OVER THE HORIZON
MULTI-DOMAIN OPERATIONS & STRATEGY

Electromagnetic Pulse Threats to America's Electric Grid

Counterpoints to Electric Power Research Institute Positions

Executive Summary

The Electric Power Research Institute (EPRI) authored an April 2019 report titled**: "High-Altitude Electromagnetic Pulse and the Bulk Power System: Potential Impacts and Mitigation Strategies."** If US Government policymakers rely upon the methodology and conclusions of the EPRI report, effective high-altitude EMP protections will not be implemented, jeopardizing security of the US electric grid and other interdependent infrastructures.

Participants in the Electromagnetic Defense Task Force 2.0 (EDTF 2.0)[1] commend the work of EPRI and its supporting utilities for the testing of digital protective relays (DPRs) against ultrafast E1 high altitude electromagnetic pulses (HEMP). Readers should understand however, that if EPRI's report recommendations are to be followed, the ultimate result would be a US power grid with remaining vulnerabilities impacting large power transformers, generating equipment, communication systems, data systems, and microgrid designed for emergency backup power.

EPRI's effort draws conclusions about the survivability of the complete electric grid based on a limited assessment of the transmission grid only, omitting attention to the other two main grid sectors: generation and distribution. Furthermore, EPRI's assessment of the transmission grid focuses on transformers and digital protective relays and does not take into consideration the vulnerability of other essential electronic systems necessary for transmission grid communication and control.

To be sure, the protective relays tested by EPRI are an important component of the electric grid since they take transmission lines out of service to prevent equipment damage during grid disturbances. Therefore, EPRI's testing does further the industry's understanding of HEMP

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[1] Maj David Stuckenberg, Amb. R. James Woolsey, Col Douglas DeMaio, "Electromagnetic Defense Task Force 2.0," LeMay Paper No. 4, Air University Press, August 2019, https://www.airuniversity.af.edu/Portals/10/AUPress/Papers/LP_0004_ELECTROMAGNETIC_DEFENSE_TASK_FORCE_2_2019.PDF

effects on DPRs. However, while some test results among EPRI and recent Defense Threat Reduction Agency (DTRA) supported studies are consistent, the EPRI test results are inconsistent with those published by the Congressional Electromagnetic Pulse (EMP) Commission.

When the Congressional EMP Commission tested protective relays, it found upsets and damage at 3-5 kV injected, indicating significantly more relay sensitivity to HEMP than tests conducted by EPRI. Those tests found relay malfunctions at 15 to 80 kV injected. EPRI did not disclose the relay manufacturers and models tested, nor did EPRI analyze relay populations by model used within the US electric grid. Because of the discrepancy between the EMP Commission's test results and EPRI's test results, EPRI may have significantly underestimated the number of malfunctioning or destroyed relays during a HEMP attack.[2]

Notwithstanding these differences in test results, the EPRI-sponsored testing does indicate the need for cost-effective E1 HEMP protections for the electric grid and other infrastructures. Still, More relay testing and more research on relay populations is needed to accurately predict HEMP effects on the electric grid. EPRI did not adequately assess relay responses over the time period from the beginning of the E1 (early) pulse to the end of the E3 (late) pulse. Additionally, EPRI's report does not address interdependencies between E1 and E3 impacts on essential generation, transmission and distribution equipment. EPRI also incompletely assessed the risks of cascading grid collapse due to widespread relay malfunctions.

To its credit, EPRI used a custom-built Marx generator to produce a voltage impulse that meets the waveform specifications of MIL-STD-188-125-1 and that had a maximum open circuit peak voltage of 80 kV. EPRI conducted injection testing of relays with an incident field of 50 kV/m, the standard adopted by the International Electrotechnical Commission (IEC), and even tested DPRs and at least six types of mitigation devices to the maximum open circuit peak voltage of 80 kV/m. EPRI's testing enables electric utilities better understand how these devices would react in a HEMP environment.

EPRI used a wide range of optimistic assumptions that downplay the threat of high-altitude EMP from the detonation of nuclear weapons over the United States. Despite having access to defense-conservative Department of Defense threat scenarios, EPRI used alternative Department

[2] In the early 2000s NERC recommended that the EMP Commission test protective relays and other power electronics. Relay tests performed under contract to the EMP Commission showed the onset of serious upsets and some damage around 3-5 kV injected, a factor of three lower than the 15 kV reported level for failure onset by EPRI in April 2019. As a result, the EPRI tests indicate significantly lower failure rates for the more than one million protective relays in the electric grid. For the EMP Commission-sponsored testing of protective relays and other power system electronics, see E. Savage, W. Radasky, J. Kappenman, J. Gilbert, K. Smith and M. Madrid, HEMP Impulse Injection Testing of Power System Electronics and Electrical Components, Metatech Corporation, Meta-R-225, December 2003.

of Energy scenarios that assume adversaries would detonate nuclear weapons at non-optimal altitudes, when the optimal altitudes are available in the open literature.

For example, rather than modeling an optimal burst height of 75 km for peak E1 field strengths, EPRI chose a non-optimal burst height of 200 km, lowering the peak E1 field strength by approximately 65 percent. Rather than modeling the optimal burst height of 150 km for peak E3B field strengths, EPRI used an Oak Ridge National Laboratory scenario to assume a burst height of 400 km, significantly lowering the peak E3B field strength. EPRI used a Los Alamos National Laboratory (LANL) scenario to assume a non-optimal burst height of 200 km, again significantly lowering the maximum E3B field strength. EPRI also assumed latitudes and longitudes for its detonation scenarios that are non-optimal for producing maximum HEMP fields in the Northern Hemisphere.

Additionally, the EPRI report implies that megaton class weapons are needed to cause serious HEMP effects, which is technically incorrect. Multiple high altitude nuclear detonation scenarios will amplify high-altitude EMP effects, but EPRI assumes that adversaries will conduct a HEMP attack with only one nuclear weapon.

EPRI scientists did not use the data and modeling most accurate for assessing high altitude EMP impacts at northern latitudes, including the Soviet high-altitude nuclear tests over Kazakhstan. EPRI had available but chose not to use the HEMP model and waveforms of the Congressional EMP Commission Report of July 2017 which were derived from this real-world Soviet data.[3] The Soviet data indicates that a peak E3 high-altitude HEMP threat of 85 V/km is possible over continental United States locations. The EPRI report relied instead on a DOE Laboratory (LANL) model that projected the late-time E3 peak field of approximately 35 V/m, which is just 41 percent of the peak field that the EMP Commission recommends for US critical infrastructures.

By avoiding the use of data from declassified Soviet EMP tests on the realistic E3 threat level EPRI was able to minimize numerical estimates of damaged grid equipment, including hard-to-replace high voltage transformers.

EPRI's optimistic assumptions and scenarios obtained from non-DOD sources allowed them to reach conclusions that do not accurately portray risks to the US electric grid. For example, EPRI's report states: "Based on the assumptions made in the assessments, it was estimated that approximately 5% of the transmission line terminals in a given interconnection could potentially

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[3] Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack, "Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack Executive Report," July 2017. All of the UNCLASSIFIED reports and documents of the EMP Commission and Commission Staff Reports are listed below and can be found here: http://www.firstempcommission.org/

have a DPR that is damaged or disrupted by the nominal E1 EMP environment, whereas approximately 15% could potentially be affected by the scaled E1 EMP environment.”

The EDTF disputes EPRI’s conclusion that potential loss of 5 percent of transmission line terminals is only a “moderate” concern. Protective relay damage and associated line terminal loss from realistic HEMP scenarios could be far greater, especially with a multiple-bomb EMP attack. Relay malfunction during a HEMP attack would likely cause other electric grid systems to fail, resulting in large-scale cascading blackouts and widespread equipment damage. Notably, E1 effects on protective relays are likely to interrupt substation self-protection processes needed to interrupt E3 current flow through transformers.

According to EPRI’s test results, a high-altitude EMP attack would cause relay malfunctions at thousands of points in the grid, simultaneously. Notably, large-scale grid blackouts have occurred in the past from single-point failures, such as the Northeast Blackout of 2003 which was caused by overgrown trees contacting electric transmission lines. According to the North American Electric Reliability Corporation (NERC) technical analysis of this blackout, it affected more than 70,000 megawatts (MW) of electrical load and left an estimated 50 million people without power. In contrast, EPRI’s report concludes that a HEMP attack on the same Eastern Interconnection would cause limited regional voltage collapses and affect roughly 40 percent of the electrical load lost in the 2003 blackout.[4] Experience with cascading collapse in the Eastern Interconnection shows EPRI’s finding to be optimistic in the extreme.

EDTF recommends that the EPRI report, heavily dependent on theoretical analysis and optimistic scenarios, not be used as the basis for grid reliability standards, protection decisions, and other government/industry policies. EDTF instead recommends that the Congressional EMP Commission Reports, supported by real-world data, be used by government and industry as the most accurate assessment of the high-altitude EMP threat. EDTF recommends that the Congressional EMP Commission’s recommendations be implemented.

Background

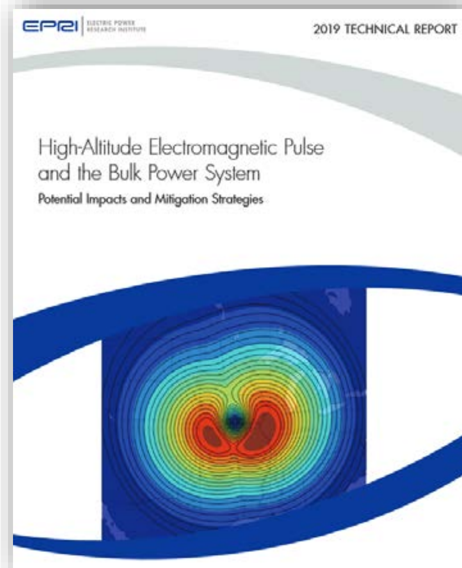
The recently issued Executive Order 13865 (Coordinating National Resilience to Electromagnetic Pulses” / March 26, 2019) directs the US government to address the

[4] Table 4-5 in the EPRI Report depicts predictions of a HEMP attack only 27,870 MW of load tripped in the Eastern Interconnection. NERC’s Technical Analysis of the August 14, 2003, blackout listed contributing factors to that single point failure as lost situational awareness, lack of visual tools, and computer problems among operating personnel and reliability coordinators. EDTF experts assert that a HEMP attack would cause thousands of equipment failures simultaneously and severely affect the visual tools, computing systems, and communication systems of operating personnel and reliability coordinators, adversely affecting a much larger electrical load and precipitating a much larger and longer duration blackout than EPRI concludes in its report. Source: https://www.nerc.com/docs/docs/blackout/NERC_Final_Blackout_Report_07_13_04.pdf

vulnerability of America's critical national infrastructure to EMPs. Every one of these infrastructures depends upon the generation, transmission, and distribution of electricity (through the system widely known as the "electric grid".)[5]

For the goals of Executive Order 13865 to be achieved in a timely and effective manner, it is critical that the nation's owners and operators of the many components of this national "grid" be provided the best scientific information on EMP and its effects on infrastructure.

On April 30, 2019, the Electric Power Research Institute (EPRI) released a report titled: "High-Altitude Electromagnetic Pulse and the Bulk Power System: Potential Impacts and Mitigation Strategies" — the report.[6] The report was the most recent product of a project initiated in 2016 by EPRI in coordination with the Department of Energy through their "Joint Electromagnetic Pulse Resilience Strategy[7]"



According to 2019 testimony before Congress by a senior executive of the Edison Electric Institute, which represents all investor-owned electric companies in the US, this EPRI project is supposed to complement and help achieve the five goals of the 2017 Department of Energy Electromagnetic Pulse Resilience Action Plan[8]: "(1) improve and share understanding of EMP threats, effects, and impacts; (2) identify priority infrastructure; (3) test and promote mitigation and protection approaches; (4) enhance response and recovery capabilities to an EMP attack; and (5) share best practices across government and industry, nationally and internationally."[9]

EDTF participants noted that immediately following the release of the report, numerous media outlets - particularly those with a focus on energy and electricity - published articles confirming that the report was meant to be a comprehensive study to achieve these goals. This media coverage included consistent positive messaging surrounding EPRI's research methodology and numerous quotes from senior executives in the electric power industry and the

[5] Executive Order 13865 (Coordinating National Resilience to Electromagnetic Pulses" / March 26, 2019) https://www.federalregister.gov/documents/2019/03/29/2019-06325/coordinating-national-resilience-to-electromagnetic-pulses

[6] "High-Altitude Electromagnetic Pulse and the Bulk Power System: Potential Impacts and Mitigation Strategies," https://www.epri.com/#/press-releases/6W97BuDklzgSWTPhK3pKWw?lang=en-US

[7] US Department of Energy, "Joint Electromagnetic Pulse Resilience Strategy," July 2016, https://www.energy.gov/sites/prod/files/2016/07/f33/DOE_EMPStrategy_July2016_0.pdf

[8] US Department of Energy, "US Department of Energy Electromagnetic Pulse Resilience Action Plan, January 2017, https://www.energy.gov/sites/prod/files/2017/01/f34/DOE%20EMP%20Resilience%20Action%20Plan%20January%202017.pdf

[9] Scott I. Aaronson, "Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance," Before the US Senate Homeland security and Governmental Affairs Committee, February 27, 2019, https://www.hsgac.senate.gov/imo/media/doc/Testimony-Aaronson-2019-02-27.pdf

organizations that represent electric power companies who confirmed that the report would provide the basis for developing mitigation solutions for “the grid” and other critical infrastructures. Most key themes and messaging surrounding the release of the report pointed toward EPRI and the electric utility industry taking very seriously the threat posed by HEMP, especially in relation to the timing of the report’s release one month after the President’s Executive Order 13865.

Since its inception, the EDTF has observed that there are thousands of patriotic Americans employed in the electric power industry who work tirelessly to build, maintain, and protect the grid upon which America’s electronic civilization relies for its survival and that these professionals – ranging from engineers, to linemen, to physical security personnel – are truly seeking the truth about natural and man-made hazards to the grid. EDTF personnel have noted that these professionals are often so busy working to provide American citizens with reliable, resilient, and affordable electricity that they rarely have the time to deeply study some of the highly technical aspects of hazards such as HEMP. Thus, it is understandable that the industry would put a substantial trust in an organization like EPRI, to whom many of them contribute financially, to provide factual and actionable research products. This tendency is reasonable, since any stakeholder emphatically seeks a fitting return on their investments.

Nevertheless, given the gravity of the threat from HEMP to America’s critical infrastructure, it is in the public interest that all HEMP research be accurate, objective, and based on sound engineering and practices. Since effective messaging surrounding the EPRI report points to the fact that it is supposed to “Improve and Share Understanding of EMP: Threat, Effects, and Impacts” and that this understanding will be the basis for the type of EMP mitigation applied to critical infrastructure called for by the President’s executive order, EDTF experts considered it vitally important that such discoveries should be transparent and available for peer review.

“EDTF experts hope that EPRI researchers and high level executives of the electric power industry will review this annex, carefully contemplate its findings, and begin to engage many of the EMS experts who were not consulted in the conduct of this three-year research effort in order to rapidly correct misunderstood EMP environments, system effects and protection requirements and set the nation on the path to truly securing its electric infrastructure from both natural and man-made EMP.”

Specifically, EDTF believes that all research on Electromagnetic Spectrum (EMS) defense, particularly that which will be relied upon for major and important decisions on infrastructure protection, should be carefully analyzed by experts, including those in the fields of electromagnetics, physics, power engineering, system engineering, space weather, and others. Experts in these fields comprise the membership of the EDTF which hosts more than 360 members from the military, federal government, national labs, academia, and industry. Many of these experts have thoroughly reviewed the EPRI report and have provided their consolidated observations herein.

Overview of EDTF Observations

The methodology and findings of the EPRI report are not only markedly dissimilar from previous EMP studies, but in many cases entirely opposed to more than 60 years of prior DOD, government, and contractor research and findings on EMP, system effects, and hardening.

Some EDTF experts noted that although EPRI represents itself as an independent scientific think tank, since it is funded by the electric utilities, it has a history of providing plausible sounding scientific rationales that support the public policy preferences of the electric power industry.

EPRI is aware of the valid concern among electric industry executives that EMP protection cost recovery is available now or will soon be needed within transmission systems in many states and at least some distribution systems (e.g. ERCOT). New EMP protection systems or retrofit protection is, with some exceptions, not currently available to protect large power transformers and generators within competitive interstate power markets. Consequently, it is not unrealistic to assume that EPRI's research on HEMP initially emphasized protection of transmission and sub-station components of the electric grid that have early prospects for cost recovery. It is our understanding that EPRI plans to extend EMP protection testing of transformers and perhaps large power generators in coming years, which is commendable. Readers should understand however, that if EPRI's April 2019 recommendations are to be followed, the ultimate result would be a US power grid with remaining vulnerabilities impacting large power transformers, generating equipment, and microgrids designed for emergency backup power. Therefore, EDTF has determined that an objective evaluation of the EPRI report is vital to transparency, DOD interests, and the wider public.

"EDTF concludes that the methodology and findings of the EPRI report are inconsistent with the 60+ years of DOD research and experience in understanding EMP environments, system effects, and protection requirements and that the report dangerously and inadequately characterizes impacts on the US electric grid for an EMP event."

The EDTF encourages the widest dissemination of this document, which explains in technical detail the shortcomings and premature conclusions associated with the EPRI research. This will enable owners and operators of critical infrastructure to make an objective and informed assessment of the current state of the art in relation to EMP as supported by a wider national knowledge base.

EDTF experts hope that EPRI researchers and high-level executives of the electric power industry will review this critique, carefully contemplate its findings, and begin to engage many of the EMS experts who were not consulted in the conduct of this three-year research effort in order to rapidly correct misunderstood EMP environments, system effects and protection requirements and set the nation on the path to securing its electric infrastructure from both natural and man-made EMP.

Detailed EDTF Technical Review

Insufficient HEMP Expertise and Modeling Data

There is a small community of national EMP technical experts, many of whom have conducted testing, published EMP research, or spent their professional lifetimes working with classified EMP data for the Department of Defense or defense contractors protecting critical systems from HEMP.

As will be discussed in detail below, EPRI did not adequately utilize, or sub-contract with enterprises possessing nuclear test coding compatible with US and Russian atmospheric nuclear testing. By failing to make appropriate use of EMP Commission declassified E3 HEMP waveforms and E3 (late-time) HEMP pulse magnitudes derived from Russian nuclear tests over Kazakhstan (held to be the best and most comprehensive EMP test data available), EPRI scientists did not have the benefit of the best modeling data which included Soviet high altitude nuclear tests pertinent to EMP effects over large land masses.

Despite having access to classified DOD environmental standards, EPRI used lower level system stresses from non-optimal attack parameters for the EPRI baseline effects assessment. And while the report may use appropriate E1 (early-time) HEMP current injections to test digital protective relays, and advances understanding of which relays may or may not be vulnerable to E1 damage, its conclusions about the severity and magnitude of a HEMP-induced blackout do not consider the cascading effects of relay damage, given that there are more than one million now deployed in the grid. Additionally, the overall EPRI conclusions with respect to limited transformer vulnerability failed to utilize then-available E3 waveform and E3 threat levels produced by the EMP Commission, which was declassified and accessible to EPRI researchers. Further, EPRI failed to perform adequate field testing of transformers before vouching for their resilience.

Mischaracterization of US DOE Laboratories' Collaboration and Endorsement

The EPRI report mentions "close collaboration with various government entities." It also lists the individuals who provided a "detailed technical review and feedback." EDTF observes that this implies an "endorsement" by these individuals and agencies. The contents of these reviews are unknown. Many of the individuals mentioned are not known to be experts in the field of EMP.

Although the EPRI research program was coordinated with the DOE EMP Action plan[10], EDTF confirmed that the Department of Energy provided no funding for this effort.

Inaccuracies on HEMP Research

EPRI's research not only ignored most of the 60+ years of EMP research by the DOD and Congressional EMP Commission but misconstrued the history of this research and

[10] US Department of Energy. "Electromagnetic Pulse Resilience Action Plan," January 2017. https://energy.gov/sites/prod/files/2017/01/f34/DOE%20EMP%20Resilience%20Action%20Plan%20January%202017.pdf

technology development as being performed mainly by the Department of Energy (DOE)—not the Department of Defense. In fact, the Department of Defense, through the Defense Atomic Support Agency, the Defense Nuclear Agency (DNA), and today through the Defense Threat Reduction Agency (DTRA), is the central repository for HEMP research and threat assessment. DOE and the national labs played little role in HEMP research and threat assessment historically. DOE and the national labs focused on nuclear weapon designs and radiation outputs rather than nuclear effects. In the DOD, after the end of the Cold War and with the disestablishment of DNA and its permutation into DTRA, focus and expertise on nuclear weapon effects, especially HEMP, sharply declined. The Congressional EMP Commission, until its disestablishment in 2017, was the locus of the best HEMP expertise in the Free World.

EPRI based its research on a false premise that the Congressional EMP Commission's research was inferior to 1980s and 1990s research. EPRI claims there was disagreement among experts on the severity of E3 effects during those decades. EDTF notes that the real reason there is a difference is not because of a scientific dispute but rather because, due to less developed E3 theoretical understanding, the earlier studies in the 1980s/90s used a much lower EMP/E3 environment than the EMP Commission. The Russians provided the United States additional testing data to the EMP Commission in the early 2000s, which enabled the EMP Commission to develop empirically based E3 contours with a peak value of 85 V/km.

Most EMP research was done by the Defense Atomic Support Agency during atmospheric testing, as well as the Air Force Weapons Lab, then by the Defense Nuclear Agency and then by DTRA within DOD, yet the report implies that the bulk of the research was done by DOE. EPRI claims that EMP Commission Chairman Dr. William R. Graham is at variance with the DOD perspective on EMP. Dr. Graham *created* the DOD perspective on EMP. Moreover, EMP Commission staffers like Dr. William A. Radasky and Dr. George H. Baker played prominent roles in developing DOD's understanding of the HEMP threat and protecting US military systems from HEMP, including development of the DOD HEMP Military Standards.

Thus, the EPRI report's implication that DOE created the DOD HEMP Military Standards, and that EPRI's work is consistent with the historical HEMP threat (while the Congressional EMP Commission's work supposedly is not), is a misrepresentation.

EPRI's claim that their report is consistent with historical HEMP threat assessments is also misleading as it conflicts with the nearly six decades of broad and deep scientific consensus on the HEMP threat as potentially catastrophic. EDTF recognizes that this consensus was reached by experts who have spent their lifetimes doing real-world testing of HEMP effects on real infrastructure using DOD approved equipment and procedures.

EPRI's view is that the HEMP threat is no more consequential than localized or regional blackouts. EPRI's view is contradicted by the Congressional EMP Commission (whose views, as an official Congressional Commission, serve as the basis of public policy), the Congressional

Strategic Posture Commission[11], the National Academy of Sciences, Engineering, Medicine[12], the series of Metatech reports as sponsored jointly by the US Federal Energy Regulatory Commission and Oak Ridge National Laboratory[13], the Electromagnetic Defense Task Force[14], and major HEMP studies by the Department of Defense since 1963.

Misleading Use of the Terms "Conservative" and "Worst Case" For Research Approach

In the area of infrastructure protection, the term "conservative" means that an infrastructure owner would assume a reasonable upper-bound threat and add a safety margin on top of that to be absolutely certain that the infrastructure assets will survive this threat.

EPRI's report makes use of this term "conservative" at times in the proper context, such as when it states, "a conservative approach is to compare the maximum peak voltage obtained from the simulations with the lowest expected BIL (Basic Insulation Level) in a substation" (4-13). EPRI's consistent use of these terms throughout the report leads the reader to believe that the goal of EPRI's research and testing methodology is to ensure that infrastructure can be protected to withstand an adversary's HEMP attack where the adversary used its most effective methods of attack to achieve the highest possible HEMP fields against America's infrastructure.

In reality, as will be further explained in the technical review of EPRI's research on the effects of E1 and E3 HEMP, EPRI chose to ignore readily available unclassified data on means

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[11] Congressional Strategic Posture Commission, "Congressional Commission on the Strategic Posture of the United States," 2009, https://www.usip.org/publications/2009/04/congressional-commission-strategic-posture-united-states
[12] The National Academies Science, Engineering, Medicine, "Enhancing the Resilience of the Nation's Electric System," The National Academies Press, 2017
[13] Oak Ridge National Laboratory (ORNL). Geomagnetic Storms and Their Impacts on the US Power Grid (Metatech Meta-R-319). Oak Ridge, TN: January, 2010, https://www.ferc.gov/industries/electric/indus-act/reliability/cybersecurity/ferc_meta-r-319.pdf
ORNL, Electromagnetic Pulse: Effects on the US Power Grid (Metatech Meta-R-320). Oak Ridge, TN: January, 2010, https://www.ferc.gov/industries/electric/indus-act/reliability/cybersecurity/ferc_meta-r-320.pdf
ORNL, The Late-Time (E3) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the US Power Grid (Metatech Meta-R-321). January 2010, https://www.ferc.gov/industries/electric/indus-act/reliability/cybersecurity/ferc_meta-r-321.pdf
ORNL, Low-Frequency Protection Concepts for the Electric Power Grid: Geomagnetically Induced Current (GIC) and E3 HEMP Mitigation (Metatech Meta-R-322). January 2010, https://www.ferc.gov/industries/electric/indus-act/reliability/cybersecurity/ferc_meta-r-322.pdf
ORNL, Intentional Electromagnetic Interference (IEMI) and Its Impact on the US Power Grid (Metatech Meta-R-323). January 2010, https://www.ferc.gov/industries/electric/indus-act/reliability/cybersecurity/ferc_meta-r-323.pdf
ORNL, High-Frequency Protection Concepts for the Electric Power Grid (Metatech Meta-R-324). January 2010, https://www.ferc.gov/industries/electric/indus-act/reliability/cybersecurity/ferc_meta-r-324.pdf
[14] Major David Stuckenberg, Amb. R. James Woolsey, Col Douglas DeMaio, "Electromagnetic Defense Task Force 2.0," LeMay Papers No. 4, Air University Press, August 2019, https://www.airuniversity.af.edu/Portals/10/AUPress/Papers/LP_0004_ELECTROMAGNETIC_DEFENSE_TASK_FORCE_2_2019.PDF
Maj. David Stuckenberg, Amb. R. James Woolsey, and Col. Douglas DeMaio, LeMay Paper, Air University, 2018, https://airuniversity.af.edu/Portals/10/AUPress/Papers/LP_0002_DeMaio_Electromagnetic_Defense_Task_Force.pdf

to achieve optimum HEMP field strengths when specifying their HEMP environments. EDTF experts agree that a good faith effort to analyze the vulnerability of the US electric power grid should at a minimum begin with the peak unclassified HEMP field strengths and would add an additional safety margin to be able to claim a "conservative" analysis.

Inaccurate and Misleading Conclusions Based on Research Methodology

EPRI consistently makes narrow conclusions about HEMP vulnerabilities but bounds these narrow conclusions with numerous significant exceptions to their analysis.

For example, in the report EPRI concludes that HEMP is not a problem for the national grid while only researching its effects on segments of the grid that are interconnected – the transmission systems for the Eastern and Western Interconnection, and ERCOT in Texas. EPRI failed to address generation systems, distribution systems, programmable logic controllers, and other electronic systems associated with grid operation, communication and control.

Not only did the study limit its focus to the transmission system, its research on E1 HEMP primarily assessed the vulnerability of digital protective relays, which represent only one class of component of the grid and tends to be more resilient to E1 than other grid elements. It is also noted that not enough detail was provided with regard to the E1 HEMP field testing procedures and the injection testing. Some of their work appears to indicate higher level of DPR survival than previous peer review studies have found. Electronic systems within digital data communication systems required for DPR functionality during normal grid operations tend to be more sensitive to HEMP transients than the DPR devices themselves. For that reason, it is important to test the substation communications equipment also. To its credit, the EPRI study did perform tests of surge protection devices (SPDs), EMP-protected substation control housings, and (to a lesser extent) fast automatic switching devices, as possible future solutions to reduce the E1 HEMP transients reaching the equipment.

Many other electronic systems provide visibility and control, vital to the operation of the grid, which must also be assessed for vulnerability to HEMP. These include supervisory control and data acquisition systems (SCADAs), open air sensors, communications systems, uninterrupted power supply (UPS) batteries, insulators, etc.

The report's narrow focus on DPRs creates the mistaken impression that DPRs are the only major vulnerable component of the grid.

EPRI's report states: "Based on the assumptions made in the assessments, it was estimated that approximately 5% of the transmission line terminals in a given interconnection could potentially have a DPR that is damaged or disrupted by the nominal E1 HEMP environment, whereas approximately 15% could potentially be affected by the scaled E1 HEMP environment." The EPRI definitions of the nominal and scaled E1 HEMP environment are also in question due to the method they used to establish these levels.

This assumption ignores the potential impact caused by the failure of other critical protective components. Also, though EPRI tested numerous models of DPRs, they provided no assessment of EMP impacts related to the failures of these DPRs related to their role in protecting other grid assets including preventing bus and transformer overload, protecting against over and under frequency conditions, and protecting against over and under voltage conditions.

EDTF's initial assessment is that a loss of 5-15 percent of transmission line terminals due to disrupted/damaged DPRs is not a "moderate" concern. The loss of these line terminals could cause the grid protective control systems, operational systems, to cascade, resulting in large-scale blackouts. Large-scale grid blackouts have occurred from single-point failure locations in the past. Failure of 15 percent or even 5 percent of grid relays are likely to have larger effects with longer-term diagnostic and recovery times.

Neither transformer manufacturers nor relay manufacturers were named as key collaborators for the EPRI report, nor did the report indicate that manufacturers agreed with the findings. Since there are different thermal models for different transformers, this collaboration and consensus are vital to achieving accurate results. The same can be said for relay manufacturers.

The criticality and function of the different relay models should have been assessed and prioritized, based on their effects upon grid stability. Information on where a relay is connected and what a relay controls is essential to understanding how the upset or failure of the relay would affect the grid collapse or contribute to blackout recovery procedures.

The study did not consider the possibility of follow-on HEMP events when assessing relay vulnerabilities. For example, an initial HEMP attack could render a number of relays inoperable, causing grid debilitation due to the loss of transformer isolation, fault protection, and islanding capabilities. Thus, a follow-on HEMP attack on a grid with a portion of damaged or disrupted DPRs would likely cause increased and catastrophic equipment damage from flashovers, uninterrupted overloads, faults, and cascading events resulting in a wider scale and longer duration blackout. Also, a second HEMP attack after damaged DPRs are replaced, could eliminate the ability to recover due to depletion of DPR spare inventories.

Regarding spares, the report did not address problems related to the installation of replacement relays, such as the availability (number of spares), the lead time (under extreme circumstances and demand), the technical labor associated with replacing the relays (including the engineering experts and the digital and computer equipment needed to program them), the logistics to deliver them from the supplier through the technician installing them on site (lack of working vehicles, fuel availability, work force staying home, extreme demand, etc.).

The EPRI report does not address the impact on infrastructures that support the power grid such as natural gas pipelines, communication systems (which can enable DPRs), transportation for equipment delivery (gasoline, vehicles, etc.). Furthermore, many grid operators rely on replacement equipment manufacturers that could have also been affected or on overseas components and that may not be available in a post-EMP environment. EPRI also did not assess the impact on logistics and the availability of qualified personnel to perform grid restoration.

Despite all these research gaps, the EPRI report concludes, "research findings do not support the notion of blackouts encompassing the contiguous United States (CONUS) and lasting for many months to years."

This categorical conclusion is premature since the EPRI assessment was limited to the transmission grid. In addition to problems with EPRI's incomplete and non-defense-conservative assessment of the transmission grid, unaddressed HEMP-induced failures of the generation, distribution, and communication systems could precipitate much larger area and longer-term blackouts.

Compounding the limitations of their assessment, EPRI used non-optimal height of burst/yield combinations for developing the E1 HEMP environments and used a non-bounding and unvetted E3 HEMP field environment, thus reducing the effects and impacts on the power grid. More detail on the specific issues with the E1 and E3 research is described further below.

Finally, EDTF noted that EPRI did not coordinate with the Congressional EMP Commission to compare results and methodology in its HEMP research. EPRI was aware of differences because of an EMP Commission rebuttal of an earlier EPRI report on E3 HEMP. According to EDTF experts, this most recent EPRI HEMP Report repeats similar arguments and errors EPRI has made in the past.

Inaccuracies on the Effects of E1 HEMP

In the study, EPRI positioned the hypothetical high-altitude nuclear detonation over the center of the United States such that the maximum field doesn't cover the most populated portions of the country or the areas with most of the grid's generation assets.

International Electrotechnical Commission (IEC) recommends starting testing at low levels and working up to the final test level as well as field testing small objects by rotating them and recording the lowest field level for the four to six orientations during that testing. This is done because the angle of incidence of the E1 HEMP on the equipment is unknown in advance. In addition to field testing, the IEC recommends testing conducted transients to be injected on each cable that may be connected to equipment. This is because equipment is often connected by the utilities in different ways depending on the function of the equipment

EPRI's notional E1 EMP environment was created based upon non-optimal heights of burst and weapon yields and the report implies that megaton class weapons are needed to achieve a 25 to 50 kV/m effect, which is not true. For example, rather than modeling the optimal burst height of 75 km for peak E1 HEMP field strengths, EPRI chose a non-optimal burst height of 200 km which lowers the peak E1 field strength by ~65 percent (Ref: Metatech Report Meta-R-320[15], Figure 2-6). IEC 61000-2-9 and MIL-STD-461G recommends an E1 HEMP peak field level of 50 kV/m.

[15] Edward Savage, James Gilbert and William Radasky, "The Early-Time (E1) Altitude Electromagnetic Pulse (HEMP) and its Impact on the US Power Grid," (Meta-R-320), Metatech Corporation, January 2010

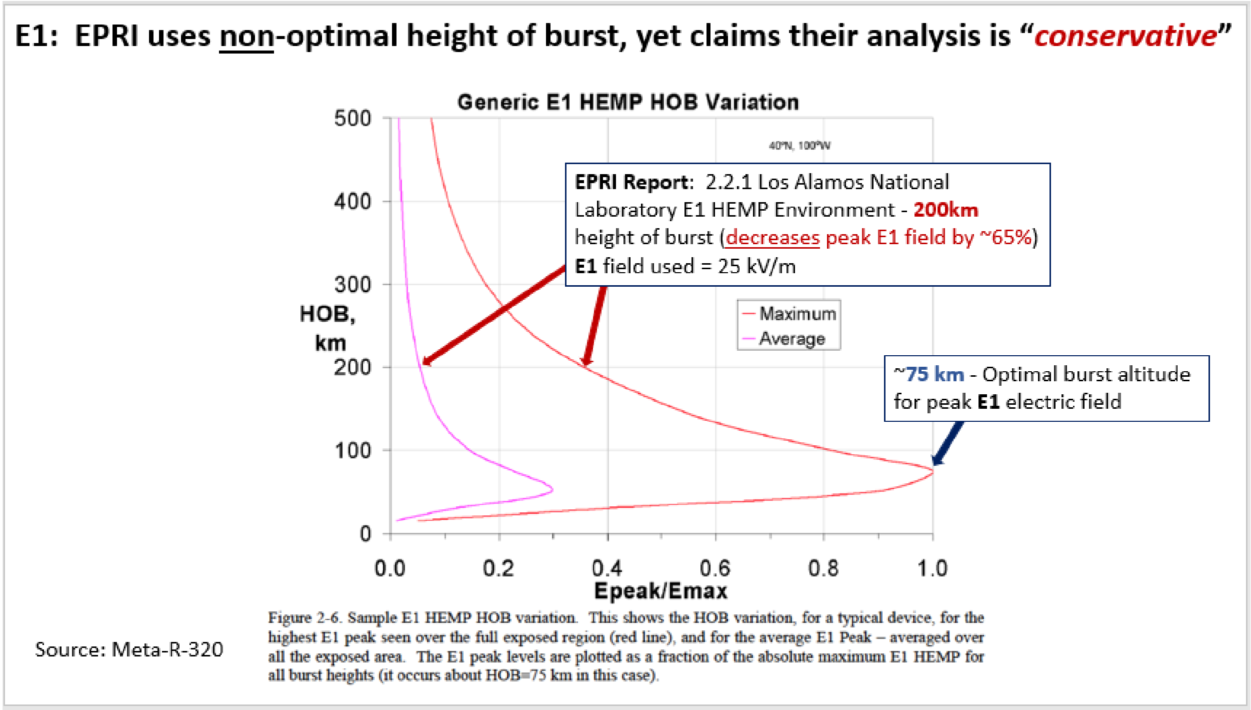


Figure 2-6. Sample E1 HEMP HOB variation. This shows the HOB variation, for a typical device, for the highest E1 peak seen over the full exposed region (red line), and for the average E1 Peak – averaged over all the exposed area. The E1 peak levels are plotted as a fraction of the absolute maximum E1 HEMP for all burst heights (it occurs about HOB=75 km in this case).

The report describes EMP peak fields as falling off significantly from ground zero but neglects to mention that fall-off is largely negated in multiple burst scenarios.[16] Also, the bursts' heights and yields selected for their E1 HEMP environment have a much faster decrease with range than a proper burst height selection would create. Thus, they have underestimated the coupling to cables.

EPRI makes premature conclusions about the impact of E1 on the power grid. This is evident from EPRI's admission of the following:

> "The limited assessment indicated that E1 HEMP impacts alone were not found to cause immediate, interconnection-scale disruption or blackout of the power grid, but this finding is not conclusive since it is unknown how damaged DPRs might respond during an actual event or how potential E1 HEMP damage to generator controls and other systems such as automatic generation control (AGC), not included as a part of this study, might affect the long-term operation of the grid. Additional research is needed to quantify and understand these uncertainties and how they might, in combination, affect the stability of the electric power grid."

[16] A Report prepared by ABB for Oak Ridge National Laboratory in January 1991 noted increasing E1 damage in scenarios involving multiple HEMP bursts: "Multiple burst increase the likelihood of system breakup and may also increase the number of insulation punctures due to repeated stress." V. J. Kruse, et al., Impacts of a Nominal Nuclear Electromagnetic Pulse on Electric Power Systems, Oak Ridge National Laboratory Report ADA237104, June 1991, p. 66, available at Defense Technical Information Center (DTIC).

Since EPRI admits large uncertainties regarding how damaged DPRs and other grid components might respond during an actual HEMP event, EDTF experts question EPRI's consistent claims that HEMP impacts will not be severe.

EPRI's conclusions about E1 effects on transformers are also premature since no transformers have been tested by EPRI at HEMP threat levels embodied in DOD, IEC or the EMP Commission specifications. Testing done in the 1980s by ORNL did show that medium voltage transformers in the distribution grid were potentially vulnerable to insulation breakdown. These test data can be found in IEC 61000-1-3.

It is problematic that the E1 environment used for the EPRI assessment is clearly inconsistent with DOD, IEC, and Mil-Std-464 levels. In addition, Russian and Chinese scientists have published E1 calculations openly that are at least twice as high as those used in EPRI's study. Finally, this does not motivate the development of mitigation technologies to preserve America's critical infrastructure against the stronger fields produced by current stockpile nuclear weapons, enhanced EMP weapons, or other future enemy capabilities.

Readily available empirical data from the Congressional EMP Commission work demonstrates that some electronic systems can be debilitated by E1 field strengths of 3-5 kV/m. Ultimately, EDTF experts are highly concerned about EPRI's unduly optimistic conclusions about E1 HEMP impacts on grid infrastructure and that EPRI significantly underestimates the capabilities of America's adversaries.

Inaccuracies on the Effects of E3 HEMP

On April 9, 2018 (more than a year ago), the US Department of Defense declassified E3B HEMP measurements evaluated from two high-altitude nuclear tests performed by the Soviet Union in 1962.[17] The declassified reports state:

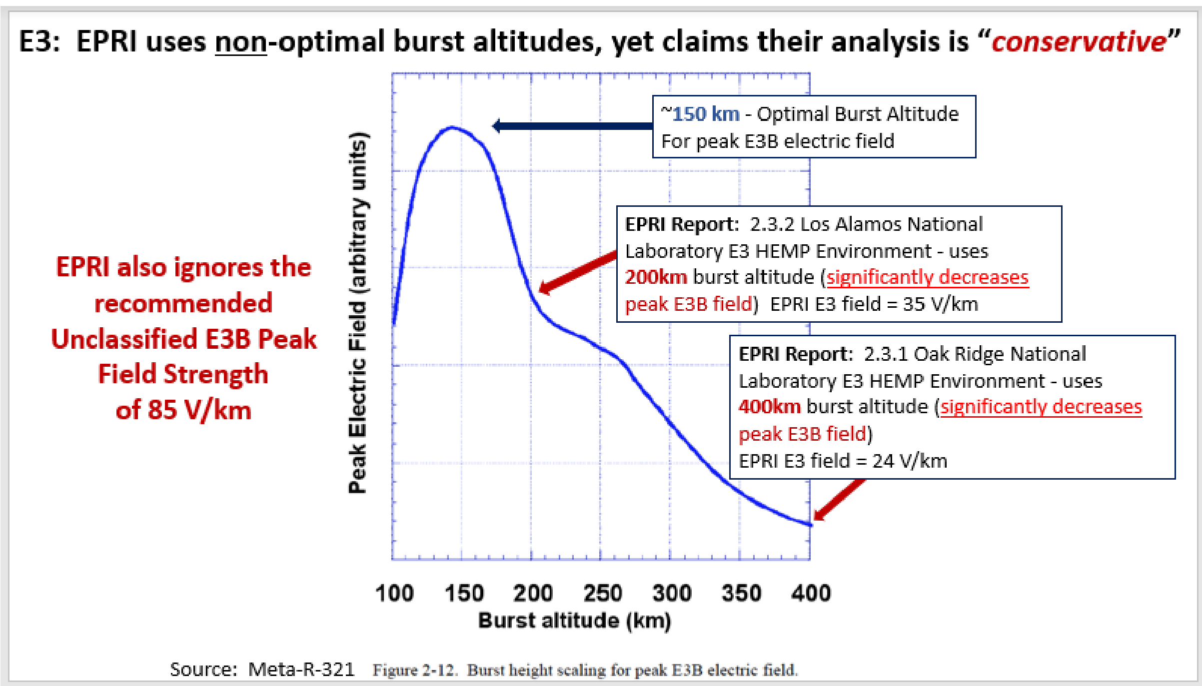
> "*A realistic unclassified peak level for **E3** HEMP would be **85 V/km for CONUS… 102 V/km** for locations nearer to the geomagnetic equator*. . ." (p. ix, 1) and makes a further note: "*This report does **not** claim that the values suggested here are absolute worst-case field levels, but rather these peak levels are estimated based directly on measurements made during high-altitude nuclear testing*. . . [emphasis added] (p. 4).

EDTF concurs that those peak levels represent reasonable bounds on the peak E3 environment.

[17] Recommended E3 HEMP Heave Electric Field Waveform for the Critical Infrastructures, July 2017, available at: https://www.hsdl.org/?abstract&did=818335. For open sources on the Russian HEMP tests over Kazakhstan, see EIS Council Report, USSR Nuclear EMP Upper Atmosphere Kazakhstan Test 184, https://www.eiscouncil.org/App_Data/Upload/a4ce4b06-1a77-44d8-83eb-842bb2a56fc6.pdf; and Jerry Emanuelson, "The 1962 Soviet Nuclear EMP Tests over Kazakhstan," Futurescience, last revision July 7, 2019, at https://www.futurescience.com/emp/test184.html.

It is important to note that principal investigators of this EPRI Report have been aware of this unclassified E3 peak field strength of 85 V/km for over a year. EDTF experts noted that they reference the report a few times (Reference 20: "Recommended E3 HEMP Heave Electric Field Waveform for the Critical Infrastructures", July 2017) with regard to the location of E3A vs. E3B and the direction of geoelectric field vector, but they make no mention of the 85 V/km recommended field strength for CONUS – the main purpose of the EMP Commission report.

EPRI's modeling uses an E3B Heave environment of 35 V/km and 24 V/km, which EDTF experts consider a low level. Once again, EPRI chose non-optimal heights of burst for their report. For example, rather than modeling the optimal burst height of 150 km for peak E3B field strengths, EPRI chose a burst height of 400 km (utilizing very old calculations provided to Oak Ridge National Laboratory) which lowers the peak E3B field significantly. Also, the data set used was for a location that is not where the maximum field would be found. For the second scenario, EPRI worked with LANL and used a non-optimal burst height of 200 km, which again lowers the maximum E3B field strength significantly. (Source: Meta-R-321[18], Figure 2-12).



In its 2017 report titled "Recommended E3 HEMP Heave Electric Field Waveform for the Critical Infrastructures," the EMP Commission stated:

> "A realistic unclassified peak level for E3 HEMP would be 85 V/km for CONUS as described in this report. New studies by EPRI and others are unnecessary since the Department of Defense has invested decades producing accurate assessments of the EMP

[18] James Gilbert, John Kappenman, William Radasky and Edward Savage, "The Late-Time (E3) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the US Power Grid," (Meta-R-321), Metatech Corporation, January 2010

threat environment and of technologies and techniques for cost-effective protection against EMP."

The EMP Commission used data from the Russian Kazakhstan HEMP tests in 1962 to give the electric power industry an unclassified and empirically based E3 environment to use for planning, which was rejected by the EPRI researchers.

The EPRI report states that the 35 V/km environment was a product of LANL but does not reference the basis for this calculation. In addition, the LANL work has not been published or peer reviewed by the experts in the field. Importantly, this LANL threat environment is 59 percent lower than the E3 peak field strength of 85 V/km which the Congressional EMP Commission recommends for protection of the critical infrastructures.

The EPRI report states multiple times that E3 HEMP (alone) will not cause widespread transformer damage due to hotspot heating from part-cycle saturation. EDTF experts agree that this is another unwarranted conclusion because no large bulk power transformers have been tested to the proper threat levels. However, past solar storms prove that even GMD field strengths far below those that would be generated by E3 HEMP will destroy EHV transformers. Furthermore, EPRI essentially ignores all other GMD/E3 effects on transformers such as: half cycle saturation effects on the cores of transformers, harmonic effects, Lorentz forces, risk of voltage breakdown across windings, failure of insulation between windings, increase in dissolved combustible gases in oil, etc., that have resulted in damage to transformers across the globe from the lower DC currents induced by moderate, lower field strength GMD events.

The report mentions that E3 affects transformers, however it omits the potential widespread E3 effects on generators, long haul communications, internet communications, and pipelines – all critical components necessary for operation of the power grid. Also, the effect of the harmonics generated during half-cycle saturation of transformer impacting low voltage equipment is also not considered.

The report minimizes the severity of E3 by mischaracterizing the difference between E3 and GMD. The report states that E3 lasts minutes and that GMD lasts for days, but this is a serious misstatement. GMD storms may last for hours and days but do not stay in a single location for many minutes, let alone days (in March 1989 the magnetic field produced at the earth's surface moved from Montreal to Alaska in about 10 minutes). In addition, the magnetic fields from a GMD event produce electric fields and geomagnetically induced currents that are related to the derivative of the magnetic field. Thus, during a GMD event, there will be a series of current pulses produced with some time separation, many of which are comparable to the duration of HEMP E3 pulses. It is noted that the GMD electric fields that caused the collapse of the Quebec power grid in 1998 were estimated to peak at 2 V/km. Nearly any E3 HEMP burst will create fields substantially higher than 2 V/km.

The EPRI report leaves out an important difference between E3 and GMD, which is the Fast Rise Time of the E3B (compared to GMD) heave wave and resulting higher peak electric fields (Source: Metatech-R-321[19]). The report further ignores the impact of the E3B heave wave in their assessment on voltage collapse on page 4-21, where EPRI states "During the first 10 seconds of the environment, the E3 EMP field is quite weak and GIC flows are minimal." It may be that EPRI is referring to the small E3A waveform that they used, which is not comparable to the E3B produced under the nuclear burst.

EPRI's report omits the importance of E3 fast onset. EPRI agrees there may be no warning for an EMP attack. The E3 waveform lasts roughly 30 seconds. Thus, once E3 occurs, it is already too late to open high voltage breakers to de-energize transformers in an attempt to save them from damage. Even *if* the electronics of DPRs and high voltage breakers were to survive the E1 pulse, the E3 pulse alone can prevent the operation of these breakers. High voltage breakers are not designed to break DC current. DC current causes "DC bias" where DC current approaches AC levels and the breakers begin to lose current zero crossings necessary for operation. The fast rise time of E3B would mean the potential for thousands of amps DC on the lines within 100 milliseconds. Breakers will not operate as expected and attempting to operate them could cause them to be damaged by arcs.

In the report EPRI mentions a potential utility operating procedure of opening breakers to de-energize transformers in order to mitigate the impacts of GMD events. First, it is necessary to point out that this strategy of "turning off the grid" has been debated and is not an industry-accepted option for large GMD events. Industry experts indicate that turning off the grid will cause more problems than it solves since restarting the grid causes large voltage transients in multiple locations. Furthermore, the NOAA warning system is unable to predict GIC levels in a particular power grid in advance. EPRI does not specify who is going to make the call to "turn off" the grid or at what point the grid should be turned off. EDTF experts have concern that this strategy would follow the initial utility operating procedures to first shed load from vulnerable transformers. This can cause larger problems in a significant GMD event since, due to lowering transmission line loading, high voltage circuit breakers become more vulnerable to E3-caused "DC Bias." [20]

Some utility engineers assert that voltage collapse in a severe GMD or E3 event will ultimately save the transformers from damage due to the breakers opening and de-energizing the transformers (removing them from harm). Again, voltage collapse requires high voltage circuit breakers to open. This may not be possible with high amounts of E3-induced DC current. Industry and EDTF experts are concerned that, because relays may not operate properly in a HEMP environment to protect transformers, the grid may not self-protect.

These are just a few of the reasons why (as EPRI mentions in their April 2019 report *and* in their multiple reports dating back to the 1980s) that the solution to protect the grid against both E3 *and* GMD is to block DC current from entering the grid using capacitors in the neutral of

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[19] James Gilbert, John Kappenman, William Radasky and Edward Savage, "The Late-Time (E3) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the US Power Grid," (Meta-R-321), Metatech Corporation, January 2010

[20] James Gilbert, John Kappenman, William Radasky and Edward Savage, "The Late-Time (E3) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the US Power Grid," (Meta-R-321), Metatech Corporation, January 2010

transformers (neutral blocking) or capacitors on all 3 phases (series capacitors). Yet, based on the information in this report, EPRI, by using low-bound E3 fields and focusing on thermal damage, finds that transformers don't need protection, that operational procedures suffice. Operational procedures, however, assume operational communication and control systems – a tenuous assumption given electronics' vulnerability to E1.

Inaccuracies on the Combined Effects of E1- E3

EPRI's report does not assess the compound damage caused by the combination of the interaction of E1, E2, and E3. However, by selecting non-optimal height of burst for HEMP weapons, EPRI's threat envelope projects only minimal E1 effects upon protective digital relays and other low voltage equipment if lacking fast surge arrestors. Consequently, EPRI misses the importance of the loss of system control and protection capability for the electric grid and other critical infrastructures on which the grid depends. Because communication and control systems (digital protective relays are a subset) may not operate properly to protect transformers, again, the grid may not self-protect.

As stated by the Congressional EMP Commission in its 2004 Executive Report[21], "The sequence of E1, E2, and then E3 components of EMP is important because each can cause damage, and the later damage can be increased as a result of the earlier damage."

Additionally, EDTF experts are concerned about the disparity between EPRI's conclusions in its Executive Summary that there are no significant combined effects of E1, E2, and E3 and the substantial uncertainties that prevent firm conclusions about the possibility and severity of these combined effects acknowledged within the main body of their report.

For example, when listing "Modeling Uncertainties Associated with Assessment of Combined E1 EMP + E3 EMP Effects," EPRI states that they did not consider impacts in their assessments to components that are critical to grid operations. EPRI states: "E1 EMP damage to control systems such as automatic generation control (AGC) were not included and could worsen the effects and make it difficult to maintain long-term frequency control. Such effects could potentially widen the area of impact."[22]

EDTF questions the accuracy of a report that fundamentally supports the view that the HEMP effects will not be catastrophic or nationwide while explicitly stating that the researchers did not assess certain effects and "such effects could potentially widen the area of impact."[23]

[21] John S. Foster, et al., Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack, Vol. 1, Executive Report, 2004, p. 6, http://www.firstempcommission.org/uploads/1/1/9/5/119571849/emp_commission_vol1_summary.

[22] EPRI Report, "High-Altitude Electromagnetic Pulse Effects on Bulk Power Systems," April 30, 2019, p. 4-25, at https://www.epri.com/#/pages/product/000000003002016784/?lang=en-US,

[23] Metatech Report R-321, publicly available since January 2010, observed: "[B]oth the E3 and E1 environments might combine inn important ways, to the detriment of the reliable operation of, and potential long-term damage to this important [grid] infrastructure." James Gilbert, John Kappenman, William Radasky, and Edward Savage, Oak Ridge National Laboratory. The Late-Time (E3) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the

Unwarranted Optimism in the Face of a REAL Threat from EMP

EDTF observes that throughout its report, EPRI consistently makes optimistic conclusions based on unsupported assumptions.

For example, in their assessment of E1 HEMP impacts on voltage stability, they found that approximately 21,500 line terminals were affected. Of these affected relays, 1 percent (215) were randomly selected and assumed to have caused simultaneous tripping. EPRI's transient stability simulation of these 215 random trips showed that the system would experience perturbation but "remain stable."

The EPRI report does not explain EPRI's methodology of choosing just 1 percent of these relays, nor does it explain how EPRI can assume that the entire system will "remain stable" when these relays are randomly tripped. Instead, it optimistically states:

> "Although it cannot be concluded from a single dynamic simulation whether or not the effects from E1 EMP alone could cause voltage instability, the system did remain stable in this one case after being subjected to a 50 kV/m E1 EMP environment, which demonstrates the ability of the bulk power system to ride through an extreme event." (emphasis added)

EDTF notes that EPRI admitted its assessment was inconclusive on this matter. Other admissible combinations and permutations of relay malfunction must be simulated to gain confidence that the system will remain stable. Logic dictates that one does not prove that a complex system will not fail based on a test using one combination of possible stresses.

EDTF is also concerned by another example of unwarranted optimism associated with grid stability. By selecting burst locations that previous EPRI studies found wouldn't result in voltage instability to validate the new E3 environment provided by LANL, EPRI side-stepped a complete analysis of E3 effects on grid stability. EPRI states:

> "The transformer thermal assessment was performed using the same 11 notional target locations that were evaluated in the previous initial study. However, due to time constraints, only a single target location in the Eastern Interconnection and a single target location in the Western Interconnection were evaluated in the voltage stability assessment. However, the two target locations that were selected were chosen to provide a meaningful test, as they were identified in the previous study[24] as target locations that were not likely to cause voltage stability impacts. Therefore, experiencing voltage

US Power Grid (Metatech Meta-R-321). January 2010, https://www.ferc.gov/industries/electric/indus-act/reliability/cybersecurity/ferc_meta-r-321.pdf

[24] EPRI, "Magnetohydrodynamic Electromagnetic Pulse Assessment of the Continental US Electric Grid Geomagnetically Induced Current and Transformer Thermal Analysis," p3.2

collapse in the updated study would be an indicator that the LANL E3 EMP environment was more severe than the previous ORNL E3 EMP environment." (underline emphasis added)

EDTF Conclusions

EDTF concludes that the methodology and findings of the EPRI report are inconsistent with the 60+ years of DOD research and experience in understanding HEMP environments, system effects, and protection requirements and that the report dangerously and inadequately characterizes impacts on the US electric grid for a HEMP event.

EDTF operates on the military's premise of planning for the reasonable upper-bound scenarios and validating results through real-world testing. EDTF concludes that the authors of this EPRI report did not operate on these premises for their research, even though they consistently use terms such as "worst case" and "conservative" in their HEMP report.

EDTF concludes that if NERC and the electric power industry establish HEMP protection benchmarks and standards based on the HEMP research conducted by EPRI (E1 and E3), that the nation's electric grid infrastructure will remain dangerously vulnerable to HEMP and thus the population of the United States will be at risk of severe, prolonged, and widespread blackouts in the event of an HEMP attack, despite patriotic electric industry professionals sincerely desiring truly effective mitigations to prepare for such an attack.

EDTF concludes that the American population and the owners and operators of the electric grid assets will actually be far less prepared for even moderate or short-duration blackouts due to the optimistic picture painted by EPRI in this report, despite the wide array of citizens, emergency management professionals, and electric utility operators who possess a genuine desire to prepare themselves for such events.

EDTF concludes that this report might severely curtail the development of effective, American-designed and manufactured HEMP-mitigating technologies for electric grid infrastructure, despite the nation possessing some of the world's most innovative thinkers and the potential for America to lead the world in this field. EPRI seems to be avoiding coming to grips with HEMP and GMD effects by choosing threat parameters that require little action.

EDTF concludes that EPRI's assertion that limited grid protection is necessary places a major burden on post-attack grid restoration. EDTF notes that the light HEMP effects predicted by EPRI also deters preparedness for grid restoration, thus prolonging the duration of HEMP blackouts. If America suffers a HEMP attack, it will need its electric grid operators to restore the grid rapidly and EPRI's report does not justify this type of preparedness.

EDTF concludes that this report might dissuade the owners and operators from taking rapid and serious action to both protect their infrastructure against HEMP and to plan for post-HEMP grid restoration, despite America's urgent need for such protections and restoration plans. Evidence of this dissuasion is manifest in the short period of time following the release of

EPRI's report as some EDTF personnel working on HEMP-mitigation efforts alongside electric industry partners have lost both momentum and the interest of their industry partners.

EDTF Recommendations

Because of its incomplete system assessment, use of non-bounding HEMP environments and scenarios, system-wide effects conclusions-based assessment of the transmission grid only, lack of details on the actual testing performed on DPRs, lack of test data on large transformers, and the omission of communication and data transfer systems from their assessment, EDTF recommends that the EPRI report not be used as the basis for transmission grid HEMP protection planning.

EDTF strongly recommends that the Congressional EMP Commission Reports be used by government and industry as the most accurate assessment of the HEMP threat and that EMP Commission recommendations for protecting electric grids and other life-sustaining critical infrastructures be implemented.[25]

EDTF recommends that the Department of Energy look to the Department of Homeland Security's "Electromagnetic Pulse (EMP) Protection and Resilience Guidelines for Critical Infrastructure and Equipment" published on February 5, 2019 by the National Coordinating Center for Communications (NCC) as a model for the type of helpful research product that can help owners and operators of infrastructure begin working on protecting that infrastructure against HEMP.[26]

EDTF has concerns that both federal and state regulators do not yet provide adequate financial incentives to reimburse costs to protect key electric generation and distribution facilities from solar storms and man-made HEMP attack.

Both the Federal Energy Regulatory Commission (FERC) and Regional Transmission Organizations have existing authority to provide cost recovery for investments in protecting high priority elements of the *bulk transmission system*. It is notable that much of the equipment tested within the EPRI HEMP research program of 2016-2019 is already eligible for cost recovery through the regional transmission organizations or ERCOT: protective relays, surge protection devices, and substation control housings with EMP protection are already cost-reimbursable under the Federal Power Act and in ERCOT.

EDTF recommends some combination of financial incentives for prioritized electric generation and distribution would be beneficial to accelerate HEMP and solar storm protection. Tier 1 electric customer Power Purchase Agreements (PPAs) and on-site resilient microgrids

[25] All of the UNCLASSIFIED reports and documents of the EMP Commission and Commission Staff Reports are listed below and can be found here: http://www.firstempcommission.org/

[26] National Coordinating Center for Communications (NCC). "Electromagnetic Pulse (EMP) Protection and Resilience Guidelines for Critical Infrastructure and Equipment," Version 2.2, US Department of Homeland Security, February 5, 2019, https://www.dhs.gov/sites/default/files/publications/19_0307_CISA_EMP-Protection-Resilience-Guidelines.pdf

could be deployed for customers requiring all hazards system reliability. Energy tax credits might be revised to make credit-eligible the costs of added resilience, subject to investment caps or reductions in energy credits for non-resilient energy systems.

EDTF recognizes that the American military and American society currently rely on the bulk power electric grid for survival and that this system will only be adequately protected through collaboration between the nation's foremost HEMP experts and the owners and operators of this system. EDTF also recognizes that America is blessed with an open and free society, an innovative entrepreneurial spirit, and highly adaptive corporate and government leadership. EDTF recognizes that all these commendable qualities are requisite in both the military and in the electric power industry and that no other nation on Earth could change course as quickly as America to protect its own people, economy, and national security. Since the electric power industry employs EPRI to conduct research and provide recommendations for the operation and protection of the grid and all of its components, EDTF highly recommends that industry leaders encourage EPRI to use this technical review to update its research and reassess its conclusions on the effects of HEMP on the bulk power electric system.

Through collaboration on an acknowledgement of the real threat environment, on realistic and peer-reviewed HEMP testing, and on creative cost recovery, EDTF anticipates that the government and electric power industry can work together to secure the grid against man-made HEMP and natural GMD. We recommend expanded collaboration posthaste.

AUTHOR

This technical review is the consolidated work of a host of experts drawn from the more than 200 military, government, academic, and private industry personnel who attended the second Electromagnetic Defense Task Force (EDTF) summit. Appendix 6 of the report titled "Electromagnetic Defense Task Force 2.0," is a sample list of the more than 100 agencies represented at the summit. Chatham House Rules were in effect during the summit and thus attendees contributed freely to the various discussion groups without attribution. The experts who contributed to this specific document range from uniformed military personnel, to civil servants throughout a range of government agencies and various national laboratories, to internationally renowned and published engineers from the Institute of Electrical and Electronics Engineers (IEEE) Electromagnetic Compatibility (EMC) Society that deal with high power transients (HEMP, IEMI, lightning) , the International Electrotechnical Commission (IEC) that sets international electromagnetic compatibility standards, and engineering practitioners who are actively involved in hardening systems, including those associated with military systems and the bulk power system, from these high power transients.

Inquiries can be directed to Maj David Stuckenberg at: david.stuckenberg.1@us.af.mil