HYPOBATT

Hyper powered vessel battery charging system

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## 1. ABSTRACT

Standardized charging solutions are key for further growth of the electric vessel market. Due to the diversity of ships, such standardized charging solutions must be scalable and modular, both in installation as well as in operation, and with a standardized communication interface for control, monitoring, safety, and administration. Within this report the state-of-art (SoA) with regards to modern-day electric vessel charging and connecting are analyzed, market trends towards future solutions and scalability are investigated and the parameters required to determine a Key point of interest improvements baseline are listed for the generic technical requirements.

### Keywords

HYPOBATT project, vessel charging, conductive charging, standardization, marine, on shore power supply, auto-connect device.

## 2. INTRODUCTION

Maritime transport emits around 940 million tons of $CO_2$ annually and is responsible for about 2.5% of global greenhouse gas (GHG) emissions. In this regard, the International Maritime Organization (IMO), in line with the internationally agreed temperature goals under the Paris Agreement, has targeted to reduce total annual GHG emissions from shipping by at least 50% by 2050 compared to 2008. To achieve this target, Parliament's Public Health and Food Safety (ENVI) committee required shipping companies to reduce, on a linear basis, their annual average $CO_2$ emissions relative to transport work, for all their ships, by at least 40% by 2030 and to have better supply of shore-side electricity in ports. Electrification with shore power supply is one of the solutions to reach this target, and the market for electrified ships is large. Shore power can be used by marine vessels to plug into the local electricity grid and turn off auxiliary engines, air conditioning, and crew berths while at-dock, leading to less $CO_2$ emissions onsite. Under the right circumstances when a vessel is connected to shore power, overall pollutant emissions can be reduced by up to 98% when utilizing power from the regional electricity grid, (depending on the mix of energy sources). Electrification is also an important means to make maritime transport climate neutral and is successfully used within hybrid and fully electric vessels serving shorter distances.

Vessels with large battery energy storage systems (BESS) for (partially) powering propulsion systems are there already in the market for more than a decade. Initially in non-plug-in hybrid configurations [1], but in the last 6 years also in fully electric or plug-in hybrid configurations. Because of predictable and limited operational profile, ferries have been the first vessels with BESS, analogue to public transport applications in on-road electrification. Nowadays also other types of vessels are equipped with BESS, e.g., offshore supply vessels, yachts and harbor tugs. Since vessels are very diverse in types and sizes, the battery systems onboard of these vessels are also all different in size and make. Furthermore, the electrical power system and its power management systems are vessel-specifically designed as well. This implies that also the required charging systems have a large diversity. Aspects such as connection voltage, frequency, power and connector type are special designs and fabrications for almost all electric vessels, as shown later in this review.

It is expected that the number of vessels with fully electrical power systems will increase significantly in the future [1]. As a result, it will not be feasible anymore to have a dedicated and custom developed charging solution for each vessel and port. Instead, a limited number of standardized charging solutions must be developed that can charge the full diversity of vessels at all ports, enabling an accelerated scale-up of the market. These solutions need to be scalable and modular for simplification in installation, operation, and maintenance. This means:

**For installation:** based on the ship types and port infrastructure that need to be charged on a specific location, a charging solution can be configured based on standard modules.

**For operation:** vessels with different physical dimensions, charging powers and battery types can be charged from the same charger.

**For maintenance:** irrespective of specifications nor port infrastructure dependencies, the same components and procedures can be used optimizing maintenance efficiency.

**For both installation and operation:** the charger uses a standardized communication protocol for control, safety, protection, and administration. For the connection preferable a limited number of standard connectors (ACD and manual) are to be available.

This report presents a market study of the current state-of-art (SoA) technologies on charging systems and shore-side grid assistance. An overview of current and under development solutions in maritime applications including conversion and connectors from shores supply solution (cold ironing) and charging solutions for electric ships is presented. A selection of shore-side grid assistance solutions is given next to provide possible solutions to handle the required increased power demand of the port grid connection.

# 3. STATE OF THE ART

## 3.1 Charging systems

For charging applications there are two major variants, dedicated to the voltage type AC or DC, to transfer power to a battery powered EV. The sketches in Figure 1 show the principles of charging with the different power systems. Main differences of these principles are the connector systems on the one hand side and the allocation of the functional components to the on-board and off-board (stationary) side on the other hand.

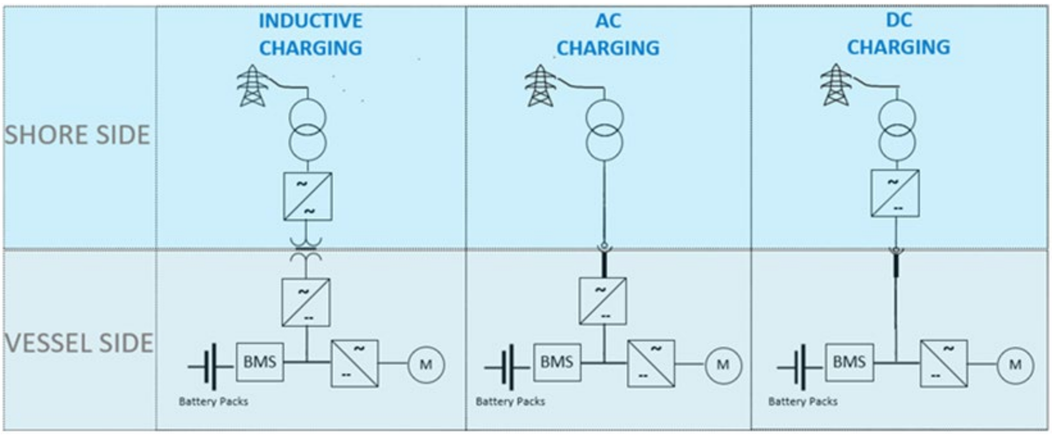


*Figure 1.* Conceptual charging solutions (Source: Stemmann Technik)

### 3.1.1 Inductive charging

In the AC system some market trials were discussing on inductive charging. Using a high-frequency AC voltage allows the use of wireless and contactless power transfer technology which is based on inductive transceiver plates. Main advantage of inductive charging is the lack of cables between the EVSE and EV. The downsides however are numerous;

• Required positioning accuracy of EV with respect to the stationary coil
• Additional high-frequency power conversion stage needed which reduces overall efficiency
• High-frequency transformer needed of significant size and weight
• All of the above adds complexity and with that costs to the overall system
• Since a HV/LV transformer is always present in high power solutions, a galvanic isolation is achieved implicitly, thereby removing an advantage of the wireless charging solution

### 3.1.2 AC charging

A shore-side AC charging system (SBC-AC) mainly consists of an off-board fixed AC supply, which transmits the energy to the vessel and the on-board charging system to charge the battery. AC charging is typically used for low as well as very high-capacity charging. OPS systems are mainly used by cruise, container, and reefer vessels, while low-capacity systems are used by fishing and small workboats. The time vessels spend at berth, which affects how much shore power the vessel could potentially use, varies from port-to-port and by vessel type. If the power supplied by an OPS is used for hotel loads of the vessel or also to charge a battery, depends on the vessel type. As stated in Table 2, SBC-AC is still in development and the interconnectivity will be harmonized with the LVSC variant of OPS. High-capacity OPS deployment depends on the availability of grid capacity as well as on the installation of different sub stations and connection points in and outside the port. It is used on larger ships with an AC primary power system. For larger ships with electrical berth or propulsion power levels beyond of 10 MW or with very high other AC loads this primary power is a high-voltage AC system. However, earthing (grounding) and touch potential are essential for safe use of a berth ship to shore connection [2]. OPS configurations currently on the market have the following optimized arrangement shown in Figure 2, whereas (1) local grid connection, (2) medium-voltage switchgear at 50/60 Hz, (3) transformer, (4) Voltage and frequency adjustment and power flow control system, and (5) cable management system (plug or socket depend on type of ships). They provide flexible solutions for all kinds of onboard grids independent of frequency range and for all voltage level of shipping industry.

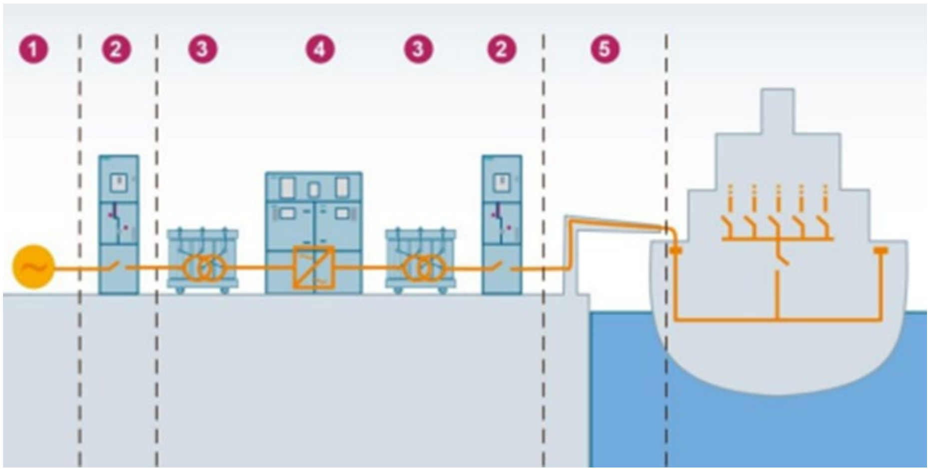


*Figure 2.* Typical OPS shore connection in Europe for berthed ships with 50/60 Hz frequency converter

For SCB-AC charging, the AC shore supply generally consists of a fixed AC supply connected to the vessels onboard power conversion system which is used to charge the battery energy storage system on the vessel. Low capacity AC charging is often seen in applications such as night-charging where there is sufficient time available to charge the batteries at lower power.

### 3.1.3 DC charging

From the vessel side a distinction can be made in DC charging topologies based on the voltage level of the main switchboard(s). Typical DC voltages in the maritime industry are 700 or 1000 V DC. These voltages are based on the 400 V AC voltage standard for 700 V DC and on the 690 V AC standard for 1000V DC. Higher DC voltage levels are not currently common due to unavailability of adequate protection systems, converter equipment, and battery management system limitations. The topologies can be further divided in fixed voltage levels or floating voltage levels where the voltage is not constant. Figure 3 shows the flowchart for DC charging topologies and the typical voltage levels.

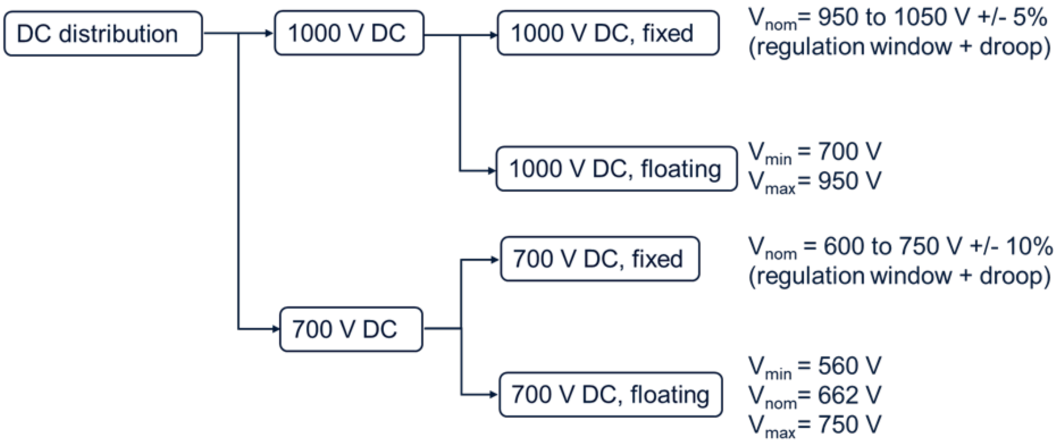


*Figure 3.* Vessel DC distribution topologies

## 3.2 Voltage levels

The choice for the voltage level is determined by the total installed power and the main consumers of the vessel (If the voltage level is not set by client requirements). 700 V DC is most practical for power levels below 500kW (due to number/size of cables involved). For smaller vessels, power ratings of around 250kW can also make use of converters from automotive industry. 1000 V DC systems are suitable for higher power applications, where otherwise 690V AC would have been used.

## 3.3 Bus voltage type

The voltage of the main switchboard can be classified as fixed voltage or floating voltage, where the voltage is not constant but determined by the voltage of the directly connected BESS. For a fixed voltage configuration a DC/DC converter is required be-tween the main switchboard and BESS. A floating voltage allows for the BESS to be directly connected to the main switchboard but requires other converters to be sized for the lowest voltage level. In the following examples, the topologies and specifications are shown for 7 vessels. These examples include two vessel with a floating 700 V bus and two examples of 1000 V fixed bus vessels.

# 4. EXAMPLES

## 4.1 Electric passenger ferry – Dordrecht, NL

In Table 1 the specifications are indicated for the passenger ferries planned for commissioning in 2022 for operation in the Dordrecht area in the Netherlands. Due to the predictable operational profile and limited energy requirements these passenger ferries are very suitable for fully electric operation.

***Table 1:*** Electric passenger ferry Dordrecht specifications

| | |
|---|---|
| **Ship type** | Passenger ferry |
| **Length in m** | 23 |
| **Charge power in kW** | 2 x 350 |
| **Charge Voltage in V** | 800 |
| **Connector type** | CCS type – 2 |
| **Ship system + voltage range in V** | Floating, 562-749 |
| **Battery capacytiy in kWh** | 180 |

These vessels have a floating DC bus with the BESS directly connected to the main switchboards. Two 350 kW High Power Charging (HPC) connections, similar to those used in the automotive industry, are placed on the portside of the vessel. An AC charging connection is placed on each side of the vessel which allows for slow (night-)charging.

## 4.2 Electric passenger ferry – Copenhagen, DK

In Table 2 the specifications are indicated for the passenger ferries operating in the Copenhagen area. These vessels have been commissioned in 2020. Similar to the previous example, these vessels are very suitable for electric operation based on their energy requirements and predictable operational profile.

***Table 2*:** Electric passenger ferry Copenhagen specifications

| | |
|---|---|
| **Ship type** | Passenger ferry |
| **Length in m** | 23 |
| **Charge power in kW** | 450 |
| **Charge Voltage in V** | 800 |
| **Connector type** | Staubli QCC2, automated |
| **Ship system + voltage range in V** | Floating, 700 |
| **Battery capacytiy in kWh** | 180 |

These vessels have a floating DC bus with the BESS directly connected to the main switchboards. An automated 450 kW QCC2 connection is used for fast charging during daily operation. Figure S2 shows a simplified single line diagram of the vessel. At each of the two stops for the passenger ferry a high-power fast charging connection is present for charging during the day. A charger station for power conversion is installed at each location. At the front of the vessel an automated shore supply connection box is installed.

## 4.3 Electric roadferry – Kingston, CA

In Table 3 the specifications are indicated for the road ferries planned for operation in the Ontario area. Two versions of this double-ended ferry are built with the main difference being the length of the vessel and the corresponding charging power and installed BESS capacity.

***Table 3:*** Electric road ferry Kingston specifications

| | | |
|---|---|---|
| **Ship type** | Road ferry | Road ferry |
| **Length in m** | 68 | 98 |
| **Charge power in kW** | 2 x 1750 | 2 x 3500 |
| **Charge Voltage in V** | 1000 | 1000 |
| **Connector type** | FerryCHARGER, automated | FerryCHARGER, automated |
| **Ship system + voltage range in V** | Fixed, 930 | Fixed, 930 |
| **Battery capacytiy in kWh** | 1800 | 1800 |

Due to the higher power levels these vessels have a fixed 1000 V DC bus. An automated charging connection is present on each end of the ferry. Figure S4 shows a simplified single line diagram of the vessel. At each of the stops for the road ferry an automated high power Stemmann charging connection is present for charging during the day. At both stops an automated mooring system pulls the ship to the quay and keeps it into position. A buffer station with a BESS is placed at each charging station which is charged when the vessel is out of port. When connected, the BESS of the buffer station is used for fast charging of the road ferry.

## 4.4 Electric tug – Auckland, NZ

In Table 4 the specifications are indicated for the electric tug operating in Auckland, NZ. The vessel has been commissioned in 2022. The operational of the tug makes it very suitable for electric operations.

***Table 4***: Electric tug specifications

| | |
|---|---|
| **Ship type** | Passenger ferry |
| **Length in m** | 25 |
| **Charge power in kW** | 1500 |
| **Charge Voltage in V** | 1000 |
| **Connector type** | 4x HPC |
| **Ship system + voltage range in V** | Fixed, 1000 |
| **Battery capacytiy in kWh** | 2784 |

Due to the high power levels the vessel has a fixed 1000 V DC bus. The vessel has two non-automated 750 kW High Power Charging connections that are used in-between jobs. Figure S6 shows a simplified single line diagram of the vessel. The charging facility in port consists of a charge station that is connected to the grid. The charging connection is connected to a charging arm placed on shore that can be lowered onto the vessel charging socket.

## 4.5 Electric ferry – Ærø, DK

In Table 5 the specifications are indicated for the electric ferry operating in Ærø, DK. The vessel has been built in 2018. The vessel is delivered as fully electric and is de-signed for future implementation of hydrogen-based propulsion solutions.

***Table 5***: Electric ferry specifications

| | |
|---|---|
| **Ship type** | Passenger ferry |
| **Length in m** | 42 |
| **Charge power in kW** | 2 x 1200 |
| **Charge Voltage in V** | 1000 |
| **Connector type** | 2x NG3 plug |
| **Ship system + voltage range in V** | Fixed, 1000 |
| **Battery capacytiy in kWh** | 1800 |

The vessel has two non-automated 1200 kW NG3 connections that are used to charge the ferry. The charging facility consists of a charge station that is connected to the grid. The charging station includes a BESS with a capacity of 700 kWh to increase the charging power. The charging connections are connected to a charging arm placed on shore that can be lowered onto the vessel charging socket.

## 4.6 Electric ferry – Søby, DK

In Table 6 the specifications are indicated for the electric ferry operating in Søby, DK. The vessel has been delivered in 2019 and is developed under a funded European Commission project.

***Table 6***: Electric ferry specifications

| | |
|---|---|
| **Ship type** | Road/Passanger ferry |
| **Length in m** | 59 |
| **Charge power in kW** | 4 x 1040 |
| **Charge Voltage in V** | 1000 |
| **Connector type** | Mobimar Nectors |
| **Ship system + voltage range in V** | Fixed, 750 |
| **Battery capacytiy in kWh** | 4300 |

The vessel has four semi-automated 1040 kW connections that are used to charge the ferry. The charging facility consists of a charge station that is connected to the grid. The charging system is placed on the on-shore ramp and is a semi-automated plug-connection that can move with the tide.

## 4.7 Electric ferry – Lavik, NO

In Table 7 the specifications for the world's first battery electric road ferry. The ship has been delivered in 2014 and operates in the south-west area of Norway.

***Table 7:*** Electric road ferry specifications

| | |
|---|---|
| **Ship type** | Road/Passanger ferry |
| **Length in m** | 79 |
| **Charge power in kW** | 1200 |
| **Charge Voltage in V** | 1000 |
| **Connector type** | Automated plug-in system |
| **Ship system + voltage range in V** | Fixed, 1000 |
| **Battery capacytiy in kWh** | 1040 |

The ship has an automated charging connection that can compensate vertically for low and high tide. A 410 kWh BESS is placed at each charging location to supply additional power for charging of the ferry.

# 5. AUTOMATED CONNECTION DEVICES

For the existing variety in vessel types and applications, different manual, semi-automated and fully automated connection device types are used as shown in section 2.1. Here, the different automated types of connection devices for DC connections are detailed to explain the current state-of-art. Variation of ACD specifications is required for different functional and non-functional reasons, e.g. power transfer capabilities (voltage/current), number of contacts in the coupler, tidal compensation be-haviour, reach, and of-course total cost of ownership. To determine the state-of-art baseline of maritime ACD solutions, the main general specifications are listed in Table 8 after which existing products and implementations are presented.


*Figure 4*: Typical ACD systems with from left to right: PANTO type, Tower type and BOW type

***Table 8***: General requirements and typical specifications of ACD connection devices

| Type | Parameters | Values |
|---|---|---|
| Electrical Specifications | Nominal Voltages / Currents | 1 kV DC 0.6 / 1 / 5 kA<br>400V AC @ 125/300A<br>600 V AC 1.6 kA<br>11 kV AC @ 600A<br>12.45 kV AC @ 700A<br>15 kV AC @ 700A |
| | Auxiliary Voltages / Power | 24 V DC,<br>230 V AC, 3kW<br>400 V AC, 11kW (Bow type worst case) |
| Environmental requirements | Ambient Temperature | -20…+40°C |
| | Humidity | 0 – 100% |
| | Inverted pantograph[1] | Electrical equipment: 65/67/69k<br>Charging lines: no IP |
| | Pollution Degree[2] | PD4 |
| Standards | Maritime Sector | IEC 80005 series |
| | EMC | IEC 61000<br>CISPR 11 / 16 / 22 |
| | Insulation | IEC 60664-1<br>IEC 60071-1 |
| Protection and Safety | Short Circuits<br>Safety<br>Safety Disconnecting time | IEC 61439-1:2021<br>Customer Agreements<br>To be defined |

The currently available Stemmann connection devises with their basic specifications can be divided in so called Panto type, Tower type and BOW type (see Figure 4). Their basic specifications are Shown in Table 9.

**Table 9**: Stemmann SBC connection devices with their basic specifications

| Feature | PANTO type | TOWER type | BOW type |
|---|---|---|---|
| Rated Voltage | 1-1.5 kV DC | 1-1.5 kV DC | 1-1.5 kV DC |
| Nominal current | 1.5 kA | 3 kA | 6 kA |
| Connection time | < 30 s | < 30 s | < 30 s |
| Set-up land | 2.5 x 1 m, H 1 m | 3.6 x 3 m, H 1.5-15 m | Radius 9 m, H 5m |
| Set-up ship | Contact bars on roof /side | Enclosed socket | Enclosed socket |
| Automatic Connection | Yes | Yes | Yes |
| Vertical compensation | 1200 mm | 5000 mm | 8500 mm |
| Horiz. Lateral compensation | ± 300 mm | ± 300 mm | ± 1500 mm |
| Horiz. Longit. compensation | 1450 mm | 1600 mm | ± 1500 mm |

[1] As for IEC 60529

[2] As for IEC 60664-1

## 5.1 Examples

**Table 10**: Operating examples for the different SBC-connection devices

| Type | PANTO type | TOWER type | BOW type |
|---|---|---|---|
| Location | Oslo, Norway | Moss-Horten, Norway | Kingston, Canada |
| Vessel | PAX | PAX | Road ferry |
| Scope | 1 Landside (2 Twin-System) | 2 Landsides<br>4 Shipsides (2Vessels) | 2 Landsides<br>2 Shipsides |
| Operation Date | 2022 | 2021 | 2021 |
| Power | 2 x 1,5 MW / 1000 V (DC) / 1500 A | 9 MW, Medium Voltage 11 kV 600 A | 6 MW, Low Voltage, 1000 VDC, 6000 A |
| Contacting | Fully automated | Fully automated | Fully automated |
| Notes | Ponton based solution for compensation | 5.5 m tidal range comp. | --- |

# 6. COMMUNICATION IN MARITIME IMPLEMENTATIONS

## 6.1 EVSE – ACD communication

For the example vessel Electric road ferry – Kingston, CA the process of mooring and charging the vessel is automated as much as possible. The vessel has an automatic mooring system that communicates with the EVSE through its own dedicated Wi-Fi system. The vessels automation system also communicates with the EVSE through a separate dedicated Wi-Fi connection.

The vessel needs to make sure that the shipside preparations have been completed and communicated before the charging sequence can start. Before the ship is moored communication is established via Wi-Fi. When this connection is established the EVSE will communicate to the ACD through fiber optic cables so that preliminary measures can be taken before the physical connection with the ship is established.

The vessel will receive status information from the mooring system and linkspan before allowing the charge system to continue its sequence. If all conditions are met the vessels automation system will indicate charging parameters to the EVSE and indicate that charging can commence. When the ACD no longer receives the signal that charging is allowed the EVSE will immediately stop the charging operation. This is used when the vessel is fully charged, but also in case of premature disconnecting of the ACD.

## 6.2 EVSE – EV communication

For the examples from Dordrecht, NL and Auckland, NZ high level communication is modulated on the CP and PE lines of CCS-2 plugs due to the absence of an additional dedicated physical layer for communication. The high-level communication uses the Modbus protocol.

Starting/stopping the EVSE Active Front End rectifiers and opening/closing the breakers and contactors happens at pre-defined instances which are captured in charging sequences. These sequences ensure that the plugs are not pre-maturely released, that the breakers are not closed onto an uncharged DC bus, that the DC switches are not opened during charging and, that the cabling is not overloaded.

To run the sequences, Powerline communication is used over the auxiliary contacts of the CCS-2 plugs. The physical layer is implemented as prescribed by IEC 61851-23:2014. The automation runs on two control PLC's (shore control PLC and vessel control PLC). An optional emergency stop of the system is controlled by two safety PLC's (shore safety PLC and vessel safety PLC) which are connected to the control PLC's. The communication and charging protocol is according to IEC/IEEE 80005-2:2016 to ensure safe operation. This protocol is original made for HV OPS, for DC charging modifications have been made.

## 6.3 Shore-side grid assistance

The crucial role of electric power as an energy source for all industrial fields is increasingly visible. Each productive sector has specific challenges which enclose their specific, versatile, adaptable, and tailored power supply requirements. The goal of shore side assistance to a vessel charging system is to provide the required energy in a smart manner, i.e. minimize the (peak)burden on the supplying grid while conforming to the vessel operating schedule without limiting it. This can be done in numerous ways, e.g. local sustainable energy generation, time-shifting of energy usage using temporary storage, or reduced charging capacity tailored to the supply-demand availability of the operation.
The general motivation for choosing between on-board and off-board charging is that on-board chargers provide flexibility, simplicity, and minimal external equipment be-sides the power outlet. Off-board chargers on the other hand, can reduce charging times with no restrictions on its size, volume, or weight. The off-board chargers result in shifting the cost, weight, and volume from the Electric Vessels (EV) to the Electric Vessel Supply Equipment (EVSE) which will be responsible to deliver power to the battery from the grid. The idea is supported by different studies [3].

## 6.4 Smart grid technologies

The centralized energy system [4] power grid system provides electricity over long distances between power units and buildings using technical tools. The growth of the power necessary to meet people's needs in the coming decades requires a strong response. The smart grid concept has helped to identify high-quality and cooperative generation and storage options. The objective of a smart grid is to allow participants and decision-makers to determine an ideal operational environment more easily for both utilities and power consumers.

The transition from a central to a more distributed smart grid system focuses on smart, green, controllable, and predictable electric system designs [5]. Smart grid technologies can help find a solution for power system problems to work with more sustainable, re-liable, safe and high-quality electricity. A smart grid has a positive effect because it al-lows renewable energy resources to communicate with various city energy resources, improving the power system's reliability and efficiency to the ports, as shown in Figure 5.

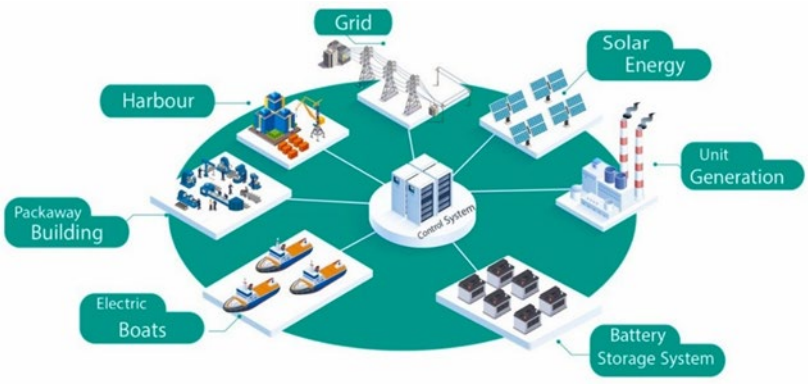


*Figure 5*: Smart grid model for port authorities

The system level control strategies used for battery recharging process can play a significant role in energy efficiency enhancement and local grid support. Based on the current and future trends regarding the shore to ship charging and the specification of the ship, a proper choice of power system architecture for the charging system and control strategy plays an important role for improving the efficiency and cost of the system.

When a ferry is at berth, onboard charging control would send the amount of required charging power, so the onshore power management system should decide the share of the grid power with the onshore battery bank accordingly. Utilizing the onshore battery reduces the stress of handling high charging power on the local grid and can allow for reducing the total electricity cost by charging during off-peak hours. On the other hand, drawing the charging power from the onshore battery bank has less energy efficiency than using the grid because of the energy loss generated by the additional power electronics converters to interface the onshore battery and the battery itself. In other words, using energy buffers such as onshore battery packs generate additional energy loss in the process of charging and discharging of onshore batteries.

## 6.5 Stationary energy storage system

Onshore batteries are charged when the application has a surplus of electrical energy, this can be e.g. overnight with low power or between the ferry dockings with higher power. Thus, in the charging station, an energy management system (EMS) and a power management system (PMS) are needed for generating the references for the charging power, the charging and discharging power of the onshore battery bank and the power from the grid. Furthermore, a Battery Management System (BMS) is usually used to perform the battery monitoring and battery cell balancing. The BMS communicates with the EMS to operate the battery in a safe and optimal manner. Hence, the onshore PMS should choose the optimal share of sources in terms of energy transfer efficiency and power quality issues at grid. In a smart charging station, the information from the port substation is considered for making the decision of load sharing between onshore batteries and the grid.

## 6.6 Energy Management System

Shoreside Energy management and multi-energy management are newly proposed energy management frameworks with little advancement or application in Maritime industry to date. The Figure 6 below shows the most advanced form of shoreside energy management to date. It illustrates various convertible energy forms present in a multi-energy system used to shift peak loads or fill up valley, thus gaining higher energy efficiency compared with single energy system, such as a conventional grid connection with a single source of energy generation.

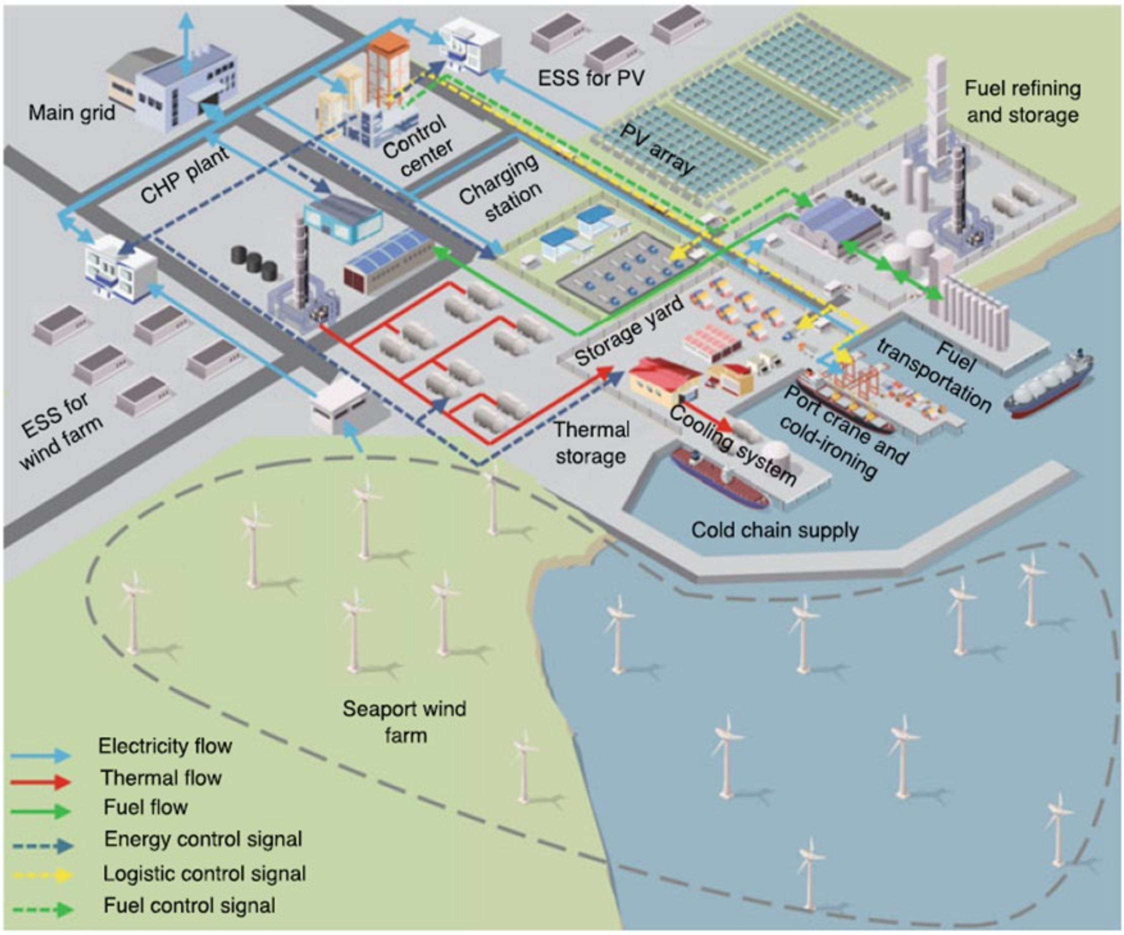


*Figure 6:* Energy flows and control in advanced shoreside energy management

State-of-art port shore-side energy management consists of power sources, which are the upper electric network (HV grid). The main power demands are the electricity demand, gas demand, heating demand, and cooling demand, which are supplied by the electrical bus, gas bus, heating bus, and cooling bus, respectively.

Current advanced applications of shoreside energy management involve the use of multiple energy sources to compensate for peaks and valleys in energy demand but this application does not involve any form of scheduling or data driven/machine learnt energy strategies as we are more accustomed to in automotive EV implementations.
Advanced applications in shore-side energy management or grid-side energy management include technologies such as National grid ESO [6], Tesla Blue Planet [7] and Monarch smart grid platform [7] [8], [9]. These technologies are highly proprietary in nature with little to no known working principle in terms high level methods of achieving flexibility and resource allocations.

Regardless of the proprietary nature of state-of-art energy management technologies, these technologies have the following in common and these are the basis for further innovation:
• Advanced data collection and visualization systems.
• Advanced situational capabilities integrating several subsystem at port level.
• Improve of technology lifespan (including BESS in vessel fleets and equipment under operational stress).
• Big Data technologies for massive time-series data storage and analytics
• Extensive Business Rules Engine and dashboards for Real-time Business Intelligence
In terms of conceptual state-of-art, shore-side energy management is split in two.
Energy management applications, like maritime applications which consist of multi energy sources and demands such as wind turbines, solar generation, energy storage, main grid, and controlled loads. These innovations have focused on the area of im-proving flexibility through controllable loads such as temperature controllable loads and price sensitive loads to develop a demand-response (DR) program. Theoretically these DR programs have been successful, especially when coupled with high-level control mechanisms such as model based EMS systems. Model based systems have been ground breaking, where by a digital twin of real components have been explicitly used to formulate the dynamics of the microgrid and the different interactions between components of the main grid and microgrid. Uncertainties have been accounted for using various optimization models like a scheduling optimizer.

Model based approaches have relied heavily on domain expertise for constructing ac-curate models and parameters for a microgrid. Therefore, model-based approaches are not transferable nor scalable, which leads to high development costs. Furthermore, if the uncertainties in the microgrid change over time, the model, predictor, and solver must be redesigned correspondingly, which significantly increases the maintenance costs.
Model-free or data-driven approaches consist of learning abstract representations of near-optimal control strategies in the microgrid from its operational data. Learning-based methods have been introduced in recent years as an alternative to model-based approaches, as they can reduce the need for an explicit system model, improve the EMS scalability, and reduce the maintenance costs of the EMS.

Shoreside energy management consists of Seaport microgrid, a newly proposed concept for seaport management. The incentive of the seaport microgrid is to make it an energy district to improve renewable energy penetration and enhance the grid storage capacity by selling the electricity to the market through the main grid.

State-of-the-art shoreside energy management are currently local energy networks in-stalled in ports, ships, ferries, or vessels, which consists of generation, storage and critical loads, and are able to operate either in grid-connected or in islanded modes and operate under both the constraints of power system and maritime transportation system.

# 7. RESULTS, CONCLUSION AND DISCUSSION

Within this study the maritime market, and shore-side grid assistance state-of-art in relation to charging equipment is given with examples of implementation and important considerations. Since existing charging solutions from the automotive market are not directly suitable for vessel charging since these lack either modularity, marine standardization, and the required power level as well as port related differences on applicability for this implementation. Within the listed examples of maritime DC charging and ACD devices, it is made clear that still a wide variety of solutions exists. These are not designed in a modular fashion across different manufacturers, nor are they standardized per application. Innovations to that end are required to provide a future-proof and rapidly scalable and reproducible solution for vessel charging.

Debatable aspects like mechanical protections around the ACD, charger-vessel communication, and tuning between different electrical energy assets in the port are vital to be addresses in the following publications of the project.

# 8. REFERENCES

[1] E. Commission, "“European Alternative Fuels Observatory," 2022. [Online].

[2] K. P. a. P. R. C. D. Paul, "Designing Cold Ironing Power Systems: Electrical Safety During Ship Berthing," *IEEE Industry Applications Magazine,* vol. 20, no. 3, pp. 24-32, 2014.

[3] K. C. S. V, "Impacts of EV on Power Systems and Minimal Control Solutions to Mitigate These," *RWE Deutschland,* 2011.

[4] A. Bayod-Rjula, "Future development of the electricity systems with distributed generation," *Energy,* vol. 34, no. 3, pp. 377-383, 2009.

[5] McDonald, "Adaptive intelligent power systems: active distribution networks," *Energy Pol,* pp. 4346-4351, 2008.

[6] N. G. -.. G. Britain, "https://www.nationalgrideso.com/who-we-are.," Who we are,” National Grid - Electricity System Operator. [Online].

[7] OSI, "https://www.osii.com/solutions/platforms/monarch.asp," Monarch smart grid platform,” OSI - AspenTech, 2022. [Online].

[8] D. D. P. S. G. S. B. A. A. R. &. M. I. Pudjianto, "Integration of distributed reactive power sources through Virtual Power Plant to provide voltage control to transmission network," *Researchgate,* 2019.

[9] J. R. C. &. B. R. M. Amaral, "Energy management systems," *48th International Universities' Power Engineering Conference (UPEC),* 2013.