Analysis and Calculation of Power System for Medium Voltage AC Electric Propulsion Ship

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Abstract. This paper introduces the advantages of integrated electric propulsion system in large and medium-sized ships. The short circuit current, grounding fault, harmonic and voltage drop in the design of medium voltage AC integrated power system are calculated and analyzed. Taking a real ship as an example, the power system design is completed.

1. Introduction

The integrated electric propulsion system adopts electric propulsion technology, which can manage the ship power station in a unified way and reasonably distribute the electric energy of the whole ship. It has the advantages of flexible equipment layout, public power station reuse and good mobility. It is especially suitable for dredgers, crane ships, offshore platforms, ice breakers, luxury postal ships and other ships.

With the development of modern ship large-scale and electric propulsion technology, there are more and more electrical equipment on board, the power demand is increasing, and the capacity of ship power station is increasing. Low voltage electric propulsion system can no longer meet the demand. Considering the large volume of low-voltage equipment, more cables and the actual equipment level of system short-circuit protection, medium voltage electric propulsion system becomes an inevitable choice.

The purpose of this paper is to calculate and analyze the short circuit current, grounding fault, harmonic, voltage drop and other key problems in the design of medium voltage AC integrated power system, and provide the design method of power system.

2. Overview of Ship

As shown in Figure 1, a large dredger adopts full electric drive mode. The ship adopts 6600V/50Hz neutral point high resistance grounding insulation system, which is powered by the ship's public power station. Three 3840kW main diesel generator sets and one 1500kW main diesel generator set provide 3-phase 6600V/50Hz power supply to the common bus, and feed the propulsion equipment and marine load through the bus. 6600V medium voltage distribution board supplies power to AC400V bus through two 6600V/400V transformers (one for use and one for standby). Another 500kW diesel generator set and a 300kW emergency diesel generator set are set up.

Two sets of propeller with rated power of 4500kW are set at the stern. The prime mover is asynchronous motor, which is driven and adjusted by frequency converter. Two sets of 450kW thrusters are set in the bow. The prime mover is asynchronous motor and driven by soft starter.
The ship is equipped with two sets of frequency conversion drive systems for dredge pump (underwater pump). Each frequency converter drives one 4000kW cabin mud pump motor and one 1700kW underwater pump motor through the dredge pump inverter switching cabinet.

The ship is equipped with two sets of frequency conversion drive systems for high-pressure water pumps, which are driven by two 1000kW asynchronous motors and regulated by frequency converters.

![Figure 1. single line diagram of power system of a large dredger](image)

### 3. Calculation of Short-circuit Current

The calculation of the maximum short-circuit current and the minimum short-circuit current are mainly divided into two parts: the calculation of the maximum short-circuit current and the calculation of the minimum short-circuit current.

The calculation of the maximum short circuit current is used to check the sectional capacity, connection capacity of the circuit breaker, the electrodynamic stability and thermal stability of the bus bar. The calculation of the minimum short circuit current mainly provides the basis for the design of the selective protection scheme and the setting of the selective protection parameters of the power system. Table 1 shows the operating conditions of the ship.

| condition        | Operation of generator | Total load power | load rate |
|------------------|------------------------|------------------|-----------|
| Departure        | 2×4224kW               | 6252 kW          | 74%       |
| Sailing (20m)    | 3×4224kW+1×1500kW      | 10554 kW         | 74.5%     |
| Dredging (28m)   | 3×4224kW+1×1500kW      | 10968 kW         | 77.4%     |
| Dredging (38m)   | 3×4224kW+1×1500kW      | 11925 kW         | 84.1%     |
| Dredging (50m)   | 2×4224kW+1×1500kW      | 8416 kW          | 84.6%     |
| Bank discharge   | 3×4224kW+1×1500kW      | 11687 kW         | 82.5%     |
| Mooring          | 1×500kW                | 377 kW           | 75.5%     |
| Emergency        | 1×300kW                | 252 kW           | 84.1%     |
| Shore            | 280kW                  | 245 kW           | 87.8%     |

Under the condition of 20 m dredging for shore power ships, 4 main generators are running on the power grid, feeding two main propulsion, mud pump, high-pressure flushing pump and other daily loads.
The unit load rate is the highest. In the system, since the main propulsion motor, mud pump motor and flushing pump motor are all driven by variable frequency, they do not contribute short-circuit current in case of system failure, so the main faults in the system are Current comes from four main generators, push motors and some daily loads.

Under parking conditions, only one parked generator unit operates in the system, and the minimum short-circuit current is the short-circuit current at the farthest short-circuit.

The over-current setting value and delay time of different Siemens integrated relay protection devices are used to realize short-circuit protection of three-phase and two-phase lines. See Table 2 for type of circuit breaker protection.

### Table 2. type of circuit breaker protection

| Type | Equip | G | MP | BP | Bus | T | HP | DP |
|------|-------|---|----|----|-----|---|----|----|
| OL   | √     |    | √  | √  |     | √ |    |    |
| SC   | √     | √  | √  | √  |     | √ |    |    |
| LV   | √     | √  |    | √  | √   | √ |    |    |
| RP   | √     |    |    |    |     |   | √  |    |
| DIF  |       |    |    |    |     |   |    | √  |
| GP   | √     | √  | √  | √  |     | √ |    | √  |
| NS   | √     |    |    |    |     |   |    |    |

### 4. Analysis of Grounding Fault

For the ship power system, grounding is the connection with the ship hull. Generally, fault analysis is mainly carried out for one-phase ground in three-phase system.

In medium voltage networks with high resistance grounding at the neutral point, the maximum capacitive current of the system occurs when a ground fault occurs:

- All generators are connected to the bus
- Medium voltage distribution board bus switch closed
- Transformers and motors are connected to the bus

Since the capacitive current component contributed by transformer is much smaller than that contributed by generator and cable when system ground fault occurs, the capacitance of transformer to ground is neglected in calculation.

Generally, uncontrolled rectified voltage source inverter is used in integrated electric propulsion system. Since rectifier diode is a unidirectional element, its DC side supporting capacitance can not provide capacitive current to AC power grid. In order to reduce harmonics in power grid, phase shifting transformers are often used to make up the frequency converter branch into 12-pulse or 24-pulse rectification. Therefore, only the capacitive component of cable contribution can be considered for the frequency converter branch when analyzing ground fault of medium voltage electric propulsion system.

The capacitive current provided by each equipment of the system is calculated using the following formula:

**LINE:**

\[ I_{C_0} = 3 \times I_{C_j} = \sqrt{3} \times U_n \times \omega \times l \times C_j \]

**MOTOR:**

\[ I_{C_0} = \frac{\sqrt{3} \times U_n \times \omega \times C_0}{2} \]

- \( C_j \) Total capacitance per phase cable to ground (F)
- \( C_0 \) Capacitance of generator per phase winding (F)
- \( l \) Cable length (m)
- \( U_n \) Voltage per phase (V)
According to CCS code and IEC standard, when single-phase grounding fault occurs in the system, the total grounding fault current of high-resistance grounding system must be less than or equal to the total grounding fault current of high-resistance grounding system.

Grounding system design is mainly used to analyze grounding resistance grounding fault current value, which is higher than the current value of grounding capacitance contribution to distribution panel under the worst conditions. The grounding capacitance of each equipment and cable connected to distribution panel must be considered here.

Based on the calculation and analysis, considering the protection strategy of the system, the design of high resistance grounding system for each generator is selected as follows:

1) Ground fault current value of high resistance grounding system
   IR0 = 3A
2) Setting current value of grounding protection
   Iset = 1A
3) Ground resistance value
   R = Un/IR0 = 1270Ohm
4) Ground resistance capacity
   P = UnIR0 = 11.43kW

5. Calculation of Voltage Drop

In order to calculate the transient and steady-state voltages of each node of power grid under different load conditions. Establish system simulation model in MATLAB. The steady-state voltage drop is calculated according to the worst case. In practice, the plant is easy to operate under full load and the load will not normally work under full load, so the voltage drop of transformers and cables is smaller than the calculated value, so the system voltage at each point under full load will be slightly higher than the calculated value.

Transient voltage drop is assumed to be the voltage drop at all points of the system power grid when a load is suddenly put into operation. Transient impact on the power grid can be neglected due to the slow load increase of variable frequency loads when they are put into operation.

The steady-state voltage drop is calculated as the voltage drop at all points of the power grid during the steady-state operation of the system. The voltage drop includes generator voltage drop, cable voltage drop and transformer voltage drop. As the main propulsion transformer, mud pump transformer, flushing pump inverter and main power transformer are all equipped with pre-magnetizing device, the starting current has no impact, and the transient impact on the power grid can be ignored. The adjustment of AVR is not considered in the transient process. The calculation results are as follows.

6. Conclusion

Through the calculation and analysis of the short-circuit current, grounding fault, voltage drop and other key issues of the medium voltage AC integrated electric propulsion ship power system, the selection of the main circuit breaker of each branch, the parameter setting of relay protection device and grounding protection device can be completed, so that the power system has perfect protection strategy and ensures the stability of the power system.

References
[1] Wu Gengshen, Li Chengyu. The Medium Voltage Electric System on the Electric Propulsion Ships. Marine Electric & Electronic Technology. 2003,23(6):15-18
[2] Wang Liang, Wang Xiaofeng, Zhang Suo, Peng Shan, Yang Linmei, Wang Liangxiu. Development of Marine Mv Power System. Mechanical and Electrical Equipment. 2003, (2):1-3
[3] Zhu Di, Wu Feiwen. On type of all-electric propulsion plan for suction hopper dredger. Ship & Boat. 2008, (5):36-41