ELECTROMAGNETIC COMPATIBILITY IN NUCLEAR POWER PLANTS*

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ABSTRACT

Electromagnetic compatibility (EMC) has long been a key element of qualification for mission critical instrumentation and control (I&C) systems used by the U.S. military. The potential for disruption of safety-related I&C systems by electromagnetic interference (EMI), radio-frequency interference (RFI), or power surges is also an issue of concern for the nuclear industry. Experimental investigations of the potential vulnerability of advanced safety systems to EMI/RFI, coupled with studies of reported events at nuclear power plants (NPPs) that are attributed to EMI/RFI, confirm the safety significance of EMC for both analog and digital technology. As a result, Oak Ridge National Laboratory has been engaged in the development of the technical basis for guidance that addresses EMC for safety-related I&C systems in NPPs. This research has involved the identification of engineering practices to minimize the potential impact of EMI/RFI and power surges and an evaluation of the ambient electromagnetic environment at NPPs to tailor those practices for use by the nuclear industry. Recommendations for EMC guidance have been derived from these research findings and are summarized in this paper.

I. INTRODUCTION

Rising maintenance costs, coupled with a lack of spare parts for instrumentation and control (I&C) systems no longer supported by the original manufacturer, are leading to greater use of digital I&C equipment in nuclear power plants (NPPs). As analog replacement parts become increasingly unavailable and as digital systems prove to be increasingly flexible, powerful, and reliable, more digital I&C upgrades will be installed in the current generation of NPPs. Perhaps even more significant for the long-term future of nuclear power, the widespread use of safety-related digital I&C systems is envisioned[1] for advanced light water reactors (ALWRs).

With the introduction of digital technologies at NPPs, there exists the potential for increased vulnerability to electromagnetic interference (EMI), radio-frequency interference (RFI), and power surges for advanced safety systems. To address this issue, guidelines for establishing EMI/RFI immunity and power surge withstand capability (SWC) are needed by the nuclear industry. As a result, the U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research engaged Oak Ridge National Laboratory (ORNL) to assist in developing the technical basis for guidance on electromagnetic compatibility (EMC).

The research into EMC issues for safety-related I&C equipment focused on understanding the potential vulnerabilities of I&C equipment to upsets caused by EMI/RFI, characterizing the electromagnetic environment at NPPs, and identifying engineering practices to ensure compatibility among electronic systems throughout their

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life cycles. An experimental investigation of the system-level effects induced by EMI/RFI and power surges was conducted to determine the consequences of electromagnetic stress on I&C system performance. Long-term measurements of electromagnetic conditions were taken at several NPPs to characterize the ambient environment. EMC design and installation practices were selected to control the impact of interference sources on nearby circuits and systems. EMI/RFI test criteria and the associated test methods were identified to evaluate the compatibility of equipment with the projected electromagnetic environment at NPPs. Similarly, SWC test criteria and methods were chosen to evaluate the impact of power surges on equipment connected to power circuits within the NPP. Finally, the test levels that should be applied for validating that safety-related I&C systems will operate properly in the intended environment were developed based on experience in other industries for similar environments and on the measured conditions at NPPs.

This paper reports the findings of the research conducted by ORNL to identify failure mechanisms and system malfunctions resulting from EMI/RFI, determine the ambient electromagnetic environment at NPPs, and investigate methods to minimize the susceptibility of I&C systems to EMI/RFI and power surge effects. In addition, recommendations for EMC guidance, derived from these research findings, are summarized in this paper.

II. ELECTROMAGNETIC SUSCEPTIBILITY

The susceptibility of digital technology to electromagnetic effects is of concern to the nuclear industry because the faster microprocessor clock rates and lower logic voltage levels being employed can increase the potential for disruption by EMI/RFI. In addition, some of the electronic circuitry in advanced I&C systems, particularly at the front end interface, remain based on analog technology. These circuits can amplify and propagate electromagnetic noise. Because of differences in susceptibility and noise generation between analog and digital equipment, the analog/digital interfaces within instrument strings are frequently the components most vulnerable to EMC problems.

The main sources of conducted or radiated EMI/RFI in electronic equipment include common impedance coupling (e.g., through ground line voltage drops that occur during current switching) and crosstalk, printed circuit board traces carrying driving- and driven-chip currents, and antenna loops formed by integrated circuits (ICs) and their decoupling capacitors. Typically, EMI/RFI-induced noise appears as a transient voltage across power supply traces as well as common impedance paths. Noise spikes are primarily a function of the IC's signal rise and fall times and its capacitive load. Thus, a measure of the inherent emission behavior is given by $C[dV/dt]$, where C is the input capacitance and dV/dt is the rise time. The higher the switching current, the greater the likelihood of noise-energy emission.

A significant effect of EMI/RFI-induced noise is illustrated in Figure 1. The state of a microprocessor is affected by the logic voltage levels of various clock and control lines connected to it. Typically, a desired change of state is induced by a voltage transition (on a rising or falling edge) as shown in the figure. If EMI/RFI is coupled onto the signal or control line, it can disrupt the process. The combination of the logic voltage level and the EMI/RFI can possibly be misinterpreted as an edge, thereby causing a change of state when none was intended.

ORNL research into the potential vulnerabilities and upsets of microprocessor-based I&C systems demonstrated how the performance of an advanced safety system might be disrupted by EMI/RFI.[2] The approach employed involved

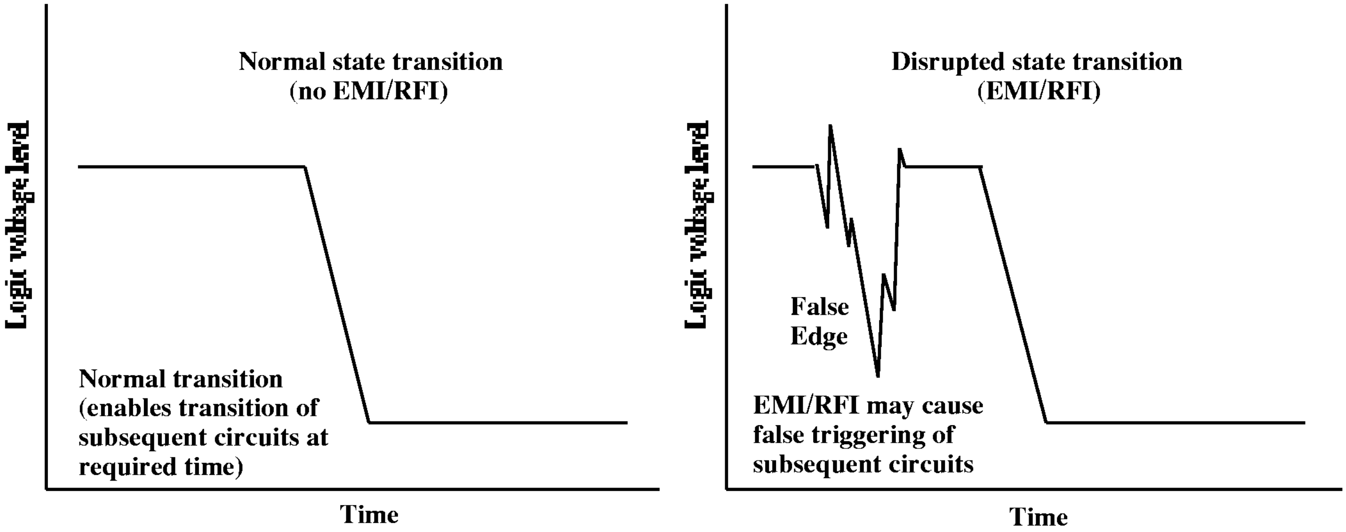

Figure 1 Illustration of the potential for false triggering of digital circuits due to electromagnetic noise

environmental testing of an experimental digital safety channel (EDSC), which was designed to be *representative of* ALWR reactor protection systems.[3]

To investigate system-level vulnerabilities, the EDSC was subjected to a range of environmental stressors, including EMI/RFI. The EMI/RFI tests were performed according to applicable test criteria and methods stipulated in Military Standard (MIL-STD) 461, "Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference,"[4] and MIL-STD 462, "Measurement of Electromagnetic Interference Characteristics,"[5] respectively. MIL-STD 461 establishes the U.S. military's emission and susceptibility requirements for electronic, electrical, and electromechanical equipment and subsystems. It also provides a basis for evaluating the electromagnetic characteristics of equipment and subsystems by setting operational acceptance criteria. The test methods corresponding to the MIL-STD 461 requirements are described in MIL-STD 462.

The objective of the EMI/RFI tests was to identify/confirm system-level EMI/RFI-induced upsets and failure modes in microprocessor-based safety systems. The majority of effects resulting from the application of the EMI/RFI were communication errors, particularly for *serial* communication links.[2] Many of these errors were intermittent timeout errors or corrupted transmissions, indicating failure of a microprocessor to receive data from an associated multiplexer, optical serial link, or network node. The largest number of upsets (i.e., 59% of all errors) observed during testing involved retransmissions, which degraded system performance but did not result in a failed function. The remaining upsets (i.e., 41% of all errors) included communications timeouts and a few instances of loss of data accuracy. These upsets affected the ability of the channel to perform its intended function. (It should be noted that the adverse effects of these types of errors can be mitigated through design.)

The EMI/RFI tests also enabled comparisons to be made with other environmental stressors due to the use of a common testing subject performing a nuclear safety function. Based on incidence of errors during testing, EMI/RFI, smoke exposure, and high temperature coupled with high relative humidity were found to be the most significant of the stressors investigated.[2] The most prevalent stressor-induced upsets—as well as the most severe—were found to occur during the EMI/RFI tests.

Studies of Licensee Event Reports (LERs) also indicate the impact EMI/RFI can have on performance for both analog and digital equipment.[6-8] From 1980 to 1991, 8% of all reactor trips and engineered safety features actuations resulting from I&C system upsets were attributed to EMI/RFI.[7] Over this time period, EMI/RFI was found to be the most frequent environmental cause of these events. In addition, LERs from 1990 to 1993 show that 19% of the events related to digital I&C equipment resulted from EMI/RFI induced by lightning.[8] Of these, 67% resulted in spurious trips and system actuations.

The potential for the increased likelihood of EMI/RFI-induced upsets for advanced I&C technology and the experience of the nuclear industry with EMI/RFI as an environmental stressor confirm the potential safety significance of EMC for both analog and digital technology. As a result, it is clear that guidance to support the establishment of a comprehensive approach to ensure the compatibility of I&C equipment with its electromagnetic environment is warranted.

III. NPP SITE SURVEY RESULTS

Until recently, very little was known about the prevailing electromagnetic conditions in NPPs. Understanding the potential hazards and stress levels is essential to developing the technical basis for adequate guidance to ensure EMC for safety-related I&C systems. Obviously, a system should be made sufficiently resistant to EMI/RFI to perform its required function. (In essence, it should be sufficiently hardened to be compatible with its working environment.) Determining appropriate immunity levels therefore requires a fairly detailed characterization of ambient conditions at the site of the equipment installation.

To properly characterize the EMI/RFI environment at NPPs, ORNL conducted a long-term survey of ambient electromagnetic conditions at several nuclear power plants.[9] A representative sampling of power plant conditions (reactor type, operating mode, site location) monitored over extended observation periods (e.g., continuous measurements for up to 5 weeks at a single location) were selected to determine more completely the characteristic electromagnetic environment for NPPs. Observations covered a 14-month period and 8 different nuclear units, representing all U.S. reactor manufacturers. A full range of operating modes—full-power operation, low-power operation, startup, coastdown, plant outage, and an unscheduled event resulting in a plant trip—were observed. Measurements were taken at locations where safety-related I&C systems either are or are likely to be installed, including control rooms, remote shutdown panels, cable spreading rooms, equipment rooms, auxiliary instrument rooms, relay rooms, and other plant areas (e.g., the turbine deck).

The nuclear units monitored included the following: one Combustion Engineering (CE) pressurized water reactor (PWR), three Babcock and Wilcox (B&W) PWRs, one General Electric (GE) boiling water reactor (BWR), and three Westinghouse (W) PWRs. Participating utility companies included Duke Power, Public Service Electric and Gas, Entergy Operations and the Tennessee Valley Authority.

The electromagnetic measurement system[10] (EMS) employed consists of two instruments developed by ORNL for long-term, unattended monitoring of ambient electromagnetic emissions. This approach minimized intrusion on the normal day-to-day operation of the plant. The requirements on the measurement system for this survey resulted in several novel instrument developments.[11]

The primary functional requirement for the EMS is to perform long-term, automatic, unattended recording of EMI/RFI levels at nuclear power plant sites. Except for setup and shutdown of the EMI/RFI monitoring instruments, no operator attention is required while the EMS makes its observations. The EMS operates in the presence and plain view of nuclear plant employees; the instruments are unadorned gray boxes, with no external displays, and no external controls except a key lock "off/on" switch whose key can be removed in either setting. The EMS is designed to be sufficiently robust to withstand extended exposure to an industrial environment.

The EMS is also designed to be unobtrusive. Other than sensing the ambient levels of electromagnetic fields and taking operating power from the plant electrical power system, it does not interact with the nuclear plant environment. The instruments are EMI/RFI hardened; no radiated energy can enter the EMI/RFI monitors except through the antennas, and no signals generated by the EMS are allowed to escape. The EMS is not intended to be connected to the plant data acquisition system.

The EMS is capable of unattended operation for several months. The instruments include an onboard uninterruptible power supply, and so they can withstand a power interruption of up to 20 minutes. In addition, the recorded data are stored on an onboard floppy disk every six hours. Thus, even in the event of a major failure, most of the recorded data would be preserved.

The overall frequency range is 305 Hz to 8 GHz. This range is derived primarily from the MIL-STD 461 radiated susceptibility criteria. It was found to be impractical to build a single device to cover the desired frequency range. Accordingly, two devices, the magnetic spectral receiver (covering 305 Hz to 5 MHz), and the electric spectral receiver (covering 5 MHz to 8 GHz), were developed.

The electric spectral receiver is configured to observe high-frequency electric fields. It uses two resistive taper antennas as broadband electric field probes. The antennas are connected to independent processing circuits, one covering 20 bands of equal width from 5 to 1000 MHz, and the other a single band from 1 to 8 GHz. The electric spectral receiver design uses heterodyne conversion and an analog peak detector.

The other receiver is configured to observe low-frequency radiated magnetic fields or conducted effects. The magnetic spectral receiver uses a passive loop antenna as a broadband magnetic field transducer or a current transformer as a transducer for conducted EMI/RFI effects. The 305 Hz to 5 MHz coverage spans 14 octaves, and the receiver simultaneously captures time-localized peak magnetic field strength present in each octave during each sampling cycle. The implementation of the magnetic spectral receiver uses a multiresolution digital filter bank, implemented in dedicated hardware.

The output of each receiver is a two dimensional matrixed histogram. One dimension is band (or bin) of frequency. The other dimension is band (or bin) of peak field strength. The entries in the histogram matrix are the running total of the number of times (i.e., number of receiver operating cycles) that the ambient EMI/RFI level falls within the intersection of a particular strength bin and a particular frequency bin. Resolution is coarse, being limited by the bin width. The cumulative histograms and their individual time tags are stored to disk every six hours as "frames." For considering rates of occurrence, the counts accumulated during any given frame can be determined by subtracting the running total counts at the starting time of that frame from the running total counts at the ending time of the frame.

The ORNL survey generated ~650,000 electric field observations, ~35.7 million magnetic field observations, and ~6.4 million conducted EMI/RFI observations. However, only a few thousand spectra showed electromagnetic fields at potentially disruptive levels. Yet, it is the strength and rate of occurrence of these rare higher levels that should determine EMI/RFI immunity levels. A statistical analysis of the data collected in this survey indicates that the probability of observing a significant EMI/RFI event in a random 30-minute spot check is on the order of 0.003. Thus, the results of the survey confirm that long-term monitoring is needed to adequately characterize the electromagnetic environment at a site.

Comparison of the observations at the different plant sites demonstrated a remarkable similarity, based on monitoring locations and operating conditions, in the electromagnetic environment from site to site. For any given frequency band, the highest observed electric field strengths varied within ±10 dB of the mean value for each frequency under the compared conditions. The comparison of the highest observed magnetic field strengths also showed a similar ±10 dB variation about the mean for most frequencies. The exception to this comparison for the magnetic fields occurred in the 5-20 kHz frequency band where a ±20 dB variation was observed.

The survey results establish characteristic emissions profiles that bound the observed electromagnetic conditions at the nuclear power plants.[9] Bounding profiles for the survey are based on the highest EMI/RFI strength observations and the associated uncertainties for the measurements. The uncertainty margin establishes an interval about the measurement results in which the values of the measured phenomenon can be expected to lie with a high level of confidence (95%). The confidence level does not provide any guarantee that there are no unmeasured events that may exceed the highest strength observations, only that there is reasonable assurance that plausible bounds on the characteristic electromagnetic environment have been confirmed. However, the wealth of data from this survey, captured during continuous monitoring for extended periods at each plant location under the variety of operating conditions, provides reasonable assurance that the highest strength EMI/RFI events were captured.

IV. ELECTROMAGNETIC COMPATIBILITY

To minimize the effects of EMI/RFI and power surges, sufficient EMC design, qualification, and installation procedures must be used. A well-designed system should be sufficiently hardened to withstand the EMI/RFI and surge levels that can reasonably be expected to occur in its environment. Application of consensus best practices regarding the design, testing, and installation of safety-related I&C system modifications or new installations can contribute to the achievement of EMC at NPPs.

The approach taken in the development of the technical basis for EMC at NPPs involved the selected endorsement of commercial and/or military standards. Consensus standards represent current best practice in the military and commercial industries and form the basis of a well-founded, systematic approach for ensuring EMC. As an example, the U.S. Department of Defense (DoD) maintains EMC standards which represent the most mature, well-established methods for conducting EMI/RFI qualification testing. The overall range of guidance from military and commercial standards bodies includes design practices, implementation approaches, and testing criteria and methods.

To avoid uncertainty in the use of these standards, which contain guidance for a broad range of application environments, effort was directed to assess each technical element embodied in the standards for its applicability, either fully or partially, to NPPs. Based on that analysis of existing standards and the understanding of the electromagnetic environment at NPPs gained as part of this research, selected practices were tailored into a framework for EMC guidance in the nuclear industry. The result is a determination of an acceptable level of EMC focused on NPP conditions and the identification of the means to accomplish that goal.

The Institute of Electrical and Electronics Engineers (IEEE) provides guidance on the engineering practices needed to control upsets and malfunctions in safety-related I&C systems when exposed to EMI/RFI and power surges. IEEE Standard (Std) 1050, "IEEE Guide for Instrumentation and Control Equipment Grounding in Generating Stations,"[12] was developed to address design and installation of grounding systems for I&C equipment specific to power generating stations. Further purposes of the standard are to achieve both a suitable level of protection for personnel and equipment, and suitable electrical noise immunity for signal ground references. This standard recommends practices for the treatment of both analog and digital systems that address the grounding, shielding, and isolation of electronic circuits on the basis of minimizing emissions and their susceptibility to EMI/RFI and power surges. These EMC practices include circuit layouts, terminations, filtering, grounding, bonding, shielding, and adequate physical separation. The standard is comprehensive in that it covers both theoretical and practical aspects of grounding and EMC. Based on an assessment of the applicability of this guidance to NPPs, it was determined that IEEE Std 1050-1996 should be recommended for endorsement and use by the nuclear industry with one exception. The exception corrects a misstatement in the standard regarding radiative coupling.[13]

Design verification measures for EMI/RFI testing (emissions and susceptibility) are beyond the scope of IEEE Std 1050. However, MIL-STD 461 and 462 were developed by the U.S. DoD as means to confirm the EMC of equipment. The application of the MIL-STD test criteria and test methods is tailored for the intended function of the equipment and the characteristic environment (i.e., which tests are applied and what levels are used depend on the function to be performed and the location of operation). These standards have been used successfully by the U.S. military for many years and are commonly referenced in commercial applications.

MIL-STD 461 contains test criteria that can be applied to address EMI/RFI effects for a selection of environments. The test methods associated with the MIL-STD 461 requirements are described in MIL-STD 462. The specific MIL-STD 461 test criteria relevant in regard to susceptibility and emissions testing for safety-related I&C systems were identified based on the understanding of the electromagnetic conditions at NPPs developed through this research.[9,13,14] These test criteria are presented in Tables 1 and 2. Table 1 lists the EMI/RFI test criteria in MIL-STD 461D[4] while Table 2 lists the corresponding MIL-STD 461C[15] counterparts. These criteria cover conducted and radiated interference (emissions and susceptibility), exposure to electric and magnetic fields, and noise coupling through power and control leads. The criteria do not cover conducted interference on interconnecting signal lines.

MIL-STD 461D provides the latest revision of the test criteria (including improvements based on experience and the most recent technical information), thus it represents current practice. However, the MIL-STD 461C test criteria, which are counterparts to the MIL-STD 461D test criteria, are also shown as an option. This option is provided to meet the needs of the nuclear power industry without

Table 1 Applicable MIL-STD 461D test criteria

Criterion	Description
CE101	Conducted emissions, power leads, 30 Hz to 10 kHz
CE102	Conducted emissions, power leads, 10 kHz to 10 MHz
CS101	Conducted susceptibility, power leads, 30 Hz to 50 kHz
CS114	Conducted susceptibility, bulk cable injection, 10 kHz to 400 MHz
RE101	Radiated emissions, magnetic field, 30 Hz to 100 kHz
RE102	Radiated emissions, electric field, 10 kHz to 1 GHz
RS101	Radiated susceptibility, magnetic field, 30 Hz to 100 kHz
RS103	Radiated susceptibility, electric field, 10 kHz to 1 GHz

C = conducted, E = emissions, R = radiated, and S = susceptibility.

Table 2 MIL-STD 461C counterparts to applicable MIL-STD 461D test criteria

Criterion	Description
CE01	Conducted emissions, power leads, 30 Hz to 15 kHz
CE03	Conducted emissions, power leads, 15 kHz to 50 MHz
CS01	Conducted susceptibility, power leads, 30 Hz to 50 kHz
CS02	Conducted susceptibility, power and interconnecting control leads, 50 kHz to 400 MHz
RE01	Radiated emissions, magnetic field, 30 Hz to 50 kHz
RE02	Radiated emissions, electric field, 14 kHz to 1 GHz
RS01	Radiated susceptibility, magnetic field, 30 Hz to 50 kHz
RS03	Radiated susceptibility, electric field, 14 kHz to 1 GHz

C = conducted, E = emissions, R = radiated, and S = susceptibility.

limiting the available test resources to those test laboratories with the MIL-STD 462D test capability. Since the criteria from either version of the standard were developed to be internally consistent and complementary, it is recommended that either set be applied in its entirety, without selective application of individual criteria (i.e., no mixing and matching of test criteria).

Electromagnetic operating envelopes associated with the MIL-STD 461 test criteria listed in Tables 1 and 2 were developed to establish testing levels.[14] The technical basis for the operating envelopes begins with the MIL-STD envelopes corresponding to the electromagnetic environment for military ground facilities, which were judged to be comparable to that of NPPs based on general layout and equipment type considerations. Plant emissions data were used to confirm the adequacy of the operating envelopes. From the MIL-STD starting point, susceptibility envelopes were adjusted to account for the plant emissions data obtained from the ORNL survey and other electromagnetic survey data from the nuclear industry.[16] The basis for adjustments to the equipment emissions envelopes included consideration of the primary intent of the MIL-STD envelopes (e.g., whether the envelopes were based on protecting sensitive receivers on military platforms) and maintaining some margin with the susceptibility envelopes. Finally, when changes to the operating envelopes from the MIL-STD origin were motivated by technical considerations, consistency among the envelopes for comparable test criteria was promoted and commercial emissions limits for industrial environments were factored into those adjustments. As a result, the operating envelopes developed as part of this research have been tailored to the NPP environment and are equivalent or less restrictive than the MIL-STD envelopes that served as their initial basis.

The control of conducted EMI/RFI is essential to protect against poor power quality and excess radiation from the power bus. The phenomena of concern are distortions of the supplied voltage level caused by changing electrical loads and the introduction of high frequency conducted EMI/RFI that can radiate from the power bus. The CE operating envelopes limit the maximum voltage distortions and high frequency conducted EMI/RFI allowed on the power bus. The CS operating envelopes provide the conducted EMI/RFI levels to which equipment can be subjected and continue to operate without performance degradation.

The control of radiated EMI/RFI is essential to protect against equipment malfunctions caused by excess electromagnetic emissions. The RE operating envelopes limit the magnetic field and electric field emissions allowed from equipment. The RS operating envelopes provide the radiated EMI/RFI levels to which equipment can be subjected and continue to operate without performance degradation.

The issue of power surge susceptibility can be addressed through the demonstration of SWC for electronic equipment. The SWC practices described in IEEE Std C62.41, "IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits,"[17] and IEEE Std C62.45, "IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits,"[18] provide a means to address the effect of power surges on safety-related I&C systems in NPPs. IEEE Std C62.41 defines a set of surge test waveforms that has manageable dimensions and represents a baseline surge environment. IEEE Std C62.45 describes the associated test methods and equipment to be employed when performing the surge tests.

Three waveforms are recommended to assess the SWC of safety-related I&C systems intended for installation at NPPs: the ring wave, the combination wave, and the electrically fast transient (EFT) waveform. The ring wave simulates oscillatory surges of relatively high frequency on the ac power leads of equipment and subsystems and is represented by an open-circuit voltage waveform. The combination wave involves two exponential waveforms, an open-circuit voltage and a short-circuit current. It is intended to represent direct lightning discharges, fuse operation, or capacitor switching on the ac power leads of equipment and subsystems. The EFT waveform consists of repetitive bursts, with each burst containing individual unidirectional pulses, and is intended to represent local load switching on the ac power leads of equipment and subsystems.

General withstand levels have been developed for each surge waveform based on an analysis of the surge environment at NPPs.[14] IEEE Std C62.41 describes location categories and exposure levels that define applicable amplitudes for the surge waveforms that should provide an appropriate degree of SWC. Location categories depend on the proximity of equipment to the service entrance and the associated line impedance. Exposure levels relate to the rate of surge occurrence versus the voltage level (e.g., surge crest) to which equipment is exposed. The withstand levels that correspond to NPP conditions are based on *Category B* locations and *Low to Medium Exposure* levels. *Category B* covers feeders and short branch circuits less than 10 meters from the service entrance. *Low to Medium Exposure* levels encompass systems in areas known for little load or capacitor switching and low-power surge activity to areas known for significant switching transients or medium- to high-power surge activity. The basis for the withstand levels provides reasonable assurance that the general power surge environment in nuclear power plants is adequately characterized.

V. CONCLUSIONS

Long-standing experience by the U.S. military, equipment performance histories from the commercial power industry, and recent confirmatory research investigations have shown that EMI/RFI and power surges are environmental conditions that can have a significant adverse impact on the performance of electronic equipment. These findings, coupled with the potential for the increased likelihood of EMI/RFI-induced upsets for advanced I&C technology, confirm the potential safety significance of EMC for both analog and digital technology. As a result, it is clear that guidance to support the establishment of a comprehensive approach to ensure the compatibility of I&C equipment with its electromagnetic environment is warranted.

To adequately address EMC issues for safety-related I&C systems, ORNL research was focused on developing a more comprehensive understanding of the electromagnetic phenomena and characterizing the ambient electromagnetic environment associated with key locations in NPPs. Based on the findings from a long-term survey of electromagnetic conditions at selected NPPs, bounding plant emissions profiles were developed. These profiles were subsequently used to confirm that the recommended EMI/RFI susceptibility operating envelopes were appropriately tailored to the NPP environment.

The ORNL research provides the technical basis for developing EMC guidance for the nuclear industry. As a result of this effort, ORNL has recommended design and installation practices to limit the impact of electromagnetic effects, testing criteria to assess the emissions and susceptibility of equipment, and testing criteria to evaluate the power SWC of the equipment. Operating envelopes characteristic of the electromagnetic environment in nuclear power plants have also been developed and serve as the basis for establishing acceptable testing levels. This guidance is applicable for all new safety-related systems or modifications to existing safety-related systems that include analog, digital, or hybrid (i.e., combined analog and digital electronics) equipment.

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