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Influence of DC Grounding Mode on DC Fault Characteristics in Ship Medium Voltage Power System

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Abstract. At present, in the background of the multiphase rectifier system is widely used in medium voltage ship power system, the influence of DC grounding mode on the characteristics of DC monopole fault is analyzed for series 12-pulse uncontrolled rectifier system and paralleled 12-pulse uncontrolled rectifier system respectively. By establishing the electromagnetic transient model of the medium voltage power system under different topologies, fault voltage, recovery speed and fault current under different grounding modes are simulated and studied, and the fault mechanism is deeply analyzed, and the advantages and disadvantages of different grounding modes are compared. As a conclusion, for series 12-pulse rectifier system, the way of high impedance grounding through the middle point of the two series rectifier bridges is proposed. For paralleled 12-pulse rectifier system, high resistance grounding mode through the middle point of split capacitances on dc side is proposed, they are beneficial to improve the stability and transient performance of the system. That it is beneficial to improve the stability and transient performance of the system.

1. Introduction

With the increasing of the electrical equipments and power capacity of ship, the advantages of the medium voltage DC power supply system are gradually embody, which is easy to be connected for system, with the less line loss and the better reliability of the power supply. The application of AC and DC hybrid power system for the whole ship power is put on the agenda again [1]. In order to improve the quality of DC power, many three-phase windings with different phases are often combined, and supplying power by 12-pulse or 24-pulse rectifier generator is a common way of the AC and DC hybrid power system. The multi-pulse rectifier synchronous generator can reduce the ripple of DC voltage and effectively improve the power quality on DC side [2, 3].

From the domestic and foreign theoretical research, many domestic and foreign scholars have focused on the design of the control system of the medium voltage power system, the research on the grounding mode is very few [4, 5]. The Tsinghua University scholars have analyzed the DC grounding mode for HVDC [6], and get the advantage of high impedance grounding, but his research object is the unloaded overhead line with IGBT, there are differences between the ship medium voltage DC system and the overhead line with IGBT. For the uncontrolled rectifier system, the DC grounding mode of ship medium voltage power system under different topology is analyzed in detail.

Generally speaking, for medium voltage DC power system, there are grounding requirements for regardless of the DC transmission network or the medium voltage power system [7]. Its function has two aspects: 1) fixing the neutral point potential, and keeping balance of the positive voltage and negative voltage; 2) testing fault by testing unit on the ground line. Therefore, a reasonable grounding mode can improve the stability and reliability of the system. For ship medium voltage power system, there are 2 kinds of faults in DC line, they are monopole grounding fault and two poles short circuit fault. The characteristics of short circuit fault have nothing to do with the earth circuit. Here, the effect of grounding mode on the monopole fault is mainly considered, and the simulation analysis is carried out through the electromagnetic transient simulation software PSCAD/EMTDC. Finally, the conclusion is drawn.

2. Series 12-pulse rectifier system

In a 12-pulse or 24-pulse rectifier system, it is often necessary to increase the voltage level by connecting the three-phase bridge rectifier circuits in series. In this way, it naturally occurs that there is a midpoint of the series-type rectifier circuits, and the grounding point is often set in this place. AS shown in Figure 1, there is a 12-pulse series rectifier system, where R and L for resistance and inductance of the AC line, R_d and C_d are protection resistors and support capacitors on DC side, R_n is midpoint grounding resistance.

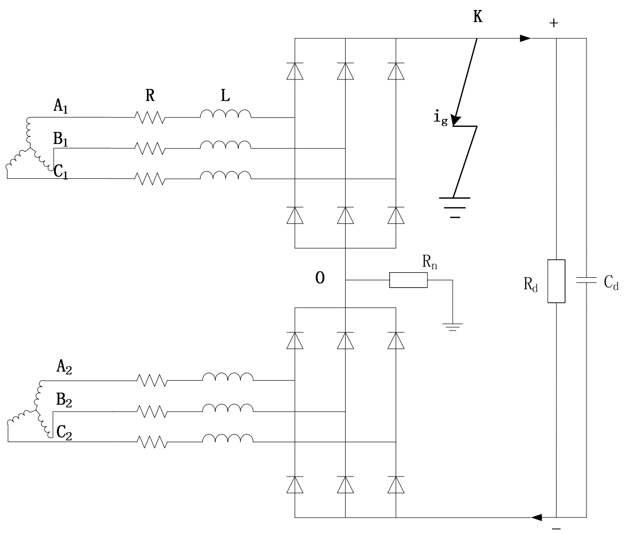

Figure 1. Schematic diagram of series 12-pulse rectifier system with grounding fault

When a single-pole ground fault occurs at the K-point of the positive DC bus, it will inevitably lead to a rapid drop in the positive voltage. If there is direct grounding at the midpoint of the DC line, that is R_n=0, the negative potential will maintain the original voltage in the steady state, which will inevitably lead to a drop in the total DC voltage u_{dc}. Although there is the presence of the supporting capacitor C_d, the DC voltage can be decreased slowly by releasing stored energy, but the DC voltage unavoidably decreases in the steady state. As shown in Fig.2, after the fault is over, the positive voltage recovers quickly, but the positive and negative voltage can not restore balance, which in turn causes an instantaneous overvoltage, and the smaller the supporting capacitance Cd, the greater the overvoltage. The direct grounding method generates a very large fault current when the positive and negative poles are unbalanced, and it is very easy to damage power electronic devices.

If the resistance grounding method is adopted at the midpoint of the DC line, the above-mentioned problem of voltage level drop and large fault current can be effectively solved. As shown in Figure 3, after the series rectifier bridge is grounded by a 400Ω resistor at the midpoint, the positive voltage drops instantly to 0V, the negative voltage becomes 2 times the original, and the DC total voltage u_{dc} does not change. Due to the presence of grounding resistance, the fault current will not be very large.

Figure 4 shows the diode current schematic, system generates a DC single-pole ground fault in the 0.6 second, the fault is eliminated in the 0.65 second. During this period, there is a slight increase in current, which can be expressed as a formula.

$$\left|\triangle i\right| = \frac{\left|u_{dc}\right|}{R_n} \tag{1}$$

It can be seen that the high-resistance grounding can effectively suppress the fault current and reduce the over-current of the power electronic component when an unbalanced fault is generated on DC side. However, if the grounding resistance is too large, the grounding purpose will not be achieved. Therefore, the choice of grounding resistance value should ensure the power electronic component withstand large current the over-current.

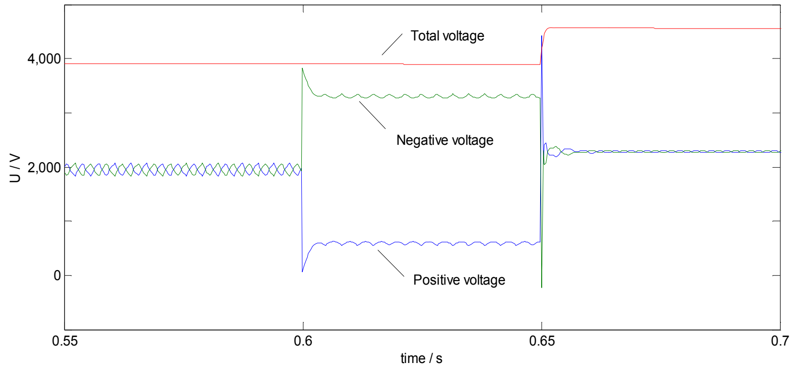

Figure 2. Fault voltage of direct grounding mode in series 12-pulse rectifier system

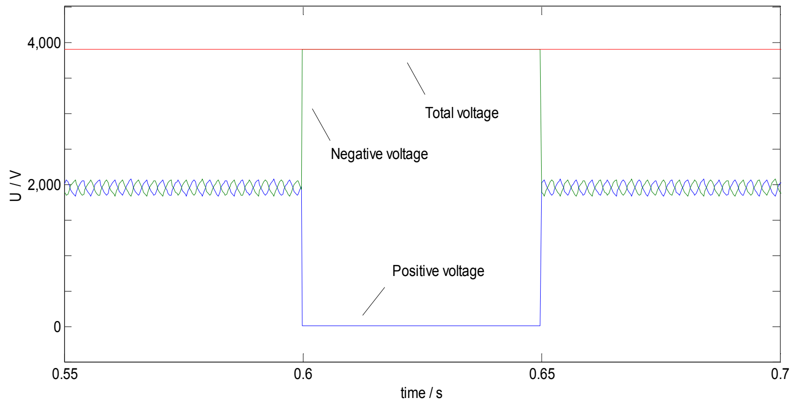

Figure 3. Fault voltage of 400 ohm resistance grounding mode in series 12-pulse rectifier system

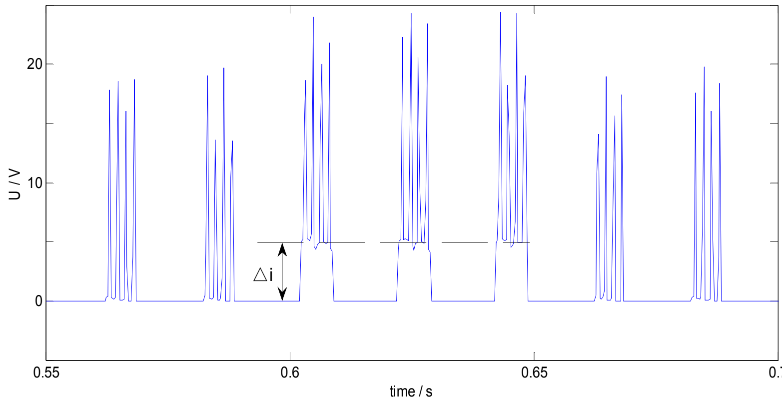

Figure 4. Bridge arm current of 400 ohm resistance grounding mode

3. Paralleled 12-pulse rectifier system

The paralleled 12-pulse rectifier system is powered by two three-phase bridge rectifiers in parallel. Since there is no natural midpoint, it is necessary to artificially set the midpoint for grounding. The general approach is grounding by the split capacitors on DC side, the structure is shown in Figure 5. When the system is direct grounded, due to the rapid discharge of the fault-split capacitor C_1, the positive voltage to the ground rapidly drops to 0. At the same time, due to charging of capacitor C_2, the negative voltage jump to double, the total DC voltage remains unchanged. When the fault is over, the voltages of split capacitors C_1 and C_2 are difficult to recover, as shown in Fig. 6.

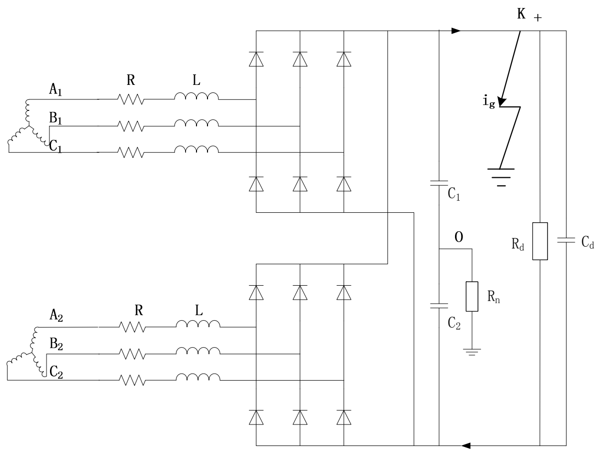

Figure 5. Schematic diagram of paralleled 12-pulse rectifier system with grounding fault

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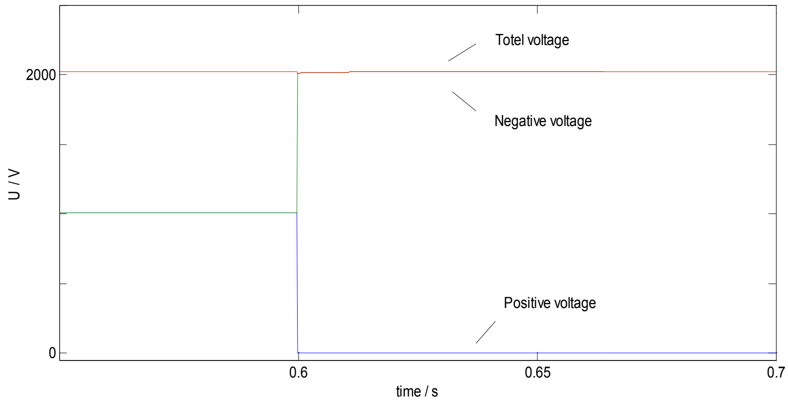

Figure 6. Fault voltage of direct grounding mode in paralleled 12-pulse rectifier system

If the midpoint is grounded by high resistance, the change of capacitor voltage can be effectively suppressed, so that the capacitor voltage can be maintained. The higher the grounding resistance is, the smaller the capacitor discharge current is, and the capacitor voltage can be maintained better under fault, when the fault is over, the voltage can be closer to the normal level, as shown in Figure 7, which is the positive voltage under different grounding resistance R_n. The voltage waveform can be seen that the larger the R_n, the restoration of the voltage will be more favorable after the fault. When the grounding resistance R_n is 10kΩ, it almost instantaneously returns to normal level. This characteristic of fault recovery is very important for a separate power system such as ship power system. Even so, R_n is not the bigger the better. First, when R_n is large enough, the split capacitor will hardly discharge under fault. The value of R_n is closely related to the voltage level and the split capacitor C_1 and C_2. And if R_n is too large, there will be not function of grounding. Therefore, when selecting the R_n value of the paralleled 12-pulse rectifier system, we should use the minimum R_n value ensuring voltage recover normal.

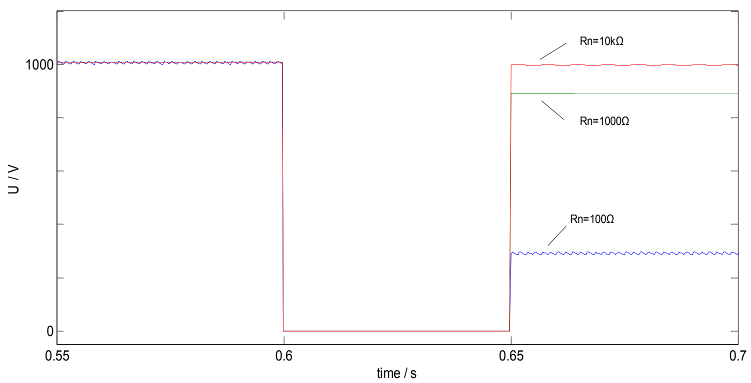

Figure 7. Positive voltage under different grounding resistance in paralleled 12-pulse rectifier system

4. Conclusion

In shipboard medium voltage power system, the monopole grounding fault will inevitably lead to the rapid drop of pole voltage and the rise of the other pole voltage. After research, no matter for series 12-pulse rectifier or paralleled 12-pulse rectifier, high resistance grounding mode has obvious advantages.

The series 12-pulse rectifier system and the paralleled type 12-pulse rectifier system with high resistance grounding have obvious advantages for fault recovery and fault current, but the resistance of

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high resistance R_n should not be too large, the value of R_n closely related to the voltage level and the split capacitances.

References

[1] Lijun Fu, Lufeng Liu, Gang Wang, et al, The research progress of the medium voltage DC integrated power system in China, J, Chinese Journal of Ship Research. 2016, 11 (1), 72-79.
[2] Ying Shao, Lijun Yuan, Operational mode analysis of 12-phase synchronous generator-rectifier-load systems, J, Proceedings of the CSEE. 2003, 23 (7), 129-133.
[3] Fangao Meng, Wei Yang, Shiyan Yang, Active harmonic suppression of paralleled 12-pulse rectifier at DC side, J, Sci China Tech Sci. 2011, 54: 3320-3331, doi:10.1007/s11431-011-4617-4.
[4] Jingjing Hu, Xidong Xu, Peng Qiu, et al, A review of the protection methods in DC distribution system, J, Power System Technology. 2014, 38 (4), 844-851.
[5] M.E. Baran, N.R. Mahajan, DC Distribution for Industrial Systems: Opportunities and Challenges, J, IEEE Transactions on Industry Applications. 2003, 1596-1601.
[6] Jie Yang, Jianchao Zhang, Guangfu Tang, et al, Grounding design analysis of VSC-HVDC system, J, Proceedings of the CSEE. 2010, 30 (19), 14-19.
[7] Minyuan Guan, Zheng Xu, DC side grounding methodology for a two-level VSC HVDC system, J, Automation of Electric Power Systems. 2009, 33 (5), 55-60.