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New approach to the fire risk and firefighting in small ships, as consequence of latest developments in Industry 4.0 for the use of hybrid propulsion.

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Abstract

The hybrid propulsion is a reality now, increasing her diffusion more and more.
The basic concept of Hybrid propulsion is the use of battery packs to store energy and consequentially operate the propulsion system of the ship, in order to have zero emission navigation, especially in areas of environmental interest.
Especially this propulsion is spreading in passenger ships, such as small passenger ferries or yacht, due to the importance of carrying people in a clean way.
This propulsion makes extensive use of Li-Ion or Li-Po batteries, storing high quantities of energy, (MWh) to provide the propulsion, furthermore, the propulsion systems are usually operating with high voltage (660 V or more) to guarantee adequate efficiency at the system.
As well know, the Lithium based batteries offer a good capability storing energy , but there is also a problem of risk of explosion in case of overheating.
The author will investigate in the paper, the consequences of the hybrid propulsion in small ships, considering the case study of small passenger ships , examining the interaction among the industrial solutions adopted for the realization of the hybrid propulsion system[1] and the specific requirements of the marine rules in terms of changes to the project, to increase the safety of the ship,
The paper will examine the aspects of fire protection not only from the point of view of the passive fireprotection but also from the point of view of the containment of problem of overheating, underlining the need of a smart and combined use of manufacturing solutions and remote control systems.
The paper will show how the use of the hybrid propulsion is for sure interesting in terms of environment protection, but at the same time, it requires some important changes to the project approach that cannot be underestimated.

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1. Introduction and state of art

One the most relevant solutions adopted recently for internal water ferries or for coastal ferries is the use of hybrid propulsion [2]. In fact, the use of hybrid propulsion, combining batteries and diesel generators, or simply the use of batteries for the propulsion, allows to obtain an important reduction of the pollution , reduction particularly significative considering that small ferries are usually operating in proximity of areas with population or historical monuments or protected environment, like, for example European lakes and especially Italian lakes in the north. (see Fig.1)

Fig. 1 – Port on Lago Maggiore for public ferries

The typical solution adopted for the hybrid propulsion is related to the use of a pack of batteries to store the energy used for the navigation.
During last years the aspect of hybrid propulsion became more and more important with the participation of world companies like ABB or Siemens cohoperation with engine manifacturers in order to realize a complete integrated set of propulsion to be used in ships, with an extensive study of the solutions published and discussed in several Symposiums about Industry 4.0 an on the net. [3-5]
In the following paragraph will be examined a typical solution used for a small ferry operating on Italian lakes, explaining the main parameters used for sizing of battery packs and the consequences on fireprotection.
In fact the nowadays technology is oriented on the use of Li-Po batteries with the salt batteries still under research , to maximize the capability of energy storage, but is well know the importance of fire protection on board ships, especially passenger ships, and also the dangerous behaviour of Li-Po batteries in presence of overheating and fire. These aspects, combined, lead to a special approach in terms of fire protection, with the adoption of unusual solution that deserve to be studied.

2. General description of case study

The solution that is becoming more and more utilized is the electrical system, [6-14]: using the concept the concept of storing energy in batteries and then using it to move the propellers.

This is a consequence of the evolution of the batteries: from the traditional Lead-acid batteries to the Li-Ion batteries and actually to the Li-Po, with the advantage of a reduction of costs and energy storable: in few years the price of traditional Li-Ion batteries dropped from 500 USD/kWh to 250 USD/kWh and is still decreasing.. At the same time, in the last 10 years the energy density moved from 200 Wh/kg to 270 Wh/kg.

As consequence the paper studies the use the last generation of batteries: the LiPo, or Lithium polymer, the LiPo offers 3 times the charge density of the traditional Ni-Cd and Ni-MH, but also improuve of about 15-20% the density of charge of the traditional Li-Ion.

In this paper, the author will examine the study of a ferry where the propulsion system is realized by the combined use of the traditional part with propellers moved by electrical engines, and diesel generators or battery packs as “prime movers” giving the possibility to have the propellers and services operated by batteries for a limited amount of time.

The main difference in the solution studied is the fact that the propulsion is not entirely provided by the batteries, but the batteries system can be considered as an addendum to traditional diesel electric propulsion system, in this way it is possible to study the possibility to add this system to vessels already with diesel electric propulsion, during a further step of construction.

The main topic of this paper is not the description of the propulsion system adopted, but the consequence in terms of fire protection of the installation on board of a battery package of over 0.8 MWh of capacity, and the possible solution adopted to prevent the risk of explosion in case of fire.

3. Ship description

The project has to deal with different rules: the Registro Italiano Navale “Rules for the classification of Inland waterway” [15], the Directive 2010/36/UE and the Registro Italiano Navale “Rules for the Classification of Ships”. It is important to underline that the Rules for this kind of ferries became more and more severe in last years, so the standards are higher and the project must deal with many parameters. with a consequent change in the geometry of the hull, subdivision, and size of the ship.

The ships considered has the main dimensions in Table 1:

Table 1. Main ship dimensions

L.o.a.	32.5	m
B max	7.15	m
T (full load)	1.9	m
Speed (operational)	12	kn
Pax	220	

The Fig.2 shows the external view of the Ship:

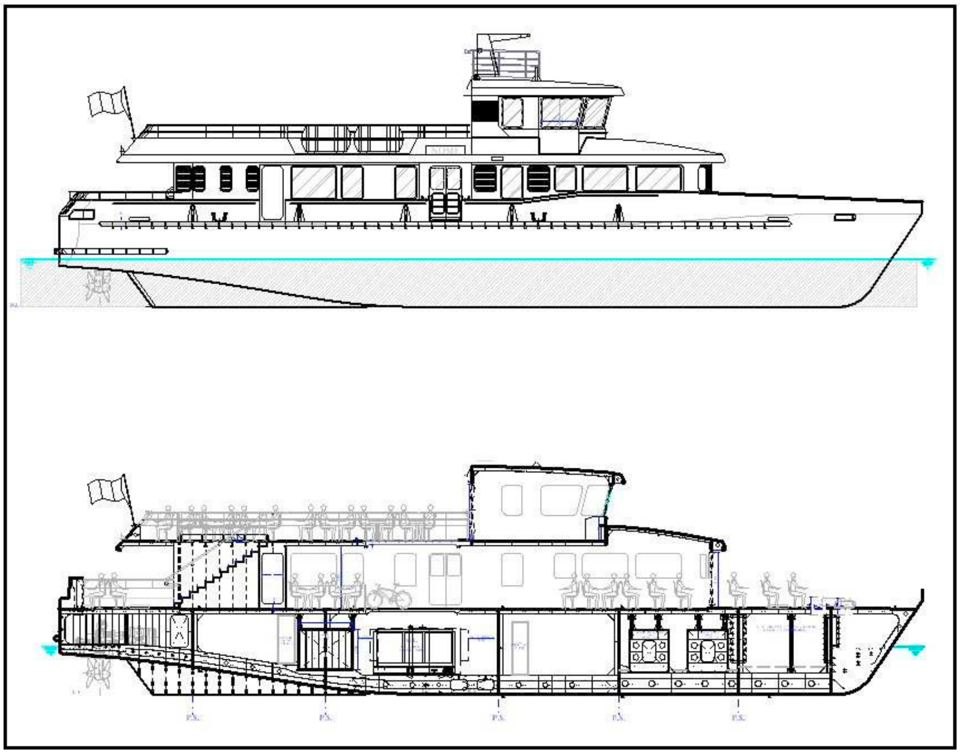

Fig. 2 – External view and longitudinal section

The propulsion/manoeuvrability was chosen trough an azimuthal system, in order to guarantee the maximum capability to operate in closed spaced. This solution also, seemed particularly convenient in addition to the hybrid propulsion because it offered the possibility to guarantee manoeuvring also during the operational phase with batteries, and solve the problem of the use of traditional rudders, with better efficiency in terms of maneuverability at very low speed.

The calculation to determine the range obtainable only with batteries needs an appropriate study of the logistic situation and consequentially this leads to technical choices to adapt the propulsion lay out.

A full electric solution, with all the operativity guaranteed by battery packs only, charged during the night, at the present time appears to be difficult to be realized in Italy: it needs mainly an high electrical capacity, in the home port, to charge batteries and this is difficult to get on the lake stops.

This evaluation had as consequence the choice of an hybrid propulsion, with large part of the operativity ensured by traditional diesel generators to operate the propellers through electric motors and a use of batteries to solve special problems.

4. Battery pack sizing

In this case, as described, the main problem to solve is to guarantee a silent approach to the pier, the stop for embarking/disembarking passengers, and then the departure.

Considering a commercial speed of 12 knots, the solution is to adopt this profile: 5 min of navigation with batteries, starting at 0.2 nm from pier at reduced speed, 15 mins of stop at the pier, 5 min of navigation to reach a distance of 0.2 nm from the pier.

The calculation scheme to be adopted in this situation is:

- 5 mins approach, Power absorbed (ship plants + propulsion) = 138 kW, that means 11.5 kWh request to battery pack

- 15 mins embarking/disembarking, Power absorbed (from Electrical consumptions, Air conditioning on, in summer day) = 70 kW, that means 17.5 kWh request to battery pack
- 5 mins depart, Power absorbed (ship plants + propulsion) = 138 kW, that means 11.5 kWh request to battery pack

All this creates a request of 11.5 + 17.5 + 11.5 = 40.5 kWh.

In consideration of a navigation time between the 2 stops of 25 mins, with 15 mins at cruising, operating by the Diesel generators, it is required an AC/DC converter of at least 160 kW to rechange, in 15 mins, the batteries with the 40 kWh used.

At this point, it is possible to estimate the components and the weight of the system and the batteries, considering an average usage of batteries at 80% of their nominal capacity, and considering also the need to guarantee the 10 years life of battery packs, avoiding the complete cycle charge-discharge.

Assuming the following graph, in Fig. 3, showing the behavior of battery during charging, as parameter to avoid a too short life of batteries, it was possible define the size of battery pack:

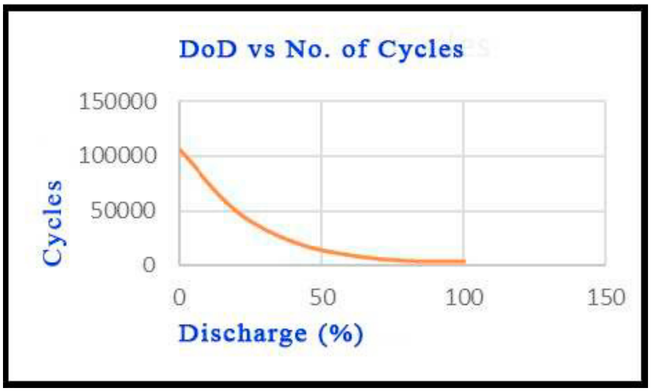

Figure 3: Cycles of charge/discharge vs % of discharge

The consequence of the use of above graph is that the capacity of battery pack must be decided to avoid a discharge at less than 70-80% of capacity, in order to avoid a shortening of life of batteries.
Considering the 40 kWh used must correspond to less than 15% of the total capacity of battery pack, the battery pack must be at least of 270 kWh of capacity.
Main data of package :
Batteries = ab. 1000 kg
Converter AC/DC = ab. 550 kg
Transformer /liquid cooled) = ab. 900 kg
Switchboards: ab. 200 kg.
For a total of 2650 kg, see Tab II for details.

Table 2. Main data of electrical system

Power of electrical engines.	2x250	kW
Type of engines	Asyncronous	
Voltage	660/50	V/Hz
Type of batteries (modular)	Li-Po	

The batteries are air cooled with an heat exchanger air/water, and are subdivided in modules, for an easy maintenance and capability to operate.

The systems drive the EP (engines for propulsion) trough conversion from DC (direct current) to AC (alternate current) , and AFE (active front end) to manage the system, the position of AFE is studied on order to avoid that a damage to their compartment can immobilize the ship. This system is obviously related to an advanced system of monitoring, custom tailored, but descending from a state of art research in the field of monitoring system[16].

4. Fire protection analysis and consequences of use of Li-Po batteries according to Industry solutions.

As studied by several authors [17] the main problem of Li based batteries, in case of fire, is their tendency to overheat and explode. The main problem ia that, also if there is no direct flame exposition, the batteries remain "active" and a temperature rise in one cell can create explosion, involving other cells with extremely dangerous consequences.

In the case of hybrid cars, for example [18] , several Fire departments are adopting the technique of submerging the car , after a fire, in a poll filled with water, for several hours, to be sure to cool down the battery pack and avoid any risk, before proceeding to the moving of car in other storage area.

This situation leads to the study of a different lay out of the ship, more difficult to realize from the construction and systems, but more safe, as will be showed.

In fact the simplest solutions seems to be the one to install the battery close to GG.EE. to reduce the length of electrical cables.

But this solution could be extremely dangerous, because the Engine Room, where the diesel generators are located, are usually effected by high temperatures.

The compartment distribution of the ship has been studied to obtain several advantages simultaneously.

In the 32 m "Lake ferries" the following arrangement, in Figure 4, shows how it has been possible to divide all the components in order to respect the criteria of the Inland water class, to have, always propulsion, for emergency:

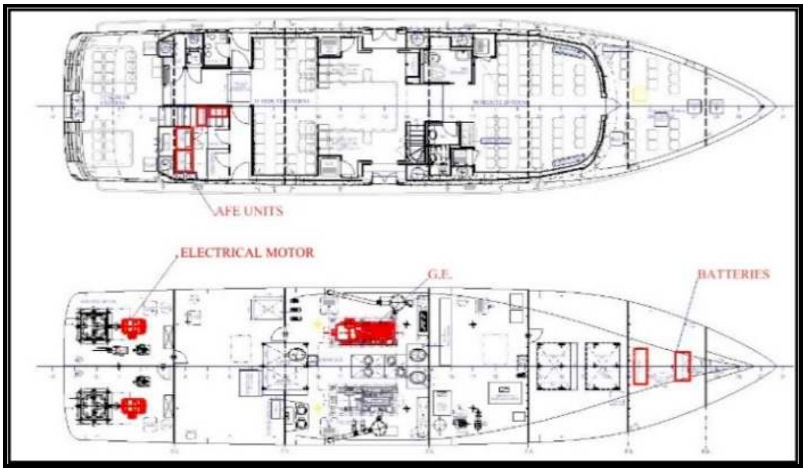

Fig. 4: Arrangement

The arrangement shows the following aspects:

1 Longitudinal bulkhead to divide each azimuthal propeller; in case of damage of one compartment, the 2nd unit is working.

2 In case of flooding of the GG.EE. room, emergency propulsion is operated by batteries; considering the short distance from ashore, the ship can navigate 20-30 mins at 2 knots and be in proximity of a shore and be safe in a short period of time.

3 All the AFE units and switchboard for power management are located above the main deck, in a position not relevant in case of damage.

4 In case of damage in the battery compartment, the propulsion is ensured by the GG.EE.

This distribution offered another advantage, the most important , in terms of fires safety: the batteries are stored in a

separate compartment, far from engines.
The relatively small size of compartment make possible , in case of fire, to fill the compartment with water , using the bilge/fire pumps, in less than 10 minutes, preventing completely the risk of overheating the batteries.
At the same time, the relatively small floodable volume of the compartment makes possible to maintain in case of flooding a sufficient stability, respecting the severe limits required by the Rules adopted, see Fig. 5.
It is important to underline that the situation with a compartment filled with water has significant differences from the situation with a compartment damaged, in terms of load and GMT reduction, this consequences oblige the naval architect to a careful evaluation of damage stability criteria.

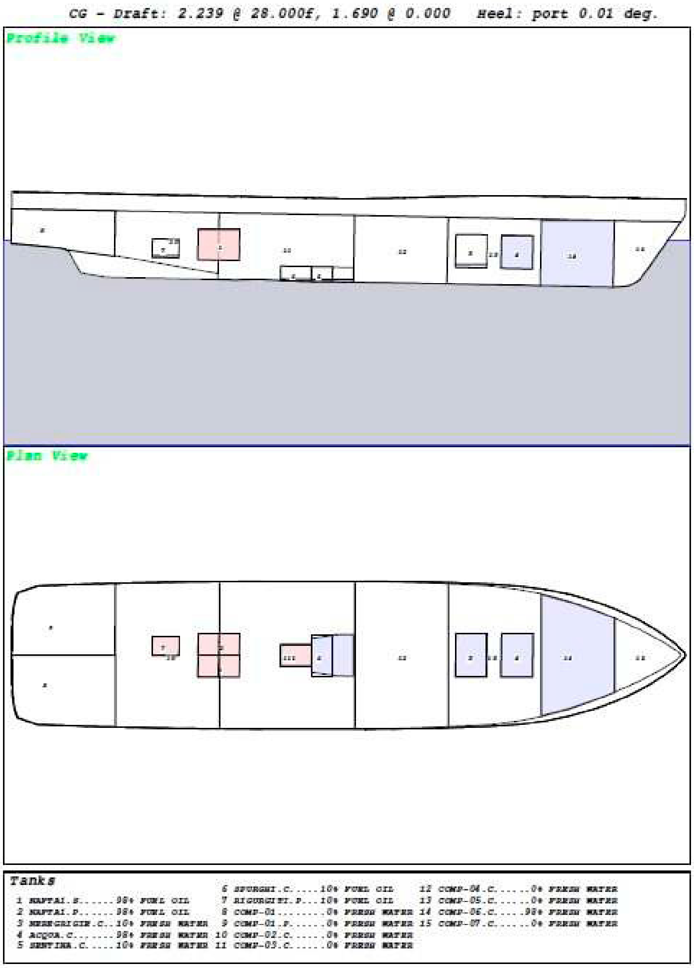

Fig. 5 – Stability with battery compartment filled

5. Conclusions

The study describes the risk connected to the use of Li-Po batteries on small ships, and offers a possible solution to reduce the risk of explosion related to the use of these batteries, by the a modification of the bilge /firefighting system. The solution studied, with the adoption of E/pumps of increased characteristics, like Mass flow rate of 45 mc/h and the possibility for the 2 pumps of operating simultaneously, makes possible fil the compartment in about 15 min. It is important to underline that the fore position of the compartment, with a “V” shape makes also possible that after only 5-6 mins of work of the 2 EE.PP. the level of water inside is high enough to basically cover and cool down more than the 80 % of the batteries ensuring a significant reduction of risk of explosion. The further developments of the Industry should foreseen an increased protection for the batteries and systems, studying also the possibility to use different batteries, like the Sodium-Ion batteries [19], less sensitive to the high temperatures. It is important to underline then the need of a strict cohoperation between the field of the Naval Architecture and ship construction and the Chemical Industry to increase the standards of fire protection**.** It is opinion of the author that the extensive use of batteries and electrical devices for the propulsion could receive a great benefit from an intensive blended approach of the systems of monitoring and control, with the installation on board of a complete intergrade system for monitoring the temperature of batteries and the energy exchanges, using thermocameras and sensors, reporting any dangerous situation to the crew, in order to prevent any possible dangerous situations.

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