Electromagnetic Interference Incidents and Compatibility Assurance in Nuclear Power Plants: A Review of Challenges and Preventive Measures

[1]Rahul Mishra

Publication Date: 2025/10/16

Abstract: Electromagnetic Compatibility (EMC) is a critical qualification parameter for safety-related Instrumentation and Control (I&C) systems in nuclear power plants (NPPs). Disruptions in system performance caused by Electromagnetic Interference (EMI), Radio Frequency Interference (RFI), or power surges can pose serious risks to plant safety and reliability. In recent years, the growing use of microprocessor-based devices, high-frequency circuits, and low-power transmitters has increased the occurrence and severity of EMC issues in NPPs. Studies and operational events have demonstrated the vulnerability of both analog and digital safety systems to EMI/RFI, reaffirming the importance of robust EMC practices. This paper highlights the significance of EMI/EMC in nuclear safety and reviews recent incidents in NPPs linked to electromagnetic disturbances.

Keywords: *Electromagnetic Interference (EMI), Electromagnetic Compatibility (EMC), Emission, Susceptibility, Coupling.*

Abbreviations

CH:	Channel
FP:	Full Power
ICA:	Ion Chamber Assembly
MCR:	Main Control Room
OBE:	Operating Basis Earthquake
PHT:	Primary Heat Transport
PPP:	Primary Pressurizing Pump
RPS:	Reactor Protection System
SDS:	Shut-down System
SSC:	Structure, System and Component
WAN:	Window Annunciation

How to Cite: Rahul Mishra (2025) Electromagnetic Interference Incidents and Compatibility Assurance in Nuclear Power Plants: A Review of Challenges and Preventive Measures. *International Journal of Innovative Science and Research Technology*, 10(10), 811-815. https://doi.org/10.38124/ijisrt/25oct383

I. INTRODUCTION

With the progressive advancement of digital technologies and the diminishing availability of spare parts for legacy analog systems, NPPs are undergoing a rapid transition toward digital I&C architectures. The obsolescence of analog components, coupled with the superior flexibility, processing capability, and reliability offered by digital systems, has accelerated the implementation of digital I&C upgrades across the existing fleet of NPPs. Moreover, the integration of safety-critical digital I&C systems is envisaged to be a defining feature of next-generation nuclear power technologies, particularly in Advanced Heavy Water Reactors (AHWRs) and Small Modular Reactors (SMRs), where enhanced automation, diagnostics, and control precision are fundamental to operational safety and efficiency.

The increasing dependence of NPPs on advanced electronic and digital I&C systems has brought significant improvements in plant safety, reliability, and operational efficiency. However, this technological evolution has also made NPPs more susceptible to EMI, which poses potential risks to the functional integrity of safety-critical systems. EMC thus becomes a crucial aspect of nuclear plant design, construction, and operation, ensuring that various electrical and electronic devices can coexist and function reliably within a common electromagnetic environment.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25oct383

In NPPs, sources of electromagnetic disturbances include high-power electrical equipment such as motors, transformers, switchgear, variable frequency drives (VFDs), as well as external factors like lightning, switching transients, and even intentional electromagnetic interference (IEMI). These disturbances can induce unwanted currents or voltages in sensitive circuits, potentially leading to malfunctions, spurious trips, or degradation of system performance. Given the safety-critical nature of nuclear operations, such disruptions are unacceptable and necessitate comprehensive EMC management throughout the plant lifecycle.

Regulatory bodies such as the International Electrotechnical Commission (IEC), Institute of Electrical and Electronics Engineers (IEEE), and International Atomic Energy Agency (IAEA) have emphasized the importance of EMC standards for nuclear applications. Standards like IEC 61000 series and IEEE Std 1050 provide guidelines for grounding, shielding, cabling, and testing to mitigate EMI and ensure compliance. Despite these frameworks, practical challenges remain due to the complex electromagnetic environment of NPPs, legacy equipment coexistence, and the increasing use of digital control systems.

II. BACKGROUND

EMC deals with the unintentional creation, transmission, and reception of electromagnetic energy that can cause undesired effects such as EMI or even physical damage to operating equipment. The main aim of EMC is to ensure that different devices operate correctly within a shared electromagnetic environment.

EMC focuses on three main categories of problems. *Emission* refers to the production of electromagnetic energy, either intentional or accidental, and its release into the environment. EMC examines unwanted emissions and the methods used to reduce them. *Susceptibility* is the tendency of electrical equipment, known as the victim, to malfunction or fail when exposed to unwanted emissions, called radio frequency interference (RFI). Immunity is the opposite of susceptibility—it is the ability of equipment to function properly in the presence of RFI. The process of making equipment resistant to interference is called hardening. *Coupling* is the process through which emitted interference reaches the victim device.

Electromagnetic compatibility, and therefore interference reduction, can be achieved by dealing with any or all of these aspects—reducing interference sources, blocking coupling paths, or hardening susceptible devices. In practice, many engineering methods such as grounding, filtering and shielding are applied to address all three aspects simultaneously.

➢ *EMI Frequency Ranges*

An important property of electromagnetic noise is its frequency. EMC standards usually cover the spectrum from 0 Hz up to 400 GHz. The first significant frequency range lies around the power network frequency, which is 50 Hz in India. Harmonics produced by non-linear loads begin at 50 Hz and extend up to 2 kHz or 2.5 kHz. Between the end of this harmonic range and 9 kHz lies a frequency region that is presently unregulated. Above 9 kHz begins the high-frequency range, also known as the radio-frequency or RF range. Radio frequency refers to all frequencies from a few kilohertz to several gigahertz. EMC standards define the upper frequency limit as 400 GHz. Current testing standards generally cover 9 kHz to 1 GHz, with newer versions extending to 2 GHz or higher.

The RF range is typically divided into conducted and radiated regions. In the lower part of the RF range, noise mainly travels through conductors rather than radiating from the device. This happens because lower frequencies require larger antenna structures. Simply put, most equipment is not physically large enough to emit low-frequency radiation. Although no exact transition point exists, standards usually specify the conducted RF range from 150 kHz to 30 MHz, with some starting at 9 kHz. The radiated range begins at 30 MHz, and its upper limit varies by standard, typically reaching 1 GHz, or for certain products, extending to 2 or even 3 GHz. To summarize, we have the following (Fig. 1) ranges:

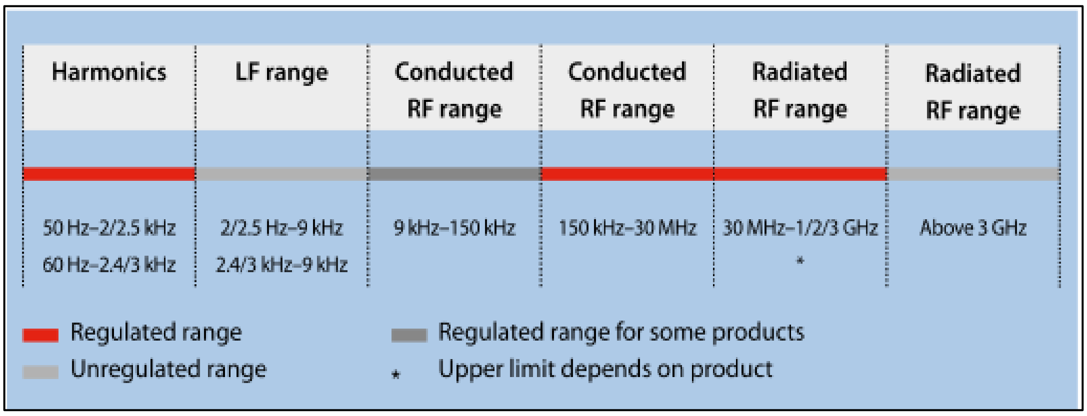

Fig. 1: EMI Frequency Ranges

A. *Types of Noise*

➢ *Differential mode noise*

When considering conducted signals, noise can appear between any two lines within the system. In a single-phase setup, this may occur between the phase (P) and neutral (N) lines. In a three-phase arrangement, it can exist between phase 1 (R) and phase 2 (Y). In direct current (DC) systems, the noise may flow from the positive to the negative terminal. This type of noise is referred to as differential-mode noise or symmetrical noise. Fig. 2 illustrates differential-mode noise in a single-phase system.

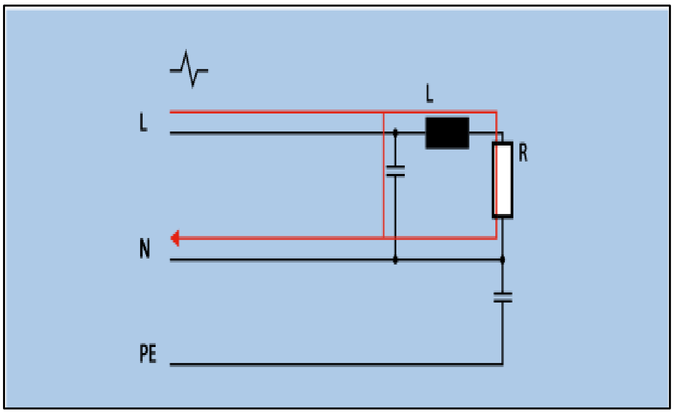

Fig.2 Differential Mode Noise

➢ *Common Mode Noise*

Noise can also be transmitted from any line in the system to the earth. In a single-phase system, signals may flow from L and P lines towards the earth. This form of noise is known as common-mode noise. The key distinction is that common-mode noise moves through all lines in the same direction and then flows toward the earth. Fig. 3 below illustrates common-mode signals in a single-phase system.

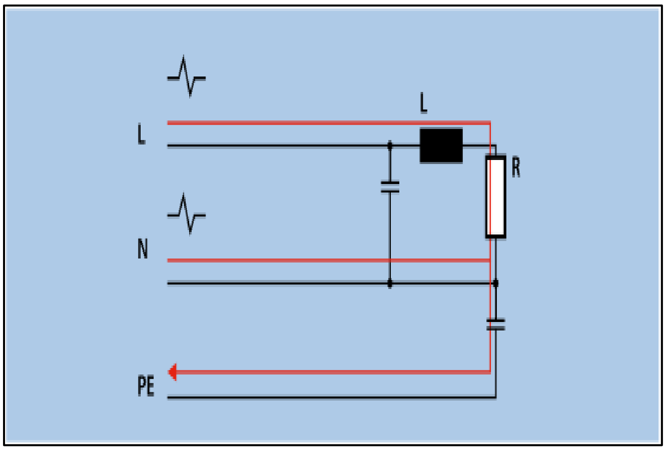

Fig. 3 Common Mode Noise

B. *Coupling Methods*

When examining the connections within an electrical or electronic system, we can identify three main ways in which interference can transfer, known as coupling paths. The first is galvanic coupling, which occurs when two parts of the system are directly connected by a conductor, allowing current to flow between them. The second is capacitive coupling, which takes place when two cables are positioned close to each other, creating an unintended or parasitic capacitor through which voltage variations can pass. The third is inductive coupling, which happens when cable loops from different circuits are placed too near each other, allowing magnetic fields from one cable to induce unwanted currents in the other. Fig. 4 below illustrates various coupling methods described above.

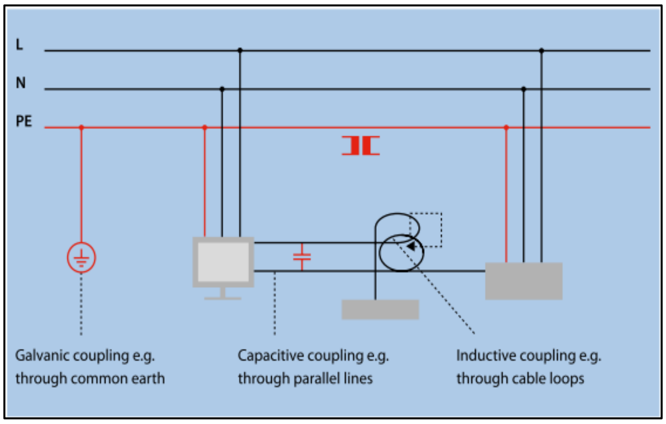

Fig. 4 Various Coupling Methods

III. PAST INCIDENTS RELATED TO EMI/EMC IN NPPS

➢ *PWR, Thihange-3, Belgium*

On October 3, 2022, TIHANGE-3 was operating at full power. Disturbance in pressure readings of Steam Generator-3 followed by low pressure signal resulted in closure of steam & feed water isolation valves. This led to pressure transient in all SGs, triggering safety injection signal and reactor scram.

The event investigations revealed that SG pressure monitoring system uses Rosemount 1154 transmitters (i.e. 80s model). These transmitters & their connectors were not qualified for EMI. Before the event, cleaning staff in auxiliary room (where these transmitters were located) were using mobile phones. The auxiliary room was made of reinforced concrete structure and hence the mobiles generated maximum transmission power during use, resulting in EMI generation and consequent disturbances in pressure readings of SG-3.

➢ *PHWR, MAPS-2, India*

On 03/09/2023, MAPS Unit-2 was under startup after Biennial Shutdown (BSD) and reactor power was about 0.1%FP. At 23.14 hrs, Reactor tripped on RPS channels-D and F actuation on 'seismic OBE more than 0.05g' parameter. During that time lightning and heavy thundering was reported. After the incident, all control room panels were scanned for abnormal alarms/indications and no abnormality was found. All plant areas walk down was done and no abnormality was reported. As per INCOIS and National Center for Seismology, there was no seismic event recorded during the said period in that region. All safety related SSCs were reported to be normal.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25oct383

After investigation, it was concluded that due to lightning surge, high voltage got induced in the long cables connecting the seismic switch to control room and caused the semiconductor devices to fail. The design specifications for the semiconductor junctions are of the order of few tens of volts and hence those devices failed under the voltage injection from lightning strike through the test circuit. The vertical module of the switch failed and Channel-F seismic trip signal got actuated and remained in tripped condition. Channel-D seismic switch actuation for a brief period of 2-3 sec. due to lightning interference resulted into reactor trip on 2/3 logic.

- *PHWR, KAPS-3, India*

KAPS-3 was operating at 0.85% FP Reactor power. Core cooling was maintained by operating all the four shutdown cooling pumps. PHT pressure and temperature were stable at 30 kg/cm 2(g) and 41°C respectively. Moderator system and Reactor auxiliaries were operating normal. At 15:49:29 hrs, on 08/10/2021, seismic channel trip appeared simultaneously in CH-D & CH-E which resulted in actuation of RPS#1 and consequently Reactor got tripped by SDS#1. During this event, heavy lightning and thunderstorm was observed in and around operating island area**.** During the event, except for actuation of seismic channel trips, no other alarm i.e. "*Seismic ground acceleration high*" and "*Error in seismic instrument*" WANs appeared in control room and also Ground acceleration system did not record any seismic event.

After investigation, it was concluded that Spurious actuation of Ch-D and Ch-E seismic switches during the thunderstorm occurred due to nearby lightning strike which might have caused Ch-D and Ch-E seismic switches' trip relay actuation due to elevation of earth potential or noise pickup in the self-test cable which is around 1 km long.

- *PHWR, KAPS-3, India*

On 05/03/2024, KAPS-4 was under cold shutdown and Reactor power was 9.8E-05% FP. At 11:53:11 Hrs, AN-133 "RPS-2 CH-J TRIP" along with AN-130 "RPS-2 RATE LOG N HIGH" appeared on MCR 6610-PL-01. CH-J reset was attempted but it remained tripped. At 11:53:47 Hrs "AN-125 RPS-2 CH-G TRIP" also appeared leading to actuation of SDS-2. AN-129 "RPS-2 CH-H TRIP" appeared due to force trip on 2/3 channels tripping.

Initially spike in rate log N signal was observed in Channel-J only and got latched. After 36 seconds spike in channel-G rate log N signal appeared. Channel H rate log value was maintaining almost zero. Rate log N high alarm in both affected channels got initiated at 36 seconds apart. If the power excursion was genuine, the alarms would have been initiated almost simultaneously in all the three channels of SDS-1 and SDS-2. No spike in RPS-1 "rate log-N" signals of CH-D, E and F was observed. No change in any reactivity device position was observed during the period.

After investigation it was found that welding work was in progress near PPP near to which SDS-2 cables were passing. Also, some material handling work was going on in SDS-2 area. At the time of incident, reactor was operating at low power i.e. 9.8E-05% FP. SDS-2 Ion Chamber input current corresponding to this power is of the order of 10^{-11}Amp. As current signal in this range is very small, any noise gets amplified by ICA. Accordingly, it was inferred that SDS-2 CH-G and CH-J log rate high signal might have generated by electronic noise from welding machine and/or vibration of cable at SDS-2 Ion Chamber area during material handling.

IV. RECOMMENDED MEASURES TO PREVENT EMI/EMC RELATED INCIDENTS IN NPPS

- *Strengthen EMC Design and Qualification*

The design and qualification of equipment must adhere strictly to international EMC standards such as IEC 61000, IEEE Std 1050, and IAEA TECDOC-1332. All safety-class instrumentation and control (I&C) devices should be qualified for electromagnetic immunity, and wherever legacy analog systems remain, retrofitting with EMI-hardened enclosures, shielded connectors, or qualified replacements should be prioritized. The use of non-qualified or commercial-grade components in safety-related applications should be strictly avoided.

- *Improve Grounding and Shielding Practices*

Proper grounding and shielding practices play a crucial role in minimizing electromagnetic disturbances. Implementing single-point grounding and equipotential bonding schemes helps eliminate ground loops and potential differences that can induce noise in sensitive circuits. Shielded cables with 360° termination at connectors should be used for low-level signal transmission, and segregation between power, control, and communication cables should be maintained. Furthermore, lightning protection zones (LPZs) designed as per IEC 62305 can significantly reduce surge propagation into control systems, enhancing system robustness during thunderstorms or switching events.

- *Cable Routing and Layout Optimization*

Attention should also be given to cable routing and layout optimization, as the physical arrangement of cables greatly influences EMI susceptibility. Signal and power cables should be routed separately, maintaining adequate spacing to avoid inductive or capacitive coupling. Twisted-pair cabling for analog and digital signals reduces differential-mode noise, while long unshielded runs should be avoided by using local signal conditioning or isolation units. This minimizes the risk of signal corruption due to electromagnetic fields from nearby high-current equipment such as motors, transformers, or variable frequency drives.

- *Control of EMI Sources*

Establishing EMI-controlled zones around critical control rooms and panels can prevent unintentional exposure from high-frequency devices like mobile phones, walkie-talkies, or welding machines. Installation of line filters, ferrite cores, and surge suppressors on the power supply lines of sensitive equipment can effectively suppress conducted interference. Regular inspection and maintenance of grounding and bonding systems should also be performed to

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25oct383

prevent corrosion or loosened connections that could increase system vulnerability.

- *Periodic EMC Audits and Monitoring*

Routine EMC audits and continuous monitoring should be institutionalized as part of the plant's preventive maintenance program. Periodic surveys using portable spectrum analyzers or field probes can help detect abnormal interference levels and identify problem areas early. Integrating real-time EMI monitoring systems in control rooms and cable galleries can further enhance situational awareness by recording transient events. Any spurious trips or anomalies should be thoroughly analyzed to determine the root cause and to establish corrective measures.

- *Personnel Training and Operational Controls*

Operating and maintenance staff should be made aware of EMC-sensitive areas and the hazards of using unshielded tools or wireless devices like radio, mobile phones, welding machines etc. near control systems. EMC requirements should also be incorporated into work permits and plant modification reviews.

V. CONCLUSION

The increasing digitalization of I&C systems in NPPs has significantly enhanced operational efficiency, monitoring accuracy, and safety diagnostics. However, this technological evolution has also introduced new vulnerabilities associated with EMI. The case studies reviewed—ranging from spurious reactor trips caused by lightning-induced surges to sensor malfunctions triggered by mobile phone emissions and welding operations—highlights the critical importance of EMC in maintaining the functional integrity of safety-class systems.

Ensuring EMC in NPPs is not merely a design requirement but a continuous process encompassing equipment qualification, installation practices, grounding, shielding, and periodic assessment throughout the plant lifecycle. International standards such as IEC 61000 and IEEE 1050 provide the necessary framework, but their effective implementation requires plant-specific adaptation and rigorous compliance monitoring. As the nuclear sector moves toward advanced reactor concepts such as AHWRs and SMRs, where digital I&C systems play a dominant role, EMC assurance must be integrated at every stage—from conceptual design to commissioning and operation.

REFERENCES

[1]. Richard T.Wood, Paul D. Ewing, Stephen W. Kercel and Kofi Korsah, "Electromagnetic Compatibility in Nuclear Power Plants".
[2]. Philip E. VanWiltenburg, "Mitigation of EMI generated by a Variable Frequency Drive Controller for an AC Induction Motor".
[3]. Le Yang and Shuo Wang, University of Florida, "Electromagnetic interference modeling and suppression techniques in variable frequency drive system".
[4]. Schaffner white paper on "Basics in EMC/EMI and Power Quality".
[5]. Root Cause Analysis reports