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I&C Equipment Qualification Methods on EMI for Nuclear Power Plants

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Abstract

As the possibility and trend of using digital technology in safety systems for retrofitting in existing plants and newly-using for future nuclear power plant are growing, Electromagnetic Interference (EMI) and Radio Frequency Interference(RFI) are considered as potential common failure causes to microprocessor-based systems for nuclear power plants. This paper presents the current status of EMI qualification methods and suggests the basic approaches and principles of qualification of EMI/RFI for Instrumentation and Control (I&C) equipment for nuclear power plants to be built in the near future.

1. Introduction

The various benefits of digital technology have promoted the considerable use of computers and programmable equipment in safety-related systems as well as non-safety systems for nuclear power plants. In fact, an old plant protection system has been replaced by a microprocessor-based protection system in Kori Unit 1 plant and a Programmable Logic Controller(PLC)-based plant protection system will be introduced for Ul-Chin Unit 5&6 plants. However, in spite of many advantages in digital technology, concerns of potential Electromagnetic Interference/Radio Frequency Interference(EMI/RFI)-related failures in digital systems have been issued because of the inherent natures of microprocessor-based systems such as low logic voltage level and high clock frequency. It is certain that digital systems are much more likely to be vulnerable to electromagnetic noise than relay-based analog systems [1-3].

The US Nuclear Regulatory Commission(NRC) and the Electric Power Research Institute(EPRI) have performed a lot of research to address the problems and effects on EMI/RFI

and to establish electromagnetic compatibility for I&C equipment in nuclear power plants[3-7]. Both organizations made their efforts to identify the applicable and acceptable standards and Electromagnetic Interference/Electromagnetic Susceptibility(EMI/EMS) levels for nuclear plants(NPPs).

This paper presents regulatory codes and standards regarding EMI/RFI qualification in Section 2. Based on the regulations, key principles and strategies to address EMI/RFI problems are described in Section 3. Section 4 suggests a general EMI qualification procedure.

2. Regulatory Framework

Qualification of safety-related instrumentation and control equipment for operability under design environmental conditions is a prerequisite under 10CFR50, Appendix A. EMI/RFI is an environmental condition affecting electrical systems; however, historically, electromechanical relay-based systems are considered immune to the effects of EMI/RFI. Therefore, no particular code and standard specified EMI/RFI problems for nuclear power plants before. As computer systems were considered to be used in safety systems, IEEE Std 7-4.3.2 required to address EMI vulnerability of computer systems in Annex C in 1993.

However, nuclear vendors conducted their own approaches to qualify digital safety systems against EMI environments. For example, ABB-CE performed the EMI/RFI qualification for ANO-2 Core Protection Calculator (CPC) in 1970s in accordance with MIL-STD-461A[2]. These tests were limited to susceptibility tests only, because there was no other digital safety equipment in the vicinity of CPC. Recent practices are that US utilities should meet the requirement by demonstrating that the EMI/RFI emission level in the site is much less than equipment's susceptibility level. Then the NRC reviews the utilities' plant specific equipment qualification documents on a case-by-case basis[1].

The current trend to use digital technology even for safety systems has motivated the US NRC to raise concerns about the need to establish regulatory guides and standards on the electromagnetic issues. Oak Ridge National Laboratory has issued a series of reports addressing EMI/RFI related concerns for nuclear power plants under the research programs sponsored by the US NRC [3,6,7]. The reports described ambient electromagnetic noise in American nuclear power plants and recommended the applicable requirements and standards to ensure the electromagnetic compatibility levels of the safety systems. They refer to MIL-STD-461C/D [8,9] and IEEE C62.41-1991 [10] for EMI/RFI and Surge Withstanding Capability(SWC) qualification. The NRC

has issued a draft regulatory guide, DG-1029 [11], based on above research results. The draft guide cited MIL-STD-461C/D for EMI/RFI testing and IEEE Std C62.41-1991 for surge withstand testing, while it has not changed its previous position of acceptance for EPRI-TR-102323[5].

In other hand, the EPRI organized a working group to perform a research project on EMI resolution for nuclear power plants. The working group's mission was to (1) measure and evaluate nuclear plant EMI/RFI emission levels, (2) recommend an appropriate set of EMI/RFI equipment emissions levels and susceptibility test levels to qualify safety-related equipment for use in nuclear plant installations, and (3) develop products for the nuclear power industry to minimize the effects of EMI on plant I&C equipment[4,5]. In 1994, the working group published a topical report as the research result, EPRI TR-102323, "Guidelines for Electromagnetic Interference Testing in Power Plants," which describes the recommended generic digital equipment qualification method for a plant's electromagnetic environment. The key point of TR-102323 is that the generic method eliminates the need of site specific electromagnetic surveys, because its qualification criteria is determined on the basis of the general site electromagnetic environment in US representative nuclear power plants. EPRI has published its new version, EPRI TR-102323 R1, in January 1997 without major changes. The nature of the revision is to add more detail in areas where the NRC commented. The most significant change is an increase of the margin between the plant emissions limit and the susceptibility limit from 6dB to 8dB. In a Safety Evaluation Report (SER) on April 17th 1996, the US NRC accepted the EPRI approach on the condition that a suitable demonstration is provided that the electromagnetic environment at the plant is similar to those plants identified in TR-102323.

In Europe, the International Electrotechnical Commission(IEC) developed the EMC standards as IEC-801 Part1-Part5[12]. It focuses only on the immunity capabilities of electrical systems for industries regardless of the emission levels.

Briefly, there can be two approaches and acceptance criteria for EMI/RFI qualification for nuclear power plants' safety systems. One is to qualify equipment in accordance with MIL-STD-461C/D, and the other is to follow the methods of EPRI TR-102323. IEC-801 or its revised equivalents will be able to be options or supplements for some cases.

In Korea, the general regulation requirement on EMI/RFI for general equipment is described in Section 29-4 in Radio Wave Act[13]. An Enforcement Regulation for Registration of Electromagnetic Compatibility is describing the registration procedure of electromagnetic

compatible equipment[14]. It authorizes 'Notices of the Ministry of Information and Communication' to establish and commit the acceptable criteria of EMI/RFI emission and susceptibility level in Sections 3 and 4 of Enforcement Regulation for Registration of Electromagnetic Compatibility. Under the authorization, Notice 1997-41, 1997-42, 1996-78, and 1996-79 of the Ministry of Information and Communication [15] are identifying the standards for some kinds of equipment to meet. However, those regulations and notices don't provide any specification to electric equipment for nuclear power plants. The main purpose of the above standards is to regulate emission levels and secure susceptibility levels on high frequency equipment, ignition engines, broadcasting equipment, home electric equipment and motors, illuminators, high voltage equipment, computer-related equipment, etc. For I&C equipment to be used for Korean nuclear facilities, a domestic regulatory guide on EMI/RFI is under development by the Korean Institute of Nuclear Safety(KINS) as Safety Regulatory Guides 9-17. Therefore, the above US regulatory standards or international requirements should be applied for qualification on EMI/RFI conditions for the domestic nuclear power plants until the regulation is finalized.

3. Recommended Principles of EMI/RFI Qualification

3.1. Difference from General Environmental Qualification

Although EMI/RFI is regarded as an environmental stressor, its qualification method will be different from the methods of general environmental qualification because of the different characteristics and the lack of operational experience, information, and criteria with EMI/RFI influences regarding digital technology for nuclear power plants. The most significant difference is that the electromagnetic ambient conditions are not completely able to be determined or controlled by designs or systems. An electromagnetic environment is mostly determined by direct measurements at the corresponding locations and is time dependent, too.

3.2. Exemption of Aging Assessment

It is not expected that any significant aging mechanisms on I&C equipment from long term EMI/RFI exposure exist in the nuclear plant area. Although surge transients may cause an aging mechanism, any state-of-the-art technology is not available for general age conditioning on I&C equipment. Therefore, aging assessment can be exempted unless it is known to be needed for certain cases.

3.3. Test Oriented Qualification Methods

Because any typical model or quantitative analysis method for EMI/RFI qualification has not been developed nor commonly used yet, it is recommended to conduct the EMI/RFI qualification of electrical and I&C equipment by type testing to the extent practical.

3.4. Standards Application for EMI/RFI/EMS testing and verification

While EPRI TR-102323 suggests new limit curves and test conditions on EMI/RFI testing for nuclear power plants and is accepted by NRC, the military standards are still reliable because they have come from the wide variety of experience and use in military. Therefore, it is recommended that either EPRI TR-102323 or MIL-STD-461D should be applied for EMI/RFI qualification for safety systems in a conservative manner. For SWC test criteria, IEEE Std C62.41-1991 and IEEE Std C62.45-1992 [16] will be another acceptable criteria for nuclear power plants.

The selection of test items in MIL-STD-461D should be made on the basis of the army ground facility applicability. The basic applicability requirements are CE102, CS101, CS114, RE102, and RS103 for general ground equipment. In addition to the basic items, additional criteria such as CE101, RE101, and RS101 should be included to the applicability requirement items, because both low frequency and high frequency requirements are important. MIL-STD-461D doesn't specify the application limits for Army ground facilities on CE101 and RE101. Therefore, the limit of CE101 for Navy surface ships or the limit of CE01 of MIL-STD-461C should be a substitute for CE101 in nuclear applications. For RE101 application, it is recommended that the limit of RE101 for Army aircraft is applicable to power plants. For SWC testing, a qualification process will be able to take CS 115 and CS116 or IEC-801 Part 4,5 in place of C62.41-1991 because they simulate impulses and transients.

3.5. EMC-oriented Design and Installation

Any equipment tested under the strictest manner can not be guaranteed to be compatible to its environment unless emissions and coupling paths from surrounding sources are controlled. The design and installation practices described in IEEE Std 1050-1989 [17], "Guide for Instrumentation and Control Equipment Grounding in Generating Stations," provide useful guidelines for controlling upsets and failures caused by EMI/RFI. It is regarded as an acceptable EMC design and installation practice for nuclear power plants by NRC [11]. It comprises 8 sections and the key contents are contained in sections 4, 5 and 6. Section 4 (Design Considerations for Electrical Noise Minimization) provides an in-depth overview of typical noise

sources, noise coupling methods, and techniques useful for minimizing electrical noise. Section 5 (Grounding) describes the principles and guidelines for grounding I&C systems in power plants. Section 6 (Typical Grounding Requirements for Generating Station Applications) shows the typical acceptable practices for grounding in certain situations. Other documents referenced in IEEE Std 1050-1989 such as IEEE Std 518-1982 [18], "IEEE Guide for the Installation of Electrical Equipment to Minimize Noise Inputs to Controllers from External Sources," and IEEE Std 665-1987 [19], "IEEE Guide for Generating Station Grounding," offer more details on some topics than IEEE Std 1050.

In addition to grounding technology, more practices to minimize EMI emissions and couplings should be implemented in nuclear power plants [4,5]. Those practices will include controlling the use of wireless transceivers, arc welding, ignition engines, electric concrete crushers, etc., separation between signal cables and power cables, rigorous shielding, and so on.

3.6. Site Noise Survey

The noise levels of a plant are very important data to verify or estimate the possibilities of EMI/RFI hazards to digital equipment in nuclear power plants. Furthermore, it is a technical basis to ensure that the Class-1E equipment will be operating properly in its location of the plant. However, in the case of a new plant construction, it is impossible to map electromagnetic noise in the power station before operation. Therefore, it is recommended that similar plants shall be chosen to undergo site survey and the measured data will be used as a reference for EMI qualification for I&C equipment until it is superseded by the site survey data taken after the plant's startup and operation.

In addition, periodic measurements of the electromagnetic environment will be recommended to verify and trace the plant's EMI/RFI situation, because EMI/RFI characteristics are very variant in time and location and are very difficult to predict.

3.7. Tailoring

Although the EMI/RFI test standards address the applicable guidelines and acceptable criteria, flexibility, so called, 'Tailoring' is given to the application cases as a principle. The application criteria may be derived from operational and engineering analysis on equipment or the environment it is to be installed in. The concept of tailoring is appropriate for application in safety-related systems for nuclear power plants, too. It is expected that the environment of equipment,

functions, degree of importance, interconnecting architecture with other systems, and failure modes are different for each application. Therefore, when analyses or engineering practices reveal that the requirements in the standards are not appropriate for a certain application, the requirements or applicable limits may be tailored and incorporated in the system design.

EPRI TR-102323 doesn't allow any tailoring concept. However, from the above reasons, the 'Tailoring' concept should be applied to EMI/RFI qualification requirements for safety related electrical systems for nuclear power plants in Korea. This flexibility should be incorporated into the system design of I&C systems for nuclear power plants.

4. EMI/RFI Qualification Procedures

In a narrow interpretation, 'qualification procedure' will be limited to only the activities to do testing and make documentation on EMI/RFI for corresponding equipment including EMI test plan, test procedure, testing, test report, evaluation reporting, etc. However, this report assumes it as an overall strategy and procedure for activities to secure high quality in instrumentation and control systems against electromagnetic noise. The first step of activity regarding EMI/RFI qualification is to review and analyze the historical electromagnetic ambient data of domestic and other nuclear power plants to justify the applicable criteria for the scheduled new plants. Second, the system design should be performed with appropriate EMC engineering practices described above. The system requirements or criteria of EMI/RFI are incorporated or tailored into the system design specifications. The third step will be EMI/RFI testing on emissions and susceptibilities in accordance with the EMI qualification specification identified by the system design documents. Fourth, design or assembling may be modified to meet the EMI/RFI criteria if the test result is improper with the system specification. After design or assembly modification, re-testing should be performed to verify the performance improvement. Performing site survey on the new plant will be the last step to verify the electromagnetic noise of the newly-built plant and to justify the applied EMI testing criteria on the basis of the review of ambient noise data of the existing power plants in the first step.

The long term periodic measurements of the electromagnetic environment of the inaugurated plant will be necessary to verify and trace the plant's EMI/RFI situation during the plant's life.

5. Conclusion

EPRI TR-102323-R1 and MIL-Std 461D referred by DG-1029 will be the basic EMI/RFI qualification standards for the new plants to be built in Korea. IEC-801 or the revised equivalent will be an option in case of Electrostatic Discharge(ESD), Electric Fast Transient(EFT), and surge transients. In any case, the application of those criteria in a conservative manner is preferable, and as well, the tailoring concept should be allowed on the basis of engineering review and analysis of equipment or systems. Site survey will be a significant factor in terms of EMI/RFI qualification for nuclear power plants to verify and make a basis for establishing requirement criteria. Therefore, long term periodic measurements of the electromagnetic environment for plants having many microprocessor-based I&C systems in safety and important control systems should be taken.

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