Demand Analysis and Application Discussion of Wireless Shore Power Technology for New Energy Ships

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Abstract. The ship sector has also ushered in a new wave of pure electrification in recent years. However, behind ship electrification, the difficulty of supplying shore power to new energy ships directly caused by traditional ship shore power has attracted extensive attention in the sector. In this context, wireless charging technology can theoretically address the limitations of the traditional shore power system and create a shore power system that is more suitable for the field of new energy ships. This paper will discuss the demand and technological path of wireless shore power technology in the field of new energy ships and envisage the key technologies to be broken through.

Keywords: wireless, shore power, new energy, ships.

1. Introduction

Similar to the automotive sector, the ship sector has also ushered in a new wave of pure electrification in recent years. Taking the "electricity substitution" proposed in China's energy development policy to promote the development of the transportation sector as an example, the Energy Development Strategy Action Plan (2014-2020) [1] (GBF [2014] No. 31), Guiding Opinions on Promoting Electricity Substitution [2] (FGNY [2016] No. 1054) and some other guidance documents have clarified the requirements for promoting the development and application of electric energy in vehicles and ships. However, behind the pure electrification of the ship itself, the difficulty of charging the marine power battery pack caused by the limitation of the shore power system has affected the wide application of new energy ship technology such as pure battery ships. This is mainly due to two reasons: a) the marine power battery packs generally have a large capacity. Considering the commercial reduction of charging time, the existing ship shore power equipment requires too many cable connections, which greatly increases the material and labor costs of charging new energy ships; and b) for the current main types of pure battery ships, such as cruise ships and passenger ships, they have the need to charge the battery in a short time at the port. The traditional shore power charging method requires a long overall charging cycle due to the cable connection operation. Therefore, this solution cannot meet the objective needs of the relevant markets.

In this context, the wireless shore power system for ships may become an ideal fast shore power solution. As the wireless charging technology can realize complete circuit isolation on the power supply side and the load side, the circuits on both sides can be packaged independently. Therefore, the plugging and unplugging of cables during the shore power charging will be completely avoided, which will greatly reduce the preparation time for charging operation and make quick response to the flexible power supply needs of new energy ships. In addition, the risk of interface friction and leakage caused by wired connections will be eliminated, which improves the safety of field operations and reduces the cost of equipment maintenance.

2. Demand of Wireless Shore Power Technology for New Energy Ships

Combining the generation concept of fast shore power, this part analyzes the demand of wireless shore power technology for new energy ships from the aspects of technological demand and market potential.

2.1 Analysis of technological demand

At present, several major factors restricting the large-scale application of new energy ships equipped with large-capacity power battery packs, including pure battery-powered ships, include:

(1) Low energy density and low endurance of battery system;

(2) High initial investment of battery system, resulting in significantly higher cost of new energy ships than that of conventional ships;

(3) Incomplete charging system, complicated charging process, and high labor intensity; and

(4) Further improvement required for the safety of the battery system.

Except for the last one, the other three problems can be solved or partially solved by the fast charging system. For example, with regard to the problem of ship endurance, if fast charging or replenishment can be achieved, it will enable the ship to be quickly charged during the docking, thereby improving the ship's endurance, effectively reducing the capacity of the onboard battery system, and thus effectively reducing the cost of the whole system. It is of great significance to cruise ships and ferries, which are currently the main application objects of battery ships. Suppose a cruise ship has 8 voyages per day and that each voyage lasts for 30 minutes and requires 20 minutes for berthing. If the ship cannot be charged during the docking, the battery capacity must be configured based on the total power consumed during the 8 voyages. If the battery can be charged during the docking, and the charging time is considered as 15 minutes during each docking, the total charging time will be 105 minutes during 7 dockings. Even if the charging current is calculated as 0.5C, the battery can be fully charged 0.875 times. Therefore, the capacity of the onboard battery can be reduced by 47%, thereby greatly reducing the cost of the battery system and increasing the freight space.

Therefore, technically speaking, pure battery-powered ships have a significant demand for fast charging equipment represented by the wireless shore power system. It can greatly expand the application range of pure battery-powered ships and relieve users of concerns.

2.2 Market analysis

2.2.1 Pure battery-powered ships and hybrid ships with energy storage systems.

In recent years, the application of pure battery-powered ships has been basically recognized in China and is currently in the initial stage of rapid development. The main application types of ships include inland river (lake) cruise ships, law enforcement vessels, ferries, port tugs, port administration ships, etc.

According to the statistical yearbook of the National Bureau of Statistics of China, the number of civil motor vessels was 131,700 [3] in 2017 and 125,700 [4] in 2018, with a year-on-year decrease of 4.56%. According to the ship registration data from CCS, the net tonnage of inland lake ships in China was 219 million tons in 2017 and 195 million tons in 2018. Affected by the decline in the total number of civil motor vessels, the number of inland lake ships showed a slight decline trend [5].

According to the prediction of Gaogong Industry Institute Co., Ltd. (GGII), the current range of marine lithium battery power is 1.2 ~ 1.35 kWh/ton [5]. If the unit power of each ship is calculated as 1.3 kWh, the total number of civil ships drops by an average of 4.9% each year in the next few years, and the average net tonnage per unit ship is calculated as 1,780 tons/ship, the lithium battery market for electric ships will be 35.41 GWh (approximately 15,000 ships) by 2025, accounting for 34.7% of the total shipments of electric vehicle batteries in China in 2018. If every 5 ships need one set of charging systems by average, the demand for ship charging systems will be about 3,000 sets by 2025, and the total market capacity should be at the 5-billion level.

2.2.2 Port shore power system.

Technically speaking, fast shore power charging equipment represented by the wireless shore power system is mainly used to transmit electrical energy to ships. The transmitted electrical energy can not only charge the onboard energy storage system, but also provide energy for daily loads after the ship docks in the port. Therefore, it will have a wide range of application prospects in the port shore power construction that is vigorously promoted in China. From the perspective of its applications in foreign countries, the wireless port shore power devices [6] have also been applied, especially in the shore power wharves used by large-capacity ships.

From the perspective of shore power industry layout in China, the Shore Power Layout Plan of Ports [7] issued by the Ministry of Transport in July 2017 has orderly promoted the construction of port shore power facilities, optimized the energy consumption structure, reduced the emission of air pollutants by ships at the port, and promoted the supply-side structural reform in transportation and the development of green transportation.

The overall goal of the plan is to realize that more than 50% of the specialized berths for container ships, ro-ro passenger ships, mail liners, passenger ships above 3,000 tons, and dry bulk carriers above 50,000 tons have the capability to supply shore power to ships in major ports and ports within the ship emission control zone across China. At the same time, ports with a large demand for shore power and relatively good basic conditions are encouraged to strive for 100% coverage of shore power at berths.

By the end of 2020, a total of 493 specialized berths capable of supplying shore power to ships will be deployed in major ports and ports within the ship emission control zone across China, including 366 coastal berths and 127 inland river berths. By the berth types, there are 277 specialized berths for container ships, 77 specialized berths for ro-ro passenger ships, 9 specialized berths for mail liners, 29 specialized berths for passenger ships above 3,000 tons, and 101 specialized berths for dry bulk carriers above 50,000 tons, respectively. If each berth is provided with 2 sets of shore power systems at the above wharves, considering the further construction of shore power systems and the further expansion of the inland river market, it is expected that there will be a potential market replacement demand of nearly one thousand sets of systems. The market capacity is expected to be at 1-billion level.

3. Development of Wireless Shore Power Technology for New Energy Ships

3.1 Overview and classification of wireless power transmission (WPT) technology

In view of the development and application of wireless shore power technology for new energy ships, it is necessary to sort out the main technical approaches of current WPT technology and choose a reasonable technical path for shore-to-ship power based upon the technical status and the objective demands of the marine platform.

The initial research on WPT technology began in the 1880s and the first person to carry out relevant experiments was Nikola Tesla, an American scientist, who succeeded in lighting a distant incandescent lamp in 1899 by means of 50 kHz alternating current. In 1968, Peter E. Glaser [8], an American aeronautical engineer, proposed the idea of transmitting and supplementing power to the ground from solar satellites using microwaves, that is, establishing "Solar Power Satellite" on the geosynchronous orbit. In the ensuing 1977-1980, a proof-of-concept study was jointly organized by the United States Department of Energy and the National Aeronautics and Space Administration, demonstrating the feasibility of the program. Since the 21st century, breakthroughs have been made in the research of WPT technology. In 2007, André Kurs [9] et al. from MIT realized WPT over a moderate distance based on the principle of magnetic coupling resonance by lighting up a 60W bulb within a distance of more than 2m, with the transmission efficiency up to about 40%. In recent years, researchers from all over the world have conducted in-depth research on WPT and made major headway theoretically and practically.

According to relatively mature technical routes summarized in the sector, the common WPT technology mainly involves three types, i.e. magnetic inductive coupling (MIC), microwave power transmission (MPT), and magnetic coupling resonant (MCR) [10].

For MIC-WPT, alternating current is introduced to the primary side of the transformer and induced current is generated at the secondary side of the transformer on the basis of fundamentals of loose coupling transformer, so as to achieve WPT [5].

With respect to MPT, its success is mainly attributable to the following theory. The microwave power generator converts the DC power into microwave energy, which is focused by the transmitting antenna and transmitted to the receiving antenna with high efficiency. Then, the microwave energy is converted into DC power and supplied to the back-end load after being rectified by rectenna and filtered. However, the power transmission under this technology involves atmospheric loss, rain attenuation, and shelter loss, etc [11].

The MCR-WPT, also taking the electromagnetic field as the medium, is applied to achieve WPT through coupling resonance between the transmitting coil and the receiving coil in line with the theory of near-field strong coupling [12]. As the transmitting coil and the receiving coil with the same resonant frequency are used to transfer power, objects with the frequency different from the design one are largely unaffected. Compared with MIC wireless charging technology, the MCR-WPT combines the characteristics of high transmission efficiency, long transmission distance, and good tolerance for offset. The comparison of the three technical routes is shown in Table 1.

Table 1. Comparison of technical routes for WPT technology

Technical route	Description of principle	Applicable scenario	Disadvantages
MIC	Electromagnetic induction and inductive coupling of loose coupling transformer	Transmission scenarios of mm-level, with a small offset between the transmitter and receiver	Short transmission distance, poor tolerance for offset, and high requirements for application scenarios
MPT	Microwave transmission	Long-distance transmission scenarios, with lenient requirements for transmission and reception location	Low transmission efficiency and vulnerable to energy loss by many factors
MCR	Electromagnetic induction and coil coupling resonance	Transmission scenarios of m-level, with a moderate offset allowed between the transmitter and receiver	Small technology accumulation in the early stage and low power level

In the case of selection of technical routes for wireless charging technology in the context of shore-to-ship power, more consideration will be given to transmission efficiency, tolerance for offset, and transmission distance. Transmission efficiency, first of all, is the key to efficient power supply in a short period of time, which conforms to the design concept of fast shore power supply equipment. Due to the special environment where a ship is located, the shore side and the ship side may always have relative displacement to some extent during charging, so the tolerance for offset should also be included in the key consideration scope of the wireless shore-to-ship power system. In terms of transmission distance, the increase of effective transmission distance allows a larger effective operating range for charging, offering more options for charging docking schemes. To sum up, the paper believes that the wireless shore power technology for new energy ships should be developed based on the path of MCR wireless charging technology.

3.2 Key technologies of WPT

With new energy ships equipped with a power battery pack as the application objects, the ship- and shore-side systems are designed on the basis of MCR wireless charging technology. The network structure can be simplified as shown in Fig. 1.

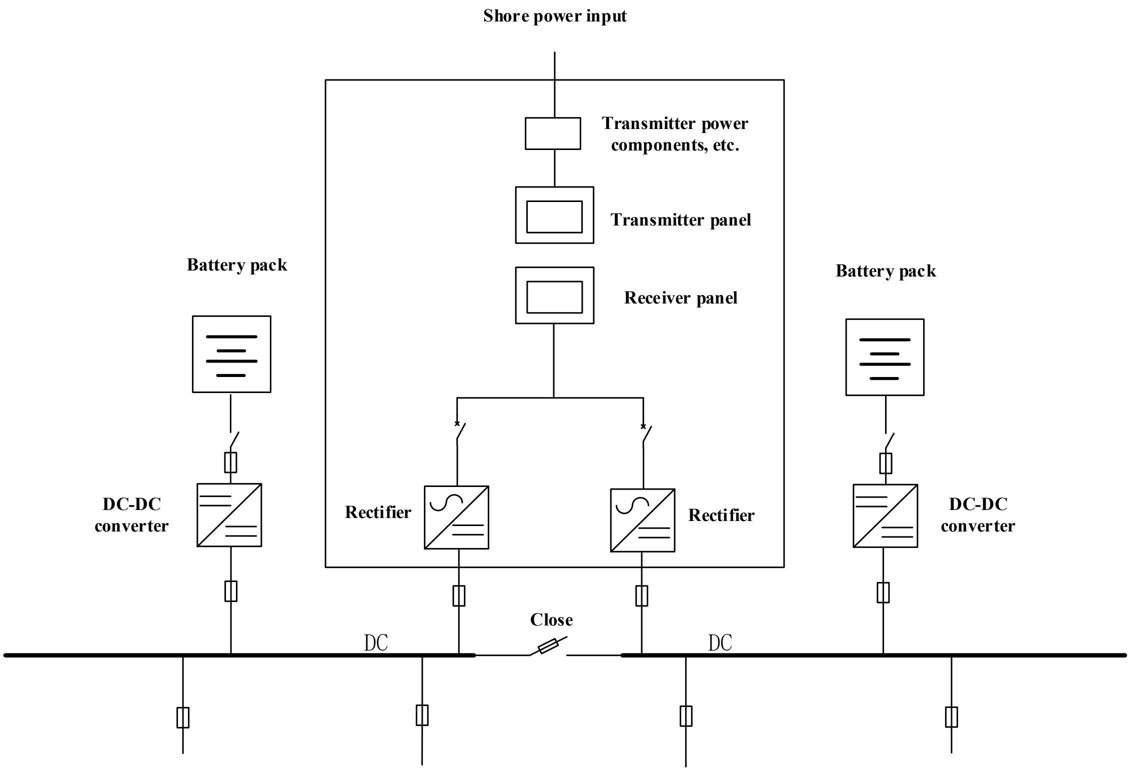

Figure 1. Schematic diagram of wireless shore power structure for new energy ships

During the hardware design of the wireless shore power system, in addition to achieving the basic function of energy transmission, it is also necessary to make adaptive adjustments depending on the application environment of new energy ships. First, priority should be given to high-power energy transmission for the wireless shore power system, to meet the demand of power supply for new energy ships in a short period of time. Meanwhile, lithium iron phosphate or ternary lithium battery pack is mostly adopted as marine energy storage devices. If the wireless charging system is used to charge the power battery pack directly, the charging strategy of the charging power regulation device of the system needs to be adjusted according to the charging characteristics of different battery packs. Assuming that the system is of the network structure as shown in Fig. 1 and supplies power for a DC bus, the corresponding changes should be made according to parameters such as bus voltage. Charging power adjustment can be considered to be completed by the ship's own battery management system. To achieve the function of charging power adjustment, part of the system should be designed to transmit the state of charge of the battery on the ship side to the shore side in real time for closed-loop control and common wireless communication modes should be considered for the form of communication. Guided by the design thinking above, a basic principle topology of the charging system is shown in Fig. 2.

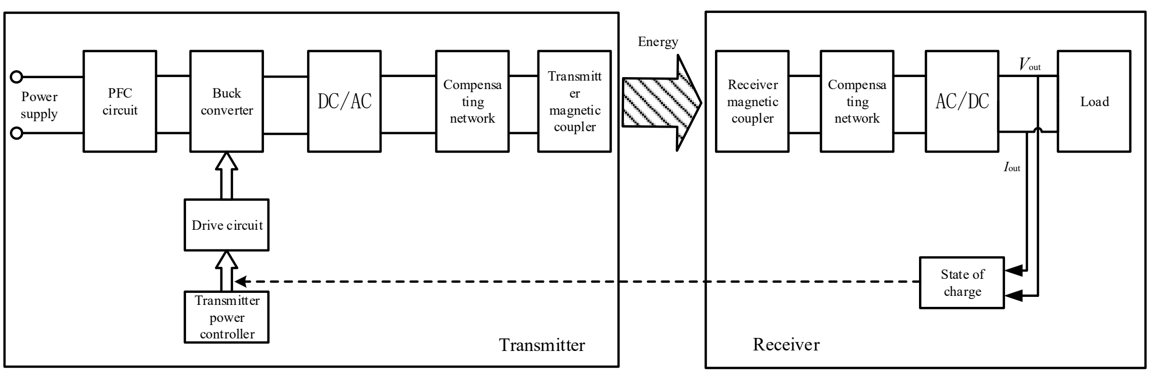

Figure 2. Principle diagram of wireless shore power for new energy ships

In light of demand and the current situation of technology development, the paper believes that the breakthrough point for designing the wireless shore power system for new energy ships should still focus on high power. Considering the development of hardware and control strategy, the key technologies should specifically incorporate the design technologies of magnetic coupling coil and power transmitting device.

The magnetic coupling coil serves as the carrier for the transfer of wireless charging energy. The structure design of its hardware has a direct bearing on power transmission capacity and efficiency, and tolerance for offset, so the magnetic coupling mechanism should be designed to accomplish the transmission power of MW level. During technology research, a single coil shall be taken as the research object for high power optimization, to determine the maximum transmission power of a single coil. In the course, parametric modeling, electromagnetic field simulation analysis, and thermal stability analysis of the magnetic coupling device are carried out by virtue of three-dimensional finite element software, and iterative optimization is conducted according to the simulation results and physical testing.

The design technology of the power transmitting device is mainly used for the parallel design of multiple sets of power components so as to adapt to the magnetic coupling and expand the capacity of the output power of the entire system. Specifically, the design covers not only the parallel design of multiple coils but also that of the inverter unit, focusing on power-sharing of multiple power components and coils, the circular current after multiple inverters are of parallel connection, and the driving signal synchronization.

4. Summary

For the purpose of the paper, the technology and market demand of wireless shore power system for new energy ships are analyzed, the basic technical path of wireless charging technology sorted out, and the key technologies during the research of shore power technology for new energy ships preliminarily envisaged, striving to provide useful guidance for the research and application of wireless shore power technology.

With regard to the application of wireless shore power technology later, similar to the automotive field, relevant regulations for wireless shore power in the ship sector may be introduced in the future. From generation to application, the wireless shore-to-ship power system has to go through its only way to gradually mature. Its application value and market acceptance remain to be time-tested.

Acknowledgments

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