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Electric Power Grid Resiliency & Physical Security

By David W. Hilt

The U.S. electric system has become an integral part of our daily lives, so much so that we rarely consider how to live without it. The U.S. Department of Homeland Security, as directed by the White House, has identified the critical infrastructures in the United States. The current list includes 17 critical infrastructures with Energy at the top of the list. Indeed, the Department of Homeland Security has also noted that the remaining critical infrastructures require energy to operate.

Of course, the electric grid, while highly reliable, was designed on the basis of serving electric customers, supporting electricity markets, and serving industry's needs. Today however, the electric grid itself is integral to our modern society and to our health, safety and welfare, and recent large-scale system events have focused attention on the resiliency of the electric grid in North America. Simply put, the modern society that we live in cannot exist without the electric grid to supply the services and other critical infrastructures supporting our way of life.

Recent events including the April 2012 shooting attack on a major 500/230/115kV substation on the west coast have focused the attention of the federal government, regulators, and industry on the need for grid resiliency as well as cyber and physical security. The physical attack event resulted in damage to major power system transformers and cost millions of dollars to repair, in addition to exposing the grid to unnecessary risks.

The physical attack incident has reinforced concerns on the part of the Federal Government, the electric industry, and the public that the electric industry still needs to take additional steps to ensure the physical security of the electric system. As a result, on March 7, 2014 the Federal Energy Regulatory Commission (FERC) issued an Order requiring the development of physical security standards within 90 days, the intent of which is to enhance the resiliency and reliability of the electric grid. This order requires at least three steps:

- Risk assessments must be performed to identify "critical facilities".
- Potential threats and vulnerabilities should be assessed for those facilities.
- A security plan should be developed to address significant potential threats.

That reliability standard developed by the North American Electric Reliability Corporation (NERC), the FERC approved Electric Reliability Organization (ERO), was approved by FERC with an effective date of July 1, 2015. The standard, CIP-014, for Physical Security, will present a number of challenges to utilities including independent verification of risk and protection plans.

Electric Grid Resiliency

Reliability of the bulk electric system is a well understood concept, but resiliency is relatively new. As a concept, perhaps Terry Boston of PJM has the best analogy for what resiliency means. At a recent conference on grid resiliency, Terry highlighted a wristwatch commercial from many years ago and the tag line in the commercial "takes a licking and keeps on ticking".

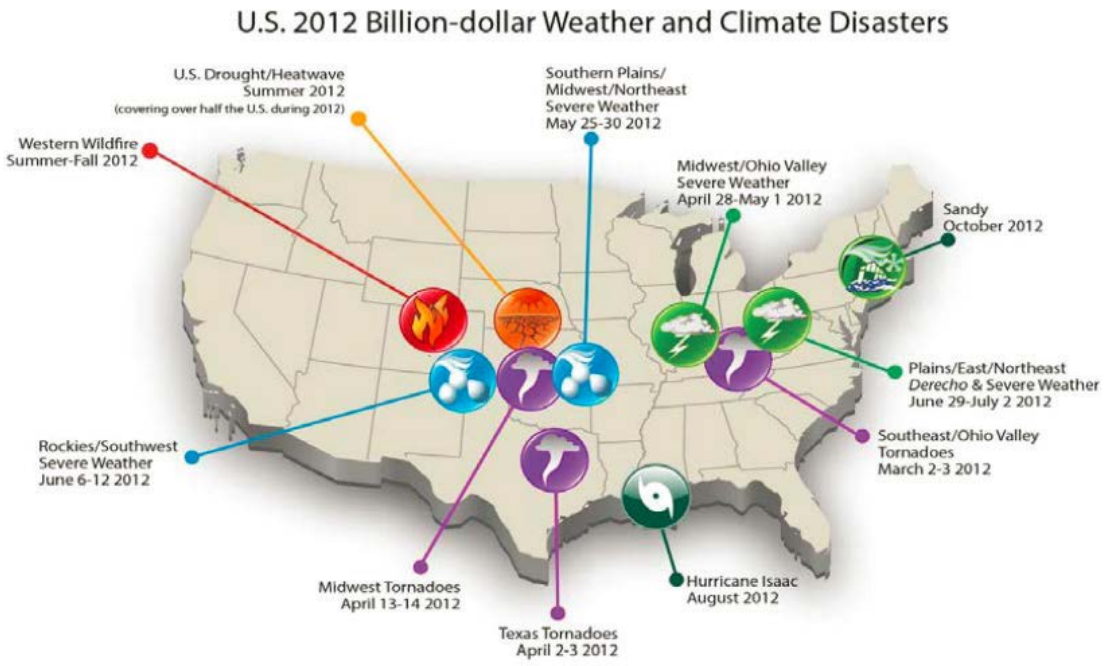
Properly executed, electric grid resiliency would allow the grid to support a wide variety of conditions that the electric system could potentially face. These include physical security threats, system blackouts and severe weather challenges, such as hurricanes (Katrina, Ike, et al), snow and ice storms, straight line wind storms, inland hurricanes, etc.

Elements of resiliency include how the system is designed, operating and maintained with a focus on resiliency. Resiliency also takes into account the sufficiency and effectiveness of recovery plans and certain relatively routine business practices, such as inventory management.

Cost of Extreme Events

Bulk power system events represent a significant impact to our comfort, convenience, and safety in addition to the economic impacts. There were 11 events in the United States in 2012 that cost the economy in excess of $1 billion each. Many of these events had significant impacts to the electric system.

According to a recent White House report, weather-related outages alone cost the economy between $18 and $33 billion annually. The Department of Energy (DOE) estimates that outages cost the economy up to $125 billion annually. The following is a graphic depiction of the events in 2012 alone.

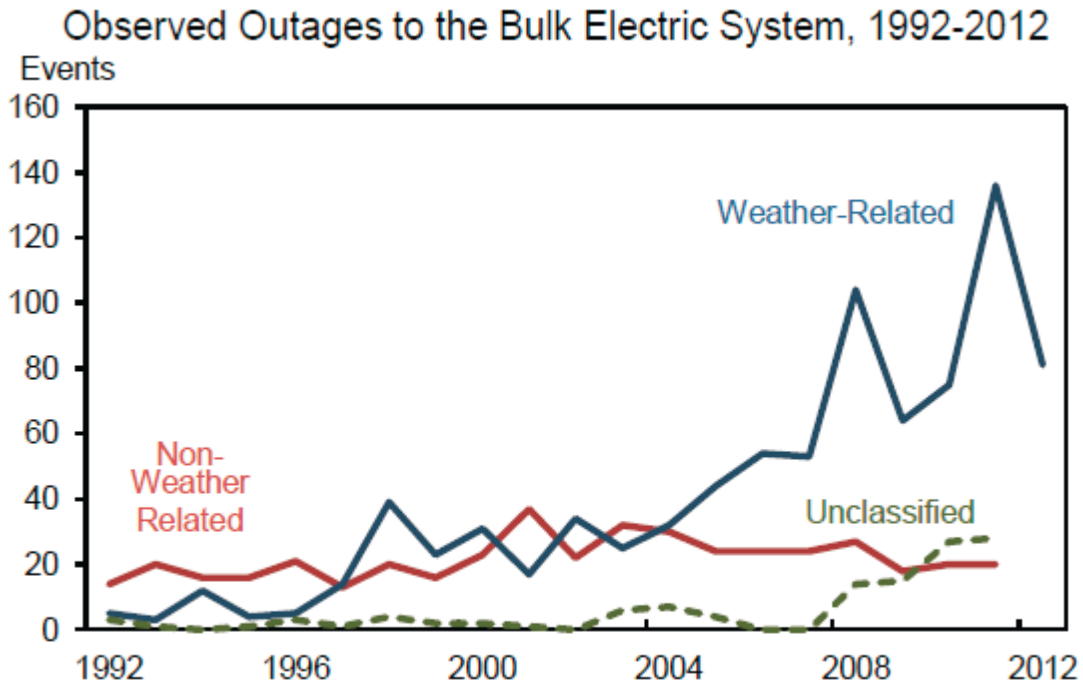


Source: National Oceanic and Atmospheric Administration

Aging Infrastructure

However, spending on U.S. electric Transmission and Distribution (T&D) infrastructure has fallen far short of growth in demand for nearly 30 years. As much as 30%-50% of the T&D network is 40 to 50 years old, while many of those system components only have useful lives of 40 to 50 years. Presently in the United States, 70% of transmission lines are 25 years or older; 70% of our large power transformers are 25 years or older; and 60% of circuit breakers are more than 30 years old.

According to the Edison Electric Institute (EEI), the U.S. electric utility industry will require a total T&D infrastructure investment on the order of $1.5 to $2.0 trillion by 2030. Further, in order to avoid power outages from component and equipment failures, analysts believe the industry will repair/replace 0.5% to 1.0% of transmission mileage annually over the next two decades. With approximately 283,000 transmission miles in North America, the annual repair/replacement of 1% of transmission mileage, at a cost of approximately $1 million per mile, represents nearly $3 billion per year in repair/replacement investment. In addition, the American Society of Civil Engineers estimates that "the U.S. will invest $566 billion by 2020 in electricity infrastructure".



Source: Energy Information Administration

Grid Resiliency Assessment Needs

With the level of investment predicted in the T&D infrastructure, the question becomes how to best allocate the resources to gain the most return for the investment in terms of grid resiliency. Owners and operators of T&D systems will need to develop a program that can show measurable improvement in system performance through system planning, design, operations and preparation for extreme events, while ensuring that costs to implement the program provide a measurable benefit.

Such an effort requires a thorough, structured, multi-step process to develop a comprehensive grid resiliency program, accomplished in steps with each step dependent on the outcome of the previous step. Further, such an effort can provide insights into where to improve physical security and address the risk from a physical attack, such as the attack on the west coast.

Starting such an effort requires some definition of the goals and objectives of a grid resiliency program, its goals, metrics and resource needs. Establishing a team is a necessary first step, in order to:

- Review available data,
- Identify applicable industry data,
- Review and identify preliminary measures of success (e.g., customers impacted, length of outages, frequency of outages, etc.) that can serve as metrics for the program, and
- Project and provide detail to the subsequent steps in the grid resiliency effort.

This "scoping effort" will determine the data and information needed and what information is available, and define the overall performance goals for the system on a proactive and reactive basis, based on actual system outage history; and identify metrics to measure success.

A risk assessment and characterization effort begins with a review of historical system events and identification of the causes of those events from available data. This research will assist in determining if certain events in specific areas of the system are likely or could be considered as imminent for reoccurrence. Some examples could include hurricanes, lake effect snow storms, ice storms, patterns for wind storms or tornados, flooding, etc.

The goals and objectives of a sound grid resiliency program should include five key elements:

- Identification of risks and design criteria.
- System planning, design, and equipment and facilities specifications and designs.
- Retrofit and maintenance of equipment and facilities.
- Operating strategies and training programs.
- Recovery planning, equipment and supplies inventory, and training.

Identification of Risks & Design Criteria

Developing a grid resiliency program requires consideration of the types of events that can challenge the resiliency of the grid in the local area of operations and those events that should be included in the design of the system, equipment and facilities. To identify the events, an analysis of historical operation is needed. This analysis primarily includes an identification of

where those events occurred on the system, and what events are to be included in the design of the system, equipment and facilities.

Risks to the system, based on the types of events, other key infrastructure interdependencies, and system performance (design) criteria can then be identified based on the actual system using automated tools that analyze the system impacts from the events looking beyond the traditional single-contingency and extreme disturbance methods. For large systems, the risks can be different in different parts of the system. Knowledge and data are imperative to assess the risks to the system based on local events.

Physical attacks on key facilities can be evaluated even though they have not occurred through a structured approach. The NERC CIP-014 standard requires a risk assessment phase to identify the critical facilities that, if rendered inoperable, would result in instability, cascading or uncontrolled separation. This is not a single contingency analysis normally used for system planning purposes, but rather an extreme disturbance. A process will be necessary that will evaluate the risk of instability, uncontrolled separation, or cascading to the portion of the bulk electric system under review. Such a process may including ranking of criticality relative to the remainder of the interconnection, a review of individual components within the system, a review of the physical design and construction of facilities and the associated vulnerabilities, and identification of elements and components within the identified critical facilities that may need to be further protected.

Planning & Design for Resiliency

Planning and design of the electrical system, equipment and facilities requires an understanding of the events and the potential impacts on the entire grid. Planning and design of the electric system for resiliency using the risks and design criteria is a multi-step process. The NERC Transmission Planning Standards (TPL) include some design basis for single and multiple contingencies as well consideration of extreme disturbances. Resiliency is about extreme disturbances and the challenge is determining what systems, loads, etc. that should be considered in the design of a more resilient system.

With the key risks to the system and the critical facilities identified, system studies can be completed to improve the system, develop operational plans and equipment specifications, improve facility designs, and assess the appropriate inventory of spare parts and equipment.

The processes should include a repeatable and uniform methodology to identify which bulk electric system facilities are most critical to electric system operations and infrastructure security.

To effectively understand grid resiliency, it is equally important to understand the impact of the grid and electric supply to other critical infrastructures and loads. The critical infrastructures in our modern society are highly interdependent and extremely dependent on the continuous supply of electric energy. Storms as well as physical and cyber-attacks may result in significant impacts to other critical infrastructures. When assessing the risk of a physical attack, for example, consideration of the critical loads that may be outaged as a result of the attack should be considered.

Such an analysis is done in addition to the traditional contingency analysis used by utilities and should result in a more appropriate categorization of the risk of outages. Further, traditional contingency analysis may not capture the mutual effects of multiple bus or line outages at a single facility, including those owned by others.

Physical Protection

The risk assessment and characterization effort will need to look to possible future events based on the historical data and other potential risks such as a physical attack. While it is not possible to predict when and where future events will occur, it is possible to identify the buses and branches in the system that, as a result of their location, configuration and electrical characteristics, pose the greatest risk for large-scale outages. These results can then be used to tailor grid resiliency efforts to focus on those facilities with the greatest risk for future events.

To assess the risk of a physical attack, the facilities with the greatest impact or risk based on their ranking can be further focused upon, analyzing components within the facilities that may pose a risk. These can include communication facilities (fiber optic terminations, microwave towers, etc.), control wiring (cables, cable ducts and locations), fencing and visual screening, equipment locations, spare inventory and location, control buildings, security and monitoring.

Constructing for Resiliency

New facilities should be constructed with grid resiliency in mind. Equipment specifications, facility design criteria, and construction practices can be developed to ensure an appropriate level of resiliency. However, the system is not new and is not being built to this new criteria. Understanding the current design criteria as well as the condition or health of system components and equipment is a necessary component of grid resiliency programs.

Reviewing any equipment or component failure data, condition and maintenance data, and field inspections provide valuable insights into component level failure risks. To improve system resiliency based on the condition assessment, priorities can be established based on the risks identified. Further, it may be worthwhile to retrofit some key facilities to meet the revised design criteria for physical protection or other factors (e.g., flood level protection), enhance inventory and spare equipment at specific locations, and evaluate maintenance practices of certain equipment and facilities.

Summary

Electric grid reliability is not a new concept and designing for reliability has taken the industry a long way to ensuring resiliency. However, given the level of criticality of the electric grid to all other infrastructures, additional effort is required to ensure a resilient grid. These steps include meeting the requirements of the NERC Critical Infrastructure Protection (CIP) Standards that establish requirements for Cyber and Physical security. Progressive electric utility planners and operators will take steps beyond those required by the standards to ensure resiliency to their customers and stakeholders. These steps include understanding; 1) the history and patterns of events on the system(s) involved; 2) the risk the system and other infrastructures of rendering facilities inoperable; 3) the mutual effect of nearby facilities to the grid for combined outages: 4)

the impact to other critical infrastructures and critical loads: 5) the components within the substations and other facilities that pose the greatest risk. From such an understanding, system planning, facility designs and retrofits, and physical and cyber protection plans can be effectively developed, implemented, managed, and maintained.

Grid resiliency is an on-going process and will require continual re-evaluation to ensure the threats, risks, and hardening measures have not changed. Further, training on the need for grid resiliency should be provided to all involved. Complacency about the grids resiliency is easily established due to it high level of reliability but hard to overcome without periodic training to establish thought processes for resilient planning, design, and operation.

About the Author

David Hilt has nearly 40 years of experience in electric power system engineering, operation, and regulatory activities. He has been a manager responsible for the design, specification, and construction of electric substations from distribution to EHV including protective relaying. He has also managed transmission and resource planning activities for a major Midwestern electric and natural gas utility providing expert testimony before FERC and state regulators for transmission expansion and 20 year resource plans. Mr. Hilt has directed the development and installation of state estimation and OASIS systems for a Midwestern Reliability Coordination Center. As a Vice President at NERC, he led the development of the compliance monitoring and enforcement program for the bulk-power system reliability standards in North America working closely with the industry, FERC, and Canadian regulatory authorities. He also developed audit programs and event analysis and investigation prorocess. While at NERC he led the investingation of the August 2003 blackout in the Northeastern United States and Canada providing the technical input to the U.S. – Canada Power System Outage Task Force report and other key system events. Mr. Hilt's recent experience includes assessment of risk from physical attack and grid resiliency with major systems involving major metropolotian areas including the assessemnt of electric systems and individual substations and their components.