Assessing the EMI/RFI Risks of Wireless Devices Using a Cognitive Radio System

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INTRODUCTION

The benefits of wireless technology in nuclear power plants (NPPs) are well known and established. The application of wireless sensors for condition monitoring [1], tablet devices for the mobile work force when performing operator rounds and electronic work packages [2], radiation dose reduction using real-time wireless dosimetry, and the general efficiencies and improvements that can be gained through the use of cell phones, wireless cameras, and other wireless devices are significant driving forces within the industry. These benefits have become even more necessary with the recent initiative, "Delivering the Nuclear Promise," which drives NPPs to reduce operating and maintenance costs to keep nuclear power competitive with other forms of power generation, while increasing efficiency and maintaining the same level of safety.

Today, nuclear facilities use wireless technology by defining specific or generic "exclusion zones" where wireless devices cannot be used. For example, a U.S. nuclear power plant has imposed the following generic stipulation for the use of wireless technology: "as a general rule, radio units should not be used within 15 feet of panels and instrument racks housing sensitive electrical/electronic equipment." Most other plants are not as restrictive and have defined more specific exclusion zones based on the type of wireless devices that may be used in the sensitive areas of the plant. However, in a study of typical exclusion zones, it was determined that exclusion distances in almost all nuclear power plants are still overly conservative and thereby severely limit the use of wireless devices in most areas of the plant. This level of conservatism may arise from the fact that most plants have historically used walkie-talkie devices for wireless communications which have a history of emitting strong and interfering signals. This is evident in the data shown in Table 1 where exclusion zones are compared for some of the commonly used wireless devices in nuclear power plants.

Table 1. Examples of Exclusion Distances in NPPs

Wireless Device	Distance (Feet)
iPad	8
Cell Phone	9
Laptop Computer	3
Wireless Dosimeter	1
Wireless Vibration Sensor	2
Walkie Talkie	13

Many exclusion zones can be reduced significantly through the use of in-situ testing of representative plant equipment [3]. For example, most exclusion zones in nuclear power plants are defined based on the power output of wireless signals and do not account for the effect of frequency. In fact, research has demonstrated through in-plant and laboratory work that the susceptibility or vulnerability of a majority of plant equipment diminishes significantly at higher frequencies as illustrated in Figure 1. This implies that the higher frequencies from devices using Wi-Fi and Bluetooth (e.g. 2.4 GHz) may not pose a significant risk to power plant equipment even when they are in very close proximity.

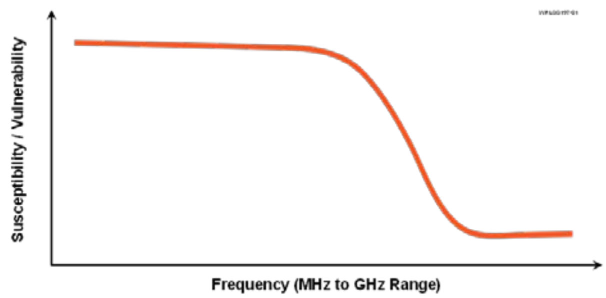

Figure 1. Illustration of Susceptibility of Plant Equipment Versus Frequency of Wireless Signals

NUCLEAR POWER PLANT IMPLEMENTATION

Nine Mile Point Nuclear Station, a General Electric Boiling Water Reactor (BWR) plant is currently implementing a Wi-Fi and distributed antenna system (DAS) in both Unit 1 and Unit 2. Both systems will enable plant personnel to use cellular and Wi-Fi devices in the plant to increase efficiency during operator rounds and maintenance activities as well as allow them to implement wireless sensors for condition monitoring purposes. In order to ensure that plant personnel can use these wireless devices in close proximity to existing plant system without causing electromagnetic and radio frequency interference (EMI/RFI), a project was initiated to establish objective exclusion zones.

The project was two-fold and included both laboratory measurements as well as on-site evaluations and testing. For EMC laboratory testing, an Apple iPad with Verizon cellular capabilities and a Samsung Galaxy S8 phone using AT&T cellular services were selected to cover different types of operating systems and cellular providers. To measure the electromagnetic emissions from the devices, guidance was used from both MIL-STD-461G RE102, "High Frequency Radiated Emissions" and RE103, "Antenna Spurious and Harmonic Outputs". In general, the RE102 test method provided the guidance for the test setup, while the RE103 test method was used to maximize and measure the transmitters' fundamental frequency output field strength by varying the antenna polarization, wireless device orientation, and spectrum analyzer settings.

Data from the devices were measured for all three different transmitters, cellular, Wi-Fi, and Bluetooth. Figure 2 shows a sample of the results for the testing of cellular LTE signal of the iPad device. The measured data from the devices were compared to the maximum levels obtained from the Federal Communications Commission (FCC) documentation for the devices. The results provide the typical emissions that can be expected from the devices in an environment with adequate signal strength while performing high data transmission intensive applications.

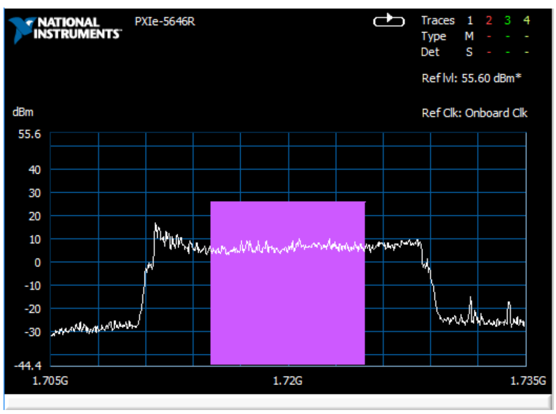

Figure 2. Spectral Plot of an LTE Signal

In conjunction with the laboratory testing, there were several activities being performed on-site with the support of plant personnel. The three main activities consisted of walk downs of existing plant systems to identify potentially vulnerable equipment, conducting EMI/RFI site surveys to understand the plant's electromagnetic environment, and performing susceptibility testing of selected plant equipment using a Cognitive Radio System (CRS).

The walkdown established the basis for the development of a comprehensive test plan for the on-site work. The site visit allowed all project stakeholders to meet and verify that all questions and concerned regarding the potentially sensitive plant systems could be addressed during the project. During the walkdown, equipment installations were evaluated to identify any observed deviations from good EMC practices such as inadequate grounding, missing shielding, cable tray discontinuity, etc. that may make the equipment vulnerable to wireless signals. The walkdown identified thirty-three (33) devices, including sensitive analog and digital equipment, throughout the plant for further evaluation in the following stages of the project.

The next activity was to perform passive wireless EMI/RFI site surveys to locate and identify signal sources and frequencies that may compete with wireless devices and/or indicate vulnerabilities of existing equipment. Numerous utilities use EMI/RFI site surveys to support site-wide implementation of wireless devices. Site surveys use passive antennas to capture and characterize the Electromagnetic Environment (EME) in a certain area and can be performed while the plant is operating. For the frequencies of interest regarding wireless devices, the EME can be made up of intentional transmitters from devices such as site radios and wireless sensors as well as unintentional sources such as clock frequencies, arcing, etc. which may radiate from plant components or cables. The frequency spectrum for twenty-two (22) locations in both Unit 1 and Unit 2 of Nine Mile Point were recorded during the evaluation. Figure 3 is a photograph of the EMI/RFI site survey testing in Unit 1's reactor building. In the plant areas, emissions could be identified from existing site communication devices, wireless radiation monitors, and cellular signals.

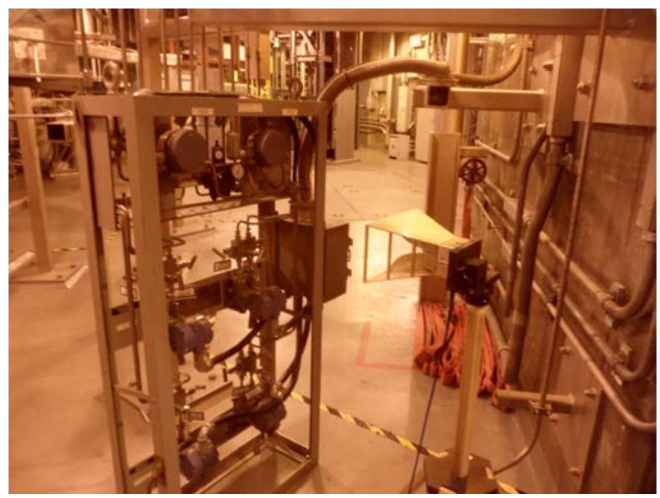

Figure 3. Mapping Location in Nine Mile Point Unit 1 Reactor Building

The most informative activity is the performance of on-site immunity testing of selected plant equipment to determine if they are vulnerable to wireless signals. The immunity testing is performed by generating RF energy at the same frequencies as wireless devices and radiating it onto equipment and cables as described in MIL-STD-461E RS103, which is the high frequency radiated susceptibility test method endorsed by NRC Regulatory Guide 1.180 Revision 1 and EPRI TR-102323 Revision 4 [4, 5]. The RS103 test method was modified to be performed onsite in a plant laboratory. In addition to the RS103 test method, actual wireless signals for LTE and Wi-Fi were generated and subjected to the plant equipment at levels consistent with the maximum power levels allowed by the protocols. All of these signals were generated using the CRS tool. This testing was coordinated with site personnel to setup and monitor the performance of the equipment while being subjected to the EMI/RFI.

Six different pieces of equipment were selected for the immunity testing including:

- Rosemount 1151 Transmitter
- Foxboro IDP10 Transmitter
- Yokogawa DX104 Chart Recorder
- Foxboro 762C Multi-Purpose Station Controller
- Crydom D53TP50D 3 Phase Solid State Relay
- Bailey 791 Controller

Each piece of equipment was subjected to the various frequencies of wireless devices between 430 MHz and 6 GHz using the RS103 pulse modulated signal as well as the signal characteristics for Wi-Fi and LTE signals. A photograph of the test setup is shown in Figure 4. The Bailey controller was the only module that exhibited vulnerability in the frequency range of 475 to 960 MHz. Troubleshooting was performed by adding additional shielding to the module to mitigate this vulnerability. With the additional shielding, the module was immune to the interfering signals.

Figure 4. Test Setup for Immunity Testing in a Laboratory at Nine Mile Point

Description of Cognitive Radio System

The Cognitive Radio System (CRS) used for the testing is equipment developed for use in nuclear power plants for electromagnetic site surveys and radiated immunity testing. The system consists of a vector signal analyzer and generator operating in the frequency range of 65 MHz to 6 GHz. The CRS module can be connected to amplifiers and antennas to record the RF spectrum and characterize the electromagnetic environment in a nuclear power plant. The system also has the ability to reproduce the recorded RF spectrum to simulate the nuclear environment or it can generate desired wireless signals such as Wi-Fi, Bluetooth, LTE, etc. Figure 5 is a picture of the CRS with the amplifier and antenna used for in-situ immunity testing.

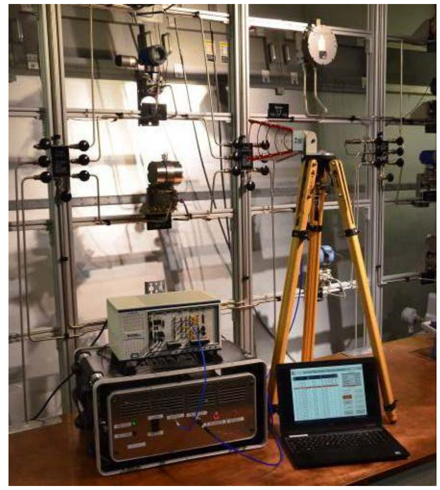

Figure 5. Photograph of the Cognitive Radio System

CONCLUSIONS

One of the barriers to the implementation of wireless sensors and communication devices at Nine Mile Point Nuclear Station is the concern for EMI/RFI of the wireless signals with existing plant equipment. Through the approach outlined in this paper, the risks associated with wireless devices can be mitigated. A majority of the plant equipment is immune to the frequencies and levels associated with wireless devices. When vulnerabilities are identified they can be managed through administrative procedures or through equipment modifications to harden them against EMI/RFI. The data collected during this investigation is being used by the site personnel in their efforts to support the use of wireless technology throughout the site without incurring a significant risk to the plant.

REFERENCES

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