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How to plug the fishing fleet?

Connectors in charging infrastructure for small fishing boats

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Fishing fleets are targeted for electrification in many parts of the world. These vessels represent a large potential for emission reductions by transitioning from fossil to hybrid or electric propulsion. However, a massive electrification of such vessels requires a disruptive green shift, introducing safe and reliable battery charging infrastructure along the coastline. Up to now, electric energy has only been supplied, if supplied at all, for auxiliary loads such as lighting, heating, and ventilation when the fishing boats are in harbor. The standard connection method has been through industrial connectors. In other sectors, such as automotive, other connector types are used. When batteries are installed on the vessels, high charging powers and currents are deployed, calling for robust connector solutions.

The purpose of this work is to give insight in relevant connector solutions for electrical charging and their advantages and limitations. This forms the basis for comparing them with respect to desired characteristics such as cost, safety, usability, capacity, and flexibility. The focus of this article is on small fishing boats, but the evaluations and findings are relevant also for other vessel segments that consider different types of connectors.

There is a need to develop standardized requirements for the interface between the vessel and the power stations in terms of power capacity, communication protocols and endurance to the marine environment. There exist standard solutions for shore power connections for larger vessels, as well as for aircraft connectors and electric vehicles, but the fishing fleet has different needs than those segments, both in terms of power demand, robustness, and ease of use. There also exist solutions with different automatic connection mechanisms, as well as wireless inductive charging and battery swapping, but these are mainly designed for larger vessels such as ferries. There is a lack of long-term experience with maritime plug-based solutions, and little is known about the long-term ageing and degradation under dynamic electrical loading in wet and salty environments, which may limit the lifetime of the connectors.

The risk of running out of power at sea is a major concern with the use of batteries on board fishing vessels. The low energy density of batteries compared to fossil fuels challenges the range and flexibility of the vessels. The operational pattern of the fishing fleet is highly irregular due to variations in fish location and weather conditions. To satisfy variable energy demands and ensure flexible zero-emission vessels, a proposed solution is to develop concepts for mobile offshore energy supply. In such solutions, which are expected to be costly, vessels can recharge from mobile power stations at sea, anchored near fishing sites. At the component level, knowledge is to some extent transferable between onshore and offshore systems. However, the absence of an electricity grid requires standalone systems and optimization of energy efficiency for recharging. Both onshore and offshore charging concepts also require high level data communication to monitor the load balance and control the power flow between vessels and charging stations. Another way to ensure that the fishing vessels will have enough energy is to use hybrid propulsion with back-up fuel, where the batteries are dimensioned for regular operation.

1 Regulatory framework

Facilitation of power supply in ports for battery charging and auxiliary loads is turning into a requirement. In July 2021, the European Commission released the Fit for 55 Package with legislation to reach CO_2 reduction targets of 55% below 1990 levels by 2030. This is an operationalisation of the European Green Deal targets and a major step towards a decarbonized EU by 2050. The package includes the Alternative Fuels Infrastructure Regulation, which requires that all ports in the Trans-European Transport Network must offer onshore power supply to vessels from 2030.

In Norway, the electrification of transport is mainly influenced by public procurement processes or regulations related to emissions (i.e., technology neutral regulations). There are governmental support programs for installation of equipment for shore power connection, onboard vessels and in ports, providing up to 50% subsidy. Most of the existing battery-electric vessels are ferries operated in the national road network, and the installation of the charging facilities for these vessels have largely been included in public procurement processes.

Norway's first full-electric passenger ferry was launched in 2015. In July 2022, 58 electric ferries are in operation, with 14 more to come before the end of the year. The maritime electrification follows the Norwegian shift to electric vehicles, where 65% of all new passenger cars sold in 2021 were full-electric. Norway's coastal fishing fleet, consisting of around 6 000 vessels which predominantly use marine diesel for propulsion, may be the next target for an electrification revolution.

2 Scenario guideline for charging infrastructure

There is a wide range in size as well as in energy and power needs of the vessels in the fishery and aquaculture sector. The Norwegian Shore Power Forum suggests vessel categories based on demand for shore power, see Table 1.

Table 1 Vessel categories based on demand for shore power

#	Category description	Example vessel type	Power level	Voltage	Standard
1	Large vessels with AC shore power connection	Well-boats	> 1 MVA	11 / 6.6 kV AC	IEC 80005-1

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2	Medium-sized vessels with AC shore power connection	Processing boats (aquaculture)	250 to 1000 kVA (1000 kVA over 3-5 connectors)	400-690 V AC	IEC 80005-3
3	Small vessels with AC shore power connection	Small fishing boats	< 180 kVA or 2x180 kVA	400 / 230 V AC	(Aquaculture connector)
4	Small vessels with AC and/or DC shore power connection	Small fishing boats	< 40 kVA (AC) < 350 kW (DC)	400 V AC 800 V DC	(CCS Combo 2)
5	Large vessels with DC shore power connection	Currently not relevant for fishing or aquaculture vessels	> 300 kW	1250 V DC	(MCS)

The most relevant vessel categories with regards to electrification of the fishing fleet, are categories 3 and 4, illustrated in Figure 1. These have the highest number of vessels and represent a large potential for emission reduction with a transition to electric propulsion. The difference between categories 3 and 4 is the option of DC shore power connection in the latter category, permitting fast charging.

Charging of electric and hybrid vessels can be divided into two main segments: fast charging and normal charging. Fast charging (typically using DC) is needed when the vessel is visiting a quay, for instance during delivery at a fish processing plant with limited time for charging. This can also be referred to as opportunity charging. Normal charging (typically using AC) can be used when vessels are in their home port and have more time for charging, often overnight.

In contrast to ferries, fishing vessels usually have a less predictable operational profile with frequent and rapid variations in power output, as well as variable range requirements demanding charging and bunkering flexibility. The operational patterns of fishing vessels are difficult to predict since they depend on the varying location of the fish. Hence, the power needs and load profiles in ports will vary significantly. In some cases, charging solutions with high capacity (high power) will be needed.

Figure 1 Photo of typical Norwegian fishing boats, belonging in categories 3 or 4 described above

The charging solutions for vessels in the fishery and aquaculture sector should be cost-effective and safe, to make it attractive to transition from fossil to electric or hybrid propulsion. They should be prepared for the future development, while considering which technologies are commonly used today. Furthermore, the solutions should be easy to use – like the charging solutions developed for electric vehicles – but robust enough to withstand the maritime environment.

To ensure safe and easy to use charging solutions, data communication is key. Electric vehicle charging typically supports both low-level and high-level communication. Low-level communication is used for safety-related functions, such as providing the maximum permissible current and indicating if the vehicle/vessel is connected and ready to charge. A pulse-width modulation voltage signal alternates between two defined levels, transmitting information over the control pilot contact. Charging solutions for fishing vessels should at a minimum support low-level communication.

High-level communication is used for more complex data transfer, such as load balancing and battery control, DC charging, "plug and charge", as well as authorization and payment services. The high-frequency signal is transferred using dedicated physical connections over IP-based protocols. Charging solutions for fishing vessels should support such communication in cases where there is a need for monitoring and balancing the charging station's total load and power flow, which could be the case when a large fleet charges simultaneously.

3 Existing market solutions & standards

A variety of connector types exist on the market today. Table 2 shows an overview of technologies considered in this article, and in which markets they are used.

Table 2 Technologies used in different markets

Technology	Automotive	Aviation	Ferries & passenger boats	Leisure boats	Fishery & aquaculture	Shipping
Shore power connections					☑	☑
Industrial connectors	☐	☑		☑	☑	☐
Aquaculture connector					☑	
Type 2 connector	☑			☑	☑	
CCS Combo 2	☑	☐	☑	☑	☑	
CHAdeMO	☑		☑			
GB/T	☑					

☑ Applicable to and used in suggested market segment

☐ Applicable to and to some degree used in suggested market segment

Little to no use in suggested market segment

3.1 Shore power connections

Vessel categories 1 and 2 in Table 1 use the following IEC standards today, respectively:

1. IEC/IEEE 80005-1:2019 for high voltage shore connection (> 1 MVA)
2. IEC PAS 80005-3:2014 for low voltage shore connection (≤ 1 MVA)

These standards are so far mainly used for auxiliary loads, and not for battery charging. Both refer to separate standards which describe the connectors, with design requirements etc. Connectors for high voltage (HV) shore connections are described in IEC 62613-1&2, while connectors for low voltage (LV) shore connections are described in IEC 60309-5. IEC 80005-3 is a publicly available specification which is still under development and may eventually also include vessel categories 3 and 4, thereby becoming more future proof. It specifies a 350 A connector, which provides high capacity but is costly and cannot easily be handled manually. In terms of flexibility, the connector can be used at different voltage levels (e.g., 400 V, 440 V or 690 V), but only in three-phase systems. It has a control pilot circuit, but no other form for communication.

3.2 Industrial connectors (CEE)

Industrial connectors are by far the most common connection type and is found in the vicinity of industry buildings, marinas, camping sites, and parking garages. A main difference to many other connectors evaluated in this article is the lack of communication lines. In most cases, safe use requires administrative measures due to the lack of a control pilot circuit. On the other hand, industrial connectors are easy to use, and the cost is low. Furthermore, different types have been developed for several voltage and current levels, as well as for both one-phase and three-phase systems. The most relevant standard for industrial connectors is IEC 60309, but there also exist many vendor-specific types that do not, or only partly, fulfil the requirements of the standard. Figure 2 shows the sockets of industrial connectors at a marina. Industrial connectors are commonly used by fishing vessels, especially small and/or old vessels (category 3 described above). However, they are not considered future proof, since their suitability for battery charging of vessels is questionable.

Figure 2 AC industrial sockets installed at a marina

Airports have standardized connectors for power supply of parked aircrafts from aircraft ground power units. These are based on the ISO 461-1/2 standard. The power supply is 115 V 400 Hz or 28 V DC. Typical current rating of the AC system is 90 kVA, 450 A. Large airplanes may have multiple sockets.

3.3 Preliminary Norwegian standard connector for aquaculture application

The Norwegian Shore Power Forum is working to standardize a three-phase connector for the aquaculture sector that can be handled manually, has sufficient power rating, supports communication, and is safe to use and mechanically robust for a maritime environment. The forum has decided to employ a connector with a current rating of 250 A and voltage level of 400 V at 50 Hz or 440 V at 60 Hz. Communication is said to be supported, but not implemented in the current design of the connector. The four electrical contacts (three phases and ground) and four pilot contacts are arranged similarly as the 350 A, 690 V design referred to in the IEC 80005-3 standard. Since the standard is still under development, today's use is limited. The aim is that battery charging should be supported in a better way than in the shore power standards. Furthermore, the cost is expected to be lower than for the IEC 80005-3 connector.

3.4 Type 2 connector

The IEC 62196 Type 2 connector is widely used for charging electric cars, employing the grid voltage and frequency. The European Commission has announced the use of Type 2 as the common standard for electric vehicles in the EU, resulting in mass production and low cost. The connector has a control pilot circuit as part of the low-level communication, but no high-level communication. It has a rated charging power of 43 kW, which could be too low for some applications and for the larger batteries of the future.

In North America and Japan, the Type 1 connector is more common. The voltage and current characteristics are similar, and the communication protocol is the same for Type 1 and 2, hence only the socket (and not the entire charging station) must be replaced for different markets. Type 2 is more flexible than type 1, since it can handle both one-phase (70 A) and three-phase (63 A) AC, while type 1 only supports one-phase (32 A) AC.

Although there are already pilot installations, it is still unclear whether the Type 2 connector can be applied to maritime vessels without modifications. For example, in Oslo, Norway, a maritime charging station for leisure boats have been installed with both AC charging with type 2 connectors and DC charging with CCS Combo 2 connectors (Figure 3). Such low-risk installations will help to gain experience using automotive connectors in maritime applications. Several manufacturers are developing maritime charging solutions based on Type 2, including Zaptec APM and Easee equalizer.

Figure 3 Maritime charging station with Zaptec charger and type 2 connector in Oslo. Image: Plug

3.5 CCS Combo 2

The Combined Charging System Combo 2 (CCS Combo 2) consists of the type 2 connector with the addition of two pins for DC voltages up to 920 V. This enables faster charging but increases the cost compared to the type 2 connector, since rectifiers are needed on shore. Both low-level and high-level communication is supported. The power rating is specified to 350 kW using DC. In North America and South Korea, the CCS Combo 1, which consists of the type 1 connector and two DC pins, is more common. The CCS Combo 2 is more flexible than CCS Combo 1, since it can handle both DC, one-phase AC, and three-phase AC.

CCS Combo 2 is being considered for charging of electric vehicles, electric vessels, and small electric airplanes. Tesla, the world's largest electric car manufacturer, offers its new cars in Europe compatible with CCS Combo 2. In Florø, Norway the world's first combination charger which can be used by vehicles and vessels at the same time has been installed. Another example is the MINE Smart Ferry in Thailand, which uses 26 CCS Combo 2 connectors for charging.

3.6 MCS

CharIN, the organisation behind the CCS connector, is now developing a new charging standard for higher power: the Megawatt Charging Standard (MCS), which was launched and demonstrated in June 2022. The final publication of the standard with technical specifications and requirements is expected in 2024. MCS is intended for charging of large electric vehicles such as heavy-duty trucks and buses, but is also expected to support applications in marine, aerospace, mining and agriculture. According to CharIN, the MCS connector will be rated for DC voltages up to 1250 V and currents up to 3000 A, with a maximum power rating of 3 MW.

In the on-going EU project TrAM, where a battery powered DNV class 1A HSLC compliant vessel is developed, Multiple CCS Combo 2 connectors are used in parallel to supply 2.3 MW charging power. It is planned to replace the CCS Combo 2 connectors with the MCS when it is commercially available. However, the MCS will be backwards compatible with CCS (presumably through an adapter).

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3.7 CHAdeMO

CHAdeMO is a DC rapid charging system with a connector developed by Japanese automotive manufacturers and Tokyo Electric Power Company. The connector supports DC only, has a rated charging power of 400 kW, and supports high-level communication. The cost is similar to CCS Combo 2. CHAdeMO was used on the "RAICHO-I" 10-passenger vessel in Japan in 2011. Since then, CHAdeMO has scarcely been used as a charging solution for vessels. However, it is still commonly used for charging of electric vehicles produced by Japanese manufacturers.

3.8 GB/T

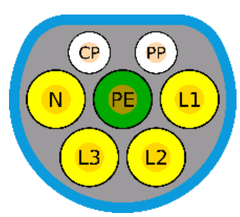
The GB/T charging standard is commonly used for AC and DC charging of electric vehicles in China. The GB/T AC standard uses a connector with a pin layout similar to Type 2, but the two connectors are not compatible. The AC connector is rated for a charging power of 28 kW and supports both one-phase and three-phase systems. The cost is slightly lower than for Type 2. The GB/T DC fast charging standard uses a different connector shown in Table 3, which is rated for a charging power of 250 kW and supports high-level communication. The cost is slightly lower than for CCS Combo 2 and CHAdeMO.

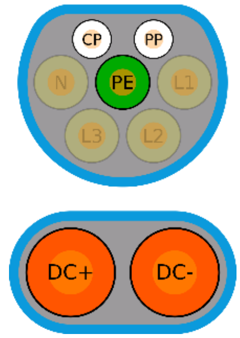
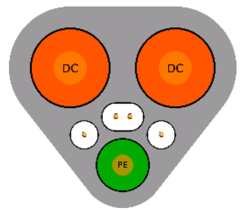
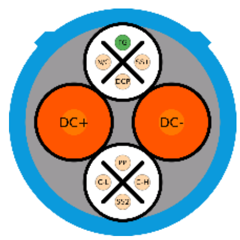
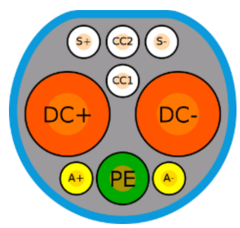
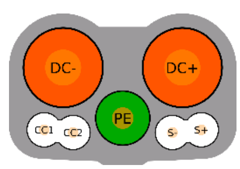
3.9 ChaoJi (CHAdeMO 3.0)

China Electricity Council and CHAdeMO are developing a new unified ChaoJi system, also known as CHAdeMO 3.0, with charging power up to 900 kW. The new system will replace both GB/T DC and CHAdeMO, and will feature backward compatibility with these two connectors, as well as with CCS, through adapters.

Table 3 presents some of the most commonly used automotive connectors in the world today. Note that MCS and ChaoJi are proposed solutions that have not yet been standardized.

Table 3 Overview of common automotive connectors. Images by Mliu92, Wikimedia Commons licence CC BY-SA 4.0

Connector	Type	Voltage	Current	Power	Layout	Pin symbols
Type 2	AC	230 V and 400 V rms	63 A	43 kW		CP: control pilot PP: proximity pilot PE: protective earth N: neutral L1/L2/L3: line 1/2/3

CCS Combo 2	DC	200-920 V	350 A	350 kW		CP: control pilot PP: proximity pilot PE: protective earth DC+: positive power DC-: negative power
MCS	DC	1250 V	3000 A	3 MW		DC: pos./neg. power C: communiacation PE: protective earth
CHAdeMO	DC	1 kV	400 A	400 kW		FG: ground SS1/SS2: sequence signal N/C: not connected DCP: charging enable DC+/DC-: pos./neg. power C-H/C-L: communication PP: proximity pilot
GB/T	DC	1 kV	250 A	250 kW		S+/S-: signalling CC1/CC2: confirmation DC+/DC-: pos./neg. power PE: protective earth A+/A-: Auxiliary power
ChaoJi (CHAdeMO3.0)	DC	1500 V	600 A	900 kW		DC+/DC-: pos/neg power PE: protective earth S+/S-: signalling CC1/CC2: confirmation

4 Alternative charging methods

In addition to conventional plug-based methods for power transfer over AC or DC, there exist alternative methods such as automated connection, wireless charging, and battery swapping.

4.1 Automated connection

Many of the charging systems for electric ferries require power capability in the multi-MW power range. Furthermore, these systems usually have very short charging intervals and require fast and automated connection and disconnection, which complicate the use of conventional plug-based connectors. Several different concepts have been adopted depending on the requirements for the individual vessels, including pantographs or open sliding contacts, gravity-assisted plugs, and wireless power transfer.

4.2 Wireless charging

There are two types of wireless power transfer: capacitive and inductive. For high-power battery charging, most of the research and applications have been based on inductive power transfer, where the energy transfer is based on a magnetic field between a transmitter and a receiver coil. The two coils act like a transformer with a low mutual inductance. Converters are used for generating a high-frequency square-wave voltage for the transmitter coil and rectifying the high-frequency output of the receiver coil. The two coils provide galvanic isolation, so that there is no need for a dedicated onboard transformer. A 1.2 MW inductive charging system was successfully tested on the ferry MF “Folgefonn” in Norway in 2017.

Using wireless power transfer technology for charging of vessels has some advantages over wired solutions. Firstly, because plugs, receptacles, and dynamic cables can be replaced by a set of coils, the maintenance requirements and safety issues associated with harsh environments and salt water are eliminated. Secondly, it enables the maximum utilisation of docking time to charge the batteries, since there is no need for connecting and disconnecting plugs and receptacles. This is particularly advantageous in situations where vessels are frequently berthed for short periods. Enhanced available charging time decreases the required power level for charging, which may in turn reduce the infrastructure costs.

Wireless charging systems also poses some challenges, for instance related to cost and onboard weight. The efficiency of the power transfer is sensitive to the distance between the coils, and the requirements for maintaining the power transfer capability under misalignment of the coils. The efficiency can be improved by increasing the transmission frequency and/or the coil dimensions. However, the transmission frequency is limited by challenges with losses and thermal management, while increasing the coil dimensions lead to increased weight and volume.

4.3 Battery swapping

Battery swapping is a method where discharged onboard batteries are exchanged with fully charged batteries while the vessel is at berth. This rapid method can be suitable for vessels which have a critical docking time. Also, the onshore battery packs do not have to be charged in a short time, thereby avoiding peak loads, and allowing a flexible and smooth load profile. Hence, battery swapping can be less demanding for the local power grid compared to wired and wireless charging systems. Furthermore, the need for high-power onboard converters for fast charging is eliminated. However, battery swapping could require excessive capital expenditures, since large robotic equipment to perform the exchange process and extra battery packs onshore may be necessary.

4.4 Off-grid charging

Battery swapping could be used for charging at locations with no grid connection, such as fishing grounds far from shore. Another solution for off-grid charging is using hydrogen fuel cells to power the chargers. Both solutions require logistics where batteries or hydrogen are transported to the mobile power station. Alternatively, the required electricity could be produced locally using offshore wind turbines, floating solar panels, or wave energy converters.

Even though alternative methods for power transfer such as automated connection, wireless charging, battery swapping, and off-grid charging have certain advantages, the conventional approach using physical connectors is still considered the most easily achieved and practically feasible solution to plug and charge the fishing fleet. The remainder of the article will focus on the reliability and quality of such contacts for maritime charging stations.

5 Charging connector quality

The (minimum) quality of a connector is closely linked to the standard it is designed for and tested under. The various connector solutions are related to one or multiple standards, each with a set of tests and acceptance criteria which the connectors must pass. The tests of three relevant standards are compared to assess their suitability for connectors used to charge fishing vessels. The following standards are considered (with their titles shortened to illustrate the most relevant market segments):

- ✓ IEC 60309-1: Industrial connectors (and LV port connectors)
- ✓ IEC 62613-1: HV port connectors
- ✓ IEC 62196-1: Vehicle connectors

As indicated, the LV port connectors are placed in the same category as the industrial connectors, since the tests of the LV port connection standard is very similar to the tests of the industrial connector standard.

Table 4 presents an overview of key electrical, environmental, thermal, and mechanical tests included in the three standards. In many of the tests, the acceptance criterion is no breakdown or no damage. In other cases, and where appropriate, the acceptance criterion is given. Obviously, the test schemes cannot be fully described and hence, the representation focuses on the main points.

The testing schemes of the different standards are in many respects quite similar. This is the case for the temperature rise, humid conditions, heat and fire resistance, and many of the mechanical tests. However, there are also some differences. The HV port standard sets, naturally, higher requirements for the electrical insulation and for the ability to withstand short circuits. For the tests on insertion and withdrawal of the connectors, the HV port standard includes 350 operations, whereas the vehicle standard includes 5 000 and the industry standard up to 5 000 operations (depending on size), the latter while subjected to current and voltage. For a fishing vessel charger, the 5 000 operations range would be much more suitable than 350 operations, which only corresponds to one mating operation per day for one year, far less than the expected lifetime of the connectors.

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Thermal and current cycling is very important for the long-term quality of the contacts within the connectors, but only included in the vehicle standard, and there only with 250 cycles in total. For fishing vessel applications, this likely represent less than a year in operation.

The corrosive conditions test is important for maritime applications. The industry standard recommends and the HV port standard includes salt spray tests. In the vehicle standard, the connectors are instead immersed (after removal of protective grease) in an ammonium chloride solution. Notably though, the corrosion tests are not combined with current cycling, neglecting the long-term effects on contacts operating in corrosive environments.

Table 4 Key electrical, environmental, thermal, and mechanical tests from connector standards

Item	IEC 60309-1 Industry connectors	IEC 62613-1 HV port connectors	IEC 62196-1 Vehicle connectors
Nominal current range	≤800 A	≤ 500 A	≤ 63 A AC ≤ 630 A DC
Nominal voltage range	≤1000 V AC ≤1000 V DC	≤ 12 kV	≤ 690 V AC ≤ 1000 V DC
Thermal and current cycling	-	-	10 cycles between -40 and 125°C without load 240 cycles with rated load at 70°C ambient
Short-circuit	10 kA	25 kA for 1 s	10 kA
Temperature rise	Rated current. Criterion: ≤50 K	Rated current. Criterion: ≤50 K	Rated current or above Criterion: ≤50 K
Insulation resistance	500 V Criterion: > 5 MΩ	On pilot contacts only	500 V Criterion: > 5 MΩ
Dielectric strength	500 V – 3 kV for 1 min	2 kV for 1 min, 32 kV for 1 min, 75 kV lightning impulse for 2x10 pulses	500 V – 3 kV for 1 min
Humid conditions	Relative humidity at 91-95% at around 25°C for 7 days	Relative humidity at 91-95% at around 25°C for 7 days.	Relative humidity at 91-95% at around 25°C for 7 days
Corrosive conditions	Salt spray recommended in corrosive environments.	Salt spray: 5% salt fog solution for 200 h	All grease removed. Immersion in 10% ammonium chloride for 10 min, followed by 10 min in moisture saturated air
Insert/withdraw connector	10-50 cycles with excess current/voltage, 125-5000 cycles with nominal current/voltage, 125-1000 cycles without current/voltage	350 cycles without current/voltage	5000 cycles without current/voltage
Heat and fire resistance	125°C and 650/850°C	125°C and 650/850°C	100/125°C and 650/850°C
Shock/drop test	Eight drops from 0.75 m	Eight drops from 1.2 m. Impact: as described in IEC 60068-2-75	Eight drops from 1.0 m. Impact: 5 blows with energies of 1-4 J

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Pull tests of terminals	Mass between 0.4 and 70.3 kg, force from 35 to 9650 N	Mass between 0.4 and 20.0 kg, force from 35 to 578 N	-
Pull test of cable anchorage	100 pulls at 80-600 N then 1 min at torque 0.35-5 Nm	100 pulls at 1334-2668 N then 1 min at torque 10.8-16.3 Nm	100 pulls at 160-600 N then 1 min at torque 0.6-11 Nm

6 Attaining reliable connectors for maritime charging stations

The mechanical and initial performances of the connectors seem well covered by the standards compared above. However, the long-term performance of the electrical contacts within the connectors (cable-to-socket, socket-to-plug, and plug-to-cable) is either neglected or covered only limitedly.

The connector between the charging station and the vessel carries a large charging current (up to several hundred amperes). The connector should have low contact resistance during its full lifetime to avoid overheating. The electrical contacts within the connectors are generally relatively inexpensive and seemingly simple. Neglection of the assurance of contact quality has proved to be a potential hazardous approach. The contacts may be subjected to considerable electrical, thermal, chemical, and mechanical loads. These initiate contact aging and degradation, which potentially leads to increased contact resistance and temperature rise, and ultimately to fire hazards and to down-time of the vessel and the charging station.

The principles for qualifying the long-term contact performance of connectors for maritime charging stations are the same as for any other application. There should be a combination of cables, connectors, and tools (if any) which is proven for the application, i.e., the connection should be tested under a relevant testing scheme. A key question is then, under which conditions should the connections be tested?

For contact material (such as cable shoes) used by the power utilities, the commonly used standard in Europe is IEC 61238. In this standard, the contacts are exposed to 1000 current cycles varying the temperature between 35°C and approximately 100°C and to six short-circuits raising the temperature to 250°C within 1s. This standard is considered reliable, since very few (correctly assembled) connections tested according to it fail.

One should note, though, that most utility contacts are exposed to limited load variations during their lifetime, for many contacts only between 40-60% of full load, leading to moderate temperature variations. In contrast, for contacts used in charging applications, the load often varies between zero and full load, sometimes with several cycles per day. Hence, there is reason for some concern. For instance, in medium voltage grids, field experience has revealed numerous failures in systems with high and intermittent loads.

For maritime charging applications, an additional aspect to consider is the presence of humidity and salt, which increase the risk of corrosion, and which can accelerate the aging rate of the contacts. The influence of corrosion on maritime charging connections needs to be determined.

7 Picking connector technology for the fishing fleet

In Table 5, different connector solutions which exist on the market today are compared with respect to the desired characteristics discussed in the scenario guideline. With the eye on the demands of the fishing fleet, requiring communication possibilities and high-capacity charging, the list can be narrowed. Neither shore connectors, nor industrial connectors enable communication. The same is partly true, or at least unknown, for the aquaculture connector, which also lack a track-record. The type 2 connector only allows charging powers up to 43 kW, a clearly limiting factor. The CCS Combo 2, the CHAdeMO and the GB/T connectors have many features in common. They all emerge from and are proven in the automotive industry, and they allow communication and fast charging. The CCS Combo 2 is the most widely used connector today, across land, sky, and sea. It is also the most flexible solution, since it supports DC, one-phase AC, and three-phase AC.

Hence, the CCS Combo 2 seems suitable for battery charging of small fishing vessels. This is a mass-produced standard solution, with standard communication protocols and battery management systems. If fast charging is not needed, the lower cost Type 2 connector is a viable alternative. AC shore power should then be connected to the vessel's DC bus through standard onboard chargers prepared for 400 V (and also for 230 V in Norway). Two Type 2 connectors can be used in parallel if the AC power demand of the vessel is larger than 43 kW over time.

Table 5 High level comparison of existing market solutions

Characteristics	Shore connectors	Industrial connectors	Aquaculture connector	Type 2 connector	CCS Combo 2	CHAde-MO	GB/T
Cost	High	Low	Medium	Low	Medium	Medium	Low-medium
Safety	High	Medium	High	High	High	High	High
Usability	Low	High	Medium	High	High	High	High
Communication	Low	Low	Medium	Medium	High	High	High
Capacity	High	Low-high	Medium	Low	High	High	Low-medium
Voltage and current flexibility	Medium	Medium	Low	Medium	High	Low	Medium
Today's use	Medium	High	Low	High	High	Medium	Medium
Future proof	Medium	Low	Medium	Medium	High	High	High

Although the CCS Combo 2 connector has many favorable characteristics and in most respects are tested according to a well-suited standard, its suitability for long-term operation in maritime environments should be assessed. The vehicle standard only includes 250 temperature cycles, and these cycles are not combined with corrosive exposure.

To establish a testing regime suited for connections for the fishing fleet, a research study is indeed welcome. Such a study has the possibility to include many different parameters (overcurrent, overtemperature, corrosive exposure, vibrations), and can perform many thermal cycles on multiple connectors. The goal would be to determine which parameters determine the long-term connector quality, and to set appropriate testing parameters and acceptance criteria.

On a final note, a connector should be tested under the applicable standard using the correct installation tooling and connected to the very cable type that will be used in the application. A recurrent problem is that contacts and connectors may be designed according to a standard, following the general geometrical and material requirements, but they have not been tested appropriately and hence, particularly their long-term performance is unknown. This lack of quality verification represents a substantial risk to the reliability of the connectors.

8 Conclusions

Charging of small fishing vessels with electric or hybrid propulsion has many similarities to charging of electric cars. Among the connectors on the market today, we recommend going for a CCS Combo 2 connector where high charging powers are needed. Where solely lower charging powers are needed, the Type 2 connector can be more suitable and less costly.

However, the coastal climate in which the fishing vessels operate urge for studies on the influence of humid and corrosive environments on the connectors' long-term performance. Tests reflecting such conditions should be a part of any future standard for connectors for the fishing fleet.

For Further Reading

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