EMP and Its Impact on Electrical Power System: Standards and Reports

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Abstract: **The purpose of the given publication is to give to civil specialists the information on accessible standards and reports in the field of EMP/HEMP which they can use at an estimation of danger of EMP for the power electrical and electronic equipment and development of means of protection.**

Key words: **high altitude electromagnetic pulse, HEMP, EMP, geomagneticaly induced currents, GIC, intentional destructive electromagnetic impacts.**

The problem of intentional destructive electromagnetic impacts on electronic and electric equipment became apparent a few years after the USA conducted a series of nuclear test explosions coded "Operation Crossroads" on Bikini Atoll in the Marshall Islands (3800 km south-west of Hawaii) in 1946. During those test explosions a new physical phenomenon was discovered: the emergence of a powerful impulse of electromagnetic emission, encompassing an extensive area, which immediately caught the attention of military men. From 1958 until 1962 both the USA and the Soviet Union conducted a series of high burst tests (40 to 450 km) in order to investigate this phenomenon. It was revealed that the High Altitude Electromagnetic Pulse (HEMP) can destroy electronic equipment, communication systems, radio-stations and radar from a distance of thousands kilometers from the center of the explosion. At that time information about this phenomenon was kept quiet. Recently, however, it has become known that since the 1980s several countries started to put their efforts into the development of a so-called "super-EMP" nuclear weapon, where the EMP (electro-magnetic pulse) effect is significantly magnified compared to an ordinary nuclear weapon.

The problem of intentional destructive electromagnetic impacts on electrical power systems becomes recently more and more actual in connection with two modern trends: an extending application of microelectronics and microprocessor-based devices and systems in electric power industry - on the one hand, and intensive designs special equipment for distance destruction of electronic devices and systems - with another. The most powerful method for such destruction is the HEMP as a result of high-altitude nuclear explosion. The history of experimental high-altitude nuclear explosions includes already half a century. During this time many tens the scientific reports and standards in details presenting this phenomenon and measures of protection from it, have been published. But great part of these reports was not published widely and was not available for civilian engineers. Therefore, a civilian specialists working in the various technical sectors had no idea until recently about this phenomenon, or of the dangers that it posed (and some are still not aware even now).

Today, the most restricted before reports can be free downloaded from Internet, but the problem of civilian engineers is absence information about such reports and standards. Purpose of the article is informing civilian specialists in power engineering about lots of reports and standards which now available for use.

STANDARDS

1. Standards of International Electrotechnical Commission:

1.1 **IEC TR 61000-1-3** Electromagnetic compatibility (EMC) — Part 1–3: General—The effects of high-altitude EMP (HEMP) on civil equipment and systems.

1.2 **IEC 61000-1-5** High power electromagnetic (HPEM) effects on civil systems.

1.3 **IEC 61000-2-9** Electromagnetic compatibility (EMC)—Part 2: Environment—Section 9: Description of HEMP environment—Radiated disturbance. Basic EMC publication.

1.4 **IEC 61000-2-10** Electromagnetic compatibility (EMC)—Part 2–10: Environment—Description of HEMP environment—Conducted disturbance.

1.5 **IEC 61000-2-11** Electromagnetic compatibility (EMC)—Part 2–11: Environment—Classification of HEMP environments.

1.6 **IEC 61000-2-13** Electromagnetic compatibility (EMC)—Part 2–13: Environment—High power electromagnetic (HPEM) environments—Radiated and conducted.

1.7 **IEC 61000-4-23** Electromagnetic compatibility (EMC) - Part 4-23: Testing and measurement techniques - Test methods for protective devices for HEMP and other radiated disturbances.

1.8 **IEC 61000-4-24** Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 24: Test methods for protective devices for HEMP conducted disturbance - Basic EMC Publication.

1.9 **IEC 61000-4-25** Electromagnetic compatibility (EMC) - Part 4-25: Testing and measurement techniques - HEMP immunity test methods for equipment and systems**.**

1.10 **IEC 61000-4-32** Electromagnetic compatibility (EMC) – Part 4-32: Testing and measurement techniques – High-altitude electromagnetic pulse (HEMP) simulator compendium.

1.11 **IEC61000-4-33** Electromagnetic compatibility (EMC) – Part 4-33: Testing and measurement techniques – Measurement methods for high-power transient parameters.

1.12 **IEC 61000-4-35** Electromagnetic compatibility (EMC) - Part 4-35: Testing and measurement techniques - HPEM simulator compendium.

1.13 **IEC 61000-4-36** Electromagnetic compatibility (EMC) - Testing and measurement techniques - IEMI Immunity Test Methods for Equipment and Systems.

1.14 **IEC/TR 61000-5-3** Electromagnetic compatibility (EMC)—Part 5–3: Installation and mitigation guidelines—HEMP protection concepts.

1.15 **IEC/TS 61000-5-4** Electromagnetic compatibility (EMC)—Part 5: Installation and mitigation guidelines—Section 4: Immunity to HEMP—Specifications for protective devices against HEMP radiated disturbance. Basic EMC Publication.

1.16 **IEC 61000-5-5** Electromagnetic compatibility (EMC)—Part 5: Installation and mitigation guidelines—Section 5: Specification of protective devices for HEM conducted disturbance. Basic EMC Publication.

1.17 **IEC 61000-5-6** Electromagnetic compatibility (EMC) – Part 5-6: Installation and mitigation guidelines – Mitigation of external EM influences.

1.18 **IEC 61000-5-7** Electromagnetic compatibility (EMC) - Part 5-7: Installation and mitigation guidelines - Degrees of protection provided by enclosures against electromagnetic disturbances (EM code).

1.19 **IEC 61000-5-8** Electromagnetic compatibility (EMC) - Part 5-8: Installation and mitigation guidelines - HEMP protection methods for the distributed infrastructure.

1.20 **IEC 61000-5-9** Electromagnetic compatibility (EMC) - Part 5-9: Installation and mitigation guidelines - System-level susceptibility assessments for HEMP and HPEM.

1.21 **IEC 61000-4-36** Electromagnetic compatibility (EMC) - Testing and measurement techniques - IEMI Immunity Test Methods for Equipment and Systems.

2. Standard of Institute of Electrical and Electronics Engineers (IEEE)

2.1. **IEEE P1642** Recommended Practice for Protecting Public Accessible Computer Systems from Intentional EMI.

3. Standard of European Commission

3.1. **Topic SEC-2011.2.2-2** Protection of Critical Infrastructure (structures, platforms and networks) against Electromagnetic (High Power Microwave (HPM)) Attacks.

4. Military Standards of USA

4.1 **MIL-STD-2169B** High –Altitude Electromagnetic Pulse (HEMP) Environmental, 2012 (Classified).

4.2 **MIL-STD-188-125-1** High –Altitude Electromagnetic Pulse (HEMP) Protection for Ground Based C41 Facilities Performing Critical. Time-Urgent Mission. Part 1 Fixed Facilities, 2005.

4.3 **MIL-STD-188-125-2** High –Altitude Electromagnetic Pulse (HEMP) Protection for Ground Based C41 Facilities Performing Critical. Time-Urgent Mission. Part 2 Transportable systems, 1999.

4.4 **MIL-STD-461F** Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, 2007.

4.5 **MIL-STD-464C** Electromagnetic Environmental Effects. Requirements for Systems, 2010. Test Operations Procedure Report No. 01-2-620 High-Altitude Electromagnetic Pulse (HEMP) Testing.

4.6 **MIL-STD-1377** Effectiveness of Cable, Connector, and Weapon Enclosure Shielding and Filters in Precluding Hazards of Electromagnetic Radiation to Ordnance (HERO), 1971.

4.7 **MIL-HDBK-240** Hazards of Electromagnetic Radiation to Ordnance (HERO) Test Guide, 2002.

5. Standards of NATO

5.1 **NATO AECTP-500** Ed. 4. Electromagnetic Environmental Effects Test and Verification, 2011.

5.2 **NATO AECTP-250** Ed.2 – Electrical and Electromagnetic Environmental Conditions, 2011.

REPORTS

1. EMP Theory

1.1 Report DTIC ADA955391: Capabilities of Nuclear Weapons. Part 2. Damage Criteria. Change 1. Chapter 7. Electromagnetic Pulse (EMP) Phenomena. NNA EM-1 / P. J. Dolan. – Defense Nuclear Agency, 1978.

1.2 Report DTIC ADA059914: Effect of Multiple Scattering on the Compton Recoil Current. – Mission Research Corp. for Defense Nuclear Agency, 1978.

1.3 Report AFWL-TR-80-402: EMP Interaction: Principles, Techniques and Reference Data / K. S. H. Lee. - Air Force Weapons Laboratory, 1981.

1.4 Interaction Note 435: Interaction of High-Altitude Electromagnetic Pulse (HEMP) with Transmission Lines. An Early-Time Consideration / K. S. H. Lee, at al. – LuTech Inc., 1983.

1.5 Report DTIC ADB094426: A Guide to Nuclear Weapons Phenomena and Effects Literature / Kenneth E. Gould. – Defense Nuclear Agency, 1984. Unclassified in 1986.

1.6 Interaction Note 458: A Study of Overhead Line Responses to High Altitude Electromagnetic Pulse Environments / F. M. Tesche. – LuTech Inc., 1986.

1.7 Report ORNL/Sub/86-18417/1: A Nominal Set of High-Altitude EMP Environments / C. L. Longmire, R. M. Hamilton, J. M. Hahn. - Oak Ridge National Laboratory, 1987.

1.8 Report ORNL/Sub/85-27461/1: The Effects of Corona on Current Surges Induced on Conducting Lines by EMP: A Comparison of Experimental Data with Results of Analytic Corona Models / J. P. Blanchard, F. M. Tesche, and B. W. McConnell, Oak Ridge National Laboratory, 1987.

1.9 Report DTIC ADA234306: Comparison of the Frequency Spectra of HEMP and Lightning / M. A. Uman. – Defense Nuclear Agency, 1991.

2. Geomagneticaly Induced Currents and its Impact on Power System

2.1 Report ORML/Sub-83/43374/1/V3: Study to Assess the Effects of Magnetohydrodynamic Electromagnetic Pulse on Electric Power Systems / J. R. Legro, N. C. Abi-Samra, and F. M. Tesche. - Oak Ridge National Laboratory, 1985.

2.2 Report ORNL-6665: Electric Utility Industry Experience with Geomagnetic Disturbances / P. R. Barnes, D. T. Rizy, B. W. McDonell. - Oak Ridge National Laboratory, 1991.

2.3 High-Impact, Low-Frequency Event Risk to the North American Bulk Power System. - A Jointly-Commissioned Summary Report of the North American Electric Reliability Corp. and the U. S. Department of Energy's November 2009 Workshop. NERC, 2010.

2.4 Report Meta-R-322: Low-Frequency Protection Concepts for the Electric Power Grid: Geomagnetically Induced Current (GIC) and E3 HEMP Mitigation / J. Kappenman. - Metatech Corp., 2010.

2.5 Geo-Magnetic Disturbances (GMD): Monitoring, Mitigation and Next Steps. A Literature Review and Summary of the April 2011 NERC GMD Workshop. – North American Electric Reliability Corp. (NERC), 2011.

2.6 Effect of Geomagnetic Disturbances on the Bulk Power System and Electromagnetic Pulse Effect on the U. S. Power Grid / Thomas S. Popik. – Task Force on National and Homeland Security, 2012.

2.7 Report A2-304: Effects of Geomagnetically Induced Currents on Power Transformers and Power Systems / R.Girsis, V. Vedante, K. Gramm. – CIGRE, 2012.

2.8 Report A2-303: Behavior of Transformers Under DC/GIC Excitation: Phenomenon, Impact on Design / Design Evaluation Process and Modeling Aspects in Support of Design / T. Ngnegueu, F. Marketos, F. Devaux. – CIGRE, 2012.

2.9 Report LUTEDX/(TEIE-7242)/1-21/(2013): Geomagnetic disturbances and their impact on power systems / Olof Samuelsson. - Division of Industrial Electrical Engineering and Automation Faculty of Engineering, Lund University, 2013.

2.10 Report LUTEDX/(TEIE-5328)/1-062/(2014) GIC Distribution / Carlos David Fernández Barroso. - Division of Industrial Electrical Engineering and Automation Faculty of Engineering, Lund University, 2014.

3. EMP Impact on Power System

3.1 Report ORNL-4958: Power System EMP Protection, Final Report / H. Marable, P. R. Barnes, and D. B. Nelson. - Oak Ridge National Laboratory, 1975.

3.2 Report ORNL-4919: Effect of Nuclear Electromagnetic Pulse (EMP) on Synchronous Stability of the Electric Power System / R.W. Manweiler. – Oak Ridge National Laboratory, 1975.

3.3 Report DTIC ADA014489: Electromagnetic Pulse and Civil Preparedness. – Defense Civil Preparedness Agency, Washington, 1975.

3.4 Report ADA009228: Electromagnetic-Pulse Handbook for Electric Power Systems / Edward F. Vance. – Stanford Research Institute, 1975.

3.5 Report HCP/T5103-01: Impact Assessment of the 1977 New York City Blackout. – U. S. Department of Energy, Division of Electric Energy Systems, 1978.

3.6 Report NUREG/CR-3069: Interaction of Electromagnetic Pulse with Commercial Nuclear Power Plant / D. M. Ericson, D. F. Strawe, S. J. Sandberg, etc.- Sandia National Laboratories, 1983.

3.7 Report ORNL/Sub/82-47905/1: Electromagnetic Pulse (EMP) Interaction with Electrical Power Systems / H. W. Zaininger. - Oak Ridge National Laboratory, 1984.

3.8 Report ORNL-6033: Nuclear Electromagnetic Pulse (EMP) and Electric Power Systems / P.R. Barnes, E. F. Vance, and H. W. Askins. - Oak Ridge National Laboratory, 1984.

3.9 Report ORNL/Sub-84/73986/1: HEMP-Induced Transients in Transmission and Distribution (T and D) Lines / N. Engheta, K. S. H. Lee, F. C. Yang. - Oak Ridge National Laboratory, 1985.

3.10 Report ORNL/Sub/84-89643/1: Study for a Facility to Simulate High Altitude EMP Coupled Through Overhead Transmission Lines / D. Smith. - Oak Ridge National Laboratory, 1985.

3.11 Report ORNL/qub/84-89642/2: Design Concepts for a Pulse Power Test Facility to Simulate EMP Surges in Overhead Power Lines / R. Dethlefsen. - Oak Ridge National Laboratory, 1985.

3.12 Report ORNL/Sub/84-89642/1: Design Concepts for a Pulse Power Test Facility to Simulate EMP Surges in Overhead Power Lines: Part 1, Fast Pulse / A. Ramrus - Oak Ridge National Laboratory,1985.

3.13 Report ORNL/qub/84-89642/2: Design Concepts for a Pulse Power Test Facility to Simulate EMP Surges in Overhead Power Lines: Part 2, Slow Pulses / R. Dethlefsen. - Oak Ridge National Laboratory, 1986.

3.14 ORNL/Sub/83-43374/V1: Study to Assess the Effects of Electromagnetic Pulse on Electric Power Systems - Phase I Executive Summary / J. R. Legro, et al. - Oak Ridge National Laboratory, 1985.

3.15 Report ORNL/Sub/83-43374/V4: Study to Assess the Effects of Nuclear Surface Burst Electromagnetic Pulse on Electric Power Systems- Phase I Final Report / J. R. Legro, et al. - Oak Ridge National Laboratory, 1985.

3.16 Report ORNL/Sub/83-43374/1/VI: Study to Assess the Effects of High-Altitude Electromagnetic Pulse on Electric Power Systems- Phase I Final Report / J. R. Legro, et al. - Oak Ridge National Laboratory, 1986.

3.17 Report No. AST 88-2081: HEMP-Type Impulse Transfer Tests on High-Voltage Bushing Current Transformers at the Maxwell Laboratory / E. R. Taylor. - Westinghouse AST, 1988.

3.18 Report No. AST 88-7072: HEMP-Type Impulse Tests on High-Voltage Potential Transformers at the Maxwell Laboratory / E. R. Taylor. - Westinghouse AST, 1988.

3.19 Report DTIC ADA206952: The Effects of High-Altitude Electromagnetic Pulse (HEMP) on Telecommunications Assets. – National Communication System, 1988.

3.20 Report ORNL/Sub/88-02238/1: HEMP Test and Analysis of Selected Recloser -Control Units / T. K. Liu, et al. - Oak Ridge National Laboratory, 1989.

3.21 Report EP 1110-3-2: Engineering and Design - Electromagnetic Pulse (EMP) and Tempest Protection for Facilities. – Department of the Army, U. S. Army Corps of Engineers, 1990.

3.22 Report ORNL/Sub/83-43374/2: Impacts of a Nominal Nuclear Electromagnetic Pulse on Electric Power Systems / V. J. Kruse, D. L. Nickel, J. J. Bonk. - Oak Ridge National Laboratory, 1991.

3.23 Report ORNL/Sub/85-28611/2: Impact of Steep-Front Short-Duration Impulses on Power System Insulation / L. M. Burrage, ct. al. – Oak Ridge National Laboratory, 1991.

3.24 Report ORNL/Sub/83-43374/2: Impact of a Nuclear Electromagnetic Pulse on Electric Power Systems (Phase III, Final Report). - Oak Ridge National Laboratory, 1991.

3.25 Report CD-90-0014: An Assessment of the Electromagnetic Pulse (EMP) Effects on the U.S. Civilian Infrastructure - Unclassified Summary and Recommendations / P. Chrzanowski, J. Futterman. - Lawrence Livermore National Laboratory, 1992.

3.26 Report ORNL/Sub-88-SC863: HEMP-Induced Transients in Electric Power Substations (final report) / C. V. Wiggins, D. E. Thomas, T. M. Salas. - Oak Ridge National Laboratory, 1992.

3.27 Report ORNL/Sub-91-SG913/1: Recommended Engineering Practice to Enhance the EMI/EMP Immunity of Electric Power Systems / C. W. Wagner, W. E. Feego. - Oak Ridge National Laboratory, 1992.

3.28 Report ORNL-6708: Electromagnetic Pulse Research on Electric Power Systems. Program Summary and Recommendations / P. R. Barnes, B. W. McConell, J.W. Van Dyke. - Oak Ridge National Laboratory, 1993.

3.29 Report OPNL/Sub/91-SG105/1: HEMP Emergency Planning and Operating Procedures for Electric Power Systems / T. W. Reddoch, L. C. Markel. - Oak Ridge National Laboratory, 1993.

3.30 Report ORNL/TM - 1999/93: Assessment and Testing of Long-Line Interface Devices / P. R. Barnes, B. W. McConnell. - Oak Ridge National Laboratory, 2000.

3.31 Technical Manual TM 5-690: Grounding and Bonding in Command, Control, Communications, Computer, Intelligence, Surveillance and Reconnaissance (C41SR). – Headquarters Department of the Army, 2002.

3.32 Report for Congress RL32544: High Altitude Electromagnetic Pulse (HEMP) and High Power Microwave (HPM) Devices: Threat Assessments / Clay Wilson. - Congressional Research Service, 2008.

3.33 Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack. Critical National Infrastructures. – 2008.

3.34 Critical Infrastructure Strategic Initiatives Coordinated Action Plan. - Technical Committee Report. – North American Electric Reliability Corp. (NERC), 2010.

3.35 Report Meta-R-320: The Early-Time (E1) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the U.S. Power Grid / E. Savage, J. Gilbert, W. Radasky. – Metatech Corp., 2010.

3.36 Report Meta-R-321: The Late-Time (E3) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the U.S. Power Grid / J. Gilbert, J. Kappenman, W. Radasky, E. Savage. - Metatech Corp., 2010.

3.37 Report Meta-R-323: Intentional Electromagnetic Interference (IEMI) and Its Impact on the U.S. Power Grid / W. Radasky, E. Savage. - Metatech Corp., 2010.

3.38 Report Meta-R-324: High-Frequency Protection Concepts for the Electric Power Grid / W. Radasky, E. Savage. - Metatech Corp., 2010.

3.39 Strategy Research Project: Electromagnetic Pulse – A Catastrophic Threat to the Homeland / R. Oreskovic. – U. S. Army War College, 2011.

3.40 Report HC 1552: Developing Threats to Electronic Infrastructure. - House of Commons, Defence Committee, 2011.

3.41 Report HC 1552: Developing Threats Electro-Magnetic Pulses (EMP). – House of Commons, Defence Committee, 2012.

3.42 Report 5200.44: Protection of Mission Critical Functions to Achieve Trusted Systems and Networks (TSN). – U. S. Department of Defense, 2012.

3.43 Critical Infrastructure Protection Committee Strategic Plan. – North American Electric Reliability Corp. (NERC), 2012.

3.44 Report 3002000796: Electromagnetic Pulse and Intentional Electromagnetic Interference (EMI) Threats to the Power Grid: Characterization of the Threat, Available Countermeasures, and Opportunities for Technology Research. – Electric Power Research Institute (EPRI), 2013.

3.45 Report 113-85: Assured Microelectronics Policy. – U. S. Department of Defense, 2014.

3.46 E-Pro Report (International Electric Grid Protection) / Chris Beck. – Electric Infrastructure Security Council, 2013.

3.47 Report FM 3-38: Cyber Electromagnetic Activities. – Headquarters Department of the Army U. S., 2014.

3.48 Report of CIGRE C4.206 Working Group: Protection of High Power Network Control Electronics Against Intentional Electromagnetic Interference (IEMI). – CIGRE, 2014.

3.49 Report INL/EXT-15-35582: Strategies, Protections and Mitigations for the Electric Grid from Electromagnetic Pulse Effects. – Idaho National Laboratory (INL), 2016.