Statement Prepared by
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Introduction

We wish to thank the House Homeland Security Subcommittee on Emerging Threats, Cybersecurity, and Science and Technology for inviting us to submit this written statement with regard to the protection of the critical electric infrastructure of the United States against cyber and other physical threats.

While this statement will draw upon the experience and capabilities of Metatech Corporation, headquartered in California with its largest operation in New Mexico, the opinions expressed in this statement are those of Dr. William Radasky, Ph.D., P.E., President of Metatech and Mr. John Kappenman, P.E., Metatech Consultant.

Our capabilities and experience

Metatech Corporation was founded in 1984, and in its early years focused its work completely on the understanding of the various forms of electromagnetic pulse (EMP) created by nuclear detonations (HEMP, SREMP, SGEMP, etc.). The purpose of understanding these intense electromagnetic fields was to determine the appropriate protection for military electronic systems so that these systems could still operate in the case of a nuclear burst. A burst at high-altitudes (defined as above 30 km) can create a high-altitude electromagnetic pulse (HEMP) that can illuminate the Earth within a line of sight. Two bursts at several hundred kilometers altitude could fully expose the entire United States. This type of EMP is considered one of the most severe due to its wide area of coverage and it near simultaneous illumination of electronic equipment and systems.

With the end of the cold war and the subsequent reduction of nuclear stockpiles in the world, the threat of a major nuclear war has been reduced. On the other hand, the possibility of one or two nuclear bursts at high-altitudes launched by a terrorist organization over the United States seems to have increased (as suggested by the EMP Commission). In the early 1990s, Dr. Radasky began his work with the International Electrotechnical Commission (IEC) to examine the threat of HEMP to civil society. He has chaired IEC SC 77C since 1991, and this subcommittee has produced 20 voluntary standards and publications covering both HEMP and more recently the threat of electromagnetic weapons to civil society (known as IEMI). This committee has drawn upon the standard types of protection that are available within the electromagnetic compatibility (EMC) community and extended them to these more severe threats.

In the 1990s Dr. Radasky and Mr. Kappenman joined forces to examine the threat of geomagnetic (solar) storms on high voltage power grids. Mr. Kappenman had worked in this field for many years with the power industry, studying the impacts of storms on power grids, and Dr. Radasky and his colleagues had worked on advanced forms of electromagnetic numerical analysis stimulated by their earlier work on EMP. It was during this time that we discovered the very strong relationship between the impacts of geomagnetic storms and the late-time portion of the HEMP (known as E3) on the electric power grid. While the generation mechanisms of these disturbances are completely different, the waveforms produced and their impacts on the power grid are very similar.

At the present time Metatech Corporation is the leading company worldwide providing new developments and understandings relating to space weather (geomagnetic storms due to intense solar activity) and its impact on large power grids. Our company has in fact been involved in the vulnerability and risk assessment for the power grids in England and Wales, Norway, Sweden and portions of Japan. Metatech developed and provided continuous space weather forecasting services for the company that operates the electric power grid for England and Wales. Since May 2002, Metatech has been providing similar vulnerability and risk assessments for the U.S. electric power grid to the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP Commission). Metatech has carried out investigations for FEMA under Executive Order 13407 to examine the potential impacts on the U.S. electric power grid for severe geomagnetic storm events. In addition, Metatech work has been formative in the January 2009 Report by National Academy of Sciences "**Severe Space Weather Events—Understanding Societal and Economic Impacts Workshop Report**". The assessments performed by Metatech indicate that severe geomagnetic storms pose a serious risk for long-term outages to major portions of the North American grid. While a severe storm is a low frequency of occurrence event, it has the potential for long duration catastrophic impacts to the power grid and the country. The impacts could persist for multiple years with the potential of significant societal impacts; in addition the economic costs could be measured in the several Trillion Dollars per year range and could pose the risk of the largest natural disaster that could affect the U.S.

What is HEMP and how does it impact the power system?

As indicated earlier, HEMP is produced by a nuclear detonation above 30 kilometers altitude. Intense electromagnetic fields are produced in space by the high-energy radiation leaving the detonation, and these fields propagate downward to the Earth's surface. Because of different types of interactions, there are actually three main pulses created, covering three time frames: less than 1 microsecond, from one microsecond to 1 second, and beyond 1 second. These time regimes have been given the notations of E1, E2, and E3, respectively. As we will discuss in this statement, each of these "pulses" creates different types of problems in modern electric and electronic equipment and systems; this is due to the "coupling" of the electromagnetic fields to the electric power lines themselves and to the control wiring in substations and power generation facilities.

What are other similar EM threats that can be dealt with at the same time?

There are two other significant power system electromagnetic threats of concern to power systems. One is a geomagnetic storm, which begins with the ejection of charged particles from the Sun; these particles travel to the Earth and create large current flows in the ionosphere at levels of up to millions of amperes for a severe storm. The frequency of occurrence of geomagnetic storms follows the solar cycle (~11 years), but it is expected that severe storms with the potential for catastrophic impacts to power grids in the U.S. occur once every ~30 years, based on historical evidence. As in the case of the E3 HEMP, this electromagnetic disturbance couples well to long transmission lines and creates geomagnetically induced currents (GICs) that can create power blackouts and damage to large transformers.

Another electromagnetic threat of concern is that produced by electromagnetic weapons used by criminals or terrorists producing intentional electromagnetic interference or IEMI. These weapons have become more powerful and easier to obtain in recent years due to advances in solid-state electronics. These electromagnetic fields are very similar to those produced by E1 HEMP and will impact the electric power system in a similar fashion. The main difference is that the area affected by IEMI is much less than for HEMP, although the attack is silent and would not be understood in the same way as a cyber attack. In addition an IEMI attack would not leave any trace to determine how the attack occurred, since the electromagnetic fields would arrive simultaneously at several locations in a system, creating multiple failures of hardware and software.

What effects are expected on the power grid from HEMP?

For the operation of the electric power grid, the HEMP E1 and E3 pulses are the most important. Research performed for the EMP Commission clearly indicates the following concerns:

1) Malfunctions and damage to solid-state relays in electric substations (E1)
2) Malfunctions and damage to computer controls in power generation facilities, substations, and control centers (E1)
3) Malfunctions and damage to power system communications (E1)
4) Flashover and damage to distribution class insulators (E1)
5) Voltage collapse of the power grid due to transformer saturation (E3)
6) Damage to HV and EHV transformers due to internal heating (E3)

It should be noted that these effects could result in widespread blackouts due to the large geographic footprint of these environments and the fact that they are simultaneous in nature. In particular a single high-altitude burst above the United States would create an E1 pulse that would arrive at all locations within one power cycle. In addition, widespread damage, especially to HV and EHV transformers could require years to recover due to worldwide production limits.

Costs of hardening

Given the potentially enormous implications of power system threats due to space weather, it is important to develop effective means to prevent a catastrophic and crippling failure of the electric power grid. Recent detailed examinations also conclude that the U.S. and other world electric power grid infrastructures are becoming more vulnerable to disruption from geomagnetic storms and E3 HEMP environment interactions for a wide variety of reasons. This trend line suggests that even more severe impacts can occur in the future for reoccurrences of large geomagnetic storms. These trends of increasing vulnerability remain unchecked, as no design codes have been adopted to reduce geomagnetically induced current (GIC) flows in the power grid during such a storm. Present operational procedures utilized by U.S. power grid operators largely stem from experiences in recent storms, including the March 1989 storm, while storms as much as ten (10) times larger than this storm are only recently understood to have occurred before with the certainty they will occur again. In retrospect, it is also now clear that present U.S. power grid operational procedures are based largely on this out-of-date storm experience, and these procedures will not reduce GIC flows sufficiently; therefore these current procedures are unlikely to be adequate to prevent widespread blackout or damage to key equipment for historically large disturbance events in the future. The same trend line and theme of increasing vulnerability is also true with respect to the fast transient effects of the HEMP E1 and IEMI threat conditions.

Since both hardening and improved operational mitigation development is necessary, it may be helpful to define these terms more clearly. Hardening is a process of modifying the power grid in order to block or reduce GIC in key transformer assets. Operational mitigation is the action of taking various operational actions for the purpose of posturing the power grid (or key assets) to minimize GIC exposure (e.g., removing spare transformers from service based upon an alert/forecast of a severe storm). This combination provides a layered and complimentary approach, in that both act to improve the security of the grid. It is also important that both actions are functionally independent, in that failure to enact a timely or proper operational procedure does not defeat the hardening measures, which reduce the GIC. Infrastructure hardening is clearly the more effective and reliable approach; operational mitigation is highly dependent on the quality of alert/forecast capability and the fact that the varying states of power system operation during a storm may limit the range of effectiveness and flexibility for taking meaningful actions.

E1 HEMP standards and network upgrades

Presently in substations and other power grid facilities, relay and control devices span many generations of designs from electromechanically operated relays to multi-function microprocessor based relays and control devices. The widespread applications of multi-function devices are being used to provide added capabilities to the operation of the power grid; however these devices introduce new vulnerabilities to the E1 HEMP environment. Existing standards have taken into consideration the unique and harsh electromagnetic environment common in a high voltage substation. As a result there are a variety of standards for substation-based protective relays and relay support systems that have evolved over the years. While these evolutions provide protection against some of the threats posed by the E1 HEMP environment, some gaps and shortfalls in immunity test threshold levels continue to exist that if filled would make these devices more robust in their ability to withstand the E1 HEMP or IEMI threats. While the current electromagnetic transient test levels of concern are from sources not related to the E1 HEMP or IEMI environments, some of the similarities illustrate the significant opportunities that are possible for dual application.

Many activities are currently underway within the IEEE and International Electrotechnical Commission (IEC) to update and improve the EMC immunity of electronic equipment used in factories, power substations and power generating stations including nuclear power plants. The IEC has developed a set of electric fast transient (EFT) tests that are very similar to the waveforms coupled by E1 HEMP to cables. The EFT test pulse has a rise time of 5 ns and a pulse width of 50 ns. The typical EMC test levels suggested are between 1 and 4 kV. As noted in Metatech's work, EI HEMP can under some circumstances produce more than 10 kV, with a similar waveform. Of particular interest is the fact that some companies in the European power industry have suggested that higher levels of immunity test standards be applied to power system control electronics. It is clear that if EM standards are developed that have a dual application (normal usage and HEMP), then the possibility of acceptance of these standards will be more positive. In addition, recent work led by Metatech with Cigré is examining the additional protection that would be required in substations to eliminate the threat of IEMI. Protection against IEMI would provide protection against E1 HEMP.

Given the ongoing work and the fact that the U.S. has several HEMP and power system experts involved in the work of the IEC, these new international standards could be analyzed for their application to power system equipment in the U.S. to improve the hardness of the overall power system to HEMP. In addition to the EMC work, there is also continuing work in the IEC to develop further HEMP standards for the civil infrastructure with heavy participation of several U.S. HEMP experts. This work should be directly supported through research funding to develop cost-effective ways to apply the new IEC standards to improve the hardness of important civil systems.

As the EMP Commission Report has noted, there are several thousand major substations and other high-value components on the transmission grid. With the development of standardized and hardened equipment, a continual program of replacement and upgrade with HEMP-hardened components will substantially reduce the cost. The estimated cost for HEMP-hardened replacement units and HEMP protection schemes is in the range of $250 million to $500 million. Approximately 5,000 generating plants of significance will need some form of added protection against HEMP, particularly for their control systems. As the EMP Commission noted, these costs are in the range of $100 million to $250 million.

Power grid hardening and mitigation for E3 HEMP and geomagnetic storms

Both the E3 portion of a HEMP environments and naturally occurring geomagnetic storms can cause the flow of geomagnetically induced currents (GIC) through transformers in an exposed power grid. The GIC, if large enough, can disrupt the AC performance of the grid causing initial blackouts and also creating the potential for permanent damage to large transformers, which can lead to restoration delays of the power grid. Hardening of the power system is optimally done through the application of passive devices or circuit modifications that block or reduce the flow of GIC in a power grid. Because GIC accesses power systems through the multiplicity of grounded neutral leads of wye-connected transformers, the most effective point at which to place blocking or limiting devices is also in these neutral-to-ground leads. Neutral GIC blocking devices have been actively researched since the early 1990s, and several hardware versions have been successfully deployed for blocking stray DC or GIC flows into exposed transformers.

The analysis performed to date for the EMP Commission by Metatech indicates that the conceptual design of installing neutral resistors on the transformer neutral-to-ground connections is the preferred option of protection. These resistors would be low resistance – on the order of 5 ohms. Even though small, they would substantially increase the resistance in the power line network; since they are located in the neutral to ground connection, they would not substantially decrease the efficiency of operation of the power grid. These devices would allow a significant reduction of the GIC currents induced (around 60% reduction in overall GIC levels are estimated from the studies). The advantage of this design is that it will be relatively simple to develop with lower engineering trade-off risks and lower overall installed costs compared other more exotic devices. In order to evaluate this option more completely, it will be necessary to carefully study the economic aspects of this approach and to move forward with a funded R&D effort to fully engineer and test the prototypes.

The EMP Commission in their report estimated costs for switchable ground resistors for high-value transformers are estimated to be in the range of $150 million. Further studies are needed to determine the number and location of high-value transformers, but preliminary estimates are for some ~5000 such transformers to be considered on the 230 kV, 345 kV, 500 kV and 765 kV networks. These cost estimates are based upon simple devices that are still at a conceptual stage of development. Metatech has been briefing various interested government agencies and organizations on a comprehensive R&D program that would finalize the design requirements for the protection system and would develop better estimates of costs; therefore total costs several times larger than the previous EMP Commission estimate might be foreseeable.

With respect to the overall cost of hardening, it is also important to keep in mind the cost of outages, even when they are of short duration. A hardening program that expends even as much as ~$1 billion to protect the U.S. power grid against a severe geomagnetic storm, an event that has occurred before and is certain to occur again, is still far cheaper than the costs of a widespread blackout to the U.S. economy. For example the DOE estimated that the August 2003 Blackout, (affecting ~60 million people in Midwestern and NE US) cost about $10 Billion. If we instead only elect to black out or shut down the power grid based on forecast alerts of this sort of event, it would cost more than 10 times the hardening cost just in terms of the economic impact to the U.S. When one factors in that forecasts will no doubt come with false alerts, then the costs of hardening are indeed quite prudent.

Operational mitigation training

The EMP Commission also recognized the importance of developing a capability to monitor and evaluate the unique set of adverse effects on critical systems and to speed their restoration. Operators and others in a position of authority must be trained to recognize that a HEMP attack, an IEMI attack or a severe geomagnetic storm is occurring or is about to take place. This should be done in order "to understand the wide range of effects it can produce, to analyze the status of their infrastructure systems, to avoid further system degradation, to dispatch resources to begin effective system restoration, and to sustain the most critical functions while the system is being repaired".

The detailed power grid models that have been employed by Metatech for the EMP Commission and FEMA studies provide an excellent starting point to develop a comprehensive training program and operational avoidance procedures for the U.S. power industry to counter the harmful impacts from the E3 HEMP and severe geomagnetic storm environments.

As the EMP Commission and others have suggested, efforts to promote training centers that would have the mission of simulating, training, exercising, and testing both operational avoidance and recovery plans are important for the country. These training centers would allow the comprehensive simulation of HEMP and other major system threats, such as geomagnetic storms or coordinated terrorist attacks, whether they are physical or electromagnetic in nature (IEMI). These training centers would aid in the development of procedures for addressing the impact of such attacks to identify weaknesses, to provide training for personnel and to develop HEMP response procedures and coordination of all activities across appropriate agencies and industry.

Better and more appropriate procedures can be developed such as:

- Making decisions to remove certain high value assets (such as EHV transformers) from operation in the network to reduce their exposure to damaging GIC levels.
- Making decisions to remove key generating plant transformers from operation again to reduce their exposure to damaging GIC levels.
- Making decisions to reduce or shed load (or to create limited blackouts) in portions of the grid to reduce exposure of high value assets to damaging E1, E3, or severe geomagnetic storm environments.
- Making decisions on additional staffing under alert conditions to perform manual overrides, where possible, of operational controls that could be compromised due to E1 impacts.

Alert capabilities

In 1998, the National Grid Company, which operates the power grid for all of England and Wales, awarded Metatech a contract to develop and operate the world's first geomagnetic storm forecasting service using solar wind electrojet models. These operational electrojet models are driven by solar wind data from the ACE L1 satellite. This detailed electrojet model provided a predictive forecast capability needed by the electric power industry. Large and sudden storm onsets can erupt on a planetary scale within a matter of minutes, meaning that power systems that are concerned about the impact of these disturbances will not have any meaningful lead-time available if they depend upon local real-time monitoring alone. In the famous geomagnetic storm of March 13-14, 1989, the Hydro Quebec power grid went from completely normal operating conditions to complete province-wide blackout in an elapsed time of only 90 seconds. The electrojet predictive model will instead provide these power system operators a nominal lead-time of approximately 45 minutes for most storm events, and a somewhat smaller lead-time for major events.

The advanced geomagnetic storm forecasting system was developed to provide forecasts for the entire Northern Hemisphere, and detailed impacts of these storm conditions were further assessed for the NGC power grid across England and Wales. This system updated the forecast on a continuous one-minute cadence and became operational in May 1999. This system was deployed in the NGC System Control Room in Wokingham, England where it was continuously used as the primary space weather tool for the control of the entire national grid. In addition to these forecast capabilities, Metatech with NGC deployed 16 real-time remote monitoring locations throughout England and Wales to monitor the storm environment and impacts on the power grid. Nearly 2000 channels of data are continuously collected in real-time from this sophisticated network and made available for nowcast and system status displays in the NGC System Control Room. This geomagnetic storm forecasting system, which is highly tailored to electric power grids, is the most-advanced in the world, even exceeding the capability of the NOAA-SEC.

In addition, Metatech has successfully modeled and validated detailed power grid models throughout the world. A complete U.S. Power grid model has been fully developed for the U.S. EHV Power Grid infrastructure and was employed in both the EMP Commission studies and also in FEMA investigations under Executive Order 13407.

While it is possible to install a geomagnetic storm forecasting system in the U.S. using the approach applied in the case of England and Wales, it should be noted that this system provided the forecast to a single location, where action could be taken for the entire grid. In the U.S. the situation is different, and both for geomagnetic storms and a HEMP attack, it is necessary to develop a procedure to send the geomagnetic forecast or information concerning a missile launch at the United States to all power grid operators within minutes. In addition a coordinated response of the power grid operators needs to be determined ahead of time for different scenarios. It is important that action be taken to allow this information to be sent to those who require it.

Concerns about smart grid security

While the current situation with regard to the vulnerability of the power grid to HEMP and other high-level electromagnetic disturbances is serious, national discussions of future changes to the power grid could well make things worse. In particular the concept of the "smart grid" is under active consideration, and while the precise details of such a plan are not clear, it is clear that a major objective is to collect more data on the grid and to provide that data to the operators of the grid.

The problem with many proposals for the smart grid is that there will be a proliferation of millions of computers (smart meters), which will be placed at homes and businesses to monitor the use of power in real time. These data will allow the system operators to operate their grids more efficiently and to eliminate the need for extra margins. These distributed computers will be vulnerable to the threat of radiated and conducted high frequency threats (such as E1 HEMP and IEMI) and will be impacted by severe harmonics created during E3 HEMP and geomagnetic storms. It is clear that very high levels of electromagnetic protection should be required for these meters, yet in discussions concerning smart meters today, security seems to be a second thought. We recommend that the physical and electromagnetic security of smart grid components be raised to the highest level of consideration.

Another area of concern is the plan to build a new super-grid to connect wind power in the Midwest with the Eastern and Western grid with the construction of a new 765 kV grid. It is important to recognize that the higher voltage levels of this transmission network (relative to the 500 kV grid in most of the country) increase its vulnerability to E3 HEMP and geomagnetic storms, potentially increasing the vulnerability of the grid by a factor of 2 or more over what exists today. Plans to build such a grid should definitely consider the protection of the high voltage transformers.

Role of standards

As alluded to at several points in this statement, it is first important to make a decision that the power grid needs to be protected against HEMP and other similar electromagnetic threats such as geomagnetic storms and IEMI. Once this is done then the means to accomplish the goal should be through standards. While standards often take years to develop, in this case much of the HEMP and IEMI work has already been done in the IEC for generic systems (e.g., computers). Standards can therefore be developed rapidly to improve the hardening of hardware currently in service and also for the development of new products. This approach will allow the fastest time to reach a hardened state, while keeping the costs at a reasonable level.

Conclusions regarding FERC regulatory authority

Given that the U.S. has a very diverse, mostly private ownership of the power grid, it is difficult for industry to deal with the threats of HEMP, geomagnetic storms and/or IEMI on their own and certainly not in a piecemeal fashion. There is an argument that if a power company makes improvements to their portions of the grid and others do not, then wide area geographic threats can still have a catastrophic impact.

During the beginning of the power system work in the EMP Commission, NERC was invited to provide its recommendations regarding which power system electronics were the most important to the operation of the grid. A prioritized equipment list was provided and used by the EMP Commission to perform susceptibility tests. While this part of the collaboration was successful, follow-up discussions with NERC were not as successful. It seemed that the working level people within NERC were not willing to recommend protection standards against HEMP in spite of overwhelming evidence that this threat falls into the low probability, high consequence area. Indeed the potential consequences are so serious that it should be viewed as a Systemic Risk, one that could threaten the lives of many and alter the course of the history of this country, if ever allowed to unfold.

For this reason, we would recommend that FERC, which has already shown a strong interest in the protection of the power grid from HEMP, be given the regulatory authority to deal with the threat of HEMP and other related electromagnetic threats.