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Research on Simulation Evaluation of Stability of Integrated Power System Network

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Abstract. The ship's medium-voltage AC integrated power system, hereinafter referred to as the integrated power system, is the core part of the ship's power system. Its networking method and operational stability are crucial to the ship's power supply and navigation safety. Currently, as the power load of ships increases and the complexity of the power system increases, the integrated power system is facing many problems and challenges, including how to select the topology of the integrated power system while taking into account the requirements of stable economy, and the impact of sudden changes in load on system stability. System voltage stability when impact or short-circuit fault occurs, whether the relay protection system has sufficient selectivity, etc. Therefore, this study aims to study the stable operation of integrated power system networking through simulation evaluation.

Keywords. integrated power system; topological structure; load mutation; short-circuit fault; relay protection

1. Introduction

With the increasing power load of ships and the increasing complexity of electrical equipment, the ship's integrated power system has become the "central nervous system" of the ship 12. Among them, the medium-voltage power supply and distribution network, as an important part of the ship's power system 12, is responsible for supplying power to various ship systems and equipment. Its network stability and reliability are of great significance to the normal operation and safe navigation of ships. Therefore, studying the topology and network operation mode of ship medium-voltage power supply and distribution network 12 is of great significance for optimizing the performance of the power system and improving the reliability and stability of the power system.

As the core part of the ship's power system, the ship's medium-voltage AC integrated power system is crucial to the ship's power supply and navigation safety 12. Currently, with the increase in ship power load and the complexity of the power system,

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the integrated power system is facing many problems and challenges, such as how to select the topology of the integrated power system while taking into account the requirements of stable economy 12, and the impact of sudden load changes on system stability. impact 12, system voltage stability when a short-circuit fault occurs 12, whether the relay protection system has sufficient selectivity, etc. 12. Therefore, this study aims to study the stable operation of integrated power system networking through simulation evaluation.

In terms of solving the problem of stable operation of integrated power system networking, many domestic and foreign scholars have done a lot of research. Reference 12 proposed sewing training-based optimization (STBO). This algorithm iteratively optimizes control parameters by using a set of candidate solutions. , to find the optimal solution set that minimizes frequency deviation and enhances system stability. Literature 12 introduced Caputo's fractional-order definition into a ship power system with two parallel generators, and constructed a fractional-order ship power system with extreme multi-stability. Literature 12 uses a double closed-loop control method combined with a pulse width modulation algorithm (PWM) to control the energy storage system to smooth the power fluctuations caused by the electric propulsion system. Literature 12 modeled FC-TCR and designed a closed-loop control algorithm to ensure voltage stability to evaluate and compare the performance of PPF and FC-TCR compensators in reducing high-power SPS harmonics and improving voltage stability. Literature 12 implements a dynamic compensation device that can convert the EEN into a flexible network. When the EEN is affected by small or large disturbances, the performance of the power grid on the ship is improved. These improvements are achieved by integrating automatic voltage regulators to ensure temporary This is achieved by stabilizing the state voltage.

This study mainly uses simulation software for simulation, and combines the parameters and conditions of the actual ship power system to establish a simulation model of the integrated power system, conduct simulation experiments and data analysis, and evaluate the stability and reliability of the integrated power system network through simulation. , determine the stability and reliability of the system design scheme and ensure the safe navigation of the ship. Mainly includes integrated power system simulation modeling, integrated power system power flow calculation under different working conditions, focusing on integrated power system network topology selection, integrated power system stability under load mutation conditions, selective evaluation of relay protection schemes, Problems such as voltage stability analysis of integrated power systems under short circuit faults.

2. Network topology research

In the comprehensive power system of the slipway, the medium voltage power supply and distribution network is one of the core components of the ship's power system. The medium-voltage power supply and distribution network is mainly responsible for boosting the electric energy generated by the ship's generator set through the transformer and supplying various ship electrical equipment [5]. At the same time, it also needs to meet the different power requirements of the ship's electrical equipment. Therefore, the medium-voltage power supply and distribution network The topological structure is of extremely high importance.

Choose a tree layout as the layout method. The tree wiring method can improve the reliability of the system by providing multiple backup paths. If one branch fails, other branches can still work normally. Tree routing makes it easier to add new branches and connections. This flexibility can provide convenience when new equipment needs to be added to the slipway or the system architecture needs to be adjusted. Tree wiring can make system management and maintenance more decentralized because each branch can be managed independently. This simplifies troubleshooting and maintenance because different branches can operate independently without affecting the entire system.

The connection method should be series connection.

The cable wiring method should be centralized wiring. The electric energy generated by the ship's generator set is boosted through the transformer and then uniformly supplied to each ship's electrical equipment. By adopting centralized wiring, Slip A can simplify the wiring structure, reduce material and installation costs, and simplify the wiring design and management of the entire system. At the same time, the centralized wiring method can concentrate all connections in one place, saving space and improving the compactness of the layout. In addition, centralized wiring can make the management of the entire system more centralized and simplified. All connections are in one place, making troubleshooting, maintenance and management easier. This centralized management approach helps improve system efficiency and reliability. A centralized cabling approach may be more cost-effective in terms of material and installation costs. Tree cabling may require more cables and connectors, increasing cost and maintenance complexity.

3. Network running stability analysis simulation modeling

Three-phase alternating current is used in most ships, and diesel engines and synchronous generators are generally used as the main power supply equipment of the ship to provide electrical energy for the ship load. The synchronous generator converts the mechanical energy of the diesel engine into electrical energy, and the performance of the power generation equipment determines the performance of the power grid. Therefore, only a suitable mathematical model can correctly reflect the dynamic characteristics and adjustment accuracy of the system. For this reason, the most important thing when studying a system is to establish a suitable model. Mathematical models summarize the changing laws of dynamic systems by using mathematical expressions. The coefficient matrix of the state equation of the synchronous generator is a time-varying matrix, and since the load carried by the ship power grid is generally not completely symmetrical, the stator generally works in an asymmetric state. The rotor of a synchronous motor is symmetrical about the dq axis, so when establishing a mathematical model of the motor, it is usually converted to dq coordinates for analysis.

The synchronous generator is a high-order, nonlinear, strongly coupled multi-variable system. In the process of establishing the mathematical model of the synchronous generator, simplifying assumptions are made: the magnetic saturation phenomenon is ignored; the three-phase windings of the stator are symmetrically distributed; the rotor has a direct axis and The cross-axis structure is symmetrical; the stator magnetic potential changes sinusoidally in space; high-order harmonics are ignored (the role of the groove is ignored). The fifth-order practical model of the generator selected for this study is as follows.

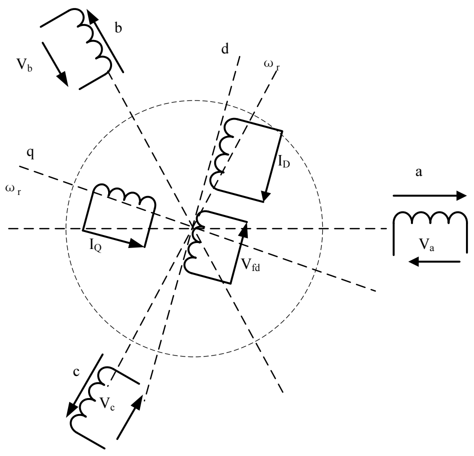

Fig.1 Structure diagram of synchronous generator

The mathematical expression of the direct axis (D-axis) of the synchronous generator is:

$$T'_{d0}\frac{dE'_q}{dt} = E_f - \frac{X_d - X'_d}{X'_d - X''_d}E'_q + \frac{X_d - X'_d}{X'_d - X''_d}E''_q \tag{1}$$

$$T''_{d0}\frac{dE''_q}{dt} = E'_q - E''_q - (X_d - X'_d)i_d \tag{2}$$

$$u_q = E''_q - r_a i_d - X''_d i_d \tag{3}$$

The mathematical expression of the quadrature axis (q axis) of a synchronous generator is:

$$T''_{q0}\frac{dE''_d}{dt} = -E''_d + (X_q - X''_q)i_q \tag{4}$$

$$u_d = E''_d - r_a i_d + X''_q i_q \tag{5}$$

Rotor motion equation:

$$J\frac{d\omega_m}{dt} = T_m - T_e \tag{6}$$

$$\frac{d\alpha_m}{dt} = \omega_m \tag{7}$$

In the formula: T′d0 and T″d0 represent the transient and sub-transient open circuit time constants on the direct axis, T″q0 represents the sub-transient open circuit time constant on the quadrature axis; Xd, X′d, X″d represents the armature reactance, transient reactance and sub-transient reactance on the direct axis of the synchronous generator, and Xq and X″q represent the armature reactance and sub-transient reactance on the quadrature axis. E′d represents the direct-axis transient electromotive force, E′q represents the quadrature-axis transient electromotive force, E″q represents the quadrature-axis super-transient electromotive force, Ud is the d-axis output voltage, Uq is the q-axis output voltage, and ra is the stator winding. value.

4. Selective protection analysis

4.1. System description

This chapter analyzes the selective protection of the 6.6kV and 380V power distribution system of the integrated power system of A slipway based on the single-line diagram of the whole ship's power system, the load calculation sheet of the whole ship's power system, and the short-circuit current calculation sheet of this project provided by the overall , forming a selective protection analysis report for the whole ship's power distribution system.

The single-line diagram of the comprehensive electric propulsion system of slipway A is shown in the figure 2 below. The system mainly includes the following contents:

There are 5 sets of diesel generator sets, 4 sets of 6600V, 50Hz, 4400kW units, 1 set of 6600V, 50Hz, 1600kW auxiliary generator sets, all 5 sets are equipped with grounding resistors, 1#, 2# main units and auxiliary units are connected to the port side medium voltage distribution Board busbar, 3# and 4# main unit are connected to the starboard medium voltage distribution board busbar;

2 sets of 6600V marine medium-voltage distribution boards (the port and starboard medium-voltage distribution boards are connected through bus tie breakers). The distribution boards are connected to the following equipment through cables:

2 sets of virtual 24-pulse shaft propeller main propulsion branches: each set has 1 phase-shifting transformer (6600V/2 × 1350V, Dd0Y11 (±7.5° respectively), 4200kVA), 1 12-pulse main propulsion inverter (3000kW), 1 main propulsion motor (3000kW, 130rpm);

2 sets of virtual 24-pulse rudder propeller main propulsion branches: each set has 1 phase-shifting transformer (6600V/2 × 1350V, Dd0Y11 (±7.5° respectively), 5500kVA), 1 12-pulse rudder propeller inverter (4000kW), 1 rudder propeller propulsion motor (4000kW, 1000rpm);

3 sets of 12-pulse side propulsion branches: each set has 1 soft starter and 1 side propulsion motor (2200kW, 1000rpm);

8 sets of 12-pulse lifting systems; each set has 1 phase-shifting transformer (6600V/2×400V, Dd0Y11, 1000kVA) and 1 12-pulse frequency converter;

2 sets of 12-pulse winch systems; each set has 1 phase-shifting transformer (6600V/2×710V, Dd0Y11, 3000kVA) and 1 12-pulse frequency converter;

2 sets of 12-pulse lifting systems; each set has 1 phase-shifting transformer (6600V/2×690V, Dd0Y11, 2000kVA) and 1 12-pulse frequency converter;

2 sets of daily distribution transformers: 6600V/400V, 50Hz, 2500kVA.

The design of the selective protection scheme of this system mainly targets the generator branch, main propulsion transformer branch, rudder propeller transformer branch, side propulsion motor branch, upgrade system power supply branch, winch system power supply branch, and hoisting system power supply. Branch circuits, daily distribution transformer branch circuits, etc.

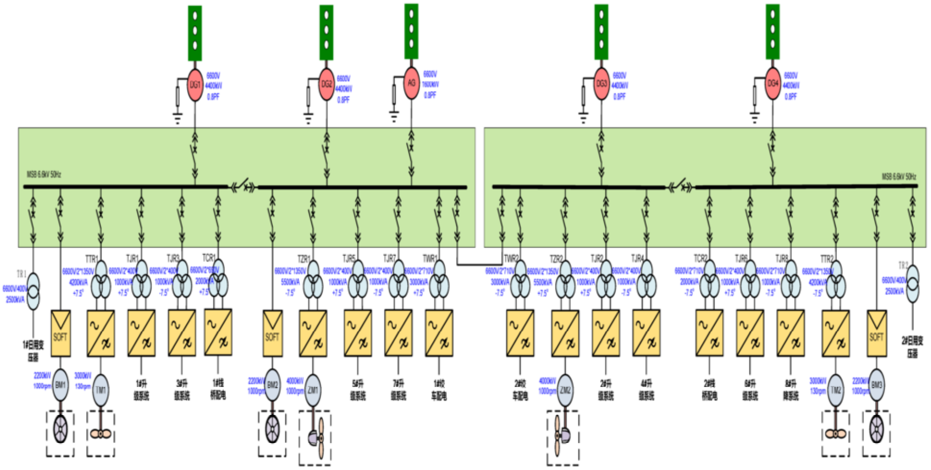

Fig.2 Single line diagram of integrated electric propulsion system

4.2. Circuit breaker and trip selection

According to the short-circuit current calculation sheet and the actual selective protection requirements of the system, the selection of the main comprehensive relay protection devices in the system is as shown in the following table:

Table 1 Main circuit breaker and trip device selection

Protection device name	Circuit breaker type	Comprehensive relay protection device model	remark
No. 1 main generator set	VD4-12/630A	REG630	
No. 2 main generator set	VD4-12/630A	REG630	
No. 3 main generator set	VD4-12/630A	REG630	
No. 4 main generator set	VD4-12/630A	REG630	
Auxiliary generator set	VD4-12/630A	REG630	

Protection device name	Circuit breaker type	Comprehensive relay protection device model	remark
Contact switch breaker	VD4-12/630A	REF615	
Number 1 to 2 main propulsion transformer	VD4-12/630A	RET615	
Number 1 to 2 propeller transformer	VD4-12/630A	RET615	
Soft initiators are pushed on sides 1 to 3	VD4-12/630A	RET615	
1~8 lifting system transformer	VD4-12/630A	RET615	
1~2 hoisting system transformer	VD4-12/630A	RET615	
1~2 winch system transformer	VD4-12/630A	RET615	
1~2 daily distribution transformer	VD4-12/630A	RET615	

4.3. Selective analysis

Take the cooperation between the main generator branch circuit, the contact switch circuit breaker, the primary circuit breaker of the daily distribution transformer, and the secondary circuit breaker of the daily distribution transformer as an example. Selectivity between 6600V equivalent generator branch (2×4400kW=8800kW), tie switch circuit breaker, daily distribution transformer primary circuit breaker, daily distribution transformer secondary circuit breaker (converted to high voltage side) The fit curve is shown in Figure 3. It can be seen from the figure that the protection between the main generator branch, the tie switch circuit breaker, the primary circuit breaker of the daily distribution transformer, and the secondary circuit breaker of the daily distribution transformer is selective.

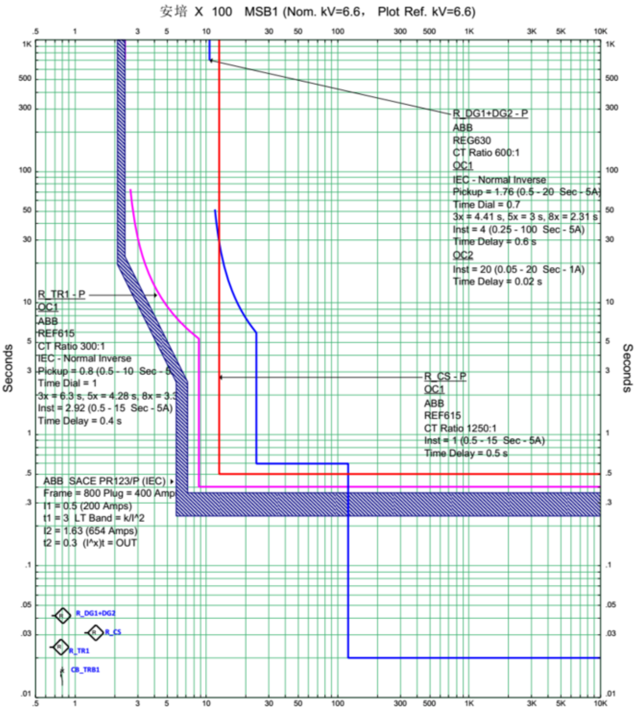

Fig.3 Main generator branch and liaison switch circuit breaker, primary side circuit breaker of daily distribution transformer, secondary side circuit breaker of daily distribution transformer selective protection matching curve

5. Transient performance simulation analysis

5.1. Short-circuit fault and voltage crossing analysis

Under cruising conditions, Shipyard A uses a total of four generators to power the entire medium-voltage system, including three main generators with a rated power of 4400kw and an auxiliary generator with a rated power of 1600kw. Electrical equipment includes two main propulsion motors with a total power of 4666.7kw, two full-rotation thruster motors with a total power of 6222.2kw, and low-voltage load power of 1526.4kw. When a single-phase grounding short-circuit fault occurs, the No. 1 main generator generates a generator-side short-circuit fault and the voltage ride-through simulation is shown in Figure 4. When the short-circuit fault occurs at 0.2s, the three-phase AC bus voltages all drop, but the degree of drop is different due to different types of short-circuit faults. Among them, when the three-phase short-circuit fault occurs, the three-phase bus voltage drops the most seriously, and has almost dropped to For a single-phase grounding short-circuit fault, the bus voltage drops slightly, but the three-phase voltage is seriously unbalanced. This result is consistent with the power system analysis theory. After the 0.7s circuit breaker removes the short-circuit fault after a short operating time, the bus voltage returns to normal.

According to the requirements of IEC62271-1 "High Voltage Switchgear and Control Equipment", the short circuit duration of the ship's integrated power system under the most serious short circuit fault is within 1s, and the recommended time is within 0.5s. According to the above simulation analysis, the ship's integrated power system can restore voltage within 0.5s under the most serious short-circuit fault, which fully meets the requirements of IEC standards and is better than the recommended indicators. Therefore, the slipway meets the stability requirements under short-circuit conditions and has excellent voltage ride-through performance.

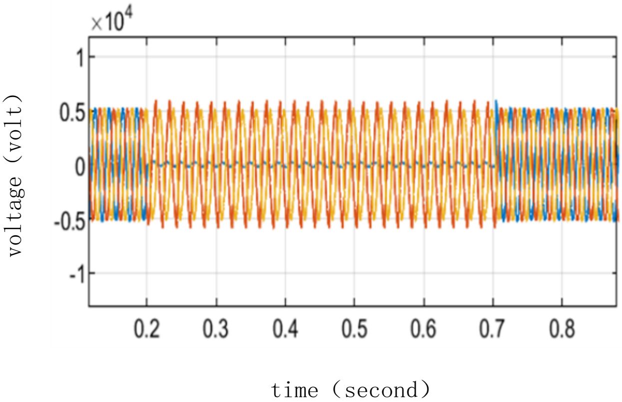

Fig.4 Single-phase grounding short-circuit voltage crossing

5.2. *Heavy load starting*

Under cruising conditions, Shipyard A uses a total of four generators to power the entire medium-voltage system, including three main generators with a rated power of 4400kw and an auxiliary generator with a rated power of 1600kw. Electrical equipment includes two main propulsion motors with a total power of 4666.7kw, two full-rotation thruster motors with a total power of 6222.2kw, and low-voltage load power of 1526.4kw. Under this load condition, the main propulsion motor starts. At this time, the simulation results of the medium voltage bus voltage are shown in Figure 5. The main thrust motor starts at 0.2s, and the loaded power is 6666.7kw, which causes the voltage of the medium voltage system to drop. After about 0.5s, the voltage rises to a steady state value.

According to IEC61000 "Power Quality Standard", the short-term voltage drop of the integrated power system should be less than 10%, and the recovery time should be less than 10s. Therefore, based on the above analysis, the voltage drop of the shipyard integrated power system due to the startup process of large motor loads fully complies with IEC standards. Stable when starting with large motor loads.

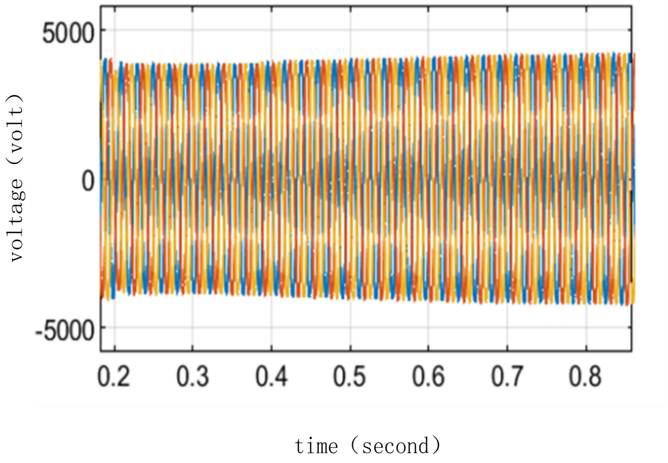

Fig.5 Three-phase voltage of medium voltage system in cruising condition

5.3. Sudden change in propulsion system load

Taking slipway A under full-speed cruising conditions as an example, the propulsion system load suddenly decreases at 1 second, and the bus voltage simulation analysis of the system switching from full-speed cruising conditions to cruising conditions is as follows.

Under full-speed cruising conditions, Shipyard A uses a total of five generators to power the entire medium-voltage system, including four main generators with a rated power of 4400kw and an auxiliary generator with a rated power of 1600kw. Electrical equipment includes two main propulsion motors with a total power of 6666.7kw, two full-rotation thruster motors with a total power of 8888.9kw, and low-voltage load power of 1526.4kw.

Under cruising conditions, Shipyard A uses a total of four generators to power the entire medium-voltage system, including three main generators with a rated power of 4400kw and an auxiliary generator with a rated power of 1600kw. Electrical equipment includes two main propulsion motors with a total power of 4666.7kw, two full-rotation thruster motors with a total power of 6222.2kw, and low-voltage load power of 1526.4kw.

At 1s, the propulsion system load suddenly decreased, the power of the main propulsion motor suddenly decreased to 2000kw, and the power of the full-turn thruster motor suddenly decreased to 2666.7kw. At this time, a 4400kw main generator was unloaded. The simulation curve is shown in Figure 6. The medium-voltage bus voltage rises and then drops to a steady-state value after 0.5s. During this process, the medium-voltage bus voltage will increase compared to the voltage before the propulsion system load suddenly decreases.

According to the CCS ship regulations, the dynamic performance of the marine power system is that the voltage fluctuation range is ±20% and the recovery time is 1.5S; the frequency fluctuation range is ±10% and the recovery time is 5S. Therefore, the slipway integrated power system has very good stability under sudden changes in propulsion load.

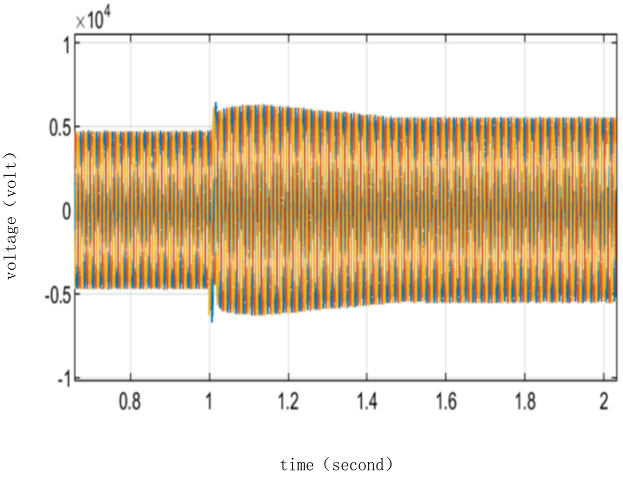

Fig.6 Medium voltage bus bar voltage during sudden load loss of main propulsion system

6. Conclusion

This article first analyzes the topology of the integrated power system of the slipway from the perspective of stability, and obtains the advantages and disadvantages of different topological design methods of the slipway. Integrating economy, the use space of the ship, and maintainability, the analysis concludes that the slipway should adopt a tree layout. method, series connection method, cable layout should adopt centralized layout method.

Based on the above analysis of the topology of the integrated power system of the slipway, and based on the mathematical models of different components of the integrated power system of the slipway, the calculation model of the integrated power system of the slipway is established by using simulation software.

Based on the short circuit calculation results, the setting value calculation and delay curve configuration are performed to obtain the setting table. According to the setting table, the selectivity between different switches under different short-circuit faults is verified. It can be found that the relay protection devices of different lines of the shipyard integrated power system meet the selectivity requirements. When a fault occurs, the fault can be minimized as much as possible. Cut off the range to ensure that the remaining part can operate stably.

By performing short-circuit calculations on the comprehensive power system calculation model of the shipyard under different working conditions and under impact conditions such as large motor load startup, static load startup, propulsion system load mutation, etc., the node voltage can still be maintained to fluctuate within the allowable range and quickly transition to a stable state.

In summary, it can be concluded that the integrated power system of the slipway has good stability.

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