Injection Insulation Monitoring of Ship Shore Power System

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Abstract: The development status of the ship's shore power system and shore power insulation system and the research status of insulation monitoring technology are described. The use of external DC power injection to monitor the insulation performance of the shore power system is studied. In order to quickly find the point of insulation reduction, the problem of selecting the line of multiple power supply branches of the shore power system is studied. In order to further accurately determine the fault point, a comprehensive insulation monitoring and line selection and phase selection scheme for ship shore power systems based on additional injection signals, comparison of branch zero sequence currents, and comparison of branch relative to ground voltage is proposed, which solves the problem of ITN-powered ship shore power System insulation monitoring problem.

Keywords: ship shore power system； injection insulation monitoring；ITN system

1. Introduction

Due to the massive burning of sulphur-containing fuel oil by ships, air pollution and noise pollution have made environmental problems in the port area increasingly severe. The deeply rooted green sustainable development has become the development trend of the new era, and the shore power system will be a necessary facility for a green and environmentally friendly port[1].

From the perspective of wire system, the power system includes TN system, TT system and IT system [2]. The shore power of ships using the TN system, the hull-seawater-earth connection is equivalent to the TT system. When a single-phase grounding occurs, the grounding protection will act immediately, which cannot meet the requirements for continuous power consumption; when using the IT system, IT cannot be economical Conveniently output 220V single-phase power, which is equivalent to designing a set of IT systems for ships, which is not economical. The three-phase three-wire IT system is equipped with a neutral wire to form a three-phase four-wire ITN system, which can continue to operate in a single-wire ground fault. However, if the neutral line is grounded, effective measures are not taken to eliminate it in time, and the grounding of other lines occurs again, and the power supply will be interrupted by a short circuit trip[3][4]. Therefore, studying the ITN system grounding detection, fault line selection, phase selection, and parameter influence is the key to solving the application of the system [5].

When the single-phase insulation is reduced, the zero sequence current flows from the fault point, and the voltage of the fault phase is reduced, so the zero sequence voltage can also be detected [6]. The zero sequence current is related to the capacitance to ground, so the more wires there are, the more accurate the measured result will be. The equivalent impedance of port power supply system and ship system at 150Hz is usually relatively small, so the influence of the third harmonic of the power grid can be ignored. At this time, grounding protection can be performed by detecting the third harmonic..

2. Injection insulation monitoring

2.1 Principle of injection insulation monitoring

Figure2.1 is an example diagram of a system using injection insulation monitoring. [7]The figure includes power system power supply, load, π-type line, ground resistance of simulated ground fault, resistance of simulated cable to ground resistance, injection source, and partial voltage of injection source Resistance and various measuring instruments。

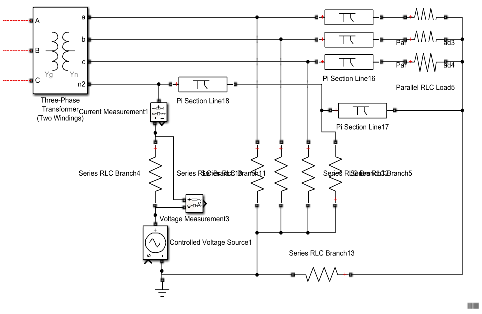

Figure2.1 Schematic diagram of injection insulation monitoring

According to the superposition theorem, only the role of the injection source is considered, and the load and cable parameters are ignored. The model only includes the injection source, the injection source voltage divider resistance and the ground resistance. Suppose the voltage divider resistance current flowing through the injection source is i0, the ground resistance current flowing through the simulated ground fault is i1, the injection source voltage is u, the voltage divider resistance voltage is u0, and the fault ground resistance voltage is u1. The voltage and current are as follows relationship.

$$u = u_0 + u_1 \quad (2\text{-}1)$$

$$i_0 = i_1 \quad (2\text{-}2)$$

The resistance of the fault grounding resistance is equal to the voltage acting on the resistance divided by the current flowing through the resistance

$$r_0 = u_0/i_0 \quad (2\text{-}3)$$

$$r_1 = u_1/i_1 \quad (2\text{-}4)$$

The measuring instrument can measure the voltage u0 acting on the voltage divider resistance of the injection source and the current i0 flowing through it. The injection source voltage is known and the grounding resistance calculation formula is obtained.

$$r = \frac{(u-u_0)}{u_0} * r_0 \quad (2\text{-}5)$$

If the neutral point voltage un is collected, the formula is transformed into

$$r = \frac{u_n}{u-u_n} * r_0 \quad (2\text{-}6)$$

2.2 System simulation

In the multi-line system shown in Figure2.2, PI Line7 positive sequence resistance is 0.1838 ohm per kilometer, zero sequence resistance is 1.838 ohm per kilometer, positive sequence inductance is 0.8912mH/km, zero sequence inductance is 4*0.8912mH/km, and positive sequence capacitance is 0.6415. uF/km, zero sequence capacitance 0.6415uF/km, line length 0.15km; cable-to-ground insulation is set to 10kΩ.

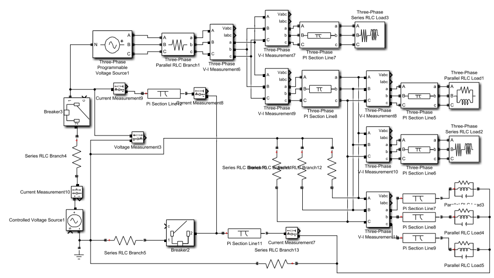

Figure2.2 System simulation figure

Take the resistance to ground as 5kΩ or 10kΩ, and the grounding point is the neutral line or phase C to get the following resistance voltage change curve.

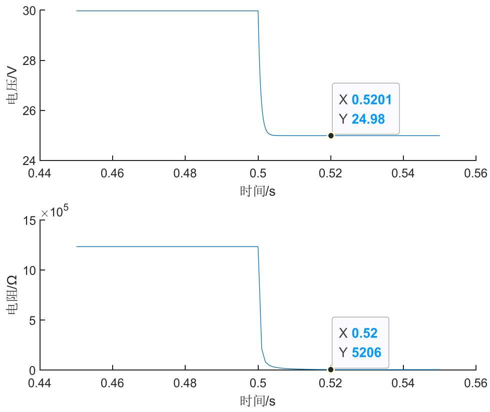

Figure2.3 5kΩ neutral ground resistance voltage curve

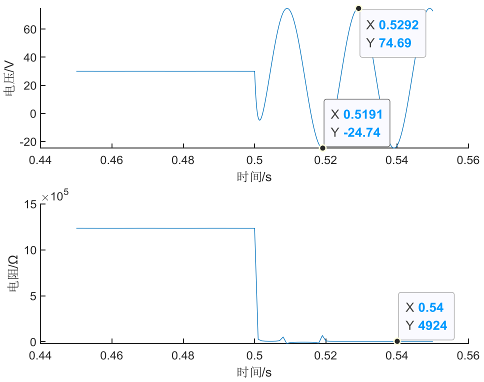

Figure2.4 5kΩ phase C resistance voltage curve

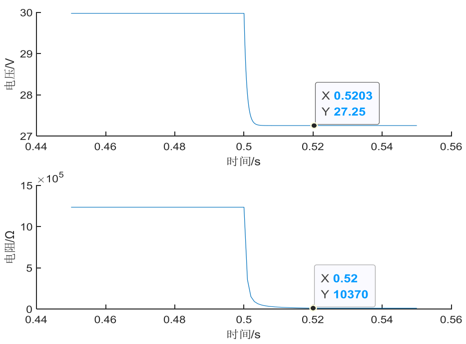

Figure2.5 10kΩ neutral ground resistance voltage curve

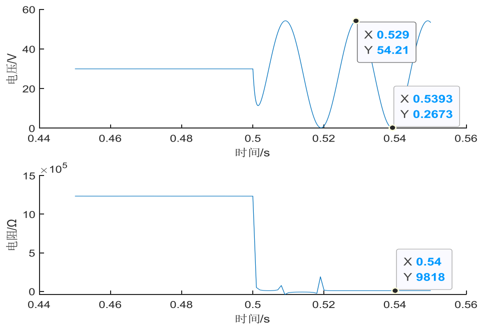

Figure2.6 10kΩ phase C resistance voltage curve

Combining the change trend and steady-state value of each curve, it can be seen that the steady-state time mainly depends on the sampling length. The steady-state process is related to the fault grounding point. The curve of the neutral line fault decreases smoothly, and the curve of the phase line transition process will rise and fall many times. Process, when the phase line is grounded, the steady state process is also related to the power frequency phase.

Table2.1 Grounding resistance calculation

position	R0/ Ω	R1/ Ω	R2/ Ω
neutral line	5	5.4153	7.339
	500	500.2	678
	5000	4981	6771
	10k	9921	13532
phase C	5	5.04	5.063
	500	499.8	502.5
	5000	4980	5037
	10k	9921	10101

Table2.1 shows the calculation of different position, neutral line or phase C, grounding through R0. R1 is the result of voltage measurement at injection terminal while R2 at fault terminal. Analyze the calculation value table of each grounding resistance, the insulation resistance to ground measured through the input terminal is more accurate, and the error range can be controlled within 2%. In the range of 10kΩ to 5Ω, the resistance value obtained by injection insulation

measurement is close to the actual resistance.

The injection-type insulation monitoring can well monitor the reduction of the insulation level, and the error of monitoring the insulation resistance at the input end can be controlled within 2%. By comparing the relationship between the measured value of the fault branch and the line parameters, it can be seen that the line distribution parameters have no significant influence on the insulation level measurement. Taking one cycle of the power frequency voltage as the sampling length, starting from the moment the ground fault is connected to the system, the measured resistance value enters a steady state after the same sampling length. The resistance transition process time mainly depends on the sampling length.

3. Fault line monitoring

3.1 Principle of fault line monitoring

Any set of three-phase voltage or current can be decomposed into a unique sum of positive sequence, negative sequence and zero sequence voltage (current), and vice versa. The process of decomposing the three-phase voltage into positive sequence, negative sequence and zero sequence is the process of finding the asymmetric component of the fault.[8]

When the insulation level of the system decreases, the zero-sequence current of the faulty branch circuit comes from the capacitive current of other normal lines and the injection insulation monitoring circuit. In a multi-branch parallel system, the zero sequence current of the fault line is equal to the sum of the zero sequence currents of other lines, and the zero sequence current amplitude of the fault line is the largest.

3.2 Fault line monitoring simulation

3.2.1 Phase sequence component analysis

Table3.1-Table3.2 are the comparison of sequence components injected by DC source, and the DC component corresponds to the 0Hz part of the table. Set the injection voltage to 50V, the signal source is a DC signal source, and the injection voltage amplitude is 50V.

Table3.1 Line 4 Phase C grounding

Source: DC	voltage:50V
R0:5kΩ	Phase C
0Hz	i0/A
Line 1	0∠0°
Line 2	0∠0°
Line 3	0∠0°
Line 4	0.0028∠0°
50Hz	i0
Line 1	0.0015∠-73.8°
Line 2	0.0006∠-73.7°
Line 3	0.0013∠-73.7°
Line 4	0.0169∠28.4°

Table3.2 Line 4 neutral line grounding

Source: DC	voltage:50V
R0:5kΩ	Neutral line
0Hz	i0/A
Line 1	0
Line 2	0
Line 3	0
Line 4	0.0007∠0°
50Hz	i0
Line 1	0
Line 2	0
Line 3	0
Line 4	0

Table3.1 is the four lines' zero sequence component i0 table of the C-phase single-phase grounding when the DC injection source is working. I0 is approximately to 0 that is less than 0.001A. Similar to no injection source, since Line 4 is a faulty line, its zero sequence current phase is different from the other three lines. Observing the DC component, it can be seen that only the faulty line 4 has a DC component, which can be used as a criterion to determine the fault The line is Line 4.

Table3.2 shows the grounding of the neutral line. The difference with no injection source is that a DC component with an amplitude of 7 mA is detected on line 4 at this time. Although the DC component directed to line 4 is monitored during the simulation, the 7mA current is much smaller than the theoretical value, so it is not suitable as a criterion.

Since the charging and discharging process is common in the cable, after measuring the positive and negative injection voltages, the calculated values in the two cases are averaged to eliminate the error generated during the charging and discharging process.

Table3.3 Line 4 Phase C grounding

Source: square	voltage:50V
R0:5kΩ	Phase C
12.5Hz	i0/A
Line 1	0∠86.8083°
Line 2	0∠86.8077°
Line 3	0∠86.8079°
Line 4	0.0035∠-0.6086°
50Hz	i0
Line 1	0.0015∠-73.7591°
Line 2	0∠-73.7137°
Line 3	0.0013∠-73.713°
Line 4	0.0169∠28.4375°

Table3.4 Line 4 neutral line grounding

Source: square	voltage:50V
R0:5kΩ	Neutral lin
12.5Hz	i0/A
Line 1	0∠86.8194°
Line 2	0∠86.819°
Line 3	0∠86.8192°
Line 4	0∠15.8634°
50Hz	i0
Line 1	0∠-157.3889°
Line 2	0∠77.316°
Line 3	0∠77.4189°
Line 4	0∠45.6662°

Observe the normal sequence component of the square wave signal source. Only the power frequency positive sequence component exists, which is similar to the measurement results of other injection source types. In the case of injection of a 12.5Hz square wave signal source, the faulty line 4 has a zero-sequence current component at a frequency of 12.5Hz, and its zero-sequence current amplitude is much larger than the other three lines, and the phase of the zero-sequence current component of line 4 is different from other lines. do not. Therefore, it is determined that the faulty line is Line 4.

3.2.2 Nuetral line selection

It is difficult to select the neutral line by the zero sequence current amplitude, and only the current generated by the injection source will flow in the faulty branch. The injection source voltage is a square wave with an amplitude of 50V and a frequency of 12.5 Hz. The fault grounding resistance is 5kΩ, which is connected to the neutral line of line 4 in 0.5s. Measure the current of the 4 neutral lines, and get the current-time curve shown in Figure3.1.

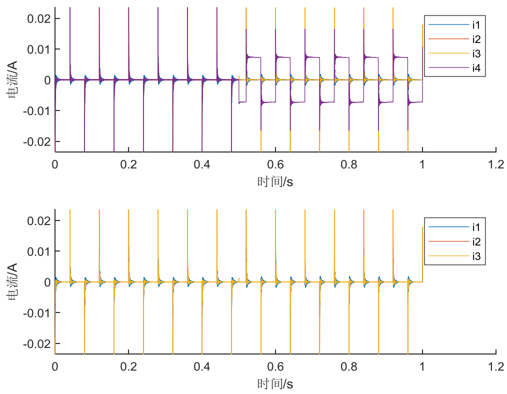

Figure3.1 Neutral line current

In Figure3.1, the upper curve is the current change curve containing 4 lines, and the lower curve is the current curve containing 1/2/3 lines. By detecting the current waveforms of each neutral line, when a certain line appears to match the injection source voltage waveform, and the amplitude is higher than the current of other lines, the neutral line of the line can be judged to be grounded and the grounded neutral line can be determined.

Comparing the measurement results of no injection signal, DC injection signal and square wave injection signal, when the phase line is grounded, the zero sequence current amplitude of the fault line is greater than other normal lines. The comparison of the zero sequence current amplitude can determine the fault line with the phase line grounded, and It is not affected by the grounding of the injection source and the neutral line via a voltage divider resistor.

When there is a neutral ground fault, the fault line cannot be judged by relying on the magnitude of the zero sequence current alone. At this time, other criteria need to be combined. It has been demonstrated in Chapter 2 that injection-type insulation monitoring can detect a drop in the insulation level of the system. After it has been determined that the insulation level has dropped and the faulty phase is the neutral line, by measuring the current injected into the source frequency component on the neutral line of each line, the line with a large current amplitude is the fault line.

4. Fault phase selection

4.1 Principle of fault phase selection

Under normal operating conditions, the ITN system is a three-phase voltage balanced system. The single-phase insulation level is reduced, the phase voltage remains unchanged, the faulty phase is connected to the earth through the grounding resistance, and the ground and the injection branch constitute the main loop of the fault current. The neutral point voltage is opposite to the fault phase voltage, and the fault phase voltage decreases, while the other two The relative ground voltage rises. After detecting the decrease of the insulation level to determine that there is a fault, by comparing the characteristics of the relationship between each phase to ground voltage, the fault phase of the faulty line can be further judged.

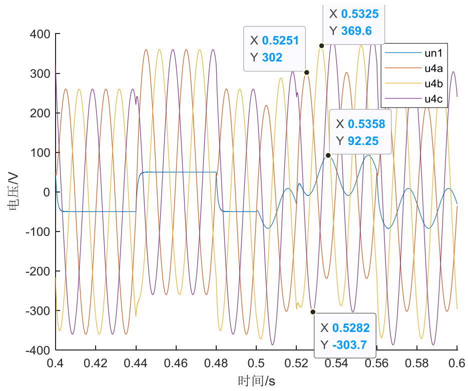

Figure4.1 Voltage of fault line

Set the injection source voltage to 50V, 12.5Hz rectangular wave, and the fault line is line 4A phase, showing the phase relationship between the fault line voltage and the neutral voltage. In the figure, un1 is the neutral voltage, and u4a, u4b, and u4c are the A, B, and C phase voltage values of line 4.

4.2 Fault phase selection simulation

When the single-phase insulation level of the system drops, the voltage of the grounding phase drops. Measure the effective value of the voltage of each phase, and detect that the voltage of a certain phase is lower than the normal operating voltage, and the voltage of the other two phases rises, and the fault phase can be determined. Using the simulation model in Figure 3.1, set a 5000 ohm insulation point to ground and record the voltage waveform.

As shown in Figure4.2 andFigure4.3, the injection source is 30V DC injection[9]. The insulation level of the system drops at 0.5s. After 0.5s, the phase voltage amplitude of the phase-to-ground fault is significantly smaller than the other two-phase voltages. For example, the insulation level of the A phase drops, and the voltages of the B and C phases also rise compared to before the fault. High, it proves that the insulation of phase A is reduced. In the case of neutral grounding, the effective value of the three-phase voltage remains the same before and after the fault is connected. Note that the integral length of the voltage RMS is a period of 0.02s, which is the same as the sampling length when calculating the system insulation level, and the transition process length of the two is basically the same. Therefore, after determining the system insulation level is reduced, such as the three-phase voltage RMS Similarly, it is proved that the insulation of the neutral line is reduced, and the effective value of a phase voltage is low, then the insulation of the phase is reduced.

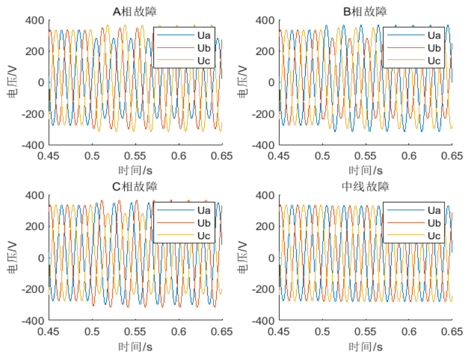

Figure4.2 Line voltage of direct injection source

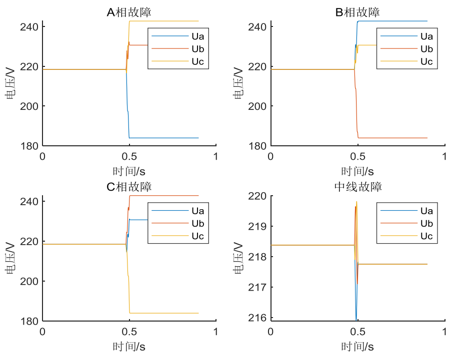

Figure4.3 Effective voltage value of direct injection source

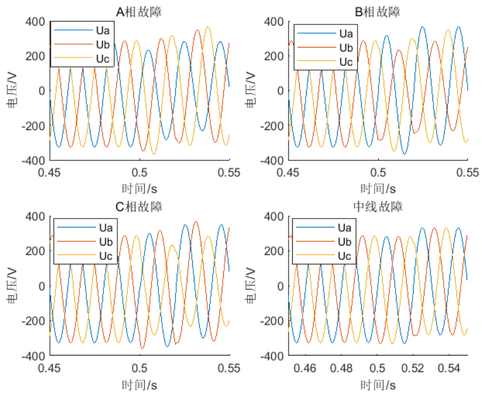

Figure4.4 Line voltage of square source

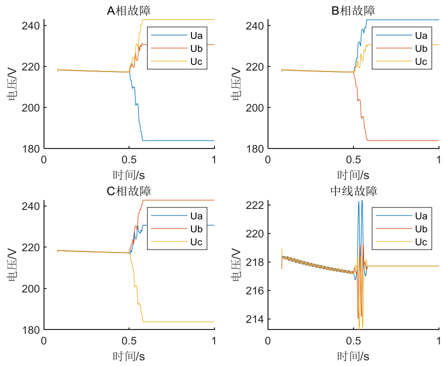

Figure4.5 Effective voltage of square injection source

Figure4.4 and Figure4.5are the measurement result when the injection source is a 12.5Hz square wave. After the insulation level drops, if the effective value of the three-phase voltage is the same, it proves that the neutral line insulation is reduced. If the effective value of a certain phase voltage is low, the phase insulation is reduced.

Through Matlab simulation, the sensitivity of the zero-sequence voltage to the change of system insulation level under different injection sources is simulated. The simulation results show that the DC and square wave injection sources can convert the system insulation level drop into a voltage signal that is easy to obtain and judge; the zero sequence voltage drop of the injection source frequency component indicates that there is a drop in insulation level; the presence of power frequency zero sequence current indicates the phase Line insulation level drops; after confirming that the insulation level drops, detect the voltage RMS level of the phase line of the faulty line, the lower phase is the fault phase, if the three-phase voltage levels are similar, it is the neutral ground fault.

5. Conclusion

This paper mainly studies the insulation monitoring of the ship shore power system using ITN power supply. Combining theoretical analysis and simulation, the following main conclusions are obtained:

(1) The injection-type insulation monitoring can be used to detect the insulation degradation of the shore power system. Injected insulation monitoring is by injecting a voltage signal into the neutral line of the ITN system to form a loop between the injection branch and the ground and the monitoring line. By measuring the voltage and current components generated by the injection source on the line, the current insulation level of the line can be calculated to realize the system Online monitoring of status. The simulation analysis results show that the method has high sensitivity after filtering out the interference components and other factors, and is basically not affected by the insulation reduction position.

(2) When there are multiple power supply branches in the shore power system, analyze that the branch with the lowest insulation has the largest zero sequence current, and compare the zero sequence current of each branch to solve the problem of multiple power supply branches in the ITN shore power system. For line selection, you can quickly find the power supply branch where the insulation reduction point is located.

(3) Analyzed the change rule of the three-phase-to-ground voltage at different fault locations. The decrease of the insulation resistance of one phase will cause the normal phase-to-earth voltage of the other two phases to increase, and the phase-to-ground voltage of the phase with reduced insulation will decrease. The voltage amplitude, the lowest phase is the fault phase. If the insulation of the neutral line is reduced, the three-phase ground voltage is the same, and combined with the shore power insulation test, it is judged that the insulation of the neutral line is reduced.

In the Matlab/Simulink simulation environment, a simulation model of the ship’s ITN shore power system was established to simulate different positions and different insulation levels. The simulation results show that the proposed method is based on the external injection signal, comparing the zero sequence current of the branch, and comparing the relative ground of the branch. The effectiveness of the integrated insulation monitoring program for the ship’s shore power system based on voltage.

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