CharIN
Ruggedized Megawatt Charging System (R-MCS)

Recommendations and specifications for Ruggedized MCS for standards bodies and solution suppliers

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Executive Summary

The collaboration between the ICMM and CharIN members has led to significant strides in the decarbonization of the mining industry. This partnership has initiated several working streams, one of which focuses on developing a unified charging solution tailored for harsh mining environments.

The white paper provides an in-depth analysis of a specialized charging system designed specifically for any application where a rigid charging connection is needed. This system, known as the Ruggedized Megawatt Charging System (R-MCS), builds upon the existing Megawatt Charging System (MCS) by enhancing voltage capacity, improving chemical compatibility, and ensuring the system is robust enough to endure the demanding conditions of mining operations. These improvements are aimed at meeting the operational needs of battery-electric heavy-duty vehicles, facilitating faster charging times, and minimizing downtime.

A key aspect of the R-MCS is its integration with automation technologies, which is essential for boosting safety and efficiency in mining activities. The system features automated coupling capabilities, reducing the need for human intervention and thereby increasing operational efficiency. The white paper details the system's specifications, including communication protocols, electrical safety measures, and hardware requirements, ensuring it meets the rigorous demands of the mining environment.

Furthermore, the white paper underscores the critical importance of global standardization and collaboration among standards organizations to enable the worldwide adoption of the R-MCS. By addressing the unique challenges faced by the mining industry, the R-MCS aims to deliver a reliable, efficient, and safe charging solution that significantly enhances the performance and sustainability of electric mining equipment.

1. Introduction

The mining industry is at a pivotal moment in its journey toward decarbonization, recognizing the urgent need to address climate change and reduce its environmental footprint. As part of this broader effort, the industry is exploring a variety of technologies, including electric vehicles (EVs), as one of several key options to enhance sustainability. This exploration is not just about compliance with regulatory pressures or responding to investor and customer demands for greener practices; it's about fundamentally transforming operations to align with global climate goals.

By adopting a technology-agnostic stance, the mining industry can leverage a range of solutions tailored to specific operational needs, ensuring that the transition to a low-carbon future is both effective and inclusive. This strategic shift not only enhances operational efficiency and safety but also positions mining companies as leaders in the global movement toward sustainability.

As the industry continues to navigate this complex landscape, the insights and frameworks developed through the ICMM and CharIN partnership will be invaluable. For those interested in delving deeper into this journey, previous publications provide a wealth of information on the pathways to achieving a sustainable mining future.

ICMM is an international organization dedicated to promoting a safe, fair, and sustainable mining and metals industry. It brings together 24 mining and metals companies and over 45 regional and commodity associations to enhance environmental and social performance across the sector. ICMM's initiatives include the Innovation for Cleaner, Safer Vehicles (ICSV) initiative, which aims to develop new generations of mining vehicles that are both cleaner and safer.

CharIN (Charging Interface Initiative e. V.) is a global, cross-industry association focused on advancing e-Mobility through the development and establishment of the Combined Charging System (CCS) as the global standard for charging battery-powered electric vehicles. CharIN's members include automakers, charging station manufacturers, component suppliers, energy providers, and grid operators, all working together to create interoperable charging solutions.

The collaboration between the ICMM and CharIN underscores this commitment to innovation and sustainability. Their previous publications have laid the groundwork for understanding the multifaceted challenges and opportunities in decarbonizing the mining sector. For instance, reports detailing best practices in sustainable mining operations highlight the importance of integrating various technologies, including renewable energy sources, advanced battery systems, and EVs, to create a holistic approach to reducing greenhouse gas emissions:

Whitepaper #1: "Recommendations and requirements for Dynamic Charging Interface" - This paper explores the initial steps and strategies for integrating dynamic charged electric vehicles into mining operations. For more detailed information, you can access the whitepaper through the following links:

Whitepaper Dynamic Charging Interface

Whitepaper #2: “SCI White Paper for X-MCS” - This document discusses the advancements in charging technologies for charging power above the general MCS level being able to support electric mining vehicles from 12MW to 24MW.

Interoperable systems are typically more reliable and safer, as they are designed to meet common standards and undergo rigorous testing. By addressing these interoperability challenges early on, the ICMM and CharIN partnership aims to accelerate the adoption of battery-electric technology in mining, ultimately contributing to a more sustainable and efficient industry.

Given the challenging operating environments encountered in most mining applications, the Ruggedized Megawatt Charging System (Ruggedized MCS or R-MCS) has been proposed to meet the mining industry’s specific requirements. Arising from the productive discussions and positive findings of the CharIN Subgroup (initiated in 2022 partnership with ICMM), this white paper articulates the R-MCS’s central design considerations (both technical and non-technical), to ensure that the R-MCS is ‘fit-for-purpose’ for the mining sector.

R-MCS aim to adapt the existing MCS connector to make it meet the mining requirements. This includes increasing the voltage (from 1’250 to 1’500 V) and the current (L4), improving the specific chemical compatibility and enhancing the ruggedization (IP 64 and IK 11 rating). Furthermore, the white paper includes recommendations for additional sealing, a lever to take advantage of the sealing, and insulation monitoring concept (IMD) for operational safety. Furthermore, it provides recommended specifications for adoption by Standards Development Organizations (SDOs).

Being based on the MCS requirements, this whitepaper discusses the chapters from the original MCS document only when there are variations in the values or the intent/considerations. This also includes suggestions for using multiple R-MCS connector to deliver higher power for charging.

1.1. Ruggedized MCS Importance to Electric Mining Equipment

There are two key technologies to broaden acceptance of battery electric industrial heavy-duty vehicles, increased operational range and decreased charge times. Charging time 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. Ruggedized MCS offers the charge rate necessary to realize widespread adoption of battery electrification in the mining vehicle market by increasing driving range gained per minute spent charging. Ruggedized MCS tries to remain as compatible as possible with MCS. Keeping the same robust communication protocol and remain plug compatible with standard MCS.

In the context of mining, machinery and vehicles follow distinct operational cycles. The Ruggedized MCS, through its accelerated charge rate reduces “Operational Delay” due to faster charging, thereby increasing “Operating Time”. Charging infrastructure should be implemented in a way to use existing pauses during the operational cycle (queue in front of unloading, loading).

1.2. Provisions for automation

While the predominate implementation of MCS charging infrastructure anticipates manual handling of connector when mating to the charging coupler on the vehicle, feature requests from the mining industry articulate a strong preference for automated coupling of R-MCS charging systems. Preferences for automated coupling often identify labor safety, improved efficiency, and potentially reduced charging time as critical objectives for automation. Consequently, provisions for automated coupling of R-MCS based charging systems are noted in this document.

1.3. Ruggedized MCS System Overview

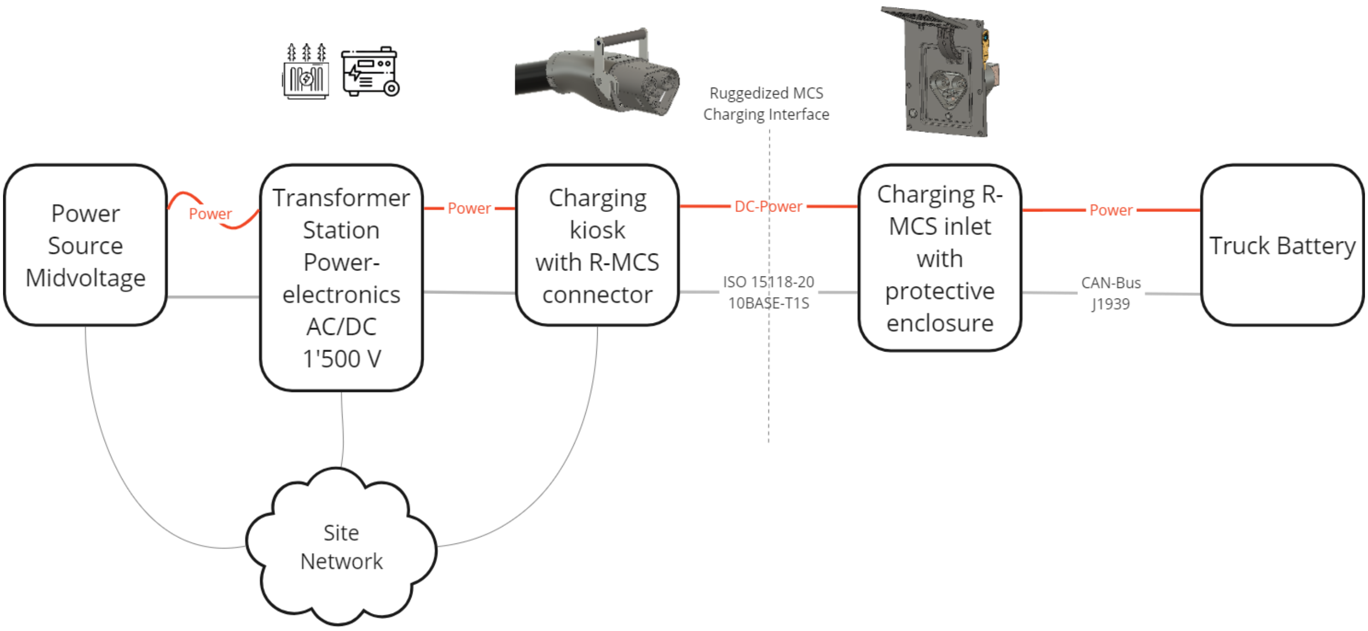

Figure 1 Overview of the Ruggedized MCS Components

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

CharIN is supporting a harmonized and accelerated development of the electrification in any industry. By having the MCS communication aligned in the truck industry and standardization we are supporting the enhancement of the MCS technology also for other applications like mining. Products will be tested and available in the market soon.

Communication shall be compatible with regular MCS communication and based on 10BASE-T1S (physical layer) and ISO15118-20 (application layer). In the case of Autonomous Charging wireless positioning and communication should be done according to IEC/CD 61851-28.

Table 1 OSI Layer model

<table>
<tr><td colspan="4">OSI layer for ISO 15118-20</td></tr>
<tr><td>7</td><td>Application</td><td rowspan="5">ISO 15118-20</td><td>Application layer messages (V2G Message)
SDP (SECC Discovery Protocol)</td></tr>
<tr><td>6</td><td>Presentation</td><td>EXI (Efficient XML Interchange)</td></tr>
<tr><td>5</td><td>Session</td><td>V2GTP (Vehicle-to-Grid Transfer Protocol)</td></tr>
<tr><td>4</td><td>Transport</td><td>TCP (Transmission Control Protocol)</td></tr>
<tr><td>3</td><td>Network</td><td>IP, DHCP</td></tr>
<tr><td>2</td><td>Data link</td><td rowspan="2">ISO 15118-3</td><td rowspan="2">10BASE-T1S
IEEE 802.3cg</td></tr>
<tr><td>1</td><td>Physical</td></tr>
</table>

2.2. Electrical

I. 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 6 kV by the EVSE
- Limitation of the Y capacitances on EVSE and EV side depending on the maximum operating voltage (see chapter VI)

II. Permissible surface temperatures

CharIN recommends in line with existing IEC 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 should 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.

Since mining areas can be in extreme conditions, are not public spaces and the charging infrastructure is operated exclusively by trained employees wearing safety equipment, such as protective gloves, a higher thermal rating can be permitted for Level (L4) charging. See ISO 13732-1 for reference.

III. Bus Voltage Range

Mining vehicles often feature a traction bus with voltage levels above 1,500 V.. The coupler's creepage distance permits a maximum voltage of 2,800 V. However, the Y-capacitors restrict increasing the voltage beyond 1,500 V, as the IMD detection time also increases with higher voltages. Surpassing this voltage threshold is feasible only with automated systems, as the detection of insulation errors with an IMD will take too much time (increase of voltage increases the time until detection of an insulation error).

Given these parameters, CharIN advises that the MCS should operate within a voltage range of 500 VDC to 1,500 VDC. While this might not accommodate every potential use case across all vehicle types, it strikes a balance between operational voltage flexibility and vehicle compatibility.

It's imperative to emphasize CharIN's recommendation for all MCS Electric Vehicle Supply Equipment (EVSE) to support this entire voltage span of 500-1,500 VDC. Historical insights from the industry underscore the risks associated with vehicle and infrastructure mismatches. Thus, EVSE manufacturers and associated MCS standards bodies are strongly cautioned against endorsing charging infrastructure that cannot uphold the full 500-1,500 V range.

IV. Target maximum current

The maximum continuous current rating recommended for Ruggedized MCS is 4'000 A DC (L4).

V. Peak Fault Current

Peak fault current should be defined at 70 kA.

VI. 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.

In contrast to regular Megawatt Charging Systems with a maximum voltage of 1'250 V, ruggedized MCS can be operated up to 1'500 V. The operation of a ruggedized Megawatt Charging Systems is not allowed in public spaces and requires trained operators wearing gloves according to IEC 60903 Class 0. Also, a specific IMD is required with a measuring resistance of 99 kΩ for the charging class above 1'250 V (versus 55 kΩ for MCS).

This modification enables any MCS vehicles to charge at a R-MCS charging station. A vehicle rated at a voltage above 1'250 V can only be charged at a R-MCS charging station.

CharIN proposes these limits:

Table 2 Y-capacitance limits

V_{dc+} to V_{dc-}	$V_{dc+/-}$ to PE	t_{lim} [s]	$Cy_{EVtotal}$ [µF]	$Cy_{EVperDCline}$ [µF]
1250 < V_{dc} < 1500	700 < V_{toPE} ≤ 825	60 s	~5 µF	~2.5 µF
1126 < V_{dc} ≤ 1250	638 < V_{toPE} ≤ 700	60 s	~5 µF	~2.5 µF
1004 < V_{dc} ≤ 1126	577 < V_{toPE} ≤ 638	60 s	~8 µF	~4 µF
V_{dc} ≤ 1004	V_{toPE} ≤ 577	60 s	~15 µF	~7,5 µF

- 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

Higher Y-capacitances on the vehicle side maybe acceptable but require a risk assessment.

VII. Power Duty Cycle

The R-MCS connector and cable are rated for 100% duty cycle at the maximum voltage and current ratings when properly integrated with proper cabling and an adequately sized thermal management system. No cooling period is required between charging cycles.

2.3. Hardware

I. Coupler Retention

The MCS interface shall include an electrically activated/actuated lock to ensure that the coupler remains engaged with the receptable during all normal operation and in case of short circuit. This electrically activated lock 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 receptable side of the MCS coupler on at least one location, and up to 3 locations, as included in the MCS coupler 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.

The lock shall have monitoring feedback to ensure proper physical mating to avoid any charging where the lock isn't physically preventing plug-pull.

II. Lever for coupler retention and sealing

A knob should be added to the MCS receptable as outlined in Figure 2 Receptable Side View and Figure 3 Receptable Front View. The knob should have a minimum pull resistance of 800 N and abrasion resistant. It is recommended that the knob is manufactured out of metal.

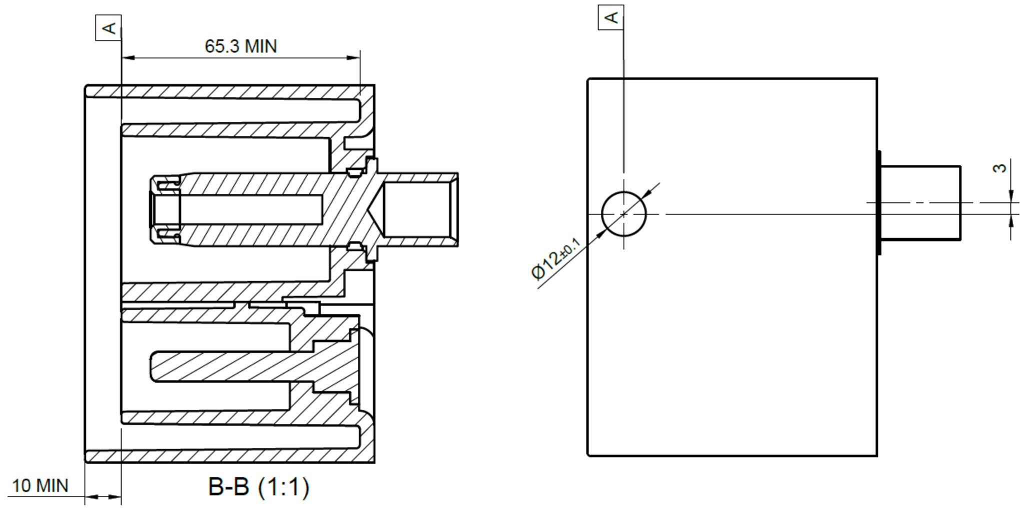

Figure 2 Receptable Side View

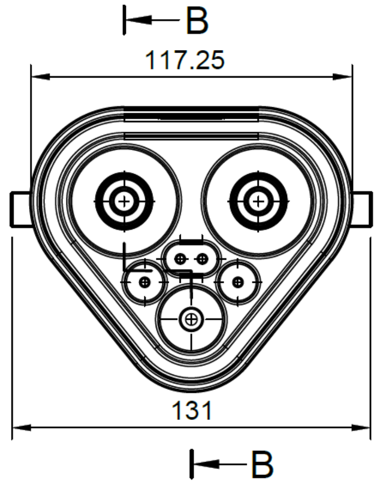

Figure 3 Receptable Front View

How the lever is designed is up to the coupler manufacturer. Figure 4 Sample Pulldown lever closed and Figure 6 Sample Push lever closed provide two examples.

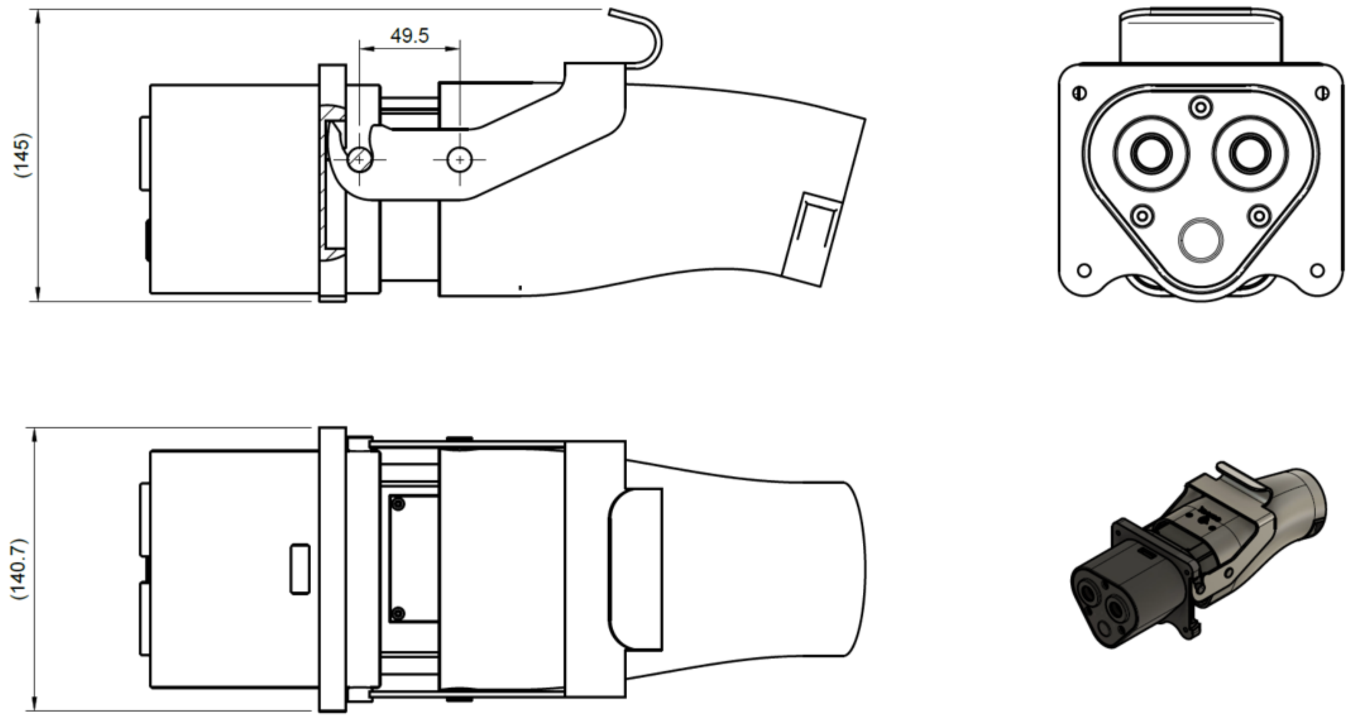

Figure 4 Sample Pulldown lever closed

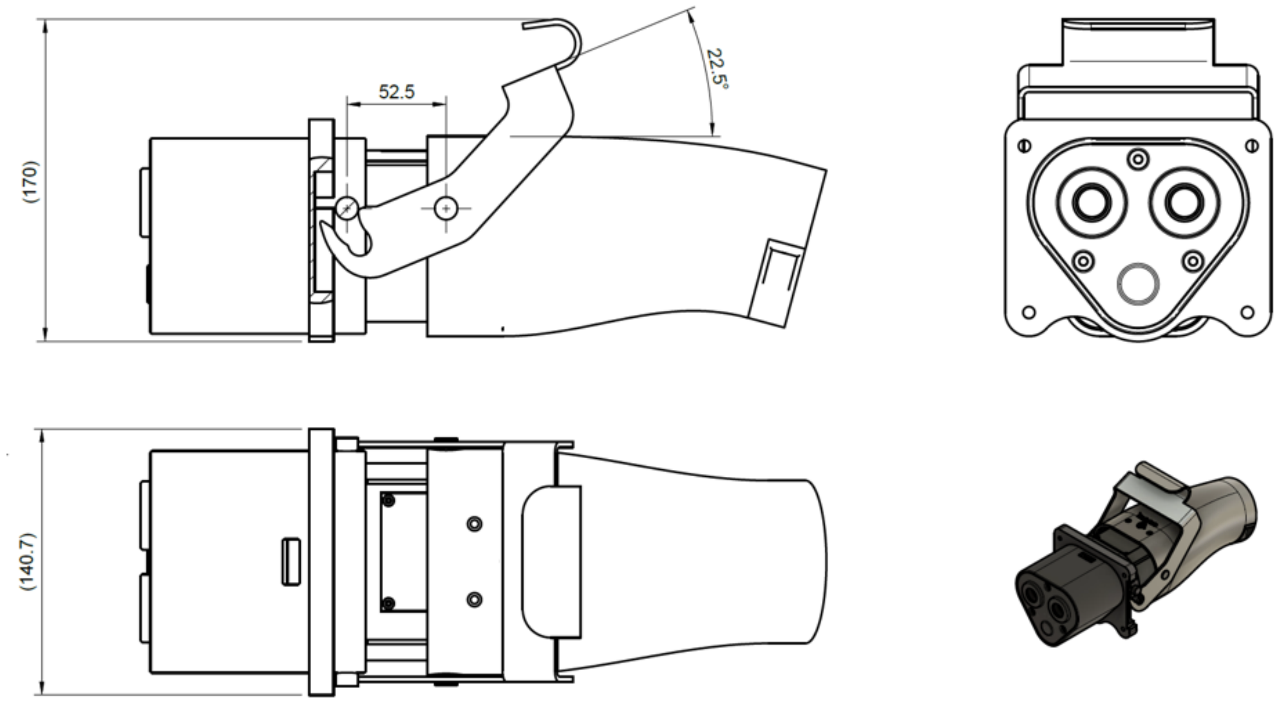

Figure 5 Sample Pulldown lever open

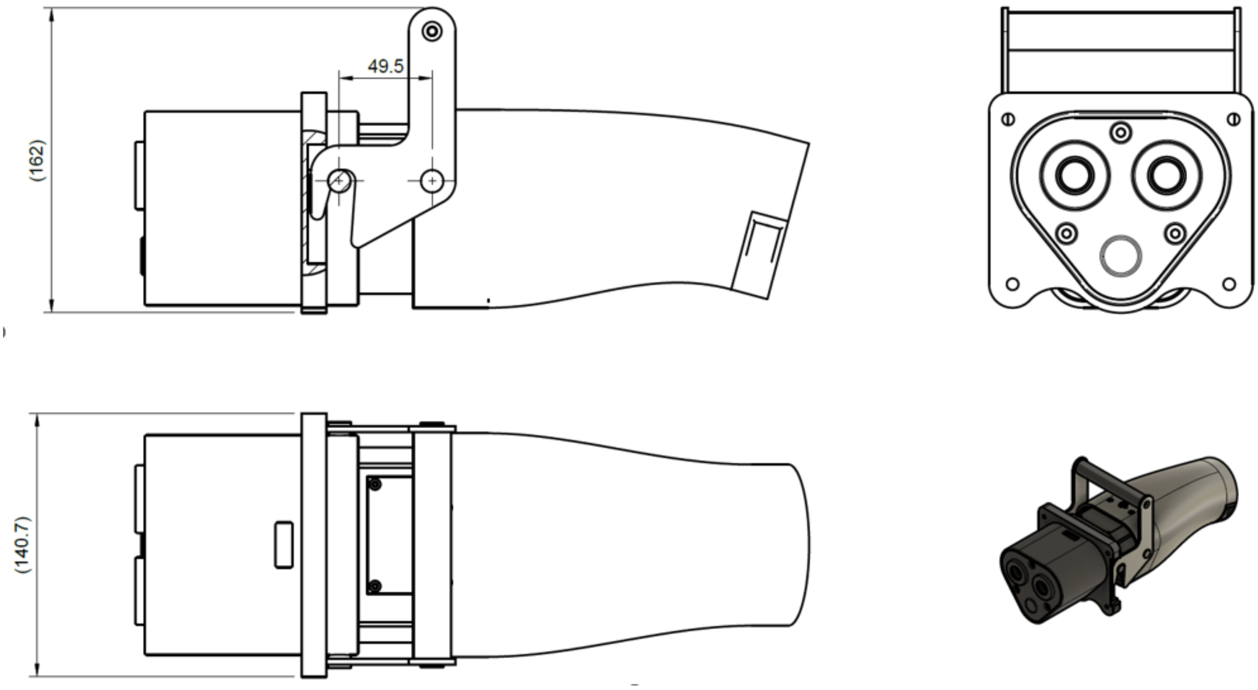

Figure 6 Sample Push lever closed

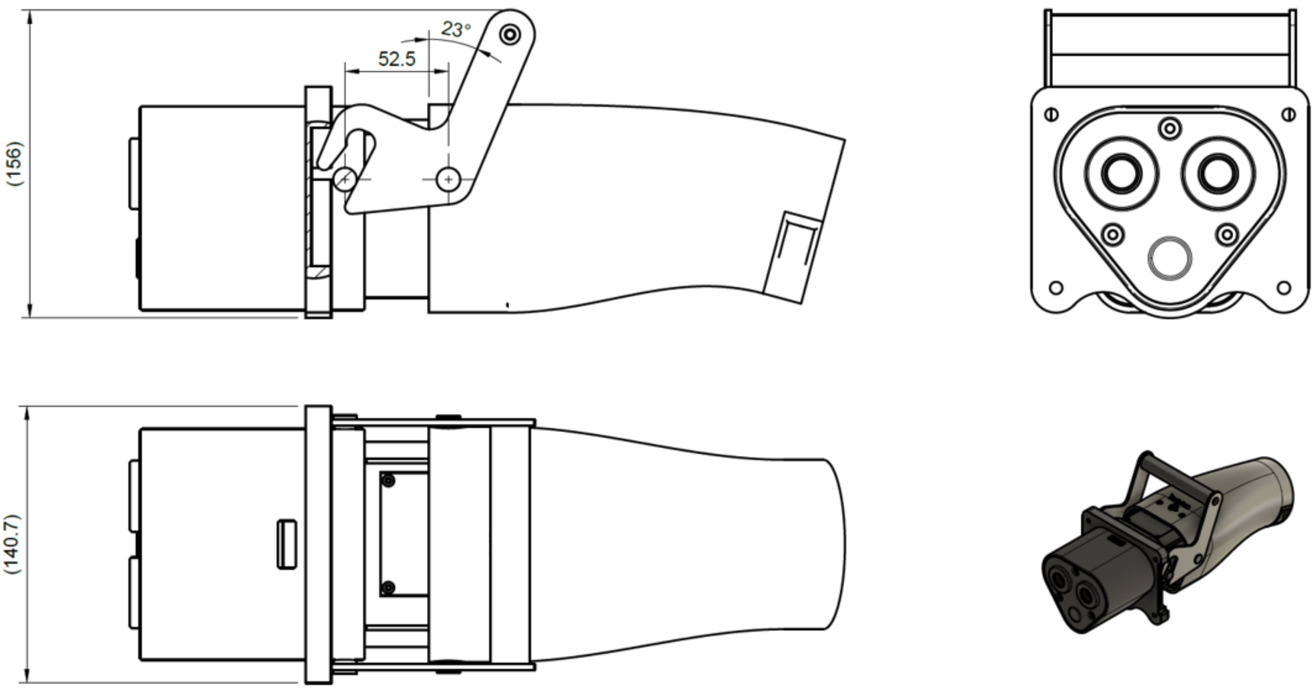

Figure 7 Sample Push lever open

III. Sealing

The datum plane A of the coupler will be moved by 1,5 mm compared to regular MCS and a 2mm flat sealing (EPDM or MVQ as an example) will be put on top of the datum plane A (see Figure 8 Ruggedized MCS datum plane A). Giving a compression ratio of 25%.

Color of the sealing is recommended to be white to recognize dirt in the connector.

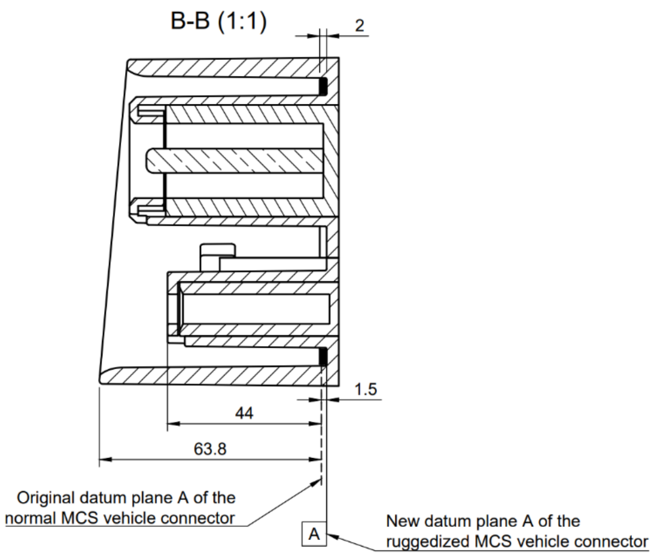

Figure 8 Ruggedized MCS datum plane A

IV. Serviceability

Maintenance Plan

Suppliers should provide a regular maintenance plan for couplers and systems, outlining necessary inspections and servicing procedures to ensure long-term reliability.

Design for Easy Maintenance

- Accessible Front and Contacts: Design these components for easy field maintenance, enabling quick servicing and reduced downtime.
- Modular Design: Where possible, incorporate a modular design to allow for part replacement without full unit disassembly.

Material Selection for Durability

- Ruggedized Shell: Use durable materials like Aluminium for the non-replaceable shell, enhancing protection and lifespan.
- Replaceable Front: Construct the coupler front from high-grade, easily replaceable plastic to balance durability with maintenance ease.

Compliance and Adaptability

- Ensure all designs meet industry standards and are adaptable to future technological changes, increasing the couplers' utility over time.

V. Torque requirement

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

VI. Insertion / Extraction Force

CharIN recommends that Ruggedized MCS should follow the same criteria as IEC 62196 for insertion and removal forces, which is currently 100 N. But should not be higher than 200 N.

VII. Impact test requirement

Given the rigorous conditions in mining environments, it's essential to test the coupler and the mated cable for impacts in accordance with IK11 (EN 62262:2002+AMD1:2021).

Table 3 Connector test standards

IK Code	IK07	IK08	IK09	IK10	IK11
Impact Energy [Joules]	2	5	10	20	**50**
Radius of striking element [mm]	25	25	50	50	**50**
Material	Steel	Steel	Steel	Steel	**Steel**
Mass [kg]	0.5	1.7	5	5	**5**
Free Fall Height [1]	0.4	0.3	0.2	0,4	**1**

VIII. 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.

IX. Markers for Automated Connection Systems

It is expected that the geometry of Ruggedized MCS is adequate to provide sufficient optical recognition features for automated connection. Therefore, no specific fiducial markers are planned for MCS.

X. Ingress Protection

R-MCS shall meet or exceed ingress protection according to IEC 63379 and as defined in the following list (IEC 60529).

Table 4 Ingress protection ratings for the components

Component	State 1	State 2	IP rating
Plug	Unmated	No machine present, charger waiting. The coupler is parked at the charging station and inactive.	IP64
Plug	Unmated	Machine at charger, pre or post connection. The coupler is in the process to plugin into the vehicle.	IP21
Receptacle	Unmated	Machine in operation. The vehicle is operational, and the receptable is protected by a flap or different enclosure.	IP69
Receptacle	Unmated	Machine at charger, pre or post connection The flap opened or other protective measurement were removed.	IP21
Both	Mated	Charger connected to machine. The charging coupler is plugged-in (mated), locked and the charging process has started.	IP64

XI. Chemical Compatibility

Chemicals to be tested against.

Table 5 Vehicle fluid or Lubricant SAE grade

Vehicle Fluid or Lubricant	SAE Grade
R134A	NA
Polyalklene Gylcol (PAG)	NA
Final Drive and Axle Oil (FDAO)	60
CK-4	15W40
Hydraulic Oil (HYDO)	10W
Diesel Fuel (20% bio fuel possible)	NA
TO-4	10W
Hydraulic Fuid Aviation (HFA)	NA
TDTO/TO-4 30/TDTO	SAE 30
TO-4	SAE 30
Water (with glycol)	NA
Diesel Exhaust Fluid (DEF)	NA

Table 6 Vehicle fluid or lubricant NLGI grade

Vehicle Fluid or Lubricant	NLGI Grade
EAG	0
MPGM	2
Final Drive and Axle Oil (FDAO)	60

Table 7 Haul road chemicals

Haul Road Chemicals
Chloride Salts
Lignin Derivatives
Asphalt emulsions
Polymers
Surfactants / Wetting Agents

Table 8 Machine cleaners

Machine Cleaners
Acidic Pre-soaks and Aluminum Brighteners
High pH Detergent
Friction Detergent
Degreaser
Concrete and Cement Cleaner

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 coupler locations also consider a maximum cable length of 15 meters.

3. Conclusion

CharIN recognizes that Ruggedized MCS is a newly developed adoption of the MCS 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 to prevent similar but subtly different standards in different regions and applications in the future.

4. References

This document was created by the Ruggedized MCS Task Force and the Charging Connections Focus Group of the CharIN Association and ICMM[1]. The purpose of this effort was to align the industry for a common charging system solution for large battery vehicles from various mining applications (including open pit and underground). 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 reference utilized to prepare these MCS recommendations are as follows:

- ISO 5474 series (especially annex in -3 for MCS)
- ISO 13732-1
- IEC 60903
- 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)
- UL2278
- UL 2251
- UL 2231
- UL 2202
- IEC TS 62893-4-2
- VDE 0250 T812
- VDE 0250 T813
- EN 62262

[1] https://www.icmm.com/

5. List of Abbreviations

Abbreviation	Definition
CCS	Combined Charging System
EV	Electric Vehicle
EVCC	Electric Vehicle Communication Controller
EVSE	Electric Vehicle Supply Equipment
IEC	International Electrotechnical Commission
IK-Rating	Impact Rating (Kinetic Energy)
IMD	Insulation Monitoring Device
IP-Rating	Ingress Protection Rating
MCS	Megawatt Charging System
R-MCS	Ruggedized Megawatt Charging System
SAE	US professional association and standards organization for transport and other industries
SECC	Supply Equipment Communication Controller