Electromagnetic Events Roundtable Discussion
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Key GAO Findings and Recommendations (2016-2019)

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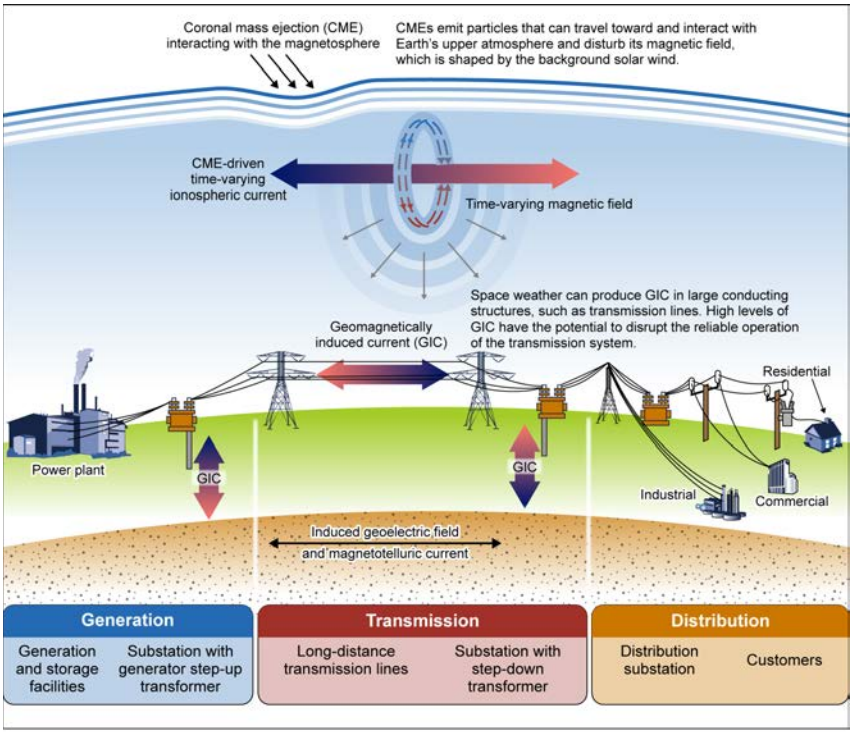
Summary: Since 2016, GAO issued three reports reviewing aspects of electromagnetic events. Such events are characterized as geomagnetic disturbances (GMDs) or electromagnetic pulses (EMPs). GMDs are a result of solar weather—conditions in the solar system that are driven by emissions from the sun. Solar emissions that are directed toward Earth interact with its magnetic field and can cause GMD that can disrupt the normal operations of a variety of technologies including satellites, communications networks, and navigation systems. EMPs are from human-made sources, such as the high-altitude detonation of a nuclear device to create a high-altitude electromagnetic pulse (HEMP).[1] A HEMP event can result in a burst of electromagnetic radiation that can disrupt or destroy electronic equipment.

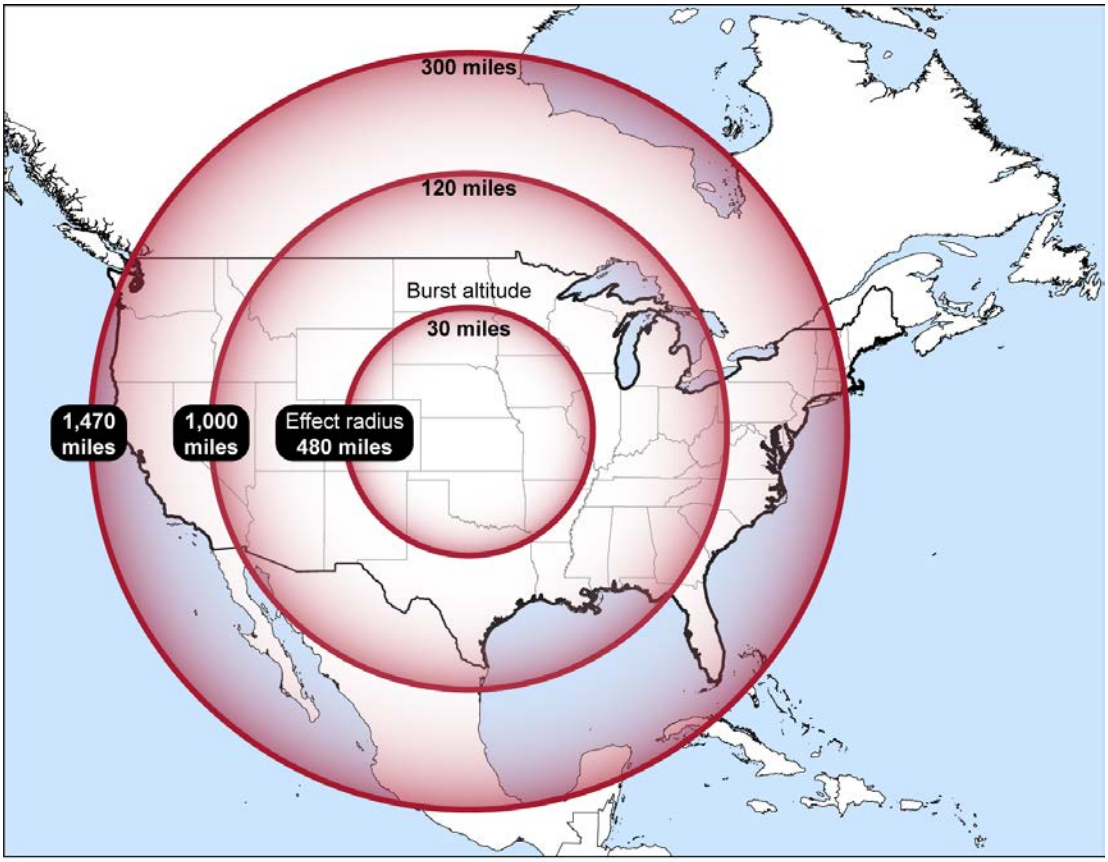
Coronal mass ejections cause geomagnetic disturbances that may interact with the electric power grid



Sources: GAO (presentation); Art Explosion (images). | GAO-19-98

[1]Non-nuclear EMP weapons—those that produce electromagnetic radiation such as devices that generate localized EMP using microwave-type technologies—can also be designed to intentionally disrupt electronics, but these weapons generally have a short range and are not a threat to multiple assets. For example, a non-nuclear EMP weapon might damage a power substation but would not widely affect the electric grid.

Estimated Impact Area of High-Altitude Electromagnetic Pulse (HEMP), by Height of Burst



Source: Gary Smith, "Electromagnetic Pulse Threats," Testimony before the House Committee on National Security (July 16, 1997); MapInfo (map). | GAO-18-67

GAO's previous related reports covered a variety of electromagnetic issues, including:

1) *federal role in addressing GMD and EMP risks*
2) *electricity supplier activities to address GMDs/EMP risks*
3) *technology available for mitigating GMD effects*
4) *status of research on GMD/EMP effects*

In GAO's 2016 review of the federal role in addressing both GMDs and EMPs, GAO made 2 recommendations to the Department of Homeland Security (DHS) and 2 recommendations to both DHS and the Department of Energy (DOE). Subsequently, as of February 2019, DHS fully implemented both of its recommendations and DHS/DOE fully implemented 1 of 2 recommendations directed to both departments. DHS and DOE are taking actions to address the remaining open recommendation, discussed in more detail below.

1. Federal agency actions to address electromagnetic risks to the electric grid

In 2016, GAO found that key federal agencies had taken various actions to address electromagnetic risks to the electric grid, and some actions align with the recommendations made in 2008 by the Commission to Assess the Threat to the United States from

Electromagnetic Pulse Attack (EMP Commission).[2] Since 2008, DHS, DOE, and the Federal Energy Regulatory Commission (FERC) have taken actions such as establishing industry standards and federal guidelines, and completing EMP-related research reports. GAO found that their actions aligned with some of the EMP Commission recommendations related to the electric grid. For example, DHS developed EMP protection guidelines to help federal agencies and industry identify options for safeguarding critical communication equipment and control systems from an EMP attack.

GAO also reported that opportunities existed to enhance federal efforts to coordinate and address electromagnetic risks to the electric grid and made several recommendations.

- **Recommendation**: GAO recommended that DHS designate roles and responsibilities within the department for addressing electromagnetic risks and communicate these to federal and industry partners.
  Status: **Implemented**: In August 2017, the DHS Office of Strategy, Policy, and Plans provided GAO with documentation regarding the status of ongoing DHS efforts to develop an EMP/GMD Strategy in consultation with federal and industry partners, as called for in the National Defense Authorization Act for 2017. As part of this effort, DHS identified for partners the DHS components that comprised the EMP/GMD Strategy Working Group including a description of their key roles and responsibilities related to addressing electromagnetic risks.

- **Recommendation**: GAO recommended that DHS and DOE direct responsible officials to review FERC's electrical infrastructure analysis and collaborate to determine whether further assessment is needed to adequately identify critical electric infrastructure assets.
  Status: **Not fully implemented:** As of February 2019, GAO was awaiting additional information about DHS' plans to implement actions identified in its EMP/GMD Strategic Plan regarding DHS's determination of critical utilities and national security assets at risk from EMP and GMD events. GAO is also monitoring DOE efforts to develop a North American Energy Model that DOE officials reported would also help identify critical electric infrastructure assets.

- **Recommendation**: GAO recommended that DHS work with other federal and industry partners to collect and analyze key inputs on threat, vulnerability, and consequence related to electromagnetic risks.
  Status: **Implemented**. In June 2016, DHS reported that the department completed the planned refresh of the Strategic National Risk Assessment, which incorporated information on potential impacts to the power system from electromagnetic events. In June and November 2017, DHS provided additional documentation identifying joint efforts between DHS's then National Protection and Programs Directorate and DOE to enhance federal efforts to analyze the hazard environments, impacts, and consequences of EMP and GMD on U.S. electric power infrastructure.

- **Recommendation**: GAO recommended that DHS and DOE direct responsible officials to engage with federal partners and industry stakeholders to identify and implement key

[2]GAO, *Critical Infrastructure Protection: Federal Agencies Have Taken Actions to Address Electromagnetic Risks, but Opportunities Exist to Further Assess Risks and Strengthen Collaboration,* GAO-16-243 (Washington, D.C.: March 24, 2016).

EMP research and development priorities, including opportunities for further testing and evaluation of potential EMP protection and mitigation options.
Status: **Implemented**. In June 2016, DHS reported completion of key activities to address this recommendation, including (1) further engagement with DOE and a coordinating council for federal, state, and industry partners to develop a joint government and industry approach to addressing EMP events, and (2) ongoing utilization of the DHS Science and Technology Directorate's process for identifying and pursuing additional opportunities to address potential EMP research and development capability gaps. In January 2017, DOE issued the Electromagnetic Pulse Resilience Action Plan. This document serves to further refine and direct the Department's efforts to reduce EMP vulnerabilities and improve the energy sector's response and recovery after EMP events through coordination with interagency partners and non-federal stakeholders. The Action Plan identifies specific deliverables and associated timeframes. Among these are specific actions to test and promote mitigation and protection approaches, such as developing and validating EMP test requirements. DOE also reported that, as of September 2017, they had funded additional research to test and evaluate GMD Mitigation Devices.

2. Electricity supplier actions to address electromagnetic risks

In February 2018, GAO reported that electricity suppliers had identified information on GMD and HEMP effects on the grid and most suppliers GAO interviewed had taken some steps to protect against GMD and HEMP.[3]

- U.S. and Canadian electricity suppliers—electricity generation and transmission owners and operators—have identified information on the potential effects of a severe GMD, resulting from a solar storm, but have identified less information about the potential effects of a HEMP, resulting from the detonation of a nuclear device, on the electric grid.

    - Government and industry have publicly reported on the potential impacts of GMD on the grid. For example, one study identified two main risks: (1) potential voltage instability, causing power system collapse and blackouts; and (2) possible damage to key system components. However, these studies do not address the unique aspects of individual suppliers' networks. Recognizing this, 11 of the 13 selected suppliers GAO contacted said they had assessed their network vulnerability; of these 11, 6 expected GMD effects to be relatively small.[4]

    - In contrast, DOE and industry officials told GAO that information on HEMP effects is limited in that suppliers lack key information to fully understand HEMP effects on their networks. Historically, the study of HEMP effects focused on impacts to military equipment rather than the commercial electric grid. Recently,

[3]GAO, *Critical Infrastructure Protection: Electricity Suppliers Have Taken Actions to Address Electromagnetic Risks, and Additional Research Is Ongoing,* GAO-18-67, (Washington, D.C.: Feb. 7, 2018).

[4]Of the remaining 5 suppliers, four did not characterize what their studies revealed with respect to the potential severity of the impact and one supplier had not completed its study. The 13 suppliers GAO interviewed were a nongeneralizable sample of 13 U.S. and Canada electricity suppliers, selected based on factors such as GMD experience and preparation for GMD and HEMP events.

DOE and industry began research to better understand HEMP effects. Of the 11 suppliers who responded to GAO about their HEMP efforts, 3 reported having studied the impact of HEMP on their networks.

- Of the 13 selected suppliers GAO contacted, 10 reported making technological and operational improvements to enhance overall network reliability that also provided some protection against GMD and HEMP risks. For example, suppliers reported making technological improvements such as replacement of some older transformers and unprotected control centers. As of May 2017, all 13 suppliers stated they had complied with a GMD regulatory standard issued by the North American Electric Reliability Corporation (NERC)—the federally designated regulatory authority responsible for developing and enforcing reliability standards–-to develop operating procedures to mitigate GMD effects.[5] A second regulatory standard—which is to be implemented in phases through 2022—will generally require suppliers to further assess their vulnerability to GMD.

Electricity suppliers GAO interviewed also described the range of costs incurred to protect against GMD and HEMP.

- Projects providing collateral GMD or HEMP protection at no specific, incremental cost—series compensation systems installed on transmission lines, replacement of older electro-mechanical protective relays used in the suppliers' grid control systems with newer digital relays, and acquisition of spare transformers or participation in shared spare transformer programs.
- Projects providing supplemental GMD or HEMP protection at minimal added cost—transformers and other transmission equipment used to control voltage levels can be made more resistant to GMDs by using certain designs or materials (2-3%+ in cost). Also, added HEMP protection to the design of new control centers has increased total project costs from about 5 to approximately 20 percent.
- Projects built primarily for GMD or HEMP protection—blocking device, with one required per transformer ($500,000); hardened control centers ($10 million); and plans or procedures to mitigate for GMD (costs vary considerably depending on level of demand and electricity generation resources available during the event).

3. Technologies available or in development that could help prevent or mitigate the effects of GMDs on the U.S. electric grid

In December 2018, GAO reported that some types of electric power transmission equipment currently in use can help prevent or mitigate the effects of GMDs.[6]

- The use of transformer designs, such as those with non-magnetic structural components and certain three-phase transformers, can limit the effect of geomagnetically induced current on transformers. The effect of geomagnetically induced current (GIC) on

[5]See NERC Reliability Standard EOP-010-1 (approved by FERC at Order No. 797, Reliability Standard for Geomagnetic Disturbance Operations, 147 F.E.R.C. ¶ 61,209, 79 Fed. Reg. 35,911 (2014)).

[6]GAO, *Critical Infrastructure Protection: Protecting the Grid from Geomagnetic Disturbances,* GAO-19-98 (Washington, D.C.: Dec. 19, 2018).

transformers is the root cause of nearly all GIC-induced disturbances in power transmission systems.[7]

- The use of auxiliary equipment, such as series capacitors and digital protective relays, can reduce the risk of service outages from GIC.
- Inductors or resistors on neutral grounds are generally used for safety purposes, but they can also reduce GMD effects, though their effectiveness is uncertain.

Technologies designed specifically to limit geomagnetic disturbance effects hold promise, but are not ready for widespread operational deployment.

- One system was developed, operationally tested, and piloted, known as neutral capacitor technology. However, following initial operational tests, the transmission system operator stated that the system was not yet ready for widespread deployment. The primary advantages of neutral capacitors over series capacitors are that only one neutral blocking capacitor is needed per transformer instead of three series capacitors, and therefore they may be less costly.

4. Research on GMD and HEMP effects on the electric grid

GMD effects

In December 2018, GAO reported that federal policymakers face three broad questions that need to be addressed regarding GMD effects on the electricity grid: (1) What is the likelihood of a large scale GMD? (2) What is the risk such storms pose to the electricity grid? and (3) What are potentially effective solutions to mitigate the effects of a large scale GMD?[8] Efforts are under way to address aspects of each question that will help inform whether additional actions are needed to prevent or mitigate the effects of GMDs on the U.S. electric grid. For example:

- NERC and the Electric Power Research Institute (EPRI) collaboratively developed a GMD research plan in response to FERC direction. This plan, in part, proposes to develop guidelines and tools to perform system-wide assessment of GIC-induced harmonics which, when completed and implemented, should improve the understanding of the effects that large GMDs and its resulting GIC flow could have on grid performance.
- NASA scientists and other researchers are exploring the physical limit of GMD.
- Vendors are developing and beginning to release GIC packages for commercially-available grid modeling tools that allow utilities to model the effects of GMD on their systems.

According to NERC, the ongoing research will advance understanding of GMD events and the potential impact on the reliable operation of the electric transmission grid.

[7]Strong GMDs can create large GIC on the grid. The degree to which GMD and accompanying GIC affect the electric power system depends on several factors, including the magnitude of the GMD, design and geomagnetic latitude of the power system, and geology of the local area, among other things.

[8]GAO-19-98.

HEMP effects

In February 2018, GAO reported that, according to DOE, more research is needed to fully investigate and evaluate how an electric utility could protect itself from, or mitigate the effects of, HEMP on its systems.[9] DOE also noted that government and industry have ongoing research efforts to better understand these potential effects and develop possible mitigation measures. For example, DOE has three ongoing research efforts related to HEMP. First, DOE is collaborating with DHS to advance the understanding of HEMP effects on the grid through research at the Los Alamos National Laboratory. Second, DOE has funded efforts underway at the Idaho National Laboratory focused on developing potential HEMP strategies, protections, and mitigations for the electric grid—including hardening of infrastructure, blocking of currents, developing a strategy for stocking and prepositioning of spare parts, as well as developing operational and emergency planning tools. Finally, DOE has enlisted the Oak Ridge National Laboratory in analyzing the vulnerability of the grid to a HEMP event, along with the potential damage from such an event, and how it would impact on the reliability and delivery of electric power.

[9]GAO-18-67.