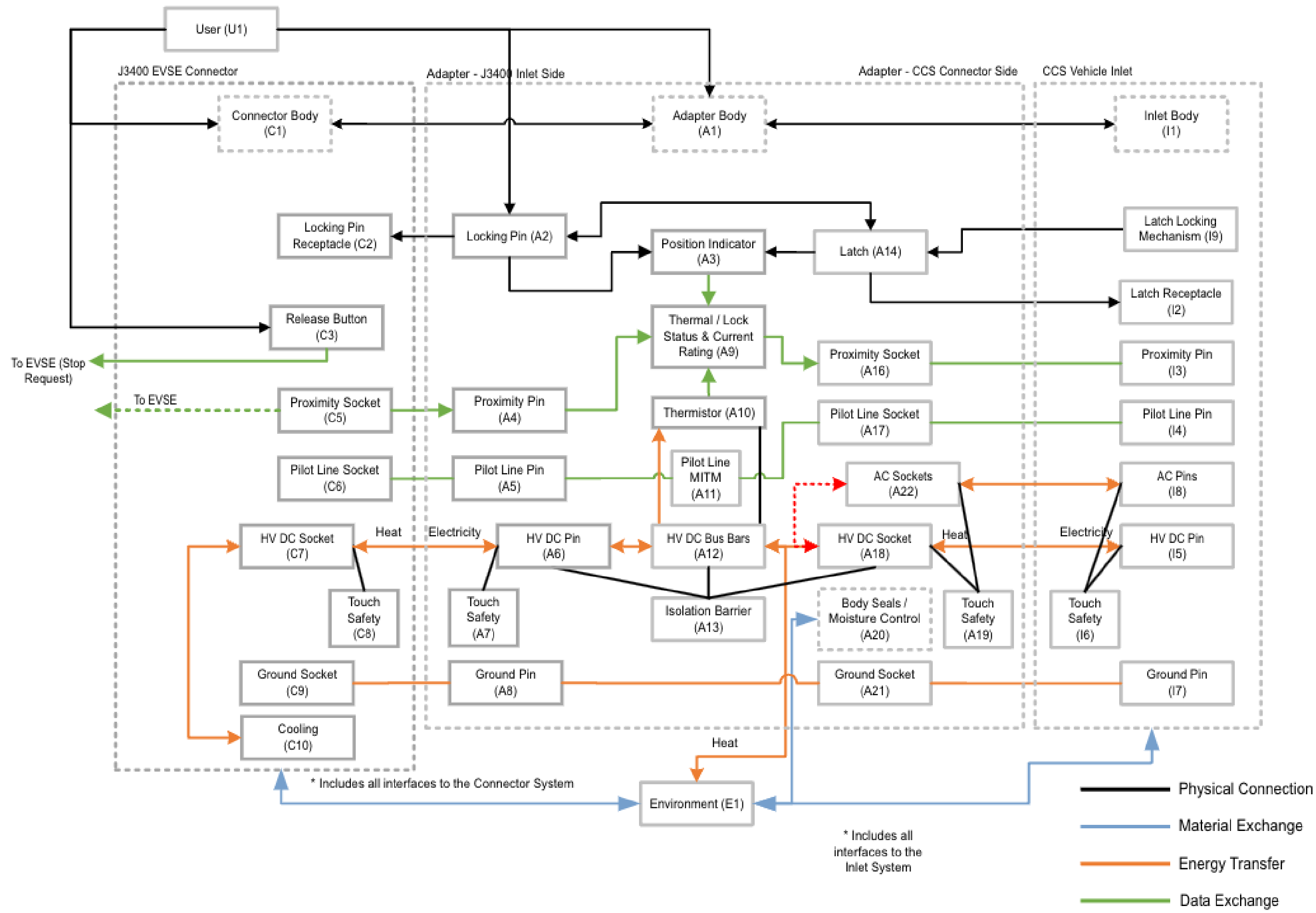

Figure 6. J3400-to-CCS adapter functional diagram, rigid body adapter

2.5 Case 3: J3400 to J3400, Cable Assembly

This functional diagram in Figure 8 showcases how a J3400 connector is used in conjunction with a J3400 vehicle through a cable adapter, shown in Figure 7. The diagram details the integration of the connector with the vehicle's inlet system via the adapter, emphasizing various key components such as the connector and adapter bodies, proximity and pilot line interfaces, and high-voltage DC connections. It features an array of safety and monitoring devices like thermistors, touch safety covers, and position indicators.

The layout efficiently illustrates the adapter's role in facilitating communication and power transfer between the connector and vehicle inlet, with clear demarcations for physical connections, material exchanges, energy transfers, and data exchanges.

This setup ensures a secure and efficient connection for charging or system operations, integrating enhancements like locking pin functionality with delay, release button with sensing, and advanced cable management features to handle the electrical and thermal dynamics effectively.

This diagram also highlights two boxes with red dotted lines, indicating an adapter feature that is invalid under J3400. If manufacturers decided to implement this feature, it could impact the way the EVSE sees an emergency shutoff rather than just a request to stop the charge session, and this could cause partial or permanent failures to the EVSE over time.

Figure 7. Adapter with cable assembly, J3400 to J3400

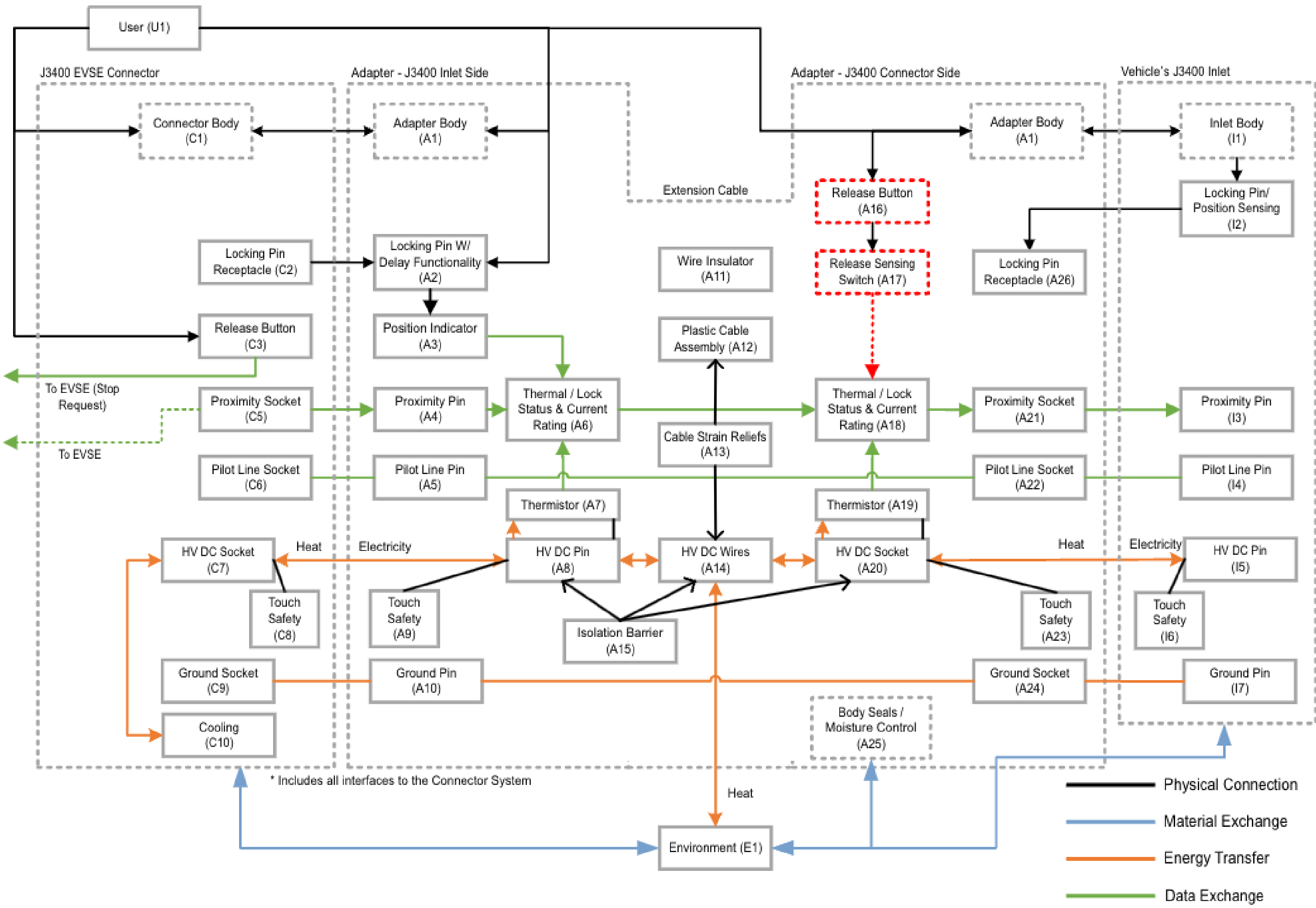

Figure 8. J3400-to-J3400 adapter functional diagram, cable adapter

2.6 Case 4: J3400 to J1772, AC Level 1/Level 2 Version, Rigid Body Adapter

This functional diagram in Figure 10 illustrates how a J3400 connector is adapted to connect with a J1772 vehicle inlet using an adapter, shown in Figure 9. The diagram includes details about various elements of the system, such as the connector and adapter bodies, locking pins, and several types of sockets and pins (proximity, pilot line, AC, and ground). It also shows the flow of electricity and heat through components like AC busbars and high-voltage DC wires. Safety features such as touch safety covers and thermistors are included to monitor temperature and ensure safe operation.

Physical connections are clearly outlined, as well as the paths for material, energy, and data exchanges, ensuring that all interactions between the J3400 connector and the J1772 vehicle inlet are seamless and efficient. The use of an adapter facilitates compatibility between these different connector standards, allowing for effective power transfer and communication within the vehicle charging infrastructure.

Figure 9. J3400-to-J1772 AC adapter

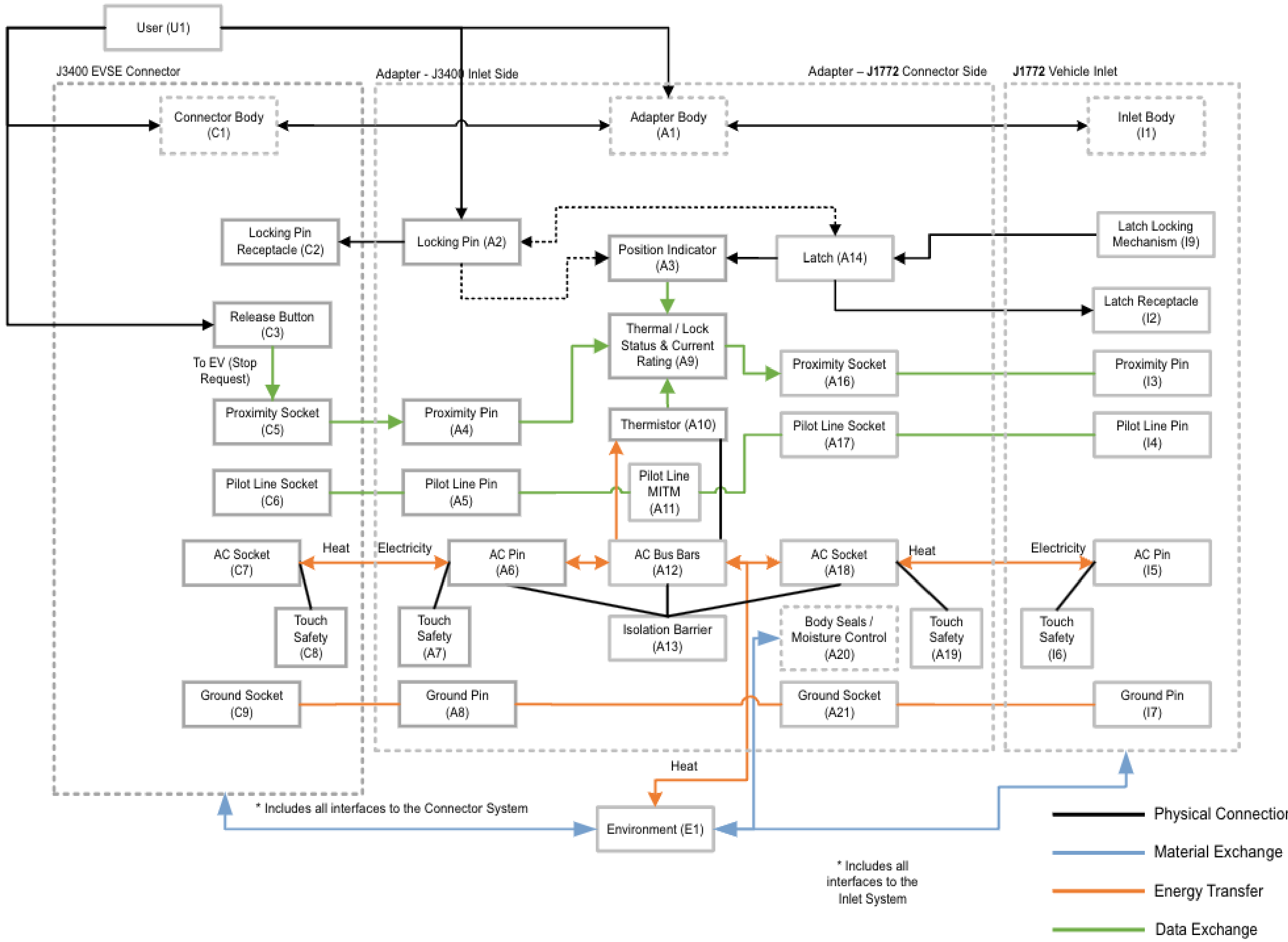

Figure 10. Functional diagram for a J3400-to-J1772 AC rigid body adapter

3 Process for the Failure Mode and Effects Analysis

FMEA is a structured risk assessment method designed to identify and mitigate potential failures in products, processes, or systems before they occur. The primary objective of FMEA is to improve safety, quality, and reliability by preemptively addressing possible points of failure within the product design (Stamatis 2003). Detailed steps of the FMEA process are listed below:

1. **Identification of failure modes:** Each component or process step is analyzed to identify all conceivable failure modes. These are ways in which the process could fail to deliver the intended output or service.
2. **Severity assessment:** The potential consequences of each failure mode are evaluated, and a severity rating is assigned based on the impact on the customer, system operation, and compliance with regulations. Severity is typically rated on a scale from 1 (least severe) to 10 (most severe).
3. **Occurrence evaluation:** This assessment is the likelihood of each failure mode occurring, again using a scale from 1 (least likely) to 10 (most likely).
4. **Detectability analysis:** The probability that the failures can be detected before they reach the customer is evaluated. Detectability is rated on a scale from 1 (highly detectable) to 10 (not detectable).
5. **Risk priority number (RPN) calculation:** For each identified failure mode, an RPN is calculated by multiplying the severity, occurrence, and detectability ratings. This metric helps prioritize the failure modes according to their risk level.
6. **Mitigation strategies and action plans:** High-risk failure modes are targeted for mitigation through design modifications, enhanced evaluation, or process changes. Specific actions are proposed to reduce the RPN, which may involve reducing the likelihood of occurrence, minimizing the severity of the failure's impact, or improving detectability.

FMEA is used in industry to not only aid in enhancing the reliability and safety of systems, but also to support compliance with standards and regulations, thereby reducing costs associated with failures and improving customer satisfaction (Carlson 2012). This approach was leveraged for the adapter work as a guide to develop a comprehensive list of failure modes to investigate.

3.1 Approach to Ranking Based on Teardown Analysis and Industry Input To Identify Occurrence

During the FMEA work, we collaborated with a group of industry experts associated with the ChargeX Consortium, an initiative funded by the Joint Office of Energy and Transportation. This team brought together professionals from various sectors, including vehicle electrification, EV charging systems, connector supply, and national research laboratories.

During the FMEA process, we identified and analyzed approximately 140–145 potential failure modes for each type of adapter. Each failure mode was assessed for its severity, frequency of occurrence, and difficulty of detection.

The results of our FMEA enabled us to identify the most critical failure modes, particularly those with the highest severity ratings. These failure modes not only occurred frequently, but were also hard to detect. Section 4: Recommendations addresses these high-risk issues, focusing on those with FMEA scores of 100 or higher.

The occurrence developed for this evaluation was based on ChargeX contributor feedback on areas of concern from prior experience with connectors and inlets, as well as the teardown analysis of third-party adapters to identify commonly misinterpreted requirements for the implementation of basic safety functions. In the future, these occurrence numbers should be reassessed once the industry has additional experience with the deployment of adapters for EV charging.

Some of the most significant risks identified resulted in the highest RPNs in FMEA as a result of limited occurrence data, leading to a higher influence from the severity ranking. Generally, these high-severity failure modes include the following scenarios:

- Users might inadvertently remove the adapter during an active charging session. This can lead to serious injuries or damage due to arcing and potential fires.
- Thermal failures due to additional stress adapters place on the cooling system of connectors by adding to the current pathway from the connector to the inlet, reduced ampacity design of adapter systems, and durability concerns from adapter systems.
- Other critical failure modes involve water or moisture getting into the adapter, damage to the casing or seals, and compromises to the internal high-voltage insulation systems that could lead to internal short circuits and a loss of isolation.

4 Recommendations

The following recommended actions were identified by the ChargeX team through discussion of the failure modes in the FMEA that obtained an RPN value of 100 or higher. These recommendations are targeted to updates in SAE and UL standards for performance or conformance of EVs, EVSE, and adapters, while considering the system implications across the entire EV-EVSE system. The recommended actions were developed by examining the four adapter configurations discussed in Section 2 and have been consolidated to define essential functions or evaluations that can be applied to all configurations. The failure modes for each configuration are identified, and aspects particular to failure modes for specific configurations are numbered. FMEA IDs can be accessed in Section 7 – Appendix (FMEA spreadsheet).

#	Recommended Action (Consolidation of FMEA Recommendations)	Targeted Standard	Affected FMEA IDs, CCS to J3400	Affected FMEA IDs, J3400 to CSS	Affected FMEA IDs, J3400 to J3400	Affected FMEA IDs, J3400 to J1772 (AC)	Robustness to Root Cause of Failure Mode
1	Forced disconnection evaluation test: A recommendation to perform a pull test on the adapter as part of conformance certification. The proposed test should consist in applying a force of up to 750 N on all four angles/orientations to remove the adapter from the connector/inlet, while also applying 50-N force to “unlock” or “unlatch” the adapter. The test conditions shall be performed after drop test, latch/lock cycling tests, mold stress test, and other potential tests. Pass criteria after mechanical tests are to check each sample for loss of electrical continuity. No loss of continuity in any circuit or change in safety circuit states should occur throughout the test.	UL 2252	1, 2, 3, 4, 5, 6, 8, 10, 12, 13, 15, 111	1, 2, 3, 4, 5, 6, 8, 10, 12, 13, 15, 111	1, 2, 3, 4, 5, 6, 8, 10, 12, 13, 15, 111	6, 111	All root causes associated with being able to pull/disconnect the adapter while under load, causing arc flash: - Wear on latches/lock pins - Forced removal - Latches/lock pins not deep enough - Debris in receiver - Wear/damage, broken pins - Design failure of retention mechanisms.
1.1	Additional recommendation: Include a performance requirement to diagnose a locked latch. This feature should be able to detect wear, debris, or incomplete engagement in latching mechanism by interrupting the proximity circuit.	J3400, J3400/1	2	2			Wear on latch pin (pin or spring).

#	Recommended Action (Consolidation of FMEA Recommendations)	Targeted Standard	Affected FMEA IDs, CCS to J3400	Affected FMEA IDs, J3400 to CSS	Affected FMEA IDs, J3400 to J3400	Affected FMEA IDs, J3400 to J1772 (AC)	Robustness to Root Cause of Failure Mode
1.2	Additional recommendations: The locking/latching portion of the adapter must be robust enough to keep the adapter in place and prevent the adapter from unlocking or disengaging from the vehicle's inlet. An analysis should be performed to identify appropriate material properties for latches and locks that may be added to or restricted from these design standards.	J3400, J3400/1, J1772		6, 10	6	6	Design failure, retention of pin in adapter (A2 to A1). The interface between the two is damaged. Debris in locking pin receptacle.
1.3	Additional recommendations: UL 2251 update: For CCS connectors, we propose that the latch should be more robust. Currently, IEC 62196 standards consider forces on the latch but do not include a drop test or account for horizontal forces when pulling the connector. ChargeX plans to define the forces applicable to the connector under normal conditions and during strain.	UL 2251	11, 111	111	11, 111	111	Arc flash when removed under load due to wear or damage to latch. Broken or cracked mechanism.
1.4	In addition, consider enhancing the robustness of drop tests—from 3 to 10 drops—in UL 2252.	UL 2252 in process	11, 111	111	11, 111	111	Arc flash when removed under load due to wear or damage to latch. Broken or cracked mechanism.
1.5	UL 2202: Presently, the standard does not include any requirement to detect proximity as part of safety designs for connectors. Review timing to require faster response time (presently 25 ms) for the proximity signal to go high when the S3 button is pushed on a slightly worn latch. If the latch is missing,	UL 2202	11, 111	111	11, 111	111	Arc flash when removed under load due to wear or damage to latch. Broken or cracked mechanism.

#	Recommended Action (Consolidation of FMEA Recommendations)	Targeted Standard	Affected FMEA IDs, CCS to J3400	Affected FMEA IDs, J3400 to CSS	Affected FMEA IDs, J3400 to J3400	Affected FMEA IDs, J3400 to J1772 (AC)	Robustness to Root Cause of Failure Mode
	the required response time should be significantly quicker (approximately 5 ms).						
1.6	Additional recommendations: On J3400/1: A recommendation to add a delay functionality between proximity “unlatch” state and allowing the user to disconnect the adapter. This allows the EV/EVSE to de-energize before the adapter is able to be physically removed. On J3400: A requirement to monitor S3 and immediately detect an unlatching event. UL 2202 must have an S3 detection procedure.	UL 2252, UL 2202, J3400/1 (delay functionality), J3400 (S3 unlatch detection)			10		Wear or damage to locking pin (I2) or the delay function (A2), delay function does not exist by design.
1.7	Additional recommendations: Thermal evaluation updates to the side load: When the cable of the adapter is subjected to external forces—such as being stepped on, brushed against, or leaned on—the torque applied to the inlet body of the reference adapter should not exceed a certain value of newton-meters. ChargeX will hold a mechanical evaluation clinic to identify the force from these typical use cases to suggest a value. Standards: A comprehensive evaluation is required to assess the impact of adding an adapter to the lever arm to determine whether the existing inlet requirement of a 20-N·m latch/lock is adequate.	UL2251, UL2252	15	15	15		Forced removal: user force exceeds latch pin, cable weight exceeds latch pin, user leans on adapter (side load).
2	A recommendation to include methods and/or mechanisms to properly recognize and protect against incorrect usage of underrated voltage adapters on higher-voltage configurations. A proper labeling that indicates the rated voltages.	UL 2252 (included in proposal for Section 6.1), J3400/1	138	138	138		Internal or external arc flash across isolation barrier, plastics or adapter parts, short circuit, fires, melting.

#	Recommended Action (Consolidation of FMEA Recommendations)	Targeted Standard	Affected FMEA IDs, CCS to J3400	Affected FMEA IDs, J3400 to CSS	Affected FMEA IDs, J3400 to J3400	Affected FMEA IDs, J3400 to J1772 (AC)	Robustness to Root Cause of Failure Mode
	Underrated voltage adapters should not be able to be listed for use at higher-voltage EV-EVSE configurations.						
2.1	Additional recommendations: J3400/1 requirement that all AC adapters for J3400 do not pass proximity from the EV to the EVSE. A detection on DC EVSE of proximity in J3400 is required. The DC EVSE does not enter pre-charge sequence without detection of valid proximity voltage. UL 2202 requirement for proximity detection to prevent pre-charge of AC onboard charger via a valid proximity voltage prevents use with DC EVSE rated at 1,000 V.	J3400, J3400/1, UL 2202			150	138, 150	No detection mechanism to differentiate AC versus DC adapters. User ignorance or misuse of AC rated adapters with DC EVSE.
3	A test procedure should be identified to determine optimal thermistor placement intended to thermal foldback and shutdown ("unlatched state") protecting all plastic components from melting or deformation by detecting the hottest points on time on all high-current circuits. Thermal detection shall be properly located and secured so they can provide reliable detection during the adapter lifetime. There should be both a steady-state and pin heating test (2 deg/min) (62196-3-1 has details on the slew rates). Testing shall be performed after shock and vibe, drop, aging, and water intrusion test. No loss of thermal detection and ability to interrupt charge should occur thought the test.	UL 2252	21, 22, 26, 32, 33	21, 22, 26, 32, 33	21, 22, 26, 32, 33	21, 22, 26, 32, 33	Thermistor fails or is missing without current-carrying pathway designed for steady-state operation of maximal connector or inlet current-carrying capacity. Thermistor not designed or retained appropriately to identify overtemperature of current-carrying components.

#	Recommended Action (Consolidation of FMEA Recommendations)	Targeted Standard	Affected FMEA IDs, CCS to J3400	Affected FMEA IDs, J3400 to CSS	Affected FMEA IDs, J3400 to J3400	Affected FMEA IDs, J3400 to J1772 (AC)	Robustness to Root Cause of Failure Mode
3.1	Additional recommendations: The thermocouple locations (different than adapter's detection point for the hottest points in the adapter) should be at (1) the busbar joints, crimp zones, or transition of the pin; (2) the busbar joints, crimp zones, or transition of the socket; and (3) either the center or any restriction within the current-carrying pathway as determined by cross-sectional area of the conductor. Thermocouple locations for reference inlet and connector per IEC 62196-3-1. The pass criteria for inlet and connector thermocouples are per the inlet and connector contact temperature requirements (e.g., 100°C), and the pass criteria for the adapter thermocouples should be below material limits (relative temperature index).	UL 2252	26, 32	26, 32	26, 32	26, 32	Components overheat due to environment, failure of thermal management system to transfer heat from connector socket to adapter pin (A6 to A12 to A18). Too much heat generated at connection from pin to busbar from poor welds or fatigue in joining technology (A9 pin to A9 busbar).
4	UL 2252 identifies that listed adapters must be designed to support 800-A current. A proposal to include an automatic thermal current derating mechanism to self-protect against overtemperatures is needed for lower-current adapters. The automatic self-protection "foldback" point must be identified at a minimum defined current. Further, to ensure a double point failure (for either foldback or shutdown) and for robust design (see recommendation 3), two thermistors (one per pin) are required. Evaluation of the thermistors should be proposed following evaluation for mechanical robustness such as the vibration, drop, and accelerated aging tests. Adapter should quickly abort charge session by signaling when critical high temperatures are present.	UL 2252 Section 55	38	38	38		Adapter is rated below maximum current of either connector or inlet system, and there is no system to prevent overcurrent.

#	Recommended Action (Consolidation of FMEA Recommendations)	Targeted Standard	Affected FMEA IDs, CCS to J3400	Affected FMEA IDs, J3400 to CSS	Affected FMEA IDs, J3400 to J3400	Affected FMEA IDs, J3400 to J1772 (AC)	Robustness to Root Cause of Failure Mode
5	UL 2252 already identifies that listed adapters must be designed to support 80 A; however, overtemperature conditions can occur for AC adapters. We propose including an automatic thermal charge interruption mechanism to self-protect against overtemperatures (no foldback feature on AC).	UL 2252 Section 55				38	Adapter is rated below maximum current of either connector or inlet system, and there is no system to prevent overcurrent. Much AC EVSE in the market does not monitor proximity and so would be unable to respond. J3400 does not require AC sensing for foldback due to the overlap in these voltages with Vehicle to Home (V2H) and Vehicle to Load (V2L) applications.
6	Water ingress test should be included in UL 2252 7.6. Proposal in process to update this protection to NEMA Type 6, IPx7 or IPx8. UL 2252, J3400/1 requirement for exposed ground surface within adapter body to improve likelihood of a ground fault detection.	UL 2252 Section 7.6, J3400/1	44, 45, 46, 47, 89, 103	44, 45, 46, 47, 89, 103	44, 45, 46, 47, 89, 103	46, 47, 89, 103	Short occurs between high-voltage positive and negative but not to ground, and fault is not detected. - Sealing gasket fails. - Sealing adhesive fails. - Shell screws/mechanical retention feature loosen. - Means of sealing (including shell) are insufficient or damaged. - Intermittent connection between busbars: failure of isolator in adapter, water intrusion.
6.1	Additional recommendation: J3400 pre-charge detection should be enhanced to include faults between high-voltage positive and	J3400 pre-charge detection	44, 45, 46, 47, 89	44, 45, 46, 47, 89	44, 45, 46, 47, 89	46, 47, 89	Short occurs between high-voltage positive and negative but not to ground, and fault is not detected.

#	Recommended Action (Consolidation of FMEA Recommendations)	Targeted Standard	Affected FMEA IDs, CCS to J3400	Affected FMEA IDs, J3400 to CSS	Affected FMEA IDs, J3400 to J3400	Affected FMEA IDs, J3400 to J1772 (AC)	Robustness to Root Cause of Failure Mode
	negative during pre-charge/fault detection in EVSE for cases of symmetric faults not detected by the ground fault isolation measurement.						- Sealing gasket fails. - Sealing adhesive fails. - Shell screws/mechanical retention feature loosen. - Means of sealing (including shell) are insufficient or damaged. - Intermittent connection between busbars: failure of isolator in adapter, water intrusion.
6.2	Additional recommendations: UL 2252 update to Section 37.2 to include immersion test following accelerated aging of gaskets.	UL 2252 Section 37.5	44	44	44		Sealing gasket fails; short occurs between high-voltage positive and negative but not to ground, and fault is not detected.
7	Adapter should pass water immersion tests once all other tests are completed (drop, aging, shock, and vibe). Recommendation for J3400 to be IPx7 rated when connected. Recommendation for UL 2251 to require IPx7 rating when connected. (See Recommendation 14) Alternatively, a recommendation for UL 2251 to include immersion requirement while mated for cable assembly greater than 1 ft (maybe 2 ft).	UL 2252 IPx7 Rated, J3400 IPx7 Rated UL2251			149		Increased risk of water immersion for cables >2 ft being on the floor/ground, resulting in loss of isolation between A8, A14, and A20.
8	Adapters should be designed as either AC or DC and have AC and DC circuits fully isolated. Recommend	UL 2252 (proposal	120, 139	120, 139			Poor design that interconnects AC and DC pins in the CCS side; J1772 AC side never meant to carry DC high

#	Recommended Action (Consolidation of FMEA Recommendations)	Targeted Standard	Affected FMEA IDs, CCS to J3400	Affected FMEA IDs, J3400 to CSS	Affected FMEA IDs, J3400 to J3400	Affected FMEA IDs, J3400 to J1772 (AC)	Robustness to Root Cause of Failure Mode
	explicitly highlighting the forbidden case of interconnecting the AC and DC pins internally. UL 2252 Section 1.6 does not allow AC/DC "overlay," and no use of AC and DC on pins has been clarified.	included Section 1.6) J3400/1					voltage. These two circuits should never be interconnected.
9	Pin caps in adapters should stay in place after all testing done and should not obstruct the socket alignment while providing proper pin isolation. A UL 2252 recommendation to include pin cap pull test.	UL 2252 Section 5 IEC-62196 Section 26.7 (end caps)	17, 19, 20, 64, 70	17, 19, 20, 64,70	17, 19, 20, 64, 70	17, 19, 20	End cap damaged, removed, or lodged; damage to subsequent chargers and spreading of problems. Overheating: pins and end caps moveable. Touch safety caps on adapter are missing, damaged, not design.
10	Adapter's proximity circuit should provide a highly reliable communication after all tests are done (e.g., drop test, shock and vibe, water intrusion). J3400/1 proposal to indicate a requirement or best practices around vibration and drop test durability for proximity circuit of adapter. J3400 proposal to indicate vehicle driveaway function should not only check for proximity, but also for Control Pilot (CP) and inlet door position.	J3400/1 J3400	97, 141	97, 141	97, 141	97, 141	Proximity circuit from end to end has intermittent or permanent discontinuity due to terminal bonds (e.g., solder, crimp, printed circuit board), quality is below reliability threshold, and connection fails.
11	EVSE should be able to recognize an adapter in thermal protection state at the beginning of the DCFC session, generate a warning message, and decide whether to start charging at the minimum allowed rate.	J3400, UL 2252	143	143	143		Already used adapter after thermal foldback is reinserted to "speed up"; thermal cycling causes the thermistor to fail, failure of body seals/moisture control (A20) causes moisture to short or engage thermistor.

#	Recommended Action (Consolidation of FMEA Recommendations)	Targeted Standard	Affected FMEA IDs, CCS to J3400	Affected FMEA IDs, J3400 to CSS	Affected FMEA IDs, J3400 to J3400	Affected FMEA IDs, J3400 to J1772 (AC)	Robustness to Root Cause of Failure Mode
	J3400 to identify a fixed current for thermal foldback in the case of an adapter presenting as foldback at start of charge. Proposal to UL 2252 would identify a minimum current evaluation to ensure all adapters meet this minimum condition in steady state.						
12	Adapter's pass criteria to provide overall structural integrity after thermal cycling, pull force testing, drop and shock and vibe tests. Provide a comment to UL 2251 Clause 6 reference to the connector meets the standardized configuration via dimensional evaluation or other manufacturing quality process (ISO 9001). Provide input to UL 2251 thermal cycling test (i.e., UL 2251 54C Misalignment) if required based on our ChargeX evaluation. This is covered in UL 2251 under the misalignment test. However, adapter may experience higher side load force due to a lever arm effect; therefore, forces should be evaluated under ChargeX and provided to UL 2251 for discussion of increasing the side load.	UL 2251 Clause 6	133, 39, 40	133, 39, 40	133, 39, 40	133, 39, 40	Increased torque due to longer lever arm, cable weight, cable tension, static load on connector/adapter, damaged contacts (C4–C7 and A7–A11), damage to adapter mating face (A1), damage to connector mating face (C1), debris in adapter mating interface (A1), debris in connector mating interface (C1).
13	Adapter pass criteria for vibration should be enhanced to provide robust design to allow passing an isolation test after shock and vibe and drop tests done. UL 2252 recommendation to include electrical functionality after vibration test. J3400/1 proposal that enclosures should be made of nonmetallic materials to reduce the likelihood of this failure mode.	UL 2252, J3400/1	92, 127	92, 127	92, 127	92, 127	Barrier/spacing is insufficient by design. Vibration of busbars in vehicle causes damage to isolation barrier.

#	Recommended Action (Consolidation of FMEA Recommendations)	Targeted Standard	Affected FMEA IDs, CCS to J3400	Affected FMEA IDs, J3400 to CSS	Affected FMEA IDs, J3400 to J3400	Affected FMEA IDs, J3400 to J1772 (AC)	Robustness to Root Cause of Failure Mode
	To identify failures associated with damage to the isolation mechanism or busbar retention mechanism.						
14	Recommend that J3400/1 does not allow for cables of greater than 1 ft. The current proposal for UL 2252 does not allow cables greater than 1 ft and would not require a recommended change. However, if adapters are to be allowed with longer cables, then the following recommendations are required: UL 2251: Recommend that the drive-over pass requirement for connectors (with an adapter connected) would need to meet dielectric withstand following drive over. J3400/1: Provide drive-over recommendations.	J3400/1 UL 2252, UL 2251			145		Increased torque due to longer EVSE cable weight, cable tension, static load on connector/adapter, being in the floor and people/objects (car tire) running over it, resulting on damaged contacts (C5–C7 and A4, A5, A8, and A10), damage to adapter mating face (A1), damage to connector mating face (C1), debris in adapter mating interface (A1), debris in connector mating interface (C1).
15	Adapter pass criteria should withstand all tests for cable assembly and provide a reliable cable insulation. Recommendation that UL 2252 should require cables listed as an EV cable assembly (UL 2263).	UL 2252 (UL 2263)			146, 147		Adapter extension worn out over time, cables getting twisted or smashed by objects/people/vehicles stepping over while cable on the ground.
16	Adapter pass criteria should withstand all tests for cable grip and provide a reliable and safe cable protection. UL 2252 should reference UL 2251 22 cable grip and Section 33 cable secureness.	UL 2252			148		Lack of strain reliefs or protective means for cable assembly and internal wire conductors from overstress and aggressive/repetitive/ continuous usage.

References

Carlson, C. 2012. *Effective FMEAs: Achieving Safe, Reliable, and Economical Products and Processes Using Failure Mode and Effects Analysis*. Hoboken, NJ: John Wiley & Sons.

Stamatis, D. H. 2003. *Failure Mode and Effect Analysis: FMEA from Theory to Execution*. Milwaukee, WI: ASQ Quality Press.

Appendix: Schematics for Proximity Circuit

This section focuses mainly on describing the different adapter approaches and the proximity circuit cases to provide a better idea of the implications for the different adapters, EVs, and EVSE types.

Case for a CCS DCFC Adapter to a J3400 EV, Rigid Body Adapter

The adapter configuration shown in Figure A-1 assumes the proximity circuit will pass through and create a reliable connection between the EV and the EVSE, with the only exception for a thermal foldback feature, which the adapter will be able to activate when the temperature increases above a certain preset point.

For this particular scenario, this CCS-to-J3400 adapter will only connect the DC+ and DC− high-power lines between the EVSE and the EV's battery. During this connection, both EV DC contactors must remain closed, while both AC contactors are open.

The schematic also shows an unsafe connection between the AC and DC circuits on the CCS side (red dotted lines), which is something manufacturers could incorrectly implement in their products as recommended against by this report. Adapters should be designed for either AC or DC and should not include both connections on the CCS side of the adapter.

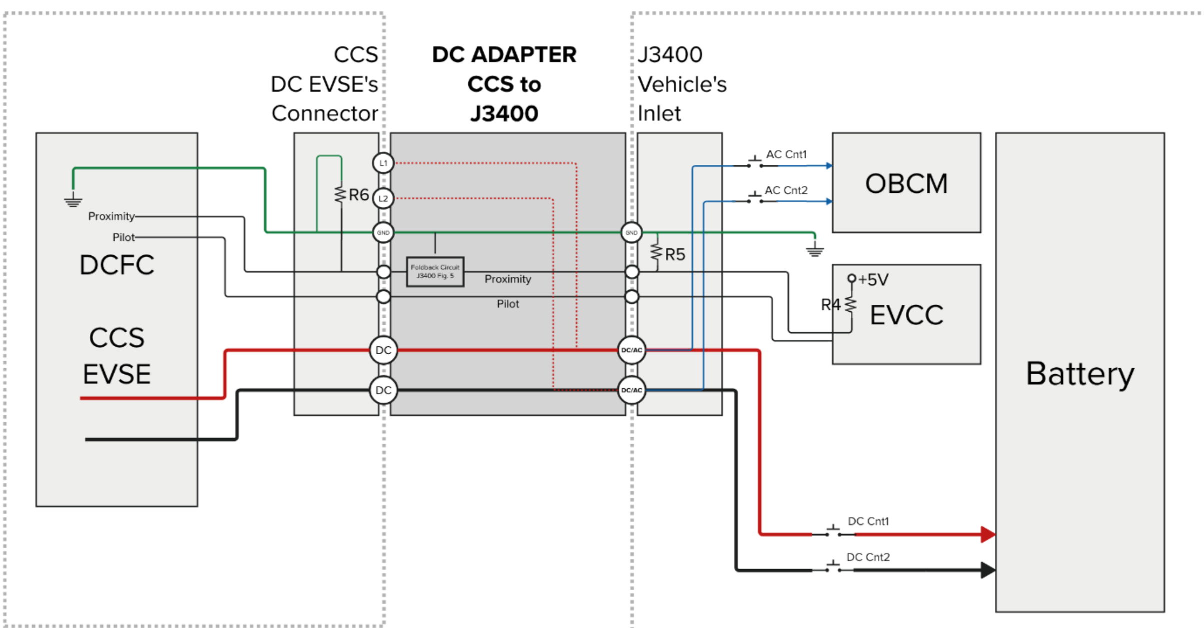

Figure A-1. Schematic for a CCS-to-J3400 adapter in connection with an EV and EVSE

Case for a DCFC J3400 Adapter to a CCS EV, Rigid Body Adapter

The reverse adapter case from J3400 to CCS, as shown in Figure A-2, has a similar configuration in which the adapter configuration will pass the proximity circuit between the EVSE and the EV, with the addition of a thermal foldback feature.

In this schematic, the unsafe connection is shown using red dotted lines and should not be implemented. For this particular scenario, the J3400-to-CCS adapter will only connect the DC+ and DC− high-power lines between the EVSE and the EV's battery. During this connection, both EV DC contactors must remain closed.

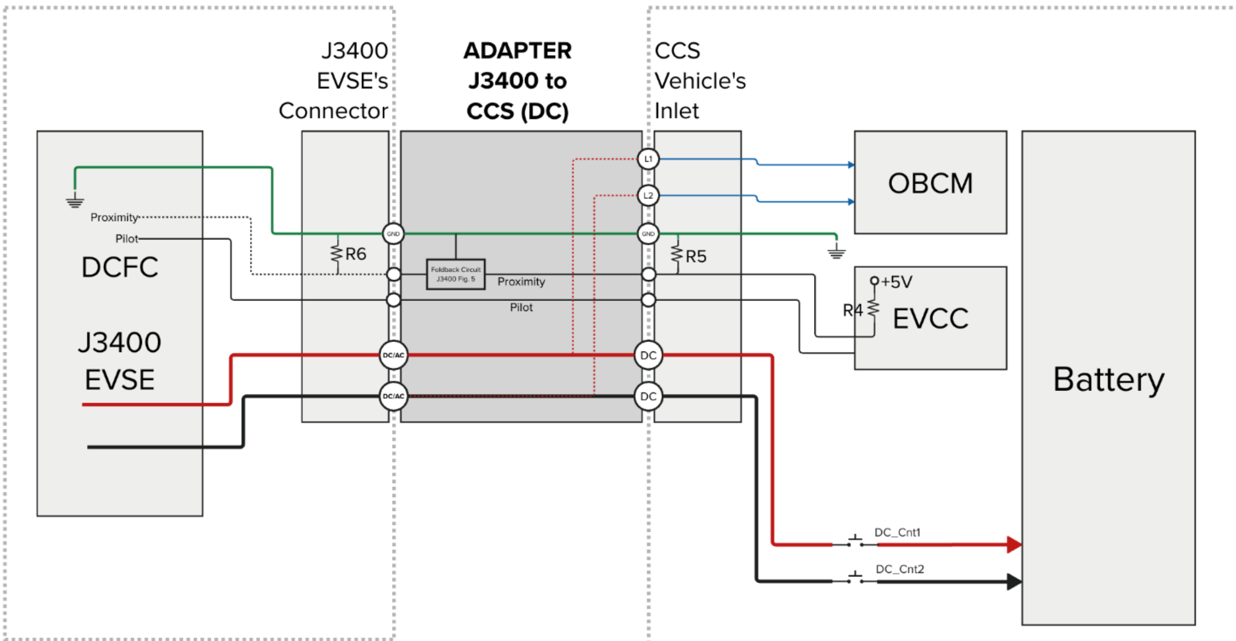

Figure A-2. Schematic for a DCFC J3400-to-CCS adapter in connection with an EV and EVSE

Case for a DCFC J3400 Adapter to a J3400 EV, Flexible Cable Adapter

Specifically for DCFC J3400-to-J3400 adapters, the proximity circuit will pass through, with the only exception being the DC thermal foldback circuitry. In the case of this adapter, and because of the nature of its construction (made of two rigid portions and joined by a cable assembly), this circuitry must include two temperature sensors, one for each side of the adapter (Figure A-3). This adapter might also be compatible with AC systems.

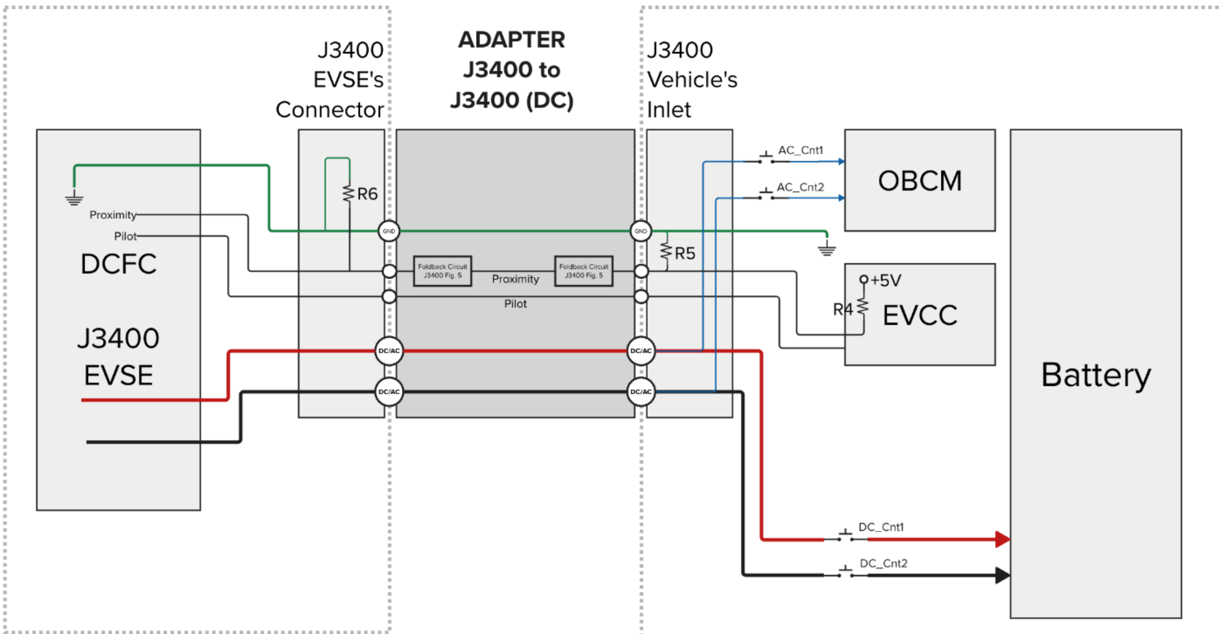

Figure A-3. Schematic for a DCFC J3400-to-J3400 adapter in connection with an EV and EVSE

Case for an AC J3400 Adapter to an AC J3400 EV, Flexible Cable Adapter

This adapter must only be used on AC charging sessions for either Level 1 or Level 2, from J3400 to J3400. This adapter must *not* pass the proximity circuit from the EV into the EVSE, as shown in Figure A-4. This is intended for the EVSE to be able to differentiate between AC and DCFC adapters and not initiate a DCFC session if this type of adapter is mistakenly used on a DCFC system. During this connection, both EV AC contactors must remain closed, and both DC contactors open.

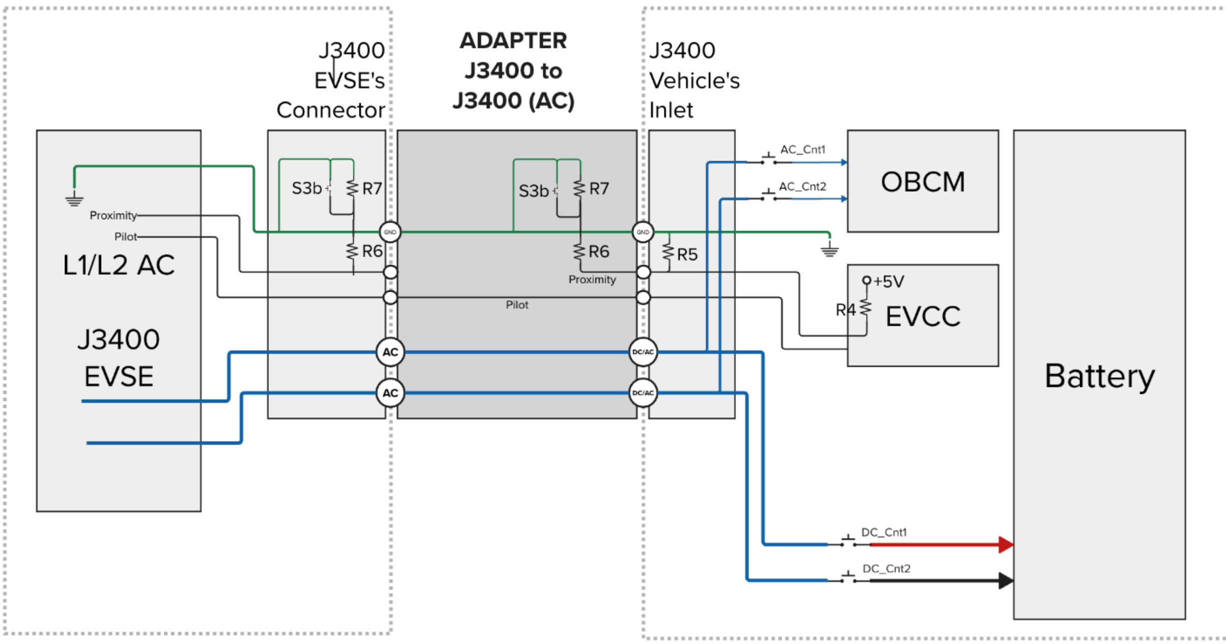

Figure A-4. Schematic for an AC J3400-to-J3400 adapter in an AC charging session

Case for an AC J3400 Adapter to an AC J1772 EV, Rigid Body Adapter

In a final case, a J3400-to-J1772 adapter (meant to be used only for AC Level 1 and Level 2 applications, as shown in Figure A-5) can be used incorrectly and cause severe damage to the vehicle's onboard charger module or the user in the event it is incorrectly used on a DCFC site and the adapter happens to pass the proximity circuit through, as shown in Figure A-6.

In this DCFC scenario, both the EV and the EVSE may assume it is a normal DCFC session, and once the EVSE activates the high-voltage output, it will quickly damage the EV onboard charger module. Figure A-5 shows the ideal use case/adapter.

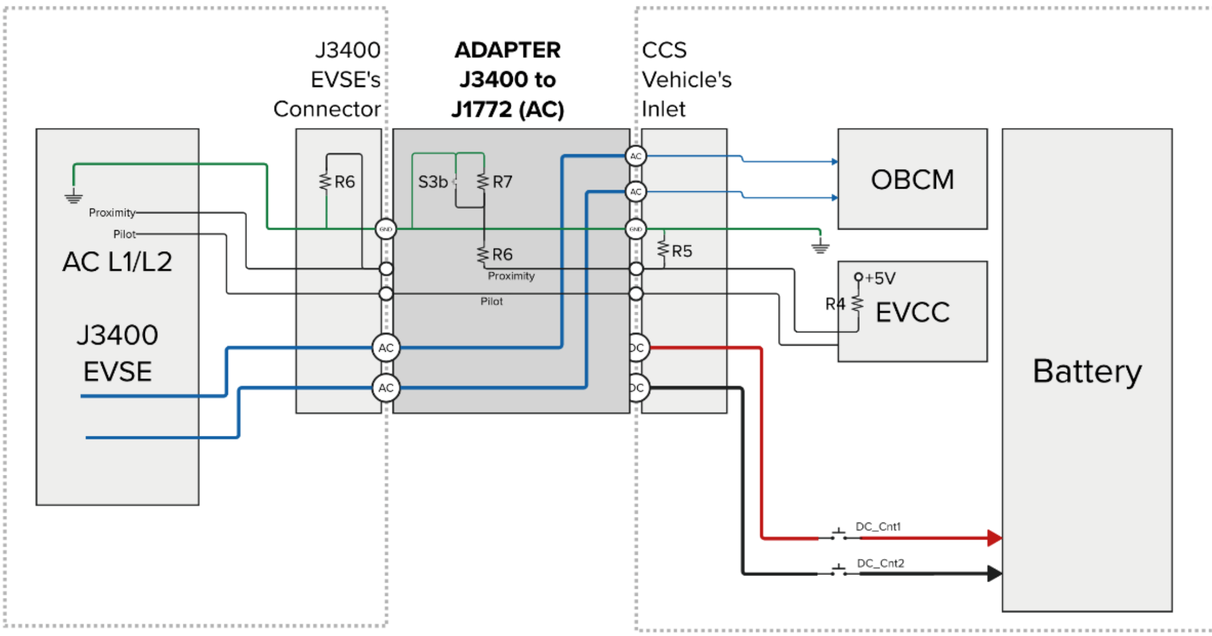

Figure A-5. Schematic for an AC J3400-to-J1772 adapter under correct use

Figure A-6 shows the wrong use case/adapter, attempting a DCFC session that the EVSE can detect because proximity is not passed to the EVSE. In other words, the EVSE is able to detect the adapter via control pilot but identifies that the wrong adapter has been used because proximity is not detected.

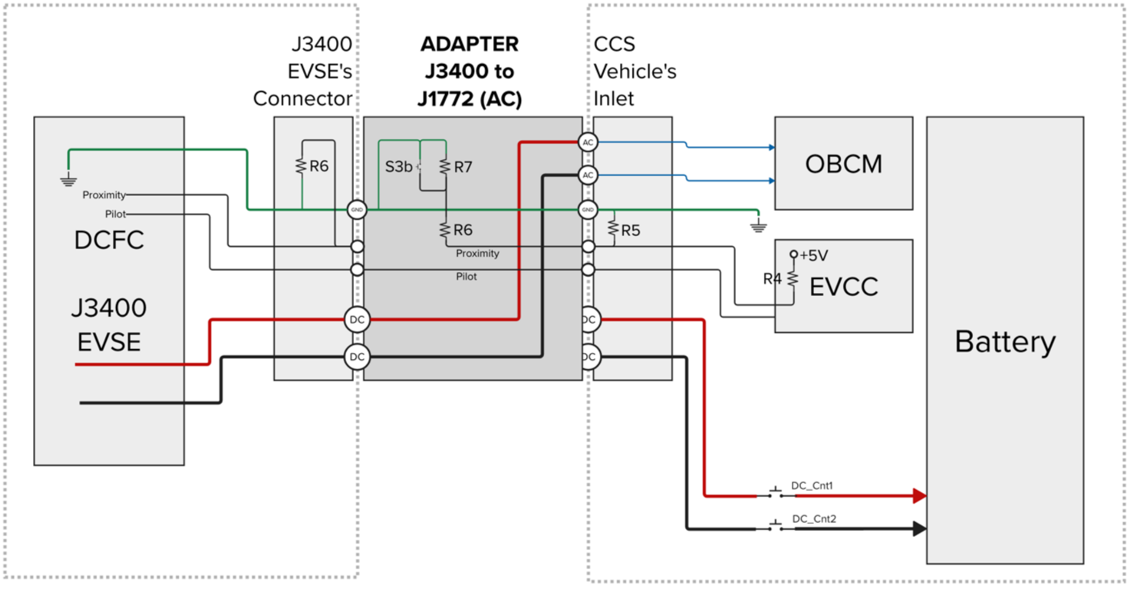

Figure A-6. Schematic for an AC J3400-to-J1772 adapter incorrectly attempting a DCFC session

About the ChargeX Consortium

The National Charging Experience Consortium (ChargeX Consortium) is a collaborative effort between Argonne National Laboratory, Idaho National Laboratory, National Renewable Energy Laboratory, electric vehicle charging industry experts, consumer advocates, and other stakeholders. Funded by the Joint Office of Energy and Transportation, the ChargeX Consortium's mission is to work together to measure and significantly improve public charging reliability and usability by June 2025. For more information, visit chargex.inl.gov.

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