Study on the Reduced Reliability of A Certain Amplifier Caused by Electrostatic Discharge (ESD)

Guixia Zhu, Jian Lan, Diliang Li, Yugang Qian, Tianmi Zhou and Yuying Hu

Research Institute of Nuclear Power Operation, Wuhan, Hubei, China

E-mail: zhugx@cnnp.com.cn

Abstract. This paper introduces and analyzes the single-channel tripping accident of a reactor as a result of false triggering of a certain amplifier caused by electrostatic discharge (ESD). In response to this problem, a simulated operational amplifier circuit platform is built in practice to verify the analysis results, and a solution is proposed at last. In addition, further analysis is made to the existing preventive maintenance plans, and cable shielding is found to be problematic; therefore, the principle and analysis of cable shielding are given here.

1. Introduction

Electrostatic discharge (ESD) is a common phenomenon in daily life. Many functions can be realized through ESD, such as electrostatic dust collection, electrostatic spraying, electrostatic separation and electrostatic printing. However, being a potentially hazard to electronic products and equipment, ESD may cause malfunction and even component damage to electronic products and equipment.

As a growing number of semiconductor components are used in various modern equipment, the current equipment is more and more sensitive to external electromagnetic disturbance. In the normal operation of equipment, an operator may also cause malfunction of equipment and even damage to hardware equipment due to harmful charges on his clothes or skin. With regard to this, more and more attention has been paid to the disturbance of ESD on the circuit, the damage to components, CMOS circuit and interface circuits [1] [2].

2. Fault Description

In a nuclear power plant, a certain type of amplifier ("A" for short) is employed in its unit to receive the weak current signal from the field self-powered detector. After being subject to amplification, dynamic compensation, differential compensation and buffering, the signal is output to the comparator and the tripping control setting loop to provide local overpower protection for the reactor shutdown system. Therefore, this amplifier is paramount to the safe operation of the nuclear reactor.
During the operation of this amplifier from 2012 to 2018, a total of 6 overpower shutdown accidents occurred, and all of them occurred during the calibration by the operators. Among them, 4 were instant disturbance (namely, the disturbance waveform lasts no more than 1s), and the other 2 disturbance waveforms were 2s and 50 minutes respectively. Figure 1 shows one disturbance lasting no more than 1s, and amplifier A indicates 127% overpower and lasts for approximate 300 ms. In terms of the disturbance lasting for 50 minutes, it was finally found through analysis that the fault was caused by the disconnection of the potentiometer center tap.

![Figure 1 Fault Output Signal Lasting 300 ms.](image)

3. Fault Cause Analysis
Figure 2 is a schematic block diagram of amplifier A. As illustrated in the figure, the detection signal of the neutron detector in the nuclear island is sent through the shielding cable to the amplifier for internal processing. R11 (FINE GAIN) represents the gain potentiometer for daily calibration, and it is mainly used to adjust the signal gain so that its voltage value can meet the requirements of the system before entering the dynamic compensation. In addition, it is also used to isolate the power supply system and indicate the signal output. GND1 represents the chassis ground of the equipment, and GND2 the shielding signal ground.
Preventive maintenance (PM) was carried out for this amplifier in 2012 and 2017, respectively, mainly involving the replacement of calibrated precision potentiometer R11 and modifications to related mechanical structure. The original wound potentiometer was replaced with the wound potentiometer of the same type during the PM in 2012, and then replaced with a slide potentiometer (RJ12-FY502) during the PM in 2017. This paper focuses on the analysis of the 2 accidents after the PM in 2017. Both of the 2 accidents occurred during the calibration execution with amplifier’s output overpower around 125% and duration no more than 1s. Figure 3 shows the original design structure of R11, in which the metal knob and R11 are regulated through an insulating connection rod. Figure 4 shows the mechanical structure of R11 after the PM in 2017, in which RJ12-FY502 is mounted into the metal shielding case as shown in the dashed red frame in the figure, and directly connected to the metal rotating rod of the metal knob without the insulating connection rod, as illustrated in Point A in the figure. There is electrical contact between metal shielding case in the red frame and the shielding case of the operational amplifier circuit, as illustrated in Point B in the figure. So we can find that at Point A, there is no electrical insulation between the metal knob on the outer dial plate and the potentiometer R11; at Point B, equipment ground GND1 is connected to shield ground GND2.

During the manual calibration of amplifier A, the operator’s hand will touch the metal knob. Since the 900V electrical insulation strength of RJ12-FY502 potentiometer body is far less than the possible electrostatic voltage, if a larger ESD occurs, the internal operational amplifier may be directly damaged and unrecoverable; if a smaller ESD occurs, it will disturb the amplifier output and cause a tripping accident as a result of false triggering. This also explains why all the false triggering accidents occurred in the calibration process. While, no similar accidents have occurred in the original mechanical structure of the amplifier.
4. ESD Experimental Verification and Countermeasures

Based on the above analysis, a proportional circuit prototype amplifier was built in practice, consisting of: a 3.3V lithium battery, whose output is used as amplifier input through voltage division; a proportional amplifier circuit based on LM2904, with output voltage of 6V; an isolated linear regulating power supply unit, with power supply voltage of 12V. Figure 5 shows the proportional circuit prototype amplifier and the laboratory simulation conditions. Figure 6 shows the ESD experimental results. When the contact-type 1 KV ESD voltage is directly applied to the metal screw of the potentiometer, the visible microsecond level vibration disturbance is output.

In response to the problems after the PM in 2017, suggestions and countermeasures are given as follows:
a. Refer to the original design plan for the mounting and shielding of the potentiometer, namely, the insulation design of the potentiometer and the knob, and the shielding design of the potentiometer.

b. It is recommended to select wound potentiometer, which is characterized by low noise, high rotational life and high reliability.

5. Problem Analysis of Cable Shielding
After the PM in 2017, equipment ground GND1 and shield ground GND2 are electrically connected at Point B. Since the distance between the neutron detector (signal source Us) and the amplifier is greater than 100 m, this will ground the low-frequency signal shielding cable at two points, where the signal circuit may be disturbed by noise. Figure 7 shows the circuit model [1] [3] of low-frequency cable shield grounding (amplifier ungrounded, signal source grounded), that is, the actual wiring equivalent diagram of amplifier A and neutron detector. As can be concluded from the equivalent diagram in Figure 8 that the equivalent noise at the amplifier input end $U_N$ is zero, which means that there is no noise disturbance theoretically. If Point D is also grounded to the equipment, a new disturbance variable $U_{G3}$ is introduced between Point D and $U_{G2}$, that is, there may be a potential difference between the two ends of the shielding cable, so $U_N$ may not be zero.

![Figure 7 Grounding Point Model of Low-frequency Cable Shield](image)

![Figure 8 Grounding Equivalent Diagram of Low-frequency Cable Shield](image)

6. Conclusion
This paper introduces and analyzes the tripping accident of a reactor as a result of false triggering of a certain amplifier caused by electrostatic discharge (ESD). In response to this problem, analysis results are verified through experiment, and suggestions and countermeasures are given. Moreover, as for the cable shielding problem caused by wrong grounding, the principle and analysis of cable
shielding are given here. Therefore, the above analysis can be used as a reference for the components replacement or preventive maintenance of amplifier of the same type.

References
[1] Yiheng Xu. 2016 Electromagnetic Compatibility in Control Engineering M. (Shanghai: Shanghai Scientific & Technical Publishers). 27-38 pp 141-56
[2] Kaiji Zhou and Zhao Gang. 2016 Principle of Electromagnetic Compatibility (2nd Edition) M. (Harbin: Harbin Engineering University Press). pp 257-76
[3] Liang Zhang. 2014 EMC Technique and Application Examples M. (Beijing: Publishing House of Electronics Industry). 22-27 pp 141-17