GRIDMETRICS/EMP – SPACE WEATHER – MAGNETIC PULSE SENSOR

INVENTORS:

CHRIS BASTIAN

MARK DZUBAN

Introduction

Background on EMP

Electromagnetic pulses (EMPs) are intense pulses of electromagnetic energy resulting from solar-caused effects or man-made nuclear and pulse-power devices. Of these, nuclear EMP has the most ubiquitous effects because of the combination of its broadband nature and large area coverage. Nuclear EMP has the demonstrated potential to disrupt, damage, or destroy a wide variety of electrical and electronic equipment. The strength and area coverage of nuclear EMP environments depends on the warhead type and yield, and the altitude and latitude of the detonation. A nuclear device detonated at altitudes between 30 and 400 kilometers generates an EMP with amplitudes in the tens of kilovolts per meter with a radius of effects from hundreds to thousands of kilometers. This high-altitude EMP (also known as HEMP) effect couples to and can disable electrical and electronic systems in general, but poses the highest risks to long-line networks, including electric power and long-haul communications. Although an EMP is also generated by low altitude or surface bursts (referred to as source region EMP or SREMP), the affected area is localized compared to a HEMP. For this reason, this action plan focuses on larger-scale EMP events produced by high altitude detonations.

A HEMP event includes three waveforms: E1, E2, and E3. The E1 waveform is a fast (nanosecond rise time, hundreds of nanoseconds duration), broad-band pulse that disrupts systems in general, including long-line electrical systems, computers, sensors, and electronic-based control systems. The E2 waveform is longer and much lower in amplitude than the E1 waveform and manifests itself by enhancing the EMP currents on long lines in the microsecond and millisecond regime. E2 current pulses are comparable to currents induced by nearby lightning strikes. The E3 waveform is a low-amplitude, long-duration pulse, persisting for hundreds of seconds that induces currents in long power and communication lines, destabilizing or damaging connected equipment such as transformers and solid state communication line drivers. E3 waveform effects are comparable to those from solar geomagnetic effects. Most conversations about EMP focus on either E1, the large initial energy pulse, or E3, the smaller and longer duration effect, but to properly address EMP, all portions of the waveform must be considered.

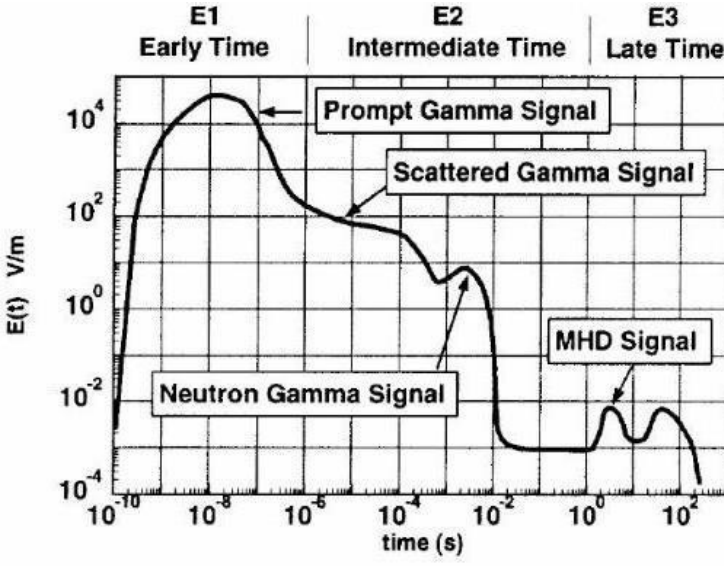


Figure 1. EMP Environment: DOD MIL-STD-464A

The Joint EMP Resilience Strategy

In response to increased concern about the potential impacts to the electric grid from a HEMP, in late 2015, the Secretary of Energy directed the development of an EMP resilience strategy in coordination with the electric power industry. In January 2016, the U.S. Department of Energy (DOE) began work with the Electric Power Research Institute (EPRI) to develop such a strategy. The *Joint Electromagnetic Pulse Resilience Strategy*[1] (Joint Strategy) was released in July 2016. The development of the Joint Strategy was a public-private collaborative effort, designed to establish a common framework with consistent goals and objectives that will guide both government and industry efforts to increase grid resilience to EMP threats.

Central to the development of the Joint Strategy was an effort to enhance shared government-industry understanding of the current status of risks from, and preparedness for, HEMP events. This is of particular importance, as will be discussed later in this document, because much of what is currently known about EMP effects to the grid is extrapolated from computer models designed for other purposes (e.g., understanding Department of Defense (DoD) system effects), or is classified and thus difficult to share with industry.

The Joint Strategy identified five strategic goals:

1. Improve and Share Understanding of EMP: Threat, 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
5. Share Best Practices Across Government and Industry, Nationally and Internationally

Current DOE Efforts to Improve EMP Resilience

In 2016, DOE had five EMP resilience-related projects underway, including the development of the Joint Strategy and DOE Action Plan.

- **Methodology to Assess HEMP Impact on the Electric Grid (Oak Ridge National Laboratory).** This project is developing an approach to assess the damage created by an EMP device that transmission planners can use for planning. The results will include a probabilistic model of bulk power system response under an EMP event, using previous research and established power systems evaluation techniques and will characterize typical SCADA and protection hardware in time domain and frequency domain.
- **EMP/GMD Impacts Study (Los Alamos National Laboratory).** This study is leveraging the best currently available experimental data; device, equipment, and system models; and simulation tools to determine EMP and GMD events of concern. This study is focusing primarily on the bulk electric power system including large generating stations, large power transformers, the transmission network, and transmission system protection. Electrical distribution systems may potentially be included, if warranted, after consideration of the consequences for the bulk power system.
- **Report on Vulnerability of and Impact to Grid from an EMP (Idaho National Laboratory).** This project on the vulnerability of the grid to an EMP will identify the potential impact on reliability and delivery of electric power. The report will address protective and mitigation measures for these vulnerabilities, including hardening of infrastructure, blocking of induced currents and voltages, stocking and prepositioning of spare parts, and operational and emergency planning.
- ***Joint Electromagnetic Pulse Resilience Strategy* (DOE, EPRI, ICF).** The Joint Strategy was designed to establish a common framework with consistent goals and objectives to guide both government and industry efforts to increase grid resilience to EMP threats. (See text.)
- **U.S. Department of Energy *Electromagnetic Pulse Resilience Action Plan* (Idaho National Laboratory and other DOE National Labs, ICF).** The DOE Action Plan is intended to guide DOE's EMP resilience research and development (R&D) activities for the next five years. *(See text.)*

[1] http://www.energy.gov/sites/prod/files/2016/07/f33/DOE_EMPStrategy_July2016_0.pdf

EMP Action Plans

Following development of the Joint Strategy, both DOE and EPRI committed to developing separate, but coordinated, Action Plans that would implement the five strategic goals. EPRI's plan focused on those actions that industry would undertake to mitigate EMP risks; DOE's plan (this Action Plan) delineates the steps that DOE will take to address EMP risks. Although the two Action Plans were developed independently, DOE and EPRI collaborated closely to ensure that the plans complement one another and avoid duplication of effort.

The U.S. infrastructure for electric power generation, transmission, and distribution is predominately owned by private industry and thus its protection lies largely in their hands. In recognition of this, EPRI's industry-focused EMP Action Plan was developed in support of its member companies and the Electricity Subsector Coordinating Council (ESCC),[2] and it was designed to inform industry investment decisions. The research that is outlined in the EPRI EMP Action Plan is scheduled for completion over the next three years.

DOE's Action Plan, by contrast, emphasizes the Federal government's ability to clarify and communicate EMP threats and impacts, reduce HEMP vulnerabilities and facilitate the energy sector's response and recovery after HEMP events. While the focus of this plan is on protection from and mitigation of HEMP effects, many of the actions proposed herein can be scaled to address high-power radio-frequency weapon (RFW) events that may impact a smaller area than a HEMP event and are also relevant to geomagnetic disturbances (GMD)[3] which are similar in system interaction and effects to the E3 portion of the nuclear EMP waveform. Table 1 below compares many of the attributes of EMP and GMD for greater context.

The DOE Action Plan was developed with input from interagency partners, the DOE National Laboratories, and the electric utility industry, in part through a one-day session with more than 50 EMP and electric power industry experts, to identify, discuss, and prioritize potential action items within the context of the five goals of the Joint EMP Resilience Strategy. Experts were also brought in individually to identify and discuss potential action items. An initial set of suggested action items was then developed by the Idaho National Laboratory with support from the Los Alamos, Sandia, Oak Ridge, and Lawrence Livermore National Laboratories.

A subsequent working group enhanced the document and compared the action items with the recommendations made in several major studies that address the EMP threat, such as the 2008 EMP Commission[4] and the 2015 Jewish Institute for National Security Affairs (JINSA) Gemunder Center EMP Task Force[5] reports. Recommendations from these and other studies were

---

[2] The ESCC serves as the principal liaison between the Federal government and the electric power sector, with the mission of coordinating efforts to prepare for, and respond to, national-level disasters or threats to critical infrastructure.

[3] In 2015, DOE worked closely with officials in the White House Office of Science and Technology Policy, other Federal agencies, and international partners, to discuss and develop a Space Weather Strategy and an Action Plan to improve preparedness of the nation to GMD events. DOE has many actions planned over the next several years in support of this strategy.

[4] There were 15 recommendations related directly to the electric power system in the 2008 EMP Commission report. DOE's Action Plan at least partially addresses 11 of these. DOE's Action Plan does not specifically mention quick fixes, does not address telecommunications directly, does not *assure* protection of electricity assets, and does not mention the need to assure an adequate number of recovery personnel. Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack, Critical National Infrastructures, April 2008. http://www.empcommission.org/docs/A2473-EMP_Commission-7MB.pdf

[5] DOE's Action Plan has action items to address at least part of 12 of the 15 recommendations of the JINSA report as it relates to the bulk electric system and one of the participants in the JINSA task force was part of the previously mentioned working group. The DOE Action Plan does not address the two recommendations related to deterrence, nor does it touch on the one related to

considered when determining DOE's final recommended action items. The working group obtained reviews from the participants in the earlier one-day session. DOE then revised the contents accordingly, addressed comments, and prioritized and vetted the final set of action items with EMP experts in order to finalize the DOE Action Plan.

Table 1. EMP versus GMD Characteristics

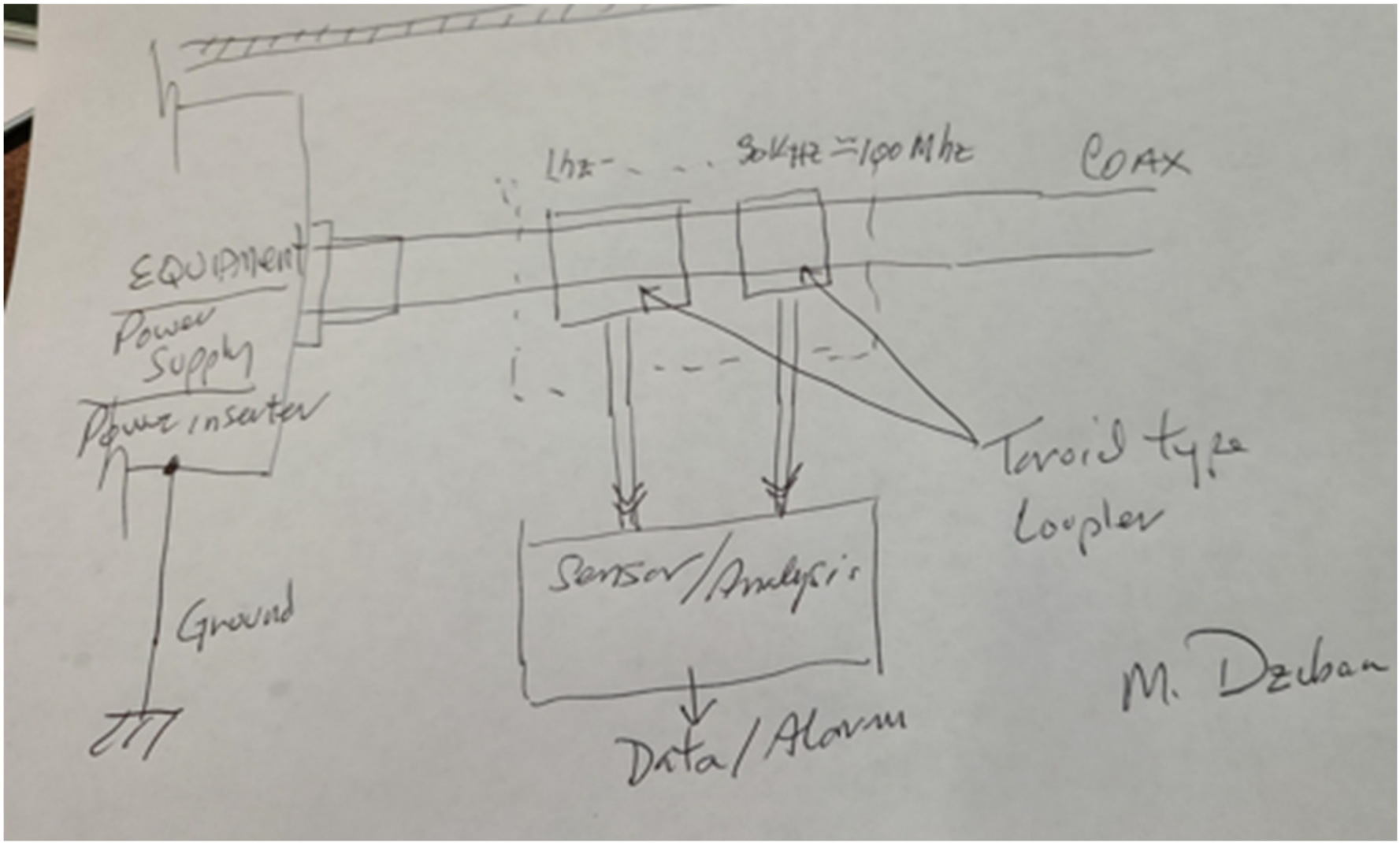
Attribute	EMP	GMD
Cause	Adversarial threat	Natural hazard
Warning	Strategic: unknown Tactical: none to several minutes	Strategic: 18 to 72 hours Tactical: 20 to 45 minutes
Effects	*E1:* High peak field – quick rise time *E2:* Medium peak field *E3:* low peak field, but quicker rise time and higher field than for GMD (possibly 3 times higher)	No comparable E1 wave forms No comparable E2 wave forms *E3:* low peak field – fluctuating magnitude and direction
Duration	*E1:* less than a 1 microsecond *E2:* less than 10 millisecond *E3 Blast:* ~10 seconds *E3 Heave:* ~1 – 2 minutes	No comparable E1 wave forms No comparable E2 wave forms *E3:* hours
Equipment at Risk	*E1:* telecommunications, electronics and control systems, relays, lightning arrestors *E2:* lightning: power lines and tower structures – "flashover", telecommunications, electronics, controls systems, transformers. *E3:* transformers and protective relays – long run transmission and communication - generator step-up transformers	*E3:* transformers and protective relays – long-haul transmission and communications – generator step-up transformers
Footprint	Regional to continental depending on height of burst	Regional to worldwide, depending upon magnitude
Geographic Variability	Can maximize coverage for E1 or E3 *E3*: intensity increases at the lower latitudes and as distance from ground zero is decreased or as yield is increased	*E3:* intensity increases near large bodies of water and generally at higher latitudes although events have been seen in southern latitudes

Structure of the DOE Action Plan

This Action Plan is structured to address each of the five strategic goals defined in the Joint Strategy. For each goal, the Action Plan describes a series of actions that will be taken to further the resilience of the grid to HEMP effects. In total, 19 actions are planned. For each action, this Plan identifies specific deliverables and suggested due dates, as well as key partners. Actions related to each strategic goal are grouped together as many of the actions build upon one another and will be performed in parallel to achieve benefits more quickly.

Progress in achieving the full set of goals and objectives of the Joint Strategy and the actions identified in this and the EPRI Action Plan also depends on the commitment of both government

insurance. Deterrence is viewed as a Government-wide responsibility, not exclusively a DOE role. Insurance was not covered since much of the industry is self-insured. Addressing Electromagnetic Threats to U.S. Critical Infrastructure. *JINSA's Gemunder Center EMP Task Force*. September 2015. http://www.jinsa.org/files/EMPreport.pdf


1hz - - - - 30KHz ≈ 100 Mhz
COAX
EQUIPMENT
Power Supply
Power inserter
Ground
Toroid type Coupler
Sensor/Analysis
Data/Alarm
M. Dzuban