How EMI/RFI Site Surveys Can Improve The Digital Upgrade Process

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INTRODUCTION

As part of equipment upgrade and obsolescence management efforts, NRC Regulatory Guide 1.180 Revision 1 and EPRI TR-102323 Revision 4 specify electromagnetic compatibility (EMC) requirements for new equipment to be installed into nuclear power plants, including safety-related, non-safety-related, and important to power production equipment. The goal of the documents is to maintain EMC by verifying that all new equipment can withstand the electromagnetic environment within a nuclear power plant (immunity testing) and that the new equipment will not increase the level of the electromagnetic environment (emissions testing). To simplify the use of these guidance documents, they were developed based on the assumption that the worst-case electromagnetic profile of the plant would be applied to all new systems regardless of their installation location within the plant. Therefore, equipment intended for installation in the reactor containment building would be subjected to the same level of EMC testing as equipment installed in the control room. This approach has served the industry well in that it provides the highest degree of assurance that equipment will operate without malfunctioning and eliminates the need to qualify the same piece of equipment multiple times for different installation locations in the same plant, each with unique levels of electromagnetic and radio frequency interference (EMI/RFI).

However, there are instances where this approach can cause unintended consequences. For instance, the installation of EMI/RFI mitigation devices such as filter components or surge suppression devices can introduce additional failure modes within a system design that may not be considered. There are other considerations such as seismic and environmental qualification that may also be impacted by the addition of mitigation components (i.e. ferrite beads or shielding materials). Therefore, while full compliance with the EMC guidance is preferred, there may be situations where undesirable modifications can be avoided by qualifying a piece of equipment for the particular electromagnetic environment in which it will be installed. In these instances, the EMC requirements can be relaxed by demonstrating, through objective evidence, that the electromagnetic environment at the installation location is adequately bounded by the EMC performance of the equipment under test. Meaning that, even though the equipment is vulnerable to high levels of EMI/RFI, it can withstand the actual levels at the point of installation.

This paper explores an example of a digital recorder that failed to meet the EPRI and NRC EMC requirements. In order to harden the system against the EMI/RFI and bring it into compliance, the device required numerous ferrite beads on each signal input line. For a twelve channel recorder, this modification would result in the addition of thirty-six ferrite beads (nearly 10 pounds). The excess weight on the installed plant cables would pose a significant risk. The site personnel evaluated several options. The option the plant selected involved the performance of an EMI/RFI site survey to characterize the electromagnetic environment at the point of installation of the digital recorders. This data has been used to justify relaxing the immunity test levels by demonstrating that the plant environment is not as severe as the EMC guidance levels. Using EMC test equipment and automated data acquisition and analysis software, the electromagnetic environments at the points of installation for the recorders were mapped and compared to the generic qualification requirements. This process revealed that the actual environment was orders of magnitude lower than the generic EMC qualification requirements, allowing the installation of the recorders without the addition of the ferrite beads.

THE EMC QUALIFICATION PROCESS

When utilities upgrade or replace electronic components, it is important to ensure that the equipment can function in the electromagnetic environment at the point of installation. In the same way that high temperatures, pressures, or radiation can damage or disrupt electronics, high levels of electromagnetic and radio frequency interference (EMI/RFI) can cause equipment to malfunction.

Before new plant equipment is installed, it must go through some level of EMC emissions and immunity testing. The degree of testing that the equipment undergoes is a function of the safety classification of the system. NRC Regulatory Guide 1.180 Revision 1 is the governing EMC document for safety-related equipment (or non-safety related equipment that could impact safety-related equipment) and specifies complete frequency coverage of EMI/RFI sources from 30 Hz to 10 GHz, as well as power line surges. EPRI TR-102323 Revision 4 is very similar to NRC Regulatory Guide 1.180 Revision 1 for the handling of safety-related equipment, but because it has a wider focus, also provides guidance for classifications of equipment including non-safety-related and important to power production systems.

The minimum amount of testing that any system should undergo is emissions testing, which measures the amount of electrical noise that a piece of equipment generates. Controlling and limiting the emissions is critical to ensuring interoperability of all systems in a plant environment. If a non-safety-related system produces excessive levels of emissions, it has the potential to disrupt a safety-related system, thus preventing proper actuation of safety features or causing a spurious actuation. In the case of safety and important to power production systems which demand the highest levels of reliability and availability, immunity testing is also specified in order to verify the levels of EMI/RFI that a piece of equipment can withstand.

If an EMI/RFI failure occurs during the qualification testing, several questions should be considered prior to determining the proper course of action including:

1. What is the degree of the failure? (or threshold level for immunity)
2. Can the equipment be modified to bring it into compliance? Is the mitigation technique feasible?
3. If a feasible solution is not possible, then will there be a significant EMC concern at the point of installation in the plant?

The first question represents the difference between the EPRI or NRC-specified level of emissions or immunity, and the actual equipment performance. This data is readily available for emissions testing; however, it is often not collected during immunity testing unless specifically requested. Therefore, it is necessary to request the determination of the immunity threshold level when encountering equipment susceptibility. To determine the threshold value during immunity testing, the level of noise being injected onto the equipment under test is lowered until the undesired behavior goes away. This level is recorded for each frequency where the equipment fails.

Next, temporary modifications to the equipment under test can be implemented to determine if there is a practical resolution to the EMC failure. Modifications can take the form of prepackaged filters or ferrite beads, rerouting of I/O and power cables, addition of shielding, improvement of grounding, or even more intrusive design changes. The EMC testing should then be performed to quantify the effect of the modification.

If the modification process is successful, the design documentation can be updated and the modifications captured in a final EMC test report. If the scope of modification becomes impractical, or no mitigating strategy can be identified, the next practical step is to determine whether the failures are bounded by the electromagnetic environment at the point of installation. In the case of an emissions failure, if the existing site emissions envelope exceeds the levels generated by the new equipment, then the device should not increase the level of emissions at the point of installation. In the case of an immunity failure, if the level of interference at the site location is significantly lower than the threshold level that the equipment can withstand, then modification may be unnecessary.

The process of measuring this information is referred to as an electromagnetic site survey. Site surveys utilize spectrum analyzers, antennas, and current probes to capture in-situ data at the point of installation to measure the frequency and amplitude of EMI/RFI within the plant and determine if the levels threaten the proper operation of the new equipment. This approach is similar to the approach taken by EPRI and the NRC when they first established their EMC guidance twenty years ago. Both entities performed separate site surveys of numerous plants and used the most conservative data to establish their respective emissions and immunity test levels. In addition, both guidance documents recognize that a survey of the electromagnetic environment, carried out in a systematic manner, can be used to relax qualification test levels.

CHALLENGES DURING A PLANT UPGRADE

As a site was implementing an upgrade of numerous Yokogawa digital recorders, they encountered an issue with trying to implement to recommended EMI/RFI solution identified during EMC qualification testing. During both high frequency conducted and radiated susceptibility testing, the monitors' readings deviated beyond the specified acceptance criteria and in some cases, the screen went completely blank. After troubleshooting, a solution was identified, but it involved installing three ferrite beads in series on each input cable to each recorder with four loops of the cable through each ferrite bead. Because the recorders supported up to 12 channels, this resulted in up to 36 ferrite beads necessary for each recorder. This additional weight and associated cable length requirement was impractical from both a cable management as well as a seismic qualification standpoint.

To ascertain whether the recorders could function satisfactorily in the installed environment without the modifications, the site performed the following steps. First, a full set of threshold data was collected for each recorder in question, without the modifications, to determine the levels of EMI/RFI that they could withstand. This testing is depicted in the left photograph of Figure 1. The equipment was set up in an RF-isolated EMC chamber. Each recorder was tested over the entire frequency range for both tests which failed (MIL-STD-461E CS114 and RS103). Next, an EMI/RFI site survey was performed at the locations in the control room of the plant where the recorders would be installed. Radiated emissions measurements were collected using various antennas along with conducted emissions using current probes on the power and signal cables that would interface with each recorder. A detailed test plan was prepared which specified the frequency ranges, instruments, and locations to be tested. Radiated emissions testing of some of the control room cabinets is shown in right photograph of Figure 1.

Figure 1. Laboratory Radiated Susceptibility Testing of the Digital Recorder (left) and In-situ Radiated Emissions Site Survey in the Control Room (right).

EMI/RFI SITE SURVEY RESULTS

Radiated emissions data was collected from the front and rear of each cabinet that would potentially house the new recorders. The highest emissions that were measured came from portable phones carried by plant personnel operating on a 900 MHz band. This band is significantly higher than the frequency bands of failure for the new digital recorders. In the frequency band where the digital recorders demonstrated susceptibility during laboratory qualification, there were no significant transmitters or sources of noise identified from the site survey.

Conducted emissions data was collected in the plant for the existing recorders that would be replaced. Because the existing power and signal cables in the cabinets would be reused, the contribution from the plant environment to the emissions on these cables were expected to remain the same. The primary sources of emissions identified in the plant during the conducted emissions tests were from switched-mode power supplies and their harmonics which were all less than 1 MHz. No significant sources of noise were identified in the frequency range where the digital recorders malfunctioned during EMC qualification testing.

After data collection, the threshold data from the laboratory testing was compared to the in-plant data collected from the control room environment to determine the minimum margin between the plant environment and the thresholds of susceptibility. The EPRI and NRC documentation recommends a minimum of 8 dB (a factor of 2.5) between the test levels applied during laboratory qualification and the levels measured during the EMI/RFI site survey. Because site surveys typically occur over a short time duration (usually 1-5 days), they may not encompass every operating mode or condition of the plant. Therefore, 8 dB of margin should be the minimum acceptable level. Using 20 dB (a factor of 10) is a better strategy in order to encompass potential changes in the electromagnetic environment associated with various plant conditions. EMI/RFI site surveys should be performed when plant conditions are expected to create the worst-case emissions.

After comparing the levels observed during the site survey to the threshold levels recorded during laboratory qualification testing, the margins for both high frequency radiated and conducted susceptibility between the measured environment and the equipment immunity level were determined to be more than 40 dB (a factor of 100). The results of the conducted susceptibility margin analysis are provided in Figure 2 and the results of the radiated susceptibility analysis are shown in Figure 3. The data analysis provided a high degree of confidence that the digital recorders, without the ferrite bead modification, could function satisfactorily in the plant environment with adequate margin to account for changing plant conditions.

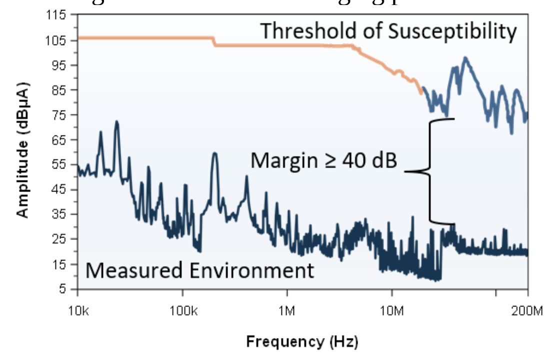

Figure 2. Conducted Susceptibility Data and Limits.

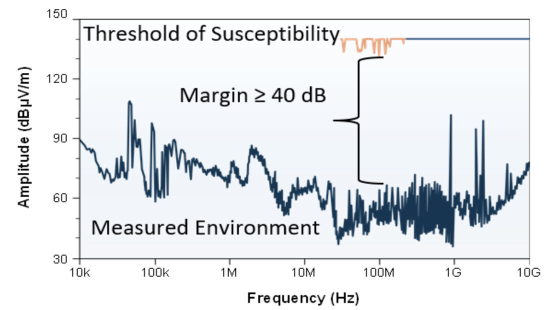

Figure 3. Radiated Susceptibility Data and Limits.

CONCLUSIONS

The EMI/RFI site survey data from the control room environment, coupled with the threshold data determined during laboratory qualification testing, was able to provide objective evidence to justify the installation of the digital recorders without the implementation of the ferrite beads. The elimination of the ferrite beads simplified the design and installation process making it easier for the site to install the new digital recorders prior to the failure of the old recorders. A similar approach can be applied to other digital upgrades to improve the implementation process and avoid potentially undesirable modifications while maintaining the same level of safety and reliability.

REFERENCES

1. "Guidelines for Electromagnetic Compatibility Testing of Power Plant Equipment," TR-102323 Revision 4, EPRI (2013).
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