Electric Infrastructure Protection (E-PRO®) Handbook

An evolving, cooperative resource for infrastructure resilience and whole community response planning and coordination, addressing severe hazards to electric infrastructure
Acknowledgments

Development and production of this Handbook, the first of its kind, would have been impossible without the help, consultation and review of many individuals and organizations. Although they cannot all be acknowledged here, the editors and publisher wish to express their deepest appreciation to the many contributors to this Handbook, worldwide.

We wish to particularly acknowledge and thank the following distinguished contributors and advisors for their generous assistance:

Dr. Daniel Baker  Director, Laboratory for Atmospheric and Space Physics, University of Colorado
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Roger Steen  Norwegian Water Resources and Energy Directorate
Keith Stefanelli  Director, Emergency Management Coordination Disaster Cycle Services, American Red Cross National Headquarters
This project would also have been impossible without the generous support and active encouragement of a number of philanthropic foundations and individuals. The authors and publisher wish to offer special commendation and thanks to these dedicated, visionary philanthropists:

Dr. Jack Templeton  
The Marcus Foundation  
The Newton D. and Rochelle F. Becker Foundation  
Steve and Rita Emerson  
The Michael and Andrea Leven Family Foundation  
Steven and Bonnie Stern  
Kenneth and Nira Abramowitz.

Published by  
The Electric Infrastructure Security (EIS) Council

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U.S. Air Force airmen unload power repair equipment belonging to Southern California Edison from a C-5 Galaxy aircraft at Stewart Air National Guard Base in Newburgh, N.Y., on Nov. 1, 2012. The Department of Defense initiated the airlift operation to aid recovery efforts in Hurricane Sandy’s aftermath. [Source: DoD photo by Master Sgt. Corine Lombardo, U.S. Army. 11/1/12]
According to industry and government studies in the United States and allied nations, there are growing risks of long duration, wide area electric outages due to a range of increasingly severe hazards, both natural and manmade. These hazards include catastrophic earthquakes, highly destructive hurricanes, Electromagnetic Pulse (EMP) weapons, sophisticated cyber attacks and coordinated physical assaults on key grid components. Many of these hazards could cause electric power outages lasting far longer, and covering a much wider area, than those caused by Superstorm Sandy, and could strike with little or no warning.

Industry, government, and non-governmental organizations are partnering to strengthen the grid’s resilience against these extraordinarily severe hazards. Deepening and expanding their collaboration into new realms is essential to meet the many resilience challenges that remain.

This Handbook provides recommendations to help utilities and their partners reduce the scope and duration of outages that severe hazards can cause. The Handbook also proposes a “whole community” approach to manage the consequences of outages that do occur, and help save many thousands of lives that may otherwise be lost.
**All hazard response and power restoration planning.**

Many of the Handbook’s proposals are structured to build resilience against all hazards, natural and manmade, that could cause catastrophic, extended duration power outages over multiple regions of the United States or other nations. This all-hazards approach to response planning is especially useful for framing recommendations to reduce the consequences such events will have for public safety, national security, and the economy. An all-hazards approach is also helpful for identifying new partnership opportunities to strengthen consequence management, and help utilities accelerate the restoration of power. In particular, the Handbook examines opportunities to build whole community preparedness against catastrophic outages, with contributions from individuals and their families, agencies at all levels of government, Non-Governmental Organizations, and the private sector.¹

**Hazard-specific mitigation: The special challenges of electromagnetic threats²**

Mitigation measures to protect the grid from damage tend to be more hazard-specific than those for response planning. The electric industry is making great strides in protecting the grid from many severe hazards, including catastrophic storms, cyber threats and coordinated physical attacks. In contrast, efforts to develop cost-effective mitigation measures against emerging electromagnetic threats (E-threats) – Severe Space Weather and Electromagnetic Pulse (EMP) weapons – are in the developing stages. The mitigation section of this Handbook will, therefore, address primarily these less familiar and especially challenging E-threats.

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¹ For an overview of whole community principles, themes and pathways to action that the Handbook applies to severe power outages, see Federal Emergency Management Agency, Whole Community, http://www.fema.gov/whole-community

² Electromagnetic threats (E-threats) to the power grid include two effects. Severe Space Weather refers to a periodic disturbance of the sun’s corona which can cause potentially damaging current to flow through power grids, due to large variations induced in the earth’s magnetic field (Geomagnetic Disturbances – GMD).; Electromagnetic Pulse (EMP), resulting from a nuclear detonation in the upper atmosphere, can cause power grid disturbances similar to Severe Space Weather, as well as a very intense, short pulse that can damage electrical equipment.
Focusing on realistic, limited, cost-effective mitigation

The potentially devastating effects of E-threats on an unprotected power grid should not lead to the mistaken belief that such threats are overwhelming and impossible to mitigate. They are neither.

Across the United States, utilities are already developing cost-effective investment strategies against EMP, and Geomagnetic Disturbances (GMD) caused by Severe Space Weather. (For the United States, the Federal regulatory process is providing a set of mandatory mitigation requirements for GMD).³ What is missing is a framework to share these emerging best practices across the full range of resilience stakeholders, and to sustain progress on a voluntary, collaborative basis to build resilience against these non-traditional hazards. The Handbook provides such a framework, and identifies a spectrum of relatively modest but high-payoff investment options that utilities may wish to consider.

The Handbook as a decision support tool

Neither the Handbook’s E-threat specific mitigation options nor the proposals for all-hazard consequence management and power restoration are intended to be prescriptive in a “one size fits all” manner. Each utility and their partner organizations in government and beyond face unique circumstances and requirements for building resilience against catastrophic outages. Rather, the recommendations provide a set of especially promising, operator-oriented, actionable options for partners to adjust to their own needs, and establish a framework for the multi-year collaborative process that will be required to build resilience through expanded partnerships.

Grid protection and restoration plans will also need to be sufficiently flexible to adapt to the operational surprises and unexpected problems that severe hazards will create. These hazards are likely to damage the grid in unanticipated ways, and also to cause cascading failures of communications, transportation, and other critical infrastructure on which utilities and their partners depend.

³ Note on “GMD” terminology: While geomagnetic disturbances (GMD) can be caused by either Severe Space Weather or EMP events, in common usage “GMD” has generally been used to refer exclusively to those geomagnetic disturbances caused by severe space weather. For consistency, the term “Geomagnetic Disturbances” and its acronym, “GMD,” refer to effects caused by space weather, except in those specific contexts where the corresponding EMP effect is discussed.
to restore power. The Handbook examines architectures for grid hardening and restoration to help meet these “real world” challenges.

This first edition focuses exclusively on resilience and restoration options associated with the electric sector, and on opportunities for support from Federal, State and NGO partners that could be crucial in recovering from severe hazards. Future editions will propose initiatives to support coordinated resilience with other critical infrastructure sectors, including natural gas pipelines and other energy systems, communications, water and wastewater systems, and other sectors vital for public health and safety.
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Executive Summary
Black Sky Hazards: The Challenge

In less than a century, electric power grids have become truly foundational. The economy, national security, and public safety of the United States and its partner nations are utterly dependent on the flow of electricity. Consistent with this critical role, utilities and other stakeholders have made the grid increasingly resilient against storms and other traditional natural hazards. Today, however, an array of novel threats are emerging that the grid was never originally designed to survive.

Cyber weapons, coordinated physical attacks on key grid components, Electromagnetic Pulse (EMP) weapons, severe solar storms, catastrophic earthquakes and other hazards of unprecedented destructiveness can all create “black sky days:” i.e., extraordinary and hazardous events that are utterly unlike the “blue sky days” in which utilities optimally function, and which would produce power outages lasting longer and covering a wider area than those created by Superstorm Sandy.

The EPRO Handbook examines how power companies, government agencies and other key stakeholders can partner to build resilience against these black sky hazards, and significantly reduce the impact and duration of the outages they may otherwise cause.
A growing number of studies have highlighted the societal disruption that extended, wide-area power outages would cause. Such outages could result in the shutdown of municipal water and wastewater systems, the failure of hospitals and pharmaceutical suppliers, and the breakdown of food manufacturing, food distribution and other critical infrastructure sectors vital to public health and safety. Without focused, comprehensive resilience and response planning against black sky hazards, such long-duration outages could put societal continuity at risk.

In response to these risks, a growing number of power companies are investing heavily to help protect the grid against non-traditional threats. Many state utility commissioners are working to develop new approaches to determine which kinds of proposed investments are prudent and cost effective against such hazards. State and federal government agencies, non-governmental organizations, global insurance companies and other key stakeholders are also forging deeper partnerships with industry to strengthen the grid’s resilience, and are seeking new resilience guidelines and analytic support for plans to reduce the duration and disruptive effects of outages that do occur.

All of these stakeholder communities came together to develop the recommendations in this Handbook. In a series of seminars and leadership conferences, utilities and Regional Transmission Operators, State and Federal regulators, leaders from all levels of U.S. and partner governments, and non-governmental organizations examined emerging shortfalls in resilience and how best to mitigate them. Participants in these Black Sky resilience and response seminars focused on three especially significant challenges, each of which offers concrete opportunities for progress.4

**First,** black sky events will not only create unprecedented requirements for first responders and their partners to save and sustain lives, but will also make those life-saving operations vastly more difficult to conduct. The flow of disaster assistance relies on transportation systems, communications networks, emergency operations centers and other facilities dependent upon electric power. When the grid goes down, many of the facilities providing these critical support functions have emergency power generators with

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4 These seminars were originally titled “The 3-Sector Black Sky Resilience and Response Seminars.”
sufficient fuel to operate for at least a few days. During wide-area outages that last substantially longer, however, generators will begin to break down and supplies of fuel for them will quickly fall short.

Given the disruptive effects that black sky hazards could create for infrastructure sectors essential to saving and sustaining lives, disaster response and recovery operations cannot be effectively organized without extensive, cross-sector planning and training. Absent such collaborative efforts, operations to manage the consequences of a catastrophic outage will be jeopardized precisely when they are most needed.

**Second**, a historic gap persists between two requirements for resilience against catastrophes: 1) plans for power restoration; and 2) “traditional” disaster response plans to manage the consequences of the event, and conduct life-saving and life-sustaining operations. Sandy highlighted the degree to which Federal, state and local leaders will emphasize accelerated power restoration as an overall disaster response priority. Until recently, however, surprisingly few states had featured power restoration support as a core focus of their response plans.

Florida, California, New York, and a number of other states are advancing new initiatives to bridge this gap. However, few mechanisms exist to share their emerging best practices. Moreover, for resilience against black sky hazards, utilities and their disaster response partners will have to extend these integrative efforts into new realms. In particular, they will need to embed power restoration support into broader disaster preparedness for: (1) non-traditional hazards such as coordinated physical attacks on key grid components; (2) multi-region events that require integrated planning for disaster response and power restoration far beyond state lines; and (3) the disruptive impact of long duration outages on infrastructure essential for both traditional disaster response and power restoration. Moreover, key partners in the U.S. disaster response system -- including the Red Cross and other nongovernmental organizations -- are rarely integrated into power restoration planning, even though their capabilities could prove uniquely valuable to support power restoration crews and other missions.
Third, while investments to protect critical grid components against black sky hazards may greatly reduce the scope and duration of future outages, more progress is needed to share prudent, cost-effective strategies to guide such investments. This has been particularly true for protection against Electromagnetic Threats (E-Threats) such as Electromagnetic Pulse (EMP) weapons and Geomagnetic Disturbances (GMD).

The Federal regulatory process is now addressing some aspects of this gap, producing a series of mandatory rules to guide investments in protection against space weather-generated geomagnetic disturbances. However, protection against GMD will still leave the grid vulnerable to other destructive effects of EMP. The Federal Government has done little to share its expertise on EMP protection options and emerging best practices. Moreover, while relatively modest investments in protecting key grid components may offer major benefits for resilience against EMP, little systematic research has been done to assess these options, or to provide a framework for making investment decisions. Providing such a framework is a primary focus of the Handbook.

A key finding of the Handbook: existing Federal policies and organizational arrangements provide a strong foundation for progress.
A key finding of the Handbook is that existing Federal policies and organizational arrangements provide a strong foundation for progress, especially through voluntary, collaborative initiatives.

The National Response Framework (NRF) and National Incident Management System (NIMS) provide especially important foundations for progress. These documents offer a basis to launch a “whole community” effort to strengthen resilience against severe outages, and integrate the full range of industry, government, and non-governmental organizations that – if prepared to operate in a disrupted environment – can help save and sustain many thousands of lives that will otherwise be at risk. Emergency Support Function 12 (ESF-12, Energy) provides the key foundation for the Handbook’s recommendations to broaden and deepen support to utilities for accelerated power restoration operations. The National Infrastructure Protection Plan, its Energy Sector-Specific planning annex and other sources of U.S. infrastructure policy provide similarly valuable starting points for building consensus on how (and how much) to protect the grid against EMP and other black sky hazards.

The EPRO Handbook leverages these existing organizational arrangements and sources of guidance, and offers recommendations that are fully consistent with them. The recommendations are also structured to help support the
development of the Power Outage Incident Annex and other ongoing Federal, state and local planning efforts to address the risks of severe outages.

Superstorm Sandy: Building on Lessons-Learned

The Handbook recommendations also support and build on the array of resilience initiatives launched in response to Sandy. The electric industry, local, State and Federal leaders and other stakeholders have created a broad range of efforts to capture the lessons learned from the Superstorm and build resilience against even more severe outages.

Helping inform and deepen integration across these initiatives is a key goal of the Handbook.

Industry Initiatives for Wide-Area Outages

The damage Sandy inflicted on the grid was unprecedented in its geographic scope. Approximately 10 million customers lost power across 24 states in the Northeast, Mid-Atlantic, and Midwest. In response the electric industry used its regional mutual assistance agreements to deploy over 60 thousand power restoration workers, from dozens of States and Canada. Now the electric industry has launched an ambitious effort to prepare for “National Response Events:” that is, the most serious outages caused by a major hurricane, earthquake, act of war or other event that requires power restoration resources from multiple U.S. regions. Utilities are also ramping up their capacity to share critical spare grid components, and – especially important – plan to invest many hundreds of billions of dollars in coming years to modernize the grid and strengthen its
resilience. As industry scales up its capacity to protect against and respond to National Response Events (NREs), a unique opportunity is emerging to expand support for those initiatives from the government and NGO communities.

**The Role of Federal, State and Local Governments**

In order to assess resilience proposals to ensure they are prudent and cost-effective from the perspective of rate payers, State Public Utility Commissions (PUCs) across the United States are beginning to develop new regulatory guidelines and assessment tools. State government energy officials and their Federal partners in the Department of Energy are also developing new initiatives to improve grid resilience, including efforts to improve planning and capabilities for power restoration under Emergency Support Function 12 (ESF-12). Organizations such as the National Infrastructure Advisory Council, the North American Electric Reliability Corporation and the Electricity Subsector Coordinating Council have launched additional resilience initiatives against “high impact” hazards. Important new opportunities are emerging to leverage these initiatives and accelerate progress in building grid resilience. The Handbook recommendations that follow propose concrete, actionable ways to do so.

Sandy has also spurred the emergence of new and immensely valuable partners for grid resilience. State and territorial governors are especially notable in this regard. Since Governors have primary responsibility for the public health and safety of their citizens, and because the National Response Framework puts them at the heart of the process for requesting Federal disaster assistance, they have long played a central role in the U.S. disaster response system. Sandy drastically raised the visibility of power restoration as a priority for disaster response. With the support of the National Governors Association, Governors across the United States are driving new initiatives to strengthen grid resilience and help accelerate restoration, including efforts by state officials in transportation, public safety, and other departments to facilitate the flow of and support for multi-state response operations. In particular, State National
Guard leaders are drawing lessons learned from Sandy and expanding their utility support missions for power restoration in severe events.

State emergency management and homeland security leaders are playing key roles in these efforts. Until Sandy, few emergency management organizations beyond the hurricane belt had focused on power restoration as a top priority for disaster preparedness. The National Association of Emergency Managers, which oversees the Emergency Management Assistance Compact system that provides for the flow of state disaster response resources (including the National Guard) across state lines, had never examined how that system might be brought in direct support of the utilities’ mutual assistance system during a catastrophic outage.

Nor had the Federal Emergency Management Association developed a plan for long-duration outages and the unique challenges for coordinating and providing the Federal disaster assistance that such outages could create. That FEMA planning effort will soon be underway.

**The Critical Role of Families and Individuals**

Individuals and their families can also make enormous contributions to their own ability to survive catastrophic outages and assist their neighbors and communities. In fact, the more severe the event, the greater the risk that government assistance will be slow to arrive, and the greater the benefits that citizen preparedness can provide. The Handbook proposes a range of measures (including initiatives to strengthen communications during severe outages) to help individuals and their families better contribute to whole community resilience against black sky hazards.
The Role of NGOs

In the United States, efforts to bring Non-Governmental Organizations (NGOs) such as the Red Cross, the United Way, and faith-based disaster response organizations into this partnership are only in the beginning stages. A recent NGO-focused seminar, conducted to develop and review the Handbook’s NGO-oriented recommendations, helped launch that exploratory effort.

As discussed in the seminar, the National Response Framework and Emergency Support Function 6 (ESF - 6, Mass Care) give NGOs vital roles in saving and sustaining lives during disasters, including emergency sheltering and feeding operations. In catastrophic outages lasting weeks or even months longer than Sandy, the disruption of food distribution, municipal water systems and other vital infrastructures, and the potential need for mass movement of people out of impacted regions, would create unprecedented requirements for mass care.

Yet, a long duration power outage would also disrupt the ability of NGOs and their volunteers to function. Given the impact that such an outage would have on communications and transportation, including the disabling of virtually all gasoline pumps, NGOs would confront unprecedented operational challenges. Little analysis has emerged on the measures that NGOs and other disaster response organizations can take to build their own resilience against catastrophic outages, so they can sustain lives on the scale that such an event will necessitate. Still less analysis has examined how NGOs could help downsize this response challenge by supporting utility power restoration crews and their families and shortening outage duration. Building on the focused seminar and a range of other consultations, Handbook recommendations are designed to help define support roles that represent a critical need for the NGO community, and address some of the crucial challenges that will be faced in performing these roles.
Recommendations for Protecting the Grid from GMD and EMP

Ideally, investments in protecting the grid can help strengthen resilience against all hazards. In practice, however, more targeted, hazard-specific investments sometimes offer especially significant benefits. As indicated in the Forward to this Handbook, mitigation of E-threats is commonly recognized as far less mature than protection against any other emerging black sky hazard.

As a result, Chapter 2 of the Handbook, summarized here, focuses on E-threat mitigation for power generation, transmission and distribution systems, addressing resilience and restoration strategies and options addressing both malicious threats – Electromagnetic Pulse (EMP) and Intentional Electromagnetic Interference (IEMI) – and GMD.

The starting point to strengthen grid resilience against E-threats is to recognize that while EMP and GMD will affect very large regions, they will damage or destroy only a fraction of exposed, vulnerable electrical and electronic components. EMP, for example, will not destroy all electrical and electronic components, devices and systems in an affected area. While complex, computer-intensive control systems (including unprotected power grid control systems) will typically fail, most electrical and electronic hardware in the region will likely survive. The bottom line: protecting all such hardware is not only impractical, it is also unnecessary.

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6 Ibid

7 Ibid
A limited, targeted set of investments in power grid equipment hardening can have enormous benefits for strengthening the grid’s resilience against E-threats, and effective protection can also be achieved at different investment levels. With careful pre-planning, operational measures to protect the grid against Geomagnetic Disturbances can also be valuable, although – in many cases – they also involve potential risks. However, while E-threat resilience measures provide a vital foundation for recovery, assured and accelerated power restoration will also require specialized sparing initiatives and restoration plan modules that address the unique challenges of GMD, and EMP and IEMI weapons.

**Targeted, Integrated, Cost-Effective Power Grid Protection Planning**

To achieve the greatest benefits for grid resilience, mitigation efforts should focus on one key objective: providing the protection measures and restoration planning needed for assured, accelerated power grid recovery from a large regional outage.

Strategic protection of carefully selected “enclaves” of restoration-critical infrastructure by power companies can provide a foundation for such assured, accelerated recovery, and the scope of this protection is subject to corporate decision making. In the detailed discussion on Chapter 2, an example of a 3-level “menu” of protection levels associated with such enclaves is provided – Minimum (Level I), Intermediate (Level II) and Comprehensive (Level III) – designed to offer decision makers examples of balanced investment scenarios compatible with different levels of “hardening” or built-in resilience, as a foundation for restoration operations. Expanded, adaptable restoration planning, along with critical support from partner communities to these corporate restoration plans, can then build on that foundation, providing an optimum, resilient path to assured recovery.
1. Strategic Protection
   Defining Secure “Enclaves” as a Foundation for Restoration

   By protecting, not an entire grid region, but carefully selected “enclaves” – critical generation and transmission assets that either remain operational or can be quickly restored – an affected grid region will have a reliable starting point for power restoration, as a cost-effective strategy for assured, adaptable resilience.

   For power generation, “black start” facilities – self-starting generation assets – will be crucial to begin the restoration process. By also protecting other selected, major generating plants, and the cranking path transmission system needed to bring start-up power to these plants from the black start generators, adaptable restoration plans will have the assets needed for accelerated restoration.

   For power transmission, protecting selected control centers and associated assets will provide an assured basis to assess and control power restoration. And given the long-lead acquisition times typical for Extra High Voltage (EHV) transformers, protection of such transformers and related hardware at critical power grid nodes or other high-priority or sensitive locations will assure continued operational availability of major, important transmission assets. (Consideration may also be given to protection of a limited set of key transmission assets that could, under some scenarios, bring in power to reenergize an affected grid area from a remote region considered less likely to be affected.)

   For distribution systems, while protection of major substations could further accelerate restoration as a secondary option, the primary strategy recommended is to assure availability of adequate, properly staged (and typically low-cost) spares, for use by restoration crews as they find and repair those occasional hardware elements damaged or disrupted by the event.

   In combination, these measures can provide a cost effective “Strategic Foundation” for accelerated power restoration by power company crews.

2. Accelerated Power Restoration

   While E-threat resilience investment in protecting strategic enclaves can provide an essential foundation, assured power restoration will also require development of focused documentation and training as part of power companies’
existing restoration planning, and targeted investments in restoration tooling and equipment hardening and other mitigation measures to ensure those plans will be effective.

E-threat restoration plan modules, optimized to address the unique requirements for repair in the disrupted environment expected for electromagnetic hazards, will be vital to assure restoration teams will have the pre-planned guidance and training needed to be effective in these scenarios. While never optimal, ad hoc, real-time restructuring of restoration plans (designed for other hazards) would be completely ineffective in the unique situations that would be encountered following an E-threat event.

E-threat-protected restoration tooling, emergency vehicles and emergency power will also be essential, to ensure that crews will have the capabilities they need as they work to restore power following a severe event. Properly protected and staged spares and replacement parts will allow such crews to work effectively, but only if they have protected vehicles to get to critical locations, and have operationally available emergency power, once they arrive. And, of course, a protected, emergency communication system will be one of the most essential systems in their restoration “toolbox.”
Recommendations for Power Restoration and Consequence Management

As the three Whole Community Black Sky Resilience and Response seminars developed proposals to reduce threats to public health and safety in catastrophic outages, and broaden partner support for utility power restoration, participants identified significant opportunities for progress for every component of whole community preparedness. Resilience and response measures reviewed and discussed addressed individuals and families, state and local governments, non-governmental organizations, the Federal government and the private sector.

One finding that cut across all of these sectors: partners can only help utilities accelerate power restoration if their efforts directly correspond to specific utility support priorities. Accordingly, sustained industry-partner dialog (which the EPRO Executive Steering Committee is structured to support) will be essential. From an industry-wide perspective, however, consensus quickly emerged on the types of support missions that will be most valuable in severe outages. Participants also identified concrete, actionable steps to help partners strengthen consequence management under severely disrupted, black sky operating conditions. Chapter 3 analyzes these recommendations.

Key Whole Community Opportunities to Support Power Restoration

1. Logistics Support for Restoration Crews

In Superstorm Sandy, dozens of military bases and other facilities provided staging sites and base camps for utility crews. Black sky events will require feeding, housing, and meeting the other support needs for far more repair personnel, distributed over far larger, multi-region geography, over a longer period than was required during Sandy and in a severely disrupted environment.
As the federal government considers approaches that could help address the needs of black sky events, mechanisms to make such facilities available should be considered as a priority.

2. **Support for the Families of Restoration Crews**

For black sky outages that last many weeks or months, and which may require utility crews to support power restoration far from their homes, providing assistance to their families will be an important support mission. Such assistance will be especially vital as the loss of electric power creates cascading infrastructure failures, resulting in severe shortages of food, water, medical care and other basic lifeline services. Given their unique capabilities to provide such services, this is a likely priority for an expanded role for the NGO community, in supporting power restoration from black sky events.

3. **Engineering Support**

Debris and road clearance proved crucial in Sandy to facilitate utility access to damaged grid infrastructure. These efforts, along with emergency evaluation of structural, infrastructure and electrical issues and related critical functions, will all be required on a much larger scale for many black sky events. Expedited inspection and repair of critical bridges and other transportation bottlenecks for restoration operations will also be essential. Additional types of specialized, trained support for restoration could also be valuable.

Given the scope of the likely need, the potential for whole-community participation in supporting this need should be explored, including, for example, the potential for an expanded NGO role in fielding volunteer, pre-certified engineering support personnel for black sky emergency events.

4. **Public Safety, Security**

Utility contractors, state and local law enforcement, National Guard personnel and other partners in Sandy provided for Wire Guarding (site safety) and Flagging (traffic control) and other security/safety related support missions. Black sky events are likely to require a broader range of support missions, and on a much larger scale.

Such events will also require extraordinarily resilient communications.
During Superstorm Sandy, the National Guard deployed the Joint Site Communications Capability and smaller, mobile systems to provide voice and internet connectivity to support first responders and emergency managers. Utilities are also working with other public and private sector partners to strengthen the resilience of communications systems essential for power restoration. A better integrated, more comprehensive effort is needed to ensure that emergency management and power restoration communications will be mutually supportive in black sky events, especially against EMP and other non-traditional hazards.

5. **Situational Awareness**

A key finding of the Department of Energy’s after action review of Sandy is that significant improvements are needed in providing for shared, real-time situational awareness of damage to the grid and associated energy infrastructure, as well as in refining and coordinating the communication of estimated times of restoration to communities and government leaders.\(^8\) Tracking restoration assets and ensuring that they were fully and optimally utilized also proved challenging in Sandy.\(^9\)

For black sky events, planning for government and NGO coordination in this process, with sustained industry participation, will be essential in building a stronger system for situational awareness and response coordination.

6. **Response Coordination**

Given the scale of response operations in Sandy, and the unprecedented level of coordination that power restoration required between industry and government in that incident, a very important and valuable

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\(^8\) DOE, Overview of Sandy Response, pp. 7-11.

\(^9\) DOE, Overview, p. 9.
innovation took place: the electric industry was given a “seat at the table” at FEMA’s National Response Coordination Center.

As industry ramps up its mutual assistance system for national response events, it will be essential to institutionalize and expand the engagement of utilities in broader disaster response decision-making. In particular, to improve information sharing, communication, and coordination during major outages, electric power industry officials will need to be embedded not only with government response teams at the Federal level, but also at state and perhaps (as needed) local emergency operations centers.

7. Government Regulations and Policies

In Sandy, state and Federal agencies quickly processed a variety of waivers to facilitate the cross-state movement of utility trucks and other mutual assistance. For the first time, utility trucks were classified as emergency responders, allowing them to go to the head of fuel lines. But Sandy also revealed numerous opportunities for additional regulatory relief, which will become urgent priorities when a more severe hazard strikes, for example expedited movement past toll booths and other potential impediments to rapid flow of resources.¹⁰


Every Governor should review the adequacy of the emergency generators and stored, on-site fuel at their Emergency Operations Centers, relocation facilities, and other critical sites and operational capabilities. These facilities are typically well-prepared for relatively short outages. However, for outages lasting more than a month, where re-supply of emergency fuel from commercial sources will be problematic, their ability to

States should consider storing additional fuel and backup generators and taking additional mitigation measures to assure continuity of operations in black sky events.

¹⁰ DOE, Overview, p. 6-7, 9-11.
function and support gubernatorial decision-making will be at risk. States should consider storing additional fuel, backup generators, and taking additional mitigation measures to manage this risk.

9. **State-to-State Mutual Assistance: Leveraging the Emergency Management Assistance Compact (EMAC) System for Consequence Management and Power Restoration.**

For decades, Governors, State emergency managers and the National Guard have used EMAC to facilitate the flow of consequence management assets across State lines. Participants in the EMAC System, including the National Association of Emergency Managers (NEMA) that oversees its governance, are now partnering with industry for the first time to examine how the system can be brought into more effective alignment and mutual support with the mutual assistance agreements used by utilities.

EMAC planning needs to be supplemented so that as industry builds out its mutual support system for National Response Events, the movement of National Guard forces and other assets to assist nationwide restoration operations under EMAC can be optimized accordingly.

**Near-Term Opportunities to Integrate Power Restoration into Catastrophic Response Planning and Exercises**

States that suffer frequent hurricanes already have detailed collaborative plans between emergency managers and utilities. Because black sky hazards could create outages of much wider geographic scope and longer duration than any yet experienced, these collaborative plans will have to be scaled up accordingly and incorporate a broader range of partners and support missions. Moreover, Sandy revealed that many other state and Federal agencies had only weak (and in some cases, non-existent) disaster response plans in place to allocate and focus response capabilities to support power restoration.

The midst of a catastrophe is no time to begin developing new mechanisms for restoration support. At all levels of government and in partnership with NGOs, traditional disaster response plans need to incorporate power restoration as a greater focus, with utilities playing a decisive role in shaping those plans at local, state, regional and national levels. These plans will also need continuous updating as threats, restoration priorities and other planning factors change.
1. **Integrating Power Restoration into FEMA Regional Playbooks**

A unique new opportunity is emerging to better integrate regional planning for consequence management and power restoration against black sky hazards. The Federal Emergency Management Agency and its State and Federal partners, including State National Guard organizations and the Department of Defense’s U.S. Northern Command (NORTHCOM), are developing “playbooks” to help plan for catastrophic events in each of the 10 FEMA regions in the United States. Each playbook will be based on a specific scenario of special concern to the region in question. In FEMA Region IX in the Western United States, for example, the playbook scenario will be based on a severe earthquake and “massive power outage” occurring in Southern California. All these scenarios, whether they involve manmade or natural hazards, would entail severe damage to electric grid infrastructure and functionality.

FEMA and its partners should bring industry into the development of these playbooks, for each of the potential black sky hazards, to provide essential input on defense power restoration support requirements, plans and operational protocols.

2. **FEMA’s Power Incident Annex**

In mid-2014, the Federal Emergency Management Agency initiated the drafting of a Federal Integrated Operational Plan focused on catastrophic power outages.

As that planning effort goes forward, FEMA should ensure the inclusion of utilities and other key stakeholders for consequence management and
power restoration, including NGOs and other partners who have not traditionally been involved in restoration planning.

3. **Leveraging the Department of Defense’s Complex Catastrophe Initiative**

NORTHCOM and US Pacific Command (USPACOM) are now in the midst of preparing and aligning U.S. military forces to provide defense support to civil authorities in complex catastrophes -- that is, “any natural or man-made incident, including cyberspace attack, power grid failure, and terrorism, which results in cascading failures of multiple, interdependent, critical, life-sustaining infrastructure sectors and causes extraordinary levels of mass casualties, damage, or disruption severely affecting the population, environment, economy, public health, national morale, response efforts, and/or government functions.”

New York Army National Guard Members prep a generator to be used at polling sites in areas affected by Hurricane Sandy. [Source: National Guard Photo/Spc. J.P. Lawrence, 11/5/2012]

This planning effort has only begun to focus on how DOD military capabilities (separate from State National Guard forces) can be brought to bear to support civil authorities for power restoration operations, in ways that utilities will find most essential. DOD should collaborate with industry and Federal and State partners to ensure that restoration becomes a key focus of the Complex Catastrophe initiative.

That focus should encompass both traditional types of DOD restoration support (including installations for staging utility crews), and the novel missions executed during Sandy, including air transportation of utility trucks and the very large-scale provision of emergency fuel and generators for energy-related facilities and communications nodes.
4. **Exercises**

A state-led exercise in June 2014 exemplifies the value of such efforts. The Central United States Earthquake Consortium (CUSEC) member states of Alabama, Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri, and Tennessee conducted an exercise built around a severe New Madrid fault scenario. The scenario entailed massive damage to substations, transformers, high voltage transmission lines and other critical power grid components. Accordingly, industry, state and federal participants in the exercise had a strong opportunity to refine their support protocols and identify new opportunities for progress.

A broader range of state, regional and national-level exercises should incorporate the challenges of power restoration. Other states and regions conducting similar catastrophic exercises should include a similar focus on power restoration.

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**Cross-Community Planning**

**Institutionalizing Cross-Community Dialogue and Progress**

In the seminars and conferences that helped develop the recommendations summarized above, a number of participants emphasized the need to develop a sustained framework for collaboration, to support the implementation of the proposals and to build consensus on the many resilience issues that remain unresolved.

An Executive Steering Committee should be established to provide for such a collaborative framework, to help support the work of corporate, state, Federal, NGO and other stakeholders. Comprised of representatives from all the key resilience stakeholders, the Committee would provide for the sharing of best practices as utilities and their partners advance resilience against catastrophic outages, and facilitate the sustained, cross-sector dialog and coordination that a whole community effort to build such resilience will

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Planning is beginning now to enable the EPRO Executive Steering Committee to facilitate the work of corporate, State, Federal, NGO and other stakeholders.
require. Planning is beginning now, as part of the EPRO Handbook Project, to enable the EPRO Executive Steering Committee to facilitate these cross-community efforts.

Expanding into Other Sectors and Infrastructures

While power grid restoration and broad societal response and recovery operations represent the most fundamental resilience requirement for black sky hazards, it will be important to begin bringing other interconnected sectors and critical infrastructures into this planning process as soon as feasible. Communications, water and wastewater, natural gas and liquid fuel distribution systems, transportation, food production and distribution and the financial sector represent primary examples.

Future editions of the Handbook will advance recommendations from this process, in coordination and collaboration with government, NGO and corporate stakeholders.
INTRODUCTION

A unique opportunity is emerging to strengthen grid resilience against “black sky” days. A wide range of threats could create such extraordinary and hazardous events, which would be utterly unlike the “blue sky” days in which utilities optimally function, and would create power outages lasting longer and covering a wider area than those created by Superstorm Sandy. Recent initiatives by the electric industry and other stakeholders in grid resilience have provided a new collaborative foundation for progress against such hazards. Yet, the risks posed by back sky hazards are increasing even more rapidly.

This Handbook and the parallel EPRO Executive Steering Committee process are structured to help build resilience against black sky hazards, by advancing new grid protection options and by creating new, “whole community” partnerships\(^1\) to manage the consequences of black sky days and help utilities accelerate power restoration.

\(^1\) Federal Emergency Management Agency (FEMA), Whole Community, http://www.fema.gov/whole-community
The starting point for such progress lies in the growing willingness of industry to invest against catastrophic threats, and the initiatives that state utility regulators are leading to help assess when such investments are prudent and cost effective. Federal, state and local agencies and non-governmental organizations (NGOs) are also developing new collaborative relationships to help utilities restore power when severe outages occur, and to reduce the loss of life and economic damage that such outages will otherwise inflict.

**Black Sky Hazards – A Growing Concern**

However, threats to the grid are also intensifying. Evidence is accumulating that we are entering a period of increasingly severe storms. Recent analysis and exercises have helped create a deeper understanding of the resilience challenges posed by catastrophic earthquakes, severe space weather and other natural hazards.

Manmade hazards are also growing, and cyber threats, electromagnetic pulse (EMP) weapons and coordinated physical attacks on key grid components all pose significant threats to the grid.

The risk of terrorist attacks is a familiar hazard, and one that is exacerbated by the risk that returning jihadists from the Islamic State will attack the grid or other U.S. targets. Less frequently recognized is the risk that adversary nations will strike U.S. infrastructure (especially using cyber weapons) in the initial phases of a confrontation. U.S. military leaders warn that American territory is less likely to be a sanctuary in the future, and that to disrupt U.S. defense capabilities, adversaries may attack the privately owned and operated power grid on which U.S. military bases depend.

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Improving the resilience of the grid to both natural and manmade black sky hazards is essential to both societal continuity and national security.
The Objective – Assured Grid Resilience

Long duration, multi-FEMA region outages could not only threaten the ability of military bases to execute their core missions, but would also jeopardize the public health and safety of U.S. citizens on a potentially massive scale. Improving the resilience of the grid to both natural and manmade black sky hazards is, therefore, essential to both societal continuity and national security. Reducing the power grid’s vulnerability will also make the grid less attractive as a target for both terrorists and nation states, and can help deter attacks by denying adversaries the catastrophic effects they hope to achieve.

Sustained investments in grid protection will be essential to achieve resilience against black sky hazards. A practical and affordable initial goal would be to achieve a minimal threshold of protection for each hazard.

For example, against High-Altitude Electromagnetic Pulse (HEMP or EMP) weapons, a wide gap exists between current protection levels and what would be barely adequate to prevent a large regional or interconnect-wide, long duration power outage.

A practical and affordable initial goal would be to achieve a minimal threshold of protection for each hazard.

Estimated Effective range for an EMP detonating over the USA (Source: US Army Report AD-A278230, 1994)
Targeted investments to protect a critical, minimal set of assets could prevent a full scale regional blackout by protecting strategic “enclaves” in each area of the grid, which would provide generating capacity and transmission capability to serve as a foundation for power restoration. Chapter 2 of the E-PRO Handbook proposes options to achieve a minimal threshold of protection against both EMP and Geomagnetic Disturbances (GMD) induced by severe space weather, and greatly reduce the duration of the outages they will otherwise cause.

As protection measures go forward against all such black sky threats, other opportunities will also exist to accelerate power restoration and reduce threats to public health and safety. Many local and state government agencies are already partnering with industry to support restoration by clearing roads, removing debris, and conducting other missions to assist utility repair crews. A growing number of non-governmental organizations are also providing such assistance. Scaling up these partnerships to account for black sky hazards, and adopting a whole community strategy to include additional NGOs and other new partners, can significantly reduce the length of power outages and the casualties they will inflict. Chapter 3 recommends practical, concrete opportunities to strengthen whole community resilience against catastrophic outages. This Chapter examines the extraordinary challenges that utilities and their partners will confront in building such resilience.

These challenges stem not only from the direct damage the grid will suffer, but also from two ripple effects of a black sky event.

First, a wide area, long term grid outage will cause cascading failure of other infrastructure sectors that depend on electricity, including communications, transportation, and other infrastructure essential for power restoration operations. However, to support power restoration and save and sustain lives, Government agencies and NGOs must be able to function in such a severely disrupted environment.

Second, while emergency power generators can help these organizations (as well as hospitals and other critical facilities) sustain operations during
an outage, in a long duration outage covering a wide area, the availability of emergency power for critical facilities will fall far short of need, especially as generators burn out and fuel to power them becomes increasingly scarce.

These twin challenges of cascading infrastructure failure and limited emergency power will result from natural and manmade catastrophes, and constitute defining features of black sky hazards.

**Structure of the Chapter**

Section 1 of this chapter examines manmade hazards to the grid. They include threats of coordinated physical attacks on key grid components, cyber threats, and the risk of a “combined arms” attack that would employ both of these threat vectors. Section 1 also examines the threats posed by EMP. Section 2 analyzes the grid resilience implications of earthquakes and other natural hazards. Section 3 explores how cascading infrastructure failure and emergency power issues will complicate power restoration and consequence management operations, and examines other ways in which black sky events will differ from Superstorm Sandy-scale outages.
MANMADE HAZARDS

“You may not be interested in war, but war is interested in you”

(Leon Trotsky)³

As industry and regulators manage risks to the grid and assess whether specific investments in grid resilience are prudent and cost-effective, the threat of attack from adversary nations or terrorist groups pose special analytic problems. Risk is typically calculated as a function of the probability of an event, the vulnerability of the system to such an event, and the consequences that would result from the event occurring. The first of these factors -- probability -- is straightforward to assess for hurricanes and other frequently occurring natural hazards, where historical data provides a strong basis for prediction (though changing climate effects may complicate such assessments over the longer term). The likelihood of an attack on the grid cannot be assessed with

remotely equivalent confidence. Indeed, NERC’s High Impact study argues that these events are inherently unpredictable.⁴

But it would be a mistake for the electric industry and its partners to ignore the striking changes underway in the international security environment. Of course, to predict the likelihood of a coordinated attack on a specific utility by Al Nusrah, Lashkar-e-Taiba, the Islamic State of Iraq and Syria (ISIS- also known as the Islamic State of Iraq and the Levant) or other terrorist groups, we would need data that is not only unknown but unknowable (especially for making long-term investment decisions for resilience).

Similar data constraints will continue to limit the value of stochastic, probabilistic models of manmade hazards, and create “garbage in, garbage out” problems for risk assessments that rely on them. Nevertheless, changes are occurring in the threat environment that will have far-reaching implications for grid security, and which can and should help inform decisions on resilience investments against both terrorists and adversary nations.

A | The Strategic Context of Grid Resilience

For many years, utilities and government agencies have focused on the risk of physical or cyber-attack by terrorist organizations. Those risks are growing and provide a key focus of the analysis that follows. In contrast, dealing with the danger that North Korea or some other nation would attack the United States – or provide weapons of mass destruction to affiliated terrorist groups – has long been considered under the near-exclusive responsibility of the Federal Government (especially the Department of Defense).

⁴ High Impact, p. 8
However, even if utilities and their partners are not interested in war, war is interested in them. The vulnerabilities of the U.S. power grid to attack are not lost on either terrorists or potential nation state adversaries. General Martin Dempsey, Chairman of the Joint Chiefs of Staff, emphasizes the growing risk that instead of attacking our deployed forces abroad, adversaries will adopt a deeply asymmetric strategy, and attack the domestic U.S. installations and critical infrastructure on which U.S. operations abroad increasingly depend. As General Dempsey frames the problem:

“In the future, our homeland will not be the sanctuary it has been. Whether it’s cyber-attacks launched from afar or terrorists closer to home, our critical infrastructure will be threatened. This is a problem because many of our global capabilities that underwrite our superiority on the battlefield operate from the homeland. UAVs in Afghanistan are flown by pilots sitting in the continental United States. Will we still be able to operate these capabilities abroad if our power grid is brought down or the Internet stops functioning, and for how long? The joint force of 2020 really needs to own up to this monumental challenge in mission assurance. Our very effectiveness depends on it.”

Of course, the United States has a powerful military to deter such attacks on the homeland. But that is precisely why the dependence of U.S. military installations on the grid is such an important concern, and why building the resilience of the grid against both nation states and terrorist organizations is so essential.

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Terrorism and the Risks of Coordinated Physical Attack on the Power Grid

The menace once posed by Al Qaeda has metastasized. James R. Clapper, Director of National Intelligence, emphasizes that the dispersion and diffusion of the terrorist threat creates new challenges in assessing and preparing against threats of terrorism to the United States. The proliferation of Al Qaeda affiliates and “franchise” operations has presented one such challenge. According to Clapper: “There are some five different franchises at least and 12 countries that this movement has morphed into,” with chapters in Yemen, Somalia, North Africa, Syria, and beyond. Moreover, while many of these groups are locally focused, others – most notably Al Qaeda in the Arabian Peninsula (AQAP) – continue to pose a potential threat to the U.S. homeland.⁶

A more recent and rapidly growing challenge is that of westerners (including a growing number of U.S. citizens) joining jihadist groups under the banner of ISIS to fight in Syria and Iraq.

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FBI Director James Comey stated in June, 2014 that:

“There are thousands of people from all over the world, including from all parts of the United States who are traveling to Syria, learning the worst kinds of techniques and tactics, and making the worst kinds of relationships. At some point there will be some kind of diaspora out of Syria, back to Western Europe, back to North America, bringing with them those skills and relationships, and we have to be very careful to anticipate what the future might be if we were not careful.”

U.S. Attorney General Eric Holder and other U.S. officials share this concern. Indeed, Holder states that, “In some ways, it’s more frightening than anything I think I’ve seen as attorney general.” One reason for this concern is the sheer scale of the flow of westerners to jihadist training, networking and operations.

Director Clapper estimated in January, 2014 that more than 7,000 foreign fighters have been attracted to the jihadist operations in Syria and Iraq from some 50 countries in the Middle East, Europe and beyond. Moreover, “we’re seeing now the appearance of training complexes in Syria to train people to go back to their countries and, of course, conduct more terrorist acts. So this is a huge concern to all of us.”

Equally concerning is the quality of that training and the combat expertise that U.S. and other western jihadists are acquiring, including coordinated attacks on energy infrastructure. Attorney General Holder notes that, “[I]t’s a deadly combination, where you have people who have the technical know-how along with the people who have this kind of fervor to give their lives in support of a cause that is directed at the United States and directed at its allies. And it’s something that gives us really extreme, extreme concern.”

10 Holder, op cit.
The ability of terrorist organizations to establish new bases of operation in Syria and Iraq also reflects a broader trend in the terrorist threat. The United States and its partners have greatly degraded the ability of Al Qaeda’s core organization to use Afghanistan and the Federally Administered Tribal Areas (FATA) of Pakistan to plan and organize the sort of large-scale attacks exemplified by 9-11. However, terrorists are increasingly able to establish bases for such training and planning efforts in ungoverned or under-governed spaces.

The risk that the Islamic State of Iraq and Syria (ISIS) will be able to use the growing territory under its control for such purposes is only the most recent example of this trend. In Yemen, Libya, Nigeria, East Africa, and elsewhere, terror groups are exploiting the inability of local governments to control their own territory. Moreover, as terrorists battle to further weaken governmental control and expand their own infrastructure to plan and execute attacks, energy infrastructure provides high-visibility, high-impact targets for attack – and for the acquisition of expertise that can be employed against the United States and its partner nations.

Yemeni instability. Presence of rebel forces in Yemen as of September 2012– Yemen remains politically divided and inherently unstable. The lack of centralized government control and subsequent instability continues to provide a convenient operation for terrorists and radicalized militants [Source: Political Geography Now, Map by Evan Centanni]

1. Implications of Metcalf

The April 2013 attack on the Metcalf substation near San Jose, California, helped focus unprecedented attention on the risk of attacks on the grid using high-powered rifles, explosives, and other kinetic weapons. The attackers cut communication cables near a Pacific Gas & Electric substation in San Jose and fired more than 100 rifle bullets to knock out 17 of the station's 23 transformers before fleeing and avoiding capture. The damage took 27 days to repair.\(^\text{12}\)

Lost in the media uproar that followed the attacks was the fact that for decades, utilities had been well aware of the risks of physical attack, and had been investing in protection measures accordingly. As early as 1990, studies by the Congressional Office of Technology Assessment (OTA) and other organizations had determined that the nearly simultaneous destruction of two or three transmission substations could cause a serious blackout of a region or utility, with larger scale attacks risking still longer duration and wider area outages.\(^\text{13}\) In the aftermath of 9-11, industry and government measures to mitigate risks of physical attack ramped up dramatically, including initiatives for information sharing, spare equipment programs, security standards, grid security exercises, utility investments in protection (including surveillance and monitoring systems and shielding of key assets) and other measures.\(^\text{14}\)

The Metcalf attack has spurred further protection initiatives. On March 7, 2014, the Federal Energy Regulatory Commission (FERC) directed the North American Electric Reliability Corporation (NERC) to submit to the Commission new reliability standards requiring certain transmission owners “to take steps or demonstrate that they have taken steps to address physical security risks and vulnerabilities related to the reliable operation of the power grid.”


The new reliability standards will require grid owners to perform risk assessments to identify their critical facilities, evaluate potential threats and vulnerabilities, and implement security plans to protect against attacks.15

In May of 2014, NERC responded with its proposal for mandatory security standards, including requirements for risk assessments by transmission owners to identify critical transmission facilities, and the development and implementation of physical security plans to protect them.16

Metcalf has also prompted initiatives to ramp up the sharing of information and best practices regarding physical security. Most notably, in a series of meetings that included participation from the FBI, the Department of Energy (DOE), the Department of Homeland Security (DHS), NERC and FERC, and Pacific Gas and Electric (the owner of the Metcalf substation), utilities in the United States and Canada are being briefed on how the attack was conducted and emerging options and best practices for strengthening security.17

2. Beyond Metcalf: the International Dimension

The risk that well trained, deeply networked jihadists will return and launch attacks in their home countries applies not only to the United States and Canada, but also to countries in the European Union and far beyond. The January 2013 attack on the Amenas gas refinery and housing complex in southeastern Algeria highlighted the severity of this threat. A coalition of transnational militia groups attacked the gas facilities run by BP, Statoil and Sonatrach (Algeria’s state-owned energy company), resulting in a four-day stand-off that cost dozens of lives, traumatized thousands and provided an advertisement for the political value of

such infrastructure attacks for terrorists worldwide. More recent attacks have highlighted the degree to which electric grids are a prime target of attack. The June 11, 2014 strike against power lines linking the capital of Yemen, Sanaa, with the al-Qaeda stronghold of Marib provides a case in point. The attack left the entire nation of 23 million people without power. Simultaneous attacks against multiple substations have also occurred in Mexico and other nations in the past year.

Indeed, these attacks reflect a longer-term and more widespread threat than is commonly recognized. Terrorist organizations outside the United States were linked to 2,500 attacks on transmission lines or towers and at least 500 on substations from 1996 to 2006, according to a January report from the Electric Power Research Institute. Physical attacks on the grid are an increasingly global phenomenon; information on emerging best practices should be shared with utilities in partner nations accordingly.

21 Cited in Smith, op cit.
3. Implications for Security Support Missions

While the industry’s post-Metcalf security initiatives are significant and much-needed, these efforts will need to continue to evolve, and anticipate new risks of terrorist attack. Our adversaries are intelligent and adaptive. As utilities adopt improved physical security measures, terrorist groups will seek to maneuver around those improvements, and attack in ways for which industry and its partners are not as well prepared.

One such risk is that terrorist groups will not only shoot out grid components in critical substations, but also attack the replacement transformers, transportation assets, and power restoration crews as they deploy to the stricken substations. The ISIS jihadists who represent such great concern for the FBI routinely attack energy targets with simultaneous strikes against both infrastructure hardware and personnel.\(^{22}\) For the United States and most of its international partners, even one or two shootings against restoration workers in the aftermath of initial substation attacks would create dramatically different circumstances than utilities and their partners include in today’s plans, exercises, and information sharing mechanisms.

Utilities typically have well-established plans and relationships with State and local law enforcement agencies and private contractors to provide traditional types of security support, including for road security and traffic safety in equipment replacement operations. Providing security against active shooters for power restoration crews would represent a vastly different and more difficult mission. Local law enforcement capabilities could quickly be overwhelmed by competing demands for public safety and security, and the requirements for tactical, real-time information sharing necessary to protect restoration crews would create unprecedented challenges. The same would be true for public messaging and strategic communications.

In theory, if such attacks were to take place in the United States, the National Guard could provide a critical source of additional support for state and local law enforcement. Chapter III of the Handbook recommends how this assistance might best be provided. In practice, however, no plans and protocols currently exist between utilities and the National Guard or other potential force providers.

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to support the private sector against active shooters.

As industry continues to strengthen physical security, it will be essential to anticipate ways that adversaries will adapt to those improvements, and expand on existing plans, training, exercises, and partnerships accordingly. And in today’s global marketplace, physical security challenges to the grid will mandate international sharing of these evolving best practices.

C | Electromagnetic Pulse Weapons

Above and beyond the coordinated physical attacks that terrorists have employed against global energy targets, the risk is also growing that terrorists will acquire weapons capable of especially wide-area effects. Paramount of among these risks to the grid is the possibility that a terrorist group will acquire the means to conduct an EMP attack. The EMP analysis later in this chapter provides additional information on the evolution of the threat. It is worth noting, however, that the risk that terrorists will acquire and use such capabilities has been well documented for a decade. The Congressional EMP Commission noted that if terrorists acquire nuclear weapons that could be used in an EMP attack, deterring them from attacking will be especially difficult because “such groups have no state identity, have only one or a few weapons, and are motivated to attack the US without regard for their own safety.”

The United States and its partners abroad conduct a variety of programs to reduce the likelihood that terrorist groups can acquire the nuclear materials and other components necessary for building such weapons. The Cooperative Threat Reduction (CTR) program, for example, helps secure nuclear materials in the former Soviet Union. While these programs have demonstrated substantial progress in reducing the threat that nuclear materials will be stolen, current estimates assess that as of January 2012 there are were still approximately 1440 tons of HEU and around 500 tons of separated plutonium stockpiled globally
-- providing a vast array of potential targets for terrorists seeking such materials. In addition, if nuclear weapon and missile proliferation trends continue, there will be a growing risk of terrorists acquiring and using completed weapons, on potentially short timelines.

Progress in protecting electric grids against EMP attack has been much slower than for other, more familiar hazards. Only a handful of companies in the United States and abroad have invested in EMP protection equipment. Due to the rise in the threat, however, interest is growing in protection options and emerging best practices. Chapter 2 documents these options and provides a decision framework to support a tiered, sequenced investment strategy.

**Intentional Electromagnetic Interference (IEMI) Weapons**

Much like use of rifles or other means of physical attack, IEMI weapons are easily acquired, and have the potential for doing serious, local damage. These devices create a pulse which can actually be higher in magnitude than HEMP, though affecting only discrete “point” targets. Both commercial and military versions are available or under development in a growing number of nations. Sometimes characterized as a “dumb” cyber threat, as the assets most vulnerable are computers and electronics, these weapons can cause damage or destruction to microprocessors, corrupt or erase data on hard drives, cause mis-operation of relays, and cause a range of other malfunctions in electric devices.

For example, e2v, a British high-tech company, is producing a commercial EMP weapon (“Safe Stop”) designed for security services, to stop automobiles by disrupting their electrical systems.\(^{23}\) Boeing has developed the Counter-electronics High-powered Microwave Advanced Missile Project (CHAMP), in partnership with the U.S. Air Force Research Laboratory.\(^{24}\) CHAMP, a radio-frequency (RF) weapon mounted on a cruise missile, directs an electromagnetic pulse at point targets while flying over them.

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\(^{24}\) [http://www.boeing.com/Features/2012/10/bds_champ_10_22_12.html](http://www.boeing.com/Features/2012/10/bds_champ_10_22_12.html)
The imperative to anticipate new, adaptive strategies by terrorists is especially important in the cyber realm. The destructiveness and sophistication of cyber weapons are growing. These weapons are also increasingly available for purchase by terrorist groups, criminal organizations, and other potential attackers who lack the capacity to build such weapons on their own.

Industry and government have already made remarkable progress in strengthening grid security against cyber threats. This process of adaptation has not only spurred the development of new protective measures, network architecture designs and security protocols and best practices, but also remade the structure of security in the United States and its allies. Building on this new structure will be essential for meeting the more severe threats to come.

1. The Transformation of Security Architecture

Perhaps most important, new forms of collaboration between industry and government have emerged that are utterly unlike their relationships during the 20th Century. Under the traditional framework of the military-industrial complex, industry sold weapons and services to the Federal government, and the government’s armed forces in turn provided security for the nation. The rise of the cyber era has driven the development of a very different relationship. Now, utilities are attacked many thousands of times every day by cyber weapons, and are ultimately responsible to their customers and shareholders for securing their systems and operations against such threats -- transforming security into a cost center.
To help utilities meet this novel challenge, Federal agencies have partnered with them to create an unprecedented array of mechanisms for information sharing and security collaboration. The Electricity Sector Information Sharing and Analysis Center (ES-ISAC) establishes situational awareness, incident management, and coordination and communication capabilities within the electricity sector through secure information exchange regarding cyber threats. The Department of Energy and the Electricity Sector Coordinating Council (ESCC)\(^\text{25}\) also provide such assistance, as does the DHS National Cybersecurity and Communications Integration Center.\(^\text{26}\) Industry and government have also collaborated to establish voluntary initiatives to support improvements in cybersecurity, including the Electricity Subsector Cybersecurity Capability Maturity Model (ES-C2M2)\(^\text{27}\) and the 2014 Framework for Improving Critical Infrastructure Security.\(^\text{28}\) These and many other collaborative initiatives are remaking the construct of government-industry relations for security, facilitating dramatic progress in grid resilience.\(^\text{29}\)

A similar transformation in security architecture is underway within the government – in particular, between states and the Federal Departments traditionally responsible for security challenges.

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For hundreds of years the Federal government has provided for U.S. security, consistent with its constitutional responsibilities for national defense. Governors and their state National Guards played limited and clearly subordinate roles in helping the Federal government execute those duties. Cyber threats have upended this equation. Governors have primary responsibility for the public health and safety of their citizens; cyber weapons can put those citizens at grave risk. An extended power outage would jeopardize the functioning of hospitals, municipal water systems, and other infrastructure vital for saving and sustaining lives. Long duration power outages caused by cyber-attacks could also directly threaten state information networks and functions that are vital for continuity of government and the delivery of essential services.

Accordingly, governors are rising to meet the cyber challenge, and build their own cybersecurity strategies and programs for their respective states. Governor-led efforts are now underway to develop and implement strategic recommendations to improve state cybersecurity policies and programs.\(^\text{30}\) Governors in New York and other states are creating their own cybersecurity strategies in partnership with state utilities, and strengthening the ability of their emergency operations centers to protect against and respond to cyber-attacks. State information fusion centers and other collaborative organizations for information and intelligence sharing are providing new sources of data to support those efforts. Moreover, in Los Angeles and other cities, mayors are also developing their own cyber command centers and security programs, and building new partnerships with the utilities that serve them against these threats.\(^\text{31}\)

State public utility commissions (PUCs) are a critical part of this transformation. Among their other responsibilities, PUCs determine whether a proposed capital investment by a utility should be approved, with the costs passed along to rate-payers. Commissioners have deep expertise in assessing proposed investments to strengthen the reliability of the power grid against traditional natural hazards, and a well-established set of criteria to help them decide whether such investments are prudent. Now, however, utilities are


presenting commissioners with proposed investments in cyber resilience that are very different from those associated with hurricanes or other familiar hazards, and which involve security issues of entirely new dimensions. The National Association of Regulatory Utility Commissioners is helping PUCs develop new analytic tools to assess cybersecurity proposals.\textsuperscript{32} PUCs in Connecticut and other states are also developing strategic plans to help strengthen cybersecurity of the electric grid and other regulated utilities.\textsuperscript{33}

2. The Growing Threat – and the Imperative for Further Progress

While the adaptations by the United States and its allies to meet the challenges of the cyber era are remarkable, advances in cyber weaponry threaten to outstrip them. The 2014 Worldwide Threat Assessment of the Intelligence Community provides an authoritative U.S. perspective on cyber threats. The Assessment notes that critical infrastructure targets, particularly the Industrial Control Systems (ICS) and Supervisory Control and Data Acquisition (SCADA) systems used in electric power systems and other infrastructure sectors, “provide an enticing target to malicious actors.”\textsuperscript{34} The Federal Bureau of Investigation (FBI) recently noted that cyber-attacks are eclipsing terrorism as the primary threat facing the United States. As cyber-attacks become more frequent, energy systems are increasingly being targeted. The Industrial Control Systems Cyber Emergency Response Team (ICS-CERT), which is part of DHS, reported

\begin{itemize}
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responding to 198 cyber incidents in fiscal year 2012 across all critical infrastructure sectors. Forty-one percent of these incidents involved the energy sector, particularly electricity.\textsuperscript{35} The number of such reported attacks grew to 256 in 2013, with over half targeting the energy sector.\textsuperscript{36}

The weapons targeting grid ICS, data storage centers, and other components essential for operating the grid are also becoming increasingly sophisticated. Many of these attacks focus on stealing sensitive data or mapping infrastructure systems. Increasingly, however, attacks are targeted to cause physical destruction and/or mal-operation of system components. The Stuxnet attack in 2010 provided an early example of the threat shifting from data exfiltration to system destruction. The 2012 Shamoon attack on the Saudi Arabian state oil company, Saudi Aramco, highlighted the emergence of the energy sector as a key target for such destructive strikes. The attack wiped the hard drives of 30,000 ARAMCO computers, creating what General Martin Dempsey, Chairman of the U.S. Joint Chiefs of Staff, calls the “new normal” of disruptive and destructive attacks in cyberspace.\textsuperscript{37}

These threats are becoming increasingly sophisticated and potentially destructive. In the past few months, for example, the “Dragonfly” threat (also known as Energetic Bear and Havex) marks a major step forward in the malware adversaries are using to gain remote access to infrastructure systems, and then to exploit that access whenever the adversary chooses to exfiltrate user passwords, launch destructive attacks, or other goals.\textsuperscript{38}

The growing connectivity between operational control systems and web-connected information technology (IT) systems is also creating new openings for cyber-attacks. The Worldwide Threat Assessment notes that the nature and growing complexity of such linkages in energy infrastructure sectors and


\textsuperscript{38} Sobczak, op cit.
beyond “can easily cause security and/or safety problems” as cyber attackers seek new routes by which to strike. Robert J. Butler notes that by hacking into gateways or edge devices that link operational controls to the IT layer, an adversary could reprogram the control systems. Such reprogramming – especially if conducted in a way that grid operators cannot detect – could be designed to cause the system to self-destruct (as was the case with Stuxnet) or mis-operate by commanding equipment to function at unsafe speeds or breakers to open when they should be closed.”

3. The Unconstrained Market for Cyber Weapons

These weapons are increasingly available to terrorists and other adversaries, thanks to the uncontrolled, Wild West-style market on the internet where hackers sell cyber weapons to the highest bidder.

Zero day exploits exemplify this growing availability. A zero day exploit takes advantage of a software vulnerability that is unknown to the computer user and software manufacturer, leaving “zero days” for them to prepare against an attack using that flaw. Such zero day exploits can also be weaponized: they can be modified to not only gain access, but also to disrupt, disable, or destroy computer networks, their components and the hardware systems they control. Armed with weaponized zero day exploits, attackers have launched cyber operations such as the “Flame” cyber strikes against Middle Eastern nations and the “Aurora” operation against Dow Chemical, Northrup Grumman, and other major U.S. corporations.


These highly publicized attacks have provided a marketing bonanza for hackers who openly sell zero day exploits on the web, often in weaponized form, and brag about the effectiveness of their products.43

While criminals buy and use weaponized zero day exploits to steal passwords, intellectual property and other data through computer exploitation attacks, terrorists can also use them to launch destructive attacks on the grid. Eric Rosenbach, Deputy Assistant Secretary of Defense for Cyber Policy, recently highlighted the implications of this cyber weapons bazaar for U.S. security. He explained that the black market for zero day exploits and malware tools, combined with the proliferation of programs that scan for vulnerabilities in industrial control systems, are “what worries us the most,” because they so dramatically expand the array of adversaries who can acquire cyber weapons and attack the United States.44

The net result of these trends: despite the extraordinary progress that industry and government have made in building cybersecurity, and in creating new forms of collaboration, those collaborative efforts will need to ramp up and accelerate. Moreover, while sustaining progress on prevention and protection against cyber-attacks is essential, the growing destructiveness and availability of cyber weapons makes it prudent to assume that an effective, large scale cyber-attack will eventually succeed in causing a wide-area power outage with damage to critical hardware. Building partnerships to help industry accelerate the restoration of power after such an attack is a key focus of the EPRO Handbook.


with damage to critical hardware. Building partnerships to help industry accelerate the restoration of power after such an attack is a key focus of the EPRO Handbook. Equally necessary are EPRO’s recommendations to help strengthen plans, capabilities and collaborative relationships in advance of black sky events, which can substantially limit the threats such cyber-induced outages will otherwise pose to public health and safety and national security.

## Combined Arms and Cross-Sector Attacks

Terrorists may not do us the “kindness” of attacking the grid via cyber weapons alone. Integrating cyber and physical or electromagnetic attacks into a combined arms campaign, perhaps targeting other critical infrastructure sector nodes necessary to support power restoration operations, could create power outages of exceptionally wide geographic scope and long duration.

Military strategists have long understood that by attacking with multiple means at once, attackers can achieve a greater effect than if each element were used separately or sequentially. In a classic demonstration of the value of combined arms strategies, Napoleon’s *Grand Armee* employed infantry, artillery and cavalry in integrated operations to help him achieve decisive victories. Modern militaries frequently combine air, infantry and armor forces to create such synergies.

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Simultaneous, coordinated physical or electromagnetic and cyber-attacks on the grid could offer terrorists similar synergistic benefits. Recognizing the possibility that terrorists might strike in this fashion, NERC conducted an especially challenging exercise, GridEx II, to explore the grid security issues at stake in a combined arms attack – specifically, one entailing both physical and cyber-attacks.

The exercise scenario coupled a cyber-attack on the grid with coordinated physical attacks against key transmission and generation assets, including high voltage transformer substations. A major finding of NERC’s after-action report: “While the electricity industry has experienced occasional acts of sabotage or vandalism, a well-coordinated physical attack also presents particular challenges for how the industry restores power. [...] The extreme challenges posed by the Severe Event scenario provided an opportunity for participants to discuss how the electricity industry’s mutual aid arrangements and inventories of critical spare equipment may need to be enhanced.”

Gerry Cauley, president and CEO of NERC, subsequently testified to the U.S. Senate Energy and Natural Resources Committee that, “I am most concerned about coordinated physical and cyber-attacks intended to disable elements of the power grid or deny electricity to specific targets, such as government or business centers, military installations, or other infrastructures.”

The risk also exists that terrorists might launch such combined attack against multiple infrastructure sectors. Unlike the highly targeted Stuxnet virus, the “Dragonfly” malware is designed to attack a broader range of infrastructure. Power restoration depends on the functioning of communications,

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47 NERC, March 2014, p. 5.
transportation and other infrastructure sectors. If adversaries acquire cyber weapons to attack the grid and also disrupt the infrastructure that utilities need to restore power, the risk of long-duration outages would be especially severe.

This provides the crucial but little-recognized context for Former Secretary of Defense Leon Panetta’s warning that the United States could suffer a “Cyber Pearl Harbor.” Secretary Panetta did not suggest that cyber-attacks on the grid alone posed this challenge. His warning focused on a broader, combined arms attack:

“The most destructive scenarios involve cyber actors launching several attacks on our critical infrastructure at one time, in combination with a physical attack on our country. Attackers could also seek to disable or degrade critical military systems and communication networks. The collective result of these kinds of attacks could be a “cyber Pearl Harbor”: an attack that would cause physical destruction and the loss of life. In fact, it would paralyze and shock the nation and create a new, profound sense of vulnerability.”

These threats represent one of the critical challenges against which existing power restoration and consequence management plans and capabilities must be scaled up to meet, as proposed in Chapter 3 of this Handbook.

49 Sobzak, op cit.
II | STORM WARNINGS:
SEVERE WEATHER EVENTS,
EARTHQUAKES, AND OTHER
CATASTROPHIC NATURAL HAZARDS

Superstorm Sandy spurred a wave of industry and government efforts to not only prepare for natural disasters of similar destructiveness, but also build resilience against more catastrophic events. This focus on “worse than Sandy” catastrophes has been especially notable among emergency managers, State National Guard leaders and their partners who share responsibility for planning and executing consequence management operations: that is, measures to protect public health and safety, restore essential government services, and provide emergency relief to governments, businesses, and individuals affected by the consequences of a natural or manmade disaster.

The Federal Emergency Management Agency (FEMA), which leads Federal disaster response efforts when States request assistance, has helped drive this new focus on catastrophic events. FEMA Administrator Craig Fugate emphasizes that “We need to understand that as bad as Sandy was, that may
not be the benchmark that we need to limit ourselves to. There are threats and potential disasters that could be even larger.  

A | Weather Events

The Edison Electric Institute’s report, “Before and After the Storm,” documents the nationwide array of investments and emerging best practices that investor-owned utilities are making in response to lessons learned from Sandy, and in anticipation of possibly more severe events in the future. In some cases, public utility commissions and state and local leaders are also undertaking a range of initiatives to help them assess requirements and review proposals for such investments, both in the states immediately affected by Sandy and far beyond.

However, as with manmade threats, it is broadly recognized that it would be a serious mistake to assume the threats to the electric grid posed by natural hazards will inevitably remain within the limits of our recent experience, or within the bounds of straightforward scaling from such experience. Indeed, there is compelling evidence that such hazards may be increasing, either due

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to periodic, heuristic factors, or climate change effects. For example, a series of studies by the Department of Energy and other government-sponsored reports highlight the risk that climate change will produce increasingly extreme weather events and other challenges to grid resilience. DOE found in 2013 that “increasing temperatures, decreasing water availability, more intense storm events and sea level rise will each independently, and in some cases in combination, affect the ability of the United States to produce and transmit electricity...”\(^{54}\) Severe storms and other weather events are already among the leading causes of large-scale power outages. If this trend continues and increases the risk of more extensive weather damage to the grid, weather related outages are likely to grow in frequency and cost to the U.S. economy.\(^{55}\)

The 2014 U.S. National Climate Assessment updates these projections and places new emphasis on the growing risk of severe weather events to the electric grid and the broader energy infrastructure on which it depends. In particular, the study notes that “extreme storm surge events at high tides are expected to increase, raising the risk of inundating energy facilities such as power plants, refineries, pipelines, and transmission and distribution networks.”\(^{56}\)

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Earthquakes

In many regions of the United States as well as Israel and other nations, earthquakes risk causing power outages far larger and of longer duration than would result from even the most severe weather events. The New Madrid seismic zone exemplifies these risks. The New Madrid fault roughly parallels the Mississippi River, and produced a 7.7 earthquake in 1812. A recurrence of that earthquake today would damage or destroy many hundreds of electric substations, high voltage transformers and transmission lines, generators, and other grid components over a multi-state region including Illinois, Indiana, Missouri, Arkansas, Kentucky, Mississippi, Tennessee, and potentially other States. The Department of Energy has assessed that such an event would not only disrupt power in the New Madrid region but far beyond, with outages potentially affecting 100-150 million people across the Northeast, Southeast and Midwest United States.\(^{57}\)

Other U.S. regions are also at risk of catastrophic earthquakes, and Federal and state emergency managers have been ramping up

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For state-by-state estimates of expected damage and outage scope/duration, see New Madrid Seismic Zone Catastrophic Earthquake Response Planning Project: Impact of New Madrid Seismic Zone Earthquakes on the Central USA, Volume 1, October 2009: https://www.ideals.illinois.edu/bitstream/handle/2142/14810/ImpactofNewMadridSeismicZoneEarthquakeso%20theCentral%20USAVol1.pdf?sequence=3
their efforts to build preparedness against them. The 2014 Capstone Exercise of the FEMA/DHS National Exercise Program highlighted how a severe earthquake in a single state can create region-wide devastation of energy infrastructure and pose immense threats to public health and safety. The Alaska Shield 2014 exercise, conducted as a component of that broader Capstone program, provides a case in point. The scenario for Alaska Shield was based on a recurrence of the 9.2 magnitude Great Alaskan Earthquake, which struck Alaska in 1964. That scenario included significant damage to the power grid and other infrastructure both from the quake itself, and also from the tsunami it would trigger against coastlines across the greater Pacific Northwest.\(^{58}\)

Planning and exercises for catastrophic earthquakes are also underway in California. The presence of the San Andreas Fault, the Hayward Fault and other faults along much of the state create especially severe risks of long-duration, wide area power outages (and of resulting threats to public health and safety). Major earthquakes registering magnitudes between 6.3 and 8.3 have occurred in California every 5.4 years, on average, for the past 200 years. The United States Geological Survey estimates that there is a 90 percent chance that a major earthquake will strike an urban area in California within the next 30 years. Moreover, the majority of Californians live within 20 miles of a major earthquake fault.\(^{59}\)

A major exercise to strengthen earthquake preparedness in California occurred in October 2014. The State government, the California National Guard, FEMA and U.S. Northern Command are also partnering to build especially comprehensive plans to prepare for and manage the consequences

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of catastrophic earthquakes in the state. Building on this collaborative planning model and applying it to other seismic zones will be essential. In doing so, it will also be important to supplement these plans with pre-planned, multi-sector coordination to assure the best possible coordination among infrastructure stakeholders beyond the electricity sector, and to plan to make use of the full resources of the NGO community for mass care.

The Cascadia Subduction Zone poses an equally severe threat of earthquakes to the Pacific Northwest. The Cascadia Zone is a very long sloping fault that stretches from mid-Vancouver Island to Northern California and is capable of producing earthquakes of a magnitude of 9.0. Major cities affected by a disturbance in this subduction zone would include Vancouver and Victoria, British Columbia; Seattle, Washington; Portland, Oregon; and Sacramento, California. A study by the National Infrastructure Simulation and Analysis Center (NISAC) found that in such a 9.0 event, the entire region would experience extensive electrical outages, with medium-term outages forecast for the coastal areas. Restoration is expected to occur on a prioritized basis within one to eight days. Both the natural gas transmission pipeline and the networks of distribution pipelines in the affected region are likely to suffer enough damage for the majority of customers in western Washington and western Oregon to lose natural gas service. Major undersea transoceanic cables are likely to be severed, disrupting communication service to East Asia as well as between Alaska and the contiguous United States, with a two-to-three-month expected restoration time.

Of course, utilities in these seismic zones are thoroughly aware of the risks they face and have invested in resilience accordingly. In Alaska, for example, Municipal Light & Power has adopted a range of earthquake-resistant design features. These include pad-mounted transformers and switch cabinets, anchoring systems at substations, and flexible conductors at key points in the grid. The utility gains additional resilience from its loop-feed system, so that if one segment of the system goes down, the grid operators can isolate that section.

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and feed around it from different directions. Utilities in at-risk seismic zones also typically store liquid fuel in case of a disruption in the natural gas supply that power their generators, and a growing number of those generators have dual-fuel capabilities. But these risk mitigation measures can only accomplish so much. In a catastrophic earthquake, the challenges of power restoration and consequence management will be unequalled in U.S. history. Advance planning for comprehensive whole community support, including the power restoration support measures discussed in Chapter 3, will be crucial to assure rapid power restoration, with minimum human costs.

C | Geomagnetic Disturbances caused by Severe Space Weather

Typically many times each year, the sun ejects a portion of its coronal mass into space. If this highly-energetic, electrically and magnetically charged matter impacts the Earth, it can distort Earth’s geomagnetic field, inducing large, potentially damaging current in long transmission lines and transformers, the “ligaments” of a national-scale power grid. A Severe Space Weather-induced Geomagnetic Disturbance (GMD) can last anywhere from several minutes to several days. Peak geomagnetic fields during such events can vary from tens of V/km for minutes to sustained levels of up to a few V/km lasting hours to days.

Depending on the magnitude and duration of unplanned, transient current and the design and condition of transformers, especially the critical Extra High Voltage (EHV) transformers connecting those transmission lines, voltage

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63 At solar minimum CME’s are observed about once per week. Near solar maximum we observe an average of 2 to 3 CMEs per day. (solarscience.msfc.nasa.gov/CMEs.shtml)

64 The 1859 “Carrington Event” lasted 5 days, the 1921 “Railroad Storm” lasted 2 days, the 1989 “Quebec Storm” lasted for 2 days, and the 2003 “Halloween Storm” lasted 3 days.

65 GIC heuristics for any specific region depend on a variety of factors, such as latitude, geology and power system topology.
instabilities and transformer damage or degradation may result. Whether any such damage has an immediate impact or only becomes apparent during the weeks that follow the event, if a sufficient number of affected transformers are eventually taken out of service, there could be significant supply curtailments. Protective relays are also susceptible to GIC-induced harmonics, which could cause needless switching and loss of equipment such as capacitors.

Following a more detailed review of this hazard, Chapter 2 examines mitigation opportunities against GMD, including both hardware and operational measures.
DEFINING THE BLACK SKY CHALLENGE

Each of the manmade and natural hazards examined in this chapter pose specific power restoration and disaster response challenges. For example, the requirements for power restoration following a cyber-attack will differ from those against hurricanes. Restoration following a cyber attack will require malware scrubbing and other cyber-specific response operations that are radically different from the debris removal, road clearance, and other operations typically necessary after a hurricane-induced outage.

Nevertheless, these severe threats also share basic characteristics which characterize all black sky hazards – i.e., natural or manmade events capable of causing multi-FEMA region outages lasting a month or more, including acts of war by nation-states, terrorist attacks by Al Qaeda and its affiliates, or earthquakes and other natural catastrophes.

Black sky hazards: natural or manmade events capable of causing multi-FEMA region outages lasting a month or more, including acts of war by nation-states, terrorist attacks by Al Qaeda and its affiliates, or earthquakes and other natural catastrophes.

Defining black sky events and differentiating them from less severe outage
categories, such as Major Outage Events (MOES), helps focus the analysis of restoration and consequence management recommendations in the handbook chapters that follow. Clearly differentiating these categories may also support progress to develop new assessment tools for proposed investments in resilience against events of very high impact but uncertain (and in some cases, unknowable) probability.

Of course, many of the resilience measures that the EPRO Handbook recommends for black sky days will also be useful for less severe, more frequent Major Outage Events (MOEs) such as Sandy, Hurricane Irene, and the Derecho storm of 2012, as defined by IEEE Std. 1366. In addition, however, black sky hazards will also require balanced, advance investment in essential protection measures and power restoration planning and support, as well as consequence management initiatives, over and above those necessary for MOE. In fact, the requirements for building resilience against black hazards are not only quantitatively greater, but are qualitatively different.

The following section characterizes black sky events in terms of four characteristics:

- **Severe outage metrics**: Outage duration, percentage of customers losing power, and geographic scope, and other outage metrics

- **Unprecedented physical grid damage**: Large-scale physical damage to the grid, and to the infrastructure essential for power restoration;

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66 Resilience for Black Sky Days, pp. 5-6.
- **Demand for Emergency Power:** The extraordinary stress that black sky events would put on emergency power generators and fuel supplies, which, in shorter duration outages, provide essential support for hospitals, emergency operations centers, and other crucial facilities and functions.

- **Unprecedented need for mass care:** The unprecedented requirements for life-saving and life-sustaining operations created by the event, and the degree to which power outages will disrupt the delivery of those efforts.

Taken together, these event characteristics highlight the enormous preparedness challenges that black sky events entail, and exemplify the need for cross-sector collaboration that provides the focus of the EPRO Handbook and the parallel EPRO Executive Steering Committee.

### A | Severe Outage Metrics

The Edison Electric Institute’s efforts to prepare for National Response Events (NREs) offer a starting point to establish a threshold for the geographic scope of black sky events. An NRE is “a natural or manmade event that is forecast to cause or that causes widespread power outages impacting a significant population or several regions across the U.S. and requires resources from multiple Regional Mutual Assistance Groups.” This characterization of an event would be designed to facilitate the process by which utilities identify available power restoration assets and coordinate the logistics and personnel involved in restoration efforts.67

According to these geographic criteria alone, however, Sandy would be classified as a National Response Event. Sandy caused outages in 24 States across multiple FEMA regions in the Northeast, Middle Atlantic and parts of the Midwest, leaving approximately 10 million utility customers without service. [Figure 1 shows the FEMA Regions of the United States.] Additional criteria are necessary to define black sky events and differentiate them from Sandy-level disasters.

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To further clarify the resilience problems that catastrophic power outages will create, and differentiate these outages from less severe events, this Handbook adopts an additional metric: event duration. Measured by the length of a power outage, Hurricane Katrina was a more severe event than Sandy. Two weeks after Sandy made landfall, major utilities in the New York/New Jersey region had restored electricity service to 95% of their customers. 23 days after Katrina, only 75% of customers had their power restored, before Hurricane Rita struck the affected area and created additional outages. This Handbook defines catastrophic outages as those in which 90% of customers in a multi-state region lose power for at least 30 days -- that is, a month or more.

Black sky events can be further defined by the nature of the hazard that creates the outage. The definition of National Response Events again provides a useful starting point. NREs constitute only “the most significant events, such as a major hurricane, earthquake, an act of war, or other occurrence that results in widespread power outages.” 68 The Handbook’s definition of black sky hazards takes a similar approach, referring to uniquely severe manmade or natural events that could cause very long duration power outages over regions encompassing a large portion of a nation.

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The projected damage of a 7.7 New Madrid earthquake exemplifies the devastation that a black sky event could inflict on grid components, and the resulting scale of equipment repair and replacement activities for power restoration. High voltage transformers are especially important in this regard. Utilities have made great strides in strengthening mutual assistance agreements so that they share critical spare parts in the aftermath of a terrorist attack, especially in the Spare Transformer Equipment Program (STEP) and other equipment sharing mechanisms.

However, industry’s preparedness for massive natural disasters (where replacement requirements would be region-wide) is much more limited, with considerable regional and corporate variability. High voltage transformers also weigh hundreds of tons and must be transported by specialized railcars and road vehicles. A New Madrid earthquake would cause severe damage to rail lines, critical roads and bridges, fuel supplies for utility trucks, and other transportation and communications infrastructure essential for power restoration operations. The Department of Energy also projects that such an earthquake would cause breakages in ten interstate natural gas pipelines as well as damage to oil pipelines and coal railway distribution systems.

These damage projections have recently been updated and refined in greater detail by participants in the Capstone 14 New Madrid exercise, which
the Central United States Earthquake Consortium (CUSEC) conducted in June, 2014. Their assessment: large portions of an eight state region would lose electric power for many months, due to shaking-induced physical damage to power generation, transmission, and distribution systems (especially high voltage transformers, and substations). An estimated 400,000 breaks and leaks in natural gas lines would also disrupt the flow of fuel to gas-generating plants that survived.

Moreover, infrastructure critical to grid restoration efforts would be severely degraded. Thousands of cell towers and other communications nodes would be destroyed. Over three thousands bridges (including many spanning the Mississippi) would need repair before utilities could use them to move replacement components for the grid. Other road, rail and airport infrastructure would be similarly disrupted.

Finally, gasoline pipelines and distribution infrastructure to support utility crew operations would suffer massive damage, as would municipal water systems, food distribution systems, and health care facilities for crew members and their families.69

The EPRO Handbook recommends how state National Guard organizations, NGOs and other partners can support these utility crew operations. The Handbook also proposes “whole community” initiatives to help assist the families of utility crews and provide for broader societal resilience against black sky hazards.

C | Demand for Emergency Power:  
A defining characteristic of black sky events

Emergency power will be especially problematic in a black sky outage. Many key facilities and critical assets have backup generators and enough on-site supplies of fuel to power them for at least a few days. In an extended outage however, generators will be at risk of failing, and on-site fuel could be depleted without re-fueling.

These emergency power challenges have enormous implications both for the scale of consequence management operations that will be required to save and sustain lives, and the difficulty of maintaining the infrastructure functions on which power restoration will depend. Moreover, as in other resilience measures for black sky hazards, success will depend directly on the level to which advance mitigation and whole community coordination can be established before a catastrophic event occurs. Sandy and other major outages have revealed a key weakness in preparedness for such events: the longer the blackout lasts, the greater the number of backup power generators that fail, including in facilities vital for conducting disaster response operations and for saving and sustaining lives. During the Northeast blackout in 2003, for example, fully half of New York City’s 58 hospitals suffered backup generator failures. Hospital generators failed again in Sandy at New York University’s Langone Medical Center and other critical facilities.

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Black sky events will create much greater demands for emergency power and an increased scale of generator breakdowns. An outage of more than a few weeks would require many backup generators to function far beyond their design life. The ensuing demand for replacement generators at hospitals, emergency operations centers and other critical infrastructure facilities would vastly outstrip supplies.

A black sky event will also create an enormous shortfall of fuel for emergency power generators. Generators at many critical infrastructure facilities have only enough on-site fuel to operate for hours or a few days. If an electric outage lasts longer than on-site fuel can power the generator, facilities rely on commercial contractors to deliver new supplies. This resupply system will break down in a black sky event. Demand for generator fuel will quickly outstrip supply, as many hundreds of facilities in a typical state request additional fuel, and pipeline breakages interrupt the flow of fuel to local depots. In a New Madrid earthquake event, the roads and bridges that commercial providers require to conduct resupply operations will also be severely disrupted.

Chapter 3 examines these challenges for emergency power in greater detail, and proposes measures for utilities and their partners to mitigate them. Adopting such mitigation measures will be absolutely vital for power restoration support and consequence management.

D | Unprecedented Need For Mass Care:
Massive requirements for consequence management operations, and disruption of the infrastructure on which those operations will depend

A long duration, wide area outage as described above would jeopardize public health and safety on an unprecedented scale, and create enormous requirements for first responders and their partners (including NGOs) to save and sustain lives. Electricity is essential to the functioning of every sector of critical infrastructure, defined by the USA Patriot Act of 2001 as “systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters.”

For managing the consequences of a black sky outage event, a wide range of infrastructure components would fall within this definition of criticality. This “lifeline” infrastructure includes hospitals and pharmaceutical distribution systems for public health; fire and police stations for public safety; and municipal water systems and food distribution systems for sustaining life.

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72 §1016(e) of the USA Patriot Act of 2001 (42 U.S.C. §5195c(e))
Lifeline facilities and functions are typically supported by emergency power generators and fuel. As noted in the analysis above, however, these critical facilities would be disrupted in a catastrophic outage as generators failed and demands for emergency fuel resupply outstripped supply (especially if fuel distribution systems were themselves disrupted).

1. Water and Wastewater Systems as a Special Point of Vulnerability

The impact that a black sky event would have on infrastructure for water and wastewater systems illuminates the scale of the challenge that emergency managers would confront. Nothing could pose such an immediate threat to public health and safety, or be more likely to prompt a massive, unplanned migration from a major urban area, than the loss of municipal water service for drinking and fighting fires. However, as municipal water systems have grown in size and complexity to meet America’s increasing demand for accessible, high-quality water, these changes have introduced increasing vulnerability to the loss of electric power.

Water supply systems have been traditionally partitioned into three sections: obtaining the water at its source (acquisition), moving the water into the city (conveyance), and dispersing the water to residential, commercial, and industrial clients (distribution).\footnote{Templin, William E., et al. “Public Water Supply.” National Handbook of Recommended Methods for Water Data Acquisition. http://pubs.usgs.gov/chapter11/chapter11C.html.} The design and layout of water systems and their dependence on electricity varies greatly depending on the water availability as well as on state and federal legislation. San Francisco and Los Angeles rely on long aqueducts to transport meltwater from the Sierra Nevada Mountains to their surrounding areas, while Philadelphia and Washington D.C.
use local surrounding rivers. Some regions take advantage of surface water, while others access groundwater in wells.

The vulnerability to electric-related incidences of each section is increased with the introduction of pumps designated to lift water to higher ground, as pumps require electricity. Thus, surface water sources are less dependent on electricity than groundwater sources, gravity-fed transport systems are less vulnerable to electrical outages than pump-based transportation methods, and down-hill dispersal has a smaller risk of being affected by power disturbances than up-hill distribution.

In addition to pumps, reliance on other critical electronic equipment also poses a risk to the resilience of the overall water supply system. While higher water quality standards have reduced the risk of contamination (particularly through the implementation of UV lighting and ozonation), new treatment techniques tend to have a larger reliance on electricity than earlier methods, leaving treatment plants and other parts of the system more vulnerable to a power outage. Without a source of power, sensors and other measuring instruments are simply unable to determine the quality of the water.

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To mitigate potential water supply disruption due to power outages, municipal water systems often rely on multiple electric sources, and have backup power strategies in addition to the power grid. Treatment plants often have access to multiple power grids.\(^7\)

This concern for potential loss of power has led to installation of backup generators by a growing number of municipalities. However, as indicated above, in a long duration, wide area power outage emergency generators and fuel will be at risk -- leaving urban populations with an imminent threat to survival in a black sky event.

2. The Disruption of Infrastructure on which Consequence Management Operations Depend

In any catastrophe such as a new Madrid earthquake, first responders and their partners in government and beyond would encounter an enormously challenging operational environment, precisely when the requirements for their capabilities would be most urgent. NGOs, in particular, would face extensive requests for their traditional missions of mass care, emergency assistance, temporary housing and other life-sustaining activities. The loss of electric power to hospitals and other lifeline infrastructure would magnify these support requests, as would failure of key communications nodes (including cell phone service) and other critical infrastructure.

However, in an outage lasting weeks longer than Sandy, NGOs, first responders and other emergency service providers would face their own crises, making it difficult to sustain emergency operations in essential infrastructure sectors.

Special areas of concern for mass care requirements in an extended, wide-area outage:

- **Food Supply**: Disruption of food and medical supply distribution points and the transportation on which they depend;

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\(^7\) Feng Liu et al., “A Primer on Energy Efficiency for Municipal Water and Wastewater Utilities.” Energy Sector Management Assistance Program (ESMAP), February 2012.
- **Fuel for Emergency Service Providers and Police:** Failure of gas pumps and fuel distribution systems (which run on electric power), and resulting degradation of fire, police, road clearance and other emergency vehicle operations.

- **Migration Crises:** With the disruption of gas, roads, airports and other transportation system components, the ability of the affected population to move out of the disaster area will be limited. This could have important implications for mass care requirements.

- **Loss of Communication:** This occurred during Superstorm Sandy, when key Verizon cell towers ran out of emergency generator fuel.

  An additional risk to disaster response operations may arise from chemical facilities and nuclear power plants. In the aftermath of the Fukushima disaster, the Nuclear Regulatory Commission and its industry partners have adopted additional measures to ensure that their emergency power needs can be met. However, chemical plants and other at-risk facilities could also pose risks to nearby population centers as emergency power generators and fuel supplies for them come under stress. And of course, as was highlighted in Fukushima, radiological or chemical events (and perhaps even the perceived possibility of such an event occurring) would greatly magnify the difficulties of power restoration and further lengthen outage duration.
While the risks of long duration, wide area outages are growing, industry and its partners in government and beyond have already established a remarkable foundation for the progress that must continue. The only way to achieve such progress is to broaden and deepen the collaborative relationships that already exist.

For protection against E-threats, an ideal opportunity now exists to share emerging best practices in the electric industry, and identify areas where additional research and information-sharing by the Federal government is needed.

For power restoration addressing the full list of black sky hazards, whole community planning and coordination will be vital to ensure that adaptable, utility-focused support capabilities will be available from utilities’ NGO and government partners.
For consequence management, the scale of the potential threats to public health and safety (and the disruption of critical infrastructure on which response operations will depend) is so vast that a whole community strategy is necessary to reduce these threats. Chapter 3 proposes how to build and implement such a whole community approach for preparedness against black sky events.

For black sky hazards, the scale of the challenges for power restoration and to address potential threats to public health and safety is vast. Industry and its partners now have important opportunities to build on the remarkable foundation for progress they have begun developing; to provide the “whole community” effort that will be essential to meet these challenges.
Glossary

GMD – Geomagnetic Disturbance
Geomagnetic Disturbances (GMD) are large variations in the Earth’s magnetic field, caused by Severe Space Weather or EMP. These variations produce Geomagnetically Induced Current (GIC) in power grids that can cause disruption or damage to grid infrastructure or electronics. In this report, as has become common usage, Severe Space Weather-induced GMD will be referred to simply as “GMD.”

EMP (or HEMP)
(High altitude) Electromagnetic Pulse
“A single nuclear weapon exploded at high altitude above the United States will interact with the Earth’s atmosphere, ionosphere, and magnetic field to produce an electromagnetic pulse (EMP) radiating down to the Earth and additionally create electrical currents in the Earth.

“The electromagnetic fields produced by weapons designed and deployed with the intent to produce EMP have a high likelihood of damaging electrical power systems, electronics, and information systems upon which American society depends. Their effects on dependent systems and infrastructures could be sufficient to qualify as catastrophic to the Nation.

“Depending on the specific characteristics of the attack, cascading failures of our major infrastructures could result. In that event, a regional or national recovery would be long and difficult and would seriously degrade the safety and overall viability of our Nation.”

IEMI – Intentional Electromagnetic Interference
“Intentional malicious generation of electromagnetic energy introducing noise or signals into electric and electronic systems thus disrupting, confusing, or damaging these systems for terrorist or criminal purposes.”
INTRODUCTION

While many shared requirements for response and recovery operations apply across a broad range of Black Sky hazards, measures to protect the grid tend to be more hazard-specific, both in terms of protective hardware and operational procedures to mitigate damage. In this first edition of the EPRO Handbook, this grid protection chapter focuses on Electromagnetic Threats (E-threats), since relatively little material is available on best practices for protecting power grids and other critical infrastructure against these increasingly significant hazards.

For many decades, grid owners and operators have effectively protected the electric system from lightning strikes and other familiar, well-understood electromagnetic hazards. As noted in Chapter I however, E-threats also present potential resilience challenges to the electric grid, including severe space weather-induced Geomagnetic Disturbance (GMD), Electromagnetic Pulse
(EMP) and Intentional Electromagnetic Interference (IEMI). (See Glossary, inset\(^1\)).

All of these hazards can cause serious disruption or damage to power grid components. Yet, this potential damage can be significantly reduced through practical, affordable equipment protection and operational mitigation measures, many of which are now being pioneered by a growing number of utilities. What is missing is a review of emerging best practices, guidelines for strategic planning and protection options that utilities may wish to consider and adapt to their own priorities and specific circumstances.

The analysis that follows is designed to fill that gap. The first section of the chapter proposes an overall strategic framework for evaluating alternative protection levels and options, and identifies key issues and analytic findings for utilities to consider in strengthening resilience against E-threats. Section Two summarizes the physical characteristics of GMD, EMP, and IEMI threats and their implications for power grid protection. Section Three examines specific hardening options and operational measures to strengthen resilience against GMD or EMP, and provides an example of a decision-support matrix to help utilities assess the advantages and disadvantages of alternative EHV transformer protection approaches for their own unique grid configuration. Section Four reviews mitigation measures against a uniquely powerful, damaging pulse from EMP weapons (EMP E1) not found in GMD events. Section Five examines opportunities for utilities to develop supplementary power restoration plan modules focused on E-threats. Section Six provides an illustrative example of how such a module might be created and executed for a notional 30-bus electric system. Section Seven, the final section, provides a brief summary of the chapter.

As utilities assess protection options provided in the Handbook and develop and implement their own E-threat strategies, a second resource will be available to support their work: the EPRO Executive Steering Committee (ESC). The ESC includes representation from the full array of private sector, government and non-governmental organizations who helped draft the Handbook. The Committee will provide a framework for sustained coordination and dialog

\(^1\) Congressional EMP Commission Report, Overview, P.1 http://www.empcommission.org/docs/empc_exec_rpt.pdf


among industry and its partners on best practices and implementation steps addressing black sky hazards. Given the novelty of the challenges posed by E-threats, and the relatively recent development of mitigation options for the electric industry, assisting industry and its partners to address these challenges will be an especially significant focus for EPRO ESC in the years ahead. This dialog will include discussion of the North American Electric Reliability Corporation's (NERC) Reliability Standards for Geomagnetic Disturbances, which are currently being developed subsequent to the Federal Energy Regulatory Commission's (FERC) order for reliability standards against GMD, and also voluntary initiatives that utilities may wish to undertake for targeted, cost-effective mitigation above and beyond those required by the GMD rule.

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A STRATEGIC FRAMEWORK FOR E-THREAT PROTECTION

A key finding of the Handbook is that a limited, targeted set of investments in equipment hardening can have enormous benefits for strengthening the power grid’s resilience against E-threats. With careful pre-planning, operational measures to protect the grid against Geomagnetic Disturbances can also be valuable, although – in many cases – they also involve potential risks. However, while E-threat resilience measures provide a vital foundation for recovery, assured and accelerated power restoration will also require specialized sparing initiatives and restoration plan modules that address the unique challenges of GMD, and EMP and IEMI weapons.
Core Priorities and Resilience Strategies

The Congressional EMP Commission reports and other recent studies have emphasized that for both EMP and GMD, damage, while affecting very large regions, is expected for only a fraction of exposed, vulnerable electrical and electronic components. EMP, for example, will not destroy all electrical and electronic components, devices and systems in an affected area. While complex, computer-intensive control systems (including unprotected power grid control systems) will typically fail or be disrupted, most electrical and electronic hardware in the region will likely survive. The bottom line: protecting all such hardware is not only impractical, it is also unnecessary.

As a strategic framework for targeted, cost-effective investments, this chapter proposes that hardening and other mitigation measures be focused on a specific grid-resilience objective: assured, accelerated power grid recovery from a large regional outage. Accomplishing this will mean planning for strategic, protected “enclaves” or protection of restoration-critical infrastructure, coupled with measures needed for accelerated restoration.

1. Strategic Protection – Defining Secure “Enclaves”

Power grid restoration following a large regional outage can be assured only if an appropriate foundation is available to begin that process. Thus, “enclaves” of power that either remain operational or can be quickly restored to operation will provide a critical starting point for systematic restoration of the rest of the grid, as well as for serving critical loads with minimal interruption.

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4 Ibid.
5 Ibid.
These protected “enclaves” will typically fit into two categories:

- **Local Generation: Critical, local generation assets and cranking paths**
  
  In wide-area outages caused by GMD or EMP, E-threat protected “black start” generating plants will be of unprecedented importance to begin re-energizing the grid. The Federal Energy Regulatory Commission (FERC) defines “black start” capability as the ability of a generating unit or station to start operating and delivering electric power without assistance from the rest of the electric system, including in the midst of a blackout where outside power is not available.⁶

  These black start generating plants, whether they remain operational during an event or are brought back online shortly after an event, will only be able to start the process of reenergizing the grid if they are associated with operable “cranking paths” – portions of the grid that can be isolated and then energized to deliver electric power, to enable startup of one or more other (non-black start) generating units and other critical load.⁷

  FERC emphasizes that black start capabilities are essential to restart generation and restore power to the grid in the event of an outage. Utilities typically are required to have well-designed, thoroughly tested power restoration procedures, utilizing pre-designated cranking paths designed to help restart additional generators (nuclear, gas, etc). For wide-area outages caused by GMD or EMP, E-threat protection will be of paramount importance for these black start generators, for associated cranking path components and for the other major generating stations that will be “cranked” or restarted by the black start process.

- **Remote Generation: Transmission assets linking to dependable remote generation plants**
  
  In past outages, power restoration has primarily depended on a different mode of restoration: that is, using power from outside the affected region to re-energize the grid. In the 2003 Northeast U.S. blackout, the 2012

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Derecho Storm and in Superstorm Sandy, power was restored primarily by bringing electricity into the affected area from Bulk Power System (BPS) assets lying outside the range of the blackout. This method could, potentially, also be crucial in the far more catastrophic outages that E-threats could create. Indeed, E-threat restoration operations may benefit from plans and capabilities that can integrate both blackstart and “outside-in” assets. However, bringing power into the affected region will require advance designation of generation plants expected to be peripheral to the likely E-threat impacted area, with E-threat protection of EHV transformers and other BPS assets linking to these remote generation assets. For example, with GMD more likely to be a primary concern for more northern latitudes, protecting portions of the high voltage transmission system linking to large generating plants in southern latitudes may provide an additional option to help reenergize the affected portion of the grid.

2. Accelerated Power Restoration

While E-threat resilience investment in protecting strategic enclaves can provide an essential foundation, assured power restoration will also require development of E-threat restoration plans, and targeted investments in hardening and other mitigation measures to assure those plans will be effective.

- **Critical, long lead-time hardware**

As protected power enclaves come back online, power company restoration teams using E-threat restoration plans will be working to restore power in a prioritized fashion to urban water systems, major hospitals and other critical loads – but only if control centers can properly function and the high voltage transmission system that will bring power to critical substations is at least largely operational. The EHV transformers that power the “ligaments” of the high voltage transmission system are generally not easily or quickly replaced, and will be particularly critical. If locally available or rapid-replacement spares are not available, restoration efforts could be blocked in significant portions of a blacked out grid segment.

Thus, utilities may want to consider protecting a control center, and taking E-threat mitigation measures for key components essential to
operation of large regions of the grid which would be difficult to quickly repair or replace ("long lead"), in a severe, wide-area E-threat event that damages many such components.

- **Restoration tooling**
  
  Taken together, the combination of protection of strategic enclaves and E-threat protection for a control center and selected, critical long lead equipment provide a dependable basis for power grid restoration efforts. However, to implement a restoration plan, restoration teams will need properly stored and staged spares and replacement parts. In addition, these teams will need EMP-protected emergency vehicles, tooling and communication gear.

  Targeting protective measures in this fashion can help ensure that grid owners and operators will be able to effectively restore power, and to return to near-normal service conditions far more quickly than would otherwise be possible. The specific protection plans adopted by utilities will reflect their own system configurations, restoration priorities and other utility-specific factors. For example, to provide for outside-in power restoration, not all possible transmission lines to access outside power will typically need to be protected against E-threats. Sections 3-6 of this chapter provide additional decision criteria to help utilities prioritize hardening investments and other mitigation measures.
B | Selecting a Protection Architecture: A Balanced, Multi-Level Approach

While each utility will make its own determination of an appropriate level of asset protection against E-threats, Section 5 of this chapter examines three notional levels of protection to help support such decision-making for EMP mitigation.

1. Summary of Notional Protection Levels

This three-level menu is designed as an example of a balanced set of options, selected to help ensure that available resources are deployed to provide a “protection architecture” for a grid segment that minimizes overall risk. Thus, even the “minimum” hardening option provides at least the most essential resources for assured power restoration.

- **Minimum EMP Hardening.**
  EMP protection for major/critical and black start-designated power plans and associated cranking paths, the primary control center for the grid in question, and a minimum set of the most critical EHV transformers at critical grid nodes. The description of this option also includes recommendations on critical tooling and resources to support a restoration plan module that would meet core restoration needs, including critical spares and emergency communications.

- **Intermediate EMP Hardening**
  Beyond the elements of the Minimum level, hardening a wider range of power plants and a wider selection of EHV transformers, while providing for significantly more robust restoration planning and preparedness (such as increased inventories of stored critical spares in EMP-proof containers).

- **Comprehensive EMP Hardening**
  Within this highest level of notional protection, larger numbers of EHV transformers are hardened, along with protection of all control centers and of selected, major power substations.
2. Robust, Adaptable Architecture

As indicated in the Introduction to this Handbook, one additional perspective is recommended, cutting across all levels of Black Sky hazard resilience and restoration planning.

In adopting hardening options to achieve a selected level of protection, it will remain important to provide enough flexibility to adapt to the operational surprises and unexpected problems that an EMP or GMD event would inevitably create. In spite of even the most effective planning efforts, it may be that designated, critical cranking paths for local generation-based restoration will be disrupted, or will require too much trouble-shooting and rework to meet the needs of the early restoration process. The same risk will likely apply to the pre-planned, protected transmission paths at regional boundaries for remote generation, and for selected critical EHV transformers.

To ensure that any selected, discreet protection architecture is viable in such real-world conditions, additional redundancy is recommended, so that real-time changes in restoration planning are feasible. To achieve such an adaptable architecture, even for minimal protection utilities might consider protecting at least one additional black start cranking path, and making similar decisions in other areas of resilience investment and restoration planning.

The broader finding of the Handbook: adaptable, parallel architectures for protecting the grid will be essential to contend with the unanticipated “real world” challenges that an E-threat event will inevitably entail.

3. Implementation: Investment and Planning Options

Implementing the above-recommended core E-threat resilience strategies typically involves planning for a cost-effective combination of mitigation investments, operational measures and comprehensive power restoration planning.

- Implementing “Strategic Protection”

  Targeted, Prioritized Investments in Equipment Hardening:

  As reviewed above, the fundamental strategy recommended for E-threat protection measures is a combination of Strategic Protection – assuring
protection for E-threat secure enclaves – and Accelerated Power Restoration. Of these two elements, Strategic Protection is the foundation, ensuring that continuously operating or only briefly interrupted “secure power enclaves” – generation, transmission, blackstart, and cranking path assets designated as the foundation for restoration – survive even the most severe E-threat event. These measures, coupled with measures for Accelerated Power Restoration, will be crucial to ensure the operational and restoration plans will be properly resourced and effective.

To develop a specific hardening plan for E-threat resilience, the first step, therefore, is reviewing protection options, and choosing an investment level for protected power enclaves. But while industry has substantial experience in resilience measures for traditional hazards, such as flooding and other weather-related damage, most utilities have far less experience in protection against E-threats. To supplement this experience base, this chapter provides investment strategies, suggests options for different (balanced) hardening / investment levels, reviews emerging best practices and highlights tradeoffs among hardening options for both high voltage and low voltage power grid equipment.

Operational Measures to Limit Damage during an E-threat Event

Assuming that grid owners and operators receive advanced warning that a GMD event is likely to occur, a range of operational measures could also be used to mitigate physical damage to transformers and other grid components, although it is important to consider potential performance risks of such measures. This Chapter reviews operational protection measures that could supplement equipment hardening, to achieve assured E-threat protection at different levels of investment.

- Implementing Accelerated Restoration Planning

Given the unique features of an E-threat-induced power outage, restoration plan modules designed to address the consequences of severe storms and other traditional hazards will be inadequate for restoration after an EMP or GMD-induced blackout.

The EPRO Handbook proposes suggested guidelines for focused E-threat power grid restoration planning, providing options for utilities to supplement existing restoration plans with modules tailored for E-threats.
The Handbook analyzes the key planning requirements and operational phasing of restoration efforts that will be necessary against E-threats. The Handbook also identifies key restoration system components that should be protected against such hazards. As discussed below, pre-planned sparing and spare-staging strategies are essential, along with planning for practical damage assessment, diagnostic techniques and other restoration-focused preparation. This includes, as a crucial priority, EMP protection of utility trucks and other essential restoration tooling.

To provide a concrete illustration of how utilities might develop and execute an E-threat restoration planning module, the Handbook provides a plan for a hypothetical 30-bus power system. That plan illuminates not only the prerequisites for accelerating power restoration following an E-threat event, but also highlights how targeted equipment-hardening investment decisions for protected power enclaves provide an effective basis for reenergizing the grid.
II | E-THREAT CHARACTERISTICS

A number of recent studies have provided detailed descriptions of the effects of physical characteristics of space weather, EMP, and IEMI threats. This section summarizes their findings and highlights the implications for the protecting the power grid.

GMD, EMP and IEMI events differ not only in their causes but also in their associated electromagnetic effects:

- GMD is a relatively long duration effect that may be caused by either Severe Space Weather (~minutes to days) or by a “long time” EMP pulse (~minutes), known as “EMP E3.” GMD induces “geomagnetically-induced current” (GIC) that can disrupt or damage EHV transformers and associated high voltage equipment.

- EMP weapons also generate two other pulses not associated with severe space weather. (Figure 2.1 provides the waveforms for all three EMP pulses: “early-time” EMP E1, “intermediate-time” EMP E2 and “late-time” EMP E3).

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8 For a complete list of report summaries and links (including Congressional EMP Commission (2008), NAS/NASA (2008), FERC/DOE/DHS (2010), Lloyd’s (2012), please visit: http://eiscouncil.org/English/Resources/ResourcesCategory.asp?catId=267
EMP E1 is an extremely short, highly destructive pulse (arising in nanoseconds and continuing for < 1 microsecond). Although very similar to the pulse created by IEMI devices, EMP E1 from a high altitude nuclear detonation can lay down a field of tens of thousands of volts per meter, out to the horizon seen from the burst height (a region that could be up to a few thousand kilometers in diameter). An IEMI weapon creates a field of similar (or even greater) intensity, but typically over fractional kilometer ranges.

Another EMP pulse – E2 – is similar to naturally occurring lighting, though an EMP weapon generates E2 effects over a much wider area and significantly lower intensity than lighting. Standard lightning protection measures are generally considered adequate in protecting against the EMP E2 pulse.⁹

Thus, while many of the same approaches will protect against both EMP E3 and GMD, very different measures are required to protect against EMP E1 or IEMI.

![Figure 2.1](image.png) | Three portions of the EMP electric field waveform (E1, E2, E3) in volts/meter from IEC 61000-2-9

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⁹ Note: Possible interactive E1 / E2 effects, as well as the unique non-local character of E2, are both candidates for further examination. Evaluation of possible damage or degradation of existing lightning protection systems by E1 deserves study. And operationally, the large E2 footprint may suggest that periodic validation of such lighting protection may become a priority – particularly in areas where natural lighting strikes are rare.
Severe Space Weather-Induced GMD

Far-ultraviolet images of the pre-shock (left) and post-shock (right) aurora obtained with the aurora imager on NASA’s IMAGE satellite during the July 14-15, 2000, “Bastille Day” event. Courtesy NASA/IMAGE FUV team.

Typically many times each year, the sun ejects a portion of its coronal mass into space. If this highly-energetic, electrically and magnetically charged matter impacts the Earth, it can distort Earth’s geomagnetic field, inducing GIC in long transmission lines and transformers, the “ligaments” of a national-scale power grid. Severe Space Weather-induced Geomagnetic Disturbance (GMD) can last anywhere from several minutes to several days. Peak geomagnetic fields during such events can vary from tens of V/km for minutes to sustained levels of up to a few V/km lasting hours to days.

Depending on the magnitude and duration of unplanned, transient

According to NASA researchers, if the 2012 solar eruption had occurred one week earlier, massive clouds of magnetized plasma would have struck the earth. The resulting geomagnetic storm would have been at least as strong as the Carrington event, with enormous destructive power.

11 At solar minimum CME’s are observed about once per week. Near solar maximum we observe an average of 2 to 3 CMEs per day. (solarscience.msfc.nasa.gov/CMEs.shtml)
12 The 1859 “Carrington Event” lasted 5 days, the 1921 “Railroad Storm” lasted 2 days, the 1989 “Quebec Storm” lasted for 2 days, and the 2003 “Halloween Storm” lasted 3 days.
current\textsuperscript{13} and the design and condition of transformers, especially the critical Extra High Voltage (EHV) transformers connecting those transmission lines, voltage instabilities and transformer damage or degradation may result. Whether any such damage has an immediate impact or only becomes apparent during the weeks that follow the event, if a sufficient number of affected transformers are eventually taken out of service, there could be significant supply curtailments. Protective relays are also susceptible to GIC-induced harmonics, which could cause needless switching and loss of equipment such as capacitors.

In modern times, satellite-based sensors observe powerful Coronal Mass Ejections relatively frequently. Historically, the frequency at which powerful CMEs have impacted the earth is estimated as once per 100 – 200 years.\textsuperscript{14} The largest CME-event in relatively recent history, the “Carrington Event,”\textsuperscript{15} occurred in 1859, followed 62 years later by another event of similar magnitude, the 1921 “Railroad Storm.”\textsuperscript{16} Although both events caused serious damage to the global telegraph network and the related systems that existed at those times, they pre-dated development of modern power grids.

As South Africa’s experience shows, low-latitude countries can indeed be affected, and long duration, low-level GIC flows can degrade transformers, with subsequent failures occurring in the months following such events. Thus, extreme space weather GMD baseline scenarios should include extended duration low level GIC, in addition to short duration high GIC levels.

An event of this severity could recur at any moment. Indeed, such an event almost took place quite recently, when a Coronal Mass Ejection occurred in July, 2012. According to researchers from the National Aeronautics and Space Administration (NASA), if the eruption had occurred one week earlier massive clouds of magnetized plasma would have struck the earth. The resulting

\textsuperscript{13} GIC heuristics for any specific region depend on a variety of factors, such as latitude, geology and power system topology.
geomagnetic storm, according to NASA scientist Daniel Baker, would have been at least as strong as the Carrington event, with enormous destructive power.\(^\text{17}\)

![Figure 2.2](image)

**Figure 2.2** | Long-duration GIC flows observed in a transformer neutral in South Africa during the October 29 – 31 Halloween Storm

Lower level Space Weather GMD events have been observed relatively frequently. Of these the best known are the March 1989 GMD event, which caused a province-wide blackout in Quebec, Canada,\(^\text{18}\) and a GMD event in October 2003, which caused a blackout in parts of Sweden and damaged a number of EHV transformers in the South African power grid.\(^\text{19}\)

The impacts of the Halloween Storm in South Africa are of particular significance, in two different areas. Before the October 2003 event, Space Weather was not believed to be a significant concern for electric grids in

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18 NASA, The Day the Sun Brought Darkness: (www.nasa.gov/topics/earth/features/sun_darkness.html#U8kysJrdXQg)


lower-latitude countries. And for higher latitude countries, only high peak geoelectric fields were considered to be a serious concern. As South Africa’s experience shows, low-latitude countries can indeed be affected, and long duration, low-level GIC flows (see Figure 2.2) can degrade transformers, with subsequent failures occurring in the months following such events.²¹

Both of these results have become important in planning for power grid GIC protection, with concern now encompassing a much broader range of latitudes, and a growing understanding that extreme space weather GMD baseline scenarios should include extended duration low level GIC, in addition to short duration high GIC levels.

A number of protection options relevant to this combination of high peak, short duration and low peak long duration field effects, both operational and hardware-based, are outlined in later sections of this chapter.

### B | High-Altitude Electromagnetic Pulse (EMP)

A nuclear EMP event creates a powerful, damaging electromagnetic field covering a sub-continental-scale region, capable of causing widespread physical damage to control and communications equipment in the electric power grid and other critical infrastructure sectors.²²

The size of the affected region depends on burst height, and certain features of the warhead.²³

EMP could affect many different utilities and infrastructures. According to the recent

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²³ EMP field strength is primarily a function of the weapon’s gamma ray output. Since warhead size, or yield, is only weakly connected to pulse strength, small nuclear devices are also a serious concern.
government studies mentioned above, EMP, due to its very large footprint, represents a serious risk of an extended duration power outage over a large region, also likely precipitating cascading failures of all other critical societal infrastructures.

While this impact on civil power grids is a relatively recent concern, EMP has been studied and addressed diligently as a military threat for over 50 years. In the United States, EMP has been treated by DOD as an active, growing hazard. In 2011, the U.S. Defense Science Board renewed and highlighted this policy, issuing an interim report citing progress, coupled with ongoing recommendations for EMP survivability of DOD assets.

EMP has been addressed as a military threat for over 50 years, with renewed recommendations for U.S. DoD asset protection in 2011 by the Defense Science Board.

EMP was first observed in 1962 by the United States, in an upper atmosphere nuclear test over the Pacific Ocean, code-named Starfish Prime. In Hawaii,

“Starfish Prime:” U.S. Nuclear Test

For a complete list of report summaries and links (including Congressional EMP Commission (2008), NAS/NASA (2008), FERC/DOE/DHS (2010), Lloyd’s (2012)), please visit: http://eiscouncil.org/English/Resources/ResourcesCategory.asp?catId=267


over 800 miles away from the blast site, a portion of the island’s streetlights, telephone systems and other electric infrastructures were unexpectedly disrupted and damaged. Later that year, the Soviet Union performed a series of tests over Kazakhstan, code-named “the ‘K’ Project.” According to (later) published Russian reports and information on the K Project’s Test 184, publicly released by the Congressional EMP Commission and other U.S. government agencies, this over-land EMP test caused severe damage to generating stations, military electronics, transmission line insulators and other exposed infrastructure components.

28 Ibid.
29 Ibid.
EMP and IEMI: Description and Standards

For EMP, the International Electrotechnical Commission (IEC), based in Geneva, Switzerland, has developed an open-source, unclassified set of descriptive material and standards. IEC Commission material available\(^3\) includes electromagnetic compatibility assessment, EMP threat measurement, simulation and related standards and guidance, and associated information related to protection approaches. Additional detailed information can be found on the Commission’s website.\(^3\) Given the similarity of EMP E1 to IEMI in pulse waveform and effects on electronic components (though not in magnitude or footprint) the work of the International Electrotechnical Commission also has applicability to these local, non-nuclear threats.

Considerable work to address EMP protection within the framework of IEC standards has taken place in recent years. The three EMP pulses produced by a nuclear device detonated above an altitude of 30 km, reviewed above, are shown in IEC 61000-2-9 (Figure 2.1). EMP peak fields decrease, but do not disappear, for burst altitudes below 30 km, and altitude also factors into field intensity and footprint.

Referring to Table 2.1 and Figure 2.1, peak EMP E1 fields can reach tens of kV/m, lasting nearly a microsecond. For EMP resilience, effective protection is required for the most critical components or installations of a grid segment, including at least one control center, major generating stations, black start generators and cranking paths. Black start generators, for example, must either remain in operation or be capable of safe shutdown and rapid restart after the E1 pulse. Depending on the grid configuration, use of either hybrid digital / electromechanical relays, or shielding that provides 80 dB of attenuation\(^3\) would be recommended. Most grid components and subsystems, however, do not require this level of protection. As indicated above, the statistical nature of the expected hardware damage, with a relatively small fraction of hardware

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\(^3\) To review the International Standard, visit http://webstore.iec.ch/preview/info_iec61000-4-32%7Bed1.0%7Den.pdf

\(^3\) 80 dB of attenuation reduces the pulse level by a factor of 10,000 to 1 V/m
elements damaged, means acceptable E1 resilience can be achieved for most of grid hardware through strategic, properly staged sparing and expanded restoration planning.

<table>
<thead>
<tr>
<th>EMP Type</th>
<th>Electromagnetic Waveform Characteristics</th>
<th>Typical Coupling Level</th>
<th>Potentially vulnerable power system facilities and equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>Tens of kV/m; duration of nanoseconds to a micro second</td>
<td>10kHz – 1,000MHz</td>
<td>Millions of volts and hundreds of amps</td>
</tr>
<tr>
<td>E2</td>
<td>Tens of kV/m; duration of micro seconds to milliseconds</td>
<td>Many mega hertz</td>
<td>Lightning strike to ground but E2 occurs over a large area and hits the whole system at once.</td>
</tr>
<tr>
<td>E3</td>
<td>Tens of volts/km; lasts for minutes</td>
<td>Low frequency of less than one hertz</td>
<td>Space weather, geomagnetic (solar) storms</td>
</tr>
</tbody>
</table>

Table 2.1: Summary of EMP Effects on Electrical Power System
A field similar to the “early time” E1 pulse can be produced by an appropriately designed electronic device, creating a pulse which can actually be far higher in magnitude and frequency, though over much smaller regions, affecting discrete “point” targets. When manufactured as weapons, they are often referred to as “Intentional Electromagnetic Interference” (IEMI) devices, or Radio Frequency (RF) weapons. Such devices can potentially generate a much broader range of frequencies than EMP, and in some cases, unlike EMP, can produce multiple, repeated pulses as part of an attack. The pulse generation process is nearly instantaneous, and the EMP pulse propagates at the speed of light.

IEMI weapons have been characterized as a “dumb” cyber threat, as the assets most vulnerable are computers and electronics. They can damage or destroy microprocessors, corrupt or wipe out data on hard drives, cause misoperation of relays and electrical arcing in more robust power system components such as transformers. Commercial and military versions of these systems are available or under development in a growing number of nations.

To cite just two of many examples, e2v, a British high-tech company, is producing a commercial EMP weapon (“Safe Stop”) designed for use by security services, stopping vehicles by disrupting their electrical systems. Boeing, working for the U.S. Air Force Research Laboratory, developed the Counter-electronics High-powered Microwave Advanced Missile Project (CHAMP). A radio-frequency (RF) weapon mounted on a cruise missile, CHAMP directs an electromagnetic pulse at point targets while flying over them.

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33 Commercial IEMI devices are typically marketed as test equipment or, in some cases, for security services.
34 As reported at EIS Summit IV, Washington D.C. May 21, 2014.
35 e2v, RF Safe Stop (http://www.e2v-us.com/markets/security-rescue/RF-Safe-StopTM/)
36 Boeing, CHAMP – Lights Out (http://www.boeing.com/Features/2012/10/bds_champ_10_22_12.html)
While the characteristics of Space Weather, EMP and IEMI events are well understood, deployment of protective measures for most national power grids and grid segments is still at an early stage. Among E-threats, GMD protection has been accelerated by the Federal regulator rule-making process, with the Federal Energy Regulatory Commission’s rule for reliability standards against Space Weather GMD driving a two-phase process for protection efforts by Bulk Power System owners and operators. Indeed, even before FERC required such a rule for GMD, and without a regulatory requirement for EMP, some utilities were already adopting protection measures on a voluntary basis.

Prior to the FERC order, NERC had also formed the Geomagnetic Disturbance Task Force (GMDTF) in early 2011 to examine potential GMD vulnerabilities and mitigation options.\(^{38}\) Subsequent to FERC Order 779, the GMDTF had a key role in developing NERC’s recommended Phase One GMD Operational Procedure (See Section B.2), and is now contributing material that NERC will use as an input in developing recommendations for the second phase of the standards, requiring system model analysis and review of possible hardware-based protection options for FERC-regulated utilities.\(^{39}\)

The strategic approaches and the menu of options that follow are based on those initiatives, and on other emerging E-threat protection “best practices.”

**Part A** of this section begins with a review of strategic considerations that can help utilities assess protection options against GMD and EMP E3, and illustrates an approach to GIC sensitivity modeling that can help guide decisions on hardening and operational measures.

**Part B** examines E-threat operational measures

**Part C** analyzes equipment hardening options.

A concluding analysis provides an example of a transformer protection evaluation matrix, structured as an approach to help utilities weigh the advantages and disadvantages of alternative transformer protection measures.

### A | Building a Strategy: Key considerations

Power grid restoration after an E-threat event will involve repair and replacement of damaged electronic and electrical hardware distributed over a very large region. For a GMD event associated with significant grid damage, there would never be a complete, large area extended duration E-threat induced power outage.

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\(^{39}\) NERC, Geomagnetic Disturbance Operating Procedure Template (http://www.nerc.com/comm/PC/Geomagnetic%20Disturbance%20Task%20Force%20GMDTF%202013/Template_TOP.pdf)
power restoration could require aggressive efforts to identify, replace or workaround failing transformers, generators and other high voltage components distributed throughout that region. For an EMP event that disrupts control systems and other electronics over a large region, power restoration would face similar challenges for low voltage components and, possibly, high voltage hardware damaged by mis-operation of the low voltage control system.

If the power grid has been largely protected, at least to a basic level, and pre-arranged, coordinated “community-wide” support to power company teams is available from government and NGO stakeholders, this process will involve “building out” from still-operational enclaves (protected segments of the grid, either operating continuously through the event, or operating following a brief, safe shut down and restart process). In this scenario, there would never be a complete, large area extended duration power outage, and restoration of service would begin quickly from these powered “enclaves,” pre-planned and organized to maximize the rate of power restoration, while prioritizing critical facilities in the affected area. Even in this protected scenario, however, reaching high levels of grid restoration is likely to take far longer than for more common power outages.

If even basic protection has not been implemented, the process will not have functional starting points. If pre-planned and fully coordinated government and NGO support is not in place, corporate power restoration teams will not have the essential backup they will need for transportation, communication, security and lifeline services. In this scenario, restoration of service in an impaired environment over a large area will be, at best, problematic; secondary failures of critical facilities will amplify the problem, and months or even years would be required to reach pre-event service levels.40 41

Given these projections, cost-effective resilience investment could be crucial to societal health and security following such an event. Given the complexity and scope of national power grids in the United States and internationally,

40 From the Congressional EMP Commission 2008 report: “Damage or loss of these components [transformers] could leave significant parts of the electrical infrastructure out of service for periods measured in months to a year or more.” (http://empcommission.org/docs/A2473-EMP_Commission-7MB.pdf - page vi)

41 The National Academy of Sciences estimated “… recovery times of 4 to 10 years.” (http://www.nap.edu/catalog/12507.html - page 4)
the core strategy recommended for this process is a multi-level protection approach, with different levels of “hardening” for different power grid elements.

Multi-level protection typically would begin with careful prioritization of power grid asset hardening, based on an assessment of the criticality of assets in the restoration process, and realistic repair or replacement times. Restoration for other damaged hardware elements would be handled by pre-planned, strategically staged sparing. The whole restoration effort would be defined by specially tailored restoration plan modules with associated, E-threat protected restoration tooling, used by teams trained in these plans. In addition, to be effective in the complex real-world environment of a national power grid, this prioritization process will require an effective menu of protection options, with estimated effectiveness ratings in addressing the different protection needs of different hardware elements.

1. Prioritizing Protection: GIC Sensitivity Modeling

The first step in this process is prioritizing protection measures to protect high voltage power grid elements. To accomplish this, it is generally helpful to begin by using modeling to assess sensitivity of different grid nodes and components. Such a sensitivity study may be accomplished by modeling GIC flow, and especially the potential scale of GIC at different grid nodes. A brief example of such modeling is provided below.

GIC Sensitivity Model Approach – GMD and EMP E3

Extensive U.S. power grid studies have shown that transformer GIC levels at different grid locations have a highly variable but predictable behavior as a result

42 While overall GIC modeling is now generally considered a mature capability, available heuristic GIC and magnetometer data to tune such models for different regions remains limited. Risk-based assessment of relative grid node sensitivities would be significantly improved by improvements in limited data gathering and modeling, and the cost and complexity of such limited, improved data gathering and modeling appear to be low. Monitors for GIC flow and its impact on transformers and other key grid components are relatively inexpensive and easy to install, and offer grid operators advantages in system performance at all times, not just under GIC conditions. In fact, emerging industry best practices in this area will be required in the U.S. under stage 2 of FERC order 779.
of the angular orientation of an incident geoelectric field. Due to the grid’s complex topology and coupling with space weather or EMP environments, at certain field orientations and locations an exposed transformer will see no GIC flow, at any field intensity. At other locations, this orientation sensitivity can change dramatically. Thus, dependable estimates of GIC and transformer risk at different power grid locations typically require calculating grid sensitivity over a wide spectrum of intensity levels and field orientations.

In this example, a simple, uniform geo-electric field screening approach was used for the analysis of the CONUS grid’s sensitivity to severe E-threat environments. Use of a uniform geo-electric field allowed for a simple “Ohm’s Law” determination of GIC flows, providing high confidence in determining GIC-active locations within the complex network topology. While this sensitivity-study approach is an approximation, it identifies transformers which, during very large GMD events, are most likely to be at risk of excessive (> 90

Figure 2.3 | Map of the simulated U.S. Grid used in the analysis referenced in this section. Across the entire CONUS the model includes details of all 345kV, 500kV and 765kV transmission lines and transformers. In some regions of the U.S. - particularly the mid-Atlantic to Southeastern U.S. regions - the model also includes 230kV transmission network details.

Amps/phase) GIC flow. And for system analysis of smaller grid segments, this approximation will be more accurate, allowing system operators to prioritize mitigation measures by:

(a) Determining which transformers will typically experience the highest GIC flows, and (b) Evaluating the net-best protection schemes for their grid segment by reviewing net grid GIC exposure for a number of different, candidate protection schemes.

For EMP E3, since the field location is an unknown before the event, this approach provides the best available formalism for defining at-risk grid nodes, and associated transformers or generators and related high voltage components.

Using this constant-field sensitivity modeling approach, results were calculated for a full set of uniform geoelectric field rotations. Figure 2.4 shows the 500 transformers identified as having the highest GIC participation within the continental United States (CONUS). Figure 2.5 indicates the GIC levels of all 3500 transformers modeled, at various geoelectric field levels. Importantly, we see that identification of the transformers that would experience the highest GIC levels is possible for a given level of assumptions, providing an important asset to help prioritization planning for mitigation measures. Similar models could be used to help focus resilience investments by individual transmission system owners and operators.

![Figure 2.4](image-url)
2. GMD Thresholds and Standards

Given a process for prioritizing protection of high voltage power grid elements, the next step is selecting functional GMD thresholds and associated protection standards. This selection, in turn, may be somewhat simplified by the fact that naturally occurring GMD and EMP E3 have similar effects on the power grid, making most GIC protective measures effective against both. As a result, threat benchmarks that represent stressing phenomena for both malicious and natural threat drivers can provide useful design guidelines for vulnerable equipment that may be exposed to either hazard.

A candidate GMD benchmark could include the peak disturbance predicted for EMP E3, with a low level, long duration disturbance scenario example for severe space weather.

For example, a candidate benchmark for GMD and EMP E3 could be a combination of the geomagnetic disturbance expected for an EMP E3 field,
and a very long duration, relatively low level GMD event. As an example, this might include the IEC unclassified EMP E3 peak geoelectric field of 40 V/km for ~ 5 minutes (Fig 2.1 and Table 2.1), combined with the 1-3 day fluctuating but ongoing lower field levels (<5 V/km) seen in smaller geomagnetic storms, such as those recorded for the March 1989 Quebec Storm shown below in Figure 2.6\textsuperscript{44}, and the South African October 2003 Halloween storm shown in Figure 2.2.\textsuperscript{45}

\begin{center}
\includegraphics[width=\textwidth]{figure26.png}
\end{center}

\textbf{Figure 2.6.} East-West Geoelectric Fields Measured at the National Resources Canada Ottawa Geomagnetic Observatory

\begin{itemize}
  \item \textsuperscript{44} North American Electric Reliability Corporation, TPL-007 Benchmark Geomagnetic Disturbance Event Description (2014)
  \item \textsuperscript{45} John Kappenman, “An overview of the impulsive geomagnetic field disturbances and power grid impacts associated with the violent Sun-Earth connection events of 29-31 October 2003 and a comparative evaluation with other contemporary storms,” Space Weather, Vol. 3, S08C01 (2005)
\end{itemize}
Operational Measures: GMD and EMP E3

Operational procedures have been used in the electric power industry to deal with power disruptions of all kinds since the inception of the electric grid. While the risk of receiving little or no warning for EMP events makes many operational measures ineffective for EMP E3, constant monitoring and adjustment of power to load is inherent in the operation of the grid, and procedural approaches are available to manage GMD for space weather events comparable to those seen in modern times. For severe black sky-class events, GIC levels would typically be too high for conventional operational procedures to provide assured, grid-wide protection at a level that can provide for high-confidence, dependable grid-wide power restoration.

3. Guiding Principles and Themes

For severe events, operational approaches alone cannot provide for assured survival of adequate grid resources for high-confidence power restoration. Nevertheless, in conjunction with targeted equipment hardening measures, they may help significantly reduce the extent of physical damage an E-event will cause.

**Theme 1:** Equipment unloading: Unload equipment that can be negatively impacted through redispatch and reconfiguration.

Since GMD and EMP E3 can induce currents in power system components, equipment loading would be reduced where possible in this theme. Reduced loading, where possible, can increase “headroom” for GIC and harmonics. For example, interregional energy transfers could be reduced by relying more heavily on local generation, in lieu of potentially more economical long distance transmission. For a severe event, this approach may not provide adequate additional capability.

**Theme 2:** Operational relay sparing: Pre-emptively remove one set of redundant unshielded digital protection systems from service

In control schemes where redundant digital relays exist, consider removing one set of relays from service and isolating them, so they can be brought back online if the primary relays are damaged. This scenario trades increased reliability risk for the benefit of assuring an undamaged backup.
Theme 3: Operational generator and transformer sparing: Isolate lightly
loaded generators and transformers from service

In lighter load situations, it may be possible to isolate lightly loaded
generators and transformers from the system. This can protect some generating
equipment and transformers in case of widespread damage in an affected region,
so that operational assets remain for partial system restoration after the event.
The primary disadvantage of this approach is the consequent increase in loading
and damage risk on the remaining generators and transformers.

Theme 4: Controlled shutdown of portions of the EHV network – GMD Only

Given some forewarning of a severe CME event, and suitable cross-corporate
and regulatory or legislative environments, selected portions of the transmission
system could be taken out of service based on: (1) Pre-determined, identified
vulnerability, (2) Criticality and the need to save the facility for post-event
operation, (3) Redundant facility to be saved for post-event operation, and (4)
Preservation of cranking paths to facilitate system restoration after the event.

Before such steps would be taken, system analysis is required, well in
advance, to provide improved confidence that the selective outages would not
inadvertently precipitate a cascade or collapse, given the in-service topology.

A primary performance risk of this theme is the uncertainty in projecting
the level of severity of the Space Weather event, the immediate or time-deferred
impact, and the likely affected geographic region. Since these factors would
likely lead to occasional, wide-area unnecessary shutdowns, mitigation of this
consequence could involve setting the precipitating threshold for such measures
too high to be effective.

Another major concern is the risk of poor implementation across the
thousands of companies and other power grid stakeholders. This theme assumes
adequate, prearranged coordination, decision making and implementation,
across most of the energy sector and with NOAA or other federal agencies
projecting the event magnitude and providing the warning.

This theme also has many of the negative attributes of the large regional
power outage it is intended to mitigate. Since use of this approach means
there would be a definite (advertent) power outage when projected conditions
reach a defined threshold, most of the complex measures for wide-area outage
restoration, discussed in this Handbook, would, in any case, be requisite.
Theme 5: Reduce thermal and electrical output of nuclear plants

Nuclear plants typically receive special consideration in anticipation of a GMD event (or, potentially, an EMP event), due to their size and anchoring positions on the EHV transmission system. The EHV transmission system in many cases was constructed to facilitate the transfer of nuclear plant energy from remote plant sites to the load centers. If they can be preserved, there is a much better chance for accelerated restoration of the EHV transmission system.

Theme 6: Security-constrained economic dispatch

Power systems generally operate to provide energy to customers at the lowest possible cost using security-constrained economic dispatch, maximizing economic benefits while maintaining reliability of the system. This is done by operating only the most economic generation at all times of the operating day, while maintaining reliability. However, in a GMD (or potentially EMP) event, modifying economic dispatch could enhance grid GIC withstand by reducing transmission loading for selected portions of the system.

4. U.S. NERC recommended, FERC-approved GMD Operational Procedures

A. Information and Indications: The following are triggers that could be used to initiate operator action:

- External: NOAA Space Weather Prediction Center or other organizations issue Geomagnetic Storm Watch notification (1-3 day lead time), Warning (15-60 minutes lead time,) and Alert (during storm).
- Internal - System-wide: Reactive power reserves; System voltage/MVAR swings/current harmonics
- Internal - Equipment-level: GIC measuring devices; transformer hot-spots and/or sudden significant gassing; system or equipment relay action (e.g., capacitor bank tripping)

B. **Actions Available to the Operator:** The following are possible actions for Transmission Operators based on available lead-time:

- **Long lead-time** (1-3 days in advance, storm possible)
  1. Increase situational awareness
     a. Assess readiness of black start generators and cranking paths
     b. Notify field personnel as necessary of the potential need to report to individual substations for on-site monitoring (if not available via SCADA/EMS)
  2. **Safe system posturing** (only if supported by study; allows equipment such as transformers and SVCs to tolerate increase reactive/harmonic loading; reduces transformer operating temperature, allowing additional temperature rise from core saturation; prepares for contingency of possible loss of transmission capacity)
     a. Return outaged equipment to service (especially series capacitors where installed)
     b. Delay planned outages
     c. Remove shunt reactors
     d. Modify protective relay settings based on predetermined harmonic data corresponding to different levels of GIC (provided by transformer manufacturer).

- **Day-of-event** (hours in advance, storm imminent):
  1. Increase situational awareness
     a. Monitor reactive reserve
     b. Monitor for unusual voltage, MVAR swings, and/or current harmonics
     c. Monitor for abnormal temperature rise/noise/dissolved gas in transformers
     d. Monitor GIC on banks so-equipped
     e. Monitor MVAR loss of all EHV transformers as possible
     f. Prepare for unplanned capacitor bank/SVC/HVDC tripping
     g. Prepare for possible false SCADA/EMS indications if telecommunications systems are disrupted (e.g., over microwave paths)
2. **Safe system posturing** (only if supported by study)
   a. Start off-line generation, synchronous condensers
   b. Enter conservative operations with possible reduced transfer limits
   c. Ensure series capacitors are in-service (where installed)

- **Real-time actions** (based on results of day-of-event monitoring):
  1. **Safe system posturing** (only if supported by study)
     a. Selective load shedding
     b. Manually start fans/pumps on selected transformers to increase thermal margin (check that oil temperature is above 50° C as forced oil flow at lower temperatures may cause static electrification)
  2. **System reconfiguration** (only if supported by study)
     a. Remove transformer(s) from service if imminent damage due to overheating (possibly automatic by relaying)
     b. Remove transmission line(s) from service (especially lines most influenced by GMD)

- **Return to normal operation** – This should occur two to four hours after the last observed geomagnetic activity.

These procedural approaches are considered mature, and represent existing, international best-practices for “normal” GIC levels. Australia,\(^{47}\) Norway,\(^{48}\) and Sweden\(^{49}\) all have GMD operational procedures similar to those used in the U.S. New Zealand’s approach is somewhat different, in that it calls for pre-event removal of critical or sensitive transformers from the system under certain GIC conditions.\(^{50}\)

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48 Norwegian Energy Regulations (http://lovdata.no/for/sf/oe/xe-20121207-1157.html#map005)
49 Swedish Grid, 2012: Protection against geomagnetic storms-electromagnetic impact on the power system. Ser. 2011/805
50 Transpower System Operations Division: Manage Geomagnetic Induced Currents
C | Hardware Protection Measures: 
GMD and EMP E3

1. Generating Stations

- Risk

For these hazards, a primary concern is heating, torsion and vibration in the turbine. Although GIC cannot flow into the generator itself,\textsuperscript{51} harmonic currents in the high voltage windings of the GSU transformer, caused by GIC saturation, can transform to the low voltage windings and then enter the generator.

Although no serious generator damage has been documented due to low-level GMD, this is a concern for severe GMD scenarios. Any generator stator currents other than the fundamental-frequency positive-sequence create oscillating flux components in the rotor, which induce currents that can lead to rotor heating. The depth of flux penetration decreases with frequency, thereby concentrating the energy of the higher harmonic orders near the rotor surface. Excessive rotor heating may create a crack initiation site, or potentially arcing and melting at the rotor body/wedge interface. Depending on the scale and the timing of such damage mechanisms, an immediate or delayed problem could create a serious problem which may not be readily apparent.

\textsuperscript{51} The two windings in a GSU transformers are not directly connected. And while the high voltage winding is connected to ground and thus provides a path for entry of GIC, the Low voltage winding - which connects to the generator itself - is not connected to ground.
In addition, conventional negative-sequence relays for generator protection are designed to react to fundamental frequency imbalance, and may thus respond improperly or not at all to harmonic currents. Harmonic currents flowing into a generator during a GMD event also create harmonic torques of magnitudes and frequencies not encountered during normal operation. Large turbine generators are complex mechanical devices, possessing many torsional modes. The concurrent presence of a super-synchronous torsional vibration mode with a torque harmonic could potentially result in fatigue and crack initiation.

Within the generating station, in addition to the generator itself it will also be important to plan for protection of the Generator Step-Up (GSU) transformers, as for EHV transformers in the transmission system. Options for protection of GSU transformers, as for transmission system transformers, are reviewed below.

- **Overall Hardening Strategy**

  As unique, high value assets with long acquisition lead times, EHV transformers have received special attention in the many E-threat vulnerability studies that have taken place in recent years. Yet far less attention has been paid to power generating stations which also represent high value, long lead time assets. In fact, effective power grid resilience planning must address the vulnerability of both of these categories.

  A first step in generator resilience planning is assigning protection priorities for power generation stations by assessing their relative criticality and vulnerability. Designated black start generators and their cranking paths, for example, are vital, as these systems will be the surviving powered “enclaves” which – other than power coming in from outside the affected region -- will be the foundation for power restoration after a GMD or EMP-induced blackout. Other generators will also place high on the priority list, especially large generating stations essential for expedited power restoration. Nuclear power plant resilience will also be very important, for safety reasons, as critical restoration assets, with
excellent, long term (nuclear) fuel storage, and as (typically) important elements of black start generator cranking paths.

- **Protection Measures**
  As summarized above, a key to GMD/E3 protection for generators is to prevent or limit harmonics in the GSU. Referring to the available transformer protection options listed below, neutral blocking or reducing can effectively mitigate harmonics, as the harmonics arise from half-cycle saturation, which depends only on the GIC level. Series capacitors will also block the GIC, but can create subsynchronous resonance issues that may be a greater concern than the GICs themselves (though they could be used pending a rigorous engineering analysis to ensure that subsynchronous resonances will not arise). Options that do not limit GIC levels in the GSU will have no effect on harmonic generation. The GSU and generator can also be protected from GIC by bringing the system into a safe shutdown mode, tripping when unsafe GIC and harmonic levels are reached, or (preempting EMP E3-generated GIC) by tripping when an E1 pulse is detected.

### 2. Transmission System Hardening

**EHV Transformers**

- **Risk**
  The most vulnerable assets in a transmission system are the Extra High Voltage (EHV) transformers, which are subject to GIC-induced half-cycle saturation, and associated heating and harmonics. If damaged, they are
also the most difficult to replace, with manufacturing, transportation and integration schedules often measuring more than a year. All transformers will experience half-cycle saturation to varying degrees under GIC conditions. Differences in the degree of degradation result from differences in sensitivity to such saturation, based on the particular transformer design, manufacturing process, condition and age. This can lead, for example, to differences in the tendency to develop local hot spots, and in the vulnerability to such hot spots, potentially affecting transformer lifetime and, in extreme cases, leading to short-term failure.

**Low sensitivity configuration example:** Assessments of GIC sensitivity of different classes of transformer configurations can only be offered in very general terms since, as indicated above, actual sensitivity may be highly dependent on a transformer’s design, manufacturing process, age and condition. It is also difficult to narrow the assessed category further by restricting the evaluation to a particular manufacturer and design, since it is estimated that only 1.3 transformers are produced, on average, for each transformer design.\(^52\)

Nevertheless, while not immune to these effects, certain configurations are more robust than others. Three-phase, three-legged core form transformers have the highest magnetic reluctance under half-cycle saturation under GIC conditions. The United Kingdom, Norway and Sweden have adopted a policy requiring use of this design for all new transformers,\(^53\) acquired when older transformers are replaced or in new transmission projects. Finland uses this transformer configuration almost exclusively.\(^54\)

**High sensitivity configuration example:** Typically smaller and less costly than three-phase core transformers, single-phase autotransformers are quite common in transmission systems. Unfortunately, they are the most susceptible to GIC effects, since the high and low side windings are electrically connected, allowing an electrical through-path for GIC

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54 Ibid.
flow. They are also the most difficult to protect. For example, to fully block GIC in an operational autotransformer, a combination of neutral ground blocking and series capacitance is required.

- **Protection Measures**

There are a number of options for protection of EHV transformers. To provide for assured survival of adequate grid resources for high-confidence power restoration, a carefully planned combination of these options would be required.

  a. **Transformer GIC Withstand Specification** – Acquiring EHV transformers with built-in GIC protection above a designated threshold

  GIC withstand specifications could have a significant positive impact on future grid resilience to GMD. While not currently a widespread requirement for new transformer procurement, if it became common, improved GIC-withstand would become a standard feature in transformer design, resulting in greater system-wide resilience. High GIC-withstand design features typically include use of non-magnetic steel in structural members subject to heating during half-cycle saturation.

  As an example, Svenska Kraftnät, the Swedish Transmission System Operator, now applies such specifications for all new transformers, requiring GIC-withstand to 200 Amps DC for 10 minutes at full load with no deleterious thermal effects.55

  b. **Transformer De-rating** – Acquiring EHV transformers with load ratings significantly above normal usage requirements

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55 Ibid.
Transformers running at or near their designed load capacity may have smaller thermal margins and, in the event of GIC, can therefore be driven out of their designed operation temperatures more easily. Purchasing transformers with load (MVA) ratings that significantly exceed expected loads would provide larger thermal margins under GIC conditions. Transformer de-rating is actually a common practice across the industry (though not typically implemented with GMD in mind), as substations are often “overbuilt” with transformers larger than needed, in anticipation of future load growth. In such cases, substation transformers may be lightly loaded – possibly for many years – until load requirements grow to match substation capability.

c. Additional Transformers – Deploying additional transformers, to reduce transformer-specific GIC levels

Similar to de-rating, introduction of additional transformers into the system, so that GIC is “shared” across a larger number of transformers, would also result in higher thermal margins under GIC conditions. To cite one example, Transpower New Zealand implemented this strategy: “…at Invercargill an extra transformer has been installed to “share” the GIC current between 3 rather than the previous 2 transformers, thus reducing the risk.”\(^{56}\)

Both de-rating and use of additional transformers could increase system reliability and resilience, and are consistent with the NERC GMD required operational procedure of keeping as many transmission lines and transformer substations as possible in service in times of expected high GMD activity (see Subsection B.2 Operational measures for GMD/E3 above: “return outaged equipment to service”).

d. Spare Transformers – Pre-arranged, conveniently-staged spare transformers for replacement of GIC damaged units

While large transformers are expensive, long lead times for manufacturing, shipping and integration of a replacement after

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\(^{56}\) Transpower, System Operator Reports, June, 2011, (http://www.ea.govt.nz/search/?q=geomagnetic+disturbance)
an incident highlight the advantage of acquiring spares, preferably pre-positioned, on-site. (Even in cases where spare transformers are available, moving a transformer to a new location within a facility and integrating and energizing it may take weeks, even under ideal, “blue sky” conditions).

Many companies in the U.S. and around the world are implementing transformer sparing strategies. For example, Dominion includes spare transformers as part of its overall substation security strategy. Many utilities also use banks of three single-phase transformers in their EHV substations, along with single phase spares on-site or at strategic locations. When purchasing new transformers, some utilities have made it standard company practice to purchase four, so there is always one spare for each bank. And, although of limited applicability in some cases due to space constraints, a cheaper alternative is to maintain old but still-functional transformers on-site after replacement, to be used as spares in emergency situations.

Some utilities limit transformer purchases to a few standard designs to improve interchangeability, and may have pre-planned studies for combining different single phase unites if a fully equivalent spare is not available.

A number of companies in North America participate in the Edison Electric Institute’s (EEI) Spare Transformer Equipment Program (STEP). The program was designed – and is expected to be highly effective – against damage caused by terrorist attacks. EEI and its partners are now considering ways to build on the STEP program to strengthen resilience against a full range of severe hazards, and provide for the availability of many more transformer spares and other critical equipment in a major outage. Other programs

59 EEI, Spare Transformers (http://www.eei.org/issuesandpolicy/transmission/Pages/sparetransformers.aspx)
The E-Pro™ Handbook also offer significant potential to help utilities accelerate power restoration against Black Sky hazards.

Another important initiative is to provide for temporary, more easily moved substation transformers to help restore power at certain voltages. The U.S. Department of Homeland Security, working with the Electric Power Research Institute (EPRI) and transformer manufacturer ABB, has developed the Rapid Recovery Transformer, or RecX, a portable transformer intended for such use. It has been successfully installed and field tested for more than a year in Texas. The initial installation in March, 2012 involved moving the RecX prototype from St. Louis to Houston, installing and energizing it, all in less than one week, as compared to typical timeframes of several months. Future production of such systems could provide an important asset for recovery from Black Sky hazards.

Other mobile transmission system assets are also in use by some utilities, such as mobile capacitor banks modified to handle high harmonic levels, designed to improve VAR performance during GMD events. More extensive use of such mobile assets could add additional E-threat resilience to transmission systems and national power grids.

e. Series Capacitors – Used for compensation on long lines, series capacitors can help block GIC, but it is presently unlikely that they would be installed solely as a GIC control measure

Series capacitors are currently used in long transmission lines in some locations to improve transmission efficiency. These systems provide synergistic benefits, improving efficiency and also blocking GIC. For new transmission lines, this can be particularly cost-effective. Fingrid Oyj, the Finnish Transmission System Operator (TSO), uses series capacitors on their longest North-South 400 kV EHV transmission lines, a measure they consider an important

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60 DHS Recovery Transformer (RecX), developed by DHS, EPRI, and ABB.
61 ABB, U.S. rapid recovery transformer initiative succeeds using specially-designed ABB transformers (http://www.abb.com/cawp/seittp202/9a9f00ef6e90dd00c1257a7e0042e142.aspx)
aspect of their GIC resilience.\textsuperscript{62}

Use of series capacitors is also consistent with the NERC GMD operational procedure – see Subsection B.2 above, “Return outaged equipment to service (especially series capacitors where installed)” and “Ensure series capacitors are in-service (where installed).” The NERC Operational procedure recognizes that in-service series capacitors will block GIC in the transmission lines in which they are used. Again, however, it is unlikely that series capacitors will be installed solely for GIC control.

\textbf{f. Pre-planned Transformer Disconnection} – Disconnecting a transformer before a predicted severe GIC event

In certain cases, for critical or very sensitive transformers, consideration should be given to advance disconnection of the transformer from the system when high GMD is forecast. Pre-planned disconnection prior to an event could result in load shedding, but is less likely if done pre-event, since system operators would have time to re-route power. This approach is included, for example, as an element of Transpower New Zealand’s operational procedure for GMD warnings.\textsuperscript{63}

\textbf{g. Pre-planned Transformer Tripping Threshold} -- Switching transformers out of the grid in real time, based on health or threat sensors

Transformer protection can also be provided by pre-planned transformer tripping when pre-set values are reached on designated sensors. There are several parameters and sensors that may be considered for this approach.

By using appropriately designed sensors and pre-defined criteria, conventional transformer stress measurements, such as thermal warnings, harmonic levels, vibration, or noise could all be candidates for this approach. Local GIC measurements could also play a role,


\textsuperscript{63} Transpower System Operations Division: Manage Geomagnetic Induced Currents
and a measure that integrates multiple parameters may also have advantages.

One unique, and potentially highly leveraging approach for EMP E3-induced GIC would be use of local or distributed EMP E1 sensors. Given the one-to-several second time delay between the E1 and E3 pulses, an appropriately designed and E1-protected sensor and relay system could potentially allow for tripping EHV transformers in affected regions upon detection of the EMP event. Given the potential cost and performance advantages of this approach for EMP events, it may merit special focus as a subject of further investigation and prototyping.

Transformer tripping is, of course, more likely to induce power outages – when a transformer and connected transmission line drop out of the system, reliability compromise and load shedding will typically result. However, depending on the parameters and the selected tripping threshold, this may be judged as essential to protect the transformer. At some warning levels, and particularly coupled with use of the EMP E1 sensor, unplanned load shedding and power outages would be considered, under the circumstances, inevitable. In that event, given that a power outage is already likely, protecting the transformer can substantially increase the capability for expeditious power restoration.

The NERC GMD operational procedures listed in Subsection B.2 refer to this general approach: “Remove transformer(s) from service if imminent damage due to overheating (possibly automatic by relaying),” to protect transformers from damage under GIC conditions.

h. Neutral Current Blocking/Reducing – GIC currents that would enter a transformer via the neutral ground path can be blocked (using capacitors) or reduced in magnitude (using resistors)

Neutral current blocking, using a capacitor in a transformer's neutral ground path, blocks GIC from entering the transformer. Similarly, neutral current reducing uses a resistor in the neutral ground path to reduce the current entering the transformer. Such devices can be installed as a retrofit, or built in with a new installation.

Typically, two main concerns are expressed regarding the use of GIC
blocking devices: 1) Potential adverse effects on system performance, and 2) Shifting GIC flows to other, unprotected transformers. Based on new testing and research, information is now available addressing both of these concerns. To date, no industry standard blockers are in production, though a new prototype blocking system has been developed and tested, and reducing systems have been in use for several years in New Zealand (see below). Additional research into dynamic performance is now underway and should be sustained.

**Potential adverse system impacts of current blockers and dampers:**

- **Limited Experience Base:**

  While use of current blockers and dampers is relatively new in the United States, information on system performance effects of current blockers is now available from several sources. A newly-developed current blocking system is currently being field-tested in the United States to assess possible impact on system performance. In initial testing at Idaho National Laboratories (INL), the system was “invisible” to the transformers while in the passive mode, with the blocking capacitors out of the grounding path. When the device measured GIC, the capacitors were switched in and successfully blocked the current, with no recorded adverse effects to transformer or system performance.

  In addition, based on recent research on international efforts addressing transformer GIC, two countries – New Zealand and Finland – both now have experience with use of such devices. New Zealand’s transmission operator, Transpower, has an extensive 20-plus year history of using neutral grounding resistors in the neutrals at over 30 of their transformer substations. The practice

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64 EMPRIMUS Solid Ground
65 Michael Rooney (DTRA), Greg Edmiston (SARA), Dave Fromme (SARA), Case Simulation Study, Ground Interrupt Device on INL 138 kV Loop from MHD/GIC Device, August, 2013 (Distribution A, Approved for Public Release)
66 Ibid.
67 Ibid.
was originally implemented to protect transformers on New Zealand’s South Island from stray DC currents that arise when the HVDC lines linking the North and South Islands is run in monopole mode, using Earth as the DC return path. In fact, however, based on recent research using Transpower historical records, these devices provided both stray current protection and GIC reducing, with no negative impact on system performance.69

In another example, Finland’s Fingrid Oyj uses current limiting reactor coils – rated at 100-120 Ohm impedance and 2 Ohm DC resistance – on their 400, 220, and 110 kV transformer neutral grounding points. The reactors were installed to limit fault currents, but provide the dual benefit of GIC reducing, with no adverse system effects.70

- **Shifting GIC flows to other, unprotected transformers**

Based on both tests and new modeling studies, the most recent results show that GIC shifting does occur, but at a level that yields substantial net system GIC reduction. As a rough rule of thumb, based on both modeling and testing results current blockers typically yield roughly a 50% benefit in GIC reduction for the affected grid segment while, of course, providing direct protection to those (presumably sensitive or critical) transformers at which the current blockers are installed.71

- **Risk of Increased GIC in Autotransformers**

It is important to note that GIC can actually increase at an autotransformer, even with a blocking device. As an illustrative example, Figure 2.7 provides a schematic plot of modeled GIC flows for an autotransformer. This transformer is a 765/345kV autotransformer and the before and after blocking device flows are shown below for a 30 V/km geoelectric field intensity.

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71 A more complete discussion of systematic GIC reduction is presented in the online Appendix 2.1.
The blocking device only blocks GIC flow in the ground-connected winding. As a result, the net increase in GIC shown is effectively due to an abrupt shift of GIC flow in the network, with a large increase that results in the windings between the 345kV and 765kV terminals of the transformer, as the blocking device only blocks GIC flows in the ground connected winding, but the GIC flowing in the network is able to flow through the autotransformer. To fully block the GIC for an autotransformer, a series capacitor would also be needed on at least one side of the transformer. This is not the case for full transformers, because the high and low sides do not provide the electrical through-path characteristic of autotransformers.

- **Transformer Protection Evaluation Matrix**

Given their critical system-wide role and typically long lead times for repair of replacement, EHV transformers are good candidates for GMD or EMP resilience investment. In that regard, transmission system operators interested in weighing the advantages and disadvantages of the resilience options shown above may find it helpful to work through a rough evaluation matrix, similar to the example shown below.
<table>
<thead>
<tr>
<th>Transformer Hardening Options</th>
<th>Confidence Level</th>
<th>Cost Effectiveness</th>
<th>Transformer GIC Decrease</th>
<th>Transformer Harmonic Decrease</th>
<th>System Availability and Reliability</th>
<th>Overall Grid GIC Decrease</th>
<th>Hardening/Procedural</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformer Type</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>H</td>
</tr>
<tr>
<td>Transformer GIC Withstand</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>H</td>
</tr>
<tr>
<td>Specification</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transformer De-rating</td>
<td>+</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>H</td>
</tr>
<tr>
<td>Additional Transformers</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>H</td>
</tr>
<tr>
<td>Spare Transformers</td>
<td>+</td>
<td>-</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>P</td>
</tr>
<tr>
<td>Series Capacitors</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>H</td>
</tr>
<tr>
<td>Pre-planned Transformer</td>
<td>-</td>
<td>-</td>
<td>N/A</td>
<td>N/A</td>
<td>-</td>
<td>0</td>
<td>P</td>
</tr>
<tr>
<td>Disconnection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-planned Transformer</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>0</td>
<td>H/P</td>
</tr>
<tr>
<td>Tripping</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>N/A</td>
<td>0</td>
<td>H/P</td>
</tr>
<tr>
<td>- At Threshold</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- On E1 Sensor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutral Ground Blocking</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>H</td>
</tr>
<tr>
<td>(- for auto transformers)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutral Ground Reducing</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>H</td>
</tr>
<tr>
<td>(- for auto transformers)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do Nothing / System As Is</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Key for the Evaluation Matrix**
The following nomenclature is used to indicate a rough assessment of performance of the different protection options for each evaluation criterion:

*“+” – Option performs well on criterion*

*“0” – Option performs adequately on criterion*

*“-” – Option performs poorly on criterion*

For the last column, “H” indicates a hardware hardening approach and “P” indicates a procedural approach.

Table 2.2 | Transformer Protection Evaluation Matrix
For the Transformer Protection Evaluation Matrix shown, seven candidate performance criteria have been selected:

1. Confidence Level in the mitigation option
2. Cost Effectiveness
3. GIC level decrease in a given transformer
4. Decrease in harmonics in a given transformer
5. Acceptable impact on system operation and reliability
6. Overall GIC decrease in system
7. Whether the mitigation is hardware-based or procedural

The transformer protection evaluation matrix is intended to provide a helpful decision-making construct. Each individual system owner/operator would be expected to determine the relative ranking of each method and criteria, based on the unique makeup of their system and criticality of individual transformers and substations. The general trends presented would, however, be expected to apply.

In developing this table, selected ratings for the “Transformer GIC and Harmonic Decrease” evaluation criteria refer to protection of the specific transformers protected. Ratings for all other criteria refer to the impact of each hardening option on the relevant evaluation criteria as it relates to the entire power grid, or the relevant power grid segment.

Note: The ratings shown for this evaluation matrix are provided as an example, derived from multiple sources, including the assessment of delegates to the EPRO Handbook Concept Design Reviews.72

> **Review by hardening option:**
>
> • In reviewing the transformer protection options in this example matrix as a function of each of the performance criteria, there are several points of interest:

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72 EPRO Concept Design Review meetings were attended by a small group of electric power industry representatives on November 6, 2013, January 7, 2014, and as part of the EPRO Electric Sector Resilience Seminar on March 25, 2014 to provide expert input for the EPRO Handbook.
• Unsurprisingly, doing nothing -- leaving the system as-is -- yields poor performance on every evaluation criterion. Preplanned transformer disconnection also stands out as performing poorly in every applicable category. For example, it is given a “poor” rating in “confidence level” since confidence in broad, interconnect-wide implementation of such an emergency measure would likely be spotty, at best. It also receives a “poor” rating in “cost effectiveness” since it would typically result in reduced revenues. Finally, it is judged likely – given the uncertainties of any predictive process used to determine the “disconnection” requirement – to result in unnecessary load shedding, with attendant customer, legal and related costs.

• Neutral ground blocking and reducing (except for autotransformers), and series capacitors, rank very highly on all criteria, as they directly block or reduce GIC, without sacrificing availability of operational transformer assets. However, it should be noted that neutral blocking devices are still in the prototype stage.

• Preplanned transformer tripping also does well on most criteria, although tripping “at threshold” may sacrifice some overall system reliability to assure survival of the tripped asset. (Tripping on E1 sensor is not considered to have such an impact, since it would be activated in a nuclear EMP event, which makes a wide area power outage very likely). These latter approaches may also have cost advantages, as implementing such sensors is anticipated to be a very low cost, easily replicable process.

• Transformer type and GIC withstand specification options generally also rate well, although their benefits are limited to the individual transformers protected, rather than the overall power grid.

> Review by Evaluation Criteria

Confidence Level

Most mitigation strategies rate well, with the exception of preplanned transformer disconnection, as described above.
• **Cost-effectiveness**
  Most options are considered cost effective, or at least adequate. Derating, additional transformers and transformer sparing are considered the most expensive of the choices on the menu.

• **Transformer GIC Decrease, and Reduced Harmonics:**
  Note: Since GIC levels typically also relate directly to harmonics, both of these criteria tend to respond similarly to the protection options. Neutral ground blocking, tripping, installing series capacitors and adding more transformers all decrease (or eliminate) transformer GIC flow. Although derating, GIC withstand specification and selecting robust transformer types do reduce GIC vulnerability, they do not reduce GIC, giving them a rating as “adequate.”
  As noted in the matrix, GIC can actually increase in an autotransformer using neutral blocking or reducing devices, unless used in conjunction with a series capacitor.
  Pre-planned transformer removal will protect a specific transformer, but is rated as N/A for GIC and harmonic decrease because the transformer would not be in the system at all during a GIC event.

• **System Availability and Reliability**
  Most hardening options rate well or adequate against this criterion. Spare transformers will be “outside” of the operational system during an event, and are therefore not-applicable for this criterion.
  Also, an important distinction is made between “threshold” and “E1” transformer tripping for system reliability.

  » While the objective of sensor-based transformer tripping is to protect the transformer, “stress sensor threshold” tripping (based on transformer heating, vibration, GIC etc.) protects a transformer that may or may not have sustained damage if it had remained in the system, while tripping will definitely reduce the grid’s availability during the event.

  » E1 sensor tripping will also, of course, mean each tripped transformer will be unavailable to the grid. However, unlike judgment-based transformer stress-sensor thresholds, E1 sensors only trip on an actual EMP event, in which case the grid segment is, in any case, very likely to experience an outage.
• **Overall Grid GIC Reduction**

Options that include GIC blocking/reducing (neutral devices or series capacitors) or protection by pre-planned or sensor-based removal or tripping decrease overall system GIC levels (with the exception, noted above, of autotransformers). GIC withstand, derating, transformer type selection and adding transformers, do not affect net system GIC.

**Protection System Relays**

While Extra High Voltage (EHV) transformers may be the most critical, high value assets at risk from GIC, protective system relays may also be at risk.

Some digital relays measure the peak value of the current and calculate the effective equivalent value based on a 60 Hz waveform. These relays are therefore sensitive to harmonics, and can erroneously trip. During GMD/EMP events, when the harmonic content on the system increases substantially, such peak-measuring relays operate at a 20-30% lower effective current than electromechanical relays. By increasing the settings of the peak measuring relays to accommodate the higher harmonics during GIC conditions, the risk of false trips can be reduced, but this measure may compromise the reliability of the protection scheme. Industry practice is to replace such relays with others that are not sensitive to harmonics.

*Note: Electromechanical relays may be used as a backup relay system, as they are robust under E1 pulse conditions. New options are emerging which could make available new relay assemblies, using a digital relay with a backup electromechanical relay in the same housing.*

*Electromagnetic relays can be set to very high static thresholds to protect against system damage, while the digital relays can be left to whatever dynamic settings are deemed necessary to operate and optimize a post-EMP grid. In the event of EMP E1, if the digital relays fail or operate incorrectly, the electromechanical relays would take over automatically, and keep the system safe at the performance margin extremes.*
3. Distribution Systems

GIC flow is typically a concern for a power grid’s transmission systems, rather than its distribution network. GIC tends to build up in long, high voltage circuits. While transmission lines are typically used at hundreds of kilovolts, may be often hundreds of miles in length and, unlike distribution lines, are connected in meshed configurations that make their equivalent length even longer, most distribution lines are used at much lower voltage levels and are relatively short, usually less than 10 miles.73

Nevertheless, while limiting GIC concerns to transmission lines is a good rule of thumb, it would be unwise to completely dismiss the risks to distribution systems. There are notable special cases, including areas where a distribution system serves critical facilities that must be supplied. A primary example is the distribution system and loads associated with critical black start cranking paths, since these portions of the grid require effective protection against both E1 and E3 (see Section IV below). Thus, it is a good practice to look for possible distribution system GIC concerns by first identifying critical loads, and then analyzing the distribution system that serves that load.

73 Based on recent modeling, the “knee of the curve” for GIC increase vs line length is on the order of 50 km. Israel Ministry of Energy and Water Resources, EPIC Israel: E-Threat Protection for Infrastructure Continuity (January 22, 2013) (For Official Use Only – For information on this document, please contact EIS Council)
IV | PROTECTION MEASURES: EMP E1

While the same hardware protection measures adopted against Space Weather will also be effective against EMP E3, EMP also includes an additional and especially destructive electromagnetic effect: the E1 pulse. The section that follows reviews hardware sensitivities to EMP E1, and proposes hardening options which may be used, where required, for protection of assets essential for implementing a protected enclave-based power restoration strategy.

A | Power System Equipment: EMP E1
sensitivities and recommended strategies

In this section, EMP E1 sensitivities and recommended hardening options are examined for the different, relevant categories of power system equipment.

For purposes of reviewing EMP E1 sensitivity, Electrical power system equipment can be addressed in three categories.
1. Power generation and transmission equipment
2. Control equipment including sensors, relays, and associated communications
3. Auxiliary equipment including the operator communications, repair and installation vehicles and equipment, and backup generators.

1. **Power Transmission and Generation Equipment**

   The primary collectors of EMP energy associated with a power substation are the long lines entering the facility. The cross-country lines and transformers also represent items with high cost and long delay for replacement. However, the lines themselves are designed for high voltage and protected against lightning, and damage from EMP E1 is unlikely even if fields are strong enough to cause widespread insulator flashovers.

   For power generating stations, EMP E1 could be a serious concern. With generators closely monitored and controlled by distributed control systems, malfunctions could have unacceptable consequences. For black start generators, since most generator protection strategies typically call for safe shutdown of a generator, it will also be essential to assure EMP protection for the generating station’s emergency backup generator.

   For the EHV transformers, the EMP E1 voltage level is capped by the ~400 kV open circuit voltage in the coupled waveform. Since the normal operating voltages require Basic Insulation Levels (BIL) approaching 500 kV and higher, 400 kV levels are not a concern. This EMP E1 voltage level could, however, be an issue for subtransmission and distribution system transformers (less than 70 kV) where BIL levels fall below 400 kV. Further research on these issues is merited.

   The primary expected effect from E1 for these large assets would be arcing at interfaces such as insulators, circuit breakers, lightning arrestors and bushings. There is much more energy in the follow-on current after the initiation of an arc.
than in the EMP pulse, so damage is expected to be similar to the results of an arc due to natural causes, such as lightning. Of course, in contrast to localized hazards like lightning or IEMI, arcing due to EMP/E1 would be expected over a large area.

**Hardening Strategies**

- **Generator protection**
  - **Backup Diesel Generators** – For any important generating plant, assuring proper shutdown from an EMP event will require normal operation of backup diesel generators, so assuring EMP protection for these units – through a combination of shielding, filtering and validating testing – will be important.
  - **New Generating Plants** – For new generating plants, consideration should be given to providing adequate shielding and filtering for the distributed control systems and related electronics – for the generator and auxiliary systems – to allow for continued operation through an EMP event. With substantial new construction planned for the U.S. power grid, this could, over time, become an important element of overall system resilience.
  - **Existing Generating Plants** – For existing plants, it may be optimum to plan for safe and proper shutdown, perhaps triggered by a (validated) EMP E1 sensor system. This would involve initiating the shutdown process for the generators, the fuel, boiler and steam handling systems and plant controls, while simultaneously starting the (protected) backup diesel generators that power the shutdown process. Given the reported potential availability of hybrid digital / electromechanical relays, planning for gradual replacement of digital relays with hybrid models – perhaps as part of an accelerated maintenance cycle over a period of a few years – may offer a cost-effective approach to substantially reduce generator risk from mis-operation of a relay system during shutdown.
  - Following safe shutdown, it would then be an immediate priority to implement the EMP-adjusted blackstart plan for the generating plant. As for other elements of restoration planning, adequate spares of the plants distributed SCADA and other control system electronics will be important to assure timely restart.
Subtransmission and distribution system transformers

Since EMP E1 voltage levels could, potentially, represent a concern for subtransmission and distribution system transformers (less than 70 kV) where BIL levels fall below 400 kV, adequate spares should be available to replace a reasonable fraction of subtransmission transformers near 70 kV, in the event they are damaged. Consideration should be given – for transformers in this class that are used in black start or critical load cranking paths – to derating or requiring manufacturer specification to provide BIL levels above 400 kV, or protection with transient suppression devices.

Arcing at interfaces: As a statistical concern, only a fraction of the at-risk elements in the large area of an EMP E1 field footprint would likely experience direct E1-induced damage. However, consideration of the result of widespread, near-simultaneous activation of the protective circuits should be planned for, and expanded sparing of inexpensive equipment such as insulators should be provisioned. Where feasible, polymer transformer bushings should be used to prevent or reduce arcing. Transmission and distribution line insulators should be adequately spared.74

2. Control and Switching Equipment

The next largest collector of energy from radiated or reradiated fields (due to nearby conducted transients) is the sensor/control cabling, often unshielded, between the sensors and the local control center.

Protective relays are not directly connected to transmission lines and transformers, but rather through potential transformers (PTs) and current transformers (CTs) that step down grid voltages and currents to 120 volt, 5 amp levels suitable for input to sensors and relays (i.e., computers). CTs are saturable devices that are affected by overcurrents and DC currents, and

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74 Evidence provided to U.S. government commissions by Russian researchers (see Congressional EMP Commission Report) indicated an increased risk of permanent insulator damage due to flashover for a small percentage of insulators. Given this risk, providing for a modest level of increased insulator sparing would be inexpensive and prudent.
therefore vulnerable to E1-induced current. PTs, depending on type, can also be affected. The sensors, however, have the overvoltage protection of the high voltage circuit.

The relay input is typically protected for lightning-coupled stresses by proprietary, solid state circuitry having various time dependent clamping and leakage characteristics that are similar to, but not specifically intended for, EMP/E1 protection.  

- **Hardening Options/Recommendations**

  In situations where proper operation of the relay is particularly crucial, the development of hybrid digital / electro-mechanical relays might provide a viable longer-term option.

  For the near term, provisions should be made for appropriately staged and quantified sparing for sensor and relay (and associated control and communication) equipment to address potential damage. It should be noted that identifying whether electronic equipment is damaged will be difficult and time-consuming, and will require specialized crew training and other restoration support assets very different from those required for equipment repair from storm damage and other traditional hazards.

  As mentioned above, as opposed to local lightning or IEMI strikes, widespread, near-simultaneous stresses on relays must be planned for in such sparing. Use of electromechanical relays, which are less sensitive to E1 effects, or hybrid relays, may also be appropriate, as a redundant protection system, particularly on black-start cranking paths.

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75 The equipment has protection specified by IEC and IEEE specifications (IEC 60255-22-5;2008, IEC 60255-22-1;2007, IEC 61000-4-5;2005, IEEE C37.90-1-2002. The latter covers a similar frequency range but with different test approach than Appendix B of MIL-STD-188-125-1. A comparison of the test results of some of the typical equipment using MIL-STD type tests would allow direct comparison of results and prepare for discussions of the applicability of existing commercial specifications.

76 Over time, research on the applicability and effectiveness of current protection methods and standards for EMP/E1 protection may provide sufficient encouragement to reduce sparing levels for these components. Until such positive research results are available, sparing of these relatively inexpensive components provides a simple approach, which provides synergistic benefits for other hazards that may require availability of such spares.
Control equipment that must be operated during an event must be hardened/protected, along with auxiliary equipment such as the control system’s emergency generator. This is discussed in greater detail below.

### 3. Auxiliary Power System Equipment

EMP/E1 events happen in nanoseconds to seconds, so operator communications and repair operations typically will not (and need not) function during an event. They will be critical, though, for post-event recovery, repair, and restoration. Back-up auxiliary equipment (such as radios and diagnostic equipment) can be safely spared and stored in EMP-protected containers quite easily, as typically only minimal shielding or other protection is required for unpowered equipment.

E1 survivability testing is a priority for repair trucks and backup generators, since the EMP E1 survivability of these restoration-critical systems is, at this point, a somewhat open question. The Congressional EMP Commission performed EMP testing of vehicles and emergency generators in 2001, reaching generally positive results, with only a small fraction of tested vehicles exhibiting vulnerability. Given the many changes to vehicle and generator electronics over the last 15 years, new testing has become an urgent priority. For control centers, this is particularly important, since backup generators capable of handling a control center’s loads are typically quite large, generating well over 1 MW.

- **Hardening Options/Recommendations**

  Emergency/backup radio communication and diagnostic equipment should be stored unpowered within a minimal EMP shield. Unpowered backup generators should also be shielded where possible. Proper planning of the staging locations of this equipment is also important, so that operators have ready access to communications, diagnostics, and backup power when needed.

  Regarding repair trucks and backup generators, a testing program to better characterize their E1 survivability is needed, to determine whether additional protection methods are necessary. An example test plan is provided in Appendix 2.3.
B | Power System Equipment EMP E1 Protection: The “toolbox”

In this section, a “toolbox” of techniques for EMP E1 protection is reviewed.

As indicated above, while damage due to EMP is expected over very large regions, such damage is expected in only a fraction of exposed, vulnerable hardware. As a result, EMP mitigation planning will typically call for investment to directly protect only designated, predetermined facilities and hardware, while depending on expanded sparing and restoration plans – along with prearranged, multi-sector support modalities – for restoration of the remainder of the portion of the power grid in question.

In the material that follows, general guidelines are offered for best practices and techniques for protection of selected facilities and hardware for EMP E1 and IEMI. Such protection may typically be divided into four categories:

1. Shielding
2. Grounding
3. Filtering
4. Surge protection

EMP E1 resilience strategies call for protection of only designated, critical facilities, and depending on restoration for other grid assets. While damage is expected over large regions, only a fraction of exposed electrical hardware will likely be affected.

Shielding

Voltagess and currents induced by EMP E1 and E2 can damage control cables, electronics and electrical equipment if not shielded for RF effects. Such shielding can be accomplished by keeping sensitive electrical and electronic equipment in properly-designed Faraday-cage metal containers, or metal or metal-cladded buildings or shelters. Attention to tolerances must be assured in design, engineering, manufacturing, assembly and finally testing of such enclosures, since even a small opening can result in electromagnetic field leakage and induced currents and voltage. Where it is necessary for local power or control wires, sensor leads or communication cables – even as short as a few meters – to penetrate a Faraday-cage enclosure, non-linear protective devices
must be used at the cable entry point (see Filtering and Surge Protection below).

Ordinary metal cabinets and prefabricated metal buildings are generally inadequate for EMP protection of power system electrical and electronic hardware. Good E1 shielding requires an enclosure with a highly conductive surface that completely envelopes the protected area with no discontinuities. Seams, doors, ventilation ducts and other discontinuities, as well as all cables and conductors passing through enclosure walls, must be engineered to specifically exclude penetration of E1 energy.

Use of shielded cable bundles limits the current on the conductors, if properly implemented. Cable shielding can vary from solid to single layer sparse braid, and the performance of the shielding may be characterized as the transfer function from the shield to the core (singly or to bulk interior wires). Effectiveness is typically determined by measuring the resistance and inductance coupling the exterior to the interior – in the low frequency domain, it is typically dominated by the resistive term; at high frequencies, it is typically dominated by the inductive term. Shield terminations are critical to maximize effectiveness. Circumferential connection to ground at both ends of the cable minimizes coupling.

**Grounding**

Electrical Grounding is the cornerstone approach for electrical safety and protection, and E1, IEMI grounding, i.e., Radio Frequency (RF) grounding, is equally essential to divert energy from at-risk equipment and electronics.

Electrical safety grounding and RF grounding can be complementary. However, while RF grounding should also function quite effectively for electrical safety, typical electrical safety-oriented grounding methods and configurations may not provide optimal low-impedance for RF fields. Typical differences are the use of straps (increased surface area) instead of cables to reduce “skin effect” impedance for RF fields.

For conventional fault-clearing and safety purposes, the neutral and ground conductors may only be connected at one place (“single-point ground”). The ground, the neutral, and the ground rod/grounding field, connect only at the required single point, as required by IEEE Standards 80 and 142 for grounding.

However for E1 protection purposes, conventional grounding of the substation control cables, including trench-way runs in the substation yard and
the interface between the signal wire inside the Control House and the outside wiring, is quite inadequate. Instead, where E1 Protection is required, cables should be grounded with a low-impedance RF ground at the interface between the unprotected environment and the protected environment. If protective devices are also installed, such as an MOV, the low-impedance ground should be available to ensure signal cables do not carry damaging currents into protected equipment.

Inside the control house, there are other E1 pickup problems on signal wires of all types. For example, one of the weakest plug devices are the traditional Ethernet plugs, which burn/melt at relatively low levels of induced voltages and currents. There are a range of relatively straightforward upgrades which if adopted by the industry can add considerable robustness/resiliency. Ethernet plugs should only be used inside protected environments. Ethernet cables, if used, should be shielded and/or enclosed inside a conductive conduit (or “special protected area”) to ensure damaging voltages/currents do not propagate into sensitive equipment.

**Filtering**

Where appropriate, in a fashion similar to lightning protection, inductive devices with large saturation cores and capacitors are used as passive filters (e.g. a capacitor-input “pi” filter) for hardening electrical and electronic equipment against EMP-induced currents and voltages. Filters are typically protected by non-linear protective devices such as special-design metal-oxide varistors (MOVs), with faster response times than a typical lightning protector. Most digital inputs are protected with MOVs at the input to the assembly, since there is less disruption of card grounds when these devices are grounded to the chassis, which provides a low inductance path to ground and is assumed to also provide some shielding.

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77 A varistor provides “diode-like” nonlinear current–voltage behavior – high resistance at low voltage, and low resistance at high voltage.
Surge Protection

With considerable electromagnetic energy present in the radio frequency time domain, EMP E1 and E2 can induce transient currents of large amplitude in power lines, communication cables, electronic equipment, and antennas. Surge protection, such as with external transient voltage suppressors, is another method to protect against the large transients resulting from these pulses, to avoid filter damage and insulator breakdown.

It is imperative to effectively limit the transients near sensitive electrical and electronic devices by removing the surge peak of the induced transient voltages above the operating level, similar to the action of lightning arresters. Protective devices such as fuses and circuit breakers are too slow to prevent the current from flowing, and even if they were to open, the circuit is then nonfunctional until the interrupting device is reset. In many applications it is better to provide a faster recovery and/or a limitation of the voltage only while the voltage exceeds a threshold, by using a clamping device. Zener diodes and metal oxide varistors provide such a function. Typical device response times are on the order of nanoseconds.

Gas discharge tubes and spark gaps have been used for many years as protective mechanisms against overvoltage for high voltage power as well as circuit level protection. They can handle large currents, and are typically self-recovering. Circuit level spark gaps range from RF antenna protection to circuit level switching applications.

A discussion of additional relevant electromagnetic hardening principles, including engineering trade-offs, cost modeling, and the “electromagnetic hardening continuum” can be found in Appendix 2.2
Power System Equipment:
EMP E1 protection - Applying the strategies, and using the toolbox -- Emerging best-practices for different equipment types

This section examines emerging best practices for applying the “toolbox” of techniques for EMP E1 protection, reviewed above, to different categories of power system equipment.

Due to the statistical nature of EMP E1 impact, E1 protection strategies involve secure hardening and protection, not of most or all power system equipment, but only of limited, designated facilities in any one grid segment.\(^{78}\) Thus, based on the efforts of leading power companies,\(^{79}\) this section provides examples of emerging best-practice design requirements for EMP E1 and IEMI protection, but only for the limited portion of designated power generation, transmission and distribution systems, which are planned for protection.

1. Control and Instrumentation Circuits: Sensors, Relays, SCADA Systems, and Other Low Voltage Electronics

- Controls and Instrumentation:
  
  a. Physical Consolidation: To the extent practical, control and instrumentation circuits should be remoted to stations inside the primary shield.

  b. Instrumentation protection enclosures outside the protected volume: Controls and instruments that cannot be relocated into the primary protected volume should be housed in shielded enclosures (if not commercially available, a suitably designed and tested 1/8”inch highly-conductive enclosure should be fabricated to house the control and instrumentation). Required access doors should use RF-type stainless

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\(^{78}\) See discussion in section 2.1.

\(^{79}\) Information on the status of implementation of specific protection methodologies may be available. Written requests for information on provenance will be reviewed by EIS Council.
steel or aluminum or a comparable highly conductive and conductive gasket design, with appropriate RF grounding measures

c. Replace exposed, conductive control wiring: Where feasible, all-dielectric fiber optic, mechanical, or pneumatic controls should be substituted for exposed and unshielded electrical controls.

d. Fail-Safe design for remaining, unprotected controls: Where substitutes for un-shielded electrical controls is not possible, remaining exposed electrical controls and sensors should be designed such that failure modes will result in a “safe” condition. For example, failure of a sump temperature indicator should turn the pump and fan “ON.”

e. Physical considerations for IEMI protection: Emerging best practices for substation protection include, where feasible, use of perimeter fencing on electrically significant substations to attenuate IEMI devices. This can be coupled with other measures that also reduce vulnerability to physical attacks: Physical barriers, positioned, where feasible, at adequate distance to prevent near-field access, personnel access control, and related security measures.

- Wiring

  a. Rigid conduit protection of control wiring outside primary shielded EMP enclosure: All system critical wiring outside the primary EMP shielded enclosure should be run in rigid steel conduit, unless prohibited by vibration, thermal, or other considerations. Circumferentially weld conduit joints and entries into pull boxes and other shielded equipment enclosures. Appropriate RF grounding measures should be located at all points where external connections leave the protected space.

  b. Flexible conduit protection: Use short sections (25 cm or less) of flexible shielded conduit where necessary for vibration isolation or similar purposes. High-quality conduit with compatible shielded conduit connectors should be used for these applications.

80 A list should be maintained to allow for post-event checking of such controls for possible replacement or repair.
c. Design should plan for “sacrifice” of noncritical, unshielded components: If possible and appropriate, noncritical wiring and components outside the system of shielded conduits and enclosures (e.g. heater tape for water pipes) should be powered from unessential power feeders outside of the shielded space, to avoid possible vectors for electric field intrusion into the protected area.

d. RF Grounding: Appropriate RF Grounding measures should be included in wiring. I.e., grounding plan should be designed to ensure that excessive EMP-derived transients can be shunted to low-impedance system grounding with the shortest possible grounding cable distance, to prevent damaging EMP currents from flowing on critical cabling.

e. Best Practices: Emerging industry best practices for wiring include:
   1. Design for single cable entry into and out of control houses
   2. Provide for helically shielded end-to-end control cable systems
   3. Use of fiber optic cables

- Enclosures

  Applicability: Pull boxes, distribution and control panels, junction boxes, and electronic system enclosures containing system-critical wiring, controls and circuit components should be designed as EMP-shielded enclosures. The enclosures should be constructed of highly-conductive material such as welded steel or aluminum, with welded or RF-gasketed access covers/doors and appropriate RF grounding measures.

  a. Minimize Use of Unshielded, Ease-of-Maintenance Components: Wherever consistent with safe and proper equipment operation, employ designs that minimize required open, unshielded gauges, indicator lights, control switches and other components. Subsystem components requiring a direct operator interface should be remoted and monitored in a protected area, if feasible, or else installed in a manner that does not violate the EMP-shielded topology of the conduits and enclosures.

  b. Ventilation duct requirements: All air-intake or ventilation openings in shielded enclosures, required for operation, cooling or safety, should be of waveguide-below cutoff designs to maintain EMP protection.
c. Protecting unpowered repair and restoration tooling, emergency communication and similar hardware: Such equipment should be stored in EMP-protected enclosures.

- **Where to use transient suppression and attenuation devices**

  Note on grounding for transient protection: All Transient suppression and attenuation devices should include appropriate RF grounding measures

  a. **Point-of-Entry (POE) protective devices:** Surge Protection Devices (SPDs), filters, surge arresters and related measures should be used on all electrical conductors that leave the EMP shielded space.\(^\text{81}\)

  b. **Protection for power leads on (unshielded) system-critical motors and sensors:** Power leads on system-critical motors outside a shielded space should be protected with appropriate fast-acting transient surge suppressors, such as certain MOVs having an extreme-duty discharge capacity in excess of 4 kA. Similar surge protection should be provided across terminals of system-critical sensors that are outside the EMP shielded space.

- **Motors and sensors outside the shield**

  a. **Optimum EMP-protected motor configuration:** Completely enclosed fan-cooled motors in electrically contiguous metal enclosures/cases should be used wherever possible (i.e., intrinsically safe).

  b. **Optimum EMP-protected sensor configuration:** Critical or Essential System sensors should be mechanical or electromechanical, if appropriate, practical and feasible. If used, electronic sensors employing semiconductor components must include electromagnetic protective measures (such as shielded enclosures) to protect any critical electronic sensors. If protection is not feasible for selected electronic sensors, their leads must be protected to avoid introducing transients into protected systems.

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\(^\text{81}\) Conductors in a protected conduit as recommended above are still in the shielded topology, and do not require POE devices
2. Generating Stations

Shielding/High-Field protection: Given the very long repair and replacement times, and the relative ease and effectiveness of protection, Black Start generators should always be protected, and consideration should be given to protecting pre-defined, prioritized important generation stations. In addition, EMP-related modules should be included as elements of normal procedure development and personnel training for generator maintenance and restoration procedures. Another critical requirement will be to ensure the adequacy of fuel supplies for black start generators. Chapter 3 addresses these emergency fuel issues.

- Protection Requirements:
To protect generators that could be tripped offline during an EMP event, grounding and shielding are required for solid state excitation and control systems, as these systems could be either temporarily compromised or permanently damaged by the E1 pulse.

Solid state excitation and control systems requiring protection include:

1. Generator protection and control systems (P&C), and their power supplies with DC battery back-up
2. Auxiliary load systems and equipment
3. SCADA systems
4. Telecommunication systems for SCADA, voice, and data.

Protection of the actual turbine is also critical, and requires bringing the turbine into safe spindown and eventually onto rotating gear after an E1 event. The safe spindown could be compromised due to upset of lube-oil supply to bearings along the turbine/generator system. This requires a source of reliable standby/backup power to get the system onto rotating gear to ensure the turbine is not damaged, allowing eventual restoration of the generator.

- Best practice EMP E1 protection approaches (for implementation, refer to the EMP E1 protection “toolbox,” above)

  - Protective shielding or filtering for:
    a. Communication, SCADA and control-elements, and the electrically conductive paths to them
    b. Exciter circuitry
c. Gas Turbine Shut-down controls (to allow for proper cool-down)
d. Generator health assessment and diagnostic equipment

› Protection using Transient Filtering or Suppression should be provided for:
  a. GSU/Generator Windings
  b. Network Protector Configuration
  c. Other protection systems

› Expanded spares procurement and staging is appropriate, to the extent feasible, for the following subsystems and components:
  a. Key turbine control components
  b. Generator active components and exciters
  c. Sensors and communications modules
  d. GSU Transformers

3. Transmission and Distribution Systems

As discussed above, the large assets in transmission systems, such as transformers and transmission lines, are considered to be at low risk to direct E1 damage, with the exception of arcing over transformer bushings and line insulators. Polymer bushings on transformers are recommended, as is adequate sparing of transmission line insulators. E1 can have deleterious effects on lower-voltage subtransmission and distribution transformers. As indicated above, adequate sparing should be provided to allow for replacement of those subtransmission transformers that sustain damage. For critical loads, black start cranking paths and – where possible – for other subtransmission transformers as well, BIL ratings above 400 kV should be used, or transient suppression devices.

Since only a fraction of transmission and distribution control electronics and computers, relays, sensors, communication equipment and cabling will likely be affected by the E1 event, in general, protection for these systems will involve providing adequate, properly staged spares, restoration tooling and appropriate restoration planning and training. The exception, of course, is for the limited fraction of hardware involved in black-start or other critical assets and cranking paths, which must be protected to assure they can operate successfully through the E1 pulse event.
Strategic Decision-Making on EMP E1 Resilience: Balanced, effective protection

Given the wide range of EMP E1 protection approaches and the wide array of grid hardware at risk, strategic choices on grid resilience can be complex. However, to be effective, it is important that such choices utilize available resources in a balanced and prioritized fashion.

To assist this process, it is typically helpful to ensure decision-making responds to a strategically-developed menu of protection levels carefully selected to ensure that – at each level – the investment made will achieve meaningful, effective goals for overall grid resilience. The EMP E1 Protection Menu below offers an example of such an approach.

Three-level, Prioritized EMP E1 Power Grid Protection Menu:
Minimum, Intermediate, and Comprehensive Hardening

1. Minimum EMP Hardening Scenario
   - Limit comprehensive EMP hardening to major/critical and Black Start-designated power plants and associated transmission cranking paths, along with at least the primary control center. This assumes GSU and adequate EHV transformer spares are already available, (if such spares are not available, EMP-harden GSU transformer and cranking path EHV transformer(s) using one of the protective measures described above).
   - Protect a minimal, selected set of EHV transformers at the most critical grid nodes.
   - Expand conventional-hazard restoration planning to include an EMP-specific restoration module and EMP training module, with planning to assure adequate availability of trained personnel.

EMP Restoration Plan Module Recommendations
1. Adequate, properly staged EMP-protected critical emergency communication gear, low-voltage electronic and electrical system spares, diagnostic equipment (e.g., diagnostic laptops, meters, relay testers and other repair tooling) distribution line insulators
and battery back-up gear for repair or replacement of damaged hardware throughout the relevant portion of the grid. For much of this equipment, storage in EMP-proof containers is a cost-effective approach.

2. EMP-hardened emergency back-up power systems, such as diesel and natural gas generators, with adequate fuel storage, DC batteries and DC/AC inverters.

3. Annual testing of EMP-hardened special equipment.

4. Adequate EMP-protected mobile diagnostic equipment, selected for fault-finding appropriate for EMP disrupted and damaged hardware (e.g., a portion of the repair truck fleet could be designated with special equipment, in an EMP-proof enclosure).

5. Validation that repair trucks and emergency diesel generators are not vulnerable to EMP (e.g., test samples at EMP test facility).

6. Ongoing coordination with appropriate government and NGO support providers (see chapters 3 and 4).

### 2. Intermediate EMP Hardening Scenario

*Additional measures, beyond the Minimum EMP Hardening Scenario*

- Provide comprehensive EMP protection for additional power plants, beyond the black start and major/critical installations in the Minimal EMP Hardening Scenario.

- Protect a wider set of EHV transformers, based on an assessment of additional, critical grid nodes.

**EMP Restoration Plan Recommendations**

1. Increase the portion of inventory stored in EMP-proof containers at other facilities, in addition to black start and critical power plants and associated cranking paths.

2. Further increases to the inventory of low voltage electronic and relay spares.

3. Increased inventory of EMP-designated repair trucks.

4. Install a redundant, electromechanical relay protection system on critical and black-start cranking paths.
3. Comprehensive EMP Hardening Scenario

Additional measures, beyond the Intermediate EMP Hardening Scenario

- Provide comprehensive EMP protection for most or all power plants, beyond the black start and critical installations in the Intermediate EMP Hardening Scenario.

- Harden most EHV transformers, using one or more of the measures reviewed below.

- Comprehensive, or near-comprehensive protection (shielding, grounding changes and hardware replacements with tested, EMP-robust components) for all control centers, and additional (non-critical) power substations.
Chapter Two: Power Grid Protection – Electromagnetic Threats

V | RESTORATION PLANNING

While the E-threat protection options examined above can provide cost-effective resilience to ensure that “enclaves” of power survive an E-threat event as a foundation for overall grid restoration, this foundation can only be effective, in a severely disrupted environment, if it is coupled with well-conceived and broadly supported and coordinated restoration planning.

In the United States, the energy sector is well-positioned to address a full range of common causes of power grid outages. Power companies diligently maintain and train to restoration plan modules addressing terrestrial weather, earthquakes, physical security and many other hazards. Although E-threats are typically not yet part of this planning in most power companies, in recent years some leading companies have added EMP and GMD restoration modules to their restoration plans. In this section, key features of E-threat restoration planning will be reviewed.

82 In the U.S., transmission operators have a mandatory NERC requirement to develop and maintain a robust power system restoration plan, which must be submitted to their respective NERC-approved Reliability Coordinators on an annual basis for review and approval. The recommendations in this section are envisioned to be additional modules to existing plans.
Both development and implementation of any power system restoration plan requires the participation of engineers and specialists from the many disciplines involved in power system restoration. It is thus essential that such plans outline well-defined, systematic approaches based on thorough knowledge of the system in question: its capabilities, unique requirements, and the availability of resources (and, of course, any such plan must be thoroughly communicated, and subject to periodic training). As a result, there are intrinsic limitations to any general discussion of the elements of such a plan, including that provided here. As one approach to help provide more detailed restoration planning insight, an example of a restoration plan for a hypothetical 30-bus system is provided below, in Section V.

It should also be noted that the example restoration plan below is not intended to provide extremely detailed step-by-step procedures for restarting individual facilities and components. Instead, each restoration-critical facility and function listed in this plan will require updates and supplementary modules to its own detailed step-by-step restart procedure, to ensure successful implementation when called upon as part of the power system restoration plan.

A | System Restoration Guidelines

Please note that this discussion is intended to provide general guidelines to help develop power system restoration planning for recovery from an E-threat event. Like all restoration planning, these guidelines are intended to help form a foundation for a plan that must, by definition, be flexible and adaptable to the actual system condition, resources, available personnel and many other factors.

First, it is important to clarify that adapting standard recovery plan modules to the needs of restoration after an EMP-induced blackout is only effective and feasible if, at a minimum, advance resilience steps have been taken, similar to those outlined above (Sections IB and IIIC, and the Minimum EMP Hardening Scenario, IVD). For this purpose, an inventory of critical equipment and systems required for system restoration must be made as part of the system restoration plan, and appropriate EMP-hardening must be carried out well in advance of an event.
1. System Restoration Challenges following an EMP-Induced Blackout

Table 2.3 lists major challenges associated with the system restoration following a post-EMP event type blackout that may not be an issue under the “normal” system restoration following a conventional blackout. Table 2.3 also provides possible options to overcome such challenges.

<table>
<thead>
<tr>
<th>Restoration Challenges</th>
<th>Minimum EMP Hardening Scenario Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Potentially extensive physical damage/misoperation to long lead-time electric equipment, such as transformers at multiple sites over a large geographic area.</td>
<td>Increase the EMP resiliency of long lead-time critical equipment, such as generators and transformers using the methods described above in Sections III and IV. Procedures to operate transformers at reduced levels under known threat conditions.</td>
</tr>
<tr>
<td>2. Damage throughout the affected grid to a statistical fraction of IC-based electronic equipment, such as those associated with SCADA, communication, control and protective systems for control centers, cranking path substations, and blackstart power plants.</td>
<td>Increase the EMP resiliency of long lead-time critical equipment, such as generators and transformers using the methods described above in Sections III and IV.</td>
</tr>
<tr>
<td>3. Communication system inoperable.</td>
<td>Acquire adequate number of emergency radio type communication gear and store at strategic locations. Work with a coordination committee to develop a common emergency radio communications plan to communicate with government and NGO support organizations.</td>
</tr>
<tr>
<td>4. Potential insulator flashovers, especially at distribution voltage levels.</td>
<td>Adequate numbers of distribution insulator spares stored at strategic locations in the vicinity of distributor feeder and stations designated to serve the pre-defined critical load.</td>
</tr>
<tr>
<td>5. Data vulnerability and credibility due to misoperation of computer-based work stations and electronic devices -- in control center and in blackstart power plant cooling, lubrication, and boiler system controls.</td>
<td>Provide appropriate grounding and shielding at the Control Center, black start plants and other critical facilities.</td>
</tr>
<tr>
<td>6. Limited availability of skill-set-specific technical crews for damage assessment, protection relay diagnostics and reset, and communications equipment.</td>
<td>Measures taken for focused EMP restoration plan training, including potential cross-training to increase available pool of engineers, technicians and telecommunication experts.</td>
</tr>
<tr>
<td></td>
<td>Challenges</td>
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<tr>
<td>7</td>
<td>Transportation challenges to bring EMP repair crew to unmanned stations to assess the damage, make repairs and reset protection and control systems.</td>
</tr>
<tr>
<td>8</td>
<td>Challenges in identifying damaged equipment at multiple damaged sites, and finding and transporting spares.</td>
</tr>
<tr>
<td>9</td>
<td>Unavailability of backup and emergency power at sites critical for rapid system restoration.</td>
</tr>
<tr>
<td>10</td>
<td>Assumed no availability of help through the mutual assistance program, as all impacted power companies will be busy addressing their own problems.</td>
</tr>
<tr>
<td>11</td>
<td>Inadequate spares, of even common, inexpensive items, to repair damage.</td>
</tr>
<tr>
<td>12</td>
<td>Support may be needed from federal agencies to transport crew and heavy equipment from non-impacted areas.</td>
</tr>
<tr>
<td>13</td>
<td>Fuel unavailable for natural gas-fired generators, especially those to be used as blackstart generators.</td>
</tr>
<tr>
<td>14</td>
<td>Independent generators connected to the transmission system fail due to EMP event.</td>
</tr>
<tr>
<td>15</td>
<td>Independent generators connected to the transmission system may not be aware of EMP impacts.</td>
</tr>
</tbody>
</table>
16. Cranking paths must be selected and "critical load" must be identified and selected initially as part of the system restoration process.

A coordination plan must be in place with the distribution operators to connect the critical load feeders in a coordinated manner. Work with EPRO ESC and with government and/or NGOs to recommend methods to enhance availability of outside electricians to certify load.

17. Inability of using nuclear power plants – with large equivalent on-site fuel supply – as black start power plants due to need for external power to provide cooling.

Harden nuclear power plants to allow for rapid restoration, once adequate power is restored to provide power for external cooling.

18. Lifeline support services (food, water, heating) unavailable for repair crews and their families.

Work with EPRO ESC on recommendations for appropriate government agencies and NGOs for support services.


Review with EPRO ESC to clarify requirements and recommendations.

Table 2.3: System Restoration Challenges Following an EMP Event Related Blackout

### B. System Restoration Strategy

Virtually all power companies today maintain mature system restoration planning and training programs, with a variety of modules addressing different, common hazards. These plans provide an excellent starting point for EMP restoration planning. What is needed, beyond typical, existing plans, is an EMP restoration module, to include additional elements addressing the unique features of this hazard: an extended duration outage over a subcontinent-scale region, accompanied by widespread damage of a statistical fraction of exposed electronics. Based on this fundamental resilience and restoration strategy, the basic elements of the EMP Restoration Plan Module can then be clearly defined.

#### 1. Basic Elements of an EMP Restoration Plan Module

- **Command and Control:** Review the normal command and control process for restoration planning, to make any changes required to address the longer term, more complex process.

- **Multi-Sector Support Coordination:** Participate in coordinated, multi-sector planning for government, NGO and corporate support to affected areas.
- Emergency Communication with Critical Users (Loads): Maintain an updated, EMP protected database, and suitably deployed, EMP-protected emergency communication gear, for key personnel representing critical loads.

- EMP-certified Repair Crew: Develop and maintain an adequate crew of specially trained (and potentially cross-trained) repair personnel.

- Shared Personnel Data Base: Maintain an updated, EMP protected data base of restoration – critical management and power repair crew personnel – to be shared with multi-sector support organizations.

- External Support Data Base: Develop and maintain an updated data base of corporate, government and NGO support organizations.

- EMP-Protected Emergency Repair Vehicles: Ensure availability, and periodic testing, of adequate, properly staged, EMP-immune repair vehicles.

- EMP-Protected Power Supplies, Tooling and Spares: Maintain adequate supplies of EMP-immune or EMP protected emergency power supplies and diagnostic and repair tooling, spares.

- EMP-Protected Inventory Documentation: Maintain regularly updated, EMP protected documentation of locations of all spares, tooling and transportation equipment associated with the restoration plan.

- EMP-Protected Emergency Communications: Maintain EMP protected, suitably deployed emergency communications gear, co-located with repair personnel, critical facilities and other key contacts.

Table 2.4 lists high value assets critical for expeditious system restoration and the associated protection, control and communication systems along with suggested hardening measures to minimize the equipment damage/misoperation, which in turn, will help in reducing the restoration time.
<table>
<thead>
<tr>
<th>Facility</th>
<th>Equipment</th>
<th>Location</th>
<th>EMP Hardening and Mitigation Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Start Power Plant</td>
<td>Generator/Turbine</td>
<td>Inside power plant building</td>
<td>Grounding and shielding of solid state excitation and control systems, auxiliary load and SCADA systems</td>
</tr>
<tr>
<td></td>
<td>Generator protection and control systems</td>
<td></td>
<td>Maintain adequate inventories of spares</td>
</tr>
<tr>
<td></td>
<td>Auxiliary load systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Supervisory control and data acquisition system (SCADA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Protection</strong> Other</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Considerations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Telecommunication system for SCADA, voice and data communication</td>
<td>Inside &amp; outside power plant building</td>
<td>Grounding, shielding, filtering and surge protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>EMP protected emergency communication gear</td>
</tr>
<tr>
<td></td>
<td>Generator step-up transformers (GSUs)</td>
<td>Outside power plant building</td>
<td>Shielding of control cables for E1 protection; Selected hardware-based E3 protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Spare transformer(s) and emergency backup power for transformer cooling</td>
</tr>
<tr>
<td></td>
<td>GSU Protection and control system</td>
<td>Inside power plant building</td>
<td>Grounding, shielding, filtering and surge protection</td>
</tr>
<tr>
<td></td>
<td>Power supply system with DC battery back-up for protection and control systems</td>
<td></td>
<td>Maintain an adequate spares inventory</td>
</tr>
<tr>
<td></td>
<td>Auxiliary equipment and its protection and control system</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Protection</strong> Other</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Considerations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High voltage (HV) or Extra high voltage (EHV) substation at black start power plant - Connection to transmission lines</td>
<td>HV/EHV Circuit breakers</td>
<td>Outside power plant building</td>
<td>Grounding, shielding, filtering and surge protection</td>
</tr>
<tr>
<td></td>
<td>Switches, reactors, capacitors, Transmission lines from station</td>
<td></td>
<td>For transformers: Selected hardware-based transformer E3 protection</td>
</tr>
<tr>
<td></td>
<td>Current and Potential transformers</td>
<td></td>
<td>Maintain EMP protected: Adequate spares inventory</td>
</tr>
<tr>
<td></td>
<td>Control building housing protection and control systems for substation and transmission lines</td>
<td></td>
<td>Emergency communication system</td>
</tr>
<tr>
<td></td>
<td>Remote terminal units (RTUs), Telecommunication for the SCADA system, and cables</td>
<td></td>
<td>Adequate, EMP-protected long term backup power (e.g., diesel generator set).</td>
</tr>
</tbody>
</table>
| Cranking path - transmission lines and substations to deliver power, restart other power plants and connect loads | Transmission line wires and hardware  
Substation equipment, DC batteries and backup power  
Control building housing protection and control systems for substation and transmission lines  
RTUs and telecommunication  
Control cables | Outside power plant property, traversing a large area | Grounding, shielding, filtering and surge protection | Maintain EMP protected:  
Adequate spares Inventory, including distribution line insulators.  
Emergency Comm. System  
Adequate back up power |
|---|---|---|---|---|
| Primary system control center (SCC), backup system control center, and transmission dispatch centers | Master terminal unit (MTU) computer for the SCADA system  
Telecommunication system  
Meters, display screens  
Control cables  
DC batteries and backup power | In building, remotely located from the black start power plant | Grounding, shielding, filtering and surge protection | Maintain EMP protected:  
Adequate spares Inventory  
Emergency Comm. System  
Adequate back up power |
| System operation | If advance information is available of an imminent EMP attack, operate the system at reduced level using EMP-specific operating procedures. See operation posturing in the presence of an EMP event provided above in Section III. | | | |

Table 2.4: Typical power system facilities and equipment required for system restoration
The primary features of an effective E-threat power grid restoration plan may be best illustrated by providing a high-level example of such a plan. In this section, a restoration plan is provided for a small, hypothetical 30-Bus power system. The purpose of this hypothetical example is to show how a typical existing restoration plan can be expanded to address E-threat-induced blackouts. Given the expected very wide-area impact of these hazards, the hypothetical power system is treated as an “island,” and will be required to use its own resources for restoration.

83 The IEEE 30 Bus system one line diagram, as shown in figure 2.8, was modified to illustrate the system restoration plan. Two 345 kV tie lines (with 345/138 kV transformers) were added at Station #5 and #27, although they are assumed to be disconnected initially as part of the restoration plan. The entire system is operated at 138 kV and lower voltages except the two tie lines which are operated at 345 kV.
A | Description of the 30-Bus Power System

As shown in Figure 2.8, a hypothetical, vertically-integrated power system is defined for this review: generation, transmission, and distribution assets are owned and operated by the same company. The system has its own control area, operated by its control center with a full back-up control center located in a different part of the system. The system includes six power plants; two power plants are system-owned and the other four plants are owned by an independent generator company, as shown in Table 2.5. Appropriate legal agreements and contracts are in place between the transmission provider and the independent generator company, as part of the existing system restoration plan.

The 30-bus test system is comprised of 41-138 kV high voltage transmission lines, and 30 substations with a generation capability of 345 MW serving 260 MW at 24 substations linking the underlying distribution network. The system has two identical 345/138 kV transformers at Station 5 and 27, which are connected to the 345 kV tie lines owned by the neighboring systems to the south and north, respectively. A three phase 345/138 kV spare is available at Station 27, with provisions to transport the spare to Station 5 in a short time, if required.

<table>
<thead>
<tr>
<th>Generating Plant</th>
<th>Ownership</th>
<th>Connected at Sub-Station</th>
<th>Capacity, MW</th>
<th>Type</th>
<th>Blackstart Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>Independent</td>
<td>1</td>
<td>80</td>
<td>Coal</td>
<td>No</td>
</tr>
<tr>
<td>G2</td>
<td>Independent</td>
<td>2</td>
<td>80</td>
<td>Coal</td>
<td>Load Rejection Capable</td>
</tr>
<tr>
<td>G3*</td>
<td>System-Owned</td>
<td>13</td>
<td>50</td>
<td>Natural Gas (simple cycle)</td>
<td>Yes</td>
</tr>
<tr>
<td>G4*</td>
<td>System-Owned</td>
<td>22</td>
<td>50</td>
<td>Pumped Storage</td>
<td>Yes</td>
</tr>
<tr>
<td>G5</td>
<td>Independent</td>
<td>23</td>
<td>30</td>
<td>Coal</td>
<td>No</td>
</tr>
<tr>
<td>G6</td>
<td>Independent</td>
<td>27</td>
<td>55</td>
<td>Coal</td>
<td>No</td>
</tr>
</tbody>
</table>

*Blackstart Plants critical for system restoration

Table 2.5 | List of Power Plants in the IEEE 30-bus System
1. **E-threat Restoration Plan Prerequisites and Assumptions**

An E-threat Restoration Plan Module for this system will address the special needs associated with a blackout caused by an EMP strike, or a GMD event. For the purposes of this example an EMP event is assumed, since the requirements for a Severe Space-Weather induced blackout will be very similar to those needed to address EMP E3, and may be understood as a subset of this example plan.

For the purposes of this plan, it is assumed that at least minimal E-threat resilience measures have been taken throughout this 30-bus grid system. Without such embedded, pre-planned resilience for the 30-bus “island” system, a successful restoration plan would not be credible. In particular, a restoration plan without a minimally-EMP resilient grid would be dealing with an unacceptably long list of overlapping catastrophic problems:
- Direct, EMP-induced damage and inoperable hardware in a very wide area, including operationally critical hardware with lead times – and therefore minimum restoration timelines – potentially exceeding one year.

- Indirect damage to sensitive electrical and electronic equipment and systems, due to misoperation of control systems and protective relays.

- Situational assessment under these conditions would require extensive manual system evaluation, which would likely be impossible, given the complicating effect of consequent cascading failures of all other lifeline infrastructures.

- With anticipated failure of conventional communication systems, and lacking a pre-arranged emergency communication system, there will be no credible means to communicate with personnel to initiate, manage or coordinate the restoration process.

For these reasons, in addition to the other aspects of EMP resilience planning and investment recommended above, the emergency repair vehicles, tooling and other items required for restoration included in the Minimum EMP Hardening Scenario (See Section III.D) are also assumed – for this sample plan – to be available.

The restoration plan itself, as indicated below, must be designed to be adaptable, and to include elements that may be necessary to address a range of potential issues arising following an EMP event.

2. Minimum EMP Hardening Scenario for the 30-bus system

For this example grid, it is illustrative to review how the Minimum EMP Hardening Scenario could be implemented.

The primary objectives of increasing the EMP-resiliency of the 30-bus power system well in advance of an EMP-event is to ensure there remain a designated, minimum set of functional, operating power generating stations, cranking paths transmission elements (including substation.switchyard equipment), SCADA systems, restoration tooling, EMP-protected, staged spares and emergency communications. In practice, this would mean there would never be a “full” power outage after an EMP event. Instead, the system would reduce to pre-planned, operational “enclaves,” which can be used as starting points for restoration plan implementation, as power crews restore other portions of the grid to operation.
Table 2.3 above provided a generic discussion of restoration planning. Specific Minimum EMP Hardening Scenario measures for hardware within the 30-bus system are listed below. It should be noted that, synergistically, many of these measures will also help in rapid system restoration following other Black Sky Hazards, including Space Weather GMD and extreme terrestrial weather.

- Tie line EHV autotransformers at Stations 5 and 27 were installed with either (a) a neutral ground blocking device, or with (b) Protective devices for transformer tripping at E1, GIC or transformer stress thresholds.

- Acquired and stage low-band VHF radio communication gear, stored in EMP protected containers at the control center, blackstart power plant stations 13 and 22, as well as at transmission substations 2 and 15, and at residences of relevant managers and repair crew personnel.

- Distribution insulator spares stored at distribution stations 2, 12, 15, 23, and 24 to serve the critical load on feeders from these stations.

- Provide appropriate grounding and shielding at the Control Center, and at cranking path stations 1, 2, 4, 5, 12, 15, 22, 23, 24, 25, and 27.

- Blackstart power plants stations 13 and 22, all cranking path substations, as well as the Control Center equipped with back-up diesel generators and adequate supply of diesel fuel.

- All critical GSUs and EHV transformers were protected as part of resilience investment. Also, one de-energized GSU spare at each power plant.

- 1 EHV autotransformer spare at Station 27, with a transportation plan to move to Station 5, if required (EHV transformers at Station 5 and 27 are identical).

- Inexpensive electronics-based equipment spares staged along cranking path (e.g., computers, emergency radios, protection relays, and batteries/inverters for backup power).

- EMP resiliency measures for IC-based electronic equipment, using grounding, shielding, filtering and fiber-optic cabling methods.

- EMP protection put in place to assure survival or rapid repairs to relevant gas supply/pumping systems, especially the motors and associated variable speed motors.
- EMP-secure emergency vehicles to include prearranged, EMP-protected mobile diagnostic equipment. Prearranged storage of emergency vehicle fuel. Pre-planned staging of appropriate, EMP-protected spares, tooling and emergency power at all substations.

- Emergency vehicles validated for operation following EMP, based on earlier testing.

3. System Restoration Plan Module – Post Event Actions

Acronym list

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDC</td>
<td>Transmission Dispatch Center (part of the system control center)</td>
</tr>
<tr>
<td>DDC</td>
<td>Distribution Dispatch Center</td>
</tr>
<tr>
<td>GCC</td>
<td>Generation control center (part of the system control center)</td>
</tr>
<tr>
<td>PPCC</td>
<td>Power Plant Control Center</td>
</tr>
<tr>
<td>P&amp;C</td>
<td>Protection and Control</td>
</tr>
<tr>
<td>RC</td>
<td>Reliability Coordinator</td>
</tr>
<tr>
<td>SCC</td>
<td>System Control Center</td>
</tr>
<tr>
<td>SCADA</td>
<td>Supervisory Control and Data Acquisition</td>
</tr>
</tbody>
</table>

An EMP Restoration Plan Module will have many of the features found in modules for other, more common system hazards. In addition, this unique restoration plan module will include adaptable plans to build-out from the protected enclaves of still-operating EMP-protected blackstart power plants and cranking paths.

The actions recommended here, and their order, should be treated as a general guide. The actual requirements will, of course, differ for each company, and the overall plan will need to be substantially adapted to the status and damage assessment data, as it becomes available in an actual crisis.

The EMP plan module will include the following new elements:

- Develop a draft module, and solicit review and comments from other corporations with such modules.

- Develop training plan, and use lessons learned from training sessions to adjust and improve the plan.

- Include a process to regularly exchange updated, EMP-protected emergency contact information (names, phone numbers, addresses and
phone numbers) with external corporate, government and NGO support teams, through EPRO Executive Steering Committee. As part of this process, develop or arrange access to a database of external electricians who can be called upon to certify load before reenergizing after an EMP event.

- Periodic testing of EMP protection of facilities, storage enclosures, etc., as well as stored emergency diagnostic and support equipment, backup power supplies, and spares.

4. **Real-time restoration procedure elements**

- Initial coordination with multi-sector support assets (to be coordinated through EPRO Executive Steering Committee), to arrange for lifeline support to power crews and their families, special transportation assistance, security assistance, coordination with energy resource stakeholders, etc.

- Special training to cover expected equipment failure modes, manual diagnostic techniques, use of EMP-protected tooling and staged spares, emergency communication gear, and other differences from typical restoration plan modules.

- Pre-arranged command and control plan for RC and other management and decision making during an extended crisis, including provision for communication with state emergency management office, NGO support contacts, etc.

- Pre-assigned emergency roles and support locations for all personnel

- Cross-training of additional personnel, to add to available manpower for repair efforts during the emergency.

- Prearranged emergency protocols for activation and use of emergency communication equipment

- Prearranged priorities for power restoration for an extended outage

- Provisions must be made for certifying and approving load before it can be re-energized.

- Standard protocols to activate emergency communication equipment stored at strategic locations at the SCC, blackstart power plant stations
13 and 22, as well as at transmission substations 2 and 15. Plan to provide emergency communication gear to personnel directed to the blackstart and non-blackstart power plants, TCC, DDC, PPCC and field personnel.

- The SCC will establish emergency communications using such emergency gear with the TCC, DDC, and PPCC of blackstart power plants and other non-blackstart power plants, and notify them of the power system restoration plan to be carried out as agreed upon with the Reliability Coordinator.

- The SCC will use emergency communications to coordinate with repair crews, and collect information on system condition and damage assessment to adapt restoration plan module to existing conditions, developing a detailed plan, assemble resources (personnel and diagnostic equipment), and execute the plan.

- The TDC and DDC will assess and verify availability of the emergency vehicles, activate pre-arranged plans for these vehicles to pick up personnel who cannot get to staging locations, and ensure the pre-assigned repair personnel and tooling are directed to appropriate sites for system assessment, repairs and replacement.

- Based on information from remote repair crews, the TSC, DDC, and power plants will assess the adequacy of staged spares for high value assets stored at strategic locations and arrange for transportation to the locations where such spares are required.

5. **Baseline Restoration Plan Framework**

The other elements of a more standard restoration plan module for the 30 bus system remain the same as those for other hazards. For completeness, these more typical elements of a restoration plan are included here.

This subsection summarizes the overall power system restoration plan for the 30-bus power system, NOT INCLUDING new, EMP event restoration elements. This plan assumes the following:

- The SCC has overall responsibility for the power system restoration plan, and a well-established coordination and division of responsibilities exists between the TDC, DDC, GDC, and individual PPCC.

- Support groups such as telecommunication, IT, and security are well connected and coordinated with the groups described above.
A well-established top-down chain of command for and among all responsible groups/departments is in place from the functional and administrative standpoint.

Personnel to be involved are professional, well-trained to carry out system restoration, and regularly certified for power system restoration.

6. Restoration Plan Strategy

Any restoration plan must prioritize and coordinate use of resources and facilities to restore the power system in the minimum time consistent with safety, reliability and restoration priorities. Priorities are adjusted in real time based on the assessment of the actual availability of resources and condition of the system facilities. This includes the voice and data communication system, status of the SCADA system, personnel, and the status of the blackstart capable generating units G3 and G4 and other plants.

- Initially, resources must be channeled to assessment of the transmission system condition, establishment of emergency data and voice communications, and availability of the blackstart capable generating units G3 and G4, as well as the availability of emergency power from the neighboring power system, if available;

  - The power system needs to be “islanded” in two parts – Northern system and Southern system – in order to accomplish successful system restoration in an orderly and manageable manner. The entire system also must be disconnected (islanded) from the rest of interconnected network initially unless the emergency power is arranged as part of the system restoration.

  - The northern portion will be restored using the emergency power from the blackstart generator G4 at Station #22.
    - Explore the possibility of seeking mutual assistance emergency power from the Northern neighboring system interconnected at Station#27. If not, then the system must be disconnected from the Northern neighboring system, and system restoration be initiated using the internal blackstart resources.

  - Similarly, the southern portion of the system to be restored using the emergency power from the blackstart generator G3 at Station #13.
• Explore the possibility of seeking mutual assistance emergency power from the Southern neighboring system interconnected at Station#5. If not, then the system must be disconnected from the Southern neighboring system, and system restoration be initiated using the internal blackstart resources.

▷ Sectionalize the cranking paths to support the system restoration of the northern and southern portions on an independent basis by opening the line between Substation 15 to Substation 23, Synchronize the northern and southern systems after they are restored on their own and well stabilized, and critical load energized in each portion by closing the line between Substation 15 to Substation 23.

■ Assess the availability of trained personnel at the SCC, TDC, GDC, and individual PPCC;

■ Assess the re-start readiness of the non-blackstart generating units G1, G5, and G6 so that the emergency power from the blackstart capable generating units G3 and G4 can be directed to re-start these units that are critical in success of the power system restoration effort,

■ Assess the status of the load rejection capable generator G2 to see if it has successfully load rejected, and evaluate if it can be resynchronized with the blackstart generating units to provide emergency power to other non-blackstart units as soon as possible,

■ Transmission and substation crew, including the protection and control specialists and telecommunication specialists must be dispatched to check the status of the transmission lines and substation facilities, and follow further instructions as system restoration progresses;

■ Sectionalize and energize the cranking path transmission lines and associated substations critical in the power system restoration.

■ Open the tie lines with the rest of the interconnect network to initiate the system restoration in a safe and secured manner, unless help is available from the neighboring systems.

■ Restore critical network facilities,

■ All of the non-blackstart generating units must be started as soon as possible with the power from the blackstart units and keep ready for
resynchronization with the system.

- Stabilize the energized system to avoid the loss of all ready re-started plant(s);

- Gradually energize the distribution feeders to restore the pre-determined critical customer loads while stabilizing the system. Critical loads could include hospitals, law enforcement, water supply systems, civil defense, communication, essential government buildings and facilities, etc. per the list prepared earlier.

- Notify DOE, NERC, and the Reliability Entity of the system collapse event. Continue the communication with them to provide timely update on the status and progress of the system restoration effort. Fill out and send necessary forms to report the system collapse event to all required government and local agencies.

- Contact federal and state agencies for emergency communication, crew transportation and other help, as necessary using the pre-established contact and coordination information.

7. **General Considerations**

The following factors must be recognized in order to successfully restore the power system from a complete outage in a safe and reliable manner:

- The overall restoration plan must be adjusted based on the assessment of actual conditions. Any changes must then be well-coordinated and communicated to management and to all relevant crew personnel.

- This plan adaptation will be on ongoing process, since it takes time to assess actual system conditions and evaluate the validity of the SCADA data available, and establish emergency communications. In addition, it also takes time to sectionalize substations to facilitate energizing of predefined cranking path transmission lines to channel emergency power for plant startups from the black-start and load-rejection capable power plants.

- Caution must be exercised to not attempt to restore the system too quickly, either by restoring critical loads in large blocks, attempting to energize long cranking path transmission lines, or starting large motors.
at power plants being restarted. Otherwise, there is a possibility to trip the available generation because instability could result in another system collapse, which will require a repeated restart of the power system restoration process.

- Caution must be exercised while energizing cranking path transmission lines, especially long lines. Long lines, especially at higher voltage, have high charging currents, which may impose very high reactive load on the blackstart generation plants, which in turn, may trip off-line if too much reactive power demand is imposed too quickly. Excessive charging current on long lines tends to produce excessive voltages, which can damage line and station equipment. The use of autotransformers and shunt reactors can help mitigate this problem, and adding load to the line before closing can help. Guidelines for energizing transmission lines should be established.

- For generating units being restarted, automatic voltage regulators and governor controls should be placed in service as soon as practical after bringing units on-line and should remain in service to maintain the generator stability. Caution must be exercised during the initial stages of restoration to monitor generator terminal voltage and frequency and select loading the units in small blocks to avoid unit instability. If necessary forewarn the SCC and TDC as large motors are started at the plant.

8. Power System Restoration Procedure for the 30-bus System

This procedure is activated once the System Control Center (SCC) has confirmed a system-wide blackout, and the decision has been made to restore the collapsed power system per the pre-approved power system restoration plan.

This procedure, as any restoration procedure, is meant as a general guide. It may be necessary to reorder or drop some of the procedure steps, and add additional steps based on the realities of the actual condition of power plants and transmission infrastructure, personnel, and power and fuel resources. As always, any deviation from pre-planned procedures must be well communicated with all participating groups to avoid confusion and safety and reliability issues.
1. **SCC Responsibilities:**

   i. Check/assess the means of secured and reliable data and voice communication available to establish emergency communications with the RC, TDC, DDC, T&D sub-station personnel, and PPCC. Such communications means could be land telephone lines, 800 MHz radio communications, fiber optics communication, power line carrier communication, satellite phones, hand held ham radio, etc.

   ii. Contact the Reliability Coordinator to:
       - Identify the status of the system,
       - Jointly evaluate the extent of the system collapse,
       - Develop a restoration plan based on available resources and actual system conditions.

   iii. Establish emergency communications with the TDC, DDC, and PPCC of blackstart power plant, load rejection capable power plants and other non-blackstart power plants, and notify them with the power system restoration plan to be carried out as agreed upon with the Reliability Coordinator.

   iv. Determine if generator G2 has successfully load rejected, which can be used to bring on line and use to re-start other power plants as a part of the power restoration effort.

   v. Contact the power plant personnel to confirm the availability of the black-start generating units G3 and G4 and instruct to initiate the operation of black-start power plants, and successfully load-rejected power plant G2.

   vi. Initiate the operation of other power plants at minimum output and initiate the synchronization process to bring these power plants to connect to the grid with the help of the power plant, TDC and DDC personnel.

   vii. Coordinate the synchronization of all power plants being restarted and energized within the Northern and Southern regions, and synchronize the Northern and Southern islands with the help of TDC and DDC.

   viii. Coordinate the synchronization with the rest of the interconnected network with the approval of the neighboring utilities and the RC with the help of TDC and DDC.

2. **TDC Responsibilities:**

   i. Contact the personnel at the blackstart power plants G3 and G4; as well as the DDC,

   ii. Dispatch technical and support personnel to critical substations #1, 2, 3, 4, 12, 13, 15 for the Southern region and #22, 22, 24, 25, and 27, for the Northern region,

   iii. Contact the personnel at the Power plant G1, G2, G5, and G6 to receive the emergency power from the blackstart generating units G3 and G4 using the predefined cranking path transmission lines

   iv. Determine the status and availability of the pre-identified cranking paths to be used to deliver emergency power to restart other non-black-start capable
power plants, which are listed below:

- List of cranking path transmission lines for the Northern region:
  - Line from Substation 22 to Substation 24,
    - Generator leads for blackstart G3
  - Line from Substation 24 to Substation 25,
  - Line from Substation 25 to Substation 27
    - Generator leads for G1
  - Line from Substation 23 to Substation 24
    - Generator leads for G2

- List of cranking path transmission lines for the Southern region:
  - Line from Substation 12 to Substation 13,
    - Generator leads for blackstart G4
  - Line from Substation 12 to Substation 4,
  - Line from Substation 2 to Substation 4
    - Generator leads for G6
  - Line from Substation 1 to Substation 2
    - Generator leads for G5

v. Dispatch first responder station crew, P&C electricians/technicians as well as telecommunication specialists to the critical substations #1, 2, 4, 12, 13, 15, 22, 23, 24, 25, and 27

vi. Sectionalize (island) the collapsed transmission system from the rest of the interconnected grid network at Substations 5 and 27

vii. Isolate/de-energize the following non-cranking path transmission lines, so as to channel and deliver emergency power to the non-blackstart capable generating plants G1, G2, G4, G5, and G6 [Note: Substation personnel to develop a detailed step-by-step procedure to open corresponding circuit breakers/switches to accomplish the isolation of the following inter-substation lines to island the Northern and Southern regions for the system restoration purposes: 2→5; 1→3; 3→4; 4→6; 5→7; 6→7; 6→8; 8→28; 8→9; 8→10; 6→9; 2→6; 4→6; 6→10; 6→28; 4→12; 4→15; 9→10; 9→11; 10→17; 10→21; 10→22; 12→16; 16→17; 19→20; 18→19; 15→18; 27→28; 27→29; 27→30; and 15→23.]

viii. Contact personnel at substations 1, 2, 4, 12, and 13 to energize the cranking path transmission lines of the Southern region in coordination with the plant personnel at the black-start generating unit G3 to initiate the delivery of emergency power to non-blackstart capable generating units G1 and G2,
  - Cranking path from substation 12 to substation 13
  - Cranking path from substation 12 to substation 4
  - Cranking path from substation 2 to substation 2
  - Cranking path from substation 1 to substation 2

ix. Contact personnel at substations 22, 23, 24, 25, 26 to energize the cranking path transmission lines of the Northern region in coordination with the plant personnel at the black-start generating unit G4 to initiate delivery of emergency power to non-blackstart capable generating units G5 and G6,
• Cranking path from substation 22 to substation 24
• Cranking path from substation 24 to substation 25
• Cranking path from substation 25 to substation 27
• Cranking path from substation 23 to substation 24

x. Assess the status of the pre-identified cranking paths as they are energized.

xi. Assess the status of the non-blackstart generating units G1, G2, G5, and G6 being restarted.

xii. Synchronize units G1, and G2, with the Southern region system, and units G5, and G6 with the Northern region system, as they become available,

xiii. Initiate energizing non-cranking path transmission lines one by one in order to begin energizing critical customers load on a priority basis,

xiv. Energize critical customers load in a small predetermined block of 5 MW at a time while stabilizing the system,

xv. Energize the line from substation 15 to substation 23 to connect the Northern and Southern islands once all loads in the Northern and Southern regions are restored, and the respective system is well stabilized,

xvi. Work with the neighboring systems and substation personnel, SCC and RC to close the tie lines at substation 5 and 27 as appropriate and bring the system to a new normal state. Tie lines, especially with nearby well stabilized power plants, should be energized and restored as soon as possible to improve the stability of the system.

3. **DDC Responsibilities:**

i. Develop and maintain its portion of the overall system restoration plan in coordination with TDC, which include the:
   - Assessment of emergency communication methods,
   - Identification of trained personnel and the notification means,
   - Development of priority of circuit switching and critical customer load addition,
   - Procedure of clearing and adding critical customer loads,
   - Train personnel and recertify on an annual basis
   - Review the plan on an annual basis and modify as necessary

ii. Support SCC and TDC in carrying out its portion of the system restoration plan,

iii. Contact first responder personnel and dispatch them to the distribution substations and other facilities, as necessary,

iv. Follow and execute the directions from TDC to initiate isolating distribution feeders as required to facilitate the initiation of energizing the cranking path transmission lines [Note: Substation personnel to develop a detailed step-by-step procedure to open corresponding circuit breakers/switches to accomplish the isolation of the distribution feeders],

v. Keep records of all switching and other actions carried out, and communicate back to TDC,

vi. Assess the availability and status of the distribution feeders to restore the critical customer loads,
vii. Coordinate with the critical customers,
viii. Make provisions to certify load being reenergized, as appropriate
ix. Initiate sectionalizing and energizing distribution feeders in preparation for restoring critical customer loads in coordination with the TDC,

4. Telecommunication Group Responsibilities:
i. The responsibilities of the telecommunication group are:
   • Provide and maintain data and voice communications using the means available, such as a ham radio, MHz radio line, land telephone lines, fiber optics, power line carrier, and satellite telephone and data communication,
   • Provide periodical training to TDC and DDC, and substation personnel to qualify to operate MHz radio line, land telephone lines, fiber optics, power line carrier, and satellite telephone and data communication,
   • Perform bi-weekly test on the available communication means, such as MHz radio line, land telephone lines, fiber optics, power line carrier, and satellite telephone and data communication, and document the test results,
   • Develop a detailed plan and step by step procedure to assist SCC, TDC, DDC and substation personnel during the power system restoration process for voice and data communication,
   • All communication lines including back up must be kept open during the entire power system restoration process,
   • Assign and train personnel for assistance during the power system restoration process.
   • Telecommunication group shall:
     › Assess the status of the voice and data communication, such as land line telephone, radio communication, satellite telephone system between SCC, TDC, DDC, substations, and all power plants,
     › Verify the operability of voice and data communication, such as land line telephone, radio communication, and satellite telephone system between SCC, TDC, DDC, substations, and all power plants.

5. Black-Start Power Plant G3 and G4 Plant Operators’ Responsibilities:
i. Assess the status of black-start generator availability and evaluate their portion of the restoration plan based on the overall restoration plan received from the SCC/TDC,
ii. Keep Northern and Southern regions TDC informed of the status and availability of their generating units,
iii. Coordinate the closing of generator circuit breakers and switchyard circuit breakers to energize their respective cranking paths.
iv. Continuously monitor and adjust generator terminal voltage and frequency.

6. Non-blackstart Generating Units G1, G5, and G6 Operators’ Responsibilities:
i. Secure the unit from the safety and security of the equipment and personnel due to unavailability of the off-site auxiliary power in light of the total system collapse,
ii. Assess the status of black-start generator availability and evaluate their portion of the restoration plan based on the overall restoration plan received from the SCC/TDC,

iii. Keep Northern and Southern regions TDC informed of the status and availability of their generating units,

iv. Coordinate the closing of the auxiliary transformer and switchyard circuit breakers to receive emergency startup power from their respective cranking paths.

v. Coordinate large auxiliary motors start-up with the TDC, as large motors tend to draw a large amount starting current that could impact the stability of the unit delivering that power,

vi. Continuously monitor and adjust generator terminal voltage and frequency.

vii. Gradually load the unit to provide power to critical customers load while stabilizing the generating unit.

7. Load Rejection Capable Generating Unit G2 Operators' Responsibilities:

i. Secure the unit following load rejection, if successful,

ii. Assess the status of black-start generator availability and evaluate their portion of the restoration plan based on the overall restoration plan received from the SCC/TDC,

iii. Keep Northern region TDC informed the status and availability of their generating units,

iv. Coordinate the closing of generator breakers and switchyard circuit breakers to synchronize and deliver start up power to other non-blackstart plants.

v. Coordinate the startup of large auxiliary motors with the TDC as large motors tend to draw a large amount starting current that could impact the stability of the unit delivering that power,

vi. Continuously monitor and adjust generator terminal voltage and frequency.

vii. Gradually load the unit to provide power to critical loads while stabilizing the generating unit.
CHAPTER SUMMARY

Given the potential for severe, wide area impact that could result from emerging E-threats – GMD, EMP or sophisticated use of IEMI devices – this chapter has been developed to lay out recommended, cost effective protection strategies, menus of best-practice hardening options and examples of focused restoration plan modules for interested corporations and other stakeholders. It is designed as a resource, to be implemented in a manner they determine to be practical and cost-effective.84

E-threats, while high-consequence events, are amenable to considerable risk reduction through a strategy of targeted, cost effective measures, so that even in a worst-case event, there would never be a full, extended-duration wide area power outage, but rather strategic protection of critical “enclaves” of essential power grid resources. These enclaves would remain functional and available, either continuously or with brief interruptions, for rapid power grid restoration. This strategy provides a foundation for power restoration crews – with appropriate inter-corporate, government and NGO support – to use in fully restoring power grid operation.

It is important to note, however, that in the wide area disruption anticipated for such events, the power grid restoration process, reviewed in Section V, will require sustained, advance coordination and dialog among industry and its partners on best practices and implementation steps, to assure planning will be in place for critical support, when needed. As one approach to assist this process, the EPRO Executive Steering Committee, a companion process to this Handbook described earlier in this volume, is being developed as a resource for use by all of these stakeholders.

84 Additional online appendices are provided that discuss, in greater detail: Systematic GIC Reduction Using Neutral Current Blockers (Appendix 2.1); Electromagnetic Hardening Principles (Appendix 2.2); and a Potential Program for EMP Testing for Repair Vehicles (Appendix 2.3).
CHAPTER THREE

WHOLE COMMUNITY PREPAREDNESS FOR BLACK SKY EVENTS

Power Restoration Support, Consequence Management and Emergency Power
INTRODUCTION

Given the growing risk and potentially devastating impact of E-threats, coordinated cyber and physical attacks on the grid, and other manmade and natural hazards, extraordinarily broad and inclusive partnerships will be required to ensure societal continuity for black sky events.

Chapter I highlighted the catastrophic effects that such events could have for public health and safety, national security and the economy. Yet, unprecedented opportunities are emerging to reduce this potential damage. Chapter II summarized a range of resilience approaches to address emerging E-threats, the newest hazards in the black sky category. The analysis that follows recommends concrete, actionable measures to reduce the impact of the full range of black sky events, and save many thousands of lives that will otherwise be lost when -- not if -- these events strike.

The most effective strategy to save lives in long duration, multi-region outages will be to accelerate power restoration. Assisting utilities to speed the restoration of service should become a primary focus of emergency preparedness and disaster response planning.
Many utilities are already taking significant steps to harden the grid against natural and manmade hazards. They are also strengthening their ability to accelerate power restoration by expanding their arrangements for mutual assistance, so that utilities across the nation can bring power restoration crews and equipment to help utilities in a stricken region restore service. Moreover, as demonstrated in Superstorm Sandy and other major outages, local, state and Federal agencies can provide critical support to restoration operations by clearing roads, providing logistical support for utility trucks and crews, and providing other assistance that utilities request.

Vastly more support will be essential to save lives in the long duration, multi-region outages that black sky events will create. To limit threats to public health and safety during such an outage, the most efficient and effective strategy will be to accelerate power restoration, both to the general population and especially to municipal water systems, hospitals, and other facilities and functions essential for saving and sustaining life. Assisting utilities to speed the restoration of service (in ways they deem most helpful) should become a primary focus of emergency preparedness and disaster response planning.

In particular, the United States and partner nations should adopt a whole community strategy for power restoration support. Enormous untapped potential exists to expand power restoration support missions by non-governmental organizations (NGOs), and to enable individuals, families and communities to help each other survive black sky events. Promising industry opportunities for expanded power restoration partnerships also exist with all levels of government, especially with states and their National Guard organizations. This chapter identifies emerging best practices and recommends specific measures for broader, more effective restoration support to electric companies from government and NGO partners. However, capitalizing on these partnership opportunities will depend on three other requirements for progress:

**Operating in a Disrupted Environment:** For partners to assist restoration, they must be able to function during an extended blackout, with processes embedded in their disaster response plans.
severely disrupted environment, especially when their own facilities and supply chains are damaged or disabled. The recommendations that follow propose specific measures to strengthen their preparedness, as well as broader initiatives to expand and prioritize the availability of emergency power to help partners function until grid service is restored.

**Embedded Black Sky Planning:** Second, partnerships to accelerate power restoration will only be effective if they are embedded in the disaster response plans and playbooks that agencies and NGOs will follow when a black sky event occurs. For decades, too many Federal and state response plans have treated power restoration as an afterthought, rather than a core priority to help save and sustain life. Sandy helped illuminate the need to incorporate restoration into these plans. Now, a range of initiatives provide opportunities to do so, including the Federal Emergency Management Agency’s development of a Power Outage Incident Annex. This Chapter is structured to directly support these planning efforts, and also to help in the development of exercise programs, to strengthen industry-partner collaboration.

**A Framework for Sustained Engagement:** Third, because the development of these partnerships will require sustained engagement, a framework will be needed to support long-term dialog and consensus building on power restoration between industry, NGOs, government agencies, public utility commissioners, and other key stakeholders. Previous studies -- most notably the Severe Impact Resilience analysis conducted by the North American Electric Reliability Corporation (NERC) -- have proposed significant initiatives that could be applied to black sky hazards. However, the implementation of many such initiatives has lagged.

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The EPRO Executive Steering Committee (ESC) is designed to help support long-term dialog and consensus building on power restoration, and assist with refinement and adoption of recommended resilience and restoration measures.
Accordingly, as with the E-hazard protection options in Chapter 2, the proposals that follow are designed to be implemented with the help of the EPRO Executive Steering Committee. In the months and years to come, the EPRO Executive Steering Committee will help refine and support the adoption and advancement of these initiatives and, just as importantly, apply them to build cross-sector resilience with the other infrastructure sectors that depend upon (and in many cases also support) the electric grid.

**Chapter Outline**

The first section of this chapter identifies the partner support missions that industry will likely find most valuable to accelerate power restoration in a black sky event. Section Two examines how a whole community strategy provides a framework for expanding and integrating such support.

The remaining sections offer detailed recommendations for partner support within the whole community framework. Section Three proposes partnership initiatives to help individuals, families and communities become survivors rather than victims in long duration, wide area outages. Section Four examines how NGOs can expand their contributions to power restoration, by planning to address support requirements uniquely suited to these organizations. Section Five proposes state-level initiatives to address support requirements, helping utilities accelerate restoration, including an array of emerging best practices for state National Guard missions. Section Six proposes how planning for power support requirement components might be integrated into the Power Outage Incident Annex, the Regional Playbook initiative, the Complex Catastrophe planning effort, and other ongoing Federal and Regional initiatives where industry input on power priorities will be vital. Section Seven examines approaches to help support utilities and their partners as they implement steps toward assured power grid resilience and restoration, and concluding with a review of additional challenges, not yet addressed, which remain as important agenda items for future joint effort.

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PARTNER SUPPORT MISSIONS:
INDUSTRY PRIORITIES FOR ASSISTANCE

“The nine most terrifying words in the English language are, ‘I’m from the government and I’m here to help.’” Ronald Reagan, 40th President of the United States

Government agencies and NGOs can accelerate power restoration only if their assistance directly supports utility priorities and fits within industry’s overall system for power restoration (including arrangements for mutual assistance).

Clarifying industry support mission priorities is especially important for black sky events, which will produce a crush of government interest in accelerating power restoration. When President Obama turned to his Cabinet early in the response to Sandy and emphasized that support for power restoration was an overriding priority for Federal departments, department leaders heard the President’s message loud and clear. But many of those Departments -- including the Department of Defense -- had never before considered restoration of the U.S. grid as a significant mission, and scrambled
with their interagency partners to do the best they could to identify appropriate support missions and assets. Pressures to help accelerate power restoration were at least as intense at the state level. Governors Chris Christy (New Jersey), Andrew Cuomo (New York) and other governors in the stricken region made power restoration a crucial priority in their states, as did mayors and other local leaders.

Fortunately, soon after Sandy made landfall, industry and government leaders were able to create from scratch a collaborative mechanism to identify and prioritize utility support requests. But “building an airplane while flying it” is no way to manage a crisis. For the unprecedented disruption projected for black sky events, ad hoc emergency support management efforts – created without advance planning, coordination, training and critical provisioning – will fail. As industry and government continue to institutionalize the lessons learned from Sandy and build on the foundations for collaboration created during that storm, defining the support missions that will be essential for black sky events is a critical and urgent priority.

The Post-Sandy Power Restoration System: Status, trends and recommendations

The most valuable ways that partners can assist power restoration will be to either fill gaps in industry’s own capabilities, or support the massive movement of utility crews and other restoration assets that will be necessary in a black sky event. Key missions will include assistance for road safety and security, emergency food and shelter, restoration staging facilities, and other support services for utility crews – and, in some cases, their families.

To help partners develop options to execute these support missions, the first step is to review electric industry power restoration processes for such
events (including current trends and recommended additional measures) and then examine the remaining shortfalls where partner assistance will be most important.

Technician inspects Micro-grid equipment. Smart Grid technology will be invaluable to situational awareness during an outage [Source: Amy Vaughn/ DOE. 9/23/12]

1. Hardware Resilience Investments

One way that utilities speed restoration is by making targeted resilience investments: that is, investments in equipment and technology that strengthen the protection of the grid against severe hazards, and downsize the restoration challenges these hazards would otherwise create. For preparedness against major storms, Sandy helped accelerate a broad range of investments in resilience against severe storms, many of which will also be valuable against other hazards. Other measures to strengthen resilience are also in progress or under consideration by electric corporations. The section that follows provides a brief review of the growing “menu” of these resilience measures, which helps provide the basis for defining partnership support options.

Examples of Resilience Options:

- **Black Start Capability:** Significant investment is underway by some companies in black start generators and more resilient cranking paths which -- if they are protected against black sky hazards -- can become key resources for regional and multi-region power restoration plans.

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One especially important area for progress lies in adding new black start generating capacity to replace coal-fired units that will retire over the next few years due to environmental rules, including the Environmental Protection Agency’s Mercury and Air Toxics rule and greenhouse emission reduction requirements.

- **E-threat Protection:** For protection against electromagnetic threats, Chapter 2 recommended a range of hardening and operational options for utilities to consider. These measures typically focus on hardening key grid components and systems to make them less susceptible to damage, such as hardening carefully selected elements of a power grid segment to provide for protected critical asset “enclaves” following an E-threat event.

- **Addressing Storm Surges and Related Hazards:** For these hazards, investment options include undergrounding of selected power lines, relocating or protecting low-lying power substations, employment of higher design and construction standards, and a range of other measures.

- **Microgrids:** Microgrids that could function as isolatable networks in a widespread outage offer an increasingly important option for resilience, especially for ensuring sustained power for critical facilities.  

- **Smart Grid Technology:** Sandy helped accelerate the adoption of “smart grid” technology that can help utilities accelerate power restoration. Smart meters can help utilities more rapidly identify customers and service areas without power, and adjust the deployment of utility crews accordingly. Synchrophasor measurement units (PMUs) can provide grid operators with vastly improved, real-time awareness of the grid’s status, and speed efforts to reconnect regions with power. Rapid technological innovation is underway in this field and promises to create an array of opportunities to invest in grid resilience.

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- **Accelerating Restoration – New Command and Control Options, Spares and Tooling:** Other resilience options are designed to speed the recovery from damage to utility facilities or the external systems on which they depend. Some leading utilities are adding spare transformers, additional standby equipment, and power restoration materials. Others are adopting measures to strengthen communication and coordination of restoration operations, commissioning new mobile command centers, deploying satellite communication systems, and deploying new systems to speed damage assessments and more effectively deploy restoration crews.\(^5\)

**In Summary – Partnering with Industry for Hardware Resilience:**
As resilience investments addressing black sky hazards grow across the nation, these new capabilities will imply important changes for NGOs and government agencies. As reviewed in the next section (section “B”, below), industry’s partners can use this new, growing resilience architecture to define new priorities, locations and varieties of support – keyed to these changing industry resources – that will be critical to building an effective, whole community foundation for power grid resilience.

2. **Power Restoration, and Mutual Assistance:**
   **Scaling Up for National Response Events**
   As utilities make appropriate, cost-effective hardware resilience investments, the other essential advance planning requirement is to develop power restoration plans that match the challenges that black sky hazards will create. While power companies typically have well developed restoration plans, training and tooling for conventional hazards, most such companies in the United States do not yet have power restoration plan modules associated with the full set of black sky hazards. As these plans are developed, challenges associated with restoration from severe hazards will provide important opportunities for partner support.

   One vitally important element of restoration after a black sky event will be “mutual assistance:” that is, agreements and plans that enable utilities in a stricken area to request aid from other utilities, to speed restoration. New

\(^5\) The Edison Electric Institute (EEI) has provided an especially comprehensive review of initiatives to improve hardening and resilience against major storms. EEI Before and After the Storm, op. cit. Pp. 1-18
power industry initiatives to strengthen mechanisms for mutual assistance will be particularly important to restoration in severely disrupted environments. As industry’s partners develop plans and approaches to support electric companies’ power restoration efforts, support for the likely massive cross-corporate flow of restoration personnel and assets will be particularly important.

Sandy exemplified the effectiveness of the mutual assistance system. Utilities conducted the largest movement of restoration crews in history during that event, with over 70,000 utility personnel deploying to support power restoration from across the United States and Canada. While enormously effective, however, that operation also highlighted the need for utilities to refine and institutionalize mechanisms to provide for such nationwide mutual assistance, versus for more frequent, smaller-scale outages.

Investor-owned utilities are now structuring their mutual assistance system to prepare for “national response events” (NREs) that impact a large population or several regions across the U.S. and require resources from multiple regions to support power restoration. The NRE initiative has greatly improved the ability of industry to coordinate and allocate utility crews and other industry emergency restoration resources at the national level, including private contractors employed by utilities.6

Public power utilities are also ramping up their mutual assistance agreements. A number of these agreements are coordinated by state associations; in other cases, public utilities make arrangements directly with each other. Public utilities have also worked with FEMA, the National Rural Electric Cooperative Association (NRECA), and the American Public Power Association (APPA) to create an APPA-NRECA Mutual Aid Agreement, providing for a much more

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comprehensive system for restoration assistance in region-wide or multi-region outages.\(^7\)

Other components of the electric industry are also exploring new ways to collaborate and provide for mutual assistance in severe events. During Sandy, for example, three DOE Power Marketing Administrations (PMAs) -- the Bonneville Power Administration (BPA), Western Area Power Administration (WAPA), and the Southwestern Power Administration (SWPA) -- brought in 235 staff and roughly 200 pieces of equipment, in coordination with investor-owned utilities, to restore downed lines and repower substations. This was the first time WAPA or SWPA had engaged in mutual aid with investor-owned utilities as part of DOE’s ESF12 response.\(^8\) Institutionalizing and building on these innovative efforts will be essential to provide for mutual assistance during black sky events.

**In Summary – The Power Restoration Support Mission**

As power companies expand their power restoration planning to include new modules for the full set of black sky hazards, and mutual support planning

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and options continue to grow, this area will provide an increasingly vital focus for government and NGO support missions. In Sandy and even in less severe outages, government and non-governmental organizations played critical roles in facilitating the movement of utility crews, trucks, and other restoration assets. These missions will be far more critical in black sky events, but the scale of these support requirements, and the challenges that will be faced in implementing them, will be vastly greater.

B | Support Missions For Black Sky Events

Sandy after-action reports (AARs) by Federal and State agencies identified a range of opportunities to scale-up partnership support in for more severe events. In addition, a number of recent exercises have highlighted additional power restoration support requirements that catastrophes are likely to create. Two exercises are especially helpful in this regard: the Capstone 2014 Exercise (based on a 7.7 magnitude earthquake in the new Madrid Seismic Zone along the Mississippi River) and Alaska Shield (which posited a recurrence of the 9.2 1964 Alaskan earthquake).  

In particular, Capstone 2014 highlighted the degree to which the disruption of transportation and communications infrastructure in a black sky event will create enormous impediments to the flow of utility crews, replacement equipment, and other restoration assets. In a 7.7 New Madrid earthquake, thousands of cell towers and other communications nodes would be destroyed. Over three thousand bridges (including many spanning the Mississippi) would need repair before utilities could use them to move replacement components for the grid. Other road, rail and airport infrastructure would be similarly disrupted. Finally, gasoline pipelines and distribution infrastructure to support utility crew operations would suffer massive damage, as would municipal water systems, food distribution systems, and health care facilities for crew members.

and their families. Facilitating the movement of mutual assistance assets in such a severely disrupted environment will create requirements for partner support over and above those that were so effective in Sandy.

For the recommendations below, specific partner support opportunities have been drawn from Capstone 2014 and related exercises, from Sandy AARs and from focused contributions by power industry, government and NGO contributors to this Handbook.

**Note:** Transportation of EHV transformers and other critical grid components represents a unique, major support mission, reviewed separately in section “C” below.

**Recommended Power Restoration Support Missions:**
**Coordination and Robust, Adaptable Planning**

State and federal government agencies and NGOs will be vital partners in supporting power restoration, and a number of discrete dimensions of support, listed below, will be particularly critical. Maintaining connectivity between electric companies and support partners for these missions may be supported by the EPRO Executive Steering Committee, in coordination with other relevant corporate and government organizations. Nevertheless, the actual impact of any black sky event

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is impossible to predict to a level that matches these specific, carefully defined missions. Maintaining a high level of adaptability – allowing for command and control structures and an emergency asset base that can quickly respond to changing realities – will be vital to assure successful power restoration.

1. **Focusing Support Planning on (Hardware-based) Resilience Architecture**

As power companies increasingly invest in the resilience measures that will be critical for recovery from black sky events, these investments will build a “resilience architecture” within the power grid, which will serve as a foundation for power restoration. For example, planning for protected “enclaves” as starting points for re-energizing the grid will allow for an effective, pre-planned process to build back to full power grid functionality. However, for this resilience architecture to be effective, emergency lifeline supplies, communication, security, transportation and other partner support functions will need to be well-coordinated, in advance. By building-in a “reflection” of this architecture into support measures, they can be directed to the critical locations and personnel where they will be needed, and focused effectively on the requirements of this power restoration foundation.

2. **Logistics Support for Restoration Crews**

In Sandy, dozens of military bases and other facilities provided staging sites and base camps for utility crews. Black sky events will require feeding, housing, and meeting the other support needs for far more repair personnel, distributed over far larger, multi-region geography, over a longer period than was required during Sandy and in a severely disrupted environment. Additional logistics missions are likely to include supply of fuel for utility trucks, and the provision of light trailers or other transportation assets to facilitate sustained, 24-hour repair operations, including short-haul cargo transportation from staging sites to point-of-repair. Again, as with feeding and housing, the enormous scale of such support requirements in a black sky event will risk outstripping the existing arrangements that utilities have made with contractors and other service and equipment providers.
3. **Support for the Families of Restoration Crews**

For black sky outages that last many weeks or months, and which may require utility crews to support power restoration far from their homes, providing assistance to their families will be an important support mission. Such assistance will be especially vital as the loss of electric power creates cascading infrastructure failures, resulting in severe shortages of food, water, medical care and other basic lifeline services.

Support for the families of restoration personnel has never been a significant partner mission in past outages. Bringing whole community assets to help meet this novel challenge, with non-governmental organizations playing an especially significant role, exemplifies how broader partnerships can help shorten the duration of catastrophic outages.

4. **Engineering Support**

Debris and road clearance proved crucial in Sandy for facilitating utility crew access to damaged grid infrastructure. These efforts, along with emergency evaluation of structural, infrastructure and electrical issues and related critical functions, will all be required on a much larger scale for many black sky events. Expedited inspection and repair of critical bridges and other transportation bottlenecks for restoration operations will also be essential. Additional types of specialized, trained support for restoration could also be valuable.

In this regard, NGO initiatives to develop and arrange for fielding of volunteer engineering teams could be enormously helpful. As one
example, teams of volunteer, certified electricians could provide vital support by certifying load safety in close coordination with broader restoration operations.

Incident Command centers such as this one in Maryland are vital to coordinating a well-planned response [Source: MD National Guard. 7/1/05]

5. Public Safety/Security
Utility contractors, state and local law enforcement, National Guard personnel and other partners in Sandy provided for Wire Guarding (site safety) and Flagging (traffic control) and other security/safety related support missions. Black sky events are likely to require a broader range of support missions, and on a much larger scale. To facilitate expanded assistance in these and related areas, it may be necessary for electric companies to work with support personnel from other sectors to ensure the requisite skills and training will be available when needed. Advance arrangements for such training and coordination systems to direct and prioritize the deployment of such personnel will be essential. Strengthening citizen awareness of the dangers posed in highly disrupted environments, and helping them identify where such dangers exist, provides an additional whole community partnership opportunity.

6. Situational Awareness
A key finding of the Department of Energy’s after action review of Sandy is that significant improvements are needed to provide shared, real-time situational awareness of damage to the grid and associated energy infrastructure, as well as in refining and coordinating the communication of estimated times of restoration to communities and government
leaders.\textsuperscript{11} Tracking restoration assets and ensuring that they were fully and optimally utilized also proved challenging in Sandy.\textsuperscript{12} For black sky events, planning for government and NGO contributions, with sustained industry participation, will be essential in building a stronger system for situational awareness and response coordination.

7. **Response Coordination**

Given the scale of response operations in Sandy, and the unprecedented level of coordination that power restoration required between industry and government in that incident, a very important and valuable innovation took place: the electric industry was given a “seat at the table” at FEMA’s National Response Coordination Center. As industry ramps up its mutual assistance system for national response events, it will be essential to institutionalize and expand the engagement of utilities in broader disaster response decision-making. In particular, to improve information sharing, communication, and coordination during major outages, electric power industry officials will need to be embedded not only with government response teams at the Federal level, but also at state and perhaps (as needed) local emergency operations centers.

8. **Operational Planning**

States that suffer frequent hurricanes already have detailed collaborative plans between emergency managers and utilities. Because black sky hazards could create outages of much wider geographic scope and longer duration than any yet experienced, these collaborative plans will have to be scaled up accordingly and incorporate a broader range of partners and support missions. Moreover, Sandy revealed that many other state

\textsuperscript{11} DOE, Overview of Sandy Response, pp. 7-11.
\textsuperscript{12} DOE, Overview, p. 9.
and Federal agencies had only weak (and in some cases, non-existent) disaster response plans in place to allocate and focus response capabilities to support power restoration. The midst of a catastrophe is no time to begin developing new mechanisms for restoration support. At all levels of government and in partnership with NGOs, traditional disaster response plans need to incorporate power restoration as a greater focus, with utilities playing a decisive role in shaping those plans at local, state, regional and national levels. These plans will also need continuous updating as threats, restoration priorities and other planning factors change.

Utilizing the Department of Defense’s air-lift capabilities can aid in delivery of critical grid components.

9. **Pre-Scripted Mission Assignments (PSMA)**

For many years, FEMA has used PSMAs to pre-identify likely support missions for disaster support from DOD and other Federal Agencies, ranging from the provision of generators by the U.S. Army Corps of Engineers, to emergency road clearing teams from the U.S. Forest Service. These pre-scripted mission assignments drive a more rapid and responsive delivery of federal support to states, communities and tribes.¹³ PSMAs are not a panacea; in fact, FEMA and DOD did not use a single PSMA in the response to Sandy, because they were poorly

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suited to the actual support requirements that FEMA identified in the storm. However, FEMA is refining these PSMAs to help accelerate and improve the delivery of Federal assistance in response to state requests, and states themselves are increasingly developing PSMAs to coordinate their own multi-agency response operations. States, utilities and their NGO partners should consider developing PSMAs that can help pre-plan for power restoration.

10. Whole Community Exercises

Even much more extensive and detailed plans than exist today cannot provide the real-world capabilities and collaboration that a black sky event will require. The Capstone 2014 and Alaska Shield exercises provided utilities and a range of disaster response partners to identify gaps in their existing plans and build stronger collaborative relationships. State and regional exercises should occur nationwide to provide for similar capacity-building for power restoration in black sky events.

11. Whole Community Support Team Packaging

In Illinois and many other states, emergency management leaders are developing “mission-ready packages” that pre-arrange for the deployment of law enforcement, National Guard, and other disaster response elements that will collaborate to carry out specific types of missions. This template can be leveraged to design mission-ready packages to support power restoration, (including debris removal assets, security details, etc.), and help emergency managers integrate restoration support in their broader capabilities-based planning. The New York National Guard and other state guard organizations are already developing best practices in this regard in close collaboration with utilities. Analysis later in this chapter examines their initiatives to provide a basis for nationwide adaptation to local, state-specific circumstances and priorities.
12. Government Regulations and Policies:

In Sandy, state and Federal agencies quickly processed a variety of waivers to facilitate the cross-state movement of utility trucks and other mutual assistance. For the first time, utility trucks were classified as emergency responders, allowing them to go to the head of fuel lines, as well as expedited movement past toll booths and other potential impediments to rapid flow of resources. But Sandy also revealed numerous opportunities for additional regulatory relief, which will become urgent priorities when a more severe hazard strikes.\(^{14}\)

C. Transportation Support for Critical Grid Components: A unique support mission associated with transportation of transformers and related grid assets

Another realm of industry progress (and another opportunity for support from industry’s NGO and government partners) lies in efforts to prepare for replacement of transformers and other grid equipment damaged or destroyed in a black sky event. The Department of Homeland Security (DHS), with support from the electric utility industry and the Department of Energy (DOE), has been especially focused on the need to prepare for damage to extra-high voltage (EHV) transformers. The United States currently has 80,000 miles of EHV transmission lines that make up the backbone transmission grid and enables the long-haul transport of electricity. 90% of consumed power passes through these EHV lines and transformers at some point. Accordingly, DHS emphasizes that “If these transformers fail, especially in large numbers, therein lies a very big problem.”\(^{15}\)

\(^{14}\) DOE, Overview, p. 6-7, 9-11.

An especially efficient way to address this problem lies in strengthening the protection of EHV transformers and other critical grid components from damage. As noted in Chapter 2, high-impact, relatively low cost investments in protecting transformers against E-hazards can greatly reduce their vulnerability to EMP threats, and also help improve their protection against GMD effects consistent with the objectives of NERC’s Reliability Standard EOP-010-1.16 Improved protection of transformers against physical threats is also underway now that the Federal Energy Regulatory Commission has tentatively approved a rule requiring such measures under Notice of Proposed Rulemaking (RM14-15). In particular, the rule requires transmission owners and operators to provide protection for “critical” substations that house transformers and other grid equipment, and allows each utility to determine what substations are critical.17

Even after such protective measures are implemented, however, black sky events may still create the need to replace significant numbers of damaged transformers across multiple FEMA regions. For such a process to be successful, it requires an available pool of spare transformers, plans for rapid, need-based manufacturing of unique transformers, and for an effective means of transporting such transformers, once available. This replacement process may well take place over an extended period, given likely limitations in acquiring the

required replacement units, depending on the scope of the available transformer pool and the expanded development of programs designed to address this need (see below). However, given implementation of appropriate protective measures for high priority transformers, critical to operation of the bulk of the power grid, this replacement process could take place in parallel with broader power restoration across the affected region.

In this scenario, utilities may be able to prioritize and sequence their equipment replacement operations, and install replacement transformers based on where they will have the greatest benefit for re-energizing the grid and serving critical loads.\(^\text{18}\)

The existing Spare Transformer Equipment Program (STEP) program provides a foundation to scale up preparedness for replacement operations in black sky events, and ensure that an adequate inventory of spares is actually available when replacement transformers are most needed. Under the STEP program, each participating electric utility is required to maintain and, if necessary, acquire a specific number of transformers. STEP requires each participating utility to sell its spare transformers to any other participating utility that suffers a “triggering event,” defined as an act of terrorism that destroys or disables one or more substations and results in a declared state of emergency by the President of the United States.\(^\text{19}\)

While STEP, as currently configured is focused on terrorism, other equipment replacement programs can support restoration operations against a broader range of hazards. For example, the North American Electric Reliability Corporation (NERC) maintains a Spare Equipment Database (SED) that enables grid owners and operators to quickly locate available spare transformers from unaffected areas.\(^\text{20}\)

Initiatives are also underway to develop smaller, more easily moved transformers to restore service on an emergency basis. EHV transformers are huge, weighing hundreds of tons, making them difficult to transport – in

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18 NERC, “Severe Impact Resilience,” p.p. 81-84 and passim
19 Edison Electric Institute, “Spare Transformers” http://www.eei.org/issuesandpolicy/transmission/Pages/sparetransformers.aspx#sthash.pDPqilYs.dpuf
some cases specialized rail cars must be used (and there is a limited supply of these). DHS has also determined that many of the EHV transformers installed in the U.S. are approaching or exceeding the end of their design lifetimes (approximately 30-40 years), increasing their vulnerability to failure.\textsuperscript{21} To address these challenges for EHV transformer replacement operations, the development of emergency replacement EHV transformers has become a key priority.\textsuperscript{22} The Department of Homeland Security (DHS) has partnered with DOE and the private sector to develop a “recovery transformer” (RecX) to meet this requirement.

Thus far, however, progress has been slow in transitioning this project to commercialized, large-scale production of RecX. Accordingly, some leading utilities are now partnering with transformer companies to develop their own replacement transformers.

While utilities and their contractors have considerable expertise in moving replacement transformers and other equipment on a limited scale, especially for pre-planned replacements in “blue sky” environments, help is likely to be needed in the disrupted environment following a black sky event. Given this need, important partnership opportunities exist to assist the movement of EHV transformers or emergency replacement transformers and other equipment.

**Recommended Critical Grid Component Transportation Missions**

Given the critical role played by EHV transformers and other essential power grid assets, and the difficulties anticipated in transport for these components in a disrupted environment, transportation support can be a unique and important mission for power industry partners in addressing black sky hazards.

- **Defining the Hardware Transportation Support Mission:**

  Utilities should consider identifying the specialized transportation support missions they will find most helpful in a highly disrupted environment. This also represents an opportunity to plan, in advance, for a highly adaptable power restoration process. Such missions could


\textsuperscript{22} Ibid
focus not just on EHV transformers, but also on other unique, real time requirements. This could include, for example, urgent needs – discovered by power restoration crews – for transportation of unavailable spares, where transportation from available sources may involve long distance travel through an environment that may include unusual physical and security challenges.

- **Coordination with Industry Partners:**
  Based on the mission analysis, utilities could match the different missions with potential partners, and begin a sustained coordination process to ensure those partners will develop and maintain an ongoing capability that connects effectively to the appropriate corporate teams and locations. As this will involve different partners and different coordination points across the nation and for different corporations, a coordination framework provided by the EPRO Executive Steering Committee can help in providing such linkage, in coordination with other corporate and government organizations.

The Air National Guard can accelerate the transportation of vital power-restoration equipment and personnel [Source: U.S Air Force photo by Capt. Nicole Ashcroft. 11/3/12]
WHOLE COMMUNITY, ALL-HAZARD PREPAREDNESS STRATEGIES

For utilities to get the extensive assistance they will need in a black sky event, it is essential to both expand the roles of their traditional partners, and also bring additional government agencies, non-governmental organizations, and other partners into a broader and more integrated system for restoration support. Two foundational documents will be especially important in building and sustaining such a system: Presidential Policy Directive 8: National Preparedness, and the National Response Framework (NRF) provide a critical foundation on which to build and sustain such a system. The recommendations for specific partner roles that follow reflect the guidance in these documents. In addition, however, two principles that undergird the disaster response system will be especially valuable in creating a broader system for power restoration support: whole community and all-hazards preparedness.
A | Whole Community

As FEMA and state emergency management agencies have placed a growing priority on planning for disasters worse than Sandy, they have also recognized that reducing the impact of these events on public health and safety will require a whole community strategy. This strategy is designed to bring a far wider range of partners and capabilities to bear for disaster response, including individual citizens and their families, local, state, tribal, territorial and Federal governments, the private and nonprofit sectors, and civic and faith-based organizations.\(^23\)

One reason to adopt a whole community approach to power restoration is that in a black sky event, cascading failures of infrastructure will put communities and all their components at enormous risk. The failure of municipal water systems dependent on electricity would pose an especially urgent threat to individuals. Loss of municipal water services would, in turn, threaten the ability of many other services and facilities to function, including fire-fighting operations that could be essential in an earthquake-induced outage. Many government agencies and emergency operations centers critical for disaster response would also be at increasing risk. Moreover, while the disruption of water supplies would create an immediate threat to public safety and government services, the loss of power to hospitals, food and medical supply distribution centers, nursing homes, transportation systems, communications and other critical infrastructure sectors would also pose a whole community challenge.

But the whole community is also critical for *meeting* that challenge. The more potentially devastating the disaster, the greater the importance of whole community contributions to disaster response -- and power restoration represents a prime example. Years before Sandy struck the United States, FEMA Administrator Craig Fugate emphasized that “the scale and severity of disasters are growing and will likely pose systemic threats” to the nation. This increasing severity called into question the way that the United States had long been organized for disaster response. Fugate noted in 2011 that:

“Our nation's traditional approach to managing the risks associated with these disasters relies heavily on the government. However, today’s changing reality is affecting all levels of government in their efforts to improve our Nation’s resilience while grappling with the limitations of their capabilities. Even in small- and medium-sized disasters, which the government is generally effective at managing, significant access and service gaps still exist. In large-scale disasters or catastrophes, government resources and capabilities can be overwhelmed.”

In the aftermath of Sandy, FEMA and many state emergency management agencies have further intensified their focus on planning for catastrophic events that would place a special premium on the response capabilities of the private sector, non-governmental organizations, and individuals and families. Leveraging these efforts to support power restoration offers a prime opportunity to strengthen preparedness against black sky events.

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As noted in Chapter I, a wide range of natural and manmade hazards could create a black sky event with power outages affecting multiple FEMA regions for a month or more. Each of these hazards will create specific power restoration challenges. In the aftermath of a cyber or EMP attack, for example, specialized operations will be required that are very different from the restoration efforts required for earthquakes, kinetic attacks, or geomagnetic disturbances.

However, regardless of the particular black-sky hazard, utilities will confront many of the same fundamental challenges for restoring power. Meeting these challenges will require efforts to support industry that are not only quantitatively larger than performed in Sandy or any other previous event, but are also qualitatively different, entailing missions that have never before been adequately planned or exercised.

Robust, adaptable response planning is also enhanced by such broad planning. As one key example, if adversaries should attack the grid with a “combined arms attack,” some combination of cyber weapons, E-threats and kinetic weapons, perhaps even under the cover of a catastrophic natural event, all-hazard response planning would provide an effective foundation for the multi-dimensional response that would be needed.

Moreover, the foundational sources of Federal guidance for restoring electricity and managing the consequences of events themselves adopt an all-
hazards approach. Presidential Policy Directive (PPD) 8: National Preparedness provides the overarching guidance for strengthening the security and resilience of the United States, and calls for systematic preparation for the threats that pose the greatest risk to the security of the Nation regardless of hazard, including acts of terrorism, cyber-attacks, pandemics, and catastrophic natural disasters.\textsuperscript{26} The National Response Framework (NRF), which provides the overarching structure for responding to such events, is explicitly all-hazard. So, too, is Emergency Support Function 12 (Energy), which is structured to help industry and its partners re-establish damaged energy systems and components for incidents requiring a Federal response -- which a black sky day most assuredly would.\textsuperscript{27} All of the recommendations in this EPRO handbook are structured to align with and directly support PPD-8, the NRF, ESF-12 and other key Federal sources of guidance.


III | RECOMMENDED PARTNERSHIP INITIATIVES: INDIVIDUALS, FAMILIES AND COMMUNITIES

Individuals and their families and communities are not usually thought of as critical partners for power restoration. However, because black sky events will create extraordinary threats to public health and safety, and because government assistance will likely be slow to arrive in such a severely disrupted environment, it is vital to strengthen citizen preparedness for catastrophic events.

FEMA Administrator Fugate has provided clear guidance on why a whole community approach is so essential for severe events. He notes that:

“In the aftermath of every disaster, especially large-scale disasters, members of the general public often take initiative and perform a host of actions, such as search and rescue, first aid, firefighting, traffic control, reunification, radio communications, transport of the injured, and recovery of remains. Disaster survivors and bystanders are usually the first ones to act in an emergency. They can be action-oriented problem-solvers. In fact, they save more lives,
perform more rescues, and transport more injured than professional first responders. In addition, “digital humanitarians” mobilize via the Internet, social media, and other platforms to collect, analyze, and distribute information in support of incident response and recovery. The capacity of survivors and members of the public to act autonomously is a critical factor that is not adequately reflected in current disaster planning efforts. To address this gap, FEMA will lead efforts to identify and encourage the immediate, independent mass-response actions of survivors and others—both as individuals and as members of grassroots groups—including faith-based and community organizations, as well as groups that form organically in the aftermath of a disaster.\(^{28}\)

In Sandy, local emergency managers and community leaders developed a range of innovative ways to help families deal with power outages. For example, when storm-damaged meters prevent power companies from restoring electricity, they partnered with electricians in the community to repair those meters and accelerate power restoration to residences. More broadly, in the days before the storm hit, the Agency worked with threatened communities to develop incident response plans and to pre-position supplies to support response efforts. Immediately after the storm, FEMA coordinated Federal resources to assist Whole Community life-saving measures and stabilization efforts.\(^{29}\) Scaled-up planning for such measures will be essential for black sky events.

### A Specific Recommendations

#### 1. Communications and Citizen Resilience:

Efforts should also be expanded to strengthen citizen resilience against power outages and other consequences of black sky hazards, enabling citizens to be survivors rather than victims in a catastrophic power outage. As one important dimension, improvements in communicating the availability of

\(^{28}\) FEMA Strategic Plan, pg. 20-21

\(^{29}\) FEMA, Sandy After Action Report, p. 1
resources, restoration times and priorities, and community needs can be particularly important.

Without an accurate sense of when power would be restored, communities will be less able to plan effectively, encouraging individuals to take ad hoc measures that may create serious problems for the power restoration process, or emergency responders. In Sandy, the ability and willingness of utilities to share restoration information with stakeholders was uneven across companies, and citizens were sometimes unable to decide when and if they could return to their homes; governments could not adequately identify needs and match them with resources.\textsuperscript{30}

Communication requirements to facilitate citizen planning and resilience will be still more important in black sky events. The NERC study, \textit{Severe Impact Resilience} notes that in long duration, wide area outages, rotating blackouts and prioritized load shedding may be necessary for extended periods.\textsuperscript{31} Information sharing strategies and communications protocols should be established in anticipation of such events.

\section{Community-Based Emergency Power: Rethinking “Critical Loads”}

Of course, improved communications plans will be of no value to citizens if their cell phones, social media and other means of communication lack the power to operate. During Sandy, charging stations were deployed in New York City and elsewhere to facilitate citizen communications,\textsuperscript{32} and such stations may also be vital to power life-critical devices in an extended outage. Ramping up plans and capabilities for such charging stations will be essential for preparedness against black sky days, as will ensuring that cell towers and other critical communications nodes have adequate emergency power, and are included as priority targets for power restoration and damage repair.

\begin{flushright}
\textbf{Communication to facilitate citizen resilience will be important in black sky events.}
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\textbf{30} DOE, Overview of Sandy Response, p. 8
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Chapter Three: Whole Community Preparedness for Black Sky Events

More generally, to help enable individuals and families assist their neighbors in a black sky event and reduce the risk of mass, unplanned self-evacuations, additional consideration must be given to which loads will be most critical to achieve such whole community resilience beyond the municipal water systems, hospitals, emergency operations centers, and other facilities that typically fall into this category. These “community-critical” loads could then be assessed for prioritized emergency power generators and fuel.

3. Emergency Gas Station Operations:

Another problem that citizens encountered in Sandy was that the loss of electricity had made many gas stations inoperative – gas pumps require electric power. To help citizens evacuate as needed in a black sky event, and also to empower them (and official response organizations) to be able to provide aid to their neighbors during emergencies, another specific recommendation is to ensure/require that gas stations have backup generators so that they can pump fuel during power outages.

Florida, for example, requires motor fuel service stations near interstate highways or evacuation routes to have transfer switches and appropriate wiring to transfer the electrical load from a utility to an alternate generated power source in the event of a power failure. The same requirement exists for motor fuel terminals and wholesalers. Florida also requires corporations or entities with at least 10 service stations in a county to have access to at least one portable generator. As with Florida, Louisiana requires certain service stations to be wired with a transfer switch and capable of switching to an alternate generated power source in the event of a power outage. But Louisiana’s law applies only to new or completely rebuilt service stations in the southern portion of the state.

Now, in the aftermath of Sandy, New York, Connecticut and other states are also either adopting or exploring options to mandate or incentivize the installation of emergency power generators at gas stations. But these power

generators will begin to break down in long-duration outages. Accordingly, consideration should also be given to pre-identifying potential evacuation routes in a catastrophic event, so that gas stations along those routes would be prioritized for power restoration.

4. Broader Societal Resilience

While much of the foregoing analysis draws on U.S. disaster preparedness policies and programs, partner nations have important lessons learned that should be applied as well to whole community preparedness. The second edition of this Handbook will examine social aspects of black sky events, and provide a broader framework for identifying and advancing societal resilience drawn from the experience of Israel, the United Kingdom, and other nations.
NGOs play a critical role in managing the consequences of disasters, and will be essential to reducing threats to public health and safety in a black sky event. Under the National Response Framework, NGOs have vital responsibilities in disaster response, including sheltering, feeding operations, emergency first aid, bulk distribution of emergency items, collecting and providing information on victims to family members, and other operations as specified by Emergency Support Function #6 (Mass Care).

The work of the American Red Cross and other NGOs in Sandy exemplifies the importance of these organizations in disaster response. The American Red Cross is the Nation’s largest provider of mass care services and is a supporting agency for ESF #6. The organization was instrumental in Sandy response and recovery efforts. During its peak operations, on October 29, the American Red Cross sheltered 10,928 residents in 258 shelters, accounting for 70 percent...
of all open shelters. In addition, as of January 28, 2013, the organization had provided over 11 million meals and snacks to survivors. In total, the American Red Cross staffed relief operations with more than 15,800 disaster responders.

Similarly, the Salvation Army performed critical response and recovery efforts. Immediately following Sandy, the Salvation Army began to coordinate the delivery of essential services and resources—including meals, snacks, water, blankets, baby formula, toiletries, batteries, and flashlights—to survivors. The Salvation Army distributed more than 4.6 million meals, snacks, and drinks to Sandy survivors across multiple states. In total, more than 7,500 Salvation Army volunteers logged more than 24,000 hours of service. In addition, Southern Baptist Disaster Relief served almost two million meals and coordinated over 40,000 volunteer days of service, with myriad other NGOs making contributions as well.

Even more extensive NGO consequence management operations will be needed for black sky events. In addition, these organizations could provide enormously important support for power restoration in multiple-region events. Implementing initiatives to strengthen such support will require sustained whole community engagement by NGOs (in partnership with individuals and their families, all levels of government, partner NGOs, and industry). Supporting these implementation and sustainment efforts will also be a key focus of the EPRO Executive Steering Committee.

While certain NGOs in hurricane belt states have significant experience in the coordination and planning needed to feed and provide other assistance to power restoration crews in “conventional” hazards, many NGOs in other regions have not yet or have only recently begun to explore opportunities to provide such valuable support. And for black sky hazards, the planning requirements to provide such services will be different, and more complex, than for more familiar hazards.

But NGOs and other partners can only support power restoration if they themselves can function in a long-duration outage. Their ability to do so poses an enormous new challenge. The ability of NGO volunteers, law enforcement officers and other personnel to assist utility crews depends on transportation systems, communications networks, emergency operations centers and other facilities dependent upon electric power. When the grid goes down, many of the facilities providing these critical support functions have emergency power generators with sufficient fuel to operate for at least a few days. During wide-area outages that last substantially longer, however, generators will begin to break down and supplies of fuel for them will quickly fall short. And in an EMP event, unprotected generators and communication systems may be inoperable.

_In sum:_ disaster response and power restoration operations cannot be effectively supported and organized without extensive, cross-sector planning and training that address the unique needs of black sky hazards. Absent such collaborative efforts, operations to manage the consequences of a catastrophic outage will be jeopardized precisely when they are most needed

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**A | Specific Support Mission Options for NGOs and Their Partner Utilities**

1. **Leverage Mass Care Capabilities**
   Given the responsibilities and expertise of NGOS for ESF 6, Mass Care, they are especially well positioned to provide for the feeding, housing, and other needs of these crews for a black sky event. Again, pre-planning for these support missions – especially when many tens of thousands of restoration personnel will be operating far from their homes, and likely unable to acquire lifeline supplies locally – will be essential.

2. **Support for the Families of Restoration Crews**
   NGOs are also uniquely well positioned to support the families of deployed utility personnel, and thereby enable those personnel to stay on station for much longer than would otherwise be possible. NGOs should consider partnering with utilities to maintain Black-Sky hazard-secure data bases tailored to pre-identify support requirements, assistance protocols, and capabilities to be utilized.
3. Engineering and Other Specialized Support

Over time, some NGOs may be able to expand their volunteer workforce qualified to execute additional support missions for which specialized training and credentialing is essential. For example, NGOs may be able to utilize volunteer certified electricians who can certify that apartment towers, transportation system facilities, and other facilities damaged in an incident are ready to safely accept power. In Sandy and other response operations, Team Rubicon (which is led by military veterans) and other NGOs also employed volunteer staff with specialized engineering skills to support utility restoration operations.\(^{35}\)

4. Road Clearance, Debris Removal, and Other Operations to Facilitate Crew Access/Movement

The Southern Baptist Disaster Relief organization and many other NGOs have volunteers skilled in chain saw operations and missions that can help utility crews gain access to disabled equipment. However, a key finding from conducting such operations in Sandy is that NGOs need reliable access to fuel to conduct their support efforts, including propane and gasoline.

5. **Cross-Train for NIMS**

To facilitate support for power restoration support by NGOs, law enforcement agencies and other public safety organizations, a growing number of utilities are adopting National Incident Management System (NIMS) doctrine, protocol and procedures. A number of recent events (including the 2011 tornado outages in Alabama and other states served by the Tennessee Valley Authority) have highlighted the benefits of having utility crews and their NGO and their public sector collaborators cross-trained in NIMS. This is an emerging best practice for all NGOs and their utility partners to consider.

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**B | Strengthening NGO Continuity of Operations Effectiveness in a Black Sky Event**

As noted above, NGOs can only contribute to mass care and power restoration support if they themselves can survive in a black sky event. These organizations need to be able to sustain critical operations in a wide area, long duration outage that creates cascading failures of water, communications, transportation, and other infrastructure on which volunteers and their families depend.

One especially important requirement for maintaining continuity of operations is to have adequate emergency power. Section Seven examines the challenges of providing for emergency power in a severely disrupted environment, both for NGOs and state and local agencies that can assist power restoration. In addition to this requirement, however, NGOs will also encounter other challenges for operating a black sky event.

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Specific recommendations

1. Managing Untrained Volunteers
   Prepare for an influx of spontaneous, untrained volunteers. In a Black Sky event, NGOs may be flooded with spontaneous volunteers. If NGOs can incorporate them into the execution of basic functions for which specialized training is not required, doing so can free up trained volunteers to execute more specialized support tasks.

2. Coordinating Staging And Shelter Locations
   Pre-coordinate with utilities in selecting NGO logistics hubs and shelter locations. Ad-hoc sheltering will undoubtedly happen in the area of impact, but shelter location choices should be made with infrastructure needs (especially power) taken into consideration, so that they are located to facilitate resupply and prioritized power restoration.

3. Supply Pre-Staging At Houses Of Worship
   Consider the use of Houses of Worship for pre-staging of supplies and points of distribution. NGOs may wish to consider planning in advance for the disruption of food distribution and other mass care supplies in a black sky event, and develop options to use churches, synagogues, and other houses of worship to support assistance operations for utility crews and the general public. Again, if this option appears viable, specific locations should be selected with regard to ease of logistical resupply and prioritized power restoration.

4. Define NGO Support Requirements
   In a black sky operating environment, NGOs may only be able to function if they have assistance from other partners above and beyond what might be necessary in more familiar disaster response operations. For example, food transportation and distribution operations may need additional security provided by law enforcement or National Guard personnel. Partners should identify these black sky support requirements and reach out to sources of assistance to meet them.
STATE AND LOCAL AGENCIES: RECOMMENDED SUPPORT REQUIREMENTS

Unprecedented opportunities exist for expanded state and local government support to utilities. A growing number of governors, state directors of emergency management, and National Guard leaders are pioneering initiatives with their local utilities to clarify support missions for worse-than-Sandy events and integrate them with their core disaster response plans. However, these emerging best practices are not being shared in a sustained, cross-sector, multi-partner dialog that will be essential for strengthening power restoration for black sky outages.

Emergency managers in Florida, Georgia and other states in the hurricane belt have long built power restoration for severe weather events into the core of their disaster response plans and exercises. In response to Sandy, New York and other states struck by the storm are rapidly doing the same. In too many other states and localities, however, the historic divide between power restoration and “traditional” disaster response management and planning endures today, and
in states already addressing the issue, emerging black sky hazards will mandate new dimensions in response planning.

Until these dimensions are added and other states and localities make power restoration an important aspect of disaster response planning, the United States will miss key opportunities to build broader and more effective whole community partnership to support power restoration. The recommendations that follow capture some especially valuable state-level initiatives and propose ways they could be scaled up to help accelerate restoration in black sky events. Again, supporting these implementation and sustainment efforts will also be a key focus of the EPRO Executive Steering Committee.

Planning for state and local support for power restoration and consequence management must also account for the environment in which such operations would need to go forward. Sandy illuminated the degree to which these decisions by the Governor will be made in a white-hot political environment. A catastrophic power outage will represent a severe political crisis for every elected official in the affected region. Federal, state and local leaders will create urgent and incessant demands for information on how quickly power will be restored (“Estimated Time of Restoration”). They will also be extraordinarily concerned with the allocation of scarce resources and will likely attempt to influence such decisions. Moreover, black sky hazards may jeopardize the functioning of the communications and other infrastructure on which governors and local leaders depend.

Specific recommendations to meet these challenges fall into two categories: options for state and local governments as a whole, and specialized power restoration support opportunities for the National Guard.
A | State and Local Governments

1. Situational Awareness

In most states, a black sky event will immediately overwhelm the ability of local first responders and their NGO partners to manage the consequences of the event. For governors to guide the operations to support them with state response assets, as well as to request Federal aid and support from other states (under the Emergency Management Assistance Compact system), they will need the ability to gather and integrate data on emerging response requirements and other situational information. These situational awareness systems will also need the ability to function in a long duration, wide area power outage. Specific options to meet these challenges:

a. State and Local Fusion Centers: Consider using DHS-funded State and local fusion centers to support shared industry-government situational awareness and coordinated action. A number of States are exploring the use of DHS-funded State Fusion Centers to support critical infrastructure and emergency response operations, and are strengthening the ability of utilities to participate and feed data into these centers. A recent report by the Majority Staff of the House Committee on Homeland Security Report on Fusion Centers, noted that an increasing number of fusion centers are including Critical Infrastructure and emergency response operations within their information sharing priorities.37 During Hurricane Sandy, New Jersey’s Regional Operations Intelligence Center (ROIC) conducted preliminary damage assessments at critical infrastructure sites and facilities. Other states are now building on that model and are including support for power restorations as a new role for fusion center information sharing with industry. State Guard efforts are also underway to build a common operating picture to support disaster response operations (including critical infrastructure restoration) that

The E-Pro™ Handbook will be interoperable with FEMA, NORTHCOM and NGB common operating pictures (COPs).

Tangled power lines represent the confusion that can arise from a lack of situational awareness [Source: McKay Savage, 7/20/08]

b. Fusion Center Roles: It is important to note, however, that the role of fusion centers varies significantly between the 72 that are federally certified. Some work with other government agencies and the private sector, some do not. The information they possess is most effective for the establishment of the “baseline” of critical infrastructure/key resources (CI/KR). Populating that regional/national COP with the information they have is vital but the real time management of the COP is unlikely to fit into their mission scope (especially because most are not in constant operation).

c. Leverage New Common Operating Picture (COP) Technology. State National Guard organizations and their State and Federal partners are also developing geospatially-based common operating pictures that can display the disposition of disaster response forces and damage to bridges and other critical infrastructure essential for power restoration. Such efforts to improve situational awareness for Governors will have especially strong benefits if they integrate data from utilities and other critical infrastructure owners and operators who are able to provide for consistent messaging on restoration timelines.

d. Regional Situational Awareness. For cooperation across state lines, a key finding of the Capstone 14 New Madrid exercise is that
multi-state, public/private situational awareness will be essential in catastrophic events. The standardization of data sharing (what data is needed and how it should be formatted) is essential to simplify and maximize access to information, and make it “digestible” to more incident management and geospatial platforms. To provide for power restoration support, it will be especially important for utilities and their partner organizations to determine what information should be shared, above and beyond typical data on customer outages.

2. Embed Utility Representative In State And Local Emergency Operations Centers (EOCs)

In Florida, California, and a growing number of other states, EOCs have at least one seat designated for representatives of the electric industry so that those representatives can prioritize requests for assistance, help emergency managers oversee response and restoration operations, and provide reach-back to industry on timelines and restoration bottlenecks. In other states, including Illinois, utilities have established a system of regional command centers that are co-located with public safety emergency operations centers. This improves coordination and reduces the need for redundant lines of communication during response operations.

3. Integrate Black Sky Hazard Power Restoration into New State Plans for Responding to Catastrophes

FEMA is partnering with State emergency management and homeland security leaders across the nation to build plans for catastrophic events, many of which focus on the specific hazards in that State that pose the greatest risk -- that is, 1) hazards that are most likely to strike; 2) hazards to which the State is especially vulnerable; and 3) hazards that would have the most devastating consequences should an event occur.

California has three such plans for region-specific hazards from South to North: the Southern California Catastrophic Earthquake Response Plan, the Bay Area Readiness Response Plan, and the Cascadia Earthquake and Tsunami Response Plan. Hawaii, Florida, and many other States are also building hazard-specific plans for events more destructive than they have ever before experienced. These plans vary widely in the degree to which they include
power restoration as a major area of focus, and the extent to which emergency managers have included utility perspectives on support requirements. Such integrated planning should become the norm. As part of an expanded planning process, focused, black-sky hazard compatible planning will be an essential supplement to an area already beginning to receive increasing attention.

Inside a FEMA MERS Vehicle in Iowa. Mobile command centers such as this one allow the cross-sector coordination needed to plan and respond to severe outages [Source: FEMA/Barry Bahler, 6/18/08]


   Every Governor and mayor or other elected local leader should review the adequacy of their emergency generators and stored, on-site fuel at their Emergency Operations Centers, relocation facilities, and other critical sites and operational capabilities, for operation in each of the black sky hazard categories. These facilities are typically well prepared for relatively short outages. However, for outages lasting more than a month, where re-supply of emergency fuel from commercial sources will be problematic and normal lifeline support for key personnel and their families will be unavailable, their ability to function and support gubernatorial decision making will be at risk. States should consider storing additional fuel and backup generators and taking additional mitigation measures to manage this risk. Communications to support leadership decision-making also need to be made survivable for long duration outages, with adequate emergency power for cross-sector communications with utilities, NGOs and other key partners to support emergency operations centers.
State National Guard Initiatives and Recommendations

Across the United States, National Guard organizations are launching initiatives to scale up support for their governors in consequence management and power restoration operations. In New York, New Jersey and other States struck by Sandy, as well as Florida and other States in the hurricane belt with ample experience in power restoration support, major advances are underway to identify and prepare for the high priority roles that the Guard would play in a catastrophic power outage.

All of these efforts involve industry as a key partner. Indeed, as other States explore similar initiatives and leverage emerging best practices, it is essential that utilities be part of the process to identify the support missions that will be most important for the Guard to provide. Some of these support missions are well understood and frequently exercised in hurricane states. Road clearance, security/public safety operations, and the provision of State National Guard military installations to serve as staging bases for utility crews proved especially important in Sandy. Other potential support missions, including many of those that would be most important in a black sky event, are only beginning to be addressed.

Specific recommendations

a. Expand collaborative planning and pre-event coordination for power restoration support. A number of utilities and State National Guard organizations are developing much deeper partnership arrangements than have existed in the past, in part to account for the risk of increasingly destructive storms and other hazards. The Florida National Guard and the Florida Power & Light Company (FPL), for example, have recently agreed to greatly expand the Guard’s logistics and operational support for FPL’s power restoration operations.38

The New York Military Force (NYMF) has applied these planning and preparedness initiatives to a multi-utility framework. Prompted in part by the Moreland Commission on Utility Storm Preparation and Response, which recommended that “the state military’s role be expanded in future responses to augment power company efforts to expedite the restoration of electric power,” Governor Andrew Cuomo directed the NYMF to partner with the utility industry in examining how power restoration support operations can be improved.39

The resulting Power Restoration Working Group includes representatives from the New York State (NYS) Division of Homeland Security and Emergency Services, the NYS Public Services Commission, the NYS Division of Military and Naval Affairs, and the six electric power companies that service New York State (Long Island Power Authority, Consolidated Edison, Central Hudson Gas and Electric, National Grid, New York State Electric and Gas, and Rochester Gas and Electric). Other states and their utilities should consider adapting this model to build consensus on the specific, practical support missions of greatest value for accelerated restoration.

b. Account for emerging budget and force structure challenges. A number of Guard leaders indicate that their ability to provide engineering support will decline due to staffing and budgetary pressures. Many National Guard organizations are reducing the number of personnel

on their rosters who are capable of conducting civil engineering and infrastructure support missions on Guard installations, in favor of contracting out those requirements to the private sector. Their shift to outsourcing will leave fewer engineering-qualified personnel available for National Guard support to utilities. This trend will likely accelerate as Army National Guard budgets continue to fall and economic incentives for outsourcing grow. Accordingly, states and their utility partners should examine how to shift their focus towards missions that can be executed by general purpose forces who lack specialized power restoration training.

![Air Guard coordination allows rapid transportation of mobile generators using C-5 aircraft](Source: Capt. Nicole Ashcroft/U.S. Air Force Photo. 11/3/12)

- **c. Concentrate on missions that General Purpose Forces can perform.** There is an enormous advantage in having National Guard personnel perform road clearance, debris removal, and other support missions, instead of having highly skilled utility crews perform those missions. Doing so frees the latter crews to execute more technically demanding restoration tasks. General Purpose Force missions also require little additional training beyond what those forces already receive for their primary Guard function. Some supplementary training will be necessary (most notably, personal protection/safety training to be able to operate in the vicinity of downed power lines).

- **d. A key focus for industry-Guard collaboration should be to specify what supplementary training will be required for each general purpose force mission.** Consensus-building is also needed to determine how
and where utilities can help conduct such training on a just-in-time basis for military police, traffic control, transportation and logistical support for points of distribution (PODs) for food and materials essential to sustain disaster response and power restoration operations. As industry prioritizes these Guard missions, utilities and NGOs should also partner with the Guard to crosswalk the associated troop tasks and their training requirements with Military Occupational Specialty codes (MOS), which are used by the military to identify specific jobs that personnel are qualified to perform. Doing so will help institutionalize and facilitate power restoration as a core mission for defense support to civil authorities, and help power restoration compete against other demands on training funds and mission priorities.

Virginia National Guard Vehicles on the move. Easing the cross-state movement of assistance vehicles is vital to an effective response. [Source: Sgt. 1st Class A.J. Coyne/National Guard. October 29th, 2012]

e. **Share and leverage emerging best practices.** More needs to be done to share the advanced plans and support mechanisms that are already in place between the National Guard and local utilities, both in states such as Florida (where frequent hurricanes have helped prompt the development of such plans) but also in states drawing upon lessons learned from Sandy. The Adjutant Generals Association of the United States (AGAUS) provides a potentially valuable forum for multi-state discussion and consensus building by Guard leaders. The National Guard Bureau, the Governors Homeland Security and Advisory Council, and the EPRO Executive Steering Committee could also help sustain and expand this dialog on emerging best practices.
VI | REGIONAL, FEDERAL, AND NATIONWIDE INITIATIVES

At the Federal level, the drafting of the Power Outage Incident Annex (POIA) by the Federal Emergency Management Agency (FEMA) and the Department of Energy (DOE) will provide an especially valuable opportunity to advance restoration support planning. Many of the recommendations that follow are structured to help support the POIA drafting process.

Two additional planning efforts are underway that also provide vehicles for progress. FEMA and its state and Federal partners are building “Regional Playbooks” that are focused on the catastrophic hazards that pose especially severe risks to those regions. The Department of Defense (DOD) has launched a Complex Catastrophe initiative to help better prepare the Department to support civil authorities in events worse than Sandy, which could -- in theory -- help effectively respond to requests for assistance for power restoration. In practice, however, these plans will never achieve their full value unless industry and NGO perspectives and priorities can be incorporated into the planning process in ways that do not yet exist. Options to do so provide a key focus of this chapter.
Even the most refined plans will prove of limited value unless they are exercised. Given the wide array of partners that can help utilities accelerate power restoration, exercises will be essential to build unity of effort among them, so that organizations with separate leadership and command arrangements can function seamlessly within the architecture of the National Incident Management System.

Federal, state and local plans will also fall short unless they provide the basis for sustained engagement with industry, NGOs and other key partners in power restoration. Ongoing “whole community” dialog and collaboration between Federal agencies and their partners will be essential in order to build unity of effort across a diverse array of contributors to power restoration. Sustained dialog will also be critical to share emerging best practices. The EPRO Executive Steering Committee will facilitate that dialog and support the implementation of the specific proposals below.

**Recommendations**

1. **Leverage the Emergency Management Assistance Compact (EMAC) System for Integrated Consequence Management and Power Restoration Operations**

   For decades, Governors, State emergency managers and the National Guard have used EMAC to facilitate the flow of consequence management assets across State lines. Participants in the EMAC system, including the National Association of Emergency Managers (NEMA) that oversees its governance, are now partnering with industry for the first time to examine how the system can be brought into more effective alignment with the mutual assistance agreements used by utilities. Sandy demonstrated the enormous value of the EMAC system for power restoration but also illustrated opportunities for improvement. New York’s Moreland Commission Report on Utility Storm Preparation and Response found that the “mutual assistance system needs reform,” and cited a number of problems that will be important to resolve for wide-area power outages in the future.40 Some of them involved RMAG-specific

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issues, including problems in moving capabilities and crews between RMAGs for national-level events. Other problems reflect the Guard’s reliance on the EMAC system and provide important topics for industry engagement, especially for ensuring that the EMAC system evolves in a way that is compatible with and supportive of industry’s development of mutual assistance arrangements for national response events.

Specific recommendation: Supplement EMAC Planning. Emergency managers should partner with utilities so that as industry builds out its mutual support system for National Response Events, the movement of National Guard forces and other assets to assist nationwide restoration operations under EMAC can be optimized accordingly.

2. Emergency Support Function 12: Scaling Up for Black Sky Hazards

FEMA, DOE, DOD and other Federal Departments performed remarkably well in supporting power restoration in Sandy under ESF-12, given the relative weakness of plans and coordinating mechanisms in place to provide for many of the support missions that they ultimately executed (such as the unprecedented cross-country delivery of utility trucks by DOD C-5 transport aircraft).

Nevertheless, after action reports by many of these agencies highlight the need for further improvement. FEMA’s report is especially valuable in this regard. FEMA notes that the Agency and its Federal partners “…looked to ESF #12 (Energy)—coordinated by the U.S. Department of Energy (DOE)—to coordinate Federal efforts related to energy restoration.” ESF-12 operations led by DOE fell short, however. According to FEMA: “DOE struggled to meet this requirement and lacked the operational capability to fully engage supporting Federal departments and energy-sector partners in addressing energy-restoration challenges. To focus additional attention on these needs, the President directed DOE and FEMA to establish an Energy Restoration Task Force to increase Federal, state, local, and private sector coordination on power and fuel restoration. The Task Force achieved its objectives. However, Federal partners acknowledge that ESF #12 should have inherent capacity to coordinate
across the full spectrum of relevant public-and private sector partners.”

DOE and its Federal partners are now acting on these lessons learned and are making far-reaching improvements to the ESF-12 system. These improvements must scale up to not only enable the Federal government and its partners to more effectively support industry in future Sandy-scale events, but also much more severe outages. Indeed, a key finding of FEMA’s Hurricane Sandy After-Action Report is that “FEMA must prepare for incidents that are larger and more complex.”

Specific recommendations to do so:

a. Restoration planning and capability requirements

ESF 12 is structured to assist “local, state, tribal, territorial and insular area governments with requests for energy-related emergency response actions.” A multi-state, long duration power outage will likely create massive requests from civil authorities for emergency power and power restoration assistance for critical assets and key resources within their jurisdictions, outstripping Federal capacities to provide such support.

DOE should continue to work with States and their utilities to develop a clearer definition of the Requests for Assistance (RFAs) that are likely to emerge in a catastrophic outage.

Once likely RFAs have been identified, DOE and its Federal partners (including FEMA, the Department of Homeland Security, the Department of Transportation, the Department of Defense, and DoD components such as the US Army Corps of Engineers and the

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42 FEMA, Sandy After Action Report, p. 5
Defense Logistics Agency) should assess the adequacy of current response and restoration plans and capabilities. These Departments and Agencies should also help DOE develop plans to fill the gaps that remain, and clarify principles to help prioritize the allocation of Federal support when available resources fall short of requests for assistance.

b. **ESF Operations in a Catastrophic Outage**

The Department of Energy should continue to work with its partners to clarify the roles of its Energy Response Organization, and provide for effective integration of ESF-12 functions within the broader, FEMA-led system for Federal disaster response. That planning should encompass not only traditional contributors to power restoration, but also NGOs and other “whole community” partners.

The Department should also examine how DOE Regional Coordinators could coordinate with FEMA’s Regional leadership for planning and preparedness, and to provide support in restoration operations.

In addition, DOE should continue to examine how State Energy Assurance Plans and the National Association of State Energy Officials (NASEO) can be leveraged to strengthen resilience against catastrophic outages.

c. **Authorities**

In a catastrophic outage, the Defense Production Act (DPA) and other statutory and regulatory sources of authority might facilitate power restoration assistance in novel and especially useful ways. DOE and its partners should determine how these existing authorities might be leveraged for large-scale restoration support, and identify shortfalls that may require legislative or regulatory action.

d. **Federal to Federal Assistance**

In Sandy, no significant requests were made by Federal Departments/ Agencies (D/As) for emergency power and restoration assistance for defense critical infrastructure or other critical Federal facilities and missions. A multi-state, long duration outage will likely create such RFAs, including for homeland and national security-related facilities.
DOE should explore with its Federal partners how such RFAs should be met in a prioritized fashion and in partnership with industry.

Collaboration between the US Coast Guard and FEMA ensure that assistance can get to where it is needed most [Source: Mark Wolfe/FEMA. 8/15/07]

3. Integrating Power Restoration into FEMA Regional Playbooks and National Planning Scenarios

A new opportunity is emerging to better integrate regional planning for consequence management and power restoration against black sky hazards.

The Federal Emergency Management Agency and its State and Federal partners, including State National Guard organizations and the Department of Defense’s U.S. Northern Command (NORTHCOM), are developing “playbooks” to help plan for catastrophic events in each of the 10 FEMA regions in the United States. Each playbook will be based on a specific scenario of special concern to the region in question. In FEMA Region IX in the Western United States, for example, the playbook scenario will be based on a severe earthquake and “massive power outage” occurring in Southern California. All these scenarios, whether they involve manmade or natural hazards, would entail severe damage to electric grid infrastructure and functionality.

FEMA and its partners are developing playbooks for the other FEMA Regions as well. Likely scenarios to shape the playbook effort in the other FEMA Regions:

- Region II: Improvised Nuclear Device (IND) in New York City
- Region III: IND in the NCR and a Category 5 hurricane in Norfolk/
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Tidewater Region, VA

- Regions IV, V, VI, and VII: New Madrid Seismic Zone Earthquake
- Region IX: Southern CA Earthquake
- Regions IX and X: NW Cascadia Subduction Zone Earthquake
- Region X: Alaska Earthquake

Specific Recommendation: FEMA and its partners should bring industry and NGOs into the development of these playbooks, for each of the potential black sky hazards, to provide essential input on defense power restoration support requirements, plans and operational protocols. In that regard, it will be important to ensure that playbooks addressing each of the black sky hazards are developed.

The FEMA National Planning Scenarios are a set of 15 disaster scenarios provided to assist in contingency planning for all levels of government and the private sector. The current 15 scenarios are:

- **Nuclear Detonation** – 10-kiloton Improvised Nuclear Device
- **Biological Attack** – Aerosol Anthrax
- **Biological Disease** Outbreak – Pandemic Influenza
- **Biological Attack** – Plague
- **Chemical Attack** – Blister Agent
- **Chemical Attack** – Toxic Industrial Chemicals
- **Chemical Attack** – Nerve Agent
- **Chemical Attack** – Chlorine Tank Explosion
- **Natural Disaster** – Major Earthquake
- **Natural Disaster** – Major Hurricane
- **Radiological Attack** – Radiological Dispersal Devices
- **Explosives Attack** – Bombing Using Improvised Explosive Device
- **Biological Attack** – Food Contamination
- **Biological Attack** – Foreign Animal Disease (Foot and Mouth Disease)
- **Cyber Attack**

Specific Recommendation: FEMA should update the National Planning Scenarios to include two additional black sky hazards that can cause multi-region, extended power outages: 1) Coordinated physical assaults on the power grid (perhaps as a supplement to the existing Explosives
Attack planning scenario); and 2) Electromagnetic threats (EMP and GMD).

4. DOD support for Staging Utility Crews

During Superstorm Sandy, Department of Defense (DoD) facilities provided much-needed staging and billeting areas for utility trucks and crews, over and above the bases provided by State National Guard organizations. Utilities will need staging support on a much greater scale in a black sky event. However, a number of gaps exist in DoD preparedness to provide for such expanded support -- gaps that can only be filled through collaboration between Defense installations, utilities, and other key partners for power restoration.

The most important gap is that of joint planning for long duration, wide area outages. A growing number of base commanders have established collaborative relationship with local utilities to strengthen the reliability of electric service to their installations, and – in some cases – to provide for emergency power to critical loads on base if a wide area blackout occurs. Advance planning tends to be much weaker for defense support to utilities. And few base commanders have envisioned providing logistical support for NGO operations, which will be critical to power restoration in black sky events.

Specific Recommendations

a. DOD and its Federal lead partners for ESF-12 should collaborate with utilities and NGOs on both a state-specific, regional and nationwide basis to build such plans in anticipation of black sky events, utilizing Defense installations wherever possible as staging and logistical support areas to support power restoration operations.
b. DoD and installation commanders should participate in a multi-sector, sustained coordination processes, to assure useable, common emergency communication protocols and sustained, updated black sky-survivable and usable contact databases with utilities, state and local government agencies and NGOs.

c. DOD should develop and participate in multi-sector exercises that include black sky power restoration operations as a primary focus to build expertise and identify gaps in plans and capabilities.

5. **Leveraging the Department of Defense's Complex Catastrophe Initiative**

The Department of Defense has defined a “complex catastrophe” as “any natural or man-made incident, including cyberspace attack, power grid failure and terrorism, which results in cascading failures of multiple, interdependent, critical, life sustaining infrastructure sectors and causes extraordinary levels of mass casualties, damage, or disruption severely affecting the population, environment, economy, public health, national morale, response efforts, and/or government functions.” The inclusion of power grid failure provides an ideal basis to advance industry-DOD preparedness for black sky power restoration.

DOD’s complex catastrophe initiative has only begun to focus on how DOD military capabilities (separate from State National Guard forces) can be brought to support civil authorities for power restoration operations, in ways that utilities will find most essential.
Specific Recommendation: DOD should collaborate with industry and Federal and State partners to ensure that restoration becomes a key focus of the Complex Catastrophe initiative. That focus should encompass both traditional types of DOD restoration support (including installations for staging utility crews), and the novel missions executed during Sandy, including air transportation of utility trucks and the very large-scale provision of emergency fuel and generators for energy-related facilities and communications nodes.
Chapter Three: Whole Community Preparedness for Black Sky Events

VII | EMERGENCY POWER: IMPLICATIONS FOR PARTNERS AND UTILITY SUPPORT OPERATIONS

The requirements for emergency power support created by Superstorm Sandy caught the Defense Department and other Federal Departments and agencies by surprise. Senior DoD leaders had never anticipated that civilian authorities would make such massive requests for generator and fuel assistance. Now, as DoD and its Federal partners continue to assess and act upon lessons learned from Sandy, utilities have a range of promising options to engage with the Defense Department and make that adaptation process more effective. These collaborative opportunities are especially significant for strengthening coordination and providing emergency support for utility operations, and for meeting broader emergency power requirements, including those for nuclear power plants, chemical facilities, hospitals, and other priority loads.
Black sky outages will create unprecedented demands for emergency power between the outset of the event and restoration. Defense support for emergency power would be especially necessary in two categories: 1) emergency generators; and 2) fuel for those generators and for the vehicles necessary to support power restoration and disaster response operations.

A | Emergency Generators

A growing number of police headquarters, emergency operations centers, hospitals, and other critical facilities have their own emergency power generators. The ability of these generators to sustain life-saving and life-sustaining operations will be essential in a black sky event. Yet, even in the comparatively short-duration outage created by Superstorm Sandy, a number of problems emerged for emergency power generation that a longer, wide-area blackout would exacerbate. Anticipating and planning in advance to meet these challenges will play a critical role in overall preparedness for black sky hazards, with significant implications for the ability of partners to support power restoration and manage the consequences of the event.

One challenge is that the longer an outage lasts, the greater the number of emergency generators that break down in hospitals and other lifeline infrastructure facilities. Only days after the Sandy blackout began, generators at New York University’s Langone Medical Center stopped functioning, as did the fuel pumps for backup generators at Bellevue Hospital. Breakdowns rapidly increased as emergency generators began to operate longer than they were designed to function (especially in cases where they had been poorly maintained). In longer duration outages, such breakdowns will become ubiquitous and will create enormous demand for the installation of replacement generators.


Another challenge illuminated by Sandy is that during a severe event, requirements for emergency power emerge from facilities that are not typically considered “critical” and lack generators. Outpatient healthcare facilities offer a prime example of how often-overlooked structural changes in lifeline infrastructure sectors create growing needs for backup power in an outage. Increasingly, dialysis and other crucial services are provided in small, widely distributed facilities, as opposed to being centralized in hospitals. Many of these small facilities lack adequate emergency power. The same is true of high rise apartments and nursing homes, all of which created unanticipated demands for the installation of emergency generators during Sandy.  

Moreover, energy facilities that may not be considered especially important in a “blue sky” environment can become far more critical in a crisis, and create urgent requirements to install new generators or replace ones that have broken down during an event. The Kinder-Morgan fuel terminal in New Jersey provides a case in point. When other components of the New York/New Jersey area fuel storage and distribution system shut down during Sandy, including the Colonial pipeline, providing emergency power to the Kinder Morgan terminal suddenly became vital for the entire region. The U.S. Army Corps of Engineers scrambled to purpose-build and install a generator at that Terminal as a priority over other, previously-approved installation mission assignments. Unexpected points of criticality and emergency power requirements are bound to emerge in a black sky environment, both within the energy sector and in nodes of cross-sector interdependency.

In contrast, the need for nuclear power plants to have reliable emergency power for long duration outages is a well-understood requirement, especially


after the Fukushima disaster. The earthquake and tsunami at Fukushima disabled both external and internal electrical power systems, leaving the plants with only a few hours’ worth of battery power. Nuclear power plants need electrical power to keep their reactor cores and spent fuel pools cool. Accordingly, this loss of internal and external power—known as a station blackout (SBO)—presented a significant challenge to workers at Fukushima. The Nuclear Regulatory Commission and the nuclear power industry have taken a broad range of measures to apply lessons learned from Fukushima and ensure the availability of adequate emergency power in a long-duration outage.  

Other facilities besides nuclear power plants could present significant threats to public health and safety if their emergency power supplies prove inadequate during an outage. For example, chemical facilities with potentially hazardous materials that need cooling to be kept safe must be prepared for long duration outages. This requires not only generators, but also a reliable source of replacements as breakdowns occur through extended operation. Little research exists on the degree to which the chemical industry has met this requirement, much less on the potential region or multi-region requirements that a black sky event could create for the installation of emergency generators.

The U.S. Army Corps of Engineers (USACE) will play a critical role in conducting such replacement efforts. USACE is the Federal lead for Temporary Power under the National Response Framework, and is also Federal coordinator for Emergency Support Function 3, Public Works and Engineering. Within these responsibilities, USACE coordinates with FEMA and DOE before events occur to assess emergency power requirements for key facilities and plan for support operations, and to provide for emergency power when an event occurs.

USACE performed with great effectiveness in replacing generators during Sandy. However, FEMA and DoD officials had to scramble to sort out competing requests for assistance (RFAs) for replacement generators from industry and state and local government officials. A black sky event would create a much larger gap between demands for replacement generators and available supplies.

No remotely adequate system exists to prioritize the allocation of these scarce assets in a catastrophe.

Transportation and logistic support for replacement operations could also prove challenging. In a New Madrid, Cascadia Fault, or other seismic event, the restriction of roads, bridges and rail lines could significantly impede the flow of replacement generators. Finding enough certified electricians who can safely and effectively hook up generators, and maintain them once they are installed, would also be problematic. Breakdowns are relatively frequent; simple “drop-off” of these emergency assets is not sufficient to ensure adequate emergency power.

**Recommendations to build a more effective system for emergency power**

*Identify and Prioritize Emergency Generator Requirements.* No systematic, nationwide assessment has ever been made of critical emergency generator requirements. Government and industry should partner to launch such an effort, and begin planning to fill the gaps that are identified. One such gap is in determining the amount of emergency power required. In many instances partial power is sufficient to meet immediate needs and that assessment needs to be done internally by the requestors. FEMA and USACE have recently developed an Emergency Power-Facility Assessment tool to gather critical generator power requirements data prior to disasters. Until now, however, USACE leaders have had limited opportunities to engage with industry on emergency power priorities, including those associated with supporting grid restoration (i.e., providing generators to enable the flow of natural gas to power generators). This requirements assessment process needs go forward with broad, cross-sector participation.
Improve the Request for Assistance (RFA) process. Before a black sky event occurs, it is critical to reach consensus on the criteria to prioritize the allocation of emergency generators, and to begin building state and FEMA Region plans to conduct Defense emergency power support on that basis.

B | Emergency Fuel: Resilience and allocation challenges

Sandy highlighted the degree to which emergency operations of all kinds depend on the availability of fuel, and the risk that a storm or other event will disrupt the infrastructure essential for providing that fuel. During Sandy, DOD’s Defense Logistics Agency (DLA) helped overcome the breakdown of fuel infrastructure by providing over 9 million gallons of urgently-needed diesel and gasoline for ambulances, police cars, and other vehicles over a two week period. In a black sky outage, requirements for fuel support would multiply accordingly.

Demand would be especially intense for fuel for backup generators. Backup generators at many critical infrastructure facilities often have only enough fuel stored on-site to operate for hours or a few days. If an electric outage lasts longer than on-site fuel can power the generator, facilities will rely on commercial contractors to deliver new supplies. This resupply system will break down in a black sky event. Demand for generator fuel will quickly outstrip supply, as many hundreds of facilities in a typical state request additional fuel and as pipeline system breakdowns interrupt the flow of fuel to local depots. Depending on the nature of the black sky event, there may be a range of other concerns as well. For example, in a severe earthquake scenario, the roads and bridges that commercial providers require to conduct resupply operations will also be severely disrupted.

There are no state, FEMA Region, or nationwide plans to prioritize the allocation of limited DLA fuel supplies and delivery capabilities (both of which are largely contractor-provided). Nor are there agreed-upon criteria on which to base such plans, or any assessment of what total fuel requirements might be. Significant opportunities exist for industry and NGOs to collaborate with DoD and its lead interagency partners to address these shortfalls. Recommendations to improve the availability and allocation of fuel in black sky events:
Recommendation

Engage with and support DOE liquid fuel initiatives, and prioritize advance planning for emergency fuel stockpiles distribution. Drawing on lessons learned from Sandy, the Department of Energy has a range of efforts underway to gain better situational awareness of fuel distribution issues in major events, to stockpile fuel assets for emergencies, and to provide for their more effective distribution. This engagement should ensure that especially long-duration, wide area outages, fuel requirements are treated as a priority for future planning. As part of this effort, the entire emergency fuel supply-line process should be reviewed to assure it would remain viable in the aftermath of each of the black sky hazard events discussed earlier in this handbook. With FEMA and DOE as lead federal partners, consideration should also be given to engaging with DLA to help assure the availability of emergency fuel.

Out of Gas: Being unable to refuel the vehicles required for assistance and transportation of restoration equipment contributes to cascading failures. [Source: Mike Mozart. 7/24/14]
CONCLUSION: THE AGENDA FOR ACTION

This chapter has proposed an integrated set of whole community options to strengthen resilience against black sky hazards. The most difficult work lies ahead, however -- that is, to accelerate concrete, measurable progress in implementing these recommendations and tackling the preparedness challenges that remain. This final section summarizes some of the key recommendations of this chapter and examines approaches to support progress in implementing these recommendations, concluding with a review of additional urgent challenges, not yet addressed.

A Sustaining Progress

A key finding of this chapter, and a foundation for its recommendations, is that sustained whole community collaboration is essential for building resilience against black sky events, and for better integrating power restoration with “traditional” consequence management. The EPRO Executive Steering
Committee (ESC) is structured as a framework to help expand and continue this engagement and dialog, to help industry and its whole-community partners implement black sky hazard power grid resilience and restoration recommendations, in coordination with utility, government and NGO organizations.

Today, any such sustained engagement effort takes place in an environment that, increasingly, reflects new and powerful initiatives to coordinate effective power grid restoration measures addressing severe hazards. The Post-Sandy system that utilities are building to accelerate power restoration in National Response Events (NREs) provides an ideal opportunity to scale up and greatly widen partner support for such operations. In particular, supporting the movement and operations of utility crews -- and their families -- opens up new ways for NGOs and agency partners at all levels of government to support utility restoration efforts.

But partners will only be able to make these contributions if they themselves are able to function in a severely disrupted environment. Helping transform potential victims into survivors, and making individuals and families a foundation for societal resilience, would be greatly aided by implementation of the recommendations in this report to facilitate citizen communications and mobility. The recommendations to sustain functionality and continuity of operations by NGOs and state and local government agencies will also be critical.

This chapter has emphasized the critical role of governors and their state National Guard organizations in scaling up their traditional utility support missions for power restoration. Given that governors have primary responsibility for the public health and safety of their citizens, the leadership that they are exercising in the post-Sandy era to strengthen support for power restoration is absolutely essential, and can be advanced by state agency recommendations included in this report. Especially important, in the hurricane belt and other regions that suffer frequent storms, state National Guard organizations have already built up extensive plans and capabilities to execute road clearance and other support
missions. This is the foundation on which utilities and the Guard may consider developing the additional capabilities for support that this chapter proposes, in terms of improved situational awareness, expanded state support for multi-region events, and a range of other assistance operations. Sharing emerging best practices as State National Guard organizations pioneer new support initiatives will also be vital.

Finally, within the Federal Government, planning initiatives are underway that provide a valuable integrative opportunity for such preparedness levels on a regional, multi-regional and national level. Given that FEMA is the Federal lead agency to coordinate Federal support in response to state requests for assistance, and that DOE is responsible for ESF-12, the FEMA/DOE initiative to create a Power Outage Incident Annex provides a critical tool to advance integrated planning and preparedness for the whole community. So, too, does the FEMA Regional Playbook initiative and the Complex Catastrophe effort that DOD is conducting with its Federal and state partners. These initiatives create an historic opportunity to bridge the divide that persists in too many states and regions between planning for power restoration and “traditional” disaster response/consequence management.

B | Additional Challenges for Consensus Building and Joint Action

1. Prioritizing the Restoration of Power

Developing optimum, broadly accepted priorities for power restoration of differing facilities constitutes an additional opportunity for progress. Every utility has a plan that identifies critical loads to restore as quickly as possible after an outage. Hospitals, municipal water systems, emergency operations centers and other facilities essential to public health and safety are typically included in these prioritized restoration plans. Nuclear power plants and major military bases also represent critical loads in some utility service areas.

However, Capstone 14 and other recent exercises indicate that emergency managers may have a very different set of restoration priorities than utilities. In fact, given that power restoration for all major historic US outages has reached high restoration percentages within no more than several days, utility priorities
have generally had the flexibility to simply focus their priorities on the optimum planning to bring their full network back in minimum time. In a very long duration, wide-area outage, this would certainly not be the case. And facilities that might not ordinarily be as urgent for power restoration could become vital for life-sustaining operations and national security. Building consensus on restoration priorities will be a key focus of EPRO ESC going forward.

2. Cross-Sector Resilience

This handbook has focused on recommendations to expand partner support for power restoration, better integrate consequence management and restoration operations, and strengthen emergency power planning and capabilities. However, to fully prepare for a black sky event, it will also be essential to build resilience across the critical infrastructure sectors that are vital for restoring power in a wide-area outage.

In each sector, analysis will be needed to 1) examine how such an outage would disrupt the sector’s functionality and capacity to support power restoration; 2) analyze limited protection investments that could provide especially significant benefits for sector resilience; and 3) recommend how to more effectively restore critical functionality for power restoration support, even if (after such investments) the sector suffers significant disruption. Key infrastructure elements to include in this cross-sector analysis:

a. **Fuel for grid restoration operations.** In a wide area, multi-week outage, the flow of natural gas to power generators (including Black Start generators) may be severely disrupted, either through physical damage to pipelines (as in a seismic event) or through E-threat, cyber or other
threat vectors that disrupt both the grid and the fuel necessary for grid restoration. Pipeline compressors that rely on electricity will present another point of failure. Consensus-building is needed to identify potential requirements for on-site storage of fuel for Black Start generators, and how limited, prudent investments in protection could strengthen the resilience of natural gas and other fuel supplies for such generators. Analysis should also go forward on how FEMA Region-by-Region planning can best mitigate disruption in Black Start fuel supplies.

b. *Liquid fuel for utility trucks and other restoration assets.* Building on the analysis of emergency power requirements and recommendations in this chapter, follow-on analysis is needed on ways to overcome the challenges of ensuring the availability of diesel/gasoline for utility trucks and supporting vehicles (road clearance, security, etc.) when an outage renders fuel pumps inoperable.

c. *Communications.* Major disasters routinely disrupt cell communications and other telecom systems on which utilities rely for restoration operations (as with the disruption of Verizon service during Sandy). A wider area, long-term loss of power would pose potentially catastrophic risk to such communications, especially as stored on-site fuel for backup generators was depleted at key communications system nodes. The absence of a dedicated spectrum for telecom communications and resulting competition for prioritized access in an emergency will exacerbate these challenges. Follow-on analysis should examine this challenge and recommend mitigation measures.

d. *Lifeline Infrastructure.* A black sky event could jeopardize food, water, health care, and other infrastructure sectors essential for sustaining life. Given the criticality of these infrastructures, follow-on analysis is needed as an urgent priority to help develop basic strategies to address these sectors.
California National Guard Medic comforts a man in Phoenix during a mock rescue operation
[Source: California NG]
## Image References

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<td>Pennsylvania National Guard Joint Emergency Operations Center during Superstorm Sandy. [Source: The National Guard/Staff Sgt. Ted Nichols. 10/30/12]</td>
<td><a href="https://www.flickr.com/photos/thenationalguard/8139276381/">https://www.flickr.com/photos/thenationalguard/8139276381/</a> •</td>
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<td>U.S. Coast Guard helicopter takes off to provide disaster relief after Superstorm Sandy. [Source: US Navy photo by Andrew B. Church, 11/2/12]</td>
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## Chapter 1

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<td>ISIS Global Presence – ISIS continues to use tools such as social media to increase its international presence, and gain support from all over the world</td>
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<td>Yemeni instability. Presence of rebel forces in Yemen as of September 2012– Yemen remains politically divided and inherently unstable. The lack of centralized government control and subsequent instability continues to provide a convenient operation for terrorists and radicalized militants [Source: Political Geography Now, Map by Evan Centanni]</td>
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The Traditional Concept of Combined Arms Attacks


Emergency Response Vehicles [Source: Mike, 10/30/12]

Map of the New Madrid and Wabash Valley seismic zones. Red circles indicate earthquakes that occurred from 1974 to 2002 with magnitudes larger than 2.5 on the Richter scale [Source: USGS/Joan Gomberg and Eugene Schweig. [January, 2007]

Chapter 2


Backup generators (photo taken during Hurricane Gustav 2006) [Source:FEMA/Barry Bahler. 9/8/08]

USACE assisting with Generator distribution logistics [Source: FEMA/Melissa Ann Janssen 9/25/03]

FEMA earthquake response team exercise. Coordination and communication are put to the test. [Source: FEMA/Brian Glaviano. 3/7/11]

All sectors must come together to provide emergency assistance during an outage. Emergency response vehicles are unloaded from a C-5 Galaxy by members of the Georgia National Guard during an emergency response readiness exercise. [Source: Georgia Department of Defense/ Sgt. 1st Class Roy Henry.2/6/11]

Governor Cuomo tours Hugh L. Carey Tunnel flooded, during Sandy [Source: Patrick Cashin/MTA. 10/30/12]

Technician inspects Micro-grid equipment. Smart Grid technology will be invaluable to situational awareness during an outage [Source: Amy Vaughn/ DOE. 9/23/12]

Utility workers perform maintenance on power lines. Their assistance is invaluable when disaster strikes [Source: Ed Hunt/Western Area Power. 8/11/14]

Building a Resilient Grid Architecture is vital. [Source: Eva Cristescu. 8/19/09]

Incident Command centers such as this one in Maryland are vital to coordinating a well-planned response [Source: MD National Guard. 7/1/05]


A whole community effort starts with education and preparation at the local level [Source: USACE/ Jeff DeZellar. 9/19/11] http://tinyurl.com/pbchwxp

A girl walks by the wreckage of her Indiana school in the wake of a tornado The Indiana National Guard activated more than 250 Soldiers to come to the aid of the community [Source: Indiana National Guard/ Sgt. John Crosby. 3/29/09] http://usarmy.vo.llnwd.net/e2/c/images/2012/03/03/237432/original.jpg


Red Cross Shelter s such as this one provide a large part of the housing and relief options for people in stricken communities [Source: Joe Loong. 8/8/12] http://tinyurl.com/objh5we

NJ National Guard help unload a tractor to remove debris left in the wake of Hurricane Sandy [Source: NJ National Guard. 8/28/12] http://tinyurl.com/nawq3yt


Tangled power lines represent the confusion that can arise from a lack of situational awareness [Source: McKay Savage. 7/20/08] https://www.flickr.com/photos/mckaysavage/3921003774

Inside a FEMA MERS Vehicle in Iowa. Mobile command centers such as this one allow the cross-sector coordination needed to plan and respond to severe outages [Source: FEMA/Barry Bahler. 6/18/08] https://www.fema.gov/media-library/assets/images/52957


National Guard vehicles can be deployed to the scene in order to provide rapid assistance to civilian authorities during an outage [Source: FEMA/Chris Ragazzo. 11/12/12] http://www.dvidshub.net/image/781275/national-guard-convoy-coney-island-ny#UKEakIXlhE#ixzz2C1nNb91L

Collaboration between the US Coast Guard and FEMA ensure that assistance can get to where it is needed most [Source: FEMA/Mark Wolfe. 8/15/07] https://www.fema.gov/media-library/assets/images/51561?id=31523
The Department of Defense can utilize the Complex Catastrophe Initiative to leverage its significant resources in support of power restoration efforts [Source: FEMA/Michael Reiger. 5/8/07]

USACE utilizes Deployable Tactical Operations System Centers such as this to rapidly assist with repairs and provide emergency generators [Source: USACE. 5/12/08]

Power facilities such as this must have reliable access to backup generators in the event of a long-term outage, if vital parts of the grid are to remain operational.

Out of Gas: Being unable to refuel the vehicles required for assistance and transportation of restoration equipment contributes to cascading failures. [Source: Mike Mozart. 7/24/14]