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**ELECTROMAGNETIC COMPATIBILITY,
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Technical Basis for Revision of Regulatory Guide (RG) 1.180 – Guidelines for Evaluating Electromagnetic and Radio-Frequency Interference (EMI/RFI) in Safety-Related Instrumentation and Control Systems (I&C)

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The information and conclusions presented herein are those of the authors and do not necessarily represent the views or positions of the U.S. Nuclear Regulatory Commission.



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Outline

- Status of RG 1.180
- Motivation for revision
- Overview of current guidance and specific regulatory positions in RG 1.180
- Proposed updates to Electromagnetic Compatibility (EMC) guidance
- Path forward



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Regulatory Guide 1.180 Status

Regulatory Guide (RG) 1.180,

- Endorses EMC standards for safety-related instrumentation and control systems
- History
 - Revision 0, published January 2000
 - Revision 1, published October 2003
- Revision project proceeding to update guidance



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Motivation for Revision

- NRC Regulatory Guide periodic review policy – 10 years (RG 1.180, Revision. 1 was issued in 2003)
- Industry guidance has been updated
 - Electrical Power Research Institute (EPRI) has issued Revision 4 to TR 102323
- Referenced Standards have been revised
 - Issuance of Military Standards MIL-STD-461G (RG endorses MIL-STD-461E test methods)
 - Updates to Institute of Electrical and Electronics Engineers (IEEE) Std 1050 (grounding and shielding)
 - Updates to IEEE Std C62.45 (surge testing)
 - Updates to International Electrotechnical Commission (IEC) 61000 test methods
 - Issuance of IEC 62003 (new, nuclear-power-specific EMC standard)
- Resolve technical issues
 - Conducted Susceptibility (CS)-114 test envelopes
 - Increased use of wireless technology
 - New issues?



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The Current RG 1.180 Endorses Electromagnetic Compatibility Standards for Safety-Related I&C Systems

- Describes design, installation, and implementation practices to evaluate and minimize the impact of EMI/RFI and power surges on I&C systems
 - Scope covers analog, digital and hybrid equipment
 - Addresses emissions, susceptibility, and surge withstand testing
 - Describes grounding and shielding practices
- Applies to new or modified safety-related I&C equipment in existing and future nuclear power plants
- Technical basis is well documented
 - Enhanced basis for Revision 1 given in NUREG/CRs 5609 and 6782
 - Basis for initial guide given in NUREG/CRs 5941, 6431, and 6436



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RG 1.180 Employs U.S. Military and Industrial Experiences to Establish a Systematic Approach for EMC and Offers Option for International Standard

- Endorses commercial standards for design and installation practices
 - Grounding and shielding of I&C equipment (IEEE Std 1050)
- Endorses well-established testing standards
 - Power surge withstand (IEEE Stds C62.41 and C62.45 and IEC 61000)
 - Electromagnetic emission and susceptibility requirements for the control of EMI/RFI and test methods to demonstrate compliance (MIL-STD 461 and IEC 61000)
 - Tailored test limits (operating envelopes) to conditions found in nuclear power plants and industrial sites
 - Allows exemption of some test criteria under certain conditions based on technical considerations



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Current Regulatory Positions of RG 1.180 (Revision 1)

- Position 1 outlines elements of systematic EMC program
- Position 2 endorses design and installation practices [IEEE 1050]
- Position 3 endorses emissions tests [MIL-STD, IEC 61000-6, and Federal Communications Commission (FCC) Part 15] and specifies operating envelopes
- Position 4 endorses susceptibility tests [MIL-STD and IEC 61000-4] and specifies operating envelopes
- Position 5 endorses power surge withstand tests [IEEE C62.41 and IEC 61000-4] and specifies operating envelopes
- Position 6 endorses MIL-STD emissions and susceptibility tests and operating envelopes for testing above 1 Giga Hertz (GHz)
- Position 7 specifies EMC documentation that should be captured and maintained



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Position 1 Outlines the Elements of a Systematic EMC Program for Safety-Related I&C Systems

- Design and installation practices to limit the impact of electromagnetic effects
- Testing practices to assess the emissions of equipment and their susceptibility to EMI/RFI
- Testing practices to evaluate the power surge withstand capability of equipment
- Test limits characteristic of the electromagnetic environment in nuclear power plants
- Administrative controls for portable emitters



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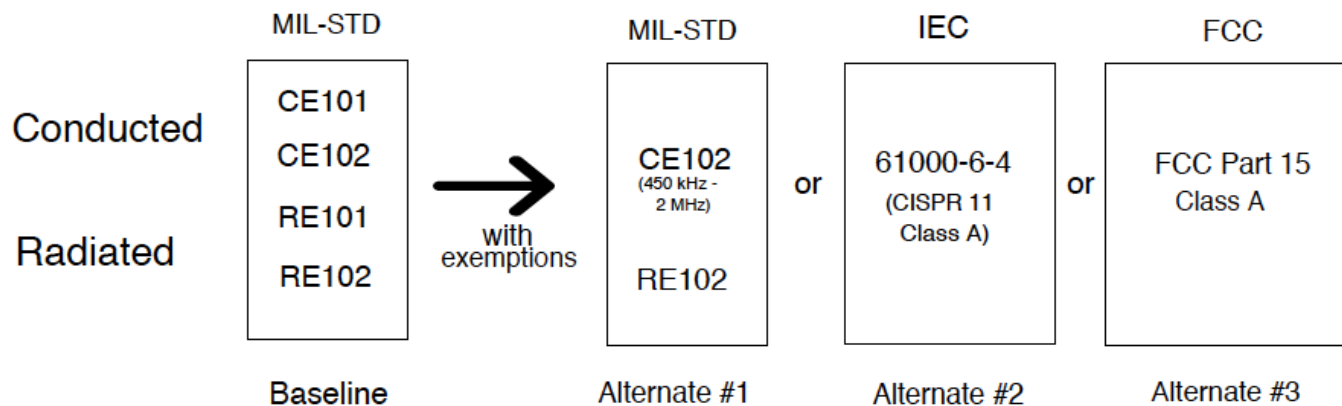
Position 2 Endorses Design and Installation Practices in IEEE Std 1050-1996 With One Exception

- Provides guidance on engineering practices needed to minimize the potential impact on safety-related I&C systems exposed to EMI/RFI and power surges
- Addresses grounding and noise-minimization techniques in a generating station environment
- Exception taken to Section 4.3.7.4 on radiative coupling concerning inaccurate characterization of field strength attenuation with distance



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Position 3 Endorses EMI/RFI Emissions Tests from MIL-STD 461E, IEC 61000-6, and FCC Part 15, Along With Associated Test Limits



- CE101 exemption is allowed if power quality control is employed
- RE101 exemption is allowed for equipment not intended to be installed in the proximity of magnetic field emitters



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Position 4 Endorses EMI/RFI Susceptibility Tests from MIL-STD 461E and IEC 61000-4, Along With Associated Test Limits

| | Baseline MIL-STD | | Alternate IEC | |
|-----------|--|---|---|--|
| | Power | Signal | Power | Signal |
| Conducted | <div style="border: 1px solid black; padding: 5px;"> CS101 CS114 </div> | <div style="border: 1px solid black; padding: 5px;"> CS114 CS115 CS116 </div> | <div style="border: 1px solid black; padding: 5px;"> 61000-4-6 61000-4-13 61000-4-16 </div> | <div style="border: 1px solid black; padding: 5px;"> 61000-4-6 61000-4-16 61000-4-4 61000-4-5 61000-4-12 </div> |
| Radiated | <div style="border: 1px solid black; padding: 5px;"> RS101(*) RS103 </div> | | <div style="border: 1px solid black; padding: 5px;"> 61000-4-8(*) 61000-4-9(*) 61000-4-10(*) 61000-4-3 </div> | |

(*) Exemption based on proximity to magnetic field emitters



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Position 5 Endorses IEEE Std C62.41 and IEC 61000-4 Power Surge Withstand Capability (SWC) Tests, Along With Their Associated Test Limits

- IEEE Std C62.41 Ring Wave or IEC 61000-4-12
 - Simulates high-frequency oscillatory surges
- IEEE Std C62.41 Combination Wave or IEC 61000-4-5
 - Two exponential waveforms
 - open-circuit voltage
 - short-circuit current
 - Represents direct lightning discharges, fuse operation, or capacitor switching
- IEEE Std C62.41 Electrically-Fast Transients or IEC 61000-4-4
 - Emulates local load switching



Position 6 Endorses MIL-STD 461E Testing Above (GHz)

- Radiated Emission (RE)102 test is applicable above 1 GHz for up to 10 times the highest intentionally generated frequency within the equipment under test
- Radiated Susceptibility (RS)103 test is applicable in the frequency range 1 GHz to 10 GHz, covering the unlicensed frequency bands where much of the high-frequency communications activity is taking place (2.45 GHz and 5.7 GHz)



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Position 7 Identifies EMC Documentation That Should be Captured and Maintained

- Documentation should provide evidence that
 - Safety-related I&C equipment meets its specification requirements and is compatible with the projected electromagnetic environment,
 - Acceptable installation practices are employed and maintained, and
 - Administrative controls have been established covering the allowable proximity of portable EMI/RFI sources
- Documentation should address
 - Identification of the equipment
 - Specifications for the equipment
 - Identification of safety functions to be demonstrated by test data
 - Test plan
 - Test results
 - Installation practices



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Potential Updates to RG 1.180 (Revision 2)

- Update endorsements to the latest version of each standard
- IEEE 1050 no longer needs an exception
- Add position on electrostatic discharge testing (IEC 61000-4-2)
- Guidance on testing above 1 GHz
 - Integrate position with Emissions and Susceptibility testing positions
 - Add IEC test methods as option



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Potential Updates to RG 1.180 (cont)

- Clarify applicability by explicitly stating
 - Emissions control also apply to non-safety-related systems and components whose operation can affect safety-related system or component functions
 - Additional testing is not required for existing installed systems and equipment
- Clarify guidance on test configuration
 - Software-based systems/equipment should be tested with functioning software and diagnostics that are representative of those used in actual operation



Potential Updates to RG 1.180 (cont)

- Clarify guidance on test configuration (cont)
 - Allow testing based on representative configuration rather than implied need to test every physical configuration
 - Test configuration should be based on bounding configuration that corresponds to the expected “worst case” interference exposure or emissions conditions
 - Justification that test configuration reasonably bounds the expected worst case conditions should be documented
 - As tested configuration should be documented to ensure that any EMC-specific configuration considerations can be implemented as part of installation, maintained, and controlled



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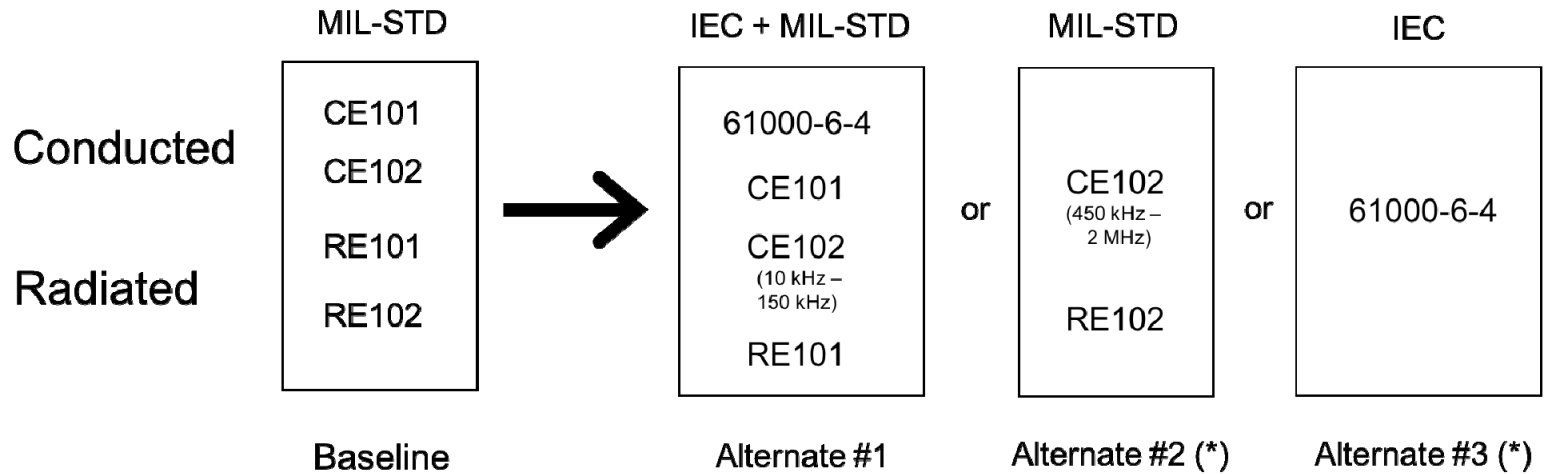
Potential Updates to RG 1.180 (cont)

- Revise position on emissions testing baseline and alternate test methods
 - Allow alternate with IEC testing for high-frequency emissions and MIL-STD testing for low-frequency emissions
 - No frequency gap permitted
 - IEC 61000-6-4 + MIL-STD RE101, CE101, and CE102 (from 10 kHz to 150 kHz)
 - Drop alternate based on FCC Class A certification and implied alternate based on The Comité International Spécial des Perturbations Radioélectriques (CISPR) 11 Class A certification
- Replace citation of CISPR 11 with CISPR 16 as IEC emissions test methods specified in IEC 61000-6-4



Potential Updates to RG 1.180 (cont)

Proposed Alternate Emissions Test Options



(*) with low-frequency test exemptions

- CE101 exemption is allowed if power quality control is employed
- RE101 exemption is allowed for equipment not intended to be installed in the proximity of magnetic field emitters



Potential Updates to RG 1.180 (cont)

- Revise guidance on surge withstand levels
 - Take exception to guidance on surge withstand limits in revised IEEE C62.41.2
 - Standard applies more conservative limit to all installation locations
 - Standard retains location categories A, B, C but drops exposure level distinctions (low, medium, high exposure)
 - Specify test limits consistent with RG 1.180, Rev. 1
 - Adapt terminology for exposure level from Medium Exposure to Elevated Exposure for signal line susceptibility and power line surge testing
 - Drop surge test limit for Category C locations (exterior locations are not in scope)

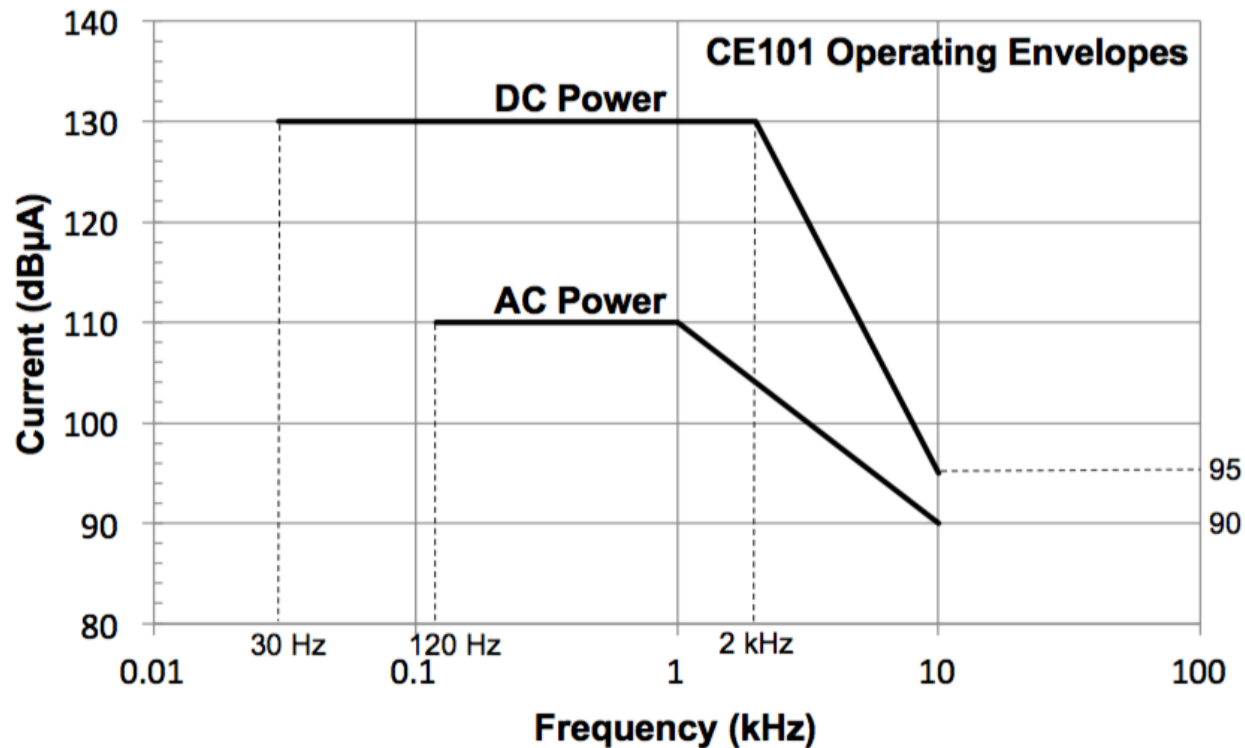


Potential Updates to RG 1.180 (cont)

- Revise test limits to reflect new analysis of data and revised rationale for applying MIL-STD basis
 - CE101 (basis for ac limit should be Aircraft rather than Submarine)
 - IEC 61000-6-4 (radiated emissions limit specified up to 6 GHz)
 - CS114 (relaxed based on overlap with Conducted Emission (CE)101)
 - Signal line susceptibility testing limits
 - CS114 (same as the power line limit)
 - CS115 (adopt standard limit rather than customized limit)
 - IEC 61000-4-5 (Level 3 for low exposure locations and Level 4 for special case elevated exposure locations)
 - IEC 61000-4-6 (Level 3 for low exposure locations)
 - IEC 61000-4-16 (Level 3 for low exposure locations)



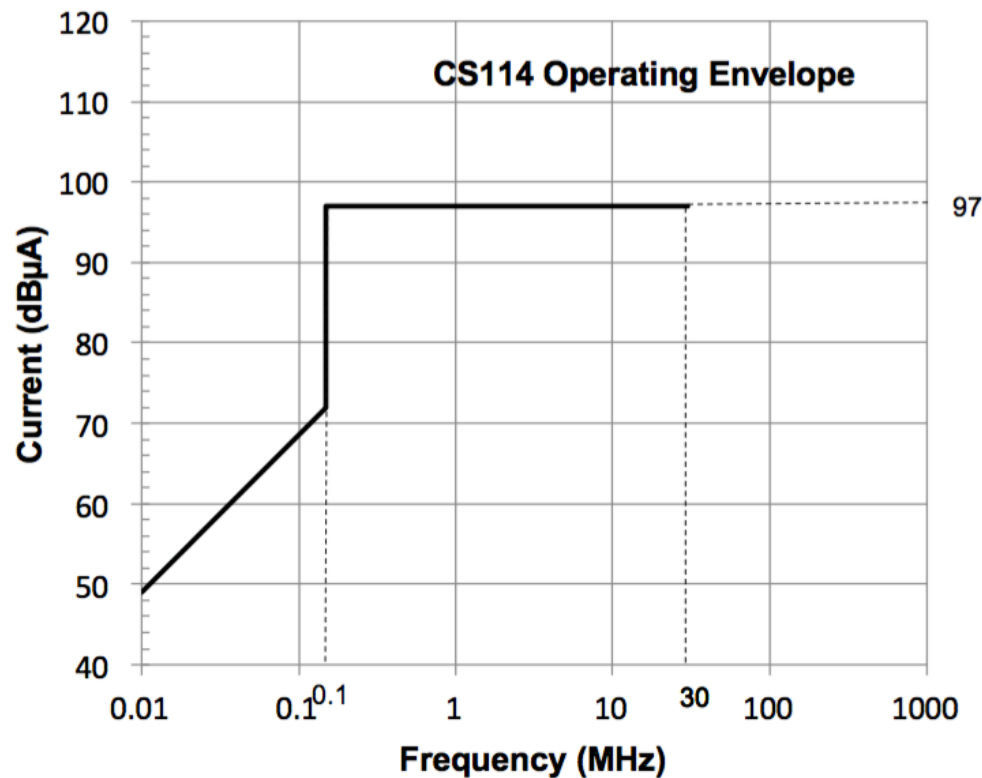
Proposed Low-Frequency Conducted Emissions (CE101) Test Limits





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Proposed High-Frequency Conducted Susceptibility (CS114) Test Limit





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Draft of Revised RG 1.180 has been Developed

- Technical Basis and Revision Recommendations have been submitted to NRC
- Draft guide (DG-1333) is undergoing review within NRC
- Once concurrence is achieved, DG-1333 should be released for public comment
- Current Estimated Schedule is around July, 2017



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Backup Slides



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Test Acceptance Criteria are Identified in Regulatory Positions

- Emissions
 - Level of emissions vs. frequency should not exceed levels of the test limits
- Susceptibility
 - At the applied level vs. frequency of the test limits, the equipment should not exhibit any malfunctions or degradation of performance beyond specifications
- Surge withstand
 - The equipment should not exhibit any malfunction or degradation of performance beyond specifications when the test pulse(s) are applied to the power lines



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Test Limits are Justified by a Well-Documented Technical Basis

- The technical basis for the test limits begins with MIL-STD limits for military ground facilities
- Review of military rationale indicates a few instances where some MIL- STD limits are too restrictive for nuclear power plants so the envelopes were tailored based on available evidence
- Test limits account for plant data from NRC/ORNL and EPRI measurements
- Industrial emissions limits (FCC and CISPR) are factored into test limits
- Comparable IEC test limits selected from standard classes



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Exemptions for Conducted EMI/RFI Tests are Given in Positions 3 and 4

- RG permits omission of low-frequency conducted emissions test based on power quality control (5% total harmonic distortion)
- RG exempts high-frequency conducted emissions test in low end of frequency range based on power quality control
- RG includes options for FCC or CISPR 11 Class A certification in lieu of high-frequency conducted emissions testing over a specified frequency range



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Exemptions for Radiated EMI/RFI Tests are Given in Positions 3 and 4

- RG permits omission of low-frequency radiated emissions test for equipment not intended to be installed in areas with other equipment that are sensitive to magnetic fields
- RG permits omission of magnetic-field susceptibility tests for equipment that is not intended to be installed in areas with strong magnetic field sources



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Status of EMC Standards

| Standard | Description | Issued | Updated |
|----------------|---|--------|---------|
| IEC 61000-4-3 | EMC Testing—Radiated RF/EM Field Immunity | 1995 | 2010 |
| IEC 61000-4-4 | EMC Testing—EFT/Burst Immunity | 1995 | 2012 |
| IEC 61000-4-5 | EMC Testing—Surge Immunity | 1995 | 2014 |
| IEC 61000-4-6 | EMC Testing—Immunity to Conducted Disturbances Induced by RF Fields | 1996 | 2013 |
| IEC 61000-4-8 | EMC Testing—Power Frequency Magnetic Field Immunity | 1993 | 2009 |
| IEC 61000-4-9 | EMC Testing—Pulse Magnetic Field Immunity | 1993 | 2001 |
| IEC 61000-4-10 | EMC Testing—Damped Oscillatory Magnetic Field Immunity | 1993 | 2001 |
| IEC 61000-4-12 | EMC Testing—Oscillatory Waves Immunity | 1996 | 2006 |



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Status of EMC Standards (cont)

| Standard | Description | Issued | Updated |
|-----------------|---|-----------------|--------------------------------|
| IEC 61000-4-13 | EMC Testing—Immunity to Harmonics and Interharmonics | 1998 | 2009 |
| IEC 61000-4-16 | EMC Testing—Immunity to Conducted CM, 0 Hz to 150 kHz | 1998 | 2011 |
| IEC 61000-6-4 | EMC Emissions for Industrial Environments | 1997 | 2006 |
| IEEE Std C62.41 | Surge Voltages in Low-Voltage AC Power Circuits | 1991 r. 1995 | 2002 |
| IEEE Std C62.45 | Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits | 1992 r. 1997 | 2002 |
| IEEE Std 1050 | Instrumentation and Control Equipment Grounding in Generating Stations | 1996 | 2004 |
| MIL-STD-461E | Control of Electromagnetic Interference Characteristics of Subsystems and Equipment | Issued 1999 | MIL- STD- 461G (2015) |



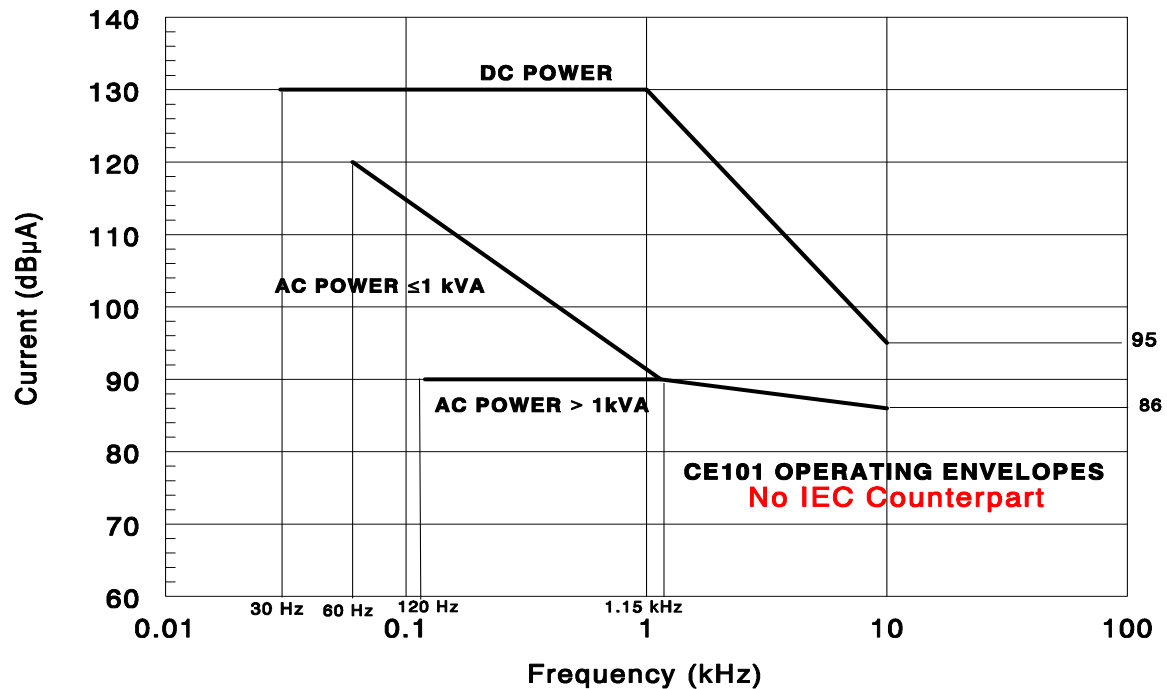
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Potential New Guidance Resources

| Standard | Description | Rationale |
|--------------------|---|---|
| EPRI TR-102323, r4 | Guidelines for Electromagnetic Interference Testing in Power Plants | Updated material |
| IEC 62003 | EMC Testing for I&C Important to Safety | Specific to NPPs |
| IEC 61000-2 Series | EM Environments and Compatibility Limits, -1 thru 13 | Characterization of EM environments |
| IEC 61000-4 Series | Additional EMC Testing and Measurement Techniques, -18 thru -35 | Damped oscillatory waves, test chambers, etc. |
| IEC 61000-5 Series | EMC Installation Practices, -1 thru -9 | Grounding and shielding practices |
| IEC 61000-6-5 | Immunity for Industrial Environments | Specific to power stations |
| IEC 61000-6-7 | Immunity for Industrial Environments | Addresses safety-related equipment |

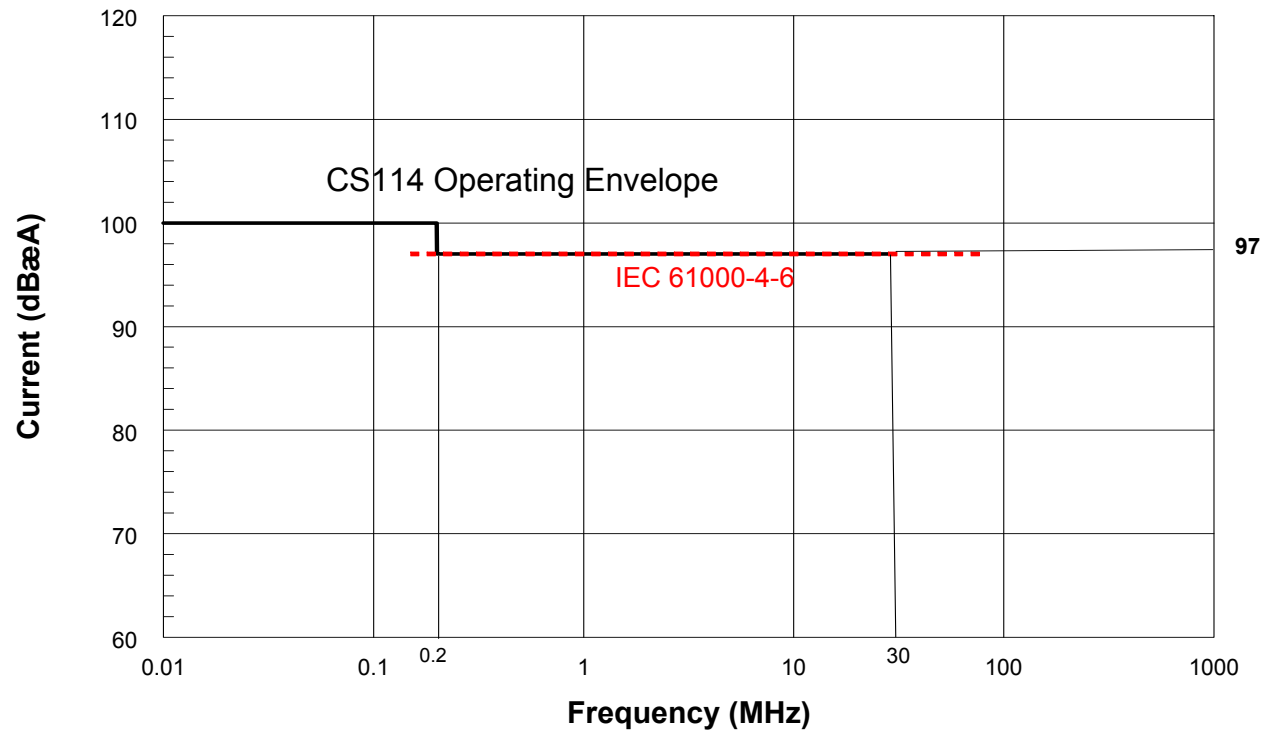


Current Low-Frequency Conducted Emissions (CE101) Test Limits



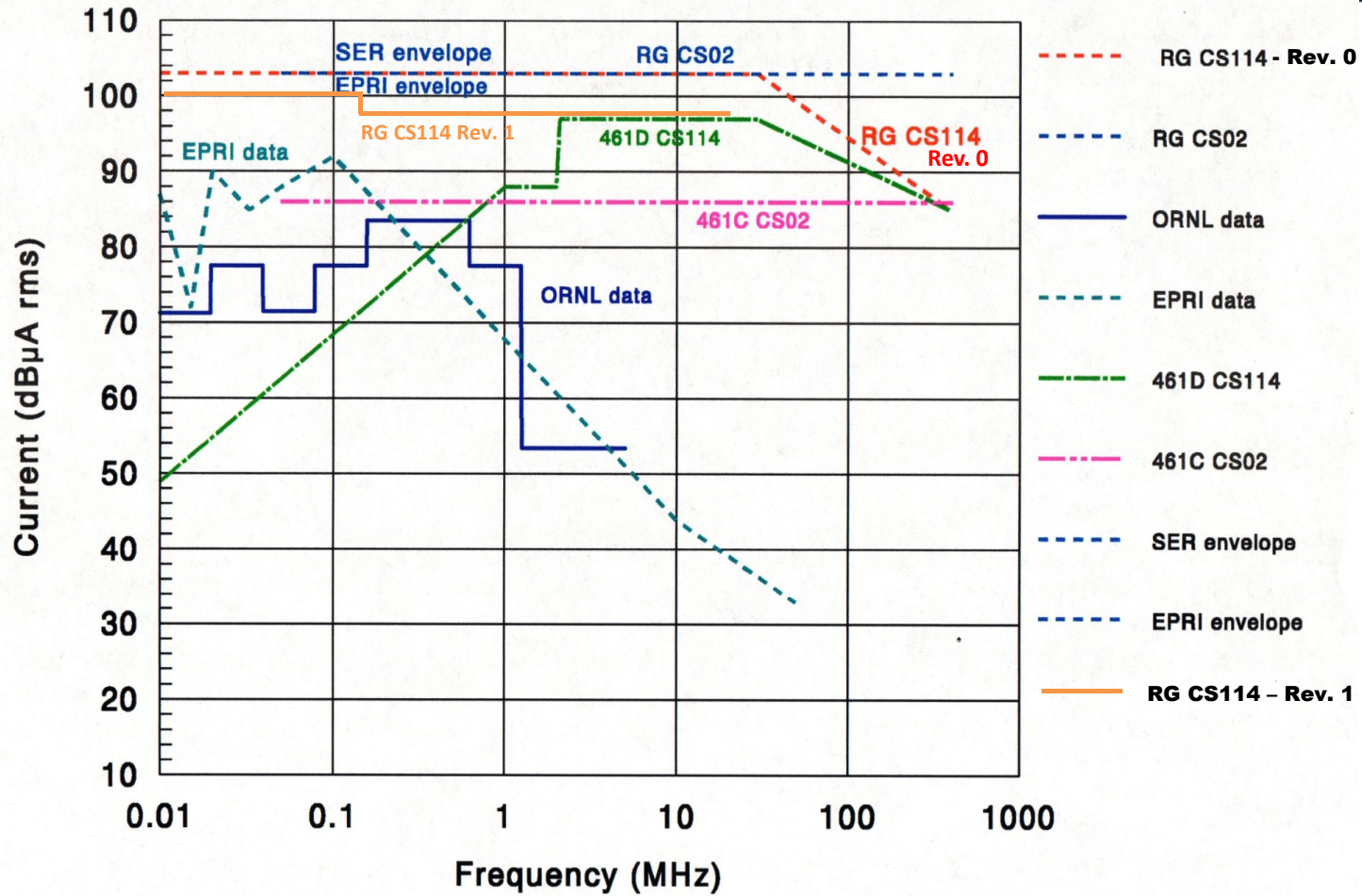


Current High-Frequency Conducted Susceptibility (CS114) Test Limits





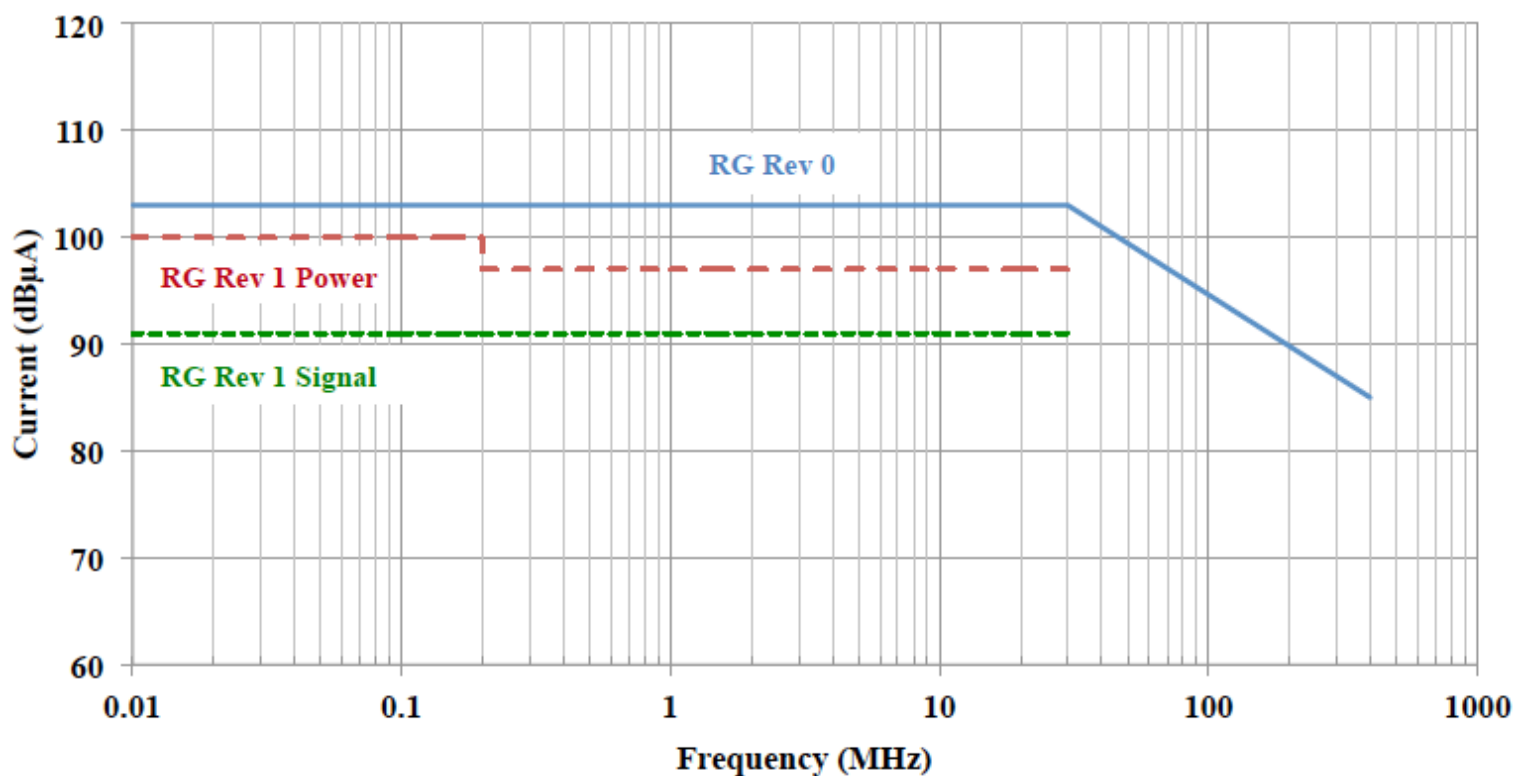
CONDUCTED SUSCEPTIBILITY, HIGH FREQUENCY





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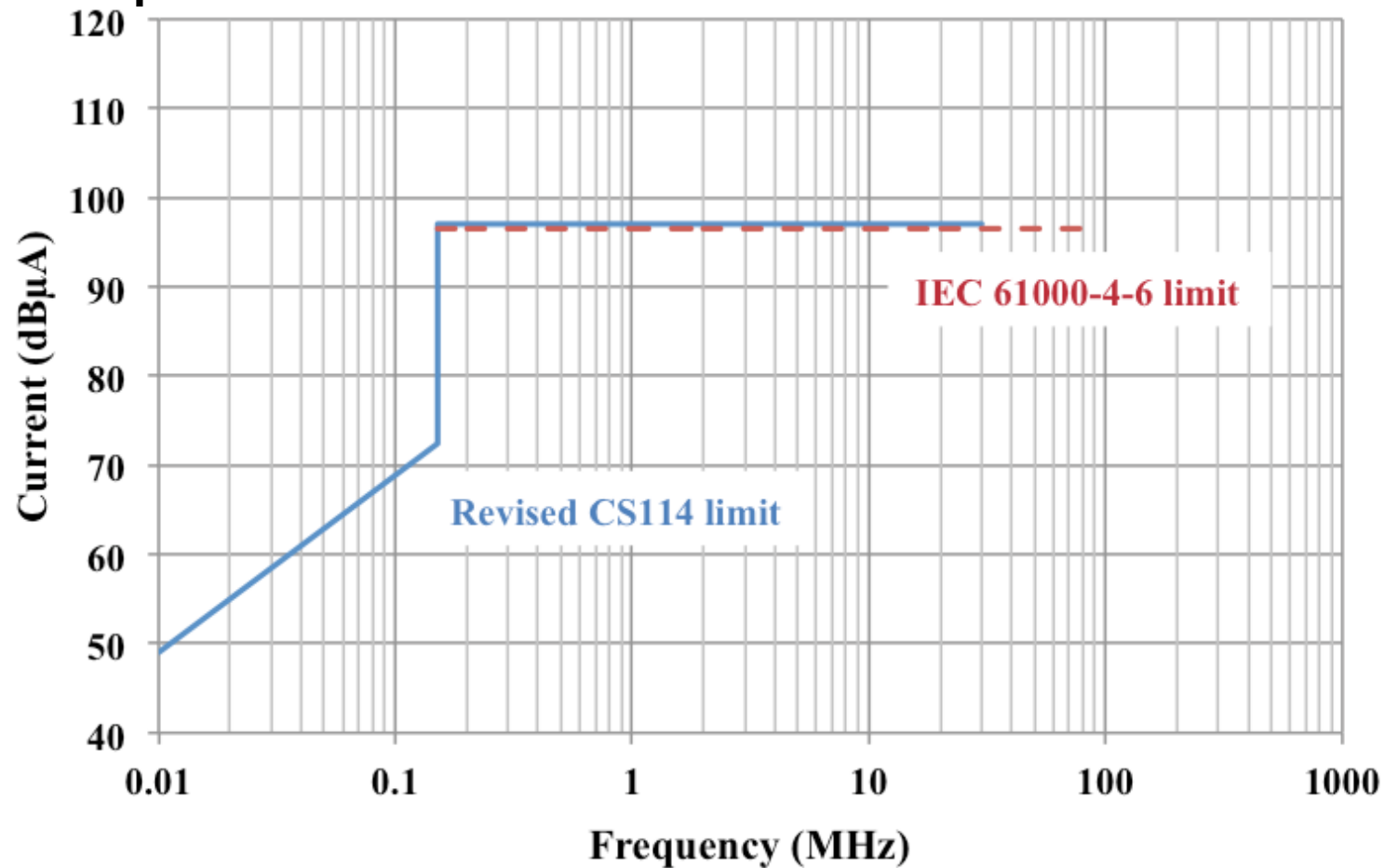
Evolution of CS114 Test Limit in RG





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Proposed Revision of CS114 Test Limit





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Coverage of Measured Data

