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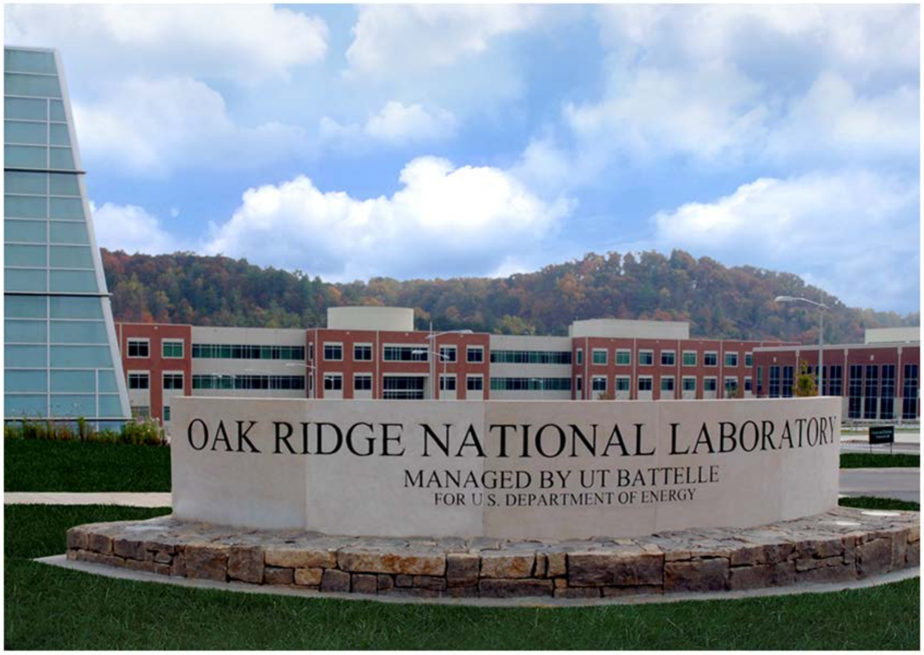
Task 5—Technical Basis for Electromagnetic Compatibility Regulatory Guidance Update (NRCHQ6014D0015)



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MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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TECHNICAL BASIS FOR ELECTROMAGNETIC COMPATIBILITY REGULATORY GUIDANCE UPDATE

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ACRONYMS

AC	alternating current
AIS	air insulated substations
CDN	coupling/decoupling network
CE	conducted emissions
CFR	Code of Federal Regulations
CISPR	Comité International Spécial Pertubations Radioélectriques
CS	conducted susceptibility
dB	decibel
DC	direct current
EFT	electrical fast transients
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EPRI	Electric Power Research Institute
ESD	electrostatic discharge
EUT	equipment under test
FFT	fast Fourier transform
GHz	gigahertz
GIS	gas insulated substations
HEMP	high altitude electromagnetic pulse
HMI	human-machine interface
HV	high voltage
Hz	hertz
I&C	instrumentation and controls
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISM	industrial, scientific, and medical
kHz	kilohertz
LV	low voltage
µA/m	microamp per meter
µV/m	microvolt per meter
MHz	megahertz
MIL-STD	Military Standard
MV	medium voltage
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PQ	power quality
RE	radiated emissions
RF	radio frequency
RFI	radio frequency interference
RG	Regulatory Guide
RS	radiated susceptibility
SNR	signal to noise ratio
SPD	surge protection device
Std	Standard
UPS	uninterruptible power supplies

ABSTRACT

Since the last revision of Regulatory Guide 1.180, *Guidelines for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related Instrumentation and Control Systems*, additional or enhanced test considerations warrant evaluation, previously endorsed standards have been revised, additional industry guidance has been developed, operational environments have evolved, and specific concerns with some of the testing methodologies have been identified. Hence, the goal of this project is to provide the US Nuclear Regulatory Commission the technical basis for developing and publishing a new revision of the regulatory guide (Revision 2).

This report serves as the technical basis document for the revision and provides the rationale for recommended changes. The structure of the document follows and summarizes the several assessment activities undertaken during the course of the project. It highlights the results of comparisons between the current versions of endorsed standards versus the versions cited in Revision 1. It also presents results of assessments of those new, relevant standards that were issued after Revision 1 was published. Comparisons with related electromagnetic compatibility guidance documents are presented, adjustments to test limits are recommended, and additional topics thought to be relevant for future guidance are addressed.

1. INTRODUCTION

The US Nuclear Regulatory Commission's (NRC's) regulations in Part 50, "Domestic Licensing of Production and Utilization Facilities," of Title 10 of the Code of Federal Regulations (10 CFR Part 50) state that structures, systems, and components important to safety in a nuclear power plant are to be designed to accommodate the effects of environmental conditions (i.e., remain functional under all postulated service conditions) and that design control measures such as testing are to be used to check the adequacy of design. Regulatory Guide (RG) 1.180 was developed to provide guidance to licensees and applicants on methods acceptable to the NRC staff for complying with the NRC's regulations on design, installation, and testing practices for addressing the effects of electromagnetic and radio-frequency interference (EMI/RFI) and power surges on safety-related instrumentation and control (I&C) systems. The initial version of RG 1.180 was issued in January 2000 and the first revision was issued in October 2003.

The first revision differed from the initial version in endorsing Military Standard (MIL-STD)-461E and the International Electrotechnical Commission (IEC) Standard (Std) 61000 series of EMI/RFI test methods, extending the guidance to cover signal line testing, incorporating frequency ranges within which portable communications devices are experiencing increasing use, and relaxing the operating envelopes (test levels) where experience and confirmatory research warranted. It also offered exemptions from specific test criteria based on technical considerations such as plant conditions and the intended locations of the safety-related I&C equipment.

Since the last revision, additional or enhanced test considerations warrant evaluation, associated RGs have been created and updated, and additional industry guidance has been developed. Additionally, the operational environment has evolved with the increase in wireless communication technology for both personal (smartphone) and industrial (remote I&C) purposes. Also, specific concerns and issues with testing methods and methodologies have been identified that must be addressed. Further, most of the standards that serve as the basis for the RG have been revised.

Therefore, the NRC's Office of Regulatory Research has contracted with Oak Ridge National Laboratory (ORNL) to incorporate new information and resolve the identified issues under NRC-HQ-60-14-D-0015, "Update to RG 1.180, Revision 2, Guidelines for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related Instrumentation and Control Systems." The ultimate goal of this project is to provide NRC with the technical basis for developing and publishing a new revision of the RG.

The objective of this report is to serve as the technical basis document for the next revision of this RG that highlights and provides the rationale for recommended changes.[1] The structure of this document follows and summarizes the several assessment activities undertaken during the course of this project to evaluate new and updated electromagnetic compatibility (EMC) standards, testing methods and limits, and relevant technology developments being incorporated into plant activities that may have EMI/RFI implications, as well as other specific issues, including impacts of electrostatic discharge (ESD) on safety equipment and impacts of increased usage of wireless devices in nuclear power plants.

Section 2 of this report lists those standards referenced in the last revision of this RG, Revision 1, and highlights the results of comparisons with the current version of those standards versus the version as

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cited in Revision 1. The objective was to determine whether or not the changes made were significant relative to updating the RG. Recommendations on endorsement where appropriate are included. Section 3 presents results of assessments of those new, relevant standards that were issued after Revision 1 was published. Again, the objective was to determine if there would be any guidance to be incorporated into Revision 2 based on the content of these new standards. Further comparisons were made between endorsed standards and related EMC guidance documents, and the results are presented in Section 4. The comparisons here were made with specific IEC standards and the Electric Power Institute (EPRI) report on *Guidelines for Electromagnetic Compatibility Testing of Power Plant Equipment*, TR-102323, Revisions 1–4. Section 5 discusses issues associated with limits for emissions, signal lines, conducted susceptibility testing (i.e., CS114), power surges, such as might be included in newly endorsed standards. Additional, relevant guidance topics are noted in Section 6. These include such topics as consideration of plant configurations during testing, treatment of power quality (PQ) practices, and issues associated with testing beyond 1 GHz. Finally, conclusions and recommendations that form the technical basis for making suggested changes and modifications to Revision 1 of this RG are presented for the purpose of making them available for inclusion in Revision 2.

2. BASIS FOR ENDORSING LATEST VERSIONS OF STANDARDS

2.1 SCOPE

The goal of this section is to summarize the results of a comparative review of the current versions of EMC standards with the versions endorsed in Revision 1 of RG 1.180. The endorsed versions of the IEC and Institute of Electrical and Electronics Engineers (IEEE) standards, as well as their current versions, are shown in Table 1 and Table 2, respectively. The endorsed MIL-STD 461E test methods are shown in Table 3.

It was decided early in the course of the review process that an undirected, automated textual comparison would not be useful, since editorial and formatting changes would overwhelm actual informative differences such as numerical values for limits. The methodology adopted was to perform the comparison in tabular form, comparing section by section on the basis of whether the changes were significant or not significant, and/or whether the change (or lack thereof) warranted a regulatory exception to be taken. The rationale and details of these comparative reviews have been documented and communicated in monthly letter status reports. A summary of the findings is provided in the subsections that follow.

Table 1. IEC EMC standards endorsed in RG 1.180, Rev. 1

Standard	Description	Version cited	Date updated
CISPR 11	Industrial, Scientific, and Medical Radio Frequency Equipment—Electromagnetic disturbance characteristics—limits and measurements	1997	2009
IEC 61000-4-3	Testing and Measurement Techniques—Radiated radio frequency, electromagnetic field immunity test	1995	2010
IEC 61000-4-4	Testing and Measurement Techniques —Electrical fast transient/burst immunity test	1995	2012
IEC 61000-4-5	Testing and Measurement Techniques —Surge immunity test	1995	2014
IEC 61000-4-6	Testing and Measurement Techniques —Immunity to conducted disturbances, induced by radio frequency fields	1996	2013
IEC 61000-4-8	Testing and Measurement Techniques —Power frequency magnetic field immunity test	1993	2009
IEC 61000-4-9	Testing and Measurement Techniques —Pulse magnetic field immunity test	1993	2001
IEC 61000-4-10	Testing and Measurement Techniques —Damped oscillatory magnetic field immunity test	1993	2001
IEC 61000-4-12	Testing and Measurement Techniques —Oscillatory waves immunity tests	1996	2006
IEC 61000-4-13	Testing and Measurement Techniques—Harmonics and interharmonics, including mains signaling at ac power port, low-frequency immunity tests	Draft—see footnote 2	2015
IEC 61000-4-16	Testing and Measurement Techniques —Test for immunity to conducted, common mode disturbances in the frequency range 0 Hz to 150 kHz	1998	2011
IEC 61000-6-4	Generic Standard—Emission standard for industrial environments	1997	2006

[2] RG 1.180, Rev. 1 based its endorsement of IEC 61000-4-13 on a committee draft being prepared for voting. The draft was issued as a final standard in 2002, but the references in the RG were not updated to reflect the actual publication date.

Table 2. IEEE EMC standards endorsed in RG 1.180, Rev. 1

Standard	Description	Version cited	Date updated
IEEE Std C62.41	Surge Voltages in Low-Voltage AC Power Circuits	1991 Reaffirmed in 1995	2002
IEEE Std C62.45	Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits	1992 Reaffirmed in 1997	2002
IEEE Std 1050	Instrumentation and Control Equipment Grounding in Generating Stations	1996	2004

Table 3. MIL-STD EMC test methods endorsed in RG 1.180, Rev. 1

Method	Description
CE101	Conducted emissions, low-frequency, 30 Hz to 10 kHz
CE102	Conducted emissions, high-frequency, 10 kHz to 2 MHz
RE101	Radiated emissions, magnetic field, 30 Hz to 100 kHz
RE102	Radiated emissions, electric field, 2 MHz to 1 GHz
CS101	Conducted susceptibility, low frequency, 30 Hz to 150 kHz
CS114	Conducted susceptibility, high frequency, 10 kHz to 30 MHz
CS115	Conducted susceptibility, bulk cable injection, impulse excitation
CS116	Conducted susceptibility, damped sinusoidal transients,10 kHz to 100 MHz
RS101	Radiated susceptibility, magnetic field, 30 Hz to 100 kHz
RS103	Radiated susceptibility, electric field, 30 MHz to 1 GHz

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

2.2 COMPARATIVE REVIEWS OF PREVIOUSLY ENDORSED IEC STANDARDS

2.2.1 Comparison of CISPR 11-1997 and CISPR 11-2010

One of the IEC technical committees devoted full time to EMC work is the International Special Committee on Radio Interference, or CISPR (acronym for the French title). CISPR 11 deals with the limits and methods for the measurement of electromagnetic disturbance characteristics of industrial, scientific, and medical (ISM) radio-frequency (RF) equipment.

A significant part of CISPR 11 is embodied in tables that specify the limits, frequencies, and characteristics of the interference signals. Therefore, this comparison focused on identifying similarities and/or differences in the tables, including the omission of tables and/or addition of new tables, and the potential regulatory impact of these changes. Many tables in the 1997 version were found to be rearranged and to have different table numbers from the 2010 version. In the update, there were also some enhancements to the tables, such as specifying the measurement of disturbance limits in units of dB µA/m at lower frequencies and in units of dB µV/m at higher frequencies. In contrast, dB µV/m units were typically maintained throughout in the 1997 version. The measurements/units used in the 2010 version are more focused on units corresponding more directly to the phenomena of interest, since magnetic fields are more predominant in the lower-frequency range, whereas electric fields are predominant in the higher-frequency range.

Another difference of note involves the language addressing emissions limits in those frequency ranges for which no limits are specified. In the 1998 version, the standard states that limits are under consideration for the frequency ranges of 9 kHz to 150 kHz and above 30 MHz for conducted emissions and for the frequency ranges of 9 kHz to 150 kHz, 150 kHz to 30 MHz, 1 GHz to 18 GHz and 18 GHz to 400 GHz for radiated emissions. The 2010 version states that no limits apply in those frequency ranges. The significance of this difference is that compliance with CISPR 11 now explicitly excludes testing in the identified frequency ranges. Effectively there is no difference in the conduct of testing since neither version provides limits to guide any testing outside of the commonly specified frequency bands. However, other IEC emissions testing standards (specifically, IEC 61000-6-4) do specify testing above 1 GHz so there is the potential for confusion if the current version of CISPR 11 were applied in full in conjunction with the other IEC emissions testing standards.

Based on the review, the CISPR 11 test methods would be acceptable, but its test limits and guidance on test applicability are not. As is the case in Revision 1 of the RG, IEC 61000-6-4 is found to be more appropriate as the base standard for endorsement of emissions testing. The findings from the review of IEC 61000-6-4 are presented in a subsequent subsection. As a final note on the review of CISPR 11, it is observed that both the endorsed version and current version of the standard cite guidance on test methods and measurement apparatus in normative references to CISPR 16. This observation is relevant in considering the treatment of test methods in reviewing IEC 61000-6-4.

2.2.2 Comparison of IEC 61000-4-3 (1995) and IEC 61000-4-3 (2010)

Part 3 of IEC 61000-4, "Testing and Measurement Techniques—Radiated, radio-frequency, electromagnetic field immunity test," discusses radiated, RF, electromagnetic field immunity tests. It establishes test levels and the required test procedures.

The comparison showed that the standard has been updated in almost every section. Most of the updates are enhancements to the original wording or improvements to the sections in terms of technical content. There were only two changes that required further evaluation/analysis:

1. The 1995 version does not discuss test levels related to protection against RF emissions from cordless digital telephones and other RF emitting devices. However, it was determined after further evaluation that this addition in the 2010 version is just the expansion of RF devices based on the proliferation of wireless devices in domestic usage and industrial applications. This should be viewed as an enhancement or improvement to the standard.

2. The required attenuation of harmonics below the fundamental for power amplifier test equipment has been "relaxed" from 15 dB in the 1995 version to 6 dB in the 2010 version. This "relaxation" means that the signal-to-noise ratio (SNR) will not be as good, and subsequently the test signal will not be as clean, but the test results and acceptance criteria are unchanged. A noisier test signal with no change in acceptance criteria makes for a more conservative test.

Based on the review, the test levels and required test procedure guidance in the 2010 version of IEC 61000-4-3 are suitable for endorsement with no exceptions or clarifications.

2.2.3 Comparison of IEC 61000-4-4 (1995) and IEC 61000-4-4 (2012)

Part 4 of IEC 61000-4, "Testing and measurement techniques—Electrical fast transient/burst immunity test," discusses the immunity of electrical and electronic equipment to repetitive electrical fast transients (EFT) and bursts of noise. It also gives immunity requirements, test procedures, and test levels needed to ensure compatibility under exposure to EFT and bursts.

Analysis of the two versions compared showed that most of the changes in the 2012 version were enhancements to information provided in the 1995 version. However, there were a few changes that needed further evaluation:

1. Table 1 of Section 5, "Test levels," in the 2012 version introduces a new repetition frequency of 100 kHz for power ports and earth ports, as well as for signal and control ports. In addition, the previous Level 4 power-port repetition rate was 2.5 kHz; the new revision uses 5 kHz universally. Further evaluation of this section (Table 1 in Section 5, "Test levels,") determined that the revised table gives a rationale for the inclusion of the 100-kHz frequency, stating that it is "closer to reality." An exception is not considered to be necessary, since the revised table only expands the testing envelope.

2. The test waveform in Figure 3 of the 1995 version appears different in the 2012 version. It includes a voltage plot and removes information about uncertainty. Further analysis showed that the waveforms appear different only in their graphical representation (two plots vs one), but the specifications are the same. In addition, the uncertainty information can be found in the text.

3. Information in Section 6.3.2 of the 2012 version is not included in the 1995 version, including additional test requirements. However, these requirements are intended as improvements that enhance the performance of the tests, i.e., calibration techniques and setup instructions.

4. There are some changes in the test setup for types of tests performed in laboratories between Section 7.2 in 1995 and the corresponding Section 7.3 in 2012. In particular, there are some differences in the dimensions of the test setup. Further evaluation determined that these changes are not expected to have any significant impact on test results. The expectation is that the reproducibility of test results will actually improve.

Based on the review, the guidance on test procedures and the associated limits in the 2012 version of IEC 61000-4-4 are suitable for endorsement with no exceptions or clarifications.

2.2.4 Comparison of IEC 61000-4-5 (1995) and IEC 61000-4-5 (2014)

Part 5 of IEC 61000-4, "Testing and Measurement Techniques—Surge immunity tests," describes immunity requirements, test methods, and a range of recommended test levels for equipment with regard to unidirectional surges caused by overvoltages from switching and lightning transients.

For the test instrumentation, two types of combination wave generators are specified. Each has its own particular applications, depending on the type of port to be tested. One type of combination wave generator is used to test ports intended for connection to outdoor symmetrical communication, and another type is used in all other cases.

A preliminary comparison of the two versions showed that although several enhancements have been made to the standard in the update, the most significant is the fact that the 2014 version has a new section (Section 6.4, with several sub-clauses) devoted to the calibration of coupling/decoupling networks

(CDNs). This section contains tables that summarize the calibration procedure for the CDNs under various conditions (e.g., symmetrical and unsymmetrical interconnection lines) and the surge waveform specifications at the equipment under test (EUT) port for symmetrical and unsymmetrical interconnection lines. It was determined that this section is a considerable enhancement over the previous version, which does not extensively address the calibration of CDNs.

Based on the review, the guidance on test procedures and the associated test levels in the 2014 version of IEC 61000-4-5 are suitable for endorsement with no exceptions or clarifications.

2.2.5 Comparison of IEC 61000-4-6 (1996) and IEC 61000-4-6 (2013)

Part 6 of IEC 61000-4, "Testing and Measurement Techniques—Immunity to conducted disturbances, induced by radio-frequency fields," describes the requirements for conducted immunity of electrical and electronic equipment to electromagnetic disturbances coming from intended RF transmitters.

Note that in the 1996 version of the standard, the frequency range of RF transmitters is stated as "9 kHz up to 80 MHz." However, in the 2013 update, the frequency range is stated as "150 kHz to 80 MHz." Further evaluation of this apparent change in scope showed that Section 5, "Test levels," of the 1996 version of the standard states the following:

> *"**No tests are required** for induced disturbances caused by electromagnetic fields coming from intentional RF transmitters in the frequency range **9 kHz to 150 kHz.**"*

This is because the 9 kHz to 150 kHz test range is covered by IEC 61000-4-16. Thus, the 2013 version simply clarified this requirement by modifying the scope to explicitly state the low-frequency limit as 150 kHz instead of 9 kHz.

Comparison of the two versions of the standard showed that additional information—clarifications and enhancements—has been added, notably in some of the diagrams, where the procedure to be followed in setting the output level for each coupling device has been added. In general, the changes were judged to enhance or clarify the guidance and make the testing easier.

Based on the review, the guidance on test procedures and associated test levels in the 2013 version of IEC 61000-4-6 are suitable for endorsement with no exceptions or clarifications.

2.2.6 Comparison of IEC 61000-4-8 (1993) and IEC 61000-4-8 (2009)

Part 8 of IEC 61000-4, "Testing and Measurement Techniques—Power frequency magnetic field immunity test," describes requirements for immunity of equipment, only under operational conditions, to magnetic disturbances at power frequencies of 50 Hz and 60 Hz related to residential and commercial locations, industrial installations and power plants, and medium-voltage (MV) and high-voltage (HV) substations.

After a preliminary comparison, only one section—Section 7, "Test setup"—was considered significant and needed further evaluation. In particular, discussion of the placement of the test generator with respect to the induction coil is contradictory in the two versions. The 1993 version states that the generator shall be placed less than 3 m from the induction coil. This means it can be as close to the coil as possible. On the contrary, the 2009 version states that the test generator shall not be placed close to the inductive coil because it (the generator) should not influence the magnetic fields. Evaluation of this apparent contradiction concluded that the intent is that the test fields should emanate only from the induction coil.

This is a more conservative approach and hence it should maintain an acceptable level of immunity assurance.

Based on the review, the guidance on test procedures and associated limits in the 2009 version of IEC 61000-4-8 are suitable for endorsement with no exceptions or clarifications.

2.2.7 Comparison of IEC 61000-4-9 (1993) and IEC 61000-4-9 (2000)

Part 9 of IEC 61000-4, "Testing and Measurement Techniques—Pulse magnetic field immunity test," establishes requirements for immunity of equipment under operational conditions to pulsed magnetic disturbances related to industrial installations and power plants, as well as MV and HV substations.

According to the foreword in the 2000 update of the standard, this version "consists of the first edition (1993) [documents 77B(CO)8 and 77B(CO)14] and its amendment 1 (2000) [documents 77B/291+293/FDIS and 77B/298+300/RVD]." Thus, the 2000 update is essentially the 1993 version consolidated with the subsequent amendment to form one document. Because of this, it was not considered necessary to compare the two versions.

The guidance on test procedures and the associated limits in the 2000 version of IEC 61000-4-9 are suitable for endorsement with no exceptions or clarifications.

2.2.8 Comparison of IEC 61000-4-10 (1993) and IEC 61000-4-10 (2000)

Part 10 of IEC 61000-4, "Testing and Measurement Techniques—Damped oscillatory magnetic field immunity test," establishes immunity requirements of equipment under operational conditions to damped oscillatory magnetic disturbances related to industrial installations and power plants, as well as MV and HV substations.

According to the foreword in the 2000 update of the standard, this version *"consists of the first edition (1993) [documents 77B(CO)9 and 77B(CO)15] and its amendment 1 (2000) [documents 77B/291+293/FDIS and 77B/298+300/RVD]. The technical content is therefore identical to the base edition and its amendment and has been prepared for user convenience."* Thus, the 2000 update is essentially the 1993 version consolidated with the subsequent amendment to form one document. Because of this, it was not considered necessary to compare the two versions.

Guidance on test procedures and the associated limits in the 2000 version of IEC 61000-4-10 are suitable for endorsement with no exceptions or clarifications.

2.2.9 Comparison of IEC 61000-4-12 (1995), IEC 61000-4-12 (2006), and IEC 61000-4-18 (2011)[3]

IEC 61000-4-12 establishes the immunity requirements and test methods for electrical and electronic equipment, under operational conditions, to non-repetitive damped oscillatory transients (ring waves) occurring in low-voltage (LV) power, control, and signal lines supplied by public and non-public networks.

The scope of IEC 61000-4-12 (1995) is different from the scope established in the 2006 version. In particular, IEC 61000-4-12 (1995) states the following (the underlining is added by the authors):

[3] IEC 61000-4-18 (2011) is the 2006 version consolidated with amendment 1 (2010). See https://webstore.iec.ch/publication/4187

This section of IEC 1000-4 relates to the immunity requirements and test methods for electrical and electronic equipment, under operational conditions, to oscillatory waves represented by:

a) non-repetitive damped oscillatory transients (ring wave) occurring in low-voltage power, control and signal lines supplied by public and non-public networks;

b) repetitive damped oscillatory waves occurring mainly in power, control and signal cables installed in high voltage and medium voltage (HV/MV) stations.

In part (b) identified above, repetitive damped oscillatory waves for MV/HV systems were eliminated from the 2006 update. The narrower scope of the 2006 version is evident from Section 1, "Scope," of IEC 61000-4-12 (2006) which states the following (the underlining is added by the authors):

This part of IEC 61000 relates to the immunity requirements and test methods for electrical and electronic equipment, under operational conditions, to non-repetitive damped oscillatory transients (ring waves) occurring in low-voltage power, control and signal lines supplied by public and non-public networks.

The difference in scope is reflected in the titles of the two versions:

- 1995 version of IEC 61000-4-12: "Testing and Measurement Techniques—Oscillatory waves immunity test."
- 2006 version of IEC 61000-4-12: "Testing and Measurement Techniques—Ring wave immunity test."

Investigations showed that the 1995 version of IEC 61000-4-12 appears to have been split into two parts, with part (b)—*repetitive damped oscillatory waves occurring mainly in power, control and signal cables installed in high voltage and medium voltage (HV/MV) stations*—incorporated into a new standard, IEC 61000-4-18. That is, the updated version of IEC 61000-4-12 appears to be now focused on power, control, and signal cables for LV applications, while IEC 61000-4-18 appears to be focused on power, control, and signal cables installed for MV/HV applications.

Based on these changes, it was considered more relevant to compare the 1995 version of IEC 61000-4-12 not only with the 2006 version but also with IEC 61000-4-18. The issues to be resolved were the following:

1. Has any important information endorsed in IEC 61000-4-12 (1995) been removed from the IEC 61000-4-12 (2006) update and if so, should any exceptions be taken?

2. Did any information endorsed in the 1995 version of IEC 61000-4-12 get moved to IEC 61000-4-18 and if so, should IEC 61000-4-18 be endorsed with appropriate exceptions?

3. Are the limits specified in IEC 61000-4-12 (2006) (and in IEC 61000-4-18 [2011], if that is also required) more or less conservative than IEC 61000-4-12 (1995)?

A. Issue #1:

Has any important information in IEC 61000-4-12 (1995) been removed from the IEC 61000-4-12 (2006) update and if so, should any new guidelines/exceptions be taken?

This issue was addressed by comparing IEC 61000-4-12 (1995) and IEC 61000-4-12 (2006). The following is a summary of the observations from this comparison:

1. In Section 5, "Test levels," of the of the 1995 version, the preferred ranges of test levels for the ring wave and the damped oscillatory wave tests are given in Table 1 and Table 2, respectively. In the 2006 version, this Table 2 is missing. The test levels section in IEC 61000-4-18 was reviewed and found to contain a table identical to Table 2 in the 1995 version. With regard to ring waves, there is no change between the two versions of IEC 61000-4-12.

2. In Section 6, "Test equipment," of both versions of IEC 61000-4-12, the main difference between the two versions is the elimination of the damped oscillatory wave test generator from the 2006 version. This test equipment is of course not required for the ring wave test. Otherwise, there are no significant additions regarding the ring wave test generator characteristics and features in the 2006 update.

3. In Section 8, "Test procedure," revisions and additional information have been included to provide improved guidance in the 2006 update. Some subsections that were in the 1995 version have also been removed from the 2006 update. However, those that have been removed completely (rather than revised in the text) are those that reference the damped oscillatory wave. An example is Subsection 8.2.2, "Test implementation with damped oscillatory waves," in the 1995 version that is no longer in the 2006 update.

In summary, the comparison showed that no important information relevant to ring waves has been removed from the updated version. However, since information relevant to damped oscillatory waves in IEC 61000-4-12 (1995) was moved to IEC 61000-4-18, the latter also needed to be reviewed for relevance and applicability.

B. **Issue #2:**

Did any information endorsed in the 1995 version of IEC 61000-4-12 get moved to IEC 61000-4-18 and if so, should IEC 61000-4-18 be endorsed with appropriate exceptions?

A review of IEC 61000-4-18 showed that the information in the 1995 version of IEC 61000-4-12 that was moved to IEC 61000-4-18 is relevant to

a. repetitive damped oscillatory waves occurring mainly in power, control, and signal cables installed in HV/MV substations, and

b. repetitive damped oscillatory waves occurring mainly in power, control, and signal cables installed in gas-insulated substations (GIS) and in some cases air-insulated substations (AIS), or in any installation due to high-altitude electromagnetic pulse (HEMP).

No information relevant to the application of non-repetitive damped oscillatory transients (ring waves) occurring in LV power, control, and signal lines, which is the test waveform endorsed in the RG, is documented in IEC 61000-4-18. Thus, no exceptions need to be taken.

In addition, the review of IEC 61000-4-18 concluded that this standard is not required unless equipment is located in close proximity to HV bus bars.

C. ***Issue #3**:*

Are the limits specified in IEC 61000-4-12 (2006) (as well as IEC 61000-4-18 [2011] if that is also applicable) more or less conservative than IEC 61000-4-12 (1995)?

This issue was resolved during the review of the 1995 and 2006 versions of IEC 61000-4-12 discussed above. In particular, Table 4 and Table 5 show the test levels for ring waves in the 1995 and 2006 versions, respectively. Observation showed that the two tables are the same. (Note: “common mode” voltage in Table 4 is the same as “line-to-ground” voltage in Table 5 and “differential mode” voltage in Table 4 is the same as “line-to-line” voltage in Table 5). Also, it has already been concluded that IEC 61000-4-18 is applicable only to control and signal cables installed in HV/MV substations, in GIS and in some cases also AIS, or in any installation highly likely to be subject to HEMP. In addition, the limits in IEC 61000-4-12 (2006) are identical to those specified in IEC 61000-4-12 (1995).

Based on the reviews of IEC 61000-4-12 (1995), IEC 61000-4-12 (2006), and IEC 61000-4-18 (2011), the guidance on test procedures and the associated limits in the 2006 version of IEC 61000-4-12 are suitable for endorsement with no exceptions or clarifications.

IEC 61000-4-18 is not required unless (safety) equipment is located in close proximity to HV bus bars. Although the definitions of “high voltage” and “medium voltage” vary widely, IEEE Std 100 [1] defines “high voltage” (as applied to electric power systems in commercial buildings and system voltage ratings) as a **“**class of nominal system voltages equal to or greater than 100,000 V and equal to or less than 230,000 V.” While the standard also acknowledges that the term “high voltage” is usually “applied to voltage levels that are greater than 1000 V,” the formal definition it gives for “medium voltage” (as applied to system voltage ratings) is “a class of nominal system voltages greater than 1000 V and less than 100,000 V.” Thus, for the purposes of this report, “medium voltage” is defined as greater than 1,000 V but less than 100,000 V; and “high-voltage” is defined as greater than 100,000 V but less than 230,000 V.

Table 4. Test levels for ring wave—Table 1 of IEC 61000-4-12 (1995)

Level	Common mode (kV)	Differential mode (kV)
1	0.5	0.25
2	1	0.5
3	2	1
4	4	2
X[1]	X	X
[1] X is an open level. This level can be given in the product specification.		

Table 5. Test levels for ring wave—Table 1 of IEC 61000-4-12 (2006)

Level	Line-to-ground (kV)	Line-to-line (kV)
1	0.5	0.25
2	1	0.5
3	2	1
4	4	2
X[1]	X	X
[1] X can be any level, above, below or in-between the other levels. This level can be given in the product standard.		

2.2.10 Review of IEC 61000-4-13 (2015)

Part 13 of IEC 61000-4, “Testing and Measurement Techniques—Harmonics and interharmonics including mains signaling at a.c. power port, low frequency immunity tests,” defines “… immunity test methods and range of recommended basic test levels for electrical and electronic equipment with rated current up to 16 A per phase at disturbance frequencies up to and including 2 kHz (for 50 Hz mains) and 2.4 kHz (for 60 Hz mains) for harmonics and interharmonics on low voltage power networks.”

RG 1.180, Rev. 1, based its endorsement of IEC 61000-4-13 on a committee draft being prepared for voting. The draft was issued as a final standard in 2002, but the references in the RG were not updated to reflect the actual publication date. Two amendments have occurred since the release of the 2002 standard (Amendment 1 in 2009 and Amendment 2 in 2015).

The full, consolidated version of IEC 61000-4-13 (2015) was reviewed for potential endorsement. The standard establishes test levels and test methods for evaluating the immunity of electrical and electronic equipment subjected to harmonics and interharmonics and mains frequencies. The test level is the "harmonic voltage specified as a percentage of the fundamental voltage." These test levels are specified in Tables 1 through 3 of the standard. Specifications for the test generator to be used for the tests can be found in Section 6 of the standard, "Test Instrumentation." Note that the test levels to be used depend on the "Electromagnetic Environment Class" in which the equipment will be used. These classes are specified in Annex C of the standard.

The review of the consolidated standard found no change of significance from the committee draft upon which RG 1.180 based its endorsement. Thus, IEC 61000-4-13 (2015) is suitable for endorsement with no exceptions or clarifications.

2.2.11 Comparison of IEC 61000-4-16 (1998) and IEC 61000-4-16 (2009)

Part 16 of IEC 61000-4, "Testing and Measurement Techniques—Test for immunity to conducted, common mode disturbances in the frequency range 0 Hz to 150 kHz," provides guidelines for testing electrical and electronic equipment with the application of common mode disturbances to power supply, control, signal, and communication ports. The standard defines test voltage and current waveforms, test levels, test equipment, test setups, and test procedures. The test is intended to demonstrate the immunity of electrical and electronic equipment subjected to conducted, common mode disturbances in the range of DC to 150 kHz, such as those originating from power line currents and return leakage currents in the earthing/grounding system.

The 2009 revision represents the direct incorporation of amendments 1 (2001) and 2 (2009) with respect to the 1998 revision.

The comparison showed that all the changes were enhancements rather than changes to normative requirements, such as test levels. In particular, there are no changes to the test levels (found in Tables 1 and 2 of Section 5, "Test levels") specified in the 1998 version. Amendment 2 (2009) also included additional text that provided clarity to the specifications for the test equipment used (Section 6, "Test equipment"). There were no changes to actual equipment specifications.

Based on the review of IEC 61000-4-16 (1998) and IEC 61000-4-16 (2009), the guidance on test procedures and the associated limits in the 2009 version of IEC 61000-4-16 are suitable for endorsement with no exceptions or clarifications. Note that at the time of this investigation, a pre-release version of a 2015 amendment to IEC 61000-4-16 was identified.[4] The amended IEC 61000-4-16 is essentially the 1998 version consolidated with the amendments already described. Thus, this updated version of IEC 61000-4-16 should also be suitable for endorsement with no exceptions or clarifications when it becomes publicly available.

[4] https://webstore.iec.ch/publication/23253

2.2.12 Comparison of IEC 61000-6-4 (1997) and IEC 61000-6-4 (2011)

IEC 61000-6-4, "Generic standards—Emission standard for industrial environments," defines emissions requirements for electrical and electronic equipment intended for use in industrial environments in the frequency range 0 Hz to 400 GHz. Equipment covered includes ISM apparatus, heavy inductive or capacitive loads that are frequently switched, and high currents associated with magnetic fields. The standard applies to an apparatus intended to be connected to a power network supplied from an HV or MV transformer dedicated to the supply of an installation feeding a manufacturing or similar plant, and intended to operate in or in proximity to industrial locations. It also applies to apparatus that is battery operated and intended for use in industrial locations. The 2011 revision represents the direct incorporation of amendment 1 (2010) to the Second Edition (2006).

Comparisons were performed on the basis of whether changes were significant or not and/or whether the change (or lack thereof) warranted a regulatory exception to be taken. Although most changes were enhancements, five changes were considered significant enough to warrant evaluations:

1. Section 8, "Measurement uncertainty," in the update is a new section that refers to CISPR 16-4-2 as the authority on measurement instrumentation uncertainty. The section states to use it where applicable, implying that it is optional. The previous revision did not address uncertainty. The requirement to specify measurement uncertainty results in a more conservative testing requirement. Therefore, no exception needs to be taken in this regard.

2. Section 9, "Application of limits for conformity of equipment in series production," in the update is a new section that describes the application of limits for testing multiple items of the same type. It provides clarification on testing multiple samples. The previous revision did not address the testing of a sample of identical pieces of equipment. Therefore, no exception needs to be taken.

3. Section 10, "Compliance with this standard," is a new section that addresses compliance with the standard. Its purpose is clarification. The previous revision did not address compliance. Therefore, no exception needs to be taken.

4. Table 1 in the 2011 update, "Emission—enclosure port expanded with different limits based on test facility," includes new sections on "Enclosure" and "AC mains." The table also has been expanded to include different limits based on the additional test methodologies, including open area test sites and transverse electromagnetic cells. These additional testing requirements are in the conservative direction, and so no exception is warranted.

Another change of significance involves the normative references in the two versions of the standard. In the 1997 version of IEC 61000-6-4, CISPR 11 is cited for guidance on test methods and measurement apparatus. CISPR 11, in turn, references CISPR 16 for specific guidance on test methods and equipment. In the 2011 version of IEC 61000-6-4, CISPR 16 is directly referenced for normative guidance on test methods and measurement apparatus. Therefore, it is appropriate for the revised RG to replace the citation of CISPR 11 for test methods with citation of CISPR 16.

Based on the review of IEC 61000-6-4 (1997) and IEC 61000-6-4 (2011), the guidance on test procedures and the associated limits in the 2011 version are suitable for endorsement with no exceptions. The reference to guidance on specific emissions test methods in the RG should be clarified to point to CISPR 16.

2.3 COMPARATIVE REVIEWS OF PREVIOUSLY ENDORSED IEEE STANDARDS

2.3.1 Comparison of IEEE C62.41 (1991) and IEEE C62.41.1/41.2 (2002)

IEEE C62.41 (1991), "IEEE Recommended Practice on Surge Voltage in Low-Voltage AC Power Circuits," discusses surge withstand practices for surge voltages in LV[5] AC power circuits.

In its introductory statements, IEEE C62.41 (1991) acknowledges that the latter is a large document (111 pages), and additional data collected toward an update of the 1991 version (reaffirmed in 1996) "…would have increased further the volume of the document." IEEE therefore decided to "… create a 'trilogy' by separating the information into three distinct documents." The intent was to "make their use more reader-friendly while maintaining the credibility of the recommendations." The expectation was that "interested parties would thus have a faster, simpler access to the recommendations for selecting representative surges relevant to their needs."

The "trilogy" of documents are

- IEEE Std C62.41.1 (2002), "IEEE Guide on the Surge Environment in Low-Voltage (1000 V and Less) AC Power Circuits"
- IEEE Std C62.41.2 (2002), "IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits"
- IEEE Std C62.45 (2002), "IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V and Less) AC Power Circuits"

Note that the wording used in these introductory remarks in IEEE C62.41 (1991) seems to imply that the standard was separated into three distinct documents in the 2002 update. This is somewhat misleading. IEEE C62.41 (1991) was actually separated into two documents in the 2002 version: C62.41.1 (2002) and C62.41.2 (2002). IEEE Std C62.45 has always been a separate document and was also revised in 2002. Reference to a "trilogy" is in the sense that they should be used together, since they all provide information, characterization, or test methods for surges in LV AC power circuits.

Since the chapters were reorganized in the 2002 version, the comparison of the two versions (1991 and 2002) was performed by "topic," using the 1991 version as the baseline. For example, Chapter 7 in the 1991 version of IEEE C62.41 was compared with Chapter 8 in the 2002 version (IEEE C62.41.1) as well as the companion document C62.41.2, since all of these address the same topic: "recommended surges." Another method of comparison used was to examine if and how important concepts had changed, such as "Location Category," "Exposure Level," "Test Waveforms," and "Test Limits."

Comparison of Location Categories and Exposure Levels

IEEE Std C62.41 (1991) describes three broad circuit location categories and exposure levels that define applicable amplitudes for the surge waveforms that should provide an appropriate degree of surge withstand capability. The location categories are based on how far from the service entrance equipment is located. The most severe location (Location Category C) is the environment from the exterior (e.g., switchyard or utility supply service drop from the pole) to the service entrance. Location Category B covers feeders and short branch circuits extending to interior locations from the service entrance. The least severe is Location Category A, which covers outlets and branch circuits located far away from the service entrance.

[5] IEEE 6.41.2 (2002) defines "low voltage" in its introduction as "1000 V and less."

Exposure levels relate to the rate of surge occurrence versus the voltage level (e.g., areas with high lightning activity or with significant switching transients). The exposure levels identified in IEEE C62.41 (1991) are Low, Medium, and High Exposure. In IEEE C62.41.2 (2002), the use of exposure level in setting test limits has been "simplified" for reasons discussed in Section 4.7, "Exposure level," of the 2002 update. First, the revised standard states that the concept of exposure levels remains qualitative because available data still do not support a more quantitative prescription. Second, the further subdivision into three subcategories (exposure levels) within each of the three location categories in the 1991 version was deemed cumbersome by some readers, and many of those specifying levels used only the largest value. As a result, the tables appearing in the 2002 update (see discussion below) show only one row of values for Category A and Category B. However, for Category C, two exposure levels (Low and High) are maintained "because of the width of the transition band connecting Location Category B to Location Category C (spanning over the service equipment)."

In summary, the definitions of Location Categories A, B and C are identical in IEEE C62.41 (1991) and IEEE C62.41.2 (2002). However, the further subdivision of Categories A and B into three exposure levels (Low, Medium, and High or A1, A2, and A3 and B1, B2, and B3) has been eliminated in the 2002 update. For Location Category C, only two exposure levels (Low and High) have been maintained.

Comparison of Test Limits and Test Waveforms

Table 6 and Table 7 show the test limits for the voltage and current surges expected for the various location categories and exposure levels in the 1991 version of IEEE C62.41. Note that these tables correspond to Tables 2 and 3 in the standard (i.e., IEEE C62.41). The tables in the updated standard (IEEE C62.41.2 [2002]) that correspond to the surge limits in the 1991 version are shown in Table 8 and Table 9. It can be seen by comparing Table 6 and Table 7 to Table 8 and Table 9, respectively, that the concept of exposure level no longer exists in the 2002 update. Exposure levels of "Low" and "High" have, however, been maintained for Location Category C, as shown in Table 10.

Elimination of the exposure levels in the 2002 update, together with the elimination of the different test limits associated with each exposure level, constitutes an unnecessary conservatism. The withstand levels discussed in Regulatory Position 5, "Surge Withstand Capability," in RG 1.180, Revision 1, are based on Category B and Category C locations, along with Low Exposure and Medium Exposure levels. To avoid the addition of unnecessary conservatism, the use of graded exposure levels should be maintained in the next revision of RG 1.180.

Based on the review of IEEE C62.41 (1991) and IEEE C62.41.1/41.2 (2002), the waveforms and withstand levels specified in IEEE C62.41.2 (2002) provide appropriate guidance on surge withstand waveform characterization and test levels for surge voltages in LV AC power circuits. Therefore, these standards are suitable for endorsement in the RG for guidance on surge withstand testing. However, an exception is taken with regard to Table 2 in IEEE C62.41.2 (2002) (shown as Table 8 in this report). This table eliminates the (low, medium, and high) exposure levels that were in the 1991 version, together with the different test limit associated with each exposure level (2, 4, and 6 kV, respectively). The imposition of the 6-kV limit on all tests without regard to exposure level is overly conservative and an exception should be taken.

The regulatory guide states that "a determination of the exposure level classification that characterizes a location is necessary to select the applicable withstand levels." This position should be maintained in the next revision of the regulatory guide.

The withstand levels discussed in RG 1.180, Revision 1, are based on Category B and Category C locations, along with Low Exposure and Medium Exposure levels. Given the elimination of guidance establishing low, medium, and high exposure conditions, it is recommended that the terminology be adjusted in the RG to characterize the exposure levels as low and elevated. It is further recommended that guidance on Location Category C test levels be deleted from the RG since the vast majority of safety-related equipment are installed in interior locations (i.e., indoors) and guidance on test levels for exterior locations is unnecessary.

Table 6. Voltage and current surges expected in location categories A and B. Test waveform is a standard 0.5 µs, 100 kHz ring wave. This is Table 3 from C62.41 (1991)

Location category	System exposure	Peak values		Effective impedance (Ω)
		Voltage (kV)	Current (kA)	
A1	Low	2	0.07	30
A2	Medium	4	0.13	30
A3	High	6	0.2	30
B1	Low	2	0.17	12
B2	Medium	4	0.33	12
B3	High	6	0.5	12

Table 7. Voltage and current surges expected in location categories B and C. Test waveform is standard 1.2/50 µs – 8/20 µs combination wave. This is Table 4 from C62.41 (1991)

Location category	System exposure	Peak values		Effective impedance (Ω)
		Voltage (kV)	Current (kA)	
B1	Low	2	1	2
B2	Medium	4	2	2
B3	High	6	3	2
C1	Low	6	3	2
C2	Medium	10	5	2
C3	High	20	10	2

Table 8. Expected maximum voltage and current surges in location categories A and B. Test waveform is standard 0.5 µs – 100 kHz ring wave. This is Table 2 from IEEE C62.41.2 (2002)

Location category	Peak values		Effective impedance (Ω)
	Voltage (kV)	Current (kA)	
A	6	0.2	30
B	6	0.5	12

Table 9. Expected voltage and current surges in location categories B and C. Test waveform is standard 1.2/50 µs – 8/20 µs combination wave. This is Table 3 of IEEE 62.41.2 (2002)

Location category	Peak values		Effective impedance (Ω)
	Voltage (kV)	Current (kA)	
A	6	0.5	12
B	6	0.3	2

Table 10. Scenario I tests for surge protection devices (SPDs) intended for location category C

Exposure	Standard tests		Optional test
	1.2/50 μs voltage generator	8/20 μs current generator	100 kHz ring wave for front-of-wave response evaluation
	Minimum open circuit voltage to be applied to SPD	Current to be driven through the SPD	
Low	6 kV	3 kA	6 kV
High	10 kV	10 kA	10 kV

2.3.2 Comparison of IEEE Std C62.45 (1992) and IEEE Std C62.45 (2002)

IEEE Std C62.45 (1992), "IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits," provides guidance for applying surge testing to the AC power interfaces of equipment connected to LV AC power circuits that are subject to transient overvoltages. This document was used as a guide for 10 years, and in the 2002 version, it was changed to a "recommended practice." This fact is also reflected in the change in the title of the document. In particular, the title of the 2002 version is "IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V and Less) AC Power Circuits." Note that the definition of LV (1,000 V or less) was introduced into the title of the 2002 version.

As explicitly stated in the 1992 version, "signal and data lines are not addressed in the guidance document, nor are any specifications stated on the withstand levels that might be assigned to specific equipment." In the 2002 version, it is stated in the "Introduction" that, together with IEEE Std C62.45, "… the two (documents) IEEE Std C62.41.1 (2002) and IEEE Std C62.41.2 (2002) present a 'trilogy' concerning the occurrence, characterization, and testing of surges in low-voltage AC power circuits. …" A review of IEEE C62.41 was performed as discussed in the previous subsection. The review in this subsection completes the review of this "trilogy" of standards.

Summary of the Key Findings from the Comparison of the Two Versions

IEEE Std C62.41 (1991) calls for relating the surge environment to the physical/electrical position of the EUT in the power system. To do so, IEEE Std C62.45 (1992) defined three location categories consistent with IEEE C62.41 (1991). Table 1 in Clause 4.7, "Voltage and current waveforms," provides a summary of applicable standard and additional waveforms for these location categories. This table is reproduced in the current report as Table 11. The corresponding table in the 2002 update is reproduced in Table 12 in the current report. Note that the location categories in this version are A, B, C—Low, and C—High. This is consistent with the categorizations in IEEE C62.41.2 (2002).

Note that the fact that five waveforms are listed does not mean that all equipment must necessarily be subjected to all five types of surges. The 100-kHz ring wave and the combination wave are recommended as basic design and test surges, i.e., standard test waveforms. The additional waveforms (EFT/burst, 10/1000 μs wave, and 5 kHz ring wave) need to be included in a test program only when sufficient evidence is available to warrant their use.[6] This position is similar in both versions of the standard. In the case of its endorsement in RG 1.180, Revision 1, the EFT/burst waveform was considered essential because it is intended to represent local load switching on the AC power leads of equipment and subsystems.

[6] For example, the EFT/burst and unidirectional 10/1,000 μs each has a unique domain of application (e.g., contactor interference, fuse operation, and load switching).

Based on the review of IEEE C62.45 (1991) and IEEE C62.45 (2002), the test methods for each waveform as specified in IEEE C62.45 provide appropriate guidance on surge withstand waveform characterization and test methods for surge voltages in LV AC power circuits. Therefore, this standard is suitable for endorsement with no exceptions or clarification for guidance on surge withstand testing.

Table 11. Summary of applicable standard and additional surge testing waveforms for location categories A, B and C (from IEEE C62.45 (1992)

Location category	100 kHz ring wave	Combination wave	5/50 ns EFT burst	10/1000 µs wave	5 kHz ring wave
A	Standard	None	Additional	Additional	Additional
B	Standard	Standard	Additional	Additional	Additional
C	None	Standard	None	Additional	Additional

Table 12. Summary of applicable standard and additional surge testing waveforms for location categories A, B, and C (from IEEE C62.45 (2002). Note the further subdivision of Category C into "C Low" and "C High"

Scenario I—Surges impinging upon the structure from outside, and generated within						Scenario II—Direct lightning flash	
Location category	**100 kHz ring wave**	**Combination wave**	**Separate voltage/ current**	**5/50 ns EFT burst**	**10/1000 µs wave**	**Inductive coupling**	**Direct coupling**
A	Standard	Standard	—	Additional	Additional	Category B ring wave	Case-by-case assessment
B	Standard	Standard	—	Additional	Additional		
C Low	Optional	Standard	—	Optional	Additional		
C High	Optional	—	Standard	Optional	—		

2.3.3 Comparison of IEEE 1050 (1996) and IEEE 1050 (2004)

IEEE Std 1050, "IEEE Guide for Instrumentation Control Equipment Grounding in Generating Stations," provides I&C equipment grounding methods to achieve both a suitable level of protection for personnel and equipment, and suitable electric noise immunity for signal ground references in generating stations. Both ideal theoretical methods, as well as accepted practices in the electric utility industry, are presented.

Results from the comparison showed that the two revisions agree in the given technical guidance and assumed values, but the 2004 revision includes far more scope and provides more clarity in many cases. The following are two examples to illustrate these general findings:

1. Section 5.3.2, "Multiple-Point Ground System," of IEEE 1050 (1996) states that "a multiple-point ground system should be considered when grounding equipment that operates at frequencies over 300 kHz, or when long ground cables are used." By contrast, the corresponding section that addresses the topic in IEEE 1050 (2004) (Section 5.2.2, "Multiple-Point Ground System) states that "a multiple-point ground system should be considered for equipment that operates at frequencies above 30 kHz and certainly when operating over 300 kHz. This is also a requirement when electrically long ground cables are used in relation to signal wavelength on the path." The wording used in the 2004 version is more conservative. The figure used in the 2004 version (Figure 14) is also preferable to the corresponding figure in the 1996 version (Figure 15) because of the unconventional way the 3-phase source voltage is drawn. Thus, the 2004 version is preferable in this regard.

2. Section 5.4 of the 1996 revision discusses grounding methods for high-, medium-, and low-susceptibility control circuits. There are no one-for-one corresponding sections in the 2004 version for these topics addressed in the 1996 version. Instead, discussions of these topics have

been reformatted and folded into the discussions under Section 6, “Signal cable shield grounding.” The grounding methods for high-medium- and low-frequency control circuits discussed in both revisions are essentially the same, but the wording in the 2004 revision provides more clarity.

Based on the review of IEEE 1050 (1996) and IEEE 1050 (2004), the guidance on grounding methods for I&C circuits in generating stations provided in the 2004 update is suitable for endorsement with no exceptions or clarifications.

2.4 COMPARATIVE REVIEWS OF MILITARY STANDARDS

Several test methods from MIL-STD 461E, *Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment*, were endorsed in RG 1.180, Revision 1, for the purpose of demonstrating the immunity of I&C equipment to EMI/RFI and limiting significant additions of noise interference into the ambient electromagnetic environment in nuclear facilities. These MIL-STD test methods are shown in Table 3 and include both conducted and radiated tests for assessing equipment vulnerability and emissions.

2.4.1 Review of MIL-STD-461F

At the onset of the project, a detailed comparison was conducted between MILSTD-461F, issued December 10, 2007, and MIL-STD-461E, issued on August 20, 1999. The methodology adopted was to perform the comparison in tabular form, comparing section by section on the basis of whether the changes were significant and whether the change warranted a regulatory exception. The rationale and details of this comparative review were documented and communicated in monthly letter status reports.

Many of the changes were superficial (e.g., adding acronyms, changing page numbers, redrawing figures, updating references). Other changes improved the test methods by offering additional guidance on their applicability, verifying proper performance during tests, changing scan rates to decrease test times, and modifying test setups. Some of the more significant changes involved adding new test methods or modifying existing methods. A summary of these changes is shown in Table 13.

The review of MIL-STD-461F found no change of significance from the MIL-STD-461E test methods upon which RG 1.180, Revision 1, based its endorsement. Most of the changes are mere refinements to improve test outcomes and will likely enhance the operation of the tested I&C systems. The CS106 and CS109 requirements are not applicable to the ground facilities thought to be similar to the nuclear facility environment, as they are intended for areas where sensitive equipment is in close proximity to noise sources, such as ships and submarines. RG 1.180, Revision 1, already requires the CS114 test for power cables, and the new RE101 and RS103 requirements offer useful enhancements.

Table 13. MIL-STD-461F vs MIL-STD-461E

Change	Rationale
Adds new CS106 conducted susceptibility requirement	New CS106 conducted susceptibility test method has been added. This type of transient susceptibility test has been successful in early identification of transient-related EMI problems
Adds new CS109 conducted susceptibility requirement	New CS109 conducted susceptibility test method has been added. Requirement is applicable to sensitive equipment and subsystems that have operating frequencies of 100 kHz or less and operating sensitivity of 1 μV or better
Adds new CS114 conducted susceptibility requirement	New CS114 conducted susceptibility requirement has been added for power cables. Add-on applies when DC power systems are used and common mode noise is generated from DC-to-DC conversion
Adds requirement when RE101 emissions exceed limit	New RE101 radiated emissions measurement to assess distance where emission levels fall within specifications. If the measured emission exceeds the limit at the 7-cm distance, increase the measurement distance until the emission falls within the specified limit
Modifies applicability and test setup for RS103 test	For the RS103 test between 30 MHz and 100 MHz, place electric field sensors at same distance as the EUT is located from the transmit antenna, directly opposite the transmit antenna and a minimum of 30 cm above the ground plane at or below 1 GHz. Above 1 GHz, place the sensors at a height corresponding to the area of the EUT being illuminated. Transmit antennas shall be placed 1 meter or greater from the test setup boundary

2.4.2 Review of MIL-STD-461G

In a very recent development, MIL-STD-461G was issued on December 11, 2015, after the start of the project; and it was thought that this standard should also be included in the review. Hence, a comparison was made between MIL-STD-461G and MIL-STD-461F. Changes in MIL-STd-461G are not as extensive as in the previous update, but they do again offer improvements in the test methods. Of note is that this version now allows the use of fast Fourier transform (FFT) receivers that allow the observation of signals in both the time and frequency domains at the same time. The FFT techniques also offer a significant reduction in measurement time compared with conventional receivers.

The CS106 test method that was added in MIL-STD-461F has been removed, and no technical rationale was offered for its removal. A new CS117 conducted susceptibility requirement for lightning-induced transients was added with limited applicability to interconnecting cables between safety-critical equipment. Its intent is to address the equipment-level indirect effects of lightning. A new CS118 conducted susceptibility requirement is also added for personnel-borne ESD that is very similar to the methods in IEC 61000-4-2. In addition, the upper frequency bounds for the RE102 and RS103 tests are extended to 18 GHz regardless of the EUT's highest generated frequency. More than likely, this has a direct link to the types of systems (e.g., radar, communications) being deployed on military platforms.

The review of MIL-STD-461G found no change of significance from the MIL-STD-461F test methods or from the MIL-STD-461E test methods, for that matter. Again, most of the changes are mere refinements to improve the outcomes of the tests. The addition of the CS117 conducted susceptibility requirement appears beneficial, but it offers no apparent advantage over the surge withstand tests endorsed in RG 1,180, Revision 1. The CS118 ESD requirement also appears beneficial, but the staff has already been looking at the IEC 61000-2 test method and finds it appropriate. Overall, the Mil-STD test methods outlined in Table 3 are still relevant, and the evolving improvements make MIL-STD-461G suitable for endorsement in the next revision of RG 1.180.

3. BASIS FOR ENDORSING NEW STANDARDS

3.1 SCOPE

In addition to comparing the standards endorsed in Revision 1 of RG 1.180 with their updated versions, this study reviewed ESD and PQ standards for potential endorsement in the next revision of RG 1.180. The ESD standard reviewed was IEC 61000-4-2, and the PQ standards reviewed were 61000-4-11, 61000-4-14, 61000-4-17, 61000-4-28, 61000-4-29, and 61000-4-34. Review of the ESD standard was prompted by a cursory search of the Licensee Event Report database that found a small number of events over the past three decades that are attributed to ESD. The review of the PQ standards was prompted by requests from users of RG 1.180 for a clearer definition of “acceptable power quality requirements” as identified in the guide. Because PQ was reviewed as a single topic, one summary is provided for all of the PQ standards rather than a summary position for each PQ standard reviewed. Also, note that IEC 61000-4-18 (2011), “Testing and measurement techniques—Damped oscillatory wave immunity test,” was reviewed as a new standard issued after RG 1.180, Revision 1, was issued in 2003. The review of IEC 61000-4-18 (2011) was performed in conjunction with IEC 61000-4-12 (2006 vs 1995) and is discussed in Subsection 2.2.9 because of its close relationship as an offshoot of IEC 61000-4-12.

3.2 REVIEW OF NEW POTENTIALLY APPLICABLE STANDARDS

3.2.1 IEC 61000-4-2, “Testing and Measurement Techniques—Electrostatic discharge immunity test”

IEC 61000-4-2 describes immunity requirements for electrical and electronic equipment subjected to static electricity discharges, i.e., the sudden transfer of charge between two objects at differing electrostatic potential. It addresses the test levels, setup, equipment, and procedures for testing electrical and electronic equipment to ensure their immunity to ESD.

The test voltage to be applied depends on the environment and installation conditions. The preferred range of test levels for the ESD test is given in Table 1 of the standard and is reproduced as Table 14 in the current report. In the table, “contact discharge” refers to the “method of testing in which the electrode of the test generator is kept in contact with the EUT or coupling plane and the discharge is actuated by the discharge switch within the generator.” By contrast, “air discharge” refers to the “method of testing in which the charged electrode of the test generator is moved towards the EUT until it touches the EUT.” The term “level” refers to the environment and installation conditions, with the highest bounding levels for industrial environments specified as 8 kV for direct contact discharge and 15 kV for indirect air discharge. These conditions correspond to environments with very low humidity and extensive use of synthetic fabrics (which promote generation of higher electrostatic charges by personnel).

It is noted that MIL_STD_461G added a new test method, CS118, to address ESD. This test method is similar to IEC 61000-4-2. However, the MIL-STD test method was not further evaluated for endorsement because the commercial standard adequately addressed the issue. Given the long history and stability of IEC 61000-4-2 compared to the limited experience with CS118, endorsement of the commercial standard was deemed sufficient.

A review of whether ESD testing should be included in the revised RG 1.180 is included in the letter report “Task 4—EMI/RFI Issues Potentially Impacting Electromagnetic Compatibility of I&C Systems” [2]. The recommendation was that the highest level (i.e., level 4) identified for test limits in the standard could serve as a conservative bound for industrial environments, which would include facilities like power plants. Since the appropriate focus for regulatory guidance should be centered on discharges that may occur during normal operation, the test points should be based on accessibility. For example, human-machine interface (HMI) components such as panel displays, keyboards, and control/input devices are touched frequently during operational activities and thus should be tested. Specifically, touch points of all HMI equipment that are electrically isolated from ground should be tested. Cables that are accessible during normal operations or are in close proximity to HMI touch points should be tested at their entry points to equipment or cabinets.

Based on the previous review, it was concluded that the tests should be performed for safety I&C equipment but optional for electrical and I&C equipment related to power production and/or non-safety equipment. In all cases, the equipment should be tested at the Level 4 test limits.

Table 14. Test limits based on the environment in which the equipment will normally be located (reproduced from Table 1 of IEC 61000-4-2)

Contact discharge		**Air discharge**	
Level	Test voltage (kV)	Level	Test voltage (kV)
1	2	1	2
2	4	2	4
3	6	3	8
4	8	4	15
X*	Special	X*	Special
*“X” can be any level. The level shall be specified in the dedicated equipment specification. If higher voltages than those shown in the table are specified, special test equipment may be needed.			

3.2.2 Power Quality Standards

3.2.2.1 IEC 61000-4-11, “Testing and Measurement Techniques—Voltage dips, short interruptions and voltage variations immunity tests.”

IEC 61000-4-11 defines the immunity test methods and the range of preferred test levels for voltage dips, short interruptions, and voltage variations in electrical and electronic equipment connected to LV power supply networks. The standard applies to electrical and electronic equipment having a rated input current not exceeding 16 A per phase. It does not apply to electrical and electronic equipment for connection to DC networks or 400 Hz AC networks.

Tables 1 and 2 in Section 5.1 of the standard describe the preferred test levels and durations for voltage dips and short interruptions. These tables are reproduced as Table 15 and Table 16 below. Note that in the tables, “Class” refers to the electromagnetic environment in which the equipment normally operates. The various classes are defined in Annex B of the standard. In particular, the classes are defined as follows:

- Class 1 environments apply to protected power supplies and equipment in environments that are sensitive to disturbances in the public utility supply and therefore are typically protected by such apparatus as uninterruptible power supplies (UPS), filters, or surge suppressors.

- Equipment in Class 2 environments is “compatible” with the normal utility supply and does not require protection as does Class 1 equipment. Therefore “components designed for application in public networks may be used in this class of industrial environment.”

- Class 3 equipment has higher compatibility levels than that in Class 2 for some disturbance phenomena. Such equipment includes welding machines, large motors that are frequently started, and (large) loads that vary rapidly.

Table 15. Preferred test levels and durations for voltage dips

(Reproduced from Table 1 of IEC 61000-4-11 (2004))

Class	Test levels and durations for voltage dips (t_s) (50 Hz/60 Hz)				
Class 1	Case-by-case according to the equipment requirements				
Class 2	0% during ½ cycle	0% during 1 cycle	70% during 25/30c cycles (“25/30 cycles” means “25 cycles for 50 Hz test” and “30 cycles for 60 Hz test”)		
Class 3	0% during ½ cycle	0% during 1 cycle	40% during 10/12c cycles	70% during 25/30c cycles	80% during 250/300c cycles

Table 16. Preferred test levels and durations for short interruptions

(Reproduced from Table 2 of IEC 61000-4-11 (2004))

Class	Test levels and durations for short interruptions (t_s) (50 Hz/60 Hz)
Class 1	Case-by-case according to the equipment requirements
Class 2	0% during 250/300c cycles
Class 3	0% during 250/300c cycles

3.2.2.2 IEC 61000-4-14, “Testing and Measurement Techniques—Voltage fluctuation immunity test.”

IEC 61000-4-14 defines methods, limits, and setup procedures for testing the immunity of equipment to voltage fluctuations. The EUT is initially operated using a steady supply voltage and is then subjected to repetitive step voltage changes. Table 17 gives the test levels for the different initial voltages: U_n, U_n – 10% U_n, U_n + 10% U_n, where U_n is the nominal voltage.

The magnitude of the voltage steps is chosen as follows:

- **Class 1:** no test required.
- **Class 2:** ΔU = 8 % U_n, for equipment intended for connection to public networks or other lightly disturbed networks. This test level is specified for Class 2.
- **Class 3:** ΔU = 12 %U_n, for equipment connected to heavily disturbed networks (i.e. industrial networks). This test level is specified for Class 3.

The definition of “class” is the same as described in the previous subsection.

Table 17. Test levels from Table 1 of IEC 61000-4-14

Class	U_n	$U_{n\,-\,10\%}\,U_n$	$U_{n\,+\,10\%}\,U_n$
Class 1	No test required.		
Class 2	$\Delta U = \pm 8\%\ U_n$	$\Delta U = +8\%\ U_n$	$\Delta U = -8\%\ U_n$
Class 3	$\Delta U = \pm 12\%\ U_n$	$\Delta U = +I2\%\ U_n$	$\Delta U = -I2\%\ U_n$

3.2.2.3 IEC 61000-4-17, “Testing and Measurement Techniques—Ripple on DC input power port immunity test”

IEC 61000-4-17 defines the test levels, test waveforms, and test methods for immunity to ripple at the DC input power port of electrical or electronic equipment. The objective of the standard is to establish a common and reproducible basis for testing electrical and electronic equipment subjected to ripple voltages, such as those generated by rectifier systems and/or auxiliary service battery chargers overlaying on DC power supply sources.

Table 18 shows the preferred range of test levels applicable to the DC power supply port of the equipment. The test levels shown in the table are a peak-to-peak voltage expressed as a percentage of the nominal DC voltage. Appendix A.2, "Selection of the test level," of the standard states the following:

> *The selection of the test level should take into account the characteristics of the rectifier system and/or the possible operating conditions during the life cycle of the battery (normal life, wear-out period). The test levels listed… are not frequency dependent; however, the lower levels are generally representative of rectifier systems with a high number of rectifier units and consequently high-frequency ripples."*

Table 18. Test levels for IEC 61000-4-17

Level	Percentage of the nominal DC voltage
1	2
2	5
3	10
4	15
X	X

3.2.2.4 IEC 61000-4-28, "Testing and Measurement Techniques—Variation of power frequency, immunity test"

IEC 61000-4-28 describes immunity tests for electronic equipment subjected to variations of the power frequency. The standard notes that, in general, electrical and electronic equipment is not susceptible to minor variations of the power frequency. Testing according to this standard should therefore be limited to products that are assessed as being susceptible to power frequency variations by virtue of design, environment, or failure consequences.

3.2.2.5 IEC 61000-4-29, "Testing and Measurement Techniques—Voltage dips, short interruptions and voltage variations on DC input power port immunity tests"

IEC 61000-4-29 describes test levels, setup, and test methods for immunity to voltage dips, short interruptions, and voltage variations at the DC input power port of electrical or electronic equipment. The standard is applicable to LV DC power ports of equipment supplied by external DC sources. Note that the scope of this standard does not cover the ripple at the DC input power port. That phenomenon is covered by IEC 61000-4-17. (See subsection 3.2.2.3).

The following voltage test levels (in percentage of the rated voltage U_T) are used:

- 0%, corresponding to interruptions
- 40% and 70%, corresponding to 60% and 30% dips
- 80% and 120%, corresponding to ±20% variations

The change in the voltage is abrupt, in the range of µs. The preferred test levels and durations are given in Tables 1a, 1b and 1c of the standard and are reproduced in Tables 19 through 21 of this report.

Table 19. Preferred test levels and durations for voltage dips (Table 1a in IEC 61000-4-29)

Test	**Test level** $\%U_T$	**Duration** **(s)**
Voltage dips	0 and 70 or X	0.01 0.03 0.1 0.3 1 X

Table 20. Preferred test levels and durations for short interruptions (Table 1b in IEC 61000-4-29)

Test	**Test condition**	**Test level** $\%U_T$	**Duration** **(s)**
Short interruptions	High impedance and/or low impedance	0	0.001 0.003 0.01 0.03 0.1 0.3 1 X

Table 21. Preferred test levels and durations for voltage variations (Table 1c in IEC 61000-4-29)

Test	**Test level** $\%U_T$	**Duration** **(s)**
Voltage variations	85 and 120 or 80 and 120 or X	0.1 0.3 1.0 3.0 10 X

3.2.2.6 IEC 61000-4-34, "Testing and Measurement Techniques—Voltage dips, short interruptions and voltage variations immunity tests for equipment with mains current more than 16 A per phase"

IEC 61000-4-34 defines the immunity test methods and range of preferred test levels for voltage dips, short interruptions, and voltage variations in electrical and electronic equipment connected to LV power supply networks. The standard applies to electrical and electronic equipment having a rated mains current exceeding 16 A per phase.

3.2.3 General Conclusions for the Power Quality Standards

Based on the review of the scopes, requirements, and test levels for the PQ standards, it is concluded that these standards need not be endorsed for application in nuclear power plants. RG 1.180 provides guidance to ensure the electromagnetic compatibility of electrical and I&C equipment for (safety system) applications in nuclear power plants. IEEE 100 defines electromagnetic compatibility as "a measure of equipment tolerance to external electromagnetic fields." By contrast, it defines PQ as "the concept of powering and grounding electronic equipment in a manner that is suitable to the operation of that equipment and compatible with the premise wiring system and other connected equipment." The presumption here is that the PQ issues are handled by ***design guidance*** limits on voltage and frequency fluctuations and so on. For example, the US military has a separate standard for PQ, and it is not part of equipment qualification. Power is a design attribute and should be treated as an electrical system. Therefore, it is concluded that the PQ standards discussed in the preceding subsections should ***not*** be incorporated into the current guidance for evaluating electromagnetic compatibility. They are best treated in a separate regulatory guide on PQ.

4. COMPARISON WITH RELATED EMC DOCUMENTS

4.1 SCOPE

This section compares the EMC test methods, recommended in Sections 2 and 3 for inclusion in the technical basis for the revised regulatory guidance, with those endorsed in other related guidance for nuclear facilities, power plants, substations, and industrial locations. It does not include any of the PQ standards described in Section 3, as the recommendation is to treat PQ as a separate issue. In addition, it does not include a comparison of limits for the EMC test methods, in that those are established specifically for the nuclear power plant environment and discussed in Section 5.

4.2 RELATED EMC DOCUMENTS

The related EMC documents that were deemed most relevant for comparison with the guidance in RG 1.180 are EPRI TR-102323, Revision 4; IEC 62003, IEC 61000-6-5; and IEC 61000-6-7. [3–6] The titles of the comparison documents are listed in Table 22, and each is followed by a brief description.

Table 22. Related EMC guidance documents

Nomenclature	Title
EPRI TR-102323, Revision 4	Guidelines for Electromagnetic Compatibility Testing of Power Plant Equipment
IEC 62003	Nuclear Power Plants—Instrumentation and Control important to safety—Requirements for electromagnetic compatibility testing
IEC 61000-6-5	Electromagnetic Compatibility (EMC)—Part 6-5: Generic standards—Immunity for equipment used in power station and substation environments
IEC 61000-6-7	Electromagnetic Compatibility (EMC)—Part 6-7: Generic standards— Immunity requirements for equipment intended to perform functions in a safety-related system (functional safety) in industrial locations

Revision 4 of EPRI TR-102323 was prepared under the guidance of the EPRI EMC Working Group, consisting of members from PSEG, MPR Associates, Tennessee Valley Authority, Southern Nuclear, Exelon, Luminant, FPL, Washington Laboratories, AMS Corp., DNB Engineering, Areva, Alion Science, and ATC Nuclear. The working group developed a technical approach for immunity testing based on establishing bounding emission limits, based on plant measurements, and then using these bounds to establish immunity test limits that can be applied to new equipment in a test laboratory. They then drafted guidance on abatement techniques that would deter the adverse impact of EMI on the operation of sensitive electronic equipment. The working group also acted as technical reviewers for the EPRI report.

IEC 62003 establishes the requirements for EMC testing of I&C equipment supplied for use in systems important to safety in nuclear power plants. This standard lists the applicable IEC test standards that define the test methods and applicable test limits necessary to ensure that nuclear safety requirements are met. Its intent is limited to the testing of equipment before installation in a nuclear power plant to demonstrate immunity to electromagnetic disturbances.

IEC 61000-6-5 specifies the EMC immunity requirements that apply to electronics and electrical equipment intended for use in power stations and substations. It also covers installations that generate or convert their own electric power, as long as they are not directly connected to the LV power network. The standard defines the immunity test requirements needed to ensure that the functions and tasks of equipment and systems installed in power plants and substations can operate reliably under realistic electromagnetic conditions. It is a generic EMC immunity standard and should be considered when preparing or revising an EMC standard referring to specific products used in power stations and substations.

IEC 61000-6-7 is intended for use by suppliers when making claims about the immunity of equipment intended for use in safety-related systems in industrial locations. It should also be used by designers, integrators, installers, and assessors of safety-related systems to assess the claims made by suppliers. The standard defines the immunity test requirements for continuous and transient, conducted and radiated disturbances, including ESD. These requirements are applicable only to functions intended for use in functional safety applications.

4.3 COMPARISON OF TEST METHODS

Table 23 provides a recap of the test methods recommended in Sections 2 and 3. Comparisons of these recommended test methods with the different test methods called out in the related guidance documents are listed in Table 24. From Table 24, it can be seen that the recommended test methods are comprehensive in their treatment and coverage of the electromagnetic phenomena that might be incurred in power plants, particularly nuclear power plants. These phenomena include ESD, radiated and conducted disturbances, continuous wave and pulsed signals, representative type transients (e.g., electrically fast, oscillatory, damped), and both low- and high-frequency disruptions. Head-to-head comparisons show that the recommended test methods include all of the EMC test methods called out in EPRI TR-102323, Revision 4, as well as superset of the test methods called out in IEC 62003, IEC 61000-6-5 and IEC 61000-6-7.

Table 23. Recap of recommended test methods

Nomenclature	Title
61000-4-2	Electromagnetic compatibility (EMC)—Part 2: Testing and measurement techniques—Electrostatic discharge immunity test
61000-4-3	Electromagnetic compatibility (EMC)—Part 3: Testing and measurement techniques—Radiated, radio-frequency, electromagnetic field immunity test
61000-4-4	Electromagnetic compatibility (EMC)—Part 4: Testing and measurement techniques—Electrical fast transient/burst immunity test
61000-4-5	Electromagnetic compatibility (EMC)—Part 5: Testing and measurement techniques—Surge immunity test
61000-4-6	Electromagnetic compatibility (EMC)—Part 6: Testing and measurement techniques—Immunity to conducted disturbances, induced by radio-frequency fields
61000-4-8	Electromagnetic compatibility (EMC)—Part 8: Testing and measurement techniques—Power frequency magnetic field immunity test
61000-4-9	Electromagnetic compatibility (EMC)—Part 9: Testing and measurement techniques—Pulse magnetic field immunity test
61000-4-10	Electromagnetic compatibility (EMC)—Part 10: Testing and measurement techniques—Damped oscillatory magnetic field immunity test
61000-4-12	Electromagnetic compatibility (EMC)—Part 12: Testing and measurement techniques—Ring wave immunity test
61000-4-13	Electromagnetic compatibility (EMC)—Part 13: Testing and measurement techniques—Harmonics and Interharmonics, low frequency immunity test
61000-4-16	Electromagnetic compatibility (EMC)—Part 16: Testing and measurement techniques—Test for immunity to conducted, common mode disturbances in the frequency range 0 Hz to 150 kHz

Table 24. Comparison of test methods

Recommended test methods[a]	EPRI TR-102323	IEC 62003	IEC 61000-6-5	IEC 61000-6-7
61000-4-2	61000-4-2	61000-4-2	61000-4-2	61000-4-2
61000-4-3	61000-4-3	61000-4-3	61000-4-3	61000-4-3
61000-4-4	61000-4-4	61000-4-4	61000-4-4	61000-4-4
61000-4-5	61000-4-5	61000-4-5	61000-4-5	61000-4-5
61000-4-6	61000-4-6		61000-4-6	61000-4-6
61000-4-8	61000-4-8	61000-4-8	61000-4-8	61000-4-8
61000-4-9	61000-4-9	61000-4-9		
61000-4-10	61000-4-10	61000-4-10		
		61000-4-11	61000-4-11	61000-4-11
61000-4-12	61000-4-12	61000-4-12		
61000-4-13	61000-4-13	61000-4-13		
		61000-4-14		
61000-4-16	61000-4-16	61000-4-16	61000-4-16	61000-4-16
			61000-4-17	
	61000-4-18		61000-4-18	
		61000-4-28		
			61000-4-29	61000-4-29
			61000-4-34	61000-4-34

[a] Test method shown in red is a new recommendation.

5. ADJUSTMENTS TO LIMITS

Recommended adjustments to the EMC test limits (operating envelopes) for emissions and immunity testing are shown in Tables 25–30. Table 25 describes the emissions test methods and Table 26 describes the recommended changes in the emissions test limits. Note that these test methods and limits include both MIL-STD and IEC. Table 27 describes the susceptibility test methods and Table 28 describes the recommended susceptibility test limits. Table 29 describes the surge test methods and Table 30 describes the recommended changes in the surge test limits. Note that the changes in both the susceptibility and surge test limits include differentiating between power leads and signal leads when conducting testing. Also, the CE101 emissions test limits and the CS114 susceptibility test limits are adjusted based on a revised rationale developed in response to claims by some users that the current limits have proven to be overly harsh and difficult to satisfy. These adjustments are important, as the susceptibility and surge tests differ from the emissions tests in that they have the potential to damage equipment if overly prescribed. In turn, this could become an unnecessary cost to the plant user. The rationale for the changes is also included in the tables. These adjustments are expected to be made in the operating envelope plots for the revised RG 1.180; thus, no plots are shown here.

Table 25. Emissions test methods

Method	Description
CE101	Conducted emissions, low-frequency, 30 Hz to 10 kHz
CE102	Conducted emissions, high-frequency, 10 kHz to 2 MHz
RE101	Radiated emissions, magnetic field, 30 Hz to 100 kHz
RE102	Radiated emissions, electric field, 2 MHz to 1 GHz
IEC 61000-6-4	Conducted emissions, high-frequency, 150 kHz to 30 MHz
IEC 61000-6-4	Radiated emissions, electric field, 30 MHz to 1 GHz

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

Table 26. Emissions test limits

Origin	Type	Adjustment	Rationale
MIL-STD	CE101	Adopt MIL-STD-461G limit for aircraft equipment whose source voltage is 28V or less as new ac power limit	Review of MIL-STD-461G guidance determined that ac power limit tailored for submarines are overly conservative to address a power plant EM environment
MIL-STD	CE102	No change	
MIL-STD	RE101	No change	
MIL-STD	RE102	Change limit above 1 GHz to bound IEC and FCC limits (@ 1 GHz → 89.5 dBμV/m)	Bound IEC and FCC while incorporating limits above 1 GHz
IEC	61000-6-4 conducted	No change	
IEC	61000-6-4 radiated	Include limits for >1 GHz 1–3 GHz →76 dBμV/m peak @ 3m 3–6 GHz →80 dBμV/m peak @ 3m Also, convert limits for 30–230 MHz and 230 MHz –1 GHz to values measured at 10 m	Incorporate >1 GHz limits and show consistency with standard

Table 27. Susceptibility test methods

Method	Description
CS101	Conducted susceptibility, low frequency, 30 Hz to 150 kHz
CS114	Conducted susceptibility, high frequency, 10 kHz to 30 MHz
CS115	Conducted susceptibility, bulk cable injection, impulse excitation
CS116	Conducted susceptibility, damped sinusoidal transients,10 kHz to 100 MHz
RS101	Radiated susceptibility, magnetic field, 30 Hz to 100 kHz
RS103	Radiated susceptibility, electric field, 30 MHz to 1 GHz
61000-4-3	Radiated susceptibility, electric field, 26 MHz to 1 GHz
61000-4-6	Conducted susceptibility, disturbances induced by radio-frequency fields
61000-4-8	Radiated susceptibility, magnetic field, 50 Hz and 60 Hz
61000-4-9	Radiated susceptibility, magnetic field, 50/60 Hz to 50 kHz
61000-4-10	Radiated susceptibility, magnetic field, 100 kHz and 1 MHz
61000-4-13	Conducted susceptibility, low frequency, 16 Hz to 2.4 kHz
61000-4-16	Conducted susceptibility, low frequency, 15 Hz to 150 kHz

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

Table 28. Susceptibility test limits

Origin	Type	Adjustment	Rationale
MIL-STD	CS101	No change	
MIL-STD	CS114	New limit—per ORNL/SPR-2016/792 [7] (power and signal lines are the same limit)	Bound data and give relief (relaxation) where CS101 bounds data
MIL-STD	CS115	New limit—5A (test applies only to signal lines)	Corresponds to MIL-STD limit for both power and signal lines
MIL-STD	CS116	No change	Corresponds to limit for Air Force ground applications (prior MIL-STD versions)
MIL-STD	RS101	No change	
MIL-STD	RS103	No change	Same limit (140 dBμV/m) but extend limit to 10 GHz
IEC	61000-4-3	No change	Same limit (140 dBμV/m) but extend limit to 6 GHz
IEC	61000-4-6	No change (same for power and signal lines)	
IEC	61000-4-8	No change	
IEC	61000-4-9	No change	
IEC	61000-4-10	No change	
IEC	61000-4-13	No change (correct RG presentation of limits)	
IEC	61000-4-16	Make signal line test limit Level 3	Signal and power line limits are the same in standard

Table 29. Surge test methods

Method	Description
IEEE C62.41	Conducted susceptibility, electrically fast transients/bursts
IEEE C62.41	Conducted susceptibility, surges
IEEE C62.41	Conducted susceptibility, 100 kHz ring wave
61000-4-4	Conducted susceptibility, electrically fast transients/bursts
61000-4-5	Conducted susceptibility, surges
61000-4-12	Conducted susceptibility, 100 kHz ring wave

Table 30. Surge limits

Origin	Type	Adjustment	Rationale
IEEE	C62.41.2	Apply *Low* and *Medium Exposure* levels given in Table 22 of RG 1.180, Rev. 1 [to be identified as *Low* and *Elevated Withstand Levels*]	Limits given in Table 2 of C62.41.2 are overly conservative. Use *Low Withstand Level* for general applications and *Elevated Withstand Level* for lines with external connection or near sources of significant switching transients
IEC	61000-4-4	*Low Withstand Level*—Level 3; only special case for *Elevated Withstand Level*—Level 4 Signal line limit is ½ power line limit	Use *Low Withstand Level* for general applications and *Elevated Withstand Level* for lines with external connection or near sources of significant switching transients
IEC	61000-4-5	*Low Withstand Level*—Level 3; only special case for *Elevated Withstand Level*—Level 4 Signal line limit is same as power line limit	Use *Low Elevated Withstand Level* for general applications and *Elevated Withstand Level* for lines with external connection or near sources of significant switching transients
IEC	61000-4-12	*Low Withstand Level*—Level 3; only special case for *Elevated Withstand Level*—Level 4 Signal line limit one level lower than power line limit (Level 2)	Use *Low Withstand Level* for general applications and *Elevated Withstand Level* for lines with external connection or near sources of significant switching transients

6. ADDITIONAL GUIDANCE TOPICS

6.1 GENERAL TOPICS

6.1.1 Extension of Endorsement of Test Methods to Future Revisions

The most recent versions of the various EMC standards were reviewed for endorsement to enable updating of the current guidance. Specifically, the current consensus test methods and the associated criteria were compared against the test methods and criteria endorsed in RG 1.180, Revision 1. It was found in every case that the standards maintained a reasonable level of qualification assurance that was either consistent with or more conservative than the older endorsed versions. There were no instances in which the level of evidence was relaxed. This finding is consistent with the assessment of standards conducted to support the update from revision 0 to revision 1 of RG 1.180.

Given the rigorous process for revising consensus standards by IEC, IEEE, and the US Department of Defense, it is expected that future revisions of these standards will serve to further improve the clarity and fidelity of the guidance on EMC practices, test methods and associated criteria. Consequently, it is recommended that the endorsements of the standards in the pending revision of RG 1.180 be generalized to endorse the current version of each standard, rather than limit the endorsements to specific dated versions. Basically, the regulatory positions can refer to the appropriate standard without specifying a particular version. The guidance can clarify that the endorsements apply to the current versions.

Among the benefits to this approach are the reduction of burden on test laboratories, licensees, and vendors, as well as a reduction in the frequency with which the regulatory guide would need revision. Regarding the first point, testing labs are certified to be capable to test against the current versions of the test methods. Requiring that the labs maintain the capability to conduct tests in accordance with dated, superseded standards is a burden that adds cost to maintain equipment and expertise for special-purpose applications.

In addition, requiring testing against older versions of the standards adds some uncertainty, given that the revision of a test method generally clarifies the procedure and/or improves the repeatability of the test. In cases in which a standard evolves beyond the endorsed version, the licensee and vendor are faced with the choice of imposing the dated test method or having to develop a conformance justification to use the current test method. A primary motivation for revising RG 1.180 was to update endorsement of the EMC standards to the latest versions. Since this guide endorses a number of separate testing standards, it is likely that one or more of the standards will be updated in the near term. Thus, the regulatory guide will quickly become out of date for some of the consensus test methods if specific dated versions are required.

As noted, there is strict control over the update process for the endorsed EMC standards; therefore, it is reasonable to enact an endorsement strategy that adopts the current versions of the standards without limitation to specific revisions.

6.1.2 Application

EMC guidance is applicable to all new safety-related I&C systems or voluntarily initiated modifications of safety-related I&C systems. The technologies covered by this guidance include analog, digital, and hybrid systems and components (i.e., analog and digital electronics equipment). Existing installed systems and equipment are not required to undergo additional testing. The emissions control aspects of this guidance also apply to non-safety-related systems and components whose operation can affect safety-related system or component functions.

6.1.3 Test Configuration

To ensure that the test operating envelopes (limits) are being applied properly, equipment should be tested in a physical configuration that is representative of its actual installation. However, in lieu of requiring that every variation of cabinet configuration be tested, it is recommended that testing be performed on a bounding configuration that reasonably represents the worst-case interference exposure and/or emissions conditions. For example, a sparse configuration of modules in a cabinet might represent the bounding interference exposure condition (e.g., limited self-shielding among cards) for susceptibility testing. Conversely, a fully loaded configuration of modules in a cabinet might represent the bounding emissions condition for emissions testing. Therefore, testing should be performed with the EUT configured in a bounding configuration for the phenomena of interest (e.g., conducted or radiated emissions, conducted or radiated susceptibility, surge). A justification that the tested configuration reasonably bounds the expected worst case should be provided to document the basis for the configuration.

Additionally, all testing should be performed with the equipment operating in its normal mode and performing its intended function(s). For software-based systems, the system should have functioning software and diagnostics that are representative of those used in actual operation.

6.1.4 Surge Testing

The definitions of the waveforms in IEEE C62.41.2 are endorsed and the establishment of the test methods in IEEE C62.45 is endorsed. However, the limits given in Table 2 of C62.41.2 are overly conservative. The *Low* and *Medium Exposure* levels given in Table 22 of RG 1.180, Revision 1, should be applied. The terminology for different exposure levels should be adjusted to characterize the locations and limits as *Low Withstand Level* for general applications and *Elevated Withstand Level* for lines with external connection or near sources of significant switching transients.

6.2 EMISSIONS TESTING

6.2.1 Application

The emissions tests should be applied to all I&C equipment; i.e., emissions testing applies to non-safety-related I&C equipment/systems as well as safety-related I&C equipment/systems. This condition applies because emissions from non-safety-related equipment can compromise the bounds captured in the susceptibility operating envelopes and affect safety-related I&C systems. Therefore, emissions from all I&C systems should be determined and controlled.

6.2.2 Mixing and Matching

It is recommended that a limited, explicitly defined form of mixing and matching be permitted among emissions test methods from different standards. Emissions tests are passive in nature and do not affect the performance of the EUT. In addition, the specifics for measurement of one phenomenon or frequency band do not affect the measurement of another phenomenon or frequency band. Thus, there is no relaxation in the EMC guidance associated with allowing limited mixing and matching for emissions tests. The only significant issue relates to frequency range coverage, in that assurance is needed that the frequency ranges overlap when the test methods are mixed. The emissions test methods from specific endorsed standards, e.g., the MIL-STD and IEC methods, are designed to be complementary in frequency range coverage. If emissions test methods from different standards are used and full coverage of frequency ranges is not provided, then supplemental testing should be undertaken to address the gaps or justification for the omission of testing in any frequency range should be documented. Since the IEC standard does not provide for low-frequency emissions testing, the MIL-STD test methods should be applied for emissions testing in the low-frequency band unless test exemptions are justified. Specifically, the CE101 test should be performed to evaluate conducted emissions from 30 Hz to 10 kHz, the CE102 test should be performed across the lower range of its frequency band to evaluate conducted emissions from 10 kHz to 150 kHz, and the RE101 test should be performed to evaluate radiated emissions from 30 Hz to 100 kHz.

6.2.3 Testing Beyond 1 GHz

It is recommended that testing guidance for frequencies above 1 GHz be incorporated in the emissions testing position rather than being maintained as a separate position. Since IEC test methods now cover testing above 1 GHz, there is no particular reason why the emissions testing position should not cover the extended frequency band beyond 1 GHz.

For the high-frequency MIL-STD emissions test, the testing is applicable up to 10 times the highest generated frequency within the EUT, or 10 GHz. For the high-frequency IEC emissions test, testing is applicable for up to 5 times the highest generated frequency within the EUT or 6 GHz.

6.3 SUSCEPTIBILITY TESTING

6.3.1 Mixing and Matching

It is recommended that the prohibition against mixing and matching of susceptibility tests be maintained. Susceptibility testing is an active test that stresses the EUT, and the test methods for susceptibility were designed to be complementary in the application of stress to demonstrate immunity. For example, the RS-103 and CS114 tests permit frequency exemptions in the MIL-STD because the test methods provide complementary coverage of the susceptibility characteristic of interest. Hence, these methods should not be selectively applied but rather should be applied in their entirety.

6.3.2 Testing Beyond 1 GHz

Susceptibility testing is not required above the 10 GHz upper frequency for MIL-STD testing (6 GHz for IEC testing) because, unlike in military applications, there are no sensitive transmitters/receivers to protect (and thus no need to go to 18 or 40 GHz or higher frequencies as is the case for military applications). Additionally, the emissions strength generated from internal clocks in equipment should drop rapidly with distance so the contribution from those sources should be manageable. The upper frequency recommendation (6 to 10 GHz) is reasonable because it bounds unlicensed frequencies for personal transmitters. These are the sources of interference that drive the upper frequency bound for susceptibility testing.

7. CONCLUSIONS AND RECOMMENDATIONS

Comparative reviews of previously endorsed standards indicate, for the most part, that the current versions of the standards are suitable for endorsement with no exceptions or clarifications. There is, however, one exception: Table 2 in IEEE C62.41.2 (2002), titled "IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000V and Less) AC Power Circuits."

With regard to Table 2 in IEEE C62.41.2 (2002) (shown as Table 8 in this report), the exposure levels (low, medium, and high) that were in the 1991 version are eliminated, together with the test limits associated with those exposure levels (2, 4, and 6 kV, respectively). The 6-kV limit is imposed on all tests without regard to exposure level. This is overly conservative. The withstand levels discussed in RG 1.180, Revision 1, are based on Category B and Category C locations, along with Low Exposure and Medium Exposure levels. The regulatory guide now holds that a determination of the exposure level classification that characterizes a location is necessary to select the applicable withstand levels. This position should be maintained in the next revision of the regulatory guide.

One new potentially applicable standard was found to be complementary to the previously endorsed standards and are recommended for endorsement. It is IEC 61000-4-2, "Testing and Measurement Techniques—Electrostatic discharge immunity test.

A cursory search of the Licensee Event Report database found a small number of events over the past few years that can be attributed to ESD. A review was conducted and the recommendation was that IEC 61000-4-2 should be part of the regulatory guidance and required for safety I&C equipment, but optional for electrical and I&C equipment related to power production and/or non-safety equipment. In all cases, the equipment should be tested at the Level 4 limits, i.e., 8 kV for contact discharge and 15 kV for air discharge.

Based on the review of several PQ standards, it was concluded that these standards need not be endorsed for application in nuclear power plants as a part of EMC guidance. It is thought that RG 1.180 is focused on ensuring EMC among safety I&C equipment. The presumption is that the PQ issues are handled by design guidance limits on parameters like voltage and frequency fluctuations. Therefore, it was concluded that the reviewed PQ standards should not be incorporated into the current EMC guidance and would be best treated in a separate regulatory guide.

Endorsements of the standards in the pending revision of RG 1.180 should be generalized to endorse the current version of each standard, rather than limit the endorsements to specific dated versions. The regulatory positions can refer to the appropriate standard without specifying a particular version and the guidance can clarify that the endorsements apply to the current versions of the identified standards.

Head-to-head comparisons with related EMC guidance documents (EPRI TR-102323, IEC 62003, IEC 61000-6-5, and IEC 61000-6-7) show that the guidance scheduled for Revision 2 of RG 1.180 either meets or exceeds any other available guidance. In addition, adjustments were made to the test limits to make them more feasible for practical implementation.

Emissions tests should be applied to all I&C equipment, i.e., emissions testing applies to non-safety-related I&C equipment/systems as well as safety-related I&C equipment/systems. This condition applies because emissions from non-safety-related equipment can compromise the bounds captured in the EMC susceptibility operating envelopes and affect safety-related I&C systems.

A limited, explicitly defined form of mixing and matching should be allowed for emissions tests because they are passive in nature and do not affect the performance of the EUT. Essentially, the gap in low-frequency-band coverage by the IEC tests should be resolved by supplementary testing using MIL_STD-461G test methods. Specifically, the CE101 test should be performed to evaluate conducted emissions from 30 Hz to 10 kHz, the CE102 test should be performed across the lower range of its frequency band to evaluate conducted emissions from 10 kHz to 150 kHz, and the RE101 test should be performed to evaluate radiated emissions from 30 Hz to 100 kHz.

Equipment may be exempt from the conducted emissions tests if the PQ requirements of the equipment are consistent with the existing power supply, and design practices include PQ controls. Equipment may be exempt from the radiated emissions tests if equipment is not intended to be installed in close proximity to other equipment that are sensitive to magnetic fields.

For the high-frequency MIL-STD emissions test, the testing is applicable for up to 10 times the highest generated frequency within the EUT, or 10 GHz. For the high-frequency IEC emissions test, testing is applicable for up to 5 times the highest generated frequency within the EUT or 6 GHz.

Susceptibility testing is not required above the 10 GHz upper frequency for the MIL-STD test methods and 6 GHz for IEC test methods because, unlike in military applications, there are no sensitive transmitters/receivers to protect at higher frequencies.

Mixing and matching of susceptibility tests should not be allowed, since these are active tests that stress the EUT and were designed to be complementary in their applications.

To ensure that the test operating envelopes (limits) are being applied properly, equipment should be tested in a physical configuration that is representative of its actual installation, and that also reasonably bounds the worst-case interference exposure and emissions conditions. All testing should be performed with the equipment operating in its normal mode and performing its intended function(s).

Software-based systems should have functioning software and diagnostics that's representative of those used in actual operation.

8. REFERENCES

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