A Study on Electromagnetic Compatibility to Adopt Wireless Technology in Nuclear Power Plants

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Abstract: Recently, increasing numbers of wireless technologies have been deployed in industrial environments such as nuclear power plants (NPPs). Adoption of wireless technologies has proved benefits in many industries in terms of saving cable costs and installation time as well as increased flexibility of information gathering through temporary sensor deployment. Nevertheless, wireless technologies are not currently deployed in nuclear industry at large due to some serious issues. The electromagnetic compatibility (EMC) between the wireless devices and the existing plant instrumentation and control systems is major issue in deploying wireless technologies in NPPs. In this paper, Electromagnetic Interference and Radio Frequency Interference (EMI/RFI) in Regulatory Guide 1.180 rev.1 are observed and other regulation standards (MIL-STD 461E, IEC 61000-4) which are endorsed in Regulatory Guide 1.180 rev.1 is also examined. It also provides EMC and EMI/RFI characteristics when transceivers such as portable and fixed wireless devices are used in free-space and multi-path environment.

Keyword: Wireless Technology, Electromagnetic Compatibility, Electromagnetic Interference, Radio-Frequency Interference

1 Introduction

Wireless technologies are one of fastest growing technologies and increasing numbers of wireless technologies have been deployed in industrial environments including nuclear power plants (NPPs). The use of wireless technology in nuclear power plants also has numerous benefits. Generally, wireless technology can be associated with a traditional wiring connection sensor and has lower costs of installing, maintaining, troubleshooting, and upgrading wiring. It can have also reduced chance of connector failure, flexibility of information gathering, and fast commissioning [1] – [3]. Nevertheless, wireless technologies are not currently deployed in nuclear industry at large due to some serious issues. The electromagnetic compatibility (EMC) is the one of major issue in deploying wireless technologies in NPPs. EMC problem has mainly two concerns: (a) electromagnetic interference (EMI) from the wireless devices which can affect the existing plant instrumentation and control (I&C) systems, and safety-related protection systems, and (b) electromagnetic susceptibility (EMS) of wireless systems in the presence of high levels of man-made EMI from other devices. To securely apply this wireless technologies to NPPs without EMC problems, it is mandatory to meet with the safety specifications enforced by the regulatory guides [4] – [6].

In this paper, Electromagnetic Interference and Radio Frequency Interference (EMI/RFI) in Regulatory Guide 1.180 rev.1 is observed and other regulation standards (MIL-STD 461E, IEC 61000-4) which are endorsed in Regulatory Guide 1.180 rev.1 are also examined. It also provides EMC and EMI/RFI characteristics when transceivers such as portable and fixed wireless devices are used in free-space and multi-path environment.

2 EMC regulatory

The U.S. Nuclear Regulatory Commission (NRC) have developed the technical basis for guidance on EMC. The Regulatory Guide 1.180 (RG-1.180) was first issued in 2000 as the test guideline of

Table 1. EMI/RFI emission testing

Test Criteria		Reg. Guide 1.180 rev1		
		Baseline (MIL-STD-461E)	Alternate #1	Alternate #2
Conduction Emission	Low Frequency 30 ~ 10kHz	CE101	IEC 61000-6-4 CIRPR 11 Class A	FCC Part 15 Class A
	High Frequency 10k ~ 2MHz	CE102		
Radiation Emission	Magnetic Field 30 ~ 100kHz	RE101		
	Electric Field 2M ~ 1GHz	RE102		

Table 2. EMI/RFI susceptibility testing

Test Criteria		Reg. Guide 1.180 rev1			
		Baseline (MIL-STD-461E)		Alternate (IEC)	
		Power leads	Signal leads	Power leads	Signal leads
Conduction Susceptibility	Low Frequency 30 ~ 150kHz	CS101	-	61000-4-13 61000-4-16	61000-4-16
	High Frequency 10k ~ 30MHz	CS114	CS114	61000-4-6	61000-4-6
	Switching Transient	-	CS115	-	61000-4-4
	Damped Sinusoid 10k ~ 100MHz	-	CS116	-	61000-4-12
Radiation Susceptibility	Magnetic Field 30 ~ 100kHz	RS101		61000-4-8, 9, 10	
	Electric Field 30M ~ 1GHz	RS103		61000-4-3	

electromagnetic waves for the I&C system of NPPs. Currently, U.S. RG-1.180 Rev1 (2003) and EPRI TR-102323 have been applied in domestic NPPs. Regulatory guides are divided to emission testing and susceptibility testing. Regulatory guides for emission testing is shown in Table 1 and susceptibility testing is shown in Table 2. EMC problem has mainly two concerns to adopt wireless technologies in NPPs. The first one is EMI from the wireless devices which can affect the existing plant I&C systems, and safety-related protection systems. It is related to radiation emission especially to electric field test RE102 due to intentional radio transmitters. The second one is EMS of wireless systems in the presence of high levels of man-made EMI from other devices. It is related to radiation susceptibility RS103.

The RE102 test addresses measurement of radiated electric field emissions in the frequency range of interest, 2 MHz to 1 GHz. This test is applicable above 1 GHz for up to 10 times the highest intentionally generated frequency within the equipment under test because of the development of faster speed microprocessors and wireless communications, which contribute to interference concerns in the very high frequency band. The test does not apply at transmitter fundamental frequency or to radiation from antennas since the test is purposed to unintentional emission.

Most plants place administrative controls on the use of portable transceivers near critical equipment. RG 1.180 has an exclusion zones for the administrative controls. The exclusion zone is defined as the minimum distance permitted between the point of installation and where portable EMI/RFI emitters allowed to be activated. To establish the size of an exclusion zone, an 8dB difference between the susceptibility operating envelope and the allowed emissions level should be maintained. The minimum distance of an exclusion zone (d) in meters should be calculated by the Equation (1) derived from the free space propagation model which is called Friis transmission equation.

$$d = \sqrt{30 P_t G_t} \Big/ E \qquad (1)$$

Where P_t is the effective radiated power of the EMI/RFI emitter, G_t is gain of the EMI/RFI emitter and E is the allowable radiated electric field strength of the EMI/RFI emitter at the point of installation.

3 Multi-path environment

The Friis equation is derived from the free space propagation model. However, it is needed to consider multi-path environment since numerous equipment act as reflectors and scatterers in the real installation environment. Therefore, we need to consider wave propagation property with multi-path environment. Equation (2) shows the multipath channel model where H is channel response due solely to multipath, g^i_t is angle-dependent normalized signal gains of the transmit antennas, g^i is angle-dependent normalized signal gains of the receiver antennas, Γ_i is the angle-dependent reflection coefficient of the i-th reflecting object, d_o is length of the direct ray path, d_i is length of the i-th reflected ray path and N is total number of reflections [7] – [9].

$$H = 1 + \sum_{i=1}^{N} g_t^i g^i \Gamma_i \frac{d_o}{d_i} e^{-jk(d_i - d_0)} \qquad (2)$$

In order to simplify the propagation environment, concrete wall, floor, and ceiling environment of 9m * 5.5m * 2.5m are set up and wave propagation characteristics are analyzed and compared with the free space propagation model. The operating frequency is 900 MHz ISM band. The permittivity of concrete is 10 and the transmitter is installed at a horizontal position of 0.1m, a vertical position of 2.75m and a height of 1.25m. The receiver is installed at a vertical position of 2.75m and a height of 1.25m and the receiving power is analyzed according to the distance variation. The polarization of transmitter and receiver is linear polarization with vertical, horizontal and diagonal (45° or 135 °) and there is no polarization mismatch loss. The antennas for transmitter and receiver are assumed to be a single patch antenna which has 3dB beamwidth 61.7° for elevation angle and 69.2° for azimuth angle. As shown in Fig. 1, the relative received power is calculated according to the distance of transmitter and receiver. Unlike the free space, the received powers of vertical and horizontal polarization are sequentially increased and decreased as the distance increases. The relative received power from multi-path of horizontal polarization is up to 3.73 dB higher than free space at the 6.1m distance. It is considered that the EMI in multi-path environment could be much larger than free space propagation as the distance increases.

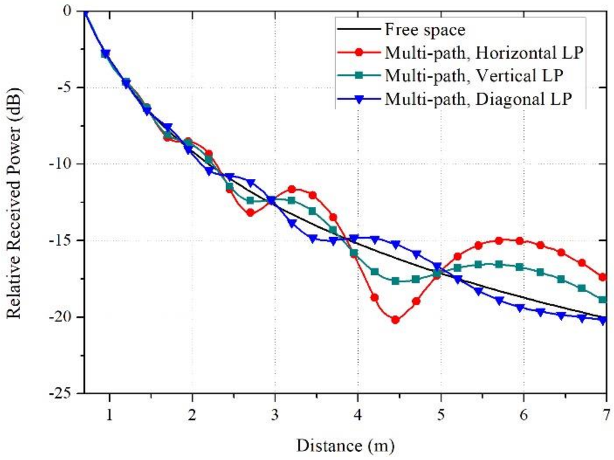

Fig.1 Relative received power with variation of polarization

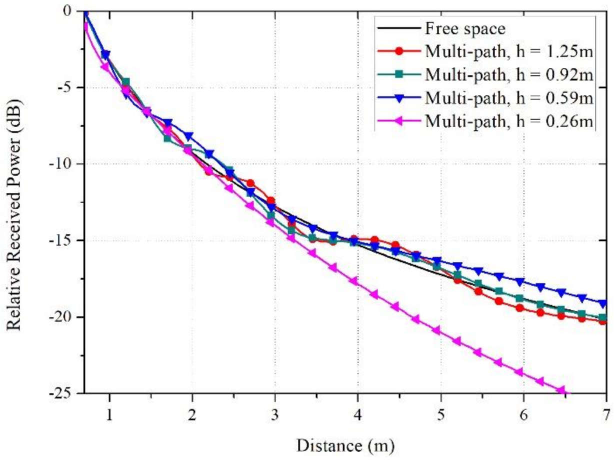

Fig.2 Relative received power with variation of height of transmitter and receiver using vertical linear polarization

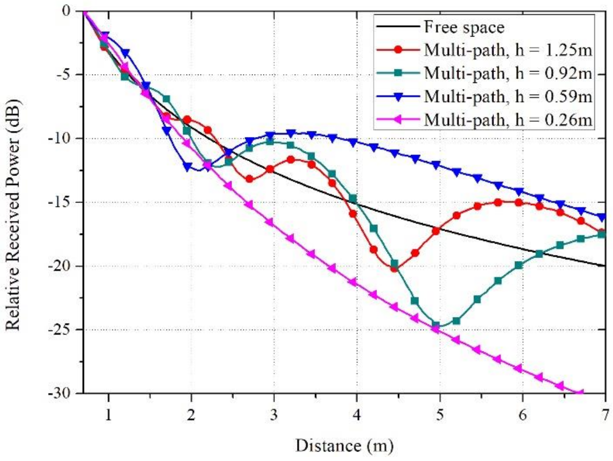

Fig.3 Relative received power with variation of height of transmitter and receiver using horizontal linear polarization

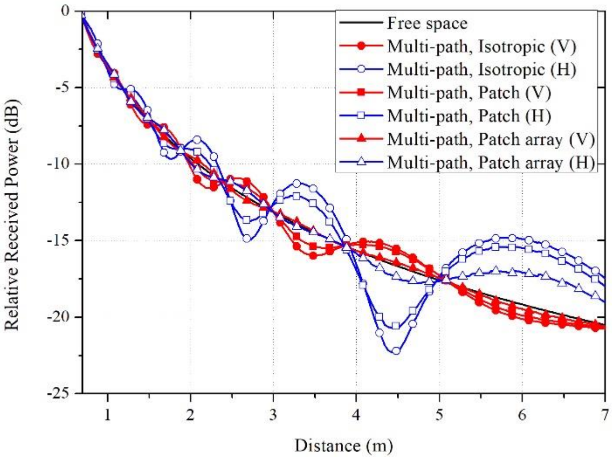

Fig.4 Relative received power with variation of antenna pattern

In order to analyze the difference of received power according to the height change, the height of the transceiver is changed while the other experimental conditions remained the same. Fig. 2 shows the relative received power with variation of the height of transceiver with vertical polarization. The vertical polarization shows similar results to free space model and is insensitive to the influence of the floor. Fig. 3 shows the relative received power with variation of the height of transceiver with horizontal polarization. The horizontal polarization is much affected by the floor than the vertical polarization and its relative received power is significantly varied with height. The relative received power from multi-path of horizontal polarization with 0.59m height is up to 4.65 dB higher than free space at the 4.6m distance.

In order to analyze the difference of received power according to the antenna pattern change, the patterns of the transmit antenna are changed while the other experimental conditions remained the same. An isotropic pattern which has 0 dBi gain, single patch antenna radiation pattern which has 8.8 dBi gain, patch array antenna radiation pattern which has 12.2 dBi gain are used for the transmit antenna pattern. Fig. 4 shows the relative received power with variation of the antenna pattern. It is assumed the same equivalent isotropic radiated power is applied to each calculation. When the antenna gain is lower, the ripple is higher since more power undergo multi-path. The relative received power from multi-path of horizontal polarization with isotropic pattern is up to 4.34 dB higher than free space at the 6.2m distance.

4 Conclusion

In this paper, EMC problems are studied to apply wireless technologies in NPPs and Regulatory Guide 1.180 rev.1 is observed and other regulation standards (MIL-STD 461E, IEC 61000-4) which are endorsed in Regulatory Guide 1.180 rev.1 are also studied. The exclusion zone for administrative controls on the use of portable transceivers near critical equipment is based on free space environment. For the real installation environment, wave propagation properties with multi-path environment according to various factors variation are analyzed.

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