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Modeling and Simulation of Ship Medium Voltage DC Power System

Zhen Zhang

School of Logistics Engineering, Shanghai Maritime University, Shanghai 201306, China.

zhen.smu@foxmail.com

Abstract

In the ship's medium voltage direct current (MVDC) power system, in order to verify the reliability and stability of the system, a modular modeling method is used to establish a generator set with a diesel engine as the prime mover; in order to achieve AC-DC conversion, adopt Modular multilevel converter (FMMC); in order to realize the voltage conversion from 6000V to 440V, a bidirectional DC-DC converter with a dual active bridge (DAB) structure is adopted. In the SimPowerSystems simulation environment, the typical operating conditions and common fault conditions of the ship's power system are simulated. The simulation results show that the system has good steady-state characteristics and dynamic performance.

Keywords

Modeling and Simulation; MVDC; Modular Multilevel Converter; Shipboard.

1. Introduction

With the increasing shortage of energy and serious pollution to the marine environment by human activities, it is more urgent to apply renewable energy to ships [1]. The traditional AC system has problems such as limited fuel efficiency, heavy equipment, reactive power, and flexibility of power conversion. The DC system can connect different types of generator sets in parallel to operate stably, improving fuel efficiency; at the same time, it is convenient for new energy systems and storage. The access of energy equipment can reduce the impact of high-power loads on the ship's power system; and power electronic equipment is widely used, so it can provide AC and DC power in a variety of frequencies or voltage ranges. In order to meet the goals of future ship power demand and high-efficiency operation, medium-voltage DC power distribution schemes have received increasing attention. According to the IEEE recommended standards for medium-voltage DC power systems from 1kv to 35kv on ships (Figure 1), medium-voltage DC power systems mainly include power generation systems with gas turbines and diesel engines as prime movers, and energy storage systems based on animal batteries and super capacitors. Propulsion loads, various AC and DC service loads, as well as high-power pulsed loads such as radars [2]. For the convenience of research, this article simplified the system. By analyzing the changes of system state parameters under different disturbances, Research on the power system.

2. System Simulation

2.1 Power generation system model

The generator set mainly converts other forms of energy (such as mechanical energy, chemical energy, etc.) into electrical energy, which is used to generate electrical energy for the entire ship. Due to the advantages of high thermal efficiency, simple structure, and good economy of diesel engines, diesel engines are generally used as the prime mover of generator sets on ships. The marine diesel power

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generation system uses the diesel engine as the prime mover, including the speed control system (Figure 2), the excitation system (Figure 3) and so on. The speed regulation system is used to maintain the constant speed of the diesel engine in the generator set (Figure 4). The excitation voltage regulation system is used to provide DC current to the excitation winding. In addition, it can also control the magnetic field current by controlling the magnetic field voltage to complete the control of the generator. The control and protection function.

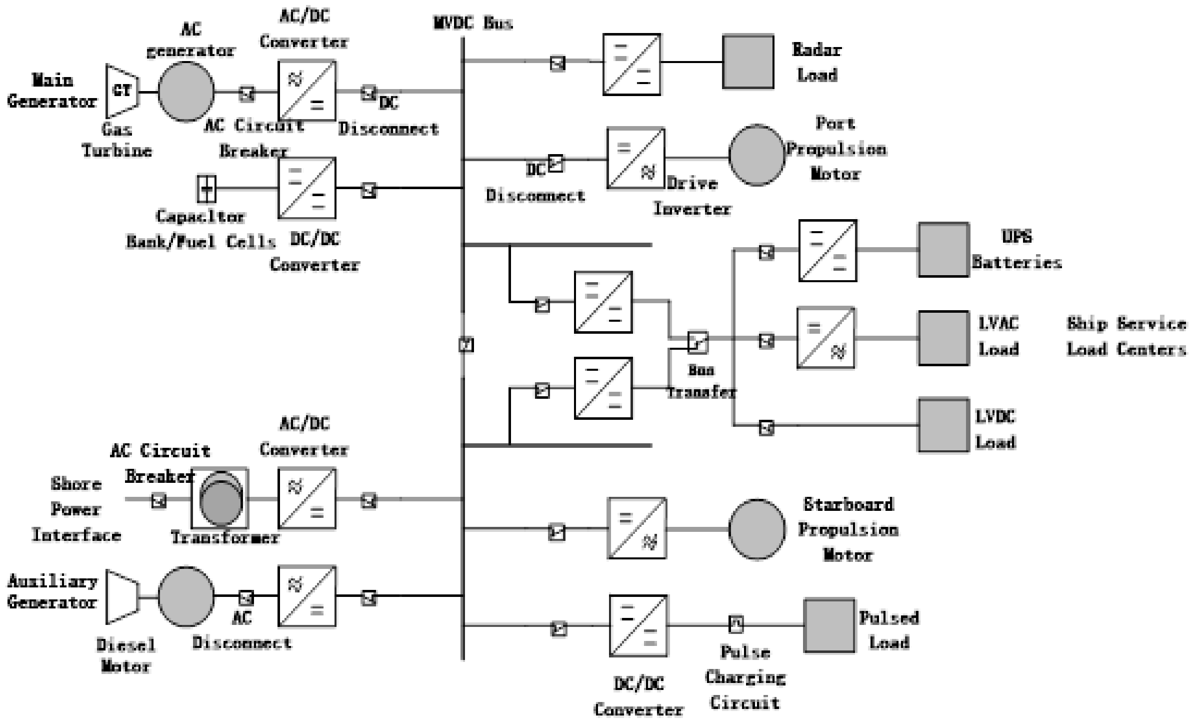

Fig. 1 Radial distributed framework

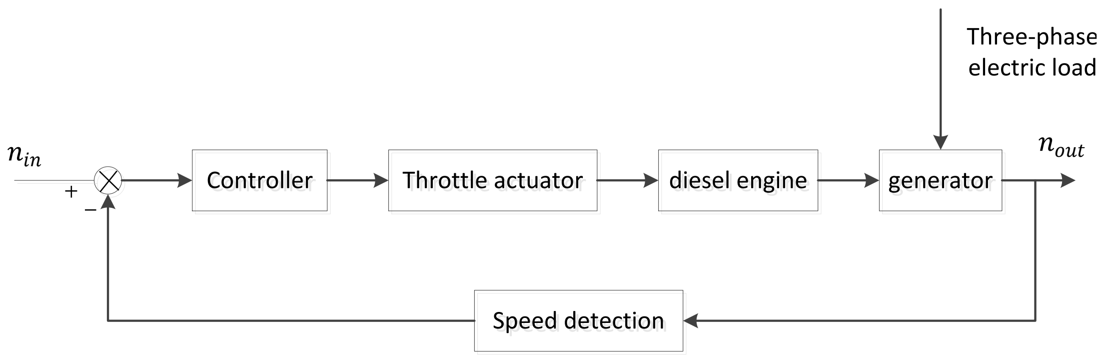

Fig. 2 Block diagram of the speed feedback control system of marine diesel generator set

Defining the overall benefit of the speed feedback unit as Ks, the transfer function can be obtained from Figure 2 as

$$K_s = \frac{U_{(s)}}{N_{(S)}} \tag{1}$$

Where $U_{(s)}$ is the DC voltage signal, and $N_{(S)}$ is the speed of the diesel engine. The mathematical model of the tachometer control unit is :

$$G_1(s) = \frac{f(S)}{U(S)} = K_2\left(1 + T_1 s + \frac{1}{T_2 s}\right) \tag{2}$$

where U is the deviation voltage, f is the control signal, and K_2 is the ratio The coefficients, T_1, T_2 are calculus coefficients.The transfer function of the actuator is :

$$G_2(s) = \frac{W(s)}{A(s)} = \frac{K_2}{1 + T_1(s)} \tag{3}$$

where W is the actual value of the throttle, and A is the given value of the throttle, K_2 is the proportional link coefficient, and T_1 is the inertia time constant [3].

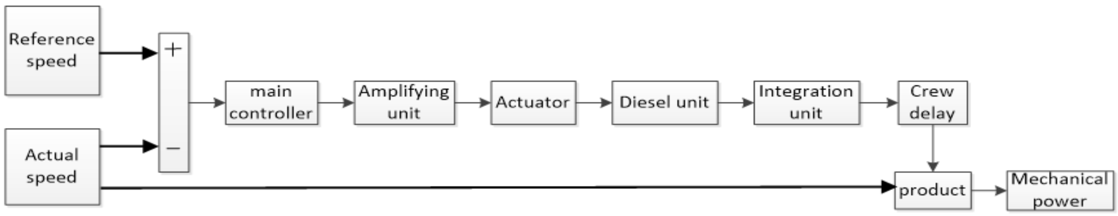

Fig. 3 Block diagram of diesel engine and governing system model

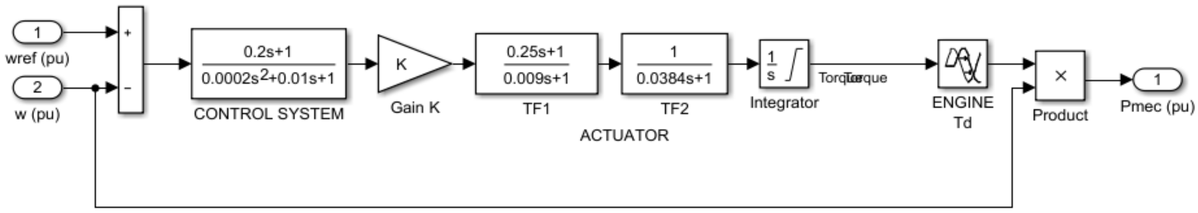

Fig. 4 Block diagram of speed control system

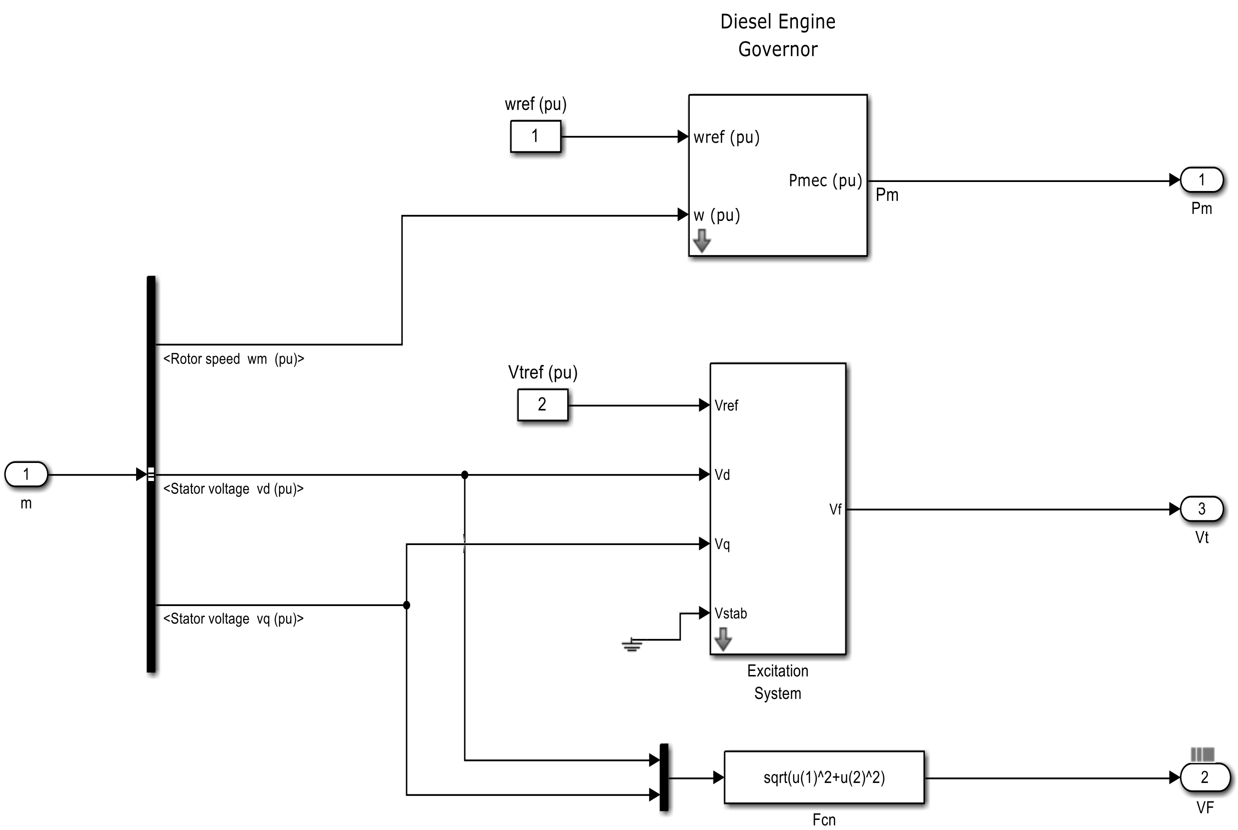

Fig. 5 Simulation model of diesel engine

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The performance of the governor directly affects the stability and reliability of diesel operation. The actual speed is compared with the given speed and then sent to the main controller. The amplifier plays a role of scaling. Combined with the main controller, it forms a proportional differential plus second-order inertia. The control unit, the oil port of the diesel engine can be regarded as an actuator, which can adjust the speed. The output speed of the diesel engine becomes torque under the action of the integral unit, and the power signal is obtained by the product of the torque and the actual speed.

According to the principle of Figure 3, the simulation in SIMULINK is shown in the figure 4.

Based on the above analysis, the diesel engine model can be obtained as figure 5.

2.2 Topology and principle of MMC

Figure 6 shows the F-MMC structure. The MMC has three-phase and six bridge arms [4]. The bridge arms are composed of N sub-modules, current-limiting inductors Ls, and bridge arm resistors Rs. The upper and lower bridge arms form a phase unit. The inductance limits the charge and discharge currents of the sub-modules, as well as the circulating current between phases. Udc is the DC bus voltage.

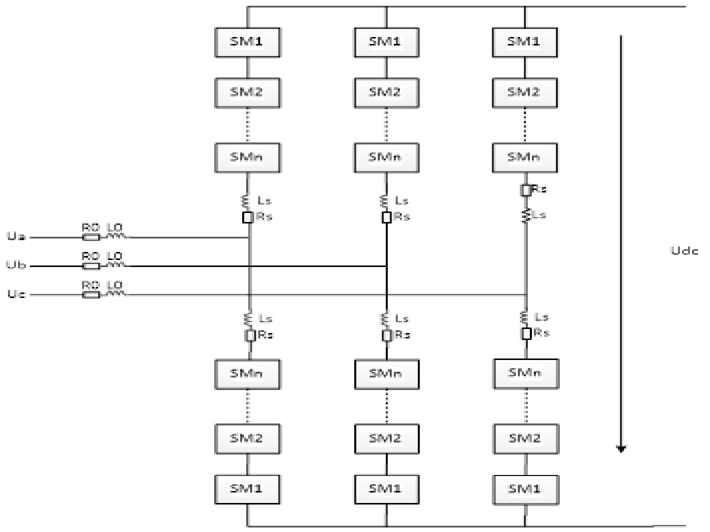

Fig. 6 The structure of FMMC

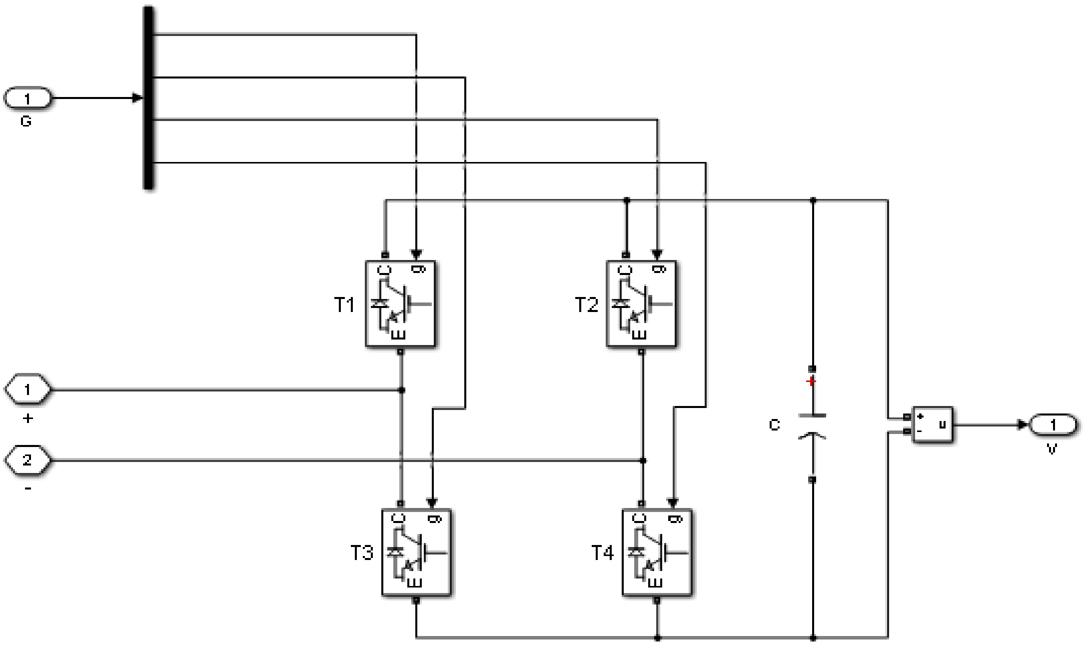

Fig. 7 Three-phase half-bridge converter topology

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T1~T4 are switching devices in a single sub-module of MMC, and Uc is the capacitor voltage. The sub-module includes four working states: output +Uc, -Uc, 0 and locked state. Under normal operation of the system, the -Uc output of the sub-module is not necessary, so the full-bridge sub-module can keep T2 off and T4 on. Changing the on state of T1 and T3 can achieve +Uc, 0 output, avoiding repeated switching Switch to reduce switching loss [5].

2.2.1 Control Strategy

The direct current control strategy and coordinate transformation are used to simplify the mathematical model and facilitate control [6]. The inner loop current control and outer loop power control methods maintain the stability of the bus voltage and the balance of power. As shown in Figure 8:

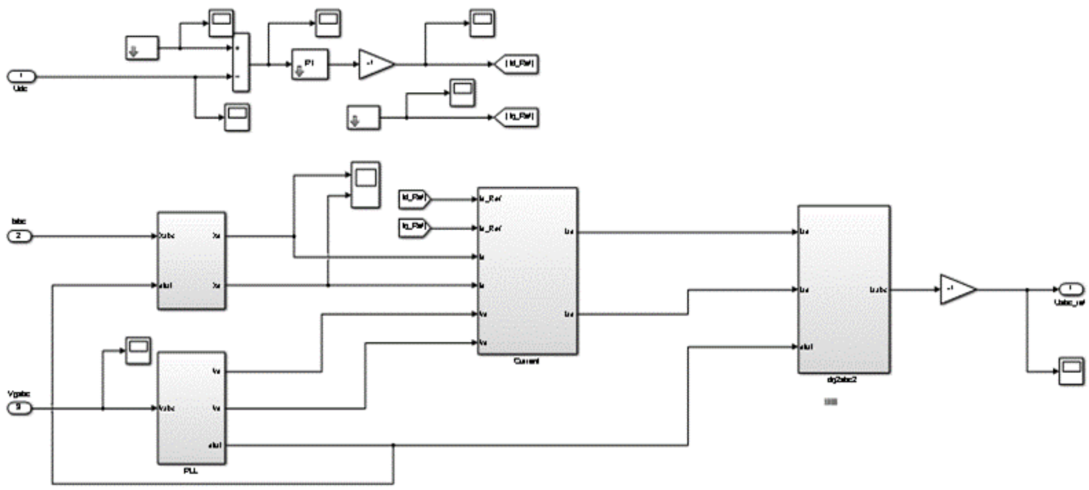

Fig. 8 MMC control simulation

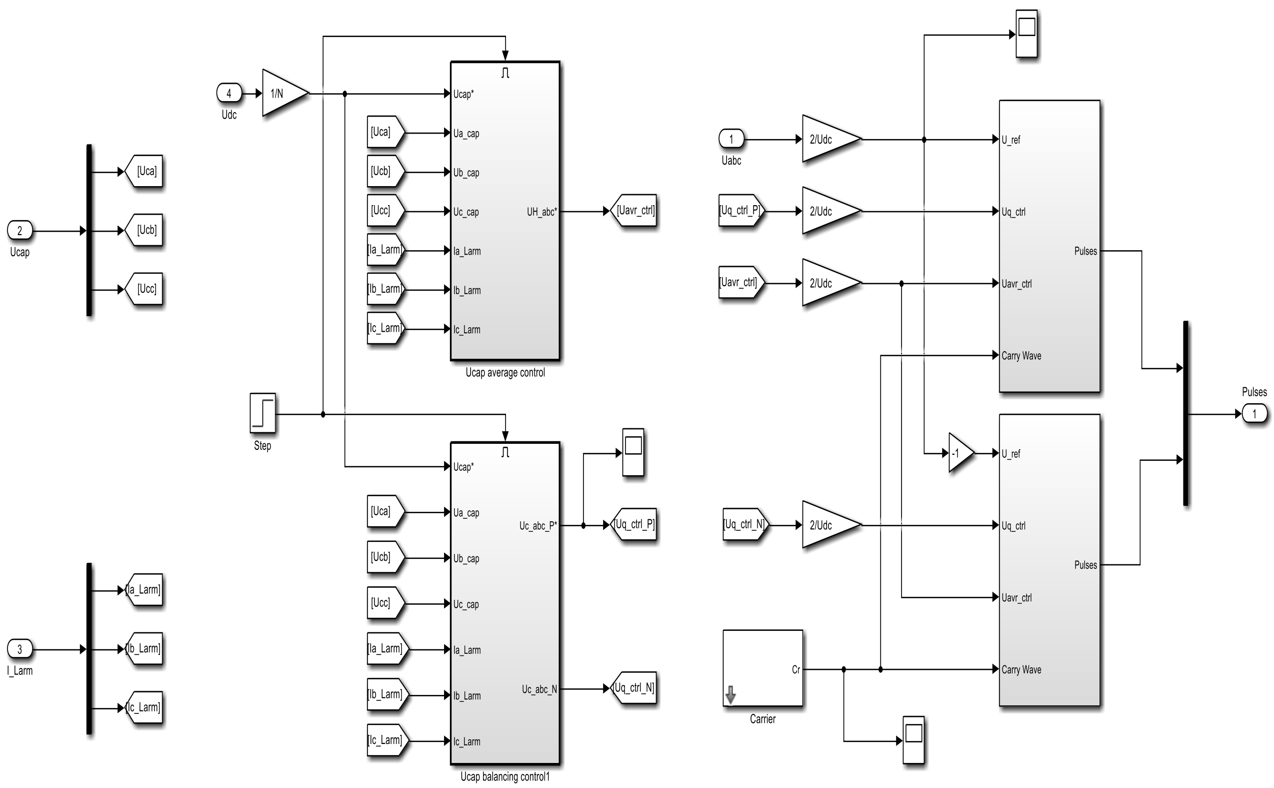

Fig. 9 MMC Modulation strategy

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2.2.2 Modulation strategy

At present, the modulation strategies used for MMC mainly include pulse width modulation (PWM) and staircase wave modulation. The former is mostly used when the number of levels is small, and has the characteristics of simple implementation and good performance in tracking modulated waves. For multi-level modulation strategies, due to the limitations of carrier phase-shift modulation, the direct approximation of the staircase wave is relatively simple and more used. This article uses seven levels, and the number of levels is small, so the carrier phase shift technology is used for modulation. The specific simulation model is shown in Figure 9:

The modulation waves of the corresponding sub-modules of the upper and lower bridge arms of FMMC are symmetrical. Because the angle difference between the module carriers in each bridge arm is π/N, and the modulation waves between the bridge arms are symmetrical, the phase difference of the full-bridge MMC is $\theta \in [0, \pi/2N]$.

2.3 Topology and control of dual active bridge DAB

The DAB converter realizes the size and direction of power transmission through phase shift control. The converter works under high-frequency conditions. During operation, two sets of high-frequency square wave voltages are generated inside the converter, and there is an adjustable phase between the two sets of voltages. Shift angle, when the amplitude of the DC voltage on both sides of the DAB converter is constant, and the magnitude and direction of the transmission power are constant, the phase shift angle will remain constant [7].

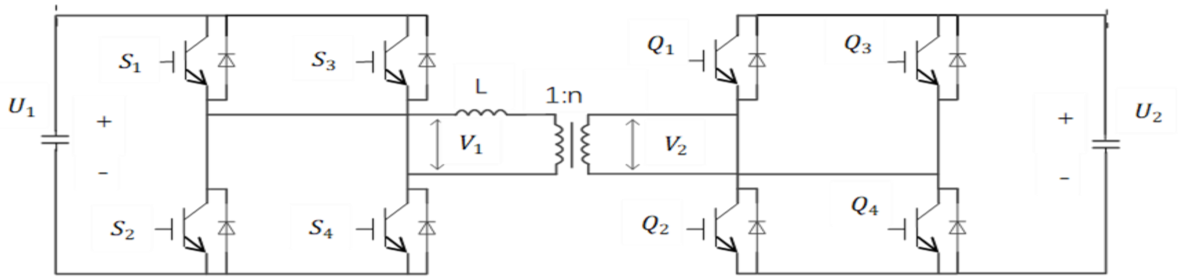

Fig. 10 DAB converter schematic

It can be seen from Figure 10 that the DAB DC/DC converter is composed of the primary and secondary H bridge, high-frequency transformer T and inductor L.The operating frequencies of the switching tubes on the two H bridges are the same. The diagonal switching tubes in each H bridge are turned on in turn, with a conduction angle of 180°.

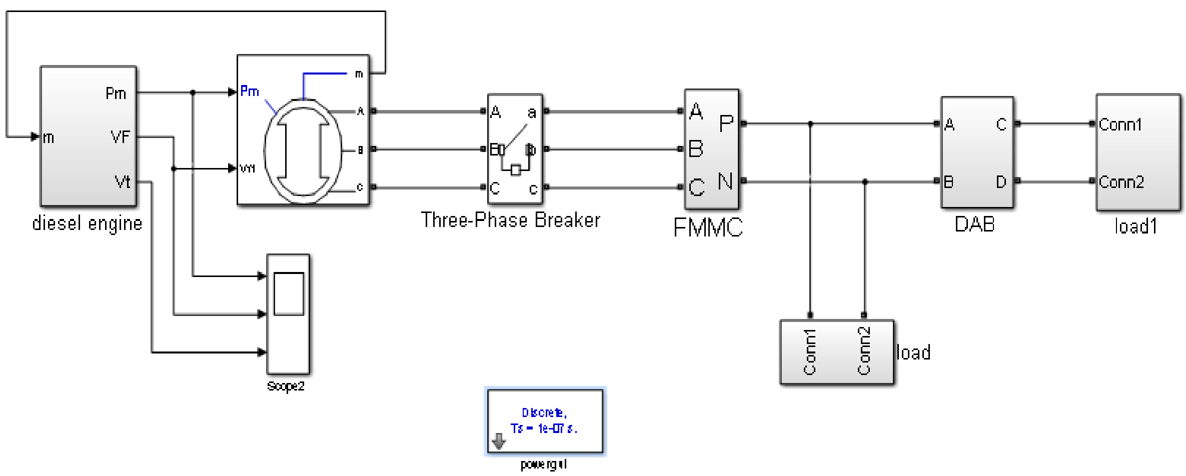

Fig. 11 Whole simulation model of ship power system

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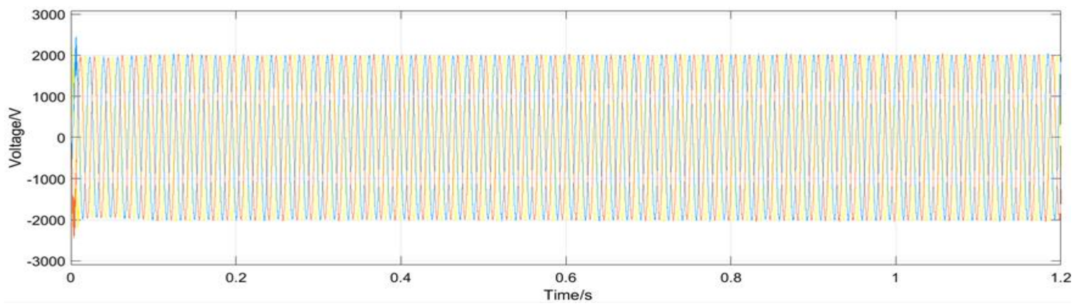
3. Simulation verification and analysis

The model built is as Figure 11.

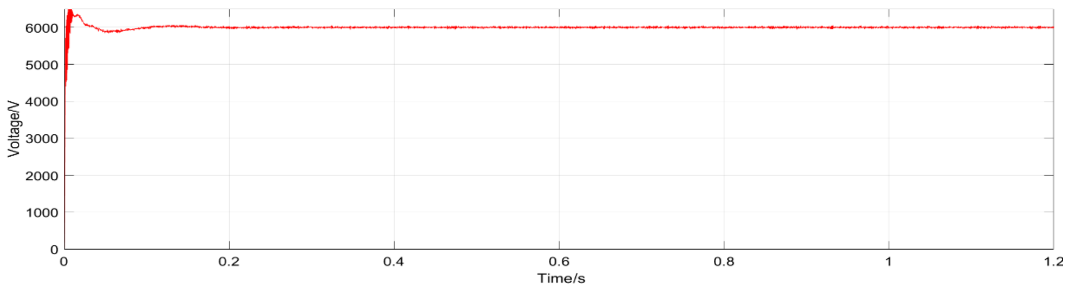
The model built mainly includes a diesel engine-based power generation system, a modular multi-level converter for AC-DC conversion, a multi-level converter for DC-DC, and some test loads, and its main parameters As shown in table 1:

Table 1. The main parameters of the system

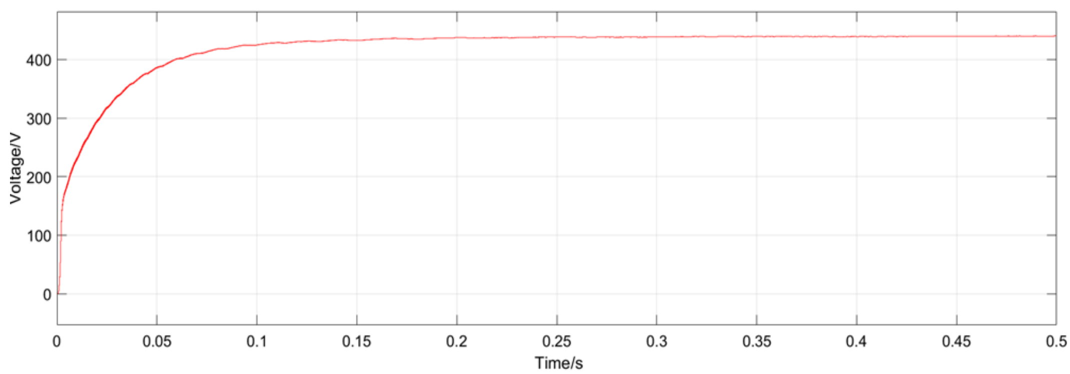
	parameter
Total system power	3.2MW
MMC	AC phase measurement voltage2400V DC side voltage6000v Number of sub-modules of single bridge arm N=6 Number of levels7
DAB	Primary voltage6000V Secondary voltage440V
Test load	0.0-0.6 50Ω 0.6-0.8 30Ω 5mH 0.8-1.2 20Ω 5mH



(a)



(b)



(c)

Fig. 12 (a) MMC AC voltage measurement, (b) DC bus voltage, (c) DC-DC converted voltage

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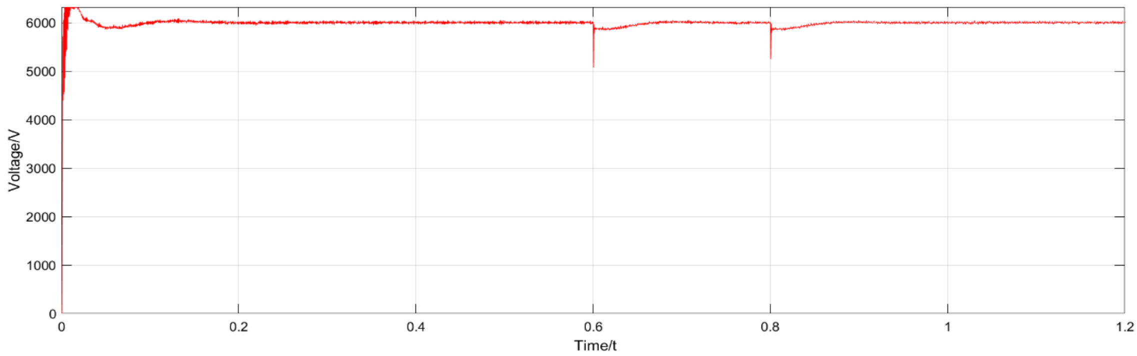
4. Simulation result analysis

The power system is simulated and run, and when the load is 50 ohms, the DC bus voltage during stable operation, the MMC AC measured voltage, and the voltage waveform after DAB transformation are obtained [8].

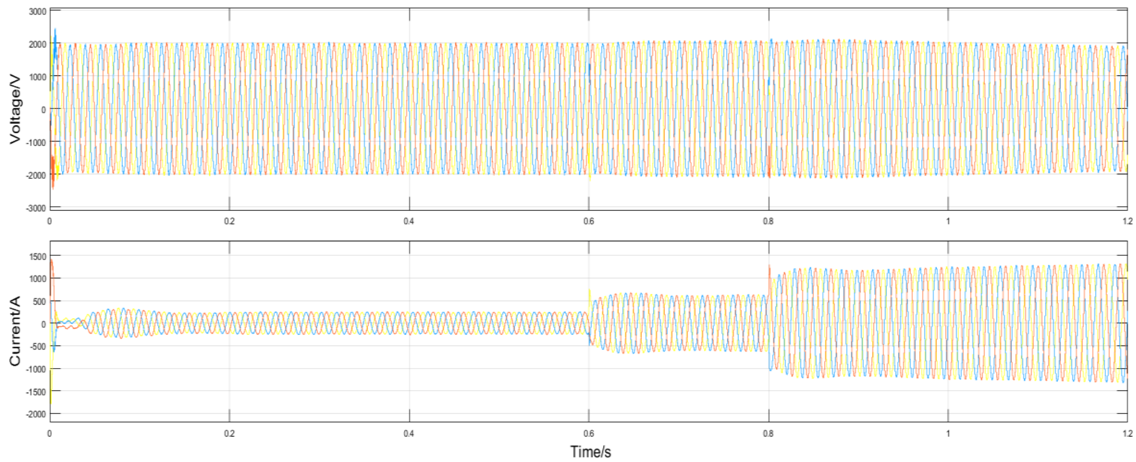
It can be seen from Figure 12(a) that when the system is running stably, the power generation system outputs a stable AC voltage with a peak value of around 2050V. Through the conversion of MMC, a stable 6000V DC voltage is output on the DC side after 0.2s. The control function of MMC keeps the bus voltage stable, and its maximum value is about 6200v, which meets the requirement of 5% of the bus voltage during stable operation [9]. It can be seen from Figure 12(c) that the DC bus voltage is transformed by the DAB converter. The value is changed from 6000v to 440, and the stable output is maintained at 0.15s, which is supplied to the living load.

4.1 Simulation of load switching

Figure 13 shows the simulation result of changing the size of the load borrowed by MMC. The figure shows that when the load changes, the bus voltage changes more drastically, but due to the control of the MMC, it can be restored to stability in 0.1s and remains at about 6000V. The output voltage of the generator basically remains stable, and the output current increases.



(a)



(b)

Fig. 13 (a)Bus voltage change, (b) The output voltage and current of the generator

5. Conclusion

This paper verifies the stability of the built system by simulating the ship's medium-voltage DC power system, simulating the ship's sailing conditions and changing the size of the load, and at the same time avoids the high cost and high risk of working condition tests and fault tests on real ships.

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The data results have important reference significance for the design, commissioning and control methods of ship power systems.

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