Research on the application of new energy pure battery powered ships in the Yangtze River

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Abstract. The Yangtze River, as the busiest inland river in the world, has implemented more stringent ship pollution prevention regulations in recent years. The new energy pure battery powered ship has the characteristics of “zero emission”, low vibration and low noise. Therefore, it has quickly become a hot spot for the green development of the Yangtze River inland shipping industry. This paper analyses the application of key technologies of new energy pure battery powered ships, and summarizes the technical standards, economic investment, management regulations and other issues faced in the actual promotion process, and puts forward related suggestions.

1. Introduction
The Yangtze River runs through 11 provinces and cities across China. The economic status and role of the Yangtze River shipping industry are becoming increasingly prominent. In 2018, the annual cargo volume of the Yangtze River trunk line reached 2.69 billion tons, continuing to rank first in the world's inland rivers. As the most busy inland waterway shipping area in the world, the Yangtze River Basin is also facing the prominent environmental pollution caused by shipping. With the optimization and adjustment of national energy structure and the strengthening of ecological environment protection, China has promulgated and implemented a series of strict regulations on ship emissions in recent years, which promotes the green development of shipping in the Yangtze River, and the green ship technology to reduce ship emissions has become the focus of extensive attention in the shipping industry. Among all kinds of green ship technologies, new energy pure battery powered ship (hereinafter referred to as "pure battery powered ship") uses electric energy to completely replace traditional fossil fuels. During navigation, it can achieve "zero emission" of NOX, SOX, CO2, PM, etc. It has the characteristics of low vibration and low noise, and can effectively prevent and control ship air pollution, optimize shipping energy structure, and improve coastal urban environment. It has become one of the hot spots in the development of green ship technology in the Yangtze River shipping industry.

2. Development of pure battery powered ships
In recent years, China's pure battery powered ships have shown a trend of accelerated development, and now more than 100 pure battery powered ships have been built and handheld orders. Pure battery powered boats are widely used, including recreational fishing boats, scenic tourist boats, passenger liners, ferries, official patrol boats, bulk carriers, container ships, engineering ships, etc.
Figure 1. 2000-ton pure battery powered self-unloading coal carrier and Pure battery powered tourist ship

With the increase of ship tonnage for pure battery power applications, the capacity of lithium batteries is also increasing. The battery capacity of the existing pure battery powered dump coal carrier reaches 2.4 MWh, and the battery capacity of the Yangtze River pure battery powered cruise ship which will be built in 2019 reaches 7.5 MWh.

| Ship Type                  | Specification | Ship Length | Ship Width | Battery Capacity (MWh) |
|----------------------------|---------------|-------------|------------|------------------------|
| Tourist ship               | 40 seats      | 30.0        | 6.0        | 0.40                   |
| Yacht                      | 54 seats      | 21.3        | 5.5        | 0.48                   |
| Official patrol boat       | 14 seats      | 18.2        | 3.7        | 0.60                   |
| Channel boat               | 8 seats       | 18.9        | 4.2        | 1.30                   |
| Dry bulk carrier           | 500 tons      | 38.5        | 7.5        | 1.80                   |
| Cruise ship                | 300 seats     | 53.2        | 13.4       | 2.28                   |
| Self-unloading coal carrier| 2000 tons     | 66.0        | 13.8       | 2.40                   |
| Scenic spot cruise ship    | 1300 seats    | 100.0       | 16.2       | 7.50                   |

3. Application of key technologies for pure battery powered ship

The key technologies of pure battery powered ship mainly include large capacity power battery networking and control, battery management system (BMS), energy management system, large capacity battery charging technology, etc. Power battery is the key of pure battery powered ship. There are three kinds of power battery schemes used in ships: all lithium battery schemes, all supercapacitor schemes, lithium battery + supercapacitor schemes. In the early pure battery powered ships, lithium battery + supercapacitor schemes were used more often. Supercapacitors are used to make up for the weaknesses of early lithium battery, to solve the problems of large load changes and frequent changes of working conditions in ship power system, to improve the stability and rapid response ability of ship power grid[1]. With the improvement of lithium battery performance and the maturity of DC networking technology, all lithium battery schemes have gradually replaced lithium battery + supercapacitor schemes as the mainstream. The lithium batteries used in China's existing pure battery powered ships are all lithium iron phosphate batteries, and only lithium iron phosphate batteries are certified by CCS. The main reason is to consider the safety and economy of large capacity lithium batteries, such as lithium iron phosphate batteries with higher temperature tolerance, more charge and discharge cycles, and lower raw material prices. Fewer ships adopt all the supercapacitor schemes, which are mainly used for ferry crossing the Yangtze River. Routes are usually only a few kilometres away and more than 20 rounds a day. The supercapacitor has the advantages of fast charging speed, long service life and more than 500,000 charge and discharge cycles. Ferry using supercapacitor can better adapt to frequent charging and discharging, compared with lithium battery scheme can significantly reduce the battery capacity configuration.
Table 2. Performance comparison of different lithium batteries

| Battery type            | Main material          | Energy density /mAh∙g<sup>1</sup> | Voltage /V | Number of cycles | Transition metal | Environmental protection | Safety performance | Temperature/℃ |
|-------------------------|------------------------|-----------------------------------|------------|------------------|------------------|------------------------|-------------------|---------------|
| lithium iron phosphate  | LiFePO<sub>4</sub>     | 170                               | 3.2~3.7    | > 2000           | Very abundant    | Non-toxic              | Good              | −20~75        |
| lithium manganate       | LiMnO<sub>4</sub>      | 148                               | 3.8~3.9    | > 500            | Abundant         | Non-toxic              | Better            | −20~50        |
| lithium cobalt oxide    | LiMnO<sub>2</sub>      | 286                               | 3.4~4.3    | Poor             | Abundant         | Non-toxic              | Better            | −20~50        |
| lithium nickelate       | LiCoO<sub>2</sub>      | 274                               | 3.6        | > 300            | Poor             | Cobalt is toxic        | Poor              | −20~55        |
| lithium titanate        | LiNiO<sub>2</sub>      | 274                               | 2.5~4.1    | Poor             | Abundant         | Nickel is toxic        | Poor              | −20~55        |
| lithium nickelcobalt    | LiNiCoMnO<sub>2</sub>  | 278                               | 3.0~4.5    | Poor             | Abundant         | Cobalt and nickel are toxic | Better          | −20~55        |
| titanium                | LiTiO<sub>2</sub>      | 175                               | 1.5~2.8    | > 800            | Poor             | Non-toxic              | Excellent         | −40~60        |

BMS, as an indispensable part of power battery system, can not only realize over-current protection, over-charge and over-discharge protection and over-temperature protection to ensure the safety of batteries, but also realize the operation of batteries in the most efficient and energy-saving situation[2]. The application of BMS in ships is a new and interdisciplinary field. Although BMS is relatively mature in the application of new energy pure battery powered vehicles, the battery capacity required by ships is much larger than that of vehicles, and the requirements of ship operating environment are more stringent, so higher requirements are put forward for BMS.

Ship onshore power supply system is the key to the energy supply of battery powered ships. In recent years, the Ministry of Transportation of China (MOT), the National Development and Reform Commission, the State Energy Administration and the State Grid Corporation have jointly promoted the construction of cold ironing. By the end of 2018, China’s inland ports had built more than 2,000 cold ironing facilities, including more than 1,000 along the Yangtze River. After more than 10 years of popularization and application, the technology of ship shore power supply system is basically mature. Most of the inland ports of the Yangtze River are low-voltage power supply schemes. The rated voltage of the ship power station is 380V (50Hz) or 220V (50Hz). Some ports in the lower reaches of the Yangtze River take into account the power supply of ships of different types and tonnages, and can provide power systems of different voltage levels and frequencies. The rated voltage of low-voltage ship power stations can be 440V (60Hz), 400V (50Hz), 380V (50Hz), 220V (50Hz), and the voltage level of high-voltage ship power stations can be 11KV/6.6KV (60Hz) or 6KV (50Hz).

4. Difficulties in the application and promotion of pure battery powered ships

In recent years, the application of pure battery powered ship has made rapid progress, but some difficulties still need to be overcome in the large-scale application of the Yangtze River Basin.

The first is economic problem. Firstly is the high cost of construction. According to the existing pure battery powered ships, the cost of pure battery-powered ships has increased more than two times compared with diesel-powered ships. Secondly, the usage cost of power battery is high. At present, the life of marine power batteries is generally within 10 years, but the life of ships exceeds 30 years. Therefore, batteries need to be replaced during the whole life cycle of ships, resulting in high cost of battery use. Finally, the operational economic advantages are not obvious. The price of electric power includes two parts: basic price and service charge. At present, service charge is higher (higher than basic price in some areas). The operational economic advantage of pure battery-powered ships is not obvious compared with diesel oil[3].

The second is the technical bottleneck. Firstly, lithium batteries used in ships have large capacity, and there are many types and scale series of ships. Therefore, the configuration of battery capacity is diversified. These factors make it difficult to achieve standardized equipments such as power battery
networking control system and BMS, while personalized configurations put forward higher requirements for control accuracy and safety reliability. The service life, energy density and charging speed of lithium batteries for ships also need to be further improved. Secondly, the application of ship power supply system also faces some technical challenges: in the upper reaches of the Yangtze River, the water level difference between dry season and flood season is more than 30 meters in a year, and the length of wharf ramp changes more than 100 meters. Therefore, the security, stability and convenience of power supply facilities are facing technical challenges. The number of ships berthed in some ports is large, and the cross-ship power supply technology needs to be solved urgently. It is also difficult for ships berthing in service areas in water to provide power supply. In addition, the existing cold ironing facilities do not fully take into account the needs of pure battery powered ships, and there are problems such as insufficient capacity, different electrical systems, and equipment compatibility, etc.

Figure 2. Different types of charging interfaces

The third is the management problem. Firstly, the development of ship type is limited. Under the current technological and economic conditions, pure battery powered passenger ships are undoubtedly more suitable for application. However, due to safety considerations, MOT has forbidden major renovations (including power systems) for passenger ships[4]. Therefore, the transformation of existing large number of diesel-powered passenger ships into pure battery power is limited. The construction of new passenger ships requires strict capacity approval[5], so the development of new pure battery-powered passenger ships is also affected. Secondly, the responsibility division system is not clear. When charging a ship, there is no clear division of responsibilities among port, ship, service provider and supervisor, and there is no safety responsibility sharing mechanism and insurance system. The pure battery power boat has higher requirements for the crew's electricity safety management, and the relevant training and qualification requirements are not clear. In addition, there are still some problems such as the difficulty of obtaining the qualification of selling electricity, the inconsistency of different port cost settlement modes, and the inconvenience of ship owner's payment.

5. Applicability of Pure battery powered ships

There are more than 90,000 inland waterway transport vessels in the Yangtze River. Among them, dry bulk carriers are the most important type, accounting for more than 70% in number and 80% in capacity. Therefore, we take dry bulk carriers as an example for analysis.

According to the average host power and typical route distance statistics of inland river dry bulk ships, combined with market research and existing experience, we calculated the investment increase of pure battery power compared with diesel power for ships of different tonnage. According to the mainstream configuration and routes of ships in the shipping market (more than 500 tons), even with lower configuration, the pure battery powered ships increase investment by more than two times higher than that of diesel powered ships, the battery power system increases investment by more than 8 times compared with the diesel power system, and the investment increases more as the ship’s tonnage increases.
Based on the operation of existing pure battery powered cargo ships, we conducted surveys on shipping companies, marine power battery plants, shore power supply service providers, ship design units, etc. It is expected that the price of power batteries will drop 30% in the near future. Under this circumstance, the following conclusions can be drawn by taking into account the application conditions of technology, economic competitiveness and other factors:

1. Pure battery powered cargo ships do not have economic advantages in the short term. The cost savings of a pure battery powered ship is mainly because the cost of electricity is lower than the cost of fuel. High investment cannot be made up by saving fuel costs alone.

2. The conditions for the suitable application of pure battery powered cargo ships in the near future: in the case of exemption of electricity service fees, the ship's tonnage is less than 1000 tons and the route distance are less than 200 kilometres. Considering factors such as economic development, high environmental protection requirements, strong policy support, small ship tonnage, and short route distance, the areas that are more suitable for preferentially promoting pure battery powered ships are the Yangtze River Delta water network and the major reservoir areas.

3. Scenic tourist ships deserve special attention. Pure battery powered scenic tourist ships can achieve tremendous social and environmental benefits and improve passenger’s comfort experience. It is the development direction encouraged by the Chinese government, such as the Pearl River Government's 40% subsidy for construction investment (battery and power system part). At the same time, the tourist passenger ships in the scenic area have higher returns and strong price tolerance, and now they have become the focus of the development of pure battery powered boats.

4. The mode of using the replaceable container modular battery for the inland small container liner is also optimistic. The power battery is designed in the form of a standard container, which can be quickly replaced while loading and unloading at the port. This method can reduce the waiting time of the ship charging; the power station can be slowly charged to extend the battery life; and the power station can be charged at night, and the electricity price discount is used to reduce the cost. The Yangtze River Delta water network area is now ready to build this pure battery-powered inland small container liners.

6. Conclusion
With the implementation of stricter new emission standards for ships, pure battery-powered ships will become one of the important directions for the development of inland ships in the Yangtze River. To promote the rapid and healthy development of pure battery-powered ships, the followings are recommended:

Firstly, pure battery power vessels increase investment, and need to further reduce battery cost. Small river shipping companies in the Yangtze River account for the majority, and it is difficult for them to invest and finance. It is necessary to explore new modes of development cooperation. For example, if an industrial alliance is formed, the whole industry chain development model will be adopted, and all
parties will participate and cooperate in advance. In view of the high initial investment of the battery, battery rental can be adopted at this stage.

Secondly, it’s necessary to study how to improve the energy density and service life of marine power batteries, improve the performance, safety and reliability of BMS and other control management systems, and optimize the fast charging technology. It’s urgent to solve technical problems such as power supply with large water level drop, power supply with anchorage in the river centre, power supply across ships.

Thirdly, it is necessary to speed up the improvement of the standard system for the application of key technical equipment such as pure battery powered ship and ship power supply system. We can adopt the cooperation of "government, industry, University and research", make full use of the existing achievements and accelerate the transformation, and promote it to provide strong support for the formulation of industry standards.

Finally, the development of pure battery powered vessels can’t be separated from policy support in the early stage. Enterprises can jointly apply for government support policies and measures, such as financial subsidies, tax and fee reductions, preferential shore electricity fees, and financing support, etc.

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