A Hybrid-Electric Passenger Vessel for Inland Waterway

Donato Padolecchia
Dept. of Engineering and Architecture
University of Trieste
Trieste, Italy
donato.padolecchia@phd.units.it

Samuele Utzeri
Dept. of Engineering and Architecture
University of Trieste
Trieste, Italy
samuele.utzeri@phd.units.it

Luca Braidotti
Dept. of Engineering and Architecture
University of Trieste
Trieste, Italy
lbraidotti@units.it

Alberto Marino'
Dept. of Engineering and Architecture
University of Trieste
Trieste, Italy
marino@units.it

***Abstract*— The problem of air pollution is one of the biggest issues discussed worldwide: due to this reason, various measures to reduce global pollution, especially CO2 emissions, are being taken by Governments. One of the main causes of pollution is represented by the transport sector, which includes also maritime transport. Therefore, it is necessary to study and find new types of propulsion that ensure a reduction of pollutant emissions. A way to achieve this aim is represented by hybrid-electric propulsion systems, capable of ensuring a good range in ZEM – Zero Emission Mode – navigation. In this paper, the application of hybrid-electric propulsion on a small boat for passenger transport in inland waters has been analysed. Based on the results of preliminary studies, a prototype of the vessel was built; the boat has been a useful and remarkable test bench to validate such a technology, in terms of eco-friendliness, energy efficiency, and reliability. Here, the theoretical estimates carried out in the early stage of design have been compared with the experimental data obtained on the prototype during a sea trials campaign carried out in a real operative environment.**

Keywords*— *Inland Waterways, hybrid – electric propulsion, Zero Emission Navigation mode, small passenger vessel, air pollution, electric navigation

I. INTRODUCTION

Currently, one of the most important environmental problems is global warming; such a phenomenon is caused by the significant increase in Global Greenhouse Gases (GHG) coming from usage of fossil fuels. In particular, carbon dioxide (CO_2) is held accountable for approximately 60% of the greenhouse effect. Among others, the transport sector has a huge impact on global CO_2 emissions, since the 25% of CO_2 derives from such an industry[1]. The problem of producing pollutant substances into the atmosphere also concerns the marine sector: indeed, in the last few years, the sea transport of both goods and people has significantly increased worldwide, and more than 90% of freight is now carried by ships. As a result, maritime transportation is responsible for more than 30% of CO_2 emissions and about 2.7% of global emissions[2].

International Organizations have been developing short, medium and long-term strategies for the problem [3]. On 13 April 2018, the IMO Marine Environment Protection Committee – MEPC – announced that Member States' delegates agreed on the target of reducing the shipping sector's overall CO_2 emissions by about 50% by 2050, of reducing pollutant emissions as soon as possible, and of continuing the efforts to phase out carbon emissions entirely [4]. Regarding the short term, until 2023, Member States are committed to promulgate some National Action Plans about CO_2 emission reductions and ship speed reduction, especially in the inland waterways, and to declare the new guidelines for fuels. It is clear that, in the next future, stricter limits are already scheduled to come into force[5].

One of the most studied and used solutions to reduce pollution in the transport sector is the development of hybrid vehicles, both terrestrial and marine [6] [7]. The use of hybrid electrical propulsion is reliable, consolidated, and suitable for various purposes in the marine scenario [8] [9]. The advantages of using electric hybrid engines instead of internal combustion engines are many and related to environmental and engineering aspects. Indeed, the main ship emissions responsible for air pollution are represented by NO_x, CO_2, SO_2, and particulate matter: these substances are formed directly during the combustion process or as chemical reaction products in the atmosphere. Due to this, hybrid electrical propulsion allows a reduction of pollutant emissions, along with a high reduction of noise pollution [10]. From an engineering point of view, if compared with internal combustion engines, electric motors at tow revs produce much torque with high efficiency. Moreover, the system is simpler and has few elements: this involves less ordinary and extraordinary maintenance than internal combustion engine systems.

Hybrid electric propulsion systems can be widely used in the maritime tourism sector and are widely applied on passenger and private yacht boats [11]. Indeed, the possibility of a ZEM navigation allows access to marine protected areas as indicated in National and International Regulations, since navigation by electric propulsion is considered equal to sailing or rowing navigation [12].

In this paper, a case study of an innovative small passenger vessel equipped with hybrid electric propulsion is proposed. In particular, a specific operating environment for this boat has been chosen: the Grado Lagoon. This area is very fragile and is surrounded by several marine protected areas and natural reserves [13] [14]. To achieve high standards of eco-friendliness in the public transport sector and to respect the neighbouring environment, the passenger vessel has been equipped with electric hybrid propulsion [15]. The main goal of the project is to fit the vessel with a propulsion system capable to perform ZEM navigation. The test scenario consist of a route within the Grado Lagoon. Along this route, a typical operative profile for this type of passenger vessel has been considered. The present work aims to compare the initial assessment and estimates carried out in the early design stage for dimensioning the propulsion system with the experimental results coming from a full-scale trial in the real environment [16].

II. GRADO LAGOON: ENVIRONMENTAL LIMITS AND CHOSEN ROUTE

The operational environment considered for the case study is the Grado Lagoon. Like many inland waterway areas, also the Grado Lagoon is characterized by peculiar features that heavily influence the design of a vessel operating in such an environment. Shallow waters, low air draught and narrow waterways have a great impact on the design of boats, as well as the minimum dimensions of the canals along the route. Indeed, the smallest breadth, the narrowest bend, and the minimum depth of the canals have to be considered. Moreover, the air draught of the vessel must be consistent with the smallest clearance of the bridges crossing the waterway along the route.

From an ecological point of view, the Grado Lagoon obliges to give particular attention to air pollution and noise emissions. There are multitudes of animal species (especially birds) and very rare plants: the natural equilibrium of the area is very delicate and must be protected against pollution. Furthermore, near the lagoon, there are several natural parks and marine reserves such as the “Riserva Naturale della foce dell’Isonzo” and the “Riserva Naturale della Valle Cavanata”.

Especially in inland waterways, the boat traffic leads to heavy effects on the surrounding environment. Therefore, during the design of vessels, it is important to study the operational context in which each unit will navigate to make the appropriate engineering choices to preserve the natural equilibrium. Regarding propulsion, it is necessary to guarantee low levels of both polluting and noise emissions; for this reason, electric hybrid propulsion is the most suitable solution, especially in the case of small units[17]. Moreover, proper hull forms can lower wave-making during navigation, aiding to reduce the erosion of both the sides of the canals and the sea bottom [18]. To reduce this phenomenon, a speed limit in the canals of Grado Lagoon has been imposed. The Ordinance n. 26/99-07 regarding “Regulation of navigation in the Grado Lagoon”, issued by the municipality of Grado on 02 September 2008, requires that all vessels with a length less than 5.5 meters have a maximum permitted speed equal to 5.4 kn, while those with a length of more than 5.5 meters have a maximum permitted speed equal to 2.97 kn.

As previously stated, the design process of a boat for inland waterways has to take into account the characteristics of both the operating environment and routes. For this reason, a route within the Grado Lagoon has been chosen (Fig. 1). This one connects Grado with Aquileia (two important Italian tourist cities) and it is developed within the Grado Lagoon and along the Natissa river (Tab. 1).

After choosing the reference route, all the environmental limits present along them have been studied: this information influences the design process of the vessel, in particular the main dimensions. For this reason, the depth, width, radius of curvature of the canals, and height above the water of the bridges along the chosen routes have been analysed.

TABLE I. MAIN CHARACTERISTICS OF THE ROUTE CONNECTING GRADO AND AQUILEIA

Route 1 – Grado - Aquileia	
Length of route	12500 meters
Minimum depth of the canal	1.46 meters
Maximum depth of the canal	8.01 meters
Average depth of the canal	3.96 meters
Minimum width of the canal	23.0 meters
Minimum air draft	2.90 meters

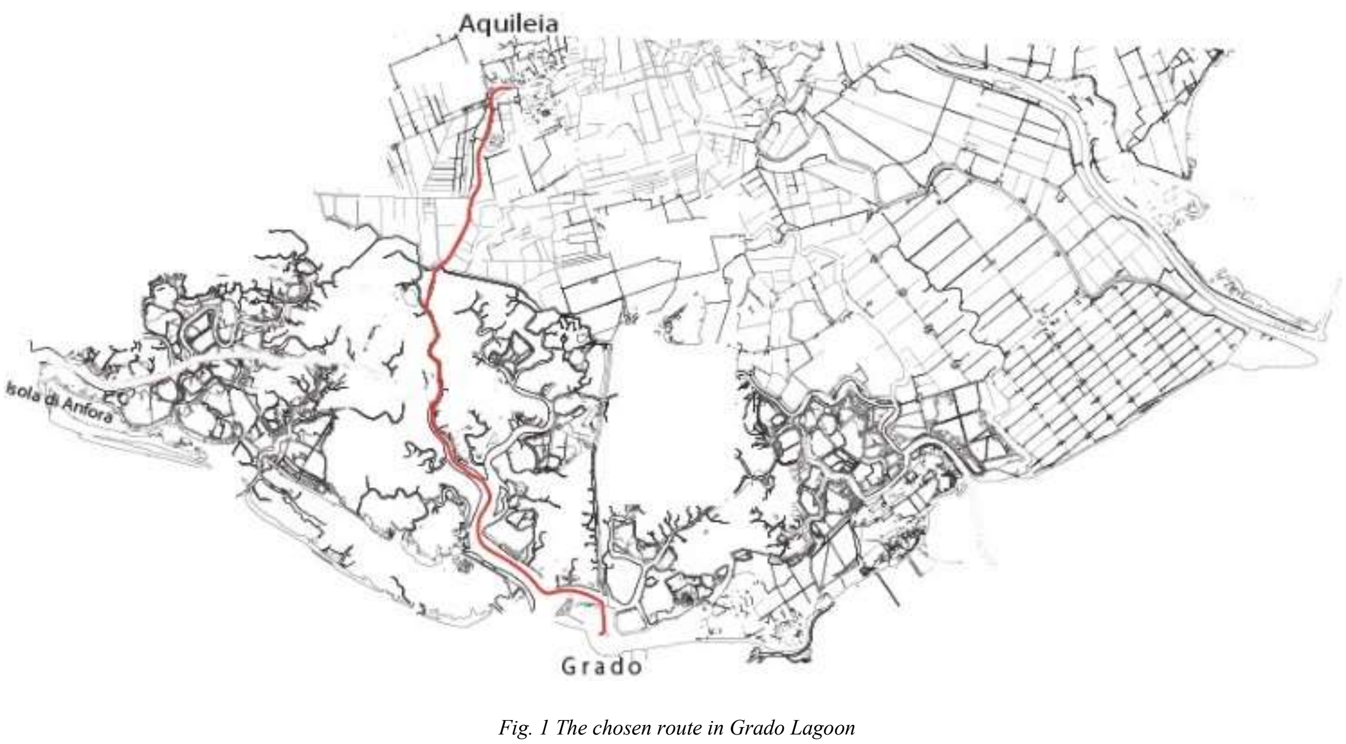

Fig. 1 The chosen route in Grado Lagoon

III. HYBRID ELECTRIC PROPULSION

One of the most interesting ways to reduce pollutant emissions is the use of hybrid electric propulsion in transport. In the last years, many studies and tests on vehicles and boats equipped with this technology have been performed, with the result of making it reliable and safe [19]. Within the marine sector, several innovative and high-performance systems, aimed at ensuring the energy required for hybrid electric propulsion in both small and large vessels, have been developed [20]: some examples are batteries, fuel cells and supercapacitors. In the case of small vessels equipped with hybrid electric propulsion, the use of batteries as energy stock is the most used choice. The integration of these propulsion systems on small ships operating on short cycles is a challenge. Indeed, the vessel typology implies maximising the passengers' boarding capacity, and therefore minimising the volume allocated to energy storage and energy/propulsion systems. The storage of energy reserves for propulsion, such as batteries, is hard to set up, due to the small spaces on board. Furthermore, for this kind of vessels, typical mission profiles include high transients of speed involving strong power demands. The available times for charging energy systems are often also limited. In order to guarantee the high power needed, it is necessary to embark on a very large number of batteries, with consequent problems regarding their positioning on board and weight distribution [21].

There are two main layouts for hybrid propulsion chains: series and parallel configuration.

A. Series Hybrid layout

In this layout, the combustion engine and the electric system are used in series [6]. The propulsion is performed by one or more electric motors connected to the propellers. The electrical power for the propulsion is generally supplied by the Energy Storage Systems (ESS), which may consist of batteries, supercapacitors, etc. This system receives energy from external sources onshore (e.g., charging columns) or from the diesel generator installed on board. One charge controller manages all energy flows electronically (Fig. 2).

Therefore, in the series hybrid layout, the endothermic system (combustion engine – generator) and electric system (electric motors) are not mechanically connected. In particular, this configuration allows the separation of the operative points of the engine and the operative points of the propeller: only the electric motor is linked to the propeller. Therefore, such a layout can increase the global efficiency of the system by optimizing the operating point of both the combustion engine and the propeller from an efficiency point of view.

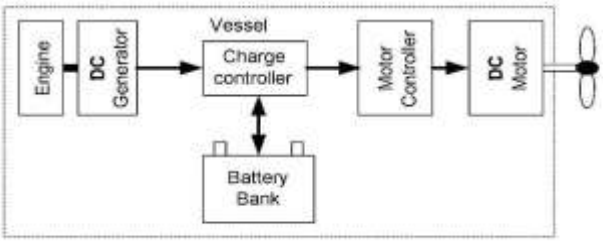

Fig. 2 Series Hybrid architecture

B. Parallel Hybrid layout

This layout is characterized by the connection between the endothermic engine, the electric motor and the propeller, which are mechanically coupled with the same shaft through a gearbox and clutches (Fig. 3). Parallel hybrid propulsion systems can operate in three different profiles:

- full-electric propulsion, in which the combustion engine is disconnected by the gearbox and only the electric motor drives the propeller. The electric motor receives energy from a ESS fitted onboard. Usually, to avoid quick battery consumption, the ship operates at low speed;
- endothermic propulsion, in which the internal combustion engine drives the propeller. The electric motor can be also dragged to recharge the ESS (the electric motor acts as a generator);
- combined propulsion, in which both an electric motor and endothermic engine simultaneously drive the propeller, allowing the ship to reach the maximum speed.

Compared with the series hybrid layout, the parallel configuration reduces the number of elements and allows the sizing optimisation of each energy source. However, it is preferred when the vessel is required to both reach high navigation speeds and guarantee short periods of full-electric navigation [22] [21].

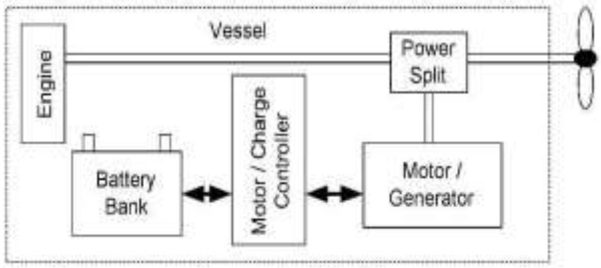

Fig. 3 Parallel Hybrid architecture

IV. THE PASSENGER VESSEL

The aim of the study has been that of designing a boat able to guarantee a high respect for the environment: this target has been achieved through a proper choice of both construction materials, preferring natural ones such as wood, linen, or bamboo wood [23], and the propulsion system, preferring one that allows low polluting emissions.

The case study concerns a small passenger vessel operating in the Grado Lagoon, therefore in conditions of internal waters. This unit has been designed and equipped with a hybrid electric propulsion system. The main particulars of the vessel are reported in Table 2.

In order to facilitate navigation in case of adverse weather conditions, and especially in case of fog, the bridge of the vessel is located forward. The boarding area is on the bridge and embarking and disembarking of passengers can be done on both sides of the boat. The passenger area is located on a lower deck than the main one and extends from the central area to the stern of the boat. The cover of the passenger room consists of a wooden superstructure.

TABLE II. MAIN PARTICULARS OF THE SMALL PASSENGER VESSEL

Length, overall	11.00 m
Length, waterline	10.50 m
Breadth	2.80 m
Draught	0.50 m
Displacement, full load	9.20 t
Speed, cruise	5.00 kn
Speed, maximum	9.00 kn
Passenger	24
Crew	1

To ensure adequate ventilation of the room, a series of openings are made on the sides of the superstructure; these can be closed with glass panels to prevent flooding from the outside. All the batteries for both the propulsion and auxiliary systems of the vessel are fitted in the passenger area. From the main deck, it is possible to access the passenger room through a stairway. The manoeuvring and propulsion are performed by two azimuth thrusters (POD), located at the stern of the vessel (Fig. 4).

V. INTEGRATED POWER SYSTEM

Hybrid-electric propulsion can be a suitable solution for small passenger vessels when ZEM navigation is required. Indeed, ZEM navigation allows the vessel to enter into environmentally protected marine areas, where it is necessary to reduce noise, air and water pollution.

To have a relevant green profile on the vessel, a full-electric solution has been developed for the propulsion system. This is resulting in adopting an Integrated Power System (IPS) designed to satisfy preliminary pre-determined energy requirements involving all the auxiliaries installed on board, i.e. manoeuvring system, engine room ventilation, outfitting, battery charger and propulsion.

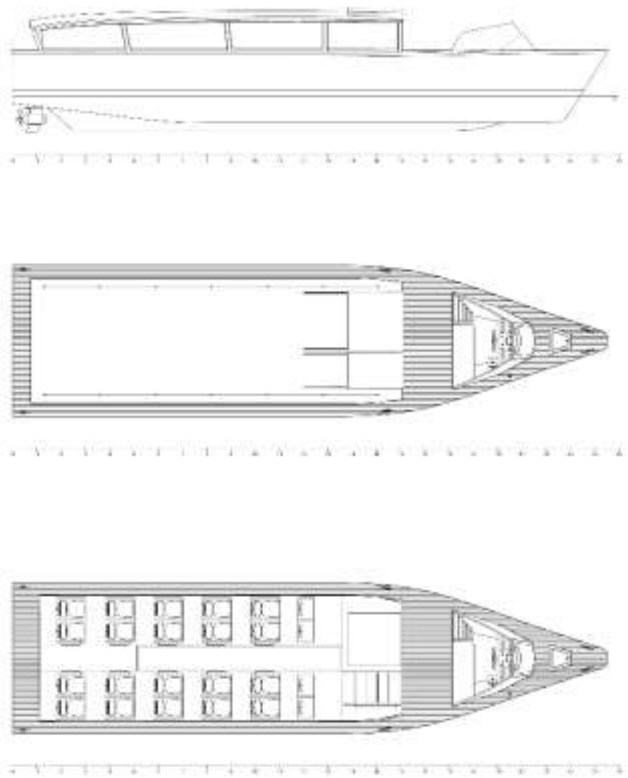

Fig. 4 General arrangements of the small passenger vessel

In a preliminary evaluation, once the vessel is sailing on a pre-determined route the above-mentioned electrical loads can be assumed as constants throughout the entire route. In such a case, considering that during transfer it is supposed to travel without battery charging, the manoeuvring loads are supposed to be around 0.5 kW, the ventilation services 0.3 kW, while propulsive loads are speed dependent, being about 1 kW at 3 knots and 7 kW at 6 knots in deep water [24]. These speeds exceed the limit in force in the Grado Lagoon. However, a service speed of 2.97 kn is not suitable for a commercial line even in the framework of slow tourism. Therefore, the vessel has been designed for a higher speed (5 kn) employing hull forms that limit the wave pattern.

With the above considerations, to achieve ZEM navigation, the energy for the propulsion is guaranteed by the set of batteries installed on board and located in the passenger area. The capacity and, hence, the sizing of the set of batteries have been studied according to the route: the target is to ensure the ZEM navigation for a whole day. The batteries have a capacity and a voltage equal to 562 Ah and 2 V, respectively: since the voltage of the electric propulsion system is 48 V, 24 batteries in series have been installed (Tab. 3).

TABLE III. MAIN CHARACTERISTICS OF BATTERIES

Capacity (nominal)	600 Ah
Capacity (C_5)	562 Ah
Voltage	48 V
Weight	36 kg

The set of batteries supplies the energy to the two electric motors installed in the two PODs at the stern. Each electric motor has an output power equal to 10 kW and a voltage equal to 48 V (Tab. 4).

TABLE IV. MAIN CHARACTERISTICS OF ELECTRIC MOTORS

Continuous power output	10 kW
Continuous power consumption	12 kW
Voltage	48 V
Current	250 A
Weight	54 kg

To increase the capacity of the accumulators, installing some batteries in parallel has been deemed necessary. Several profiles of similar vessels have been analysed and a working day of passenger transport along the chosen route has been considered. It has been hypothesized that, at the beginning of the working day, the batteries are fully charged; according to the consumption needed to perform the route, the minimum capacity of the batteries necessary to obtain a ZEM navigation has been calculated.

The batteries can be recharged through either a terrestrial charging column or the diesel generator fitted on board. Indeed, the Regulations require that an emergency diesel generator is installed on passenger transport vessels: such a generator shall ensure the required power in case of malfunction or failure of the batteries. Therefore, in these cases, the diesel generator has to supply the power to the electric motors to allow the return to port. This is why, in the considered case study, a peculiar system has been chosen: the diesel generator can supply power both to propulsion and batteries' charger at the same time.

The arrangement of the chosen hybrid electric propulsion system is shown in Fig. 5. In detail, the two azimuth thrusters, in which the two electric motors are installed, are represented in black colour, the batteries located at the centre of the vessel in green colour, the diesel generator in white colour and the two battery chargers/inverters in blue colour. In order to optimize the spaces on board and ease the installation of the electric system, all the cables run through holes made in the wooden transversal frames. Their location was defined before starting the construction of the vessel to properly cut the frames using a numerical-control machine.

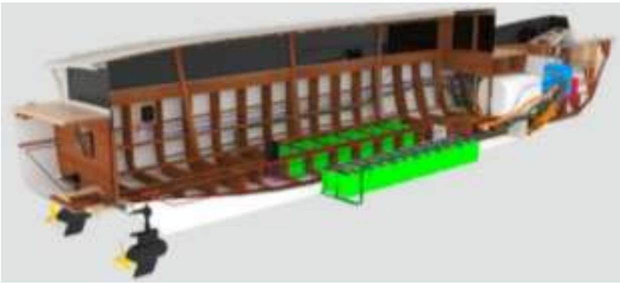

Fig. 5 Render of the propulsion system installed in the boat

VI. TRIALS

Thanks to the prototype built, it was possible to perform several sea trials in the real operative environment (the Grado Lagoon): through the experimental data collected, it the engineering choices made during the design have been verified by comparing how much they differ from the experimental records. In detail, both the correct functioning of the hybrid electric propulsion system and the autonomy of the vessel have been verified. To obtain accurate results from the sea trials, the prototype has been properly set up. Since most of the internal accommodation was not fitted at the time, the design displacement has been achieved by filling with water several kegs located on the lower deck. The full-load upright position has been chosen as a reference for the trials, thus kegs have been filled to reach null trim and heel angle at the design draught.

The sea trials were performed on 16/07/2018 with a special agreement with the Coast Guard, allowing the vessel to not respect the speed limits inside the lagoon. In particular, round-trip trials were performed along the Grado-Aquileia route: trials started at 11:08:30 and finished at 13:54:00, with a total travel time of 2 hours, 45 minutes and 30 seconds. In Figures 6-8, the data corresponding to the delivered power, the vessel speed, and the batteries State Of Charge (SOC) are shown, in relation to the theoretical data predicted in the design phase. Moreover, the trials were affected by the tidal current (Fig. 9) which, along the outward trip of the test route (Grado-Aquileia) mainly helped the vessel, far exceeding the current of the Natissa river: it is possible to see how in the first section of the route the power developed (Fig. 7) is much lower than the one assumed in the design phase. Hence, the SOC decreases less than in the first estimation. In the first part of the return trip of the route (Aquileia-Grado), instead, the power is initially well match the theoretical values as the tidal current decreases in intensity corresponding to the tide peak. In the last segment of the return trip, the boat speed was increased up to 7 kn, so the delivered power increased to 5 kW and the SOC decreases faster than the theoretical trend, thus balancing the gain obtained in the outward trip.

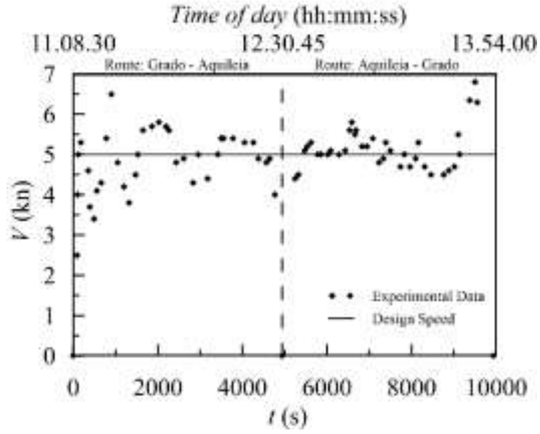

Fig. 6 Comparison of experimental and design speed

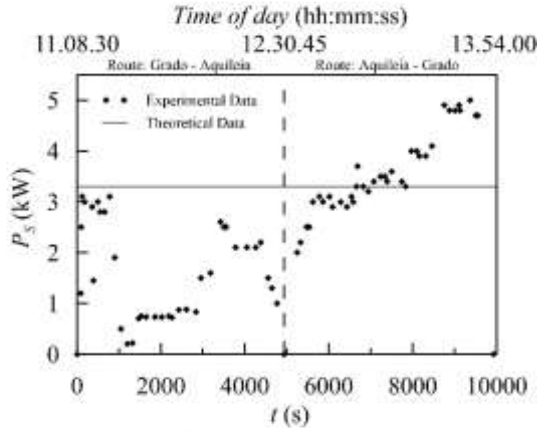

Fig. 7 Comparison of experimental and design delivered power

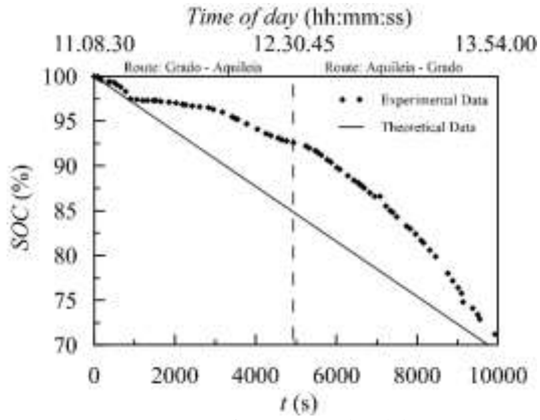

Fig. 8 Comparison of experimental and design SOC

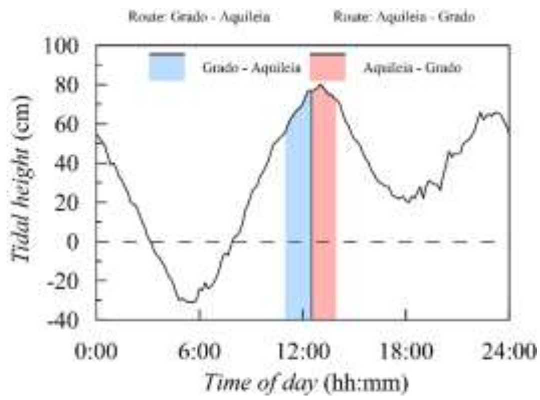

Fig. 9 Tidal trends (Source: Ispra Ambiente)

VII. CONCLUSIONS

A case study of an innovative small passenger vessel equipped with hybrid electric propulsion is proposed and built, to verify the engineering choices made during the design and how much they differ from the real case. In particular, both the correct functioning of the hybrid electric propulsion system and the autonomy of the vessel have been verified.

The analysis of the results obtained for the Grado Aquileia route shows that the theoretical assumptions made in the early design stage are reliably matched by the experimental data, both in terms of power output and the overall state of charge of the batteries. In conclusion, it can be stated that the assumptions made in the design phase were sufficiently accurate for the design route and tested vessel although they were not accounting for tides, currents, shallow water and canal effects.

Regarding the autonomy of the vessel, the data obtained during the sea trials confirmed the desired results. Indeed, the tests have shown that, concerning the theoretical data, the consumption of the battery charge is lower despite the increased speed in the last segment of the return trip: hence, the range of the boat is slightly higher than the initial prediction. As a result, assuming the average discharge rate detected on the Grado-Aquileia route, it is possible to make 3 trips (outwoard and return) per day (8h 4' 58'' of navigation) without the need to recharge the batteries.

ACKNOWLEDGMENT

This work was supported by "ZELAG – Zero Emission navigation Laguna di Grado" research program, funded by the Regione Autonoma Friuli Venezia-Giulia with POR-FESR 2014-2020, Asse 1.3b.B.

REFERENCES

[1] D. Tong *et al.*, «Committed emissions from existing energy infrastructure jeopardize 1.5 °C climate target», *Nature*, vol. 572, fasc. 7769, pp. 373–377, ago. 2019, doi: 10.1038/s41586-019-1364-3.

[2] K. Mersin, İ. Bayirhan, e C. Gazioglu, «Review of CO2 emission and reducing methods in maritime transportation», *Therm. Sci.*, vol. 23, fasc. Suppl. 6, pp. 2073–2079, 2019, doi: 10.2298/TSCI190722372M.

[3] I. S. Seddiek e M. M. Elgohary, «Eco-friendly selection of ship emissions reduction strategies with emphasis on SOx and NOx emissions», *Int. J. Nav. Archit. Ocean Eng.*, vol. 6, fasc. 3, pp. 737–748, 2014.

[4] «MEPC.304(72).pdf».

[5] V. Bucci e A. Marino, «Inland waterway gas-fuelled vessels: the basis of an innovative concept design for European rivers», presentato al 5th International Conference on Development, Energy, Environment, Economics (DEEE'14), 2014, vol. 35, pp. 305–313.

[6] C. C. Chan, A. Bouscayrol, e K. Chen, «Electric, hybrid, and fuel-cell vehicles: Architectures and modeling», *IEEE Trans. Veh. Technol.*, vol. 59, fasc. 2, pp. 589–598, 2009.

[7] T. J. McCoy, «Electric ships past, present, and future [technology leaders]», *IEEE Electrification Mag.*, vol. 3, fasc. 2, pp. 4–11, 2015.

[8] E. K. Dedes, D. A. Hudson, e S. R. Turnock, «Assessing the potential of hybrid energy technology to reduce exhaust emissions from global shipping», *Energy Policy*, vol. 40, pp. 204–218, 2012.

[9] E. A. Sciberras, B. Zahawi, e D. J. Atkinson, «Reducing shipboard emissions–Assessment of the role of electrical technologies», *Transp. Res. Part Transp. Environ.*, vol. 51, pp. 227–239, 2017.

[10] E. Pecorari *et al.*, «On which grounds a decision is taken in waterborne transport technology to reduce air pollution?», *Atmospheric Pollut. Res.*, vol. 11, fasc. 12, pp. 2088–2099, 2020.

[11] V. Bucci, A. Marinò, D. Bosich, e G. Sulligoi, «Inland waterway gas-fuelled vessels: An innovative proposal of a hybrid ship for the European network», presentato al 2015 International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles (ESARS), 2015, pp. 1–6.

[12] V. Bucci, A. Marino, D. Bosich, e G. Sulligoi, «Propulsion system design of a yacht catamaran: comparisons between conventional and different Diesel-electric solutions», presentato al 1st International MARINELIVE Conference on "All Electric Ship", 2012, pp. 1–8.

[13] V. Bucci, A. Marino, e A. Businaro, «The new hybrid small passenger vessel for the Venice Lagoon», presentato al NAV 2015-International Conference on ships and shipping reasearch, 2015, pp. 1107–1115.

[14] V. Bucci, F. Mauro, A. Marino, D. Bosich, e G. Sulligoi, «An innovative hybrid-electric small passenger craft for the sustainable mobility in the Venice Lagoon», in *2016 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM)*, Capri, Italy, giu. 2016, pp. 1388–1395. doi: 10.1109/SPEEDAM.2016.7525941.

[15] C. Nasso *et al.*, «Integrated design of an eco-friendly wooden passenger craft for inland navigation», *Int. Shipbuild. Prog.*, vol. 66, fasc. 1, pp. 35–55, 2019.

[16] A. Marinò e V. Bucci, «A simulation model for hybrid-electric inland waterway passenger vessels», presentato al Technology and Science for the Ships of the Future: Proceedings of NAV 2018: 19th International Conference on Ship & Maritime Research, 2018, p. 388.

[17] S. Bertagna, L. Braidotti, D. Padolecchia, A. Marino', e V. Bucci, «Feasibility Study of a Hybrid-electric Taxi Boat for the Venice Lagoon», in *2022 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM)*, Sorrento, Italy, giu. 2022, pp. 701–706. doi: 10.1109/SPEEDAM53979.2022.9842145.

[18] L. Braidotti, S. Bertagna, M. Zanin, D. Padolecchia, A. Marinò, e V. Bucci, «A Methodology for the Hull Forms Design of a Passenger Catamaran for the Venice Lagoon», in *Progress in Marine Science and Technology*, E. Rizzuto e V. Ruggiero, A c. di IOS Press, 2022. doi: 10.3233/PMST220065.

[19] G. Degan, L. Braidotti, D. Bosich, G. Sulligoi, V. Bucci, e A. Marino, «Feasibility Study of a DC Hybrid-Electric Catamaran for River Navigation», in *2021 Sixteenth International Conference on Ecological Vehicles and Renewable Energies (EVER)*, Monte-Carlo, Monaco, mag. 2021, pp. 1–5. doi: 10.1109/EVER52347.2021.9456624.

[20] V. Bucci, A. Marino, D. Bosich, e G. Sulligoi, «The design of a slow-cruising superyacht with zero emission navigation and smart berthing modes», in *2014 Ninth International Conference on Ecological Vehicles and Renewable Energies (EVER)*, Monte-Carlo, mar. 2014, pp. 1–8. doi: 10.1109/EVER.2014.6844094.

[21] E. Wang, D. Guo, e F. Yang, «System design and energetic characterization of a four-wheel-driven series–parallel hybrid electric powertrain for heavy-duty applications», *Energy Convers. Manag.*, vol. 106, pp. 1264–1275, 2015.

[22] L. Braidotti, S. Bertagna, A. Marino, D. Bosich, V. Bucci, e G. Sulligoi, «An Application of Modular Design in the Refitting of a Hybrid-electric Propelled Training Ship», in *2020 AEIT International Annual Conference (AEIT)*, Catania, Italy, set. 2020, pp. 1–6. doi: 10.23919/AEIT50178.2020.9241114.

[23] C. Nasso, U. La Monaca, A. Marinò, S. Bertagna, e V. Bucci, «The strip planking: An eco-friendly solution for the end-of-life of ships», presentato al Technology and Science for the Ships of the Future. Proc. of NAV 2018: 19th Int. Conf. on Ships and Maritime Research, 2018, pp. 444–451.

[24] F. Mauro, U. la Monaca, A. Marinò, e V. Bucci, «A Simulation Model for a Hybrid-Electric Craft in Restricted Waters», *J. Adv. Transp.*, vol. 2020, pp. 1–13, lug. 2020, doi: 10.1155/2020/5340814.