

New Energy Ship Power System

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Abstract: The performance of ship propulsion systems is related to the economy, safety, and reliability of ship operation. The traditional mechanical propulsion system has problems such as high noise, small speed range, flexibility, and poor economy. The development of new propulsion systems has gradually become a research hotspot in the shipping industry. Hybrid power and new energy have always been research hotspots in green ship power. Hybrid shaft with motor technology can optimize system power distribution, thereby reducing system losses and improving system efficiency. The composite energy composed of batteries, supercapacitors, fuel cells, as well as natural energy sources such as solar and wind energy, matched with energy storage devices and direct current grid technology, can achieve zero emission targets and recover and store braking energy. Based on the theme of green and efficient, analyze the power requirements of different ship types, comprehensively consider technical conditions such as energy supply, ship power distribution, drive control, and propellers, and summarize three configuration schemes for green ship power. Focus on introducing energy storage technology, DC networking technology, and shaft mounted machine frequency converter technology and the technical difficulties in the schemes. Based on the power requirements of different ship types, taking into account technical conditions such as energy supply, ship power distribution, drive control, and propulsion, three green power configuration schemes for ships are proposed. Energy storage technology, DC networking technology, and shaft motor frequency converter technology are introduced, and the technical difficulties in the solutions are summarized. Combined with actual ship demonstrations, the technical characteristics of green ship propulsion related scientific research achievements and engineering project schemes are presented.

Keywords: Green ships, Energy storage technology, DC networking, Electric propulsion system.

1. Introduction

1.1. Research background and significance

The development status of ship electric propulsion technology. As people's awareness of environmental protection continues to increase, international conventions and environmental regulations are becoming increasingly strict. The use of electric thrusters can greatly reduce fuel dependence, improve the working environment, and reduce exhaust emissions. The development of ship electric propulsion systems has gone through several stages: the first electric experimental ship appeared in China in the early 19th century, but due to numerous technical barriers, it was not fully promoted. During World War II, due to significant technological breakthroughs, power propulsion technology was gradually applied to various special vessels such as warships, icebreakers, and dredgers. Since the 1980s, significant breakthroughs have been made in the frequency conversion technology of high-power AC motors in China, which has promoted the development of ship power systems in the country. At present, with the rapid development of society and economy in our country, technological progress is advancing rapidly, especially in electronic technology. With the gradual development of power electronics, integrated circuits, automatic control, AC motors and other technologies, electrically driven ships are gradually being realized. Although early DC drive systems had the advantages of simplicity and excellent performance, their structure was complex, maintenance was difficult, and they were constrained by factors such as work location, centrifugal force, and the voltage resistance of rectifier boards, which resulted in certain limitations in the power and rotational speed of DC motors. In recent years, due to technological advancements, especially the development of power electronics technology,

the development of electric propulsion has gradually become more diversified. For example, the use of small-sized and high-efficiency AC permanent magnet drive systems has been widely adopted. The PMW variable frequency speed regulation system uses AC asynchronous motors, which have smooth control torque and high power factor. Due to the integration, high frequency, full control, and digitization of modern power electronics technology in devices, circuits, and control technology, it has been increasingly widely used in shipborne electric propulsion.

1.2. Current development status at home and abroad

Since the first electric propulsion ship used for experiments in 1838[1], electric propulsion technology has a history of over a hundred years. A large amount of research has been conducted on the electric propulsion technology of ships both domestically and internationally. Russia and Germany have explored this topic in the early stages, from relying on batteries to provide electricity on small passenger ships and adjusting the excitation voltage with thyristors to achieve speed regulation of DC motors, to its application on large ships. DC speed regulation systems have the characteristics of small power and easy regulation, but the brushes and commutators on DC motors inevitably cause problems such as sparks and mechanical friction. The development and use of high-power power electronic devices have made breakthrough progress in the speed regulation technology of AC motors, reducing the need for direct current speed regulation systems compared to DC speed regulation systems. Due to mechanical wear and maintenance costs, around the 1990s, The concept of integrated power systems for ships emerged. In 1990, the United States established the Integrated Power Systems Project Office, which shifted its technical goals from researching ship electric propulsion to researching

fully electric ships, including power generation and distribution, electric propulsion, electric energy scheduling, high-power weapon equipment, and system monitoring. In order to develop integrated power propulsion systems, the US Navy launched the "Maritime Revolution" program, SC-21 program, and the DDG-1000 ship of the DD (X) project in 1986[2]. In addition, both the US nuclear powered aircraft carrier CVN21 and the conventional powered aircraft carrier CVX-13A project used IPS. The British Navy proposed the concept of electric propulsion ships in 1995, and the UK's The Type 45 destroyer has changed from the originally planned diesel engine combined mechanical propulsion type to an electric propulsion type powered by a combination of diesel and gas engine units, The first Type 45 destroyer was delivered to the British Navy in 2008, and the first new generation aircraft carrier CVF delivered to the British Navy in 2012 also used IPS. The ELENA project in France is mainly used for the basic research of IPS for frigates. France and Italy jointly launched the European Aquitaine class frigate joint project (FREMM) in 2005, which is a continuation of the ELENA project in France. At the end of 2007, the United States proposed the next generation integrated power system (NGIPS), which plans to adopt medium voltage alternating current (MVAC) and high-frequency alternating current (HFAC) in the short term, and develop medium voltage direct current (MVDC) power system in the long term. Due to its small noise, light weight, less space occupation, Advantages such as relaxed working conditions, MVDC has become a hot research topic in current ship electric propulsion systems, but there are also problems that need to be solved, such as arc extinguishing difficulties, power regulation, grounding strategies, and lack of guarantees. China's domestic electric propulsion ships started relatively late and have few fully independent property rights, but have developed rapidly: China Shipbuilding Group 712 Research Institute has completed the localization and development of all equipment for the medium voltage 10MW class ship comprehensive electric propulsion system, which has been widely used in civil ships such as scientific research ships, cable laying ships, cruise ships, and deep-sea fishing boats; In 2017, China Shipbuilding Industry Corporation 711 Research Institute delivered the first domestically developed DC networked electric propulsion vessel with independent intellectual property rights, the "Zhenyang Qidu 3011", which saved about 15% fuel and reduced weight by about 40%; In 2021, the "Sun Yat sen University" fully electric propulsion ship, developed and designed by the 708 Research Institute of China Shipbuilding Industry Corporation, was officially delivered. It is the largest displacement and most comprehensive performance marine comprehensive scientific research internship ship in China; The "Zhifei" ship, launched in 2022, is an intelligent navigation container merchant ship independently developed by China. It adopts the electric propulsion system and autonomous navigation system developed by China Shipbuilding Industry Corporation 704 Research Institute. For the first time, it uses a diesel asynchronous generator set to provide electrical energy through AFE rectification, greatly reducing fuel consumption.

2. Green Power Solutions for Ships

2.1. Solution for pure electric propulsion system

The pure electric solution is designed for underwater

submersibles, deep-sea mobile workstations, and other ship types that do not rely on air and have high power density requirements, as well as for ships working in high environmental standards such as inland rivers and lakes. It uses technologies such as energy storage batteries, DC power distribution, and shaftless wheel flange thrusters. The structural diagram of the scheme is shown in Fig. 1.

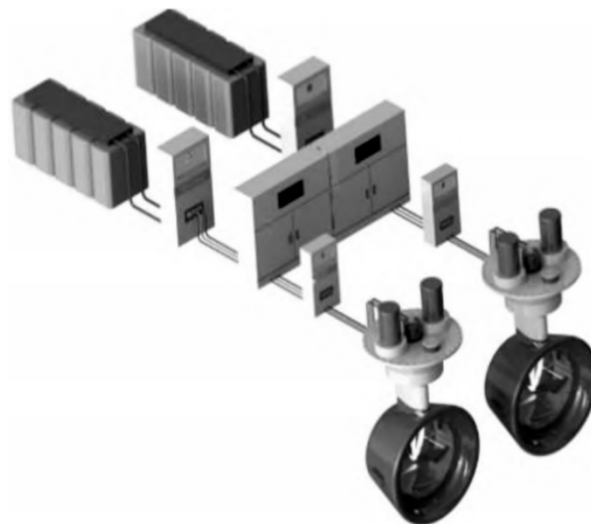


Figure 1. Electrical propulsion system

In Fig. 1, a new type of lithium iron phosphate or ternary lithium battery pack or supercapacitor is used as the energy source, which is distributed through a DC bus and driven by a frequency converter to propel the ship with a shaftless wheel rim thruster. The shaftless wheel rim thruster [3] is shown in Fig. 2.

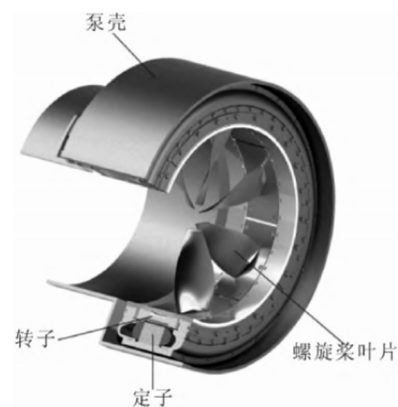


Figure 2. Shaftless wheel rim thruster

In Fig. 2, the stator of the motor is integrated into the conduit, and the rotor and propeller are integrated into one. The propeller is changed from axial connection to radial connection. This thruster has the advantages of high efficiency, low vibration and noise, small size, light weight, safety and reliability, and flexible layout.

2.2. Solution for Composite Energy Storage Electric Propulsion System

The composite energy storage electric propulsion system scheme is designed for small and medium-sized ships with high emission requirements, such as ferries, inland river boats, and special function ships. It comprehensively utilizes

composite energy, new energy storage devices, DC networking, and pod propulsion technologies. The scheme structure is shown in Fig. 3.

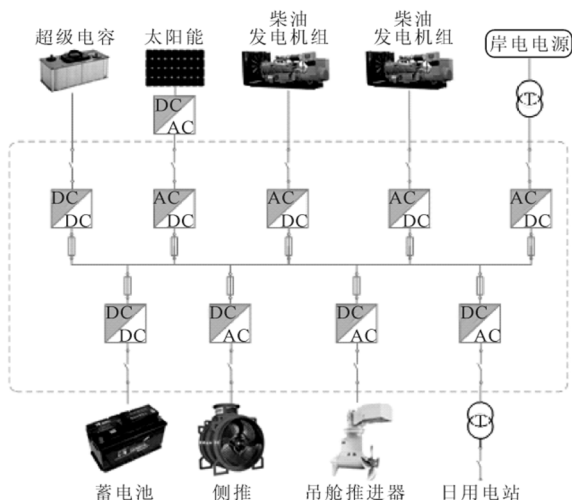


Figure 3. Scheme of Composite Energy Storage Electric Propulsion System

In Fig. 3, the power supply system is composed of a diesel generator set, a battery pack (or supercapacitor), and new energy, with the battery pack (or supercapacitor) forming the energy storage device. DC networking technology combined with energy storage technology can allocate and store electrical energy reasonably and efficiently, fully utilizing the advantages of various energy sources. The main thruster adopts a pod propulsion device, which can optimize the ship type and power system layout, improve the maneuverability and reliability of the ship. This scheme has the advantages of energy conservation and emission reduction, improved redundancy, convenient maintenance and operation, and high comfort.

2.3. Diesel electric hybrid propulsion system scheme

The diesel electric hybrid propulsion system scheme is designed for ship types with high power and multiple operating conditions, such as engineering ships and scientific research ships. It comprehensively adopts shaft motor technology, AC power distribution technology, and direct axis propulsion technology. The scheme structure is shown in Figure 2.4. According to the installation position of the shaft belt motor, there are two schemes for this scheme: coaxial shaft belt motor and gear shaft belt motor. In Figure 2.4, the shaft belt motor can operate as both a generator and an electric motor. During power generation operation, the unstable alternating current generated is rectified and inverted to be converted into constant voltage and frequency alternating current for supply to the power grid, which can achieve stable power supply within a large range of host speed changes. When operating as an electric motor, electrical energy can be obtained from the power station to enhance propulsion power.

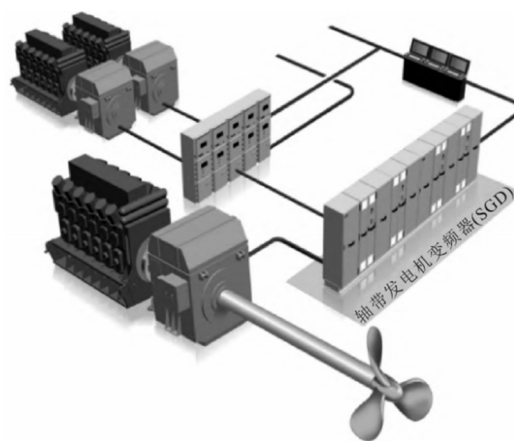


Figure 4. New diesel electric hybrid propulsion scheme

3. Key Technologies in Green Power Solutions

3.1. Energy storage technology

Among various combinations of energy storage devices, lithium batteries (or supercapacitors) are the most widely used. According to the current product performance of lithium batteries/supercapacitors, energy storage systems can have both good dynamic and steady-state characteristics. However, energy storage devices still face problems such as low energy storage density, short service life, and high initial investment, which limit their widespread application on ships[4].

3.2. Modern Axial Motor Technology

Modern shaft belt motor systems can be upgraded to traditional shaft belt motor systems through shaft belt motor frequency converters. The main functions of shaft belt motor frequency converters are to control motors, quickly and flexibly connect to the grid, and provide electrical energy to marine loads. It mainly consists of a control winding side frequency converter, a grid side filter, a grid side frequency converter, an input reactor, an output reactor, a control system, and related grid connected switches [5], as shown in Fig. 5.

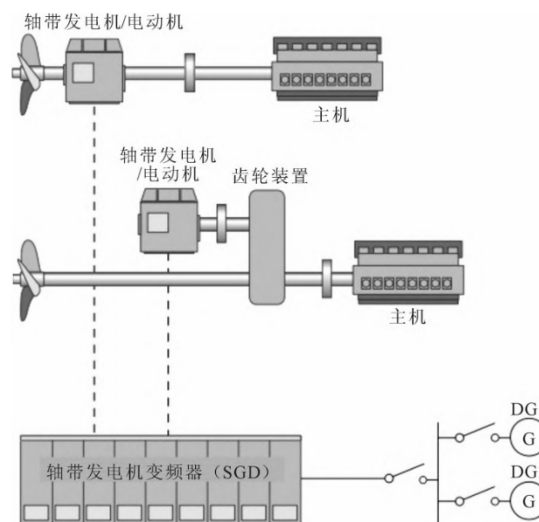


Figure 5. Installation Method of Modern Axial Motor

In 2009, China broke through the bottleneck of PTI/PTO control and integration technology and successfully applied the independently developed PTI/PTO diesel electric hybrid

power system to the Guangdong Hainan Railway Ferry No. 3 and No. 4 ships, ushering in the era of independent research and development of TI/PTO diesel electric hybrid power systems in China. Afterwards, projects such as the 5000t marine monitoring ship, Zhejiang Ocean University fishery resource survey ship, and Shanghai International Port (Group) Co., Ltd. Fuxing Shipping Company 2200kW+740kW diesel electric hybrid tugboat successively applied diesel electric hybrid power systems, expanding the application of diesel electric hybrid power systems in ship types[6]. In modern axle belt motor systems, motors can be used as both generators and electric motors[7]. There are three operating modes, as shown in Figure 3.2. Modern shaft belt motor technology can optimize the working conditions of the host, save energy and reduce emissions through shaft belt frequency converters [8]; When the main engine fails, it can provide power to the ship through the shaft belt motor, increase power redundancy, and improve the safety of ship navigation; Providing multiple operating modes increases the flexibility of ship operation [9]; Capable of connecting shore power of different voltage levels to the ship's power grid[10].

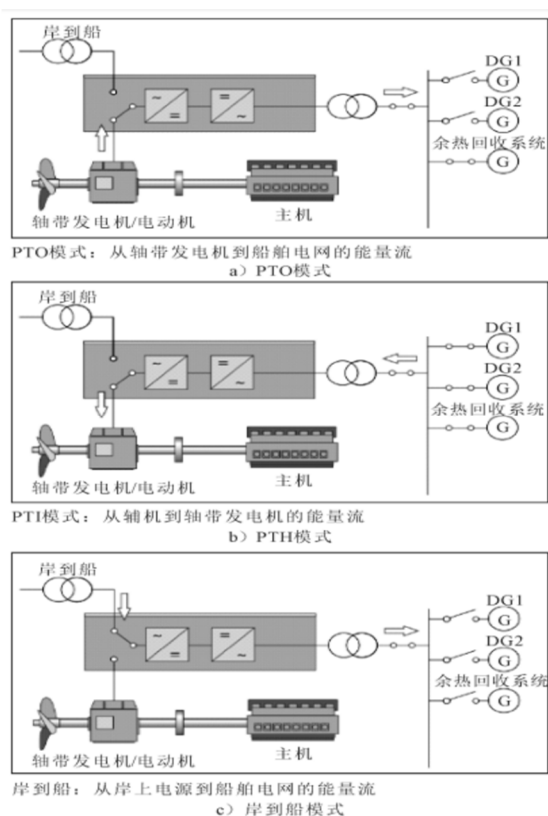


Figure 6. Operating Mode of Modern Axial Motor System

4. Conclusion

Since the 21st century, China's shipbuilding industry has

made significant progress in the technology and automation of power equipment, and many devices have also reached the world's advanced level by introducing and digesting advanced foreign technologies. With the continuous improvement of our country's technological level, the automation level of ships is constantly improving, and ship automation technology will also achieve new developments. This article analyzes the development trend of electric propulsion technology from the aspects of electric propulsion components, functions of each component, power characteristics, and shortcomings in practical application. The application of electric drive technology in ship power systems and the increasing maturity of electronic power, automatic control and other technologies have laid a solid foundation for its widespread use in shipborne power systems.

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