Modeling and Simulation Analysis of Shore-to-ship Power System

Tian-li SONG¹ and Xiao-yan XU²

¹ Electrical Engineering College, Southeast University, Nanjing, China
² Logistics Engineering College, Shanghai Maritime University, Shanghai, China

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Abstract. With the promotion of power replacement, shore-to-ship power technology has been in rapid development. By comparing the international and domestic components and ways of supplying electricity of the shore power system, high-voltage power system is selected as the simulation model according to the fact that it is the development trend. Then, the simulation model is established in order to simulate the real-world shore-to-ship power system. Finally, simulation results show that this model can provide a basis for the construction of shore-to-ship power system.

Introduction

With the rapid development of China's import and export trade and domestic trade, the role of transportation in the national economy is becoming increasingly important. In the global transportation business, shipping has obvious advantages compared to other modes of transport, and also has been in relatively rapid development [1].

In the case of port-going vessels, if shore power supply system is used to provide shore power for ships instead of auxiliary power during the port-to-port period, it will greatly reduce the emission of the ship and improve the environment of the port. Statistics show that emissions of the port city are 25% more than the figure on average, which is seen as a result of relying on port ships auxiliary power generation. This technology can greatly reduce the environmental pollution around port. Moreover, there has been in a number of ports has been in the actual applications, such as Shanghai Port, Qingdao Port, Shenzhen Port and other ports[2].

Under the background above, this paper mainly focuses on the ship electric power system as the object of study. According to the composition of the electric power system and the electrical characteristics of the ship power system, a simulation model of the ship shore power system is established and analyzed.

The Composition of Shore Power System

According to different voltage, the ship shore electric power system can be divided into high-voltage and low-voltage shore power system. High-voltage shore power system is mainly refers to shore power voltage of 6.6kV / 11kV, which supply not only generally for large-scale ships, but is also access to small vessels through the step-down transformers. By contrast, low-voltage shore power system is mostly refers to the shore power voltage of 400V / 440V shore power system, usually small load of small ships.

At present, the ship-and-shore power system is generally composed of three parts [2], as shown in Figure1.

1) Shore power supply system: According to different types of ships to provide different voltage levels and frequency of shore power.

2) Cable connection equipment: Connect the shore connection point and the ship power system promptly, can be installed in the port, ship or barge.

3) Ship power receiving system: The part ships receiving shore power, including shipboard transformer and cable winch.
Two Typical Shore-to-Ship Power System

Low-Voltage Power System

Figure 2 shows the structure of the low-voltage shore power system. Variable-frequency power supply scheme is adopted, which is currently used in Shanghai port and Los Angeles port [3].

The program uses a mobile shore power station, high-voltage cable drum, transformer and frequency structure of the main load in the main mobile warehouse. The low-voltage cable drum is installed in the deputy mobile warehouse to facilitate the movement of port handling, and it can also be placed on the shore side or barge.

The advantages of the program are:
1) It can realize 50Hz / 60Hz dual-band power supply;
2) The use of quick soft contact plugs, sockets and flexible cables;
3) The ship does not need to be retrofitted, and there is no need for the terminal to provide additional electrical facilities.

The disadvantages of the program are:
1) There are nine cables so that it will a relatively longer time to be connected, also with low safety factors.
2) The system uses diode-controlled rectifier, which is seen as a significant equipment that will an impact on the power quality of the power grid.
High-Voltage Shore Power System

Figure 3 shows the structure of the high-voltage shore power system. Variable-frequency power supply scheme is also adopted, which is currently used in Lianyungang port and Gothenburg port[4].

![Diagram of High-Voltage Shore Power System](image)

The program also involves the voltage and frequency conversion. The entire solution uses only one cable and is connected to the dock socket through a plug. The whole process requires only one person to operate. In addition, through being connected to the ship dedicated cable car, it can accomplish real-time monitoring and adjustment of the shore power supply, which will ensure its reliability.

The advantages of the program are:
1) A cable and high voltage, which can achieve uninterrupted power supply;
2) Ship owners and ports become one community of interests, which is conducive to shore-shore economic balance;
3) Because of using high-voltage inverter technology, the input current harmonic distortion is small.

The disadvantages of the program are:
The transformation cost is relatively high, because it uses on-shore network so that each converter corresponds to a separate ship.

At present, the majority of ports in China and abroad are used in the way of low-voltage power supply. However, the technology of high-voltage power supply has more advantages in energy saving, so it is chosen as the future direction of the domestic shore power research.

Modeling and Simulation of Shore Power System

According to the composition power supply of shore power system, high-voltage shore power system, which seen as the prospect, is established in Matlab/Simulink environment, including transformers, high-voltage converters, filters and the loads in use after the ships dock at the port[5,6].

Among them above, the high-voltage converter is the core of the entire program. The converter consists of a series of low-voltage power units in order to achieve high-voltage output. Its grid harmonic is small, so there is no need to use input harmonic filter and reactive power compensation device. At the same time, because of its great output waveform, there is no harmonic problem. So it is very suitable for ports and other shipbuilding industry [7]. In this paper, the high-voltage multilevel PWM voltage source converter is selected, and its schematic diagram is shown in figure 4.
Single Power Unit Module

A single power unit is the basic unit of a series multilevel PWM high-voltage converter. Therefore, this paper first simulate a power cell in order to observe the waveform of its output. Figure 5 is a power unit simulation model, including three-phase AC power, transformers, rectifier bridge, filter and inverter bridge.

It can be seen from the Figure 6 that the output voltage and frequency of three-phase power supply are respectively 10kV and 50Hz. The amplitude of output voltage square wave is about 1070V, with the frequency of 60Hz.
Simulation of High-Voltage Shore Power System

As is shown in figure 7, the shore power supply of the grid is 10kV / 50Hz. Since the high-voltage converter is directly connected to ships, so the output voltage is 6.6kV and the frequency is 60Hz. When ship docks, the majority of loads will stop working. Only lifts, windlasses, ventilation and other equipments continue to work. Therefore, the designed capacity of the converter is 500kW, rated voltage is 6000V and external load torque is 2000N * m. In the other branch, intended for lighting, the converter supply power to the lighting equipment through the 6.6kV / 440V step-down transformer, the total capacity is 10kW.

![Figure 7. Simulation model of high-voltage shore-to-ship power system.](image)

Figure 8 illustrates output voltage waveform of the converter. In order to observe the voltage and current waveforms more clearly, the image is amplified. It can be seen from the figure that the output line voltage and the peak value of A-phase current is separately around 9.3kV and 100A, the effective value is about 6.6kV and 70.7A, with the frequency of 60Hz. It can be seen that the current waveform is very similar to the sine wave without being connected to filters.

![Figure 8. Output Voltage and Current Waveform of High-Voltage Converter.](image)

Figure 9 reflects the induction motor parameters waveform. It can be seen from the figure that induction motor start-up time is about 3.5s without load. After it starts, the motor speed up to 1800r / min. Since the motor status was none-load 5 seconds before, the values of the rotor current and the stator current fluctuate at "0" after the motor starts. At the fifth second, the motor speed began to decline when the load with the torque of 2000N.m is added. Then, the motor speed is stabilized at 1750r / min 0.1s later.

![Figure 9. Induction motor parameters waveform.](image)
The simulation results show that the established model can reflect the operating characteristics of the high-voltage shore power system. In addition, it can provide the foundation for the high-voltage power system.

Summary

This paper mainly studies the shore-to-ship power system. By analyzing its compositions and power supply modes, the high-voltage power system is chosen as the study object, and then the simulation model of it is established and analyzed. As a result, the simulation consequences show that the simulation model is in accordance with the real-world shore-to-ship power system operating characteristics, which can be used as a practical reference object.

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