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Evaluation of Power Quality under Extreme Operating Conditions of Shipboard Microgrid

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Abstract

This paper studies the operation of shipboard microgrid (SMG) under extreme conditions. The power quality of the SMG when only a single generator is working has been detected and analyzed, and the impact of the high-power nonlinear load and the propeller motor on the power quality of the SMG when the SMG is operating under extreme conditions is analyzed. It provides a valuable analysis for the control of power quality under extreme operating conditions of a single motor in a SMG, and proposes feasible directions for future related research.

Keywords

Shipboard Microgrid (SMG); Power Quality; Harmonic Analysis; Voltage Unbalance; Surge Current.

1. Introduction

The power system of a ship is closely related to the ship's navigation, production, navigation, communication, daily life and other systems, and has an extremely important impact on the operation of the ship. Therefore, the analysis of ship's power system is of great significance in ship navigation. As a supplement to the main network, the SMG can quickly switch from grid-connected operation to island operation when the ship's power system fails, which can maintain power support for key systems and improve the reliability of the ship's power system [1].

However, due to the limited capacity of the motor in the SMG, the form is more variable, it needs to be connected to the ship's main network through an inverter device, and there is no strong voltage and frequency support capacity, which causes its power quality to be interfered by the load and the outside world[2]. The power quality of the SMG directly affects the safety and reliability of the ship's power system[3]

But analyzing the detailed behavior of the entire SMG is still quite complicated, especially in the case of voltage imbalance and distortion. Because every SMG, even a small SMG, has dozens or hundreds of electrical devices working at the same time, and is powered by voltages that fluctuate in frequency and amplitude, especially when pitching and rolling the ship In [4,5].

However, because the SMG usually contains generators with limited power capacity and some non-linear and high-power pulse loads that are difficult to control, a typical ship runs under different working conditions in order to adapt to different loads. Significantly different power characteristics[6]. In fact, the SMG is also very sensitive to voltage imbalance, harmonic voltage, high-intensity transient interference and frequency changes. Therefore, it is particularly important to evaluate and detect the power quality of the SMG[7]. The research and improvement of power grid performance improvement is of great significance.

In this paper, the power quality of the SMG in the extreme working state with only a single generator is analyzed. At the same time, the impact of the power quality of the SMG on the power quality of the SMG when the high-power nonlinear load starts in the SMG island operation is analyzed.

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2. Construction of SMG

The SMG should have multiple electric motors under normal conditions. However, considering the worst situation in the ship's navigation, that is, multiple engines stop working, only one engine can operate normally, and the ship has the exception of the bow thruster and the propeller motor. The rest of the loads are for full load operation[8].

The model of the SMG in this article under extreme conditions is shown in Fig.1[9], where G is a diesel generator with a rated voltage of 240V and a rated power of 357KW, load1 is a nonlinear load bow thruster, with a rated voltage of 240V and a rated power of 125KW; load 2 and load 3 are linear loads, load 2 rated voltage 120V, rated power 110KW; load 3 rated voltage 120V, rated power 90KW; transformer rated capacity is 110KVA, working frequency is 50Hz, primary side rated voltage is 240V, secondary side rated voltage It is 120V. M is a ship propeller motor with a rated voltage of 470V and a rated power of 10KW.

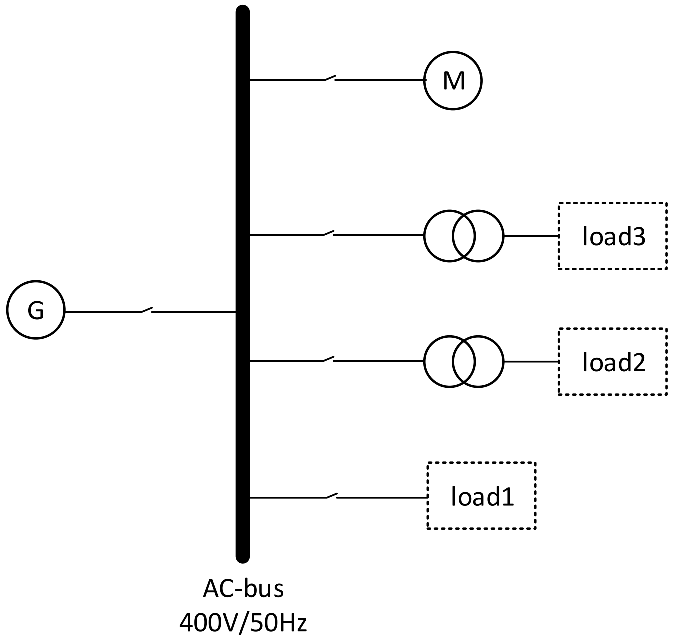

Fig. 1 model of SMG

In this model, the power quality of the ship's micro-grid can be analyzed in the extreme case where only a single generator works. When the ship is working normally, the power quality in the SMG busbar is relatively stable when multiple motors are working at the same time. However, in the case of a single motor, the operation of each load, especially the operation of a high-power nonlinear load, will affect the ship's micro power. The power quality in the grid bus has a great impact. Therefore, it is necessary to analyze the power quality when various loads are started and stopped under this condition.

The circuit of each phase of the bow thruster modeling in this model can be simplified as Fig.2.

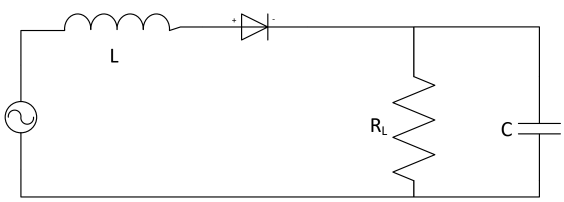

Fig. 2 One-phase equivalent rectifier circuit of bow thruster

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The line current flowing through the bow thruster can be approximated by the following second-order differential equation:

$$\mathrm{R_L} \cdot \mathrm{L} \cdot \mathrm{C} \cdot \frac{\mathrm{d}^2\mathrm{I_{h,BT\_a}}(t)}{\mathrm{dt}^2} + \mathrm{L} \cdot \frac{\mathrm{dI_{h,BT\_a}}(t)}{\mathrm{d}t} + \mathrm{R_L} \cdot \mathrm{I_{h,BT\_a}}(t) = \mathrm{V}(t+t_1) + \mathrm{R_L} \cdot \mathrm{C} \cdot \frac{\mathrm{dV}(t+t_1)}{\mathrm{d}t} \quad (1)$$

Where $I_{h,BT\_a(t)}$ is the current flowing through the bow thruster at time t, R_L, L, C are the internal resistance, inductance and capacitance of the bow thruster, and V is the voltage across the bow thruster.

3. Power quality index of SMG

The overall power quality detection indicators of the SMG can be divided into the indicators of voltage deviation, frequency deviation, harmonics and three-phase voltage imbalance. In this article, the three-phase voltage deviation, voltage harmonics, and three-phase voltage imbalance are mainly investigated.

3.1 Three-phase voltage unbalance

The three-phase voltage unbalance degree is the ratio of the root mean square value of the component based on the component generated by the voltage under the normal operation of the three-phase system. The expression is as follows

$$\varepsilon_U = \frac{U_1}{U_2} \quad (2)$$

When the power system is in a three-phase unbalanced state, the operation of electrical equipment will be negatively affected, which will reduce the output power of the equipment under normal working conditions and affect work efficiency [10].

At the same time, the mismatch of the three-phase voltage will lead to the loss of motor power and at the same time cause the decrease of the utilization rate of the motor capacity.

3.2 Voltage harmonics

Harmonics are components that differ in frequency from the fundamental wave. Reflects the degree to which the waveform deviates from the sine wave, the main indicator is the total harmonic distortion (THD), the expression is as follows

$$\mathrm{THD}_U = \frac{\sqrt{\sum_{k=2}^{M} U_k^2}}{U_1} \times 100\% \quad (3)$$

Harmonics will cause the transformer in the busbar to exceed the load, increase the reactive power of electrical equipment and reduce the service life of the load [11].

The increase of higher harmonics will lead to a significant decrease in power quality, and at the same time will also increase the probability of damage to other equipment in the SMG

3.3 Voltage deviation

Voltage deviation reflects the degree to which the operating voltage deviates from the rated voltage. It is a main indicator to measure whether the power system is operating normally. Its mathematical expression is as follows:

$$\delta_U = \frac{U_{re} - U_N}{U_N} \times 100\% \quad (4)$$

In the normal operation of the power supply system, the load will change with the change of the system operation mode, which will cause the system voltage to deviate from the rated voltage, and produce large fluctuations in the system, thereby affecting the safety and stability of the electrical equipment of the SMG [12].

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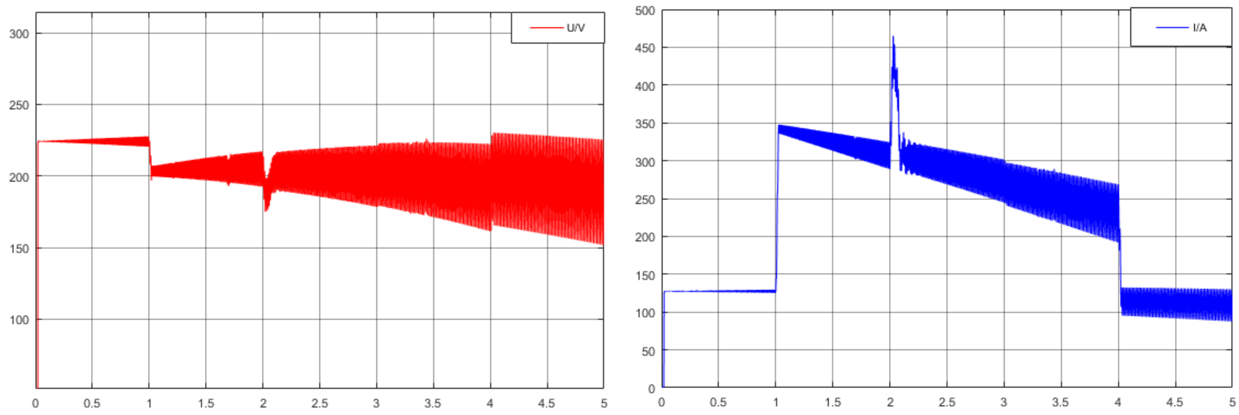
4. Power quality detection and analysis of ship micro-grid

In the research of this article, four time points are selected to test the power quality of the SMG when only one motor is working[13]. They are the power quality and the power quality when the bow thruster starts and stops with the high-power nonlinear load. The power quality when the propeller motor starts and stops.

The bow thruster starts to work in the 1s, the propeller motor starts to work in the 2s, the propeller motor stops in the 3s, and finally the bow thruster stops working in the 4s. In this process, the voltage and current changes of the AC bus are shown in Fig.3.



(a) (b)

Fig. 3 Voltage waveform(a) and Current waveform(b)

4.1 The power quality of the SMG at the 1s

At the 1s, the bow thruster started to work. At this time, it can be seen that the bus voltage has a voltage drop. From Fig.3, it can be seen that the bus voltage roughly drops by about V when the bow thruster starts to work. At the same time, there was a large voltage fluctuation.

Since the bow thruster is the most powerful non-linear load in the power grid, all harmonics can be regarded as being generated by the load alone. At this time, the bus voltage and harmonic analysis results and current waveforms are shown in Fig.4 It can be seen that there is a significant increase in harmonics when the bow thruster starts to work.

At the same time, there is an obvious mismatch in the three-phase voltage. The voltage waveform becomes extremely unstable in certain periods. In terms of current, there is an obvious surge current in the busbar when the bow thruster is working, which is nearly higher than the stable value by A, and the stable current will gradually decrease as the thruster works. The sudden and large increase of the surge current will cause obvious heat generation in the SMG line, and the long-term surge current will even endanger the normal operation of the generator.

4.2 The power quality of the SMG at the 2s

At the 2 s, the ship's propeller motor began to work. At this time, it can be seen that the bus voltage has a short voltage drop. This is because the motor consumes a large amount of current when it starts, and then returns to a normal level. The detection results of voltage harmonics, three-phase voltage are shown in the Fig.5

As can be seen in the Fig.5, when the propeller motor starts, the three-phase voltage unbalance changes little, and as the motor runs smoothly, the voltage waveform gradually returns to the state before the start, and the current appears when the motor starts. After a significant increase, it quickly fell back to normal. But at the same time, there is a slight imbalance in the current, which leads to larger current fluctuations and more serious oscillations.

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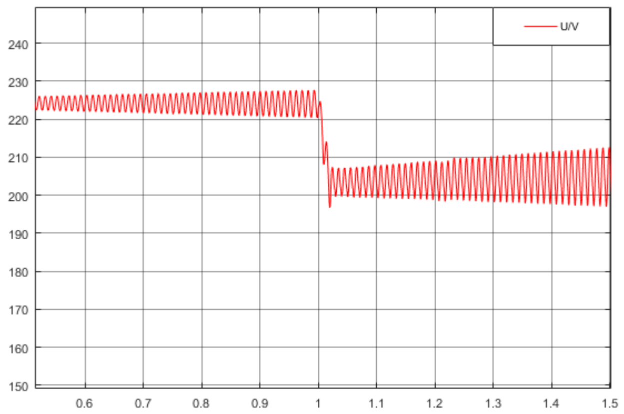
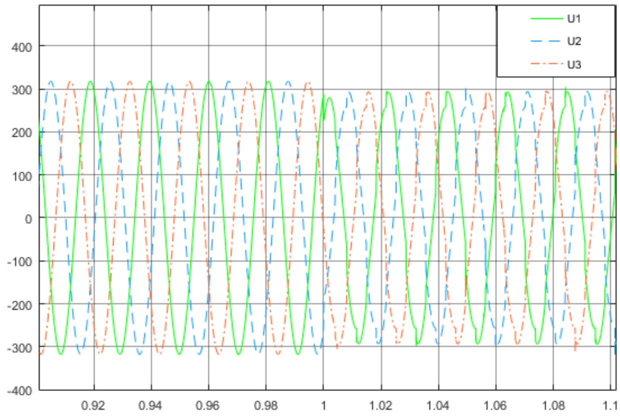
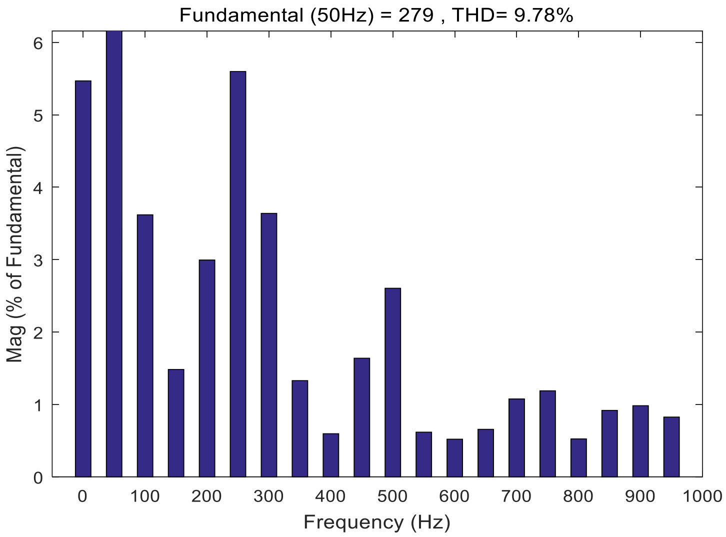


(a)



(b)



(c)

Fig. 4 Voltage waveform(a), Three-phase voltage waveform(b) and Harmonic analysis(c) at the 1s

4.3 The power quality of the SMG at the 3s

At the 3s, the ship's propeller motor stops working. At this time, there is no obvious change in the voltage and current in the bus. However, as the motor stops working, the current imbalance gradually decreases and the current waveform gradually becomes stable. At this time, the results of the detection of voltage harmonics, three-phase voltage in the bus are shown in the Fig.6.

4.4 The power quality of the SMG at the 4s

At the 4s, the bow thruster stopped working. At this time, it can be seen that the bus voltage has rebounded and returned to the normal value. At this time, the voltage harmonics, three-phase voltage waveforms are shown in the Fig.7.

It can be seen from the Fig.7 that with the stop of the bow thruster, the high-order harmonics are significantly reduced, and the three-phase voltage tends to stabilize, the unbalance degree decreases, the surge current decreases, and the current gradually returns to the normal value, and the power quality Compared with the time when the bow thruster is working, it has not been restored to the state when the SMG first started operation

4.5 Data summary

From the previous pictures and analysis, it can be seen that in the extreme operating conditions of the single motor of the SMG, there will be obvious voltage changes in the busbar when the bow thruster

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starts and stops, and the voltage amplitude can exceed 4%. This voltage change will obviously affect the power quality of the ship's micro-grid, as well as the working conditions of other devices in the micro-grid. At the same time, with the work of the bow thruster, obvious high-order harmonics appear in the SMG bus; at the same time, the start of the bow thruster will generate a large surge current in the bus, and the instantaneous value of the current can even reach A, Far exceeds the rated value of some electrical loads.

When the propeller motor in the SMG starts, there will be a slight voltage drop. As the motor runs smoothly, the voltage drop will gradually decrease. However, due to the characteristics of the motor operation, it will cause the bus current to appear. Instantaneous inrush current, but it will also gradually decrease as the motor works smoothly.

In terms of three-phase voltage imbalance, the work of the bow thruster will cause a significant imbalance of the three-phase voltage, while the operation of the propeller motor has relatively little influence on the degree of the three-phase voltage imbalance.

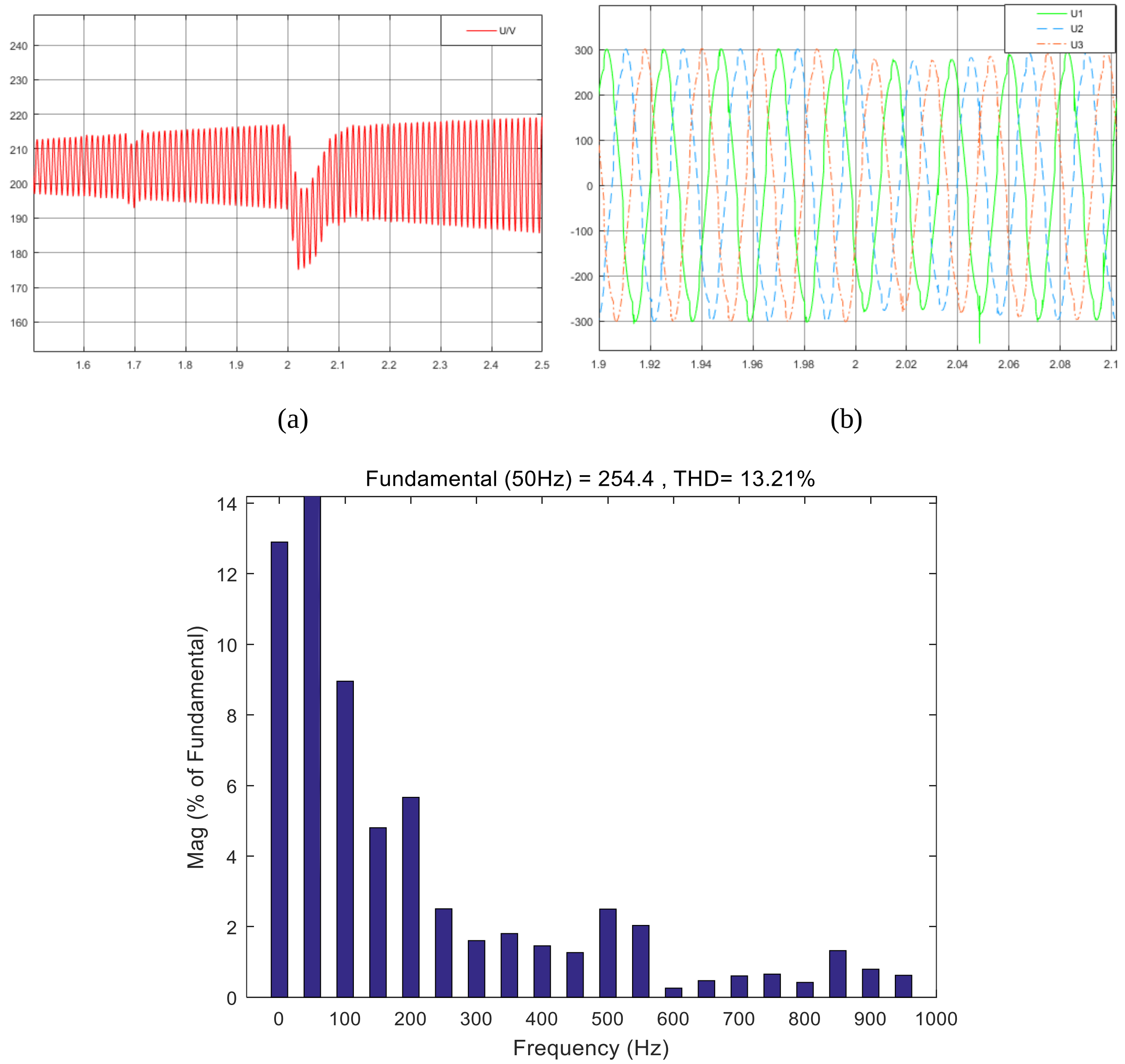

Fig. 5 Voltage waveform(a), Three-phase voltage waveform(b) and Harmonic analysis(c) at the 2s

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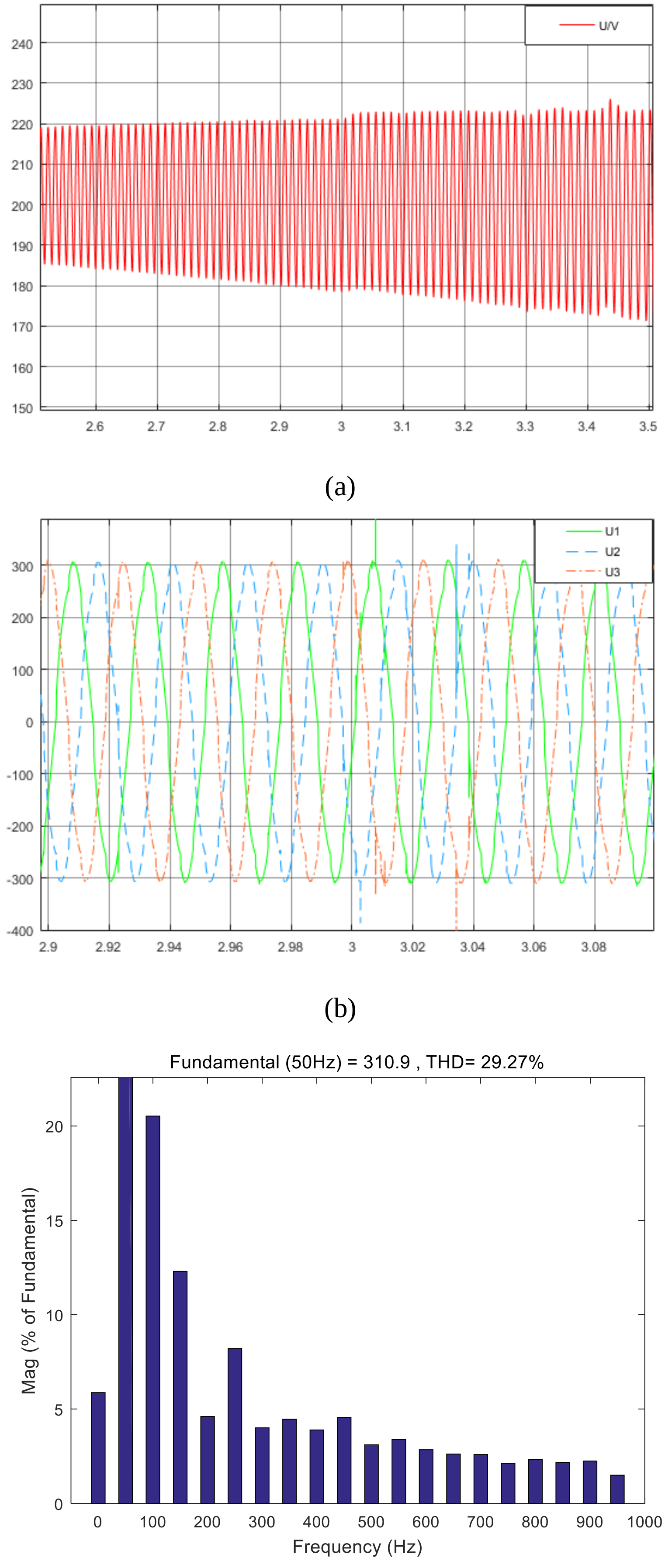

Fig. 6 Voltage waveform(a), Three-phase voltage waveform(b) and Harmonic analysis(c) at the 3s

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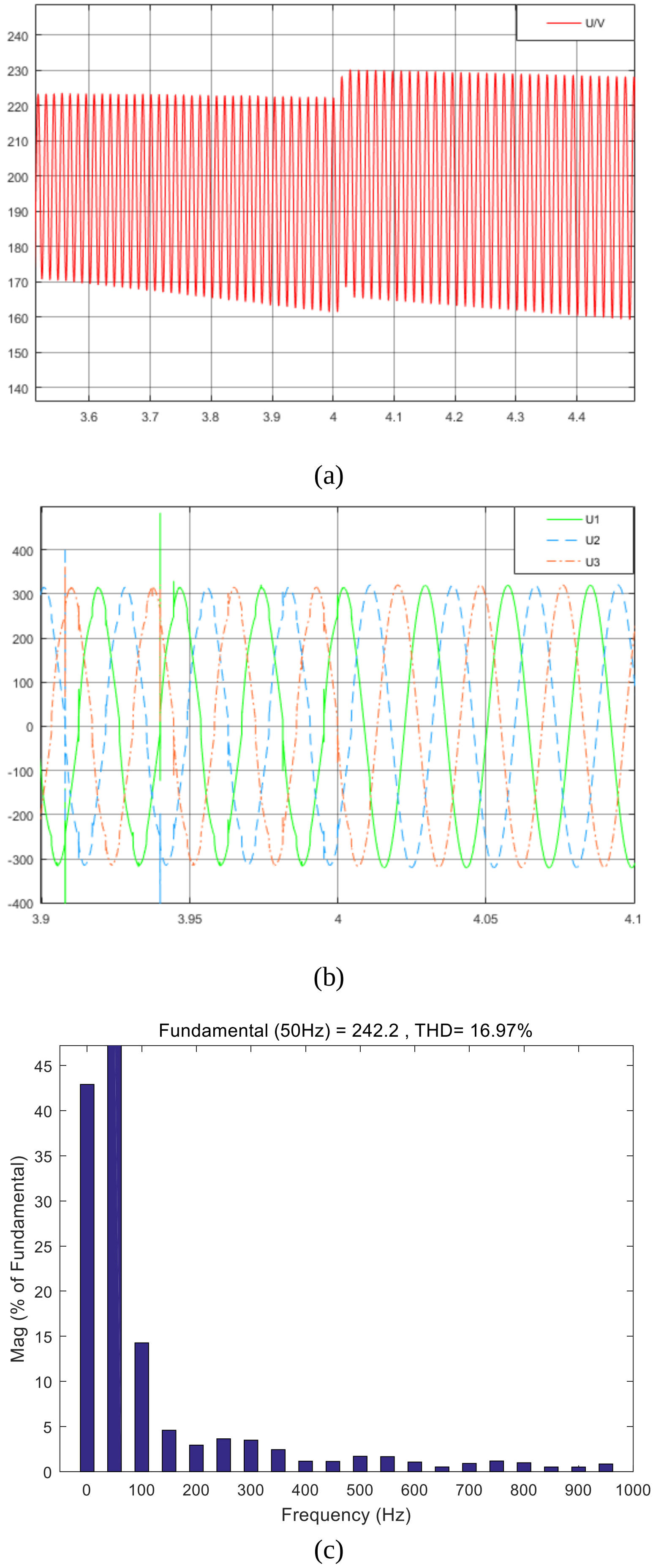

Fig. 7 Voltage waveform(a), Three-phase voltage waveform(b) and Harmonic analysis(c) at the 4s

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5. Conclusion

In the previous analysis, it can be seen that the high-power nonlinear loads in the ship's micro-grid, such as bow thrusters, will have a huge impact on the power quality of the micro-grid, resulting in large voltage deviations and harmonic components. Obvious surge currents are generated in the bus, and at the same time, it will cause the problem of mismatch of the three-phase voltage in the bus. Compared with the bow thruster, the relative propeller motor has less impact on voltage and current, and will gradually eliminate the impact as the motor runs stably. Therefore, how to suppress and improve the problems of high-order harmonics, three-phase voltage mismatch and inrush current when high-power nonlinear loads are started will be the key to the protection and research of SMG systems.

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