Research on Marine Photovoltaic Grid-connected System Based on Super Capacitor

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Abstract: Ships undertake more than 90% of the logistics and transportation of world trade, but shipping also brings about a large amount of pollutant emissions. According to statistics, 30% and 5% of global pollutants NOx and SOx come from ships. With the continuous introduction of new regulations and policies, green and low-carbon has become the current development trend of ships. The application of new energy power generation through inverter control technology to connect to the ship's power grid is one of the technical approaches, of which photovoltaic power generation technology is representative. Through the review of relevant literature and books, learn the working principles and characteristics of each component of the photovoltaic power generation system, and complete the selection and design of the main equipment of the system according to the needs of ro-ro ships.

1. Introduction

As the issue of ship pollutant discharge becomes more and more serious, the International Maritime Organization issued a series of mandatory ship emission reduction and energy efficiency rules based on the International Convention for the Prevention of Environmental Pollution from Ships in 1973, prompting major shipping countries to invest heavily The development of new energy-saving and environmentally-friendly green ships by human and financial resources has formed the main theme of the current green development of the global shipping industry. According to the ship greenhouse gas research report published in 2014 [1]: In 2012, ships emitted a total of 1.046 million tons of CO2, accounting for 3.3% of the total global greenhouse gas emissions. According to the current development trend, if effective prevention and control measures are not taken in time, by 2050, the proportion of CO2 produced by ships in the total global greenhouse gas emissions will turn 1-2 [2].

Photovoltaic power generation is clean and environmentally friendly, does not emit any waste, does not have mechanical wear, and is noise-free. Research on the application of photovoltaic power generation technology in ships is an important direction of green ship technology. Currently, there are two modes of integrating photovoltaic power generation systems into the ship's power grid: off-grid and grid-connected.

The off-grid photovoltaic power generation system is not connected to the ship's power grid. After the photovoltaic array receives solar radiation, it directly converts the solar radiation energy into electrical energy for use by the load. Because the input energy is extremely unstable, the system needs to be equipped with energy storage devices. The energy storage devices of marine off-grid photovoltaic power generation systems are generally based on lithium iron phosphate batteries, and the cost accounts for about 50% of the initial investment of the system. In addition, the lithium battery needs to be replaced...
3-4 times during the life of the ship, which is quite expensive. In addition, if the lithium battery is not properly managed, it will bring serious safety hazards.

The grid-connected photovoltaic system converts the unstable DC power generated by the components into AC power that meets the requirements of the ship's power grid through the grid-connected inverter, and then directly integrates it into the grid. Generally, there is no need to configure energy storage devices, and can make full use of the photovoltaic array. The electric energy, thereby reducing energy loss and reducing the cost of the system. However, as a distributed power source, photovoltaic grid-connected systems will cause power quality problems in the ship's power grid. For example, the direction of the power flow in the power grid changes, resulting in increased line losses and relay protection needs to be reset. In addition, photovoltaic power generation is random and fluctuating. Causes voltage fluctuations in the grid; a large number of power electronic devices are used in photovoltaic systems, which will cause harmonic pollution to the grid. As the high penetration rate photovoltaic power supply has a more prominent impact on the stability and safe operation of the ship's power system, it needs to be solved urgently. Therefore, how to break through the key technologies of photovoltaic power generation-ship power grid-connected, especially to improve the power quality and stability of high-penetration grid-connected systems, is a bottleneck for the promotion and application of photovoltaic and other new energy power generation systems on ship platforms. In the high-penetration photovoltaic grid-connected system, the introduction of energy storage devices to stabilize the output power fluctuations of the photovoltaic grid-connected system, and at the same time, can support the photovoltaic grid-connected system to operate without off-grid when the ship's grid voltage drops. This is the engineering application of the ship platform Technical approach.

2. Research status at home and abroad
The photovoltaic power generation technology as a whole has undergone continuous improvement and progress, and now a complete and mature technical system has been formed. The entire photovoltaic industry is advancing at a speed that surprised the world.

2.1. Research status of solar ship
In 2008, Japan installed an off-grid photovoltaic system with a maximum power of 40kW composed of 328 solar panels on the "Auriga Leader" ship (as shown in Figure 1), which can provide power support for 6.9% of the lighting load. 0.2% to 0.3% of power consumption is the world's first solar-powered car carrier.

!["Auriga Leader" navigation diagram](image)

In 2010, the first domestic solar-powered cruise ship "Shang Desheng" (shown in Figure 2) set sail on the Huangpu River in Shanghai. The biggest feature of this ship is the use of "solar wings", and photovoltaic panels can follow the angle of solar radiation. The change of the battery automatically rotates to maximize the use of solar energy, while using lithium batteries and diesel generator sets to form a hybrid ship. When the irradiance changes, the power required by the ship to travel is adjusted between the diesel generator set and the photovoltaic power generation system, saving fuel by more than 30% [3].
2.2. Research status of marine supercapacitor application

Energy storage systems are generally divided into two types: energy type and power type. Energy type energy storage is mainly represented by lithium batteries, which have high energy density, but long charge and discharge time and high failure rate; power type energy storage mainly Supercapacitors and flywheel energy storage are the representatives, which have high power density, high energy conversion efficiency and short charge and discharge time, but the energy density is relatively small. Sun Yuwei and others conducted research on the effect of hybrid energy storage systems on the power leveling of intermittent energy. From the perspective of the complementary characteristics of batteries and supercapacitors, they discussed the structure construction, capacity optimization and control technology development and application of hybrid energy storage systems [5].

In recent years, with the maturity of supercapacitor technology, especially its fast response characteristics can well compensate for the intermittent fluctuation of photovoltaic output power. The application of supercapacitors in ship platforms is mainly concentrated in ship electric propulsion systems. Fast discharge compensates for a sudden increase in propulsion load or quickly absorbs the feedback energy of the propeller, stabilizes the DC bus voltage, thereby enhancing the stability and reliability of the system. Zhuang Wei and others have introduced a super capacitor energy storage system into the ship's DC propulsion system to compensate for the dynamic difference between the power generation and propulsion load during the voyage, while taking into account the advantages of variable-speed power generation with DC grid power propulsion. Successfully applied on "Jiangsu Ludu 3011". In 2017, Ruihua Group was equipped with wind and solar hybrid power generation equipment on the 500-ton pure electric cargo ship "Ruihua 1", and equipped with 9 sets of lithium iron phosphate power battery packs and super capacitors as a hybrid energy storage system. In the case of full charge, it can meet 50 hours of sailing.

For photovoltaic grid-connected systems, the role of energy storage components is power regulation, so only small-capacity power super capacitor energy storage is required. Under the condition of small increase in investment, the impact of photovoltaic grid-connected on the ship's power system can be reduced.

3. Marine photovoltaic power generation application technology

Electricity is the energy source for ship power equipment, and ensuring the stability and reliability of the ship's power system is directly related to the safety of ship operations. Based on the analysis of the characteristics of the ship's power system and the photovoltaic application mode, this chapter proposes to use super capacitors as the system energy storage device to construct the structure of the marine photovoltaic grid-connected system.

3.1. Ship power system composition

The ship's power system is an isolated and complex microgrid, which is responsible for the generation, transmission, deployment and consumption of the entire ship's electrical energy [4] (as shown in Figure 2).
3). Its structure diagram mainly includes the following parts: Installations, power distribution equipment, ship power grids and electrical loads.

![Figure 3: Structure diagram of ship power system](image)

(1) The power supply device is mainly composed of a generator set and a battery, which is used to convert other forms of energy into electrical energy. The generator set is the main power source of the ship, and the battery is generally used as an emergency power source. The diesel engine is highly efficient and maneuverable. Most of the generator sets above are diesel generator sets.

(2) The main function of power distribution equipment is to distribute the electrical energy generated by the power supply device, while monitoring and protecting the operating status of the ship's power grid and electrical loads. The power distribution equipment mainly includes various power switches, measuring sensors and protection devices. According to power supply area and power load level, power distribution equipment can be divided into main switchboard, emergency switchboard and shore power switchboard.

(3) The ship power grid is the intermediate link between the generation and consumption of electric energy. It is the general term for the power cables of the whole ship. According to the load category and connection level, it can be divided into power grid, lighting grid and emergency power grid.

(4) The electric load converts electric energy into the required energy output. There are various forms of electrical loads for ships, among which power loads account for about 70% of the total power consumption of the ship. There are also lighting loads for daily life and communication and navigation systems for ship navigation.

3.2. Main features of ship power system

Compared with onshore power systems, ship power systems have the following characteristics:

(1) The capacity of ship's power station is small: the capacity of ship's power system is relatively small, generally several hundred to several kilowatts. When high-power equipment is started or stopped, it will have an impact on the ship's power system and increase the voltage and frequency of the power grid. Therefore, the ship power system has higher requirements for transient stability and steady-state stability to meet the frequent input and cut-out of large-capacity loads.

(2) Shorter distance of ship power grid transmission line: Due to the limitation of ship volume, electrical equipment is relatively concentrated, so the length of power grid is shorter. Although the loss in the process of power transmission is small, there is a strong coupling between the power supply device and the electrical load. When the electrical load is short-circuited, it will have a greater impact on the power grid. Therefore, the ship's power system requires higher protection.

(3) The environment of ship operating routes is complex and changeable: temperature, humidity, salt spray and vibration will affect the service life and operating performance of ship's electrical loads. Therefore, ship's electrical equipment has high requirements for protection level and durability, which must be met "Marine Standard".

(4) Insufficient power redundancy of newly-added power equipment: In the design of ship power system, less consideration is given to the problem of later expansion and transformation. The power
redundancy of newly-added power equipment is insufficient, so it needs to be connected to other power generation equipment as auxiliary energy.

4. Super capacitor performance advantage
At present, in real ship applications, super capacitors and lithium batteries are generally used to form a hybrid energy storage system. However, the hybrid energy storage system increases the investment and maintenance cost of the system on the one hand, and on the other hand, the hybrid energy storage system needs to be equipped with special fire extinguishing equipment, which will also give Ship operations bring safety hazards. The photovoltaic grid-connected system power is fed into the ship power station in real time, and the demand for energy storage devices is only for fast response, short-term suppression of the instantaneous power difference between the DC input side and AC output side of the grid-connected inverter, and reduces the transient power of the generator set running on the grid Load fluctuation rate. The grid-connected photovoltaic output power can be fine-tuned step by step at a small rate during the process of grid power fluctuation regulation and does not need to be kept constant for a long time. The super capacitor has a large power density and a short charge and discharge time. It has technical advantages in suppressing photovoltaic power fluctuations in a short time. Therefore, it can be considered that only super capacitors are used as energy storage equipment for marine photovoltaic grid-connected systems.

Although lithium batteries have high energy density, they are inferior to supercapacitors in terms of response speed, cycle life, and work efficiency. The advantages of using super capacitors as energy storage in marine photovoltaic grid-connected systems are [13]:

1. Improve the power quality of photovoltaic grid-connected systems: super capacitors have fast response speed and high power density, and can provide instantaneous high-power compensation. When the output power of photovoltaic grid-connected systems fluctuates due to environmental interference, the super capacitors can absorb power Fluctuations make the grid-connected output power smoothly change, thereby reducing the impact of photovoltaic grid-connected power fluctuations on the grid and improving the power quality of the grid.

2. Improve the reliability and continuity of system work: Compared with lithium batteries, supercapacitors have a wider operating temperature range, which can adapt to the environmental temperature requirements of ship navigation and improve the reliability of the system under extreme environmental temperatures. The cycle life of supercapacitors is 10 times that of lithium batteries, which extends the duration of system use.

3. Improve energy utilization efficiency: In the MPPT control circuit, the super capacitor is connected in parallel with the photovoltaic array via a bidirectional DC/DC converter. Using the energy storage characteristics of the super capacitor, the MPPT controller can always be in the state of maximum power tracking to improve the photovoltaic cell Utilization efficiency.

4. Reduce the investment cost of the system: With the advancement of supercapacitor energy storage technology, the energy density and power density of supercapacitors continue to increase, and the cost of supercapacitors provided on the market is further reduced, and supercapacitors are hardly used during use Maintenance saves equipment maintenance costs and labor costs.

5. Conclusion
With the large-scale application of modern ship automation equipment and power electronic devices, ship power grids are facing severe power quality problems. Poor power quality will affect the normal operation of ship electrical loads, cause energy waste, and even cause equipment failure, which is a serious threat Crew and ship safety. Integrate a large-capacity grid-connected photovoltaic system in the ship's power system. During grid-connected cut-in, large output power fluctuations, and off-grid cut-out links will affect the operating status of the ship's power system, causing grid voltage deviation, harmonics, distortion rate, etc. power quality issues. And with the gradual increase in photovoltaic penetration, the greater the negative impact on the power quality parameters of the ship's power system. By using super capacitors as energy storage equipment for photovoltaic power generation systems, super
Capacitors can effectively compensate for sudden changes in photovoltaic power generation, so that grid-connected power can be output smoothly, and the safety risks of marine photovoltaic grid-connected systems can be reduced. Next, a coordinated control strategy for the inverter based on the supercapacitor SOC will be formulated to centrally monitor and manage the equipment and store the parameters to facilitate the guidance of the later research work, laying a good foundation for the next installation and commissioning of the actual ship.

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