Simulation Analysis of Ship Integrated Power System Fault Characteristics

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Abstract

To study operation status and fault status of the ship integrated power system a lot of research has been completed. Short-circuit failure and loss of field failures is one of the key content. Modular thinking applies to the establishment of the system model. Simulation model is established which based on the mathematical model of system including: diesel generator and its excitation module, permanent magnet synchronous propulsion motor and load module and inverter module. Different faults are added to the system at a specific time in the simulation process. Fault state of the transient process is complete recorded. The fault status of the ship integrated power system can be obtained based on simulation results. A more accurate simulation results will be obtained because of PSCAD software which is the professional simulation software.

Keywords: Ship Integrated Power System, Short-Circuit Failure, Loss of Excitation, PSCAD

1. Introduction

Ship's power plant capacity is in a increasing, the structure is more complex with the development of ship technology. Marine integrated electric propulsion system includes generation, transmission, distribution, substation, drag, propulsion, and energy storage, monitoring and power management. The advantage of marine integrated electric propulsion system is optimizing cabin, improve performance, increase efficiency, protect the environment and achieve self-control. Part load and generator power are comparable. The system exists in a larger disturbance. Frequency and voltage is a dynamic process. Normal and the fault current is very large in generators, power lines, circuit breakers and bus due to low system voltage and short supply line [1]. In this paper, the common short-circuit failure and losses of excitation failure are modeling and simulation by PSCAD [2]. Through theoretical study and simulation analysis ship power system stability under various fault state is obtained.

2. Analysis of marine integrated electric propulsion system

2.1. Ship integrated electric propulsion system neutral grounding

Grounding method is mainly divided into two categories. High current ground need interdiction single-phase ground fault by circuit breaker; the single-phase arc capable of instant self-extinguish is small current grounding. High current ground include neutral point directly grounded, low-resistance grounding of the neutral point, the neutral point low inductance grounding. Small current grounding includes neutral point ungrounded, resonant neutral grounded and neutral point grounded through high resistance [3].

Low voltage electrical systems of traditional ships usually isolated neutral. The power system can continue to run when single-phase ground fault. But the arc at the point of failure can not be self-extinguishing with the increasingly high voltage level. The overvoltage by intermittent arc makes the failure to expand. The operation of power system reliability is reduced [4]. The three-phase
insulation systems and the neutral point grounded through high resistance system are widely used in ship middle voltage power system.

2.2. Causes and hazards of ship electric propulsion system short-circuit

The short-circuit fault is the most serious failure of the ship electric propulsion system. Short circuit means all "short circuit" between phases or between phase and earth outside the normal operating conditions. Phase-to-phase or phase-to-earth is insulation except neutral point when normal operation [5]. It is short-circuiting fault if somewhere insulation damage to constitute a passage. Damage to the insulation of electrical equipment carrier part is the main reason for short circuit. The reason of insulation causes damage includes over-voltage, insulation materials natural aging, and dirty, direct mechanical loss.

Ship synchronous generator is an important element in the ship power system. Synchronous generators sudden short circuit transient process is much more complex the constant voltage source circuit. Inrush current may reach ten times of the rated current. The short-circuit current may have a serious impact on ship power system equipment [6].

2.3. Loss of excitation.

Generator loss of excitation refers to the phenomenon that a normal operation of generators loss all or part of excitation current. The reason generator loss of field include exciter failure, the automatic excitation switch mistaken trip, rotor winding fault, failure of the circuit as well as misuse and some elements are damaged. Magnetizing current will gradually decay to zero after loss of excitation. The induced potential Ed will constantly decreases with decreasing excitation current. Electromagnetic torque will be less than the torque of the prime mover. Generator power angle will increase. Generator will be out of sync with the power system when power angle exceeds static stability limit angle. The generator will draw certain inductive reactive power from the system after loss of excitation. Rotor appears to slip. Stator voltage and active power will drop. Reactive power is reversed and increasing. The entire system voltage will drop. Generator electrical quantities are swing. The safe and stable operation of the power system is affected [7].

After the above analysis, ship power propulsion system neutral grounding short-circuits failure and loss of excitation failure are studied in this paper.

3. Modeling on a marine integrated electric propulsion system

3.1. Mathematical model of ship power system

The motor current is considered to be a symmetrical three-phase sine-wave current. Motor core saturation is ignored. The eddy current and hysteresis loss in the motor has not been added. The mathematical model of permanent magnet synchronous motor is obtained in d-q shafting [8].

Stator voltage equation:

\[ u_{sd} = R_s i_{sd} + \frac{d\psi_{sd}}{dt} - \omega \psi_{sq} \]  
\[ u_{sq} = R_s i_{sq} + \frac{d\psi_{sq}}{dt} + \omega \psi_{sd} \]  

Stator flux equation:

\[ \psi_{sd} = L_{sd} i_{sd} + \psi_f \]  
\[ \psi_{sq} = L_{sq} i_{sq} \]  

Electromagnetic torque equation:

\[ T_s = \frac{3}{2} n_p (\psi_{sd} i_{sq} - \psi_{sq} i_{sd}) \]  

Motor equations of motion:
Electromagnetic torque equation after transformed:
\[ T_e = \frac{J}{n_p} \frac{d\omega_n}{dt} \]  

(6)

Torque expression when d-axis current is zero:
\[ T_e = \frac{3}{2} n_p \left[ \psi_q i_q + \left(L_d - L_q\right)i_d i_q \right] \]  

(7)

3.2. Ship integrated power system block diagram

Figure 1 shows the ship power propulsion system block diagram which includes the engine, the synchronous generator, the converter, the permanent magnet motor and propeller.

![Figure 1. Structure diagram](image)

3.3. Diesel generator system model

Diesel generator model includes diesel prime mover torque balance model, the governor servo model, and synchronous generator model phase compound excitation device voltage adjustment model. Diesel generator model is shown in Figure 2. The generator is rated at 36.5MW, voltage level is 6.6kV, and frequency is 60Hz. A closed loop speed control system is composed of the governor mechanism and diesel generator set. Diesel prime mover is stably running at rated speed and output torque power with the governor server speed control. Synchronous generator driven by diesel engine operation, closing after the issue of electric power, supplying power to the promote motor; the generator voltage remains unchanged by adjusting the generator excitation current under the phase compound excitation surge devices [9, 10].

![Figure 2. Diesel generator mode](image)

3.4. Propulsion motor model

Propulsion motor model is shown in Figure 3. Permanent magnet synchronous motor is selected to
be propulsion motor. Permanent magnet synchronous motor has the characteristics of small size, light weight, greater power density under unit volume and so on. These advantages make the permanent magnet synchronous motor well used in pod propulsion system [11, 12]. The permanent magnet synchronous motor is rated at 36MW, rated speed 120r/min in this article.

3.5. Hysteresis current vector control model

Hysteresis current vector control model is shown in Figure 4. The given current $i_q$ and $i_d$ is converted into the given three-phase current value of motor stator by coordinate inverse transform. The PWM signal is generated in comparing between the given three-phase current and the measured three-phase current. PWM signal can be driving the inverter. The actual three-phase current changes following the given three-phase current. The actual three-phase current is eventually controlled. The three-phase sinusoidal current with variable amplitude and frequency is input to the motor stator to driving motor.

3.6. Ship integrated power system fault simulation model

Ship integrated power system fault simulation model is shown in Figure 5. Through the control of the state of the excitation voltage and excitation current, loss of excitation can be simulated; Short circuit module is added to the system to set different types of short-circuit failure.
4. Fault simulation and results analysis

4.1. Short circuit fault simulation

It requires an adjustment process from start to the steady-state operation. The load was added in the first 7 seconds. The short roadblocks time is set for 12-12.3s. The simulation time is set to 20s.

Adjustment of the three-phase fault selector switch to the single-phase ground short-circuit state, a phase short circuit fault to ground is modeled. Three-phase current process of change in the single-phase short-circuit to ground fault is shown in Figure 6. Figure 6 describe the curve of the fault phase short-circuit current up to 2 times and small changes in non-fault phase current.

Adjust the three-phase fault selector switch for the AB phase short circuit state. The process of three-phase current changing when two-phase short-circuits is shown in Figure 7. Figure 7 describe the curve of the fault current can be up to 7-8 times of the rated current and DC component makes the waveform offset. Small changes in non-fault phase current.

Figure 5. Ship integrated power system fault simulation model

Figure 6. Three-phase current of the single-phase short circuit
Figure 7. Three-phase current of the two-phase short circuit

Adjust the three-phase fault selector switch for the AB phase short circuit to ground state. The process of three-phase current changing when two-phase short-circuits to ground is shown in Figure 8. Figure 8 describe the curve of the fault current can be up to 7-8 times of the rated current and DC component makes the waveform offset. Small changes in non-fault phase current. It is basically the same as the two-phase short-circuits fault.

Figure 8. Three-phase current of the two-phase short circuit to ground

Adjust the three-phase fault selector switch for the three phase short circuit to ground state. The process of three-phase current changing when three-phase short-circuits is shown in Figure 9. Figure 9 describe the curve of the fault current can be up to 10 times of the rated current and DC component makes the waveform offset.

Figure 9. Three-phase current of the three-phase short circuit

4.2. The generator loss magnetic fault simulation.

4.2.1. Stand-alone magnetic field failure

In the loss of excitation fault simulation, excitation voltage and excitation current is set to zero in
12s. The simulation time is set to 20s.

Excitation voltage and excitation current curve of generator magnetic field failure is shown in Figure 10. The excitation voltage mutations to zero, excitation current slowly reduced to zero.

The terminal voltage curve when generator magnetic field failure occurred is shown in Figure 11. The RMS of terminal voltage is maintained at 6.6KV during normal operation. Terminal voltage gradually drops to zero after magnetic field failure.

4.2.2. Dual magnetic field failure

In the first 30s a generator completely lost the magnetic, which another generator normal operation in a non-fault state. The simulation results are shown in Figure12-15.
As shown in the figure the system is in stable operation before 30s. Speed characteristics of the two generators are very smooth. One of generators lost of field failures in the 30s. The speed of the two generators are begin to decline after a brief rise and eventually restored to the operating state before the failure. Terminal voltage is increased gradually after a brief decline. Reactive power becomes negative in the faulty generator and absorbing reactive power from the system.

5. Summary

In this paper, a marine integrated electric propulsion system simulation model is established by using the PSCAD simulation tools. Diesel generators, converters, propulsion motor and load are included in the model. A variety of short-circuit failure and loss of excitation failure are emulated and analyzed. The various curves of the three-phase current under short-circuit fault and curve of various parameters when the loss of excitation. The results from analysis on such curves indicate that three-phase short circuit fault is the most serious case of ship electric propulsion system short-circuits faults. Excitation voltage drops significantly and the terminal voltage slow decline after loss of excitation. This study has the benefits of the design and safe operation of ship electric propulsion system.

6. References