



Research and Application of Nuclear Instrumentation System EMI Design in Nuclear Power Plant

Jing Li^(✉), Li-Ming Zhang, Tian-You Li, and Jing Shang

State Key Laboratory of Nuclear Power Safety Monitoring Technology and Equipment,
China Nuclear Power Engineering Company Ltd., Shenzhen 518045, Guangdong, China
Jing_li@cgnpc.com.cn

Abstract. Nuclear instrument system (RPN) continuously monitors the neutron flux rate level and the core power level in the reactor core and participates in the operation of the reactor protection system, which is a key instrument and related to reactor safety. In the past two years, Nuclear Instrumentation (RPN) Source Range signal abnormal fluctuation events have occurred occasionally in multi-base projects. Studies have found that electromagnetic interference (EMI) is a main cause of signal abnormal. This paper discusses adding electromagnetic compatibility design from the top-level design. Through equipment design to meet the requirements of RPN signal detection equipment and cables on electromagnetic environment, improving the stability of the signal link by installing technical requirements, through equipment identification and other means to verify the cabinets' requirements for electromagnetic environment, summarize the good practical experience of the power plants in operation, formulate systematic and detailed EMI protection requirements and implementation measures for RPN system, to avoid signal flash and improve the stability of the power station.

Keywords: Nuclear Instrumentation · RPN · EMI

1 Introduction

1.1 Background

Nuclear instrument system (RPN) is one of the important systems directly related to reactor safety, which continuously monitors the reactor core power level, power change rate and axial power distribution by using a series of neutron detectors installed outside the reactor pressure vessel. The functions of the RPN system are as follows:

- (1) Protection function. Provide high neutron flux rate and high flux rate change rate signals to the reactor protection system, triggering the emergency shutdown function of the reactor. Participate in the calculation of over-temperature T and over-power T protection.

- (2) Control function. Multiplication period signal participates in boron dilution protection under shutdown condition. Trigger alarm and control rod lock signal and adjustment signal.
- (3) Monitoring function. Through continuous monitoring of reactor power, power change rate and power distribution, reactor status information during reactor loading, shutdown, startup and power operation is provided to operators.

In the past two years, Nuclear Instrumentation (RPN) Source Range signal abnormal fluctuation events have occurred occasionally in multi-base projects [1], which have affected the safety and economy of power stations to some extent. Field analysis found that electromagnetic interference (EMI) is one of the main causes of signal abnormalities.

1.2 Problem Analysis

Electromagnetic interference from nuclear power plants mainly takes the following four forms:

- (1) Enter the equipment from the outside through capacitive or inductive coupling of the equipment connection cables, and these interferences are generated by the potential difference between different reference ground on the two equipment or the potential difference on the remote equipment connection cables;
- (2) ESD interference will occur when personnel contact the control panels, chastises or cabinets;
- (3) Interphones, mobile phones, radio stations, television stations and radar stations will generate electromagnetic field radiation interference;
- (4) AC power supply is vulnerable to surge interference caused by lightning and various switch actions [2].

Under normal operating conditions, there is no essential difference between the electromagnetic environment in nuclear power plants and other types of power plants, but nuclear power plants have higher requirements for the stability, reliability and anti-interference of RPN systems. Therefore, when designing EMC of RPN system in nuclear power plant, it is necessary to fully consider the electromagnetic disturbance sources and interference types in the operating environment of RPN system, and then carry out targeted electromagnetic protection design and optimization to make the system in the best working state.

In the process of solving the flash problem, the power station has adjusted the arrangement and path of RPN system equipment and related system equipment to reduce the influence of EMI. However, there is a lack of clear theoretical basis and system adjustment methods for this adjustment, and there is also a lack of systematic research on the environmental requirements, environmental identification and classification of EMC in nuclear power stations.

In the process of power station design, the electromagnetic compatibility appraisal for single equipment is relatively standard, but the requirements of electromagnetic compatibility environment in complex nuclear power environment are lacking. Nuclear power plants under construction have limited detection and processing methods for

power measurement signal fluctuation caused by electromagnetic compatibility, and the processing and response measures are very complicated. Therefore, the establishment of corresponding specifications in the design and construction stages can effectively prevent and eliminate the occurrence of the above situations.

2 Analysis of Equipment and Layout Characteristics of RPN System

2.1 RPN System Equipment

The RPN detector generates data signals, which are transmitted through integrated cables, connecting boards, Penetration and biological shielded cables and enter the RPN protection cabinet for amplification, screening, data processing, etc. The signal transmission path can be simplified as follows (Fig. 1):

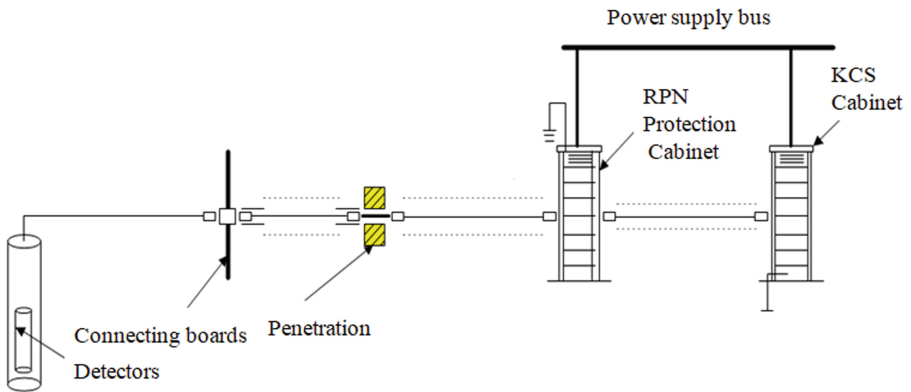


Fig. 1. RPN typical transmission line

CPR1000 Power Station has conducted EMC interference tests on RPN Source Range Channel transmission links. Because the influence of external electromagnetic interference on RPN system is mainly manifested as interference to the signal link of RPN system, the two signal links of RPN system will become the main measurement reference for EMC measurement of RPN system [3].

2.1.1 Detector Body

According to the basic structure of the neutron detector of CPR1000 power station, the neutron detectors CBL26 (Source Range Detector), CPNB44 (Intermediate Range Detector) and CC80 (Power Range Detector) have a sealed metal cladding. Electromagnetic interference has no effect on the detector. Due to the voltage difference between different ground parts, but in order to avoid the low frequency common mode current of the detector, all detector housings must be grounded (Fig. 2).

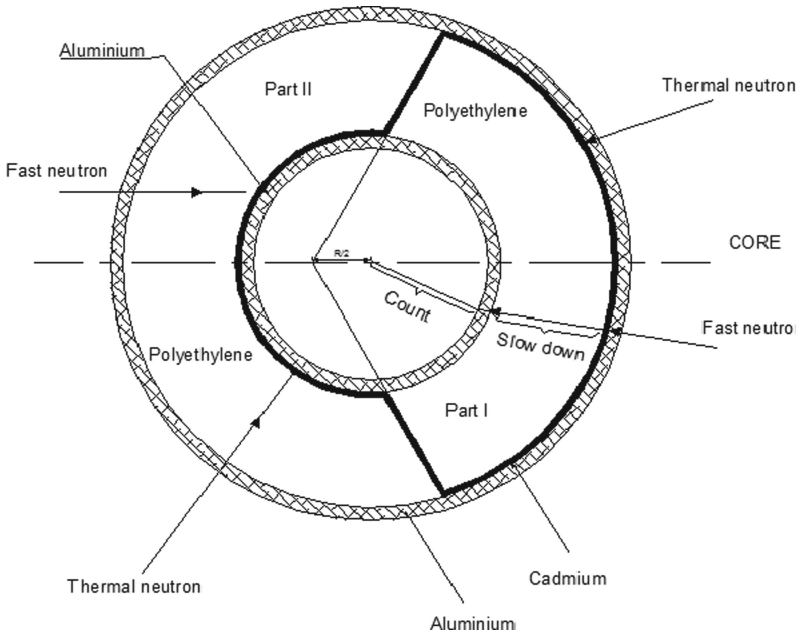


Fig. 2. Typical structure diagram of neutron detector

As shown in the above figure, the detector has an aluminum sealed cladding, which greatly attenuates electromagnetic interference, but the detector must be away from high low frequency magnetic sources.

2.1.2 Mineral Coaxial Cables

The mineral cable between the detector and the connecting plate is part of the detector.

Referring to the current design of CPR1000 power station, due to the length of the cable, the length is less than 15 m, and the support in the adjacent concrete wall, the induction mode current caused by radiation coupling on the outer shield is very low.

It is necessary to ensure that the cable without interference around the detector is close to the detector area, regardless of high frequency crosstalk or capacitive coupling to the detector.

2.1.3 RPN Cabinets, Board Cards and Equipment in Cabinets

See Fig. 3 for the schematic diagram of RPN system architecture layout. RPN system equipment is installed in 5 cabinets, 4 protection cabinets and 1 control cabinet. Protecting cabinets requires physical and electrical isolation, and the isolation of the entire channels from RPN detectors measurement to signal conditioning.

The control cabinet receives analog signals from the four protection cabinets, and the protection cabinets need to install isolation modules to realize the isolation of analog signal transmission and the control cabinet. The control cabinet sends the counting rate

signal to the reactor building, cabinet body and speaker in the main control room [4]. At the same time, it provides neutron level and neutron noise signals for KIR system, which are transmitted through hard wiring.

IP, IIP and IIIP channel protection cabinets include measurement and processing functions of three measurement channels (source range, intermediate range and power range); IVP channel protection cabinet includes a measurement and processing function of a measurement channel (power range). Each measurement channel mainly includes the following two parts: neutron detectors and processing modules. The processing module can adjust and process the signals generated by the neutron detector and provide the required data and standard signal interface for the downstream.

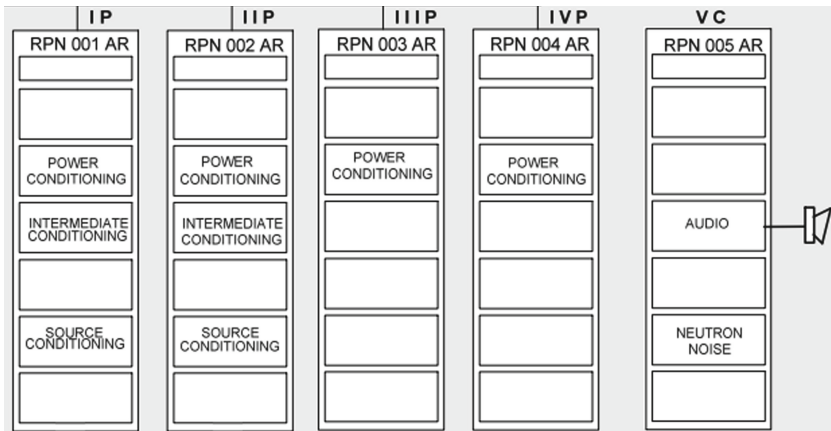


Fig. 3. Schematic diagram of detector cabinet layout

2.2 Analysis of RPN System Layout Characteristics

2.2.1 Environmental Analysis and Installation Requirements

The CPR project measured the external electromagnetic interference of RPN system, and the measurement was mainly carried out along the cable path of two source range channels. There is much electrical equipment along the RPN system source range signal link, such as: large cabinets, uninterruptible power supplies, air conditioners, lighting equipment, etc. Although these equipment have been identified by EMC, they are limited to the site space, and it is not clear whether superimposed electromagnetic interference will occur due to the proximity of the equipment.

Electromagnetic disturbance caused by field strength measuring instrument to space electromagnetic environment and electrical equipment. The current probe and spectrum analyzer are used to test the electromagnetic disturbance radiated outward through the cable connected by electrical equipment (Fig. 4).

Through the on-site survey and electromagnetic environment detection of RPN Source Range Channel, it is preliminarily concluded that:



Fig. 4. Measuring the power input line of energy-saving lamp with current probe

- (1) RPN cables pass through the room of reactor building, connection building and electrical building, and there is relatively large electromagnetic interference in some areas.
- (2) There are significant differences in electric field emission intensities of electrical equipment around cable route.
- (3) The electromagnetic disturbance caused by some electrical equipment is relatively strong, Energy-saving lamps are a main source of electromagnetic disturbance in the unit, and the corresponding suppression measures are not in place. In addition, the electromagnetic emission of energy-saving lamps exceeds the requirements of GB17743 in some frequency bands [5].
- (4) The grounding and shielding measures for some cables, trays and penetrations are not in place.

To sum up, although it is said that individual equipment and cables meet the technical requirements of EMC electromagnetic compatibility, due to the existence of connectors, there are weak links in signal connectors, especially those frequently touched in the process of installation, debugging, maintenance and testing. Acceptable installation technical requirements shall be formulated for each link. The installation technical requirements shall involve the following contents:

- a) Laying of cables in the instrument vertical shaft/shaft;
- b) Installation and wiring of neutron flux rate detectors;
- c) Cables between the cabinet and the neutron flux rate detector;
- d) Production of various connectors;
- e) Connection of cables in electronic cabinets;
- f) Continuity requirements for cable trays.

2.2.2 Grounding and Shielding Issues

Grounding and shielding measures can effectively protect the electrical system from the influence of external electromagnetic noise and greatly improve the electromagnetic environment adaptability of the electrical system. Proper grounding and shielding measures can also effectively suppress electromagnetic disturbance generated by the electrical system itself. Good grounding can provide lower grounding impedance, which is an important factor to ensure shielding effectiveness of shielding layer. However, in the process of RPN field measurement, it was found that there were many problems in grounding and shielding of shielded cables, cabinets, pallets and penetrations in the unit. The main manifestations are:

- (1) When the shielded cable is terminated, the shielding layer is discontinuous.
- (2) The tray is interrupted, resulting in discontinuous shielding layer. It may cause external electromagnetic disturbance to enter the electrical system through the fracture of the shielding layer, and the electromagnetic disturbance generated by the electrical system itself radiates outward through the fracture of the shielding layer.
- (3) The lack of overlapping measures for pallets leads to discontinuity of pallets (shielding layer) at overlapping points and large gaps. A gap of a certain length can be considered as a receiving or transmitting antenna, which can receive external electromagnetic disturbance or transmit the electromagnetic disturbance carried by it.
- (4) No shielding material is used at the gap of the cabinet. The rectangular slot of the cabinet can serve as a receiving or transmitting antenna for electromagnetic disturbance, which is not conducive to improving the adaptability of the cabinet to the electromagnetic environment [6].

2.2.3 Isolation Between Interference Source and Transmission Path

The RPN path has a long trace, from the perspective of electromagnetic compatibility, it can be considered that the RPN path is the "transmission path" to receive electromagnetic disturbance. No matter in theory or in engineering practice, it is required that the high-intensity electromagnetic noise source and the "transmission path" for receiving electromagnetic disturbance should be separated from each other in space. However, in the actual implementation process on site, it was found that the interference sources in some rooms were close to the trays of RPN system, which did not meet the requirements of isolation [7].

3 Analysis of Identification Standards for RPN Detectors

3.1 Electromagnetic Compatibility Standards Commonly Used in Nuclear Power Plants

The standards generally referred to for equipment with different safety levels in nuclear power plants are shown in the following Table 1. Safety-level equipment mainly refers to RG1.180 and IEC 62003 for electromagnetic compatibility tests, while non-safety-level equipment reference standards are more diversified than safety-level. It can refer

to special product standards, product standards or general standards for electromagnetic compatibility tests, but the specified test items and test grades are roughly same. The main reference standards are GB 11684 [8], IEC 61326 [9] and IEC 61000-6 [10].

Table 1. Reference standards for EMC tests commonly used in nuclear power plants

Safety grade	Special product standard	Product class standard	General standard	Basic standard
Safety level	RG1.180 IEC62003	–	–	IEC61000-4 MIL-STD-461E
Non-safety level	–	GB/T 11684 IEC61326	IEC61000-6-2 IEC61000-6-4	IEC61000-4

3.2 RPN Detector Evaluation Requirements

The electromagnetic compatibility test of RPN detector needs to be carried out together with secondary instrument and transmission cable. The specific test method can refer to IEC61000-4.

Acceptance basis: The test acceptance criteria for detector components are that after the detector components are connected with secondary instruments and transmission cables, the overall test results meet the electromagnetic compatibility requirements of the cabinet.

At this stage, the Electro Magnetic Compatibility of RPN system electrical equipment mainly depends on two measures:

- (1) When the equipment is delivered, the equipment supplier shall provide the EMC test qualification report;
- (2) Carry out “Nuclear Instrumentation Anti-Noise Test” on site.

The EMC test report provided by the equipment supplier of CPR1000 project is based on IEC61000-6 series, and IEC61000-6 series standard is a general standard in the field of EMC. The requirements of this series of standards are made under general conditions. The specified electromagnetic emission limit is relatively high and the electromagnetic immunity test level is relatively low. Therefore, equipment conforming to IEC61000-6 series of standards is not necessarily applicable to the electromagnetic environment in the nuclear island. For example, in IEC61000-6 series standards, for the test grade of electromagnetic radiation immunity, the standard only requires 10 V/m, and the frequency range is limited to 80 MHz–1000 MHz; For the electrical fast transient burst immunity test, the test grade is specified to be only up to ± 2 kV. Moreover, the standard is applicable to all electrical equipment working in an industrial environment. It can be seen from this that the terms in IEC61000-6 series standards are only applicable to general conditions. For Nuclear Island, the best treatment measure is to compile a targeted Electro Magnetic Compatibility test outline in combination with the monitoring data of the electromagnetic environment on the nuclear island. Only electrical equipment that meets the test requirements of the Outline can be used on the island.

3.3 RPN Cabinet Qualification Test

The following table provides which tests have been carried out and the accepted performance standards (Table 2):

Table 2. Cabinets test items

Test items	Test parameters	Reference standard	Test grade	Performance criteria
Electro Static Discharges Immunity Test (Contact Discharge)	Contact Discharge ± 4 kV	IEC 61000-4-2:2001	3 Class	A (± 4 kV)
Electro Static Discharges Immunity Test (Air Discharge)	Air Discharge ± 8 kV	IEC 61000-4-2:2001	2 Class	A (± 8 kV)
Radiation Immunity Test for Radio Frequency Electromagnetic Fields	80–1000 MHz	IEC 61000-4-3:2002	3 Class	A (10/Vm)
Electrical Fast Transient Burst Immunity Test	5/50 ns, 5 kHz	IEC 61000-4-4:2004	3 Class	A (I/O ± 1 kV) (Power Supply: ± 2 kV)
Immunity to conducted disturbance induced by radio frequency field	0.15–80 MHz	IEC 61000-4-6:2006	3 Class	A (10 V)

Note: Performance Criteria A, during and after the test, the instrument (equipment) shall be continuously operated in a predetermined manner. When the equipment is used in the predetermined way, its performance degradation or loss of function is not allowed to fall below the performance level specified by the manufacturer [11]

4 Conclusions

The improvement of EMC characteristic design for nuclear instruments is a systematic project. The research in this paper shows that electromagnetic compatibility design must be added from the top-level design of the system. Through equipment design to meet the requirements of RPN signal detection equipment and cables on electromagnetic environment; verify the requirements of the cabinet for electromagnetic environment through equipment identification and other means; the stability of the signal link is improved by installing technical requirements. Combined with RPN layout scheme and project engineering experience, formulate EMI protection requirements and implementation measures that can be implemented on site. And strengthen daily supervision to ensure that the system is in a healthy and stable operation state under good environmental conditions to ensure continuous and stable production of nuclear power plants.

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