CharIN Whitepaper Megawatt Charging System (MCS)

Recommendations and requirements for MCS related standards bodies and solution suppliers

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Contents

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1. Introduction

This document gives an overview of several technical and non-technical aspects of the Megawatt Charging System (MCS), as discussed within the CharIN Subgroup since 2018. As a descriptive summary, it provides the achievements in preparing general design aspects of an MCS. For further development this document also provides recommended MCS specifications for adoption by Standards Development Organizations (SDOs).

1.1. MCS Importance to Battery Electric Commercial Vehicle Industry

There are two key technologies to broad acceptance of battery electric commercial vehicles: increased range and decreased charge times. Charging time, which can be quantified as distance per time unit charged, should be considered across the fleet, and should also consider lost charging time due to delayed charging or even charging equipment issues. MCS offers the charge rate necessary to realize widespread adoption of battery electrification in the commercial vehicle market by increasing driving range gained per minute spent charging. MCS also offers improved robustness of communication, which will reduce downtime related to failed charging events.

Commercial vehicles customers have very specific driving patterns. The increased charge rate offered by MCS will allow customers to drive more distance per day by utilizing the mandated break-time from the hours-of-service regulations. These regulations state that drivers must take a break on occasion during their drive cycle; the exact amount varies by location, but it’s well understood that reducing charging times to fit into normal breaks in the duty cycle is an enabler for improved electrification for commercial vehicles. This is just one specific example of how the MCS charge rate can enable the market.

1.2. MCS Considerations for Public charging

Accessibility has to be considered when installing MCS chargers in public infrastructure. MCS is an enabling technology to commercial vehicle electrification. It is critical that MCS chargers are accessible by large commercial vehicles requiring drive through capabilities.

1.3. Provisions for automation

While the predominate implementation of MCS charging infrastructure is expected to be human-operated charging connectors, provision for automated coupling is possible.

2. Requirements

This chapter summarizes important requirements defined for the Megawatt Charging System with regards to safety, communication and hardware aspects. These technical requirements were discussed by numerous experts from different industries and should ensure a safe and reliable charging system.

2.1. Communication

Communication topology is an important part of the MCS specification. Following the OSI model for communication, one important part of the work done in the MCS group is defining a physical communication layer. Charging systems deployed throughout the world presently use physical layers with different technologies, each with their own pros and cons. CharIN members have successfully implemented improvements to the CCS architecture for many years, which uses power line communication (PLC) with the HomePlug GreenPHY communication protocol. This "single ended" PLC used for CCS supported a wide variety of use cases with the benefit of not needing dedicated connection pins for communication between EV and EVSE.

I. Charging Communication - Physical Layer

MCS is designed for a 6-fold higher current and up to 10-fold higher power compared to CCS. Therefore, the single-ended implementation of today's PLC was considered not robust enough for the expected increase in electro-magnetic interference (EMI) emissions compared with CCS.

After assessing different physical layers (for communication technologies) on the market (e.g. CAN, Ethernet, PLC), CharIN members came to the conclusion that the physical layer should natively support TCP/IP based communication, to easily implement the ISO 15118 communication standard without the need of additional complex middleware. Additionally, it was shown with several charging communication electro-magnetic compatibility (EMC) tests that a differential physical layer will have a significant improvement over the single-ended design of the PLC used in CCS. Due to the broadband design of PLC and the high experience of how to apply it in charging systems, CharIN recommends adapting PLC to a differential design, using the dedicated charging communication pins of the MCS connector. PLC natively supports the TCP/IP communication stack (just as Ethernet does), and can be easily adapted to a differential design while still using PLC transceivers already designed for single-ended PLC. By using unshielded twisted pair (UTP) wires and a matched impedance of 100 Ohm, the noise immunity is roughly 40 dB higher than single-ended PLC.

Based on this information, CharIN recommends differential PLC. In case other physical layers are considered in standards bodies in the future, CharIN strongly suggests that a unified differential signaling and native TCP/IP support is of utmost importance for communication robustness and interoperability. There are use cases for road vehicles which use CCS and MCS in parallel. This reduces implementation efforts as the PLC system design can be re-used. A benefit of using this differential communication and connection scheme, is that it also reduces the necessity for signal level attenuation characterization (SLAC) used in CCS implementations, because differential signals produce much less crosstalk between adjacent charging systems. For further information on SLAC, see chapter 2.2 iii.

Due to the impedance matching between the cables of the supply equipment communications controller (SECC) and electric vehicle communications controller (EVCC), and the precision of the attenuation requirements in the communication network, there is no need to calibrate every single system variant, as was required for single-ended PLC. A calibration of a hardware (HW) sample of the SECC or EVCC (a "type test") is adequate to provide robust communication.

II. High-Level Communication Application Protocol

ISO 15118 is the well-established standard with many subgroups working on different implementation details. ISO 15118-2 has been in use throughout the charging industry for many years but had some limitations as well as many different implementations due to inconsistent interpretation and implementation of the standard. In addition, other DIN and SAE protocols for communication have also been used in the charging industry for many years, but those earlier protocols also have even more limitations and loose interpretations.

As a result of the significantly more complex use cases that need supporting, such as secure handling of payment systems with "plug and charge", flexible charge management operations with fleets and large sites, vehicle to grid export power needs, etc. necessitating an improved communication protocol ultimately leading to the development of ISO 15118-20. This protocol has been published and is available for use since early 2022.

Because of the significant number of improvements offered by ISO 15118-20 compared to previous protocols, ISO 15118-20 represents the most complete and robust communication protocol available globally. As a result, CharIN recommends that MCS uses ISO 15118-20 exclusively, with no other (older) protocols supported, to ensure the absolute highest level of user experience and security to equipment using MCS.

III. High-Level Communication SLAC

As mentioned in section 2.2.i, SLAC is not necessary to ensure robust communication when differential PLC is used for the physical layer. Therefore, the CharIN members suggest eliminating the SLAC protocol, which will reduce complexity and accelerates startup times. The idea is to reduce the setup sequence of the charging communication to the exchange of the Network Management Key (NMK) only; after that, the data link is established and the ISO 15118-20 application protocol is initiated.

2.2. Electrical

I. Electromagnetic compatibility

EMC robustness is at the core of charging communication performance. The standard IEC 61851-21-2 defines the necessary requirements. CharIN members have funded studies by independent labs/research organizations into the robustness of the MCS setup using differential PLC. These tests were performed with directly injected noise profiles (bulk current injection (BCI) coupling tests) to simulate coupling of noise from the traction voltage lines and adjacent communication lines, to simulate common use cases/industry scenarios. The failure conditions for these tests were defined as the loss of just one data packet, or a latency time of > 60 ms, which is very stringent. The results of these studies showed the necessary robustness for shielded twisted pair (STP) (for all use cases) and UTP (for all common use cases) configurations with two different PLC transceiver manufacturers. These results form the bases of the recommendation of differential PLC in further sections.

II. Isolation & Safety

MCS is designed as a charging system that is galvanically isolated from the grid. All state-of-the-art electrical safety requirements from ISO 5474, IEC 60664 and IEC 61851 series were considered. Further key requirements for the system design are:

- Limitation of transient voltages between HV+ or HV- to PE to 2.5 kV by the EVSE
- Limitation of the Y capacitances on EVSE and EV side depending on the maximum operating voltage (see chapter XV)

III. HV Touch Safety

High voltage (HV) touch safety is a measure intended to prevent living objects from contacting conductive paths that may have a high voltage and/or high temperature. Globally many governmental bodies require IPXXB for high voltage connections that are outside of a passenger compartment. IPXXB is defined by IEC 60529 and is intended to prevent a defined “finger” from contacting any hazard surface. MCS never intends to have any high voltage exposure when the connector and inlet are not mated. Based upon the experience with the CCS standards development and the lessons learned toward broader adoption of the CCS interface in regions with other guidelines related to touch-safety protections, the MCS design followed these learnings and is constructed to provide IPXXB level of touch safety.

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IV. Maximum socket/pin temperatures

We recommend that the maximum temperature limit of the pin/socket contacts for MCS is set to 100°C due to the following reasons:

1. Adequate testing results demonstrate that even at 100°C contact temperature, the permissible surface temperatures defined in IEC 62196 and UL2251 are maintained. (Reference VI.)
2. Increased aging is less of a concern with materials and surface treatments available now.
3. The current standards necessitate the use of composite materials with temperature ratings exceeding 105°C. The existing limits of IEC 62196 and UL2251 are based upon former material limits thereby necessitating a maximum temperature limit of 90°C. 100°C was agreed as a compromise to provide design margin below the materials limits of 105°C
4. Today, commonly used composite plastics can be found in high-temperature grades with relatively higher working temperatures. These grades of plastics are not prohibitively expensive and would allow for a contact temperature increase to while remaining within working temperature limits.

Temperature sensing is required for the HV DC contacts on both the inlet and the connector. The sensor behavior shall follow the requirements specified in IEC TS 62196-3-1.

The type of sensor shall remain at the discretion of the inlet and connector manufacturers, respectively.

V. Contact temperature difference compared to ambient

We recommend that there to be no specific requirement for maximum temperature difference between socket/pin temperature and ambient temperature for MCS.

Existing standards specify a dual requirement:

1. A maximum socket/pin temperature (e.g., 90°C) and
2. A maximum temperature delta between ambient and socket/pin temperature (e.g., 50°C).

CharIN does not recommend tracking dual requirements like this. Rather, the focus is on limiting maximum absolute temperature, therefore only a single maximum temperature should be referenced and no reference to ambient temperature is needed.

To clarify an example, use case: If a vehicle is charging in –10°C ambient air conditions, if a delta temperature of 50°C was considered, this would require that maximum pin/socket temperatures remain below 40°C (due to the 50°C delta requirement). Having pin temperatures above 40°C would not cause issues, particularly related to safety; therefore, we should not limit the charging power as a result of this low ambient temperature.

VI. Permissible surface temperatures

CharIN recommends in line with existing standards:

The maximum permissible temperature of those parts of the accessory and cable assembly that can be grasped during normal operation carrying the rated current shall not exceed:

50 °C for metal parts,

60 °C for non-metal parts.

For parts which may be touched but not grasped, the permissible temperatures are:

60 °C for metal parts,

85 °C for non-metal parts.

VII. Short circuit protection

Based on the prospective short circuit currents from multiple battery packs, as available at the vehicle inlet, the short circuit current should be limited by the vehicle to a peak current of 70kA and $12MA^2s$ between the DC+ and DC- terminals. The EV supply equipment shall limit the peak current to 30kA and $1MA^2s$ at the vehicle connector. In case of two independent faults (one in the vehicle and one in the EV supply equipment) a short circuit current may flow through the protective conductor. Based on the added impedance of the charging cable, the peak current will be limited to 55kA, and $11MA^2s$. The EV and EVSE, including the locked coupler, shall be designed to withstand these currents. The inductance of the EVSE output circuit and of the vehicle shall be limited in coordination with the short circuit protective devices.

VIII. Bus Voltage Range

The operating voltage range for a charging system (which includes the EVSE and EV) must be established while considering a very complex amount of information. This complicated selection considers metrics such as availability of power electronics equipment for both EV and EVSE, coverage of vehicle applications, operating efficiency across the fleet usage, maximum power available, addressing high voltage safety, and balancing the challenge of simplifying power electronics architectures while meeting the needs of the use cases and optimizing value for developing and manufacturing EVSE and EV.

The industry has experience with CCS development in the past with operating ranges between approximately 200-920 VDC. Wider operating ranges (as low as 50 VDC and as high as 1000 VDC) are documented as possible but aren't implemented in typical installations. This is a useful reference when considering past and present state of the art compared to future expectations for MCS.

When considering the voltage levels that MCS must support, CharIN considers the most important factors to be supporting as many vehicles as possible (wider operating voltage range is better) while balancing that with the total operating range (wider operating voltage range increases complexity).Alternatives were considered, such as reduced operating performance with higher/lower voltages needed due to unique operating modes or battery cell chemistries. But those alternatives are not recommended by CharIN.

With those considerations, CharIN recommends that MCS should use a minimum voltage of 500 VDC and a maximum voltage of 1250 VDC. While this will not cover all possible use cases of all possible vehicle types, this is expected to provide a good compromise between operating voltage range and vehicle coverage.

It is important to note that CharIN recommends that all MCS EVSEs support the full operating range of 500-1250 VDC. Past experience in the industry have shown that it is a recipe for disaster to have vehicles and infrastructure that aren't compatible with each other. Therefore, EVSE manufacturers and other MCS standards organizations are warned very strongly against supporting development of charging infrastructure that can't support the full range of 500-1250 volts.

Note: The Connector is designed for 1500 VDC. For the lower limit 400V is in discussion.

IX. Maximum current

The maximum continuous rating for MCS has been tested up to 3000A DC. Considerations for short-term, duty-cycle ratings were deferred for future MCS development and testing. Higher currents should be carefully examined and validated against safety requirements..

X. Minimum Current

The minimum current supported by MCS shall be 0A according to IEC 61851-23 Edition 2 and IEC 61851-23-3. Because MCS uses ISO 15118-20, the mode that shall be supported is the one that allows communication to continue without charging, either with contactors closed or not, at 0A.

XI. Thermal Management Systems to Support High Currents

The following two requirements clearly define the division of responsibility with regard to thermal systems during charging

- The vehicle is responsible for complying with temperature requirements for the vehicle.
- The EVSE is responsible for complying with temperature requirements for the EVSE (including cable/connector).

Each manufacturer is empowered to choose the thermal management system of their choice, so long as they meet the temperature requirements (limits) for MCS.

CharIN proposes that the charging current and voltage limits of the EVSE shall be communicated to the EV and the EV controls how much current is requested during charging per ISO 15118-20.

To ensure that customer expectations are met at a wide variety of operating conditions, the EVSE should be designed in a way such that power ratings are provided at ambient temperatures up to 40°C.

XII. PE Pin Size

8mm diameter is used in the MCS connector design for the PE pin.

XIII. PE Wire Size

The potential equalization wire included in the MCS connector follows the industry standard that is already well established in high voltage connection, allowing a safe path for high voltage short circuit currents through the connector assembly for defined conditions.

The cable shall be capable of withstanding a short circuit current of 11 MA^2s, which typically results in a minimum cross section of 25mm^2.

XIV. Insulation requirements

The electrical insulation requirements for the MCS charging system are derived from the existing Standards with appropriate amendments to address the increased MCS charging power levels. The relevant Standards include ISO 5474 for EVs; IEC 61851-1 and IEC TS61851-23-3 (under development) for EVSEs; and IEC TS63379 (under development) for the charging connector and vehicle inlet.

XV. Touch current protection

Limiting the touch energy as an additional protection provision is an established requirement in the published stages of the 2nd edition of IEC 61851-23. Due to the higher power levels provided by MCS, higher Y capacitances will be needed in the system. There are various concepts to allow for the needed Y capacitances by still staying below the critical limits.

CharIN proposes these limits, which should be included in ISO:

V_{dc+} to V_{dc-}	$V_{dc+/-}$ to PE	Cy_{system} (µF)	$Cy_{EVtotal}$ (µF)	$Cy_{EVperDCline}$ (µF)
$1126 < V_{dc} \leq 1250$	$638 < V_{toPE} \leq 700$	$\ln((0,5*V_{dc}+75))/758)/-0,007$	$0,5* \; Cy_{system}$	$0,25 * \; Cy_{system}$
$1004 < V_{dc} \leq 1126$	$577 < V_{toPE} \leq 638$	$5/(0,5*((0,5* V_{dc})+75)^2)*1000000$	$0,5* \; Cy_{system}$	$0,25 * \; Cy_{system}$
$V_{dc} \leq 1004$	$V_{toPE} \leq 577$	30	15	7,5

- the c1 limit of figure 22 (DC) of IEC 60479 1
  (more conservative than c1 in figure 20 (AC))
- 5J limit of IEC 60335 2 76 (electric fence)
- with a human body resistance of 575Ω

XVI. Auxiliary low voltage supply

When considering use cases, CharIN reviewed the possible technical solutions of implementing an auxiliary low voltage supply in the system. This would be considered as helpful for use cases where the EVSE or EV do not have low voltage available for basic communications in order to support charging or export power features (such as vehicle-to-grid (V2G) in case of a power outage). After reviewing the technical concepts and challenges associated with different options, the conclusion is that a low voltage auxiliary supply integrated with the MCS connector is not recommended as a requirement but should be considered as an optional feature that shall not impact the function of the communication scheme utilizing the same circuit(s). When there is no auxiliary low voltage supply integrated with MCS, if an EVSE needs an ability to communicate for supporting Vehicle-to-grid operations, the EVSE should be supplied with an uninterruptable power supply (UPS) or similar. In case a vehicle has a low voltage battery problem such that it can't begin charging, it is recommended to follow the industry standard of using "jumper" cables or a "jump box" to temporarily provide low voltage power to that vehicle until it can begin charging.

2.3. Hardware

I. Coupler Retention

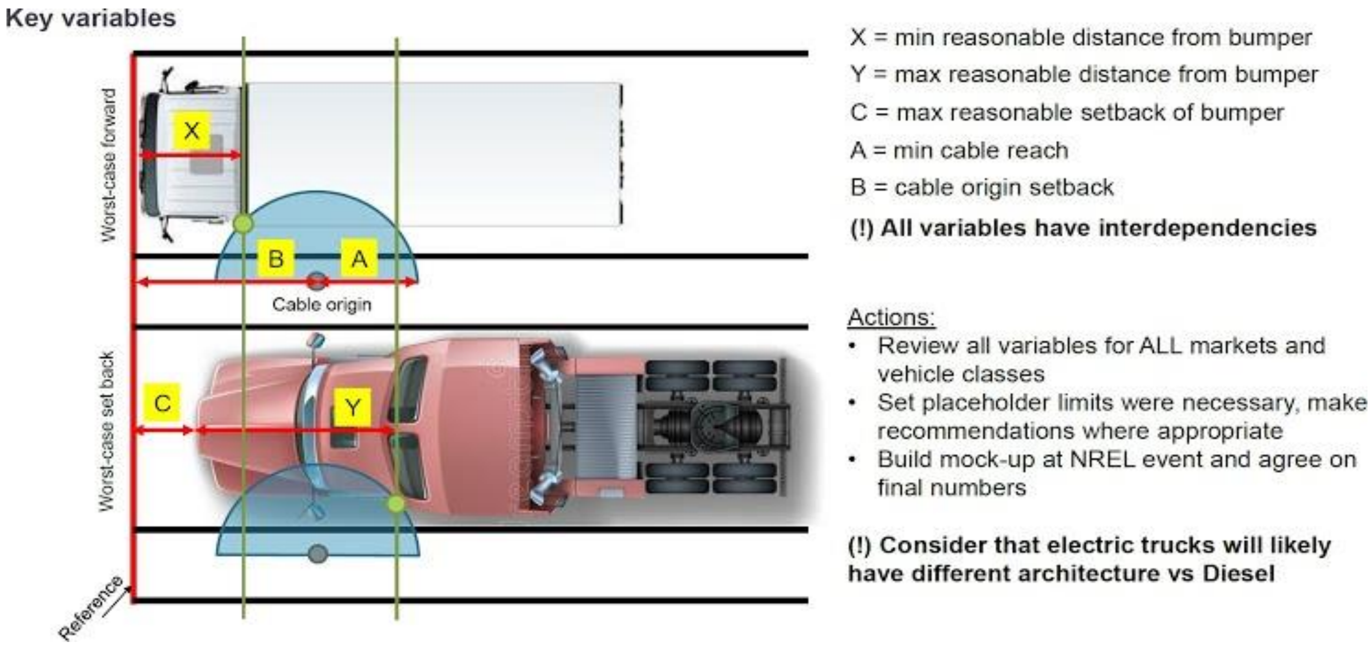
There are many lessons learned from the different implementations of CCS retaining means and latches, which included both mechanical and electrical interlock mechanisms, controlled by individual users and also by electronic devices. The recommended MCS retention is based on those lessons learned.

The MCS interface shall include an electrically activated/actuated lock to ensure that the connector remains engaged with the inlet during all normal operation and also in case of short circuit. This electrically activated retaining means shall provide feedback to the EV and shall be controlled independently of buttons or switches used for either normal user requested shutdowns or emergency shutdowns . The retaining means shall be integrated into the inlet side of the MCS coupler on at least one location, and up to 3 locations, as included in the MCS connector dimension proposals. The lock shall have a pin or slot design that operates consistently in all expected operating conditions, especially considering temperature and weather variations for charging operations in extreme environments, and with expected tolerances and wear.

II. EVSE / Port Location Recommendations

CharIN expects that MCS will be used on many different vehicles with many different use cases and configurations. CharIN recommends that for trucks, the inlet location should be on the left side of the vehicle, behind the most-forward axle. This consistent location supports best practices from experiences with early development and lessons learned from previous charging experiences.

A survey among the vehicle manufacturers within the MCS Subgroup resulted in inlet positions between 2m and 4,8m, measured from the front of the vehicle.



III. Torque requirement

CharIN recommends following the UL2251 and IEC 62196 series requirements for coupler strain relief compliance.

IV. Insertion / Extraction Force

CharIN recommends that MCS should follow the same criteria as IEC 62196 for insertion and removal forces, which is currently 100N.

Ergonomics shall be considered for any equipment (such as cables/connectors) that are meant to be handled by users. The development of MCS, over several revisions of connector geometries, considered ergonomic challenges such as the insertion forces, withdrawal forces, retention features, manufacturing optimizations, and misalignment handling.

V. Drop test requirement

CharIN expects that MCS connectors should be robust in the environment that they are operating in. While some connectors may be implemented in a way that "dropped" connectors are not relevant (such as cable hangers that prevent it), some connectors might be subject to dropping as could happen with CCS connectors in the past. MCS suppliers shall consider the user needs and provide equipment appropriate for the use case.

VI. Adapters

It is an unfortunate reality that due to a wide variety of reasons, not all EVSEs and EVs use the same connector globally over all of time. To reduce some pain points for users who want to use unmatched vehicle and EVSE charging standards, some companies and standards organizations have created “adapters” that provide the ability to use these diverse standards with some variety of electrical, mechanical, communication, etc. adaptations.

CharIN does not endorse the use of any "adapters" and supports the existing adopted Standards position that "adapters" are prohibited. CharIN strongly discourages any consideration of "adapter" for MCS.. The largest concerns around the use of adapters are inconsistent implementation of safety requirements at system level, such as thermal limits, high current protection, noise immunity, and security protocols. CharIN members understand that “adapters” are possible to use, but in order to ensure the absolute best user experience regarding safety, robustness, and performance, MCS shall not support “adapters”.

VII. Mating Durability

Depending on the region, UL 2251 No-Load Endurance Test and/or IEC 62196 mating cycles with pollution tests should apply. It is recommended that 20,000 mating cycles is considered for these tests due to the duty cycle of commercial applications.

VIII. Automated Connection

The geometry of MCS is adequate to provide sufficient optical recognition features for automated connection.

IX. Ingress Protection

MCS shall meet or exceed ingress protection according to IEC 62196 (expected to be superseded by IEC 63379 for MCS in the future) and IEC 61851.

X. Temperature restricted unlock

Because IPXXB is used for the MCS connector and inlet, no unique temperature requirements shall be used for unlocking the MCS connector. MCS suppliers shall perform validation for their components to be sure that the touch surfaces do not exceed allowed temperatures per IEC 62196 (to be superseded by IEC 63379 for MCS in the future) so that this operation is acceptable.

XI. Thermal Boundary Conditions

Thermal boundary conditions for connectors and inlets are effectively defined by the Inlet Reference Device according to the methodology of IEC TS62196-3-1. A MCS specific approach should be defined in IEC TS 63379.

XII. Cable

The distance from the SECC to the EVCC is critical for stable high-level communication. Because communication cable lengths up to 17 meters (15 meters outside vehicle plus 2 meters inside vehicle) are expected, and site layout and charging connector locations also consider a maximum cable length of 15 meters, CharIN recommends a maximum cable length of 15 meters.

For liquid cooled cables it is recommended to keep the length as short as possible in order to avoid excessive performance requirements on the cooling system and the manual handling of the cable. Therefore, the charging inlet position on heavy duty vehicles and the charge bay layout should be standardized.

3. Conclusion

CharIN recognizes that MCS is a newly developed charging interface and system which will continue to evolve as it becomes more technically detailed. CharIN was created to support, and will continue to support, standardization of charging systems which can be used globally. To continue this, CharIN urges global standards organizations and participants such as IEC, SAE, etc. to cooperate to ensure future standards are aligned and harmonized in order to prevent similar but subtly different standards in different regions and applications in the future.

4. Reference

This document was created by the MCS Task Force and the Charging Connections Focus Group of the CharIN Association. The purpose of this effort was to align the industry for a common charging system solution for large battery vehicles from various on-highway, off-highway, marine and aviation applications. . Other useful documents exist and will continue to be created and revised in standards bodies. This whitepaper is not intended to be exhaustive or frozen, and documentation will continue to be updated over time. This is a list of some of the most important reference documents considered by CharIN:

The normative standards references utilized to prepare these MCS recommendations are as follows:

- ISO 5474 series (especially annex in -3 for MCS)
- IEC 61851-23
- IEC 61851-23-3
- IEC 61851-1
- IEC 62196-1
- IEC 62196-3
- IEC TS62196-3-1
- IEC TS 63379 (under development)
- ISO 15118-20
- ISO 15118-6
- SAE J3271 (under development)
- UL 2251
- UL 2231
- UL 2202