ISSN 0554-6397
Stručni članak
(*Professional paper*)

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Implementation of Charging Stations for Hybrid and Electrical Ferries in Croatian Ports

Abstract

An important aspect of introducing hybrid or all-electric ferries on coastlines is to analyze the supporting land-based energy infrastructure to determine if it is possible to implement charging systems that such vessels rely on. The battery energy storage systems on such vessels will need to be rapidly recharged as passengers and vehicles disembark, which means that the flow of electricity through the distribution grid will be much higher and may lead to power quality issues on the local grid. Once implemented, shore connection and battery charging systems must be safe for both people and connected equipment. The issue of implementing shore connections needs to be analyzed from a technical, economic, and legal perspective. This paper presents the challenges and problems of implementing charging stations for ferries in Croatian ports as a result of the research conducted within the project METRO - Maritime Environment-Friendly Transport Systems.

Keywords: hybrid and electric ferry, battery charging stations, shore connections, battery energy storage, ferry ports

1. Introduction

The introduction of hybrid and electric ferries on coastlines is impossible if the necessary supporting infrastructure is not in place in ports [1]. For such vessels to make sense at all, and to enable the reduction or complete elimination of harmful emissions, it is necessary for all or most of the energy for propulsion to come from clean sources, primarily batteries [2].

As the available storage space for battery storage modules is usually limited, the total capacity of batteries that can be installed on a ferry is often only slightly higher than the minimum required to safely maintain an existing line. This means that the batteries need to be recharged every time (or every few trips on shorter routes) while the vessel is in port. As the time spent in port is short (especially on the routes between the coast and the islands during the tourist season), the charging system is expected to be able to recharge the batteries quickly, which means very high charging currents and therefore a high load on the local distribution network.

The electricity distribution networks on the islands and smaller towns along the Croatian coast are mostly designed to meet the needs of the local infrastructure. As there are no important industrial plants in the tourist centers, they are usually simple radial networks without bidirectional power supply and with limited capacity. A sudden load increase caused by high charging currents, as well as possible harmonic distortions caused by power electronic devices in battery charging systems, can significantly affect the quality of power supply in such networks.

Therefore, when designing a charging system, it is necessary to have a good knowledge of the vessel's operating profile and to anticipate the peak loads that may occur during battery charging. If the available resources of the distribution network cannot meet the ship's requirements, additional energy storage (ES) must be installed or some of the available renewable energy sources must be used. In addition, the battery charging system must be safe for people and port infrastructure, as well as comply with regulatory requirements and technical standards for distribution networks and shore connection systems [3][4].

The aim of this article is to shed more light on the topic of implementing charging stations for ferries in the Republic of Croatia, based on the research results of the project METRO - Maritime environmentally friendly transport systems

2. Basic features of hybrid and electrical ferries

The power requirements and configuration of the shore connection and charging system for electric and hybrid ferries depend largely on the topology of the marine power plant and the requirements of the particular line. Propulsion drives with battery ES on a ferry can be implemented in four basic ways:

- hybrid electric propulsion with diesel generators (DG) and battery ES with AC distribution,
- hybrid electric propulsion with DG and battery ES with DC distribution,
- hybrid electric drive with power take-off (PTO)/power take-off (PTI) combining mechanical and electric drive in one kinematic driveline,
- all-electric battery drive.

All-electric propulsion depends entirely on the shore-based charging system, while the other three configurations offer much greater flexibility in adapting to the capabilities and performance of the port's electrical infrastructure. Therefore, when planning the introduction of a battery-powered ferry on a particular route, it is necessary to consider multiple propulsion options and determine the peak loads and required battery charging times while the ferry is in port according to the vessel's planned operational profile.

Analysis of battery-powered ferries currently in operation shows that installed battery capacity varies between 500 kWh and 5000 kWh, with required charging powers of up to 10 MW. Fully electric ferries are small in size and capacity due to the limitations imposed by the weight of the size of the battery storage, and are suitable for maintaining shorter routes where the focus is mainly on passenger transport. It is for these very reasons that most ferries on commercial lines where there is the possibility of carrying a larger number of passengers and vehicles use hybrid propulsion or a combination of batteries and internal combustion engines[5].

Analyzing the required capacities of vessels on existing ferry lines in the Republic of Croatia, as well as the state of the distribution network (especially in smaller areas where most ferry ports are located), it can be assumed that hybrid vessels would be a more reasonable choice compared to all-electric solutions. The use of hybrid propulsion also allows for greater flexibility in the choice of battery storage size, i.e. it is easier to adjust the required power of the charging stations to the capabilities of the distribution network in a given area.

3. Battery charging solutions

Battery charging systems for electric and hybrid ferries can basically be implemented in the following ways:

- direct charging from the grid of LV,
- direct charging from the MV or HV grid,
- combined charging from the ship's own DG and the shore-side grid,
- combined charging from the shore-side grid, ES and renewable sources.

A low-voltage shore connection (LVSC) is a shore connection system that uses either 400-, 440-, or 690-V cable to connect shore and ship. It is designed to handle up to 1.5 MW.

LVSCs typically allow the integration of the charging system into the port infrastructure with relatively minor interventions in the distribution network, usually involving the upgrade or installation of a new MV / LV distribution transformer [6].

If they can meet the charging power requirements, such connections are a very good option for smaller ferry ports on shorter routes (e.g. Brestova-Porozina, Prizna-Žigljen, Valbiska-Merag and the like). Due to the relatively low investment costs and small space requirements, the filling station can be easily installed in both ports, which allows much greater flexibility in maintaining the line.

High voltage shore connections (HVSC) can deliver currents in excess of 1 MW and allow rapid charging of batteries at high current. Such systems are now widely used in container ships and cruise ships, except that there they are not used to charge the batteries but to power the ship's electrical system while in port. The integration of such systems in small ferry ports usually faces some obstacles, the most common of which are: limited capacity of the distribution system and supply lines in the port, the availability of space for the installation of HVSC-specific cables, sockets, switchboards, converters and transformers, the need to upgrade the ship's own power management system (PMS) in order to operate the ship in parallel with the shore grid and avoid power outages [7]. To overcome these obstacles, significant modifications are often required, resulting in high implementation costs.

Such systems are more suitable for larger ports that serve as hubs for multiple ferry lines to nearby islands, such as Split and Zadar, because the better developed power distribution network and higher capacity of supply lines make such connections easier to implement.

Due to the technical challenges and high implementation costs mentioned above, it is not realistic to expect that installing this type of connection for both ports on a single ferry line will be cost effective. This may somewhat limit the flexibility in terms of overnight charging of the battery storage if the ferry has to spend the night in a port where the HVSC connection is not installed. This problem can be solved to some extent by installing an LVSC in another port that is used exclusively for slow battery charging during the night.

For ports where it proves impossible or unprofitable to expand the capacity of the supply network, and where one wants to reduce emissions as much as possible, one of the solutions is combined charging via the ship's own DG and the shore-side network. In this approach, the marine battery energy storage system is charged directly from the ship's electrical grid, which is powered by diesel generators, and the battery power is then used for maneuvering in port. This approach not only reduces the number of generator operating hours, but also allows the charging current to be regulated to keep the load on the diesel generators in the optimum mode where specific fuel consumption, and therefore harmful gas emissions, are lowest. During the ferry's night stay in port, the batteries can be recharged to the extent allowed by the LVSC capabilities.

Although it is technically the most complex and requires the installation of power electronic converters, combined charging from the shore power grid and the system installed in the port area ES is probably the best solution for ferry ports, as shown by experience in the Nordic countries where such solutions have been used for some time. In the areas where this is possible, and this certainly includes the Croatian coast, part of the electrical energy for charging the batteries can be obtained from renewable sources, mainly sun and wind, which promotes the use of green electrical energy and improves environmental friendliness.

4. Distribution grid capacity analysis

Future electric charging stations must be connected to the national electricity distribution grid. The first step in introducing battery-powered vessels is to assess the condition and capabilities of the distribution network in the port in question.

The distribution network is the final stage of the electricity transmission system and is used to distribute electrical energy to end users. Typical consumers connected to the distribution network are households, industry, ports, urban infrastructures, etc. The distribution network in Croatia is divided into two parts: the medium voltage network (MV) with nominal voltages of 10/20/35kV and the low voltage network (LV) with a nominal voltage of 0.4kV [8]. The maximum connected load that the customer can reach via the medium-voltage grid is in the range between 10MW and 20 MW, of course only if the existing cable infrastructure at the desired connection point allows this [9].

Once the power demand has been determined, when it comes to connecting their equipment to the distribution network, the user does not have too much influence on the realization of the LV or MV connection point. These aspects fall within the scope of the national distribution system operator (Hrvatska Elektroprivreda - HEP in Croatia). While the user (electricity buyer) is responsible for all equipment from the connection point, the DSO has to ensure the quality, reliability and continuity of electricity supply according to the existing regulations.

For certain consumers, such as charging stations for ferries, a continuous power supply is crucial, as a power failure would prevent the charging of batteries while the vessel is in port. Power supply indicators (which are publicly available for the distribution network in the Republic of Croatia) are calculated based on data from electronic records, i.e. using the DISPO (Distribution Reliability) application, which has been in use on HEP since 2006. The application allows statistical processing of manually entered planned and unplanned outages of network components with a duration of more than three minutes.

To represent the state of power reliability, the most important indicators are: average number of long power outages per network user (SAIFI), average duration of long power outages per network user (SAIDI), and average duration of long power outages per network user (CAIDI).

As most public MV /LV substations are designed to meet the needs of households and civil infrastructure in the area where the ferry port is located, it is unrealistic to expect them to have sufficient power reserve to meet the demands of future shore connections/charging systems. It is expected that in ports with limited electricity reserves, shore-based energy storage systems or renewable energy sources (if available and economically viable) will play an important role in supporting the local grid.

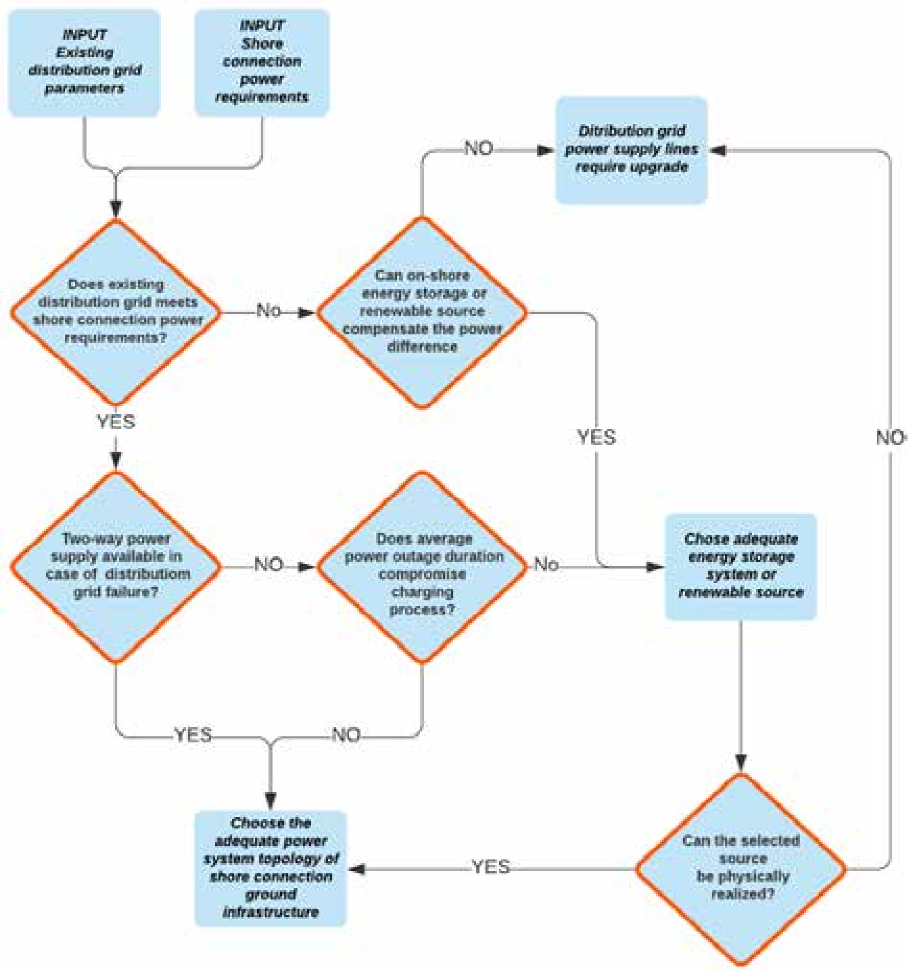

Figure 1: Suggested methodology for choosing adequate shore connection and charging system topology according to distribution grid characteristics

In this first step, it is necessary for the investor who implements the charging system, whether it is the port authority or the ferry line operator, to determine the real possibilities of the distribution network in the area covered by the ferry port of interest in cooperation with HEP. Wrong assessment of actual possibilities and load on the distribution grid by months (especially in the summer season) can jeopardize the continuity of line maintenance or its economic viability due to possible subsequent upgrade needs.

Suggested methodology for choosing adequate shore connection and charging system topology according to distribution grid characteristics is shown in Figure 1.

5. Optimizing shore side power system

Once the parameters and constraints of the distribution network are defined, which determine the possible technical solutions of the charging system in a given area, it is necessary to choose the most favorable solution from the technical and economic point of view. Due to the large number of interdependent parameters and the fact that each ferry line is specific in itself, simulations will play an important role in the evaluation of the system behavior. Although simulations cannot replace realistic measurements and tests, with well chosen and calculated electrical network parameters they can still provide satisfactory results for proper evaluation of future solutions.

In this paper, the process of optimization of shore connection and charging station components is described for the ports of Brestova and Porozina, but the same methodology can be applied to any ferry port.

The software HOMER Pro microgrid was chosen as the simulation tool. It simulates the operation of a system by performing energy balance calculations at each time step (interval) of the year. For each time step, HOMER compares the electrical and thermal demand at that time step to the energy that the system can supply at that time step, and calculates the energy flow to and from each component of the system. For systems that contain batteries or fuel-powered generators, HOMER decides at each time step how to operate the generators and whether to charge or discharge the batteries.

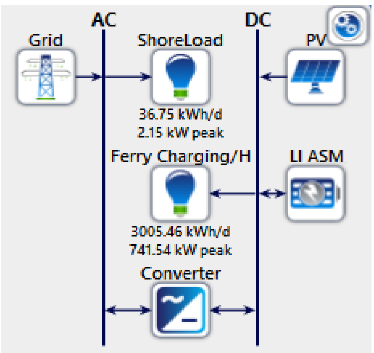

Figure 2: Ferry charging station model realized in HOMER Pro® microgrid software

It performs these energy balance calculations for each system configuration you are considering, and then determines whether a configuration is feasible (i.e., whether it can meet the power demand under the conditions you specify) and estimates the cost of installing and operating the system over the life of the project. HOMER Pro has two optimization algorithms; the original grid search algorithm simulates all feasible system configurations and HOMER Optimizer uses a proprietary, derivative-free algorithm to find the lowest cost system.

The configuration of the proposed loading station model for the ports of Brestova and Porozina, implemented in the HOMER Pro® Microgrid software, is shown in Figure 2.

The following initial parameters are used:

1. Grid parameters;
   - ◊ Grid sale capacity: 1000 kW.
   - ◊ Stand by charge (annual fee for connecting consumers to HEP's network-calculated from HEP's site for industrial consumers): $ 100 per year.
   - ◊ The purchasing price of electricity (including the price of labour and reactive power because industrial consumers pay both): $ 0.17 per kW
   - ◊ The selling price of electricity: $ 0.016 per kW

2. Grid reliability:
   - ◊ Number of power outages: 5 per year
   - ◊ Mean time to repair: 120 minutes

3. Power converter:
   - ◊ Installation costs: $ 400 per kW
   - ◊ Replacement costs: $ 300 per kW
   - ◊ Annual maintenance costs: $100 per year
   - ◊ Estimated life cycle: 15 years

4. On shore battery ES (Corvus Orca Energy is used in model):
   - ◊ Capacity of one battery bank: 125 kWh
   - ◊ DC voltage (min/rated/max): 800V/980V/1100V
   - ◊ Initial state of charge (SOC): 100%
   - ◊ Minimal allowed SOC: 20%
   - ◊ Degradation limit: 30% of full capacity (the influence of temperature on battery aging was taken into account)

5. Photovoltaics (PV):
   - ◊ A generic flat panel without curvature or active sun tracking was modelled
   - ◊ Price: $2500 per kW
   - ◊ Global horizontal irradiance (GHI) data for Brestova-Porozina area is taken from NASA database (part of HOMER software)

6. Shore side load:
   - ◊ According to data from HEP, a generalized model was developed. The port infrastructure consumed power, both in Brestova and Porozina are extremely small to have an impact on the Ferry load.

7. Ferry charging and hotel load:
   - ◊ Estimated power of the ferry hotel load is 250 kW and charging power is 500 kW. The schedule of arrivals and departures of the ferry was taken from the Jadrolinija and based on it a generalized charging schedule was made.

Simulation results based on previously defined parameters show two possible solutions for charging stations in Brestova and Porozina which are briefly summarized in Table 1.

Table 1: Summary of two possible solutions for ferry charging stations in Brestova and Porozina

	Solution 1	**Solution 2**
PV power	9.36 kW	No PV installed
Battery ES power	3 x 125 kW	3 x 125 kW
Required converter power	207 kW	338 kW
Autonomy on battery ES only	2,08 hours	2,08 hours
Estimated initial costs	$ 220000	$ 250000

The first solution includes PV panels, but the battery is almost depleted to the end and is constantly at the lower SOC limit. In this configuration, the downsizing of the converter is supported because the batteries are partially charged by the solar panels. This reduces the cost of the system, but also the reliability.

The second solution is much better in terms of reliability. The converter is larger, so it keeps the status of the battery SOC above the minimum level. Also, it is possible to install 5 to 10 kW of PV, but according to Homer, this is suboptimal from a financial point of view.

The choice of solution ultimately depends on the investor, but since reliability is paramount in such systems, option number 2 is considered the best solution. Also, if needed, it is very easy to add additional PV modules once the price and efficiency are more favorable.

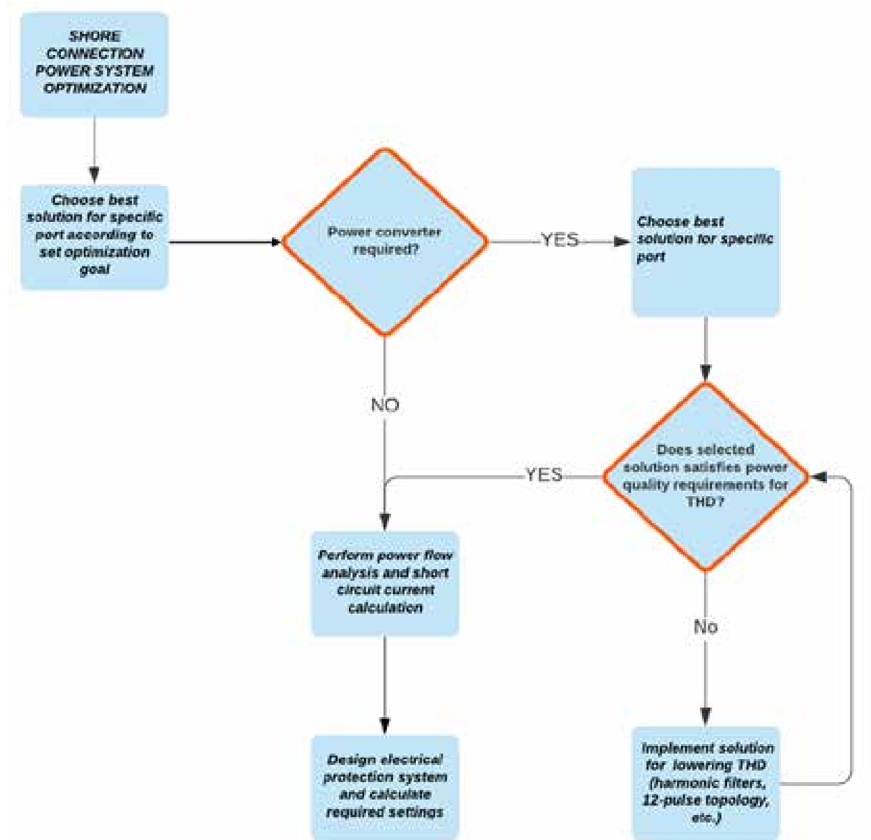

Figure 3: Suggested methodology for shore connection power system optimization

After selecting the appropriate topology for the charging station, the power flow analysis should be performed and the appropriate electrical protection system should be designed. It is also necessary to consider the impact of the converter on the power quality of the utility grid through field measurements or simulations to ensure that the proposed solution meets the requirements specified in the standard EN 50160 for the maximum allowable harmonic distortion of voltage THDv in public distribution systems.

The proposed methodology for optimizing the shore power network is shown in Figure 3.

6. Rules and regulations

When introducing hybrid and electric ferries on a large scale, it is important to focus on the regulatory context, both in terms of regulations and standardization. This chapter provides an overview of the regulations, guidelines and standards currently in place for the use of batteries and shore connections in shipping.

The design concept for these systems is included in the current LVSC draft standard, International Electrotechnical Commission (IEC)/ IEEE 80005-3. Although this application has not yet been standardized at the international level, it is usually partially covered by national standards. The general rules for the construction of LV shore connections in the Republic of Croatia are established in accordance with the European standard that defines the technical requirements for inland vessels (ES - TRIN). For currents up to 125 A, they comply with the requirements of the European Standards EN 15869-1: 2019 and EN 15869-3: 2019 and for currents above 250 A, they comply with the requirements of the European StandardsEN16840: 2017.

The stringent requirements and complexity of the issues associated with shore-side power supply to ships at berth have led to the development (in collaboration with the IMO) of the European pre-standard IEC/PAS 60092-510:2009 Electrical installations in ships - Special features - High Voltage Shore Connection (HVSC) Systems, which describes the general requirements for S2SP systems. On this basis, the International Electrotechnical Commission has issued the standard HVSC Systems - General Requirements (IEC/ISO/ IEEE Std 80005-1).

Regulation of the use of batteries in ships does not yet appear to be on the agenda of the International Maritime Organization (IMO). To date, most of the development work has been done by certain flag States and classification societies. The current relevant standards for specific maritime battery applications or battery technologies are summarized in Table 2.

Table 2: Current relevant standards for specific maritime battery applications or battery technologies [10]

Standards / Rule	Year of publication	Short description
EN 50110 Edition 2.N (2013-06-01)	2013	Operation of electrical installations -- Part 1: General requirements - Supporting documentation for batteries and electrical testing
IEC 61508 Edition: 1.0 (2005-01-20)	2005	Functional safety of electrical/electronic/ programmable electronic safety-related systems – Supporting documentation for batteries and electrical testing

IEC 61511 Edition: 1.0 (2003-12-19)	2003	Functional safety - Safety instrumented systems for the process industry sector - Supporting documentation for batteries and electrical testing
ISO 26262 Edition: 1 (2011-11-14)	2001	Road vehicles -- Functional safety - Supporting documentation for batteries and electrical testing
IEEE 45-2002	2002	Recommended Practice for Electrical Installations on Shipboard

Guidelines on battery and shore connection utilization given by the four major Class Societies member of IACS are shown in table 3.

Table 3: Guidelines on battery and shore connection utilization given by the four major Class Societies member of IACS

Class Society	Date	Type	Title
ABS	2020	Guideline	**Hybrid electric power systems for marine and Offshore applications** - Dedicated to the application of hybrid electric power systems
	2020	Guideline	**Use of lithium batteries in the marine and Offshore industries** - Provides class requirements and reference standards to facilitate effective installation and operation of lithium battery systems.
	2011	Guideline	**High Voltage Shore Connection**
BV	2020	Rules	**Rules for Classification of Ships:** Pt F, Ch 11, Sec 21 – Battery system Pt F, Ch 11, Sec 22 – Electric Hybrid Pt F, Ch 11, Sec 29 – Electric Hybrid Prepared
	2010	Rule Notes	**RN557** - High-Voltage Shore Connection System
DNV GL	2020	Rules	**Rules and Standards for classification: Ships (RU-SHIP)** Pt. 6 Ch.2 Sec.1 - Electrical Energy Storage
	2020	Rules	**Rules and Standards for classification: Ships (RU-SHIP)** Pt.6 Ch. 7 Sec. 5 - Electrical shore connections - Shore power

LR	2020	Rules	**Rules and Regulations for the Classification of Ships** Pt 6, Ch 2, 12 - Batteries
	2020	Rules	**Rules and Regulations for the Classification of Ships** Pt 7, Ch 13 – On-shore Power Supplies
	2016	Guideline	**Battery installations** - Key hazards to consider and Lloyd's Register's approach to approval

While the aforementioned standards for shore connections define the requirements and protection of standard connectors needed for cold ironing, there are no official standards yet for battery chargers and their integration. Future electric and hybrid vessels will require new solutions and topologies for shore connections characterized by the increased use of power electronics devices, the integration of energy storage and environmentally friendly renewable sources, and the use of DC distribution systems. Accordingly, there is a need to extend existing standards or develop new ones that incorporate these solutions, with the aim of facilitating an easier transition to greener solutions for ferry and RO - RO transport.

7. Conclusions

With existing and future regulations aimed at reducing maritime emissions, shipping companies are forced to look for alternative environmentally friendly propulsion solutions. One such solution, which is particularly suitable for coastal ferries in the Republic of Croatia, is the use of battery energy for propulsion, either in the form of all-electric or hybrid propulsion.

The introduction of such vessels is impossible without adequate shore-side electrical infrastructure, especially the battery charging system. The design and analysis of the shore connection and charging system should include the vessel design, shore connection technology and port electrical infrastructure in order to have the right amount of information to choose the best solution for the application. It is very important to accurately determine the electrical power requirements of the ferry port in question so that the distribution system operator can assess whether the existing infrastructure meets the requirements or whether an upgrade is needed, which will ultimately determine the choice of shore connection topology. Such infrastructure projects involve several stakeholders, primarily the port authority, the ferry operator and the distribution system operator. It is expected that the legal and administrative work and the obtaining of the necessary permits will take a long time, so that such projects need to be planned several years in advance.

This paper proposes the methodology for planning shore connections and charging systems for ferries using the ports of Brestova and Porozina as examples, but the proposed methodology can be used for any port.

While the existing draft standard IEEE /IEC 80005-3 defines the requirements and protective measures for standard connectors needed for cold ironing, the standards for battery chargers and their integration do not officially exist yet. There is a need to extend existing standards or develop new ones that incorporate these solutions, with the ultimate aim of enabling an easier transition to more environmentally friendly solutions for ferry transport.

8. Acknowledgements

The research was funded by European Regional Development Fund (ERDF), through the 2014–2020 Interreg V-A, Italy—Croatia CBC Programme, by means of the 2017 Standard call research project “METRO—Maritime Environment-friendly TRanspOrt systems” (Project ID: 10044221), Priority Axis: Maritime transport.

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