

North American Charging Standard

AC/DC Pin Sharing Appendix



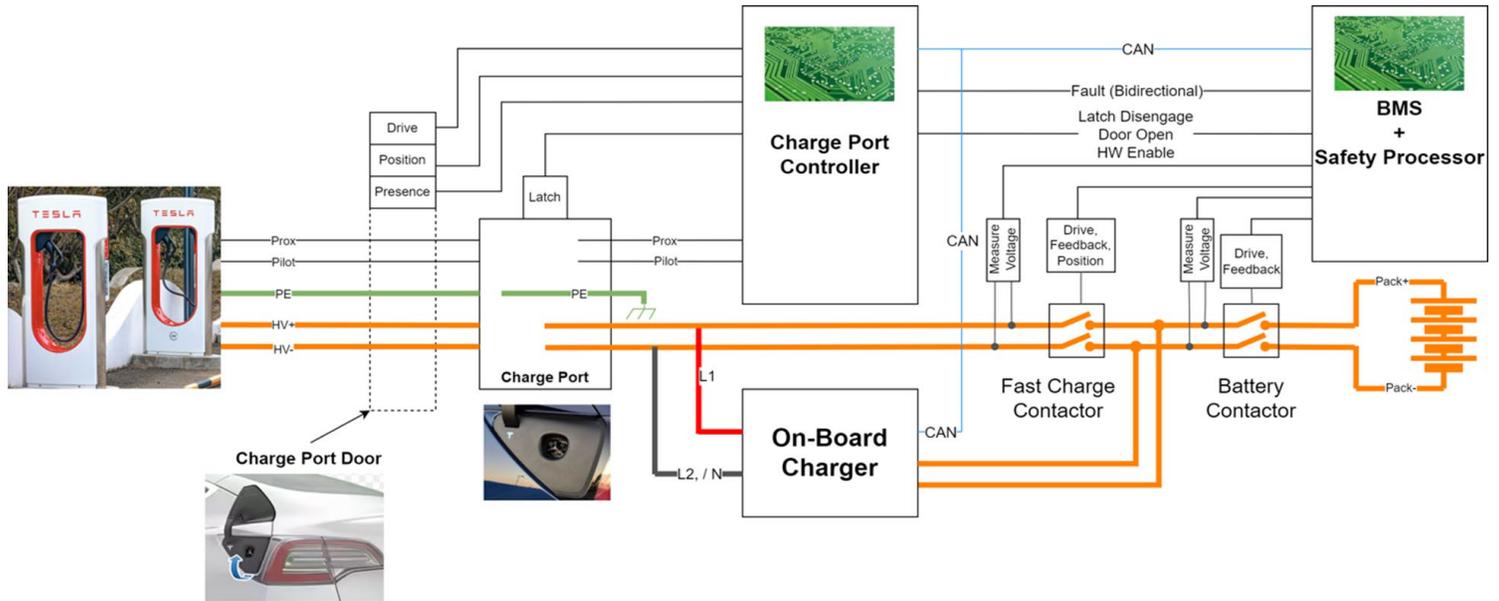
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1. Overview

The North American Charging Standard uses a shared pair of conductors for AC and DC charging. When DC charging, these pins are connected to a DC EVSE and when AC charging they are connected to line/neutral or line/line depending on the grid configuration.

The following diagram shows a system implementing AC and DC pin sharing:



1.1 Components

Charge Port Controller

Drives and detects state of charge port door and latch, interfaces with EVSEs

On-Board Charger

Onboard AC to DC power converter used for AC charging

BMS + Safety Processor

Battery management system, responsible for system coordination, contactor control, and safety functions

BMS - CP: Fault (Bidirectional)

Hardware circuit controlled by BMS which disables the ability to drive the charge port door open and disengage the latch. Charge port door can still close and latch can still engage (always safe actions) when enable line is de-asserted.

1.1 Components, cont.

BMS - CP: Latch Disengage/ Door Open HW Enable

Hardware fault circuit which can be set by either charge port controller or BMS. Redundant method to indicate faults in case of CAN failure. Disables charge port's ability to request AC voltage via pilot.

Charge Port Door

Charge door covering high voltage inlet, managed by charge port controller. Door hinge position and door cover presence sensors used for redundant inlet exposure detection (for example, if door breaks off, position may indicate door is closed but presence sensor will indicate door is not present)

Contactors

Switches used to connect high voltage links. Can include auxiliary mechanical position sensing as a stuck-closed detection mechanism.

Voltage Measurements

Differential (HV+ to HV-) and common-mode (HV+/- to chassis) voltage sensing, which can be used for contactor stuck-closed detection.

2. Safety Analysis

With shared pins, the system must be designed to avoid connecting the battery pack to an AC electrical grid, which may result in high severity failures of grid and battery components. This section outlines an example safety analysis used to generate system design and requirements to avoid this failure mode.

2.1 Hazards and Risks Assessment

A hazards and risks assessment can be used to derive the ASIL level of the failure mode and primary safety goal:

Function: Don't connect HV battery to an AC electrical grid

Malfunction: System allows HV battery to be connected to an AC electrical grid

Worst-Case Scenario: Stationary vehicle charging

Hazardous Effect: Damage to grid-connected devices and possible thermal event

Safety Hazard: Severe failure of grid-connected devices, thermal event

Reliability Hazard: Damage to vehicle components rendering the vehicle inoperable

Exposure Rating: E4: >10% of average vehicle operating time

Severity Rating: S3: Life threatening or fatal injuries

Controllability Rating: C3: No action can be taken by user once failure has occurred

Reliability Rating: R3: Permanent damage to vehicle

The above ratings are used to derive a safety criticality level of SCL2(D) and reliability criticality level of R3. This gives the resulting safety goal (*avoid connecting the battery pack to an AC electrical grid*) an ASIL rating of ASIL-D.

2.2 Safety Concept

The following are examples of functional safety requirements used to meet the safety goal (*avoid connecting the battery pack to an AC electrical grid*) with the system from Figure 1:

1. The fast charge contactors shall be inhibited from closing if the fast charge link is not connected to a DC EVSE.
2. The fast charge contactors shall be inhibited from closing if there is AC voltage greater than 30Vrms within 40Hz to 70Hz detected on the fast charge link.
3. The fast charge contactors shall be inhibited from closing if the vehicle detects an AC EVSE is connected.
4. Charge cable connection must be disallowed (via latch engagement and disallowing door opening) if the fast charge link is energized with high voltage DC.
5. If the system detects that the charge cable may be connected while the fast charge link is energized with high voltage DC when cable connection is not allowed, it shall disconnect the battery pack from the fast charge link within one second.
6. If either fast charge contactor is detected as closed, the system shall disallow requesting voltage from an AC EVSE.

The system should be designed to meet the functional safety requirements above, and analysis completed to ensure that the implementation can be composed to meet a safety rating of ASIL-D. ASIL level decomposition can be used to reduce the required ASIL level of each function to lower ASIL levels that together meet the ASIL-D requirement.

Mechanisms that can be used for meeting ASIL-D requirements using ASIL decomposition:

- Redundant detection mechanisms for features such as fast charge contactor closed state, AC present on fast charge link, etc.
- Requiring consensus among multiple independent components to make decisions such as fast charge contactor actuation.

2.3 FMEA

The following are some example failure modes, effects, and design controls for this function in a vehicle system:

Requirement	Failure Mode	Effect	Severity	Cause	Occurrence	Design Controls
Detect state of fast charge contactors	Fast charge contactor is detected as open when it is mechanically closed	DC pack voltage on AC grid upon connection of AC EVSE	10	Contactors state feedback fails during overcurrent event which welds contactors	1	<ol style="list-style-type: none"> 1. Redundant disconnect measures: Pack contactors & fast charge contactors 2. Redundant contactor state measurement: voltage measurement & mechanical position feedback
Actuate fast charge contactors	Fast charge contactor actuated closed while fast charge link is connected to AC grid	DC pack voltage on AC grid during AC charging	10	Software bug	1	<ol style="list-style-type: none"> 1. Redundant contactor control; two controllers with two processors must agree on contactor actuation 2. Fast charge link voltage measurement must match battery voltage to close fast charge contactors 3. AC voltage detection on fast charge link
Detect presence and type of EVSE	System falsely determines DC EVSE is connected when AC EVSE is connected	DC pack voltage on AC grid during AC charging	10	Software bug	1	<ol style="list-style-type: none"> 1. Fast charge link voltage measurement must match battery voltage to close fast charge contactors 2. AC voltage detection on fast charge wires 3. EVSE interface signals such as prox and pilot, or CCS comms, denotes EVSE type. Qualification of DC EVSE connection requires indication via comms interface
Request voltage from AC EVSE	System requests voltage from AC EVSE when DC voltage is present on fast charge link	DC pack voltage on AC grid upon connection of AC EVSE	10	Software bug	1	<ol style="list-style-type: none"> 1. DC voltage removed from fast charge link using contactors/fuse if charge cable is connected and not determined to be DC EVSE 2. BMS - CP fault line asserted if fast charge contactors are unexpectedly closed, which prevents requesting voltage via pilot state on charge port controller via hardware

2.3 FMEA, cont.

Requirement	Failure Mode	Effect	Severity	Cause	Occurrence	Design Controls
Disconnect pack from charge inlet if fast charge contactors are unexpectedly closed & charge cable can be connected	Unable to isolate DC voltage from charge port	DC pack voltage is available at charge port. HV touch hazard & DC pack voltage on AC grid upon connection of AC EVSE with EVSE relays closed	10	FC contactors unexpectedly closed	1	<ol style="list-style-type: none"> 1. Redundant disconnect measures: pack contactors & fast charge contactors 2. Electronically actuated fuse inside battery can be used to disconnect if all contactors fail
Block connection of any charge cable with unexpectedly closed fast charge contactors	Connection to AC EVSE is allowed with DC voltage on fast charge link	DC pack voltage on AC grid upon connection of AC EVSE with EVSE relays closed	10	Charge port door forced open with FC contactors welded	1	<ol style="list-style-type: none"> 1. Charge port door and latch can both be used to discourage charge cable detection when fast charge contactors are closed unexpectedly 2. Detection of user overriding either charge port door or charge port latch, indication to system that cable connection is no longer blocked, system responds by removing battery pack using pack contactors or electronically actuated fuse

3. Other Considerations

3.1 On-Board Charger DC Voltage Withstand

Tesla's implementation has the AC input of the on-board charger directly connected to the fast charge link. With this implementation, DC high voltage will be applied to the AC input of the on-board charger whenever DC fast charging is active. The on-board charger must be designed to withstand this DC voltage and must not attempt to convert power when DC fast charging is active to avoid damage to the on-board charger power converters. The maximum DC voltage that the on-board charger must withstand can be derived as the greater of maximum pack voltage and maximum voltage seen during the DC charging external isolation check

If the on-board charger cannot meet this voltage withstand requirement, an alternative option is to separate the on-board charger from the fast charge link using relays or contactors.

Failure modes of DC EVSEs must also be considered when choosing the maximum withstand voltage. Tesla has encountered situations where DC EVSEs applied higher than expected DC voltage during external isolation testing, caused either by vehicle or EVSE malfunctions, resulting in damage to the on-board charger or other components connected to the fast charge link. An example of this is EVSEs rated for maximum voltage supported by the CCS standard unexpectedly applying this maximum voltage to a vehicle advertising it does not support this range. While it is not required to ensure there is no damage to components due to this failure mode, manufacturers should consider this malfunction when designing the system and at minimum ensure the failure is contained and does not pose safety hazards.

3.2 Fast Charge Contactor Weld Detection

Tesla’s implementation of fast charge contactor weld detection compares differential and common-mode DC voltages sensed on either side of the contactors. If the differential or common mode voltage matches, the fast charge contactor is diagnosed as welded.

If a similar weld detection strategy is used, the detection should be designed to trigger only when DC voltage is present, as AC voltage waveforms seen while AC charging may cross DC voltage match thresholds for brief periods. Hardware or software filtering and/or AC/DC component detection of the fast charge link voltage can be used to mitigate this concern.

Tesla has additionally encountered AC EVSEs that apply AC voltage with DC offset with or without the EVSE relays closed which may trigger voltage match detection. This can be caused by devices within the EVSE used for insulation monitoring, weld detection, residual current detection, or other functions. An example of one such device is the Bender RCMB613, which partially conducts the AC voltage waveform through diodes in its residual current detection circuit:

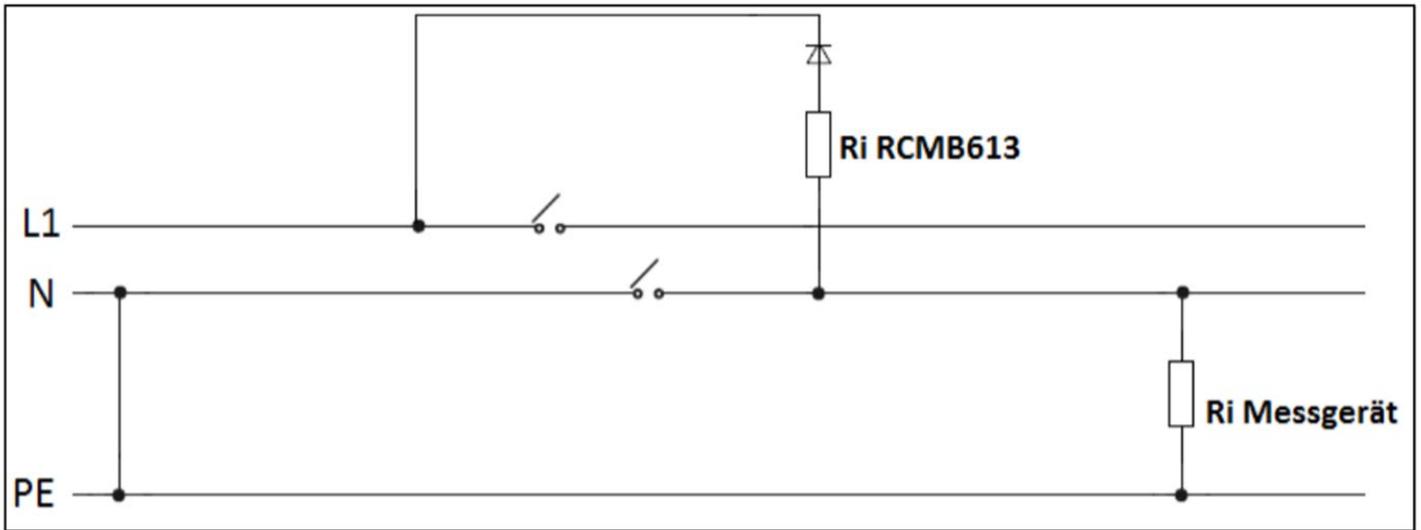


Figure 2: Bender RCMB613 Residual Current Detection Circuit

To mitigate these types of issues, the vehicle may implement targeted detection of this scenario to disqualify weld detection, such as checking for: (charge cable connected) AND (DC voltage detected) AND (50-60Hz AC voltage waveform detected). Alternatively, standards may be updated to dis-allow AC EVSEs from applying any voltage waveform to the output when the EVSE relays are open.