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Application of AC Electric Propulsion and Control Technology in Marine Ships

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Abstract: **Marine electric propulsion has the characteristics of good economy and good system maneuverability. In recent years, more and more small and medium-sized civil ships have gradually adopted AC propulsion technology. With the increase of marine electronic equipment, in the application of electric propulsion technology, more and more marine electronic equipment lead to serious power load exceeding the standard. How to make better use of AC electric propulsion system to achieve dynamic balance of power load is a serious problem. This paper describes the latest progress in the application of marine AC power supply system from the aspects of power electronic devices, frequency converters, permanent magnet motors and AC power control in the development of ship AC power supply system are discussed.**

Keywords: Electric propulsion, Power Electronics, Inverter, Permanent magnet motor

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1. Introduction

The use of an AC motor as a main power or auxiliary power to propel a ship to sail is called AC electric propulsion [1]. AC power propulsion can be used as a power device or a joint power device for surface ships, underwater vehicles, or as a side thrust device for positioning or moving offshore platforms.

Electric propulsion has good economy. Multiple medium speed diesel engines on a ship are used for power generation [2]. The number of generators can be selected according to the power load, so that the unit can always operate in the efficient working area to achieve the maximum economy [3]. Compared with ships of the same power, the fuel consumption of electric propulsion is about 10% less than that of internal combustion engine propulsion. In addition, the electric propulsion system has good maneuverability. After the electric propulsion system is adopted, the operation and control are convenient, the starting acceleration is good, the braking is fast, the switching between the forward and reverse speeds is fast, the speed of the propulsion motor is easy to adjust, and the constant torque can be provided under various forward and reverse speeds [4-7]. Therefore, the best working characteristics can be obtained, so that the ship can achieve excellent maneuverability.

In the mid-to-late 1980s, it was apt to adopt AC electric propulsion on ships. The power supply grid could be either AC or DC grid [8]. Both AC and DC grid electric energy were converted by inverters to the required AC supply propulsion motors. Generators and propulsion motors are AC motors [9-11]. The ship is navigated by the frequency converter controlling the speed of the AC propulsion motor or the constant speed AC motor driving the variable pitch propeller. The key to the realization of AC power propulsion is power electronic devices, high-power high-voltage frequency conversion technology, AC motors and their control technologies.

2. Power Electronics

Power electronic devices are the basis for modern AC speed control. From the 1950s to the present, power electronic devices have made amazing progress. Development of a semi-controlled thyristor as a fully-controlled thyristor; development of voltage control from current control; development of high-frequency power switching elements from low-frequency power switching elements; development of modular components and integrated components from monolithic components; For high-power components. Overall, power electronic devices are developing in three directions: high power, high frequency, and easy drive. The power electronic device originally applied in the AC speed control system is a semi-controlled device thyristor SCR， The current fully-controlled devices have mainly high-power bipolar thyristors. BJT(Bipolar Junction Transi Stor), Turn off thyristors GTO(Gate Turn Thyristor), High Speed Switch Devices Power Field Effect Transistors(Power MOSFET), Insulated gate bipolar transistor IGBT(Isolated-Gate Bipolar Transistor) Wait. The devices used in existing electric propulsion systems are SCR and GTO and will be replaced by IGBT. GTO and SCR appeared almost simultaneously, and SCR was first widely used. Due to the complexity of the GTO drive and its late entry into practical use, its application technology has matured, and it has grown to larger capacity, higher operating frequency, and to current-controlled types. Mitsubishi Corporation of Japan has introduced 6kV, 6kA water-cooled GTO devices, domestic 2.5kV, 2kA.

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IGBT is a composite device that combines the features of both BJT and MOSFET. Because of its size advantages and the ability to provide sufficient rated voltage and current, it becomes a mature device with extremely high application value. It is now replacing the power thyristor and becomes a small and medium capacity. The main components of the power conversion device are widely used in AC frequency conversion, switching power supply and other equipment. Germany has introduced single-tube 3.3kV and 1.2kA IGBT. The voltage level of devices constructed with IGBT is rapidly increasing. It is feasible to construct a 40 MW frequency converter using IGBT. This rated power limit can meet the needs of the ship's electric propulsion. In the study of permanent magnet propulsion motor prototypes in the United Kingdom, inverters based on IGBT technology were used.

In addition, the integrated gate commutated thyristor IGCT and MOS off thyristor MTO are the two most recent monolithic power electronic devices. They have similar characteristics as the MCT (MOS control thyristor), but have higher rated voltage and rated current, and can be hard-switched. Manufacture is relatively simple and inexpensive. There is no similarity between IGCT and IGBT. Its rated value is 4.5kV and 3kA. A 100MVA power converter using IGCT has been manufactured. The MTO is still under development and is expected to have ratings of 10kV and 2kA.

The power IC（Power Integrated Circuit—PLC）It integrates power electronic devices and driving circuits, protection circuits, partial detection circuits, and interface circuits with microcomputers on a single chip. It has the advantages of high reliability, small size, versatility, and ease of use. Due to the technical problems of insulation and heat dissipation, it is still at a low voltage and low power level. With the rapid development of science and technology, the integrated circuit will be widely used.

3. Frequency converter

AC drive motor control or variable speed drive mainly depends on variable frequency conversion（Variable Voltage Variable Frequency, Also called VVVF）Speed control technology, which is composed of power electronic components of the static transformer inverter. According to the structure of the inverter transformer circuit of static type, it is divided into two categories: indirect variable voltage inverter and direct variable voltage inverter.

Indirect variable voltage frequency converter (referred to as indirect frequency converter) is a type of rectifier that is composed of high-power switching elements to convert AC power into DC power, and an inverter composed of high-power switching elements converts DC power into AC power. The frequency converter, its principle is shown as in Fig. 1. As there is a DC link in the middle, it is also called a variable-voltage inverter with an intermediate DC link, or an AC-DC-AC frequency converter.

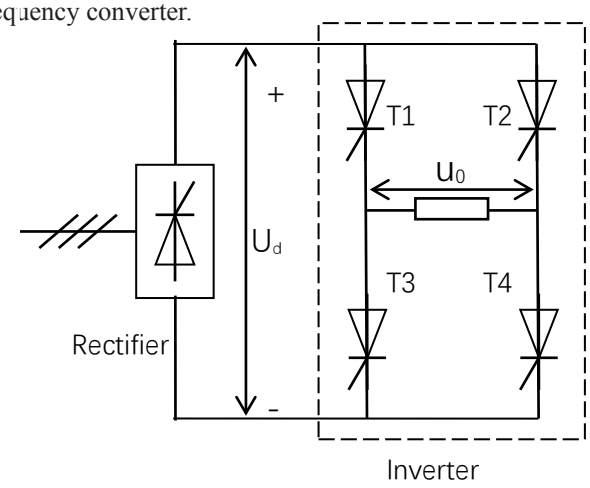

Figure 1. Indirect frequency converter principle

Direct voltage transformer (abbreviated as direct frequency converter), there is no DC link in the middle, the positive rectifier and counter rectifier work in turn, and directly converts constant voltage constant frequency (CVCF) AC power into variable voltage variable frequency (VVVF) AC power supply. Therefore, it is called direct frequency converter or AC-AC frequency converter, the principle of which is shown in Figure 2. Also known as a cycloconverter or cycloconverter (Cycloconverter), In the multi-phase direct drive, each phase consists of two anti-parallel thyristor (SCR, GTO) rectifiers, the positive and the negative. The positive and negative rectifiers are

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controlled by the control system. They are in rectifying and inverting states according to a certain cycle, so that the output voltage of the variable frequency inverter is obtained on the load. Its amplitude is determined by the control angle of each group of rectifiers and the output voltage. The frequency is determined by the switching frequency of

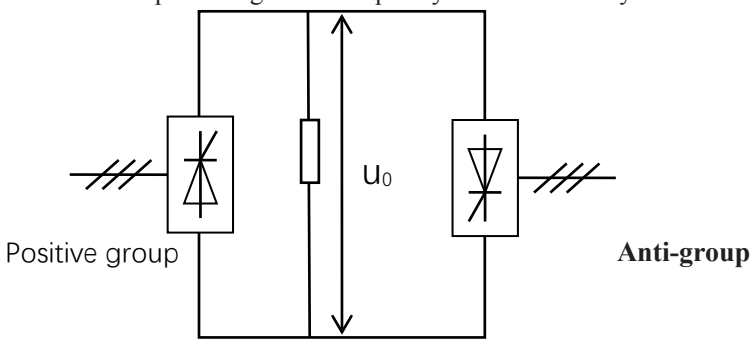

Figure 2. Principle of direct drive

the two sets of rectifiers.

ABB Finland has developed two types of AC drive products for ship propulsion: One is a DC converter. (Cyclo),Synchronous motor with control power of 3-20 MW, output suitable for low speed direct coupling with propeller（0—±80—200r/min）,This technology has been used in outboard pod drives. The second is the pulse width modulation frequency changer（Sami PWM）,Squirrel-cage induction motor with 0.5-8.0 MW control power, outputting high-speed gears that need to reduce gear speed（0—±900—1800r/min）.Both drives use advanced AC speed control technology, and their control performance meets or even exceeds the conventional DC control system. Drive the fixed-distance propeller to work, and the maximum torque can be obtained both in forward and reverse directions from zero speed to full speed. This direct frequency converter is adopted by the “Fantasy” series cruise ship of the Miami Carnival Shipping Line.

4. Permanent magnet motor

Compared with conventional motors, permanent magnet motors have high power density and high torque density. The propulsion system consists of low noise, high efficiency, and good maintenance. There are many different types of permanent magnet synchronous motors with power ranging from a few hundred watts to several gigawatts for ship propulsion. The permanent magnet synchronous motor tends to be used in ship electric propulsion systems.

High current densities in strong magnets and stator windings are two key technologies for the development of high-power, high-torque high-performance permanent magnet motors. The way to obtain a strong magnetic field is to use a high magnetic energy product rare earth permanent magnet material (such as neodymium iron boron NaFeB, samarium cobalt SmCo), neodymium iron boron cheaper than samarium cobalt, and mechanical strength, but its poor temperature performance, corrosion resistance Weak ability. The way to increase the current density in the stator windings is to use an efficient, integrated coolant system to dissipate heat quickly.

The direction and intensity of the magnetic field of the permanent magnet motor are fixed, and the way to change the rotational speed and torque of the motor is to control the stator winding current frequency and strength. The controller controlling the speed and torque must relate the instantaneous rotor position to the reference waveform and issue a current command to the power switch. The key is to determine the stator phase current applied time, which is determined by the rotor position, so Hall sensors, optical encoders or solvers can be used to automatically detect the rotor position and speed. Although the controller makes the permanent magnet motor complicated, in the range from the standstill to the maximum rotational speed, the control of starting, stopping, and matching the load with the motor becomes simple, and the low loss can be accurately adjusted.

5. AC motor control technology

After the invention of the vector control technology in the 70’s, the AC motor control technology only achieved a breakthrough. Vector control is a high-performance asynchronous motor control method. It controls the torque current and the excitation current of the motor based on the dynamic mathematical model of the motor, and has similar control performance as the DC motor. The main difference between vector control and scalar control is that the former controls the magnitude and phase of the current, while the latter only controls the magnitude of the current. After more than 20 years of development, vector control technology has been widely used in asynchronous motor frequency control. However, this technique requires correct estimation of the motor parameters, and

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improving the accuracy of parameter estimation is still a subject of research. From a theoretical point of view, the vector control principle of the AC motor based on the accurate understanding of the magnetic field of the motor is but the practical application of this technology depends on the technology and cooperation of the drive controller and the power electronics converter. AC motor control and direct torque control, decoupling control and other AC speed control technology.

Vector control can also be used in synchronous motor variable-frequency speed control systems. Because the synchronous motor's magnetic field is established with the rotor current and the stator current, the magnetic field of the asynchronous motor is only established by the stator current. When the vector control is used, the synchronous motor and the asynchronous motor are different.

The microprocessor-based digital control is the development direction of the AC motor controller. Its advantages are: (1) the controller has a high degree of standardization of the hardware circuit, low cost, and high reliability; (2) can be replaced or modified as needed Control software, great flexibility; (3) Eliminating the impact of temperature drift in the simulation control, good stability; (4) The ability of information storage, monitoring, fault diagnosis, and hierarchical control is continuously improving; (5) With the CPU speed and With the increase of storage capacity, various new and more complex control strategies can be realized. The problems faced are: (1) quantized errors generated during analog digitization, affecting control accuracy and smoothness; (2) discretization of the sampling period, affecting the real-time nature of the control, and even causing instability of the closed-loop system; (3) parameter values , amplitude limiting values, etc. have been written into the program and should not be adjusted at any time.

6. Conclusion

The AC propulsion system consisting of AC propulsion motors or permanent magnet AC propulsion motors is used in both the British Navy's comprehensive all-electric propulsion strategy program and the U.S. Navy's integrated power system program. In the integrated electric propulsion systems that the British, American, Japanese, Dutch, German, and other countries are striving to research and develop, in addition to the key technologies such as permanent magnet motors and high-frequency-switching power electronic converters, there are regional power distribution related to electric propulsion. And module design technology. With the development of key technologies such as high-power power electronics, inverters, permanent magnet motors and AC motor control, more advanced AC power propulsion systems will also be produced.

References

[1] Hansen J F, Wendt F., History and state of the art in commercial electric ship propulsion, integrated power systems, and future trends[J]. Proceedings of the IEEE, 2015, 103(12): 2229-2242.
[2] Hu L, Tang L, Wen P, et al., Research on Fault Location Algorithm with Traveling Wave Based on Determinant of Matrix A[J]. Journal of Applied Science and Engineering Innovation, 2018, 5(3): 73-79.
[3] Apsley J M, Gonzalez-Villasenor A, Barnes M, et al., Propulsion drive models for full electric marine propulsion systems[J]. IEEE Transactions on Industry Applications, 2009, 45(2): 676-684.
[4] Kim S, Jeon H., Comparative Analysis on AC and DC Distribution Systems for Electric Propulsion Ship[J]. Journal of Marine Science and Engineering, 2022, 10(5): 559.
[5] Hardan F, Norman R, Tricoli P., Control and operation of a ship AC/DC microgrid under transient propulsion and manoeuvring load conditions[J]. International Journal of Electrical Power & Energy Systems, 2022
[6] Xu P, Na N., Study on antibacterial properties of cellulose acetate seawater desalination reverse-osmosis membrane with graphene oxide[J]. Journal of Coastal Research, 2020, 105(SI): 246-251.
[7] Thantirige K, Rathore A K, Panda S K, et al., Medium voltage multilevel converters for ship electric propulsion drives[C], 2015 International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles (ESARS). IEEE, 2015: 1-7.
[8] Xu P., Research on the Prediction Model of Urban Power Grid Short-term Load based on BP Neural Network Algorithm[C], Advanced Materials Research. Trans Tech Publications Ltd, 2014, 926: 954-957.
[9] McCann II E F, Mole C J. Superconducting electric propulsion systems for advanced ship concepts[J]. Naval Engineers Journal, 1972, 84(6): 35-45.
[10] Li H, Xu P, Liu D, et al. Low-voltage and fast-response SnO2 nanotubes/perovskite heterostructure photodetector[J]. Nanotechnology, 2021, 32(37): 375202.
[11] Ono Y, Shiraishi K, Yamashita Y. Application of a large hybrid turbocharger for marine electric-power generation[J]. Mitsubishi Heavy Industries Technical Review, 2012, 49(1): 29.

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