BEST PRACTICES FOR STORM RESPONSE ON U.S. DISTRIBUTION SYSTEMS

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INTRODUCTION

Power delivery systems, particularly distribution systems in the United States, whether they are overhead or underground, have always been vulnerable to the effects of major storms. In fact, virtually every utility has had to respond to a major storm event in its history. Some utilities, because of their geography, must deal with such events nearly every year. For most utilities, "storm events" include hurricanes, tornadoes, windstorms, thunderstorms, lightning, sleet, snow and ice. In 2009, the DSTAR consortium[1] commissioned a study of the best practices for utility storm response. The study examined the practices, procedures and experiences of U.S. utilities during major storm occurrences with the goal of understanding and conveying what went right and what went wrong during the build-up, restoration and ramp-down phases. The investigation included detailed utility surveys, interviews with storm bosses, vendors and consultants, and reviews of reports, proceedings, and papers. The result is comprehensive discussion of many important aspects of storm restoration with an emphasis on best practices and lessons-learned from past experiences. This paper summarizes some discussion items and key findings from the study, particularly revealing cases, and recommendations from utility experiences.

BEFORE THE STORM – PREPARATION

Storm response begins long before an event occurs and continues long after the worst is over. The term "response" is specifically chosen to encompass everything the utility does to actively prepare for, combat and recover from a storm event.

The most important factor that determines the impact of a storm event is how the electrical system is designed, constructed, and maintained to withstand storm forces and elements. As such, the study begins with an overview of storm-hardening activities typically undertaken by utilities during normal operation. Following this, the report covers important aspects of storm preparation, personnel training, early detection, warning and tracking systems, as well as the impact of these measures on the planning horizon for various types of storms.

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[1] DSTAR (**D**istribution **S**ystems **T**esting **A**pplication and **R**esearch) is a consortium of North American utilities that fund pragmatic, near-term, distribution-related R&D projects of common interest. GE Energy acts as Program Manager for DSTAR and conducts most of the research and software development on behalf of the DSTAR members. Information on DSTAR operation and products is available at Hwww.dstar.orgH.

Storm Hardening

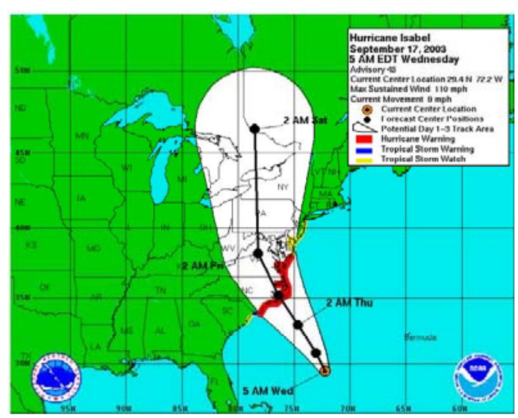
Storm-hardening activities aim to reduce the impact of future storms by assessing the infrastructure to identify ways to make it more resilient. State Utility Commissions are paying more attention to storm hardening as a result of the fallout from recent, particularly devastating storms, and the increase in customer complaints. For example, on April 25, 2006, the Florida PSC issued Order No. PSC-06-0351-PAA-E1, requiring the investor-owned electric utilities to file plans and estimated implementation costs for ten ongoing storm preparedness initiatives on or before June 1, 2006. Among the ten ongoing initiatives were several measures aimed at hardening the T&D system: a three-year vegetation management cycle for distribution circuits; an audit of joint-use attachment agreements; a six-year transmission structure inspection program; and hardening of existing transmission structures. Some of the more common storm hardening activities include: tree trimming/vegetation management, system design changes, and maintenance activities such as pole inspection/replacement programs.

Preparation and Training

Apart from hardening the system to withstand the impact of a storm, the next most effective activity is preparing and training for storm restoration. This includes all activities that enable utility mobilization and power restoration as soon as possible after a storm, and to ensure continuity of business operations. The study found that best in class performers developed and maintained a comprehensive emergency response plan (ERP), to guide response during major events.

With regard to training, one key recommendation from the report is to conduct annual storm drills to exercise and refine all phases of the ERP. A leading practitioner of storm drills, Florida Power and Light (FPL), commented in a press release, "*every year we train our employees and practice different scenarios because we know that every hurricane is different and each brings with it its own set of problems. We practice our dry run as if it was a real storm. We countdown from 72 hours until the hurricane makes landfall and follow through with the storm event post-landfall to study what significant problems we might encounter. The lessons we learn are captured and incorporated into a preparedness plan*."

Early Warning and Tracking



The argument for early warning and tracking is illustrated by Baltimore Gas and Electric (BGE) Company's experience during the Hurricane Isabel in 2003. Baltimore Gas and Electric Company. BGE began monitoring Hurricane Isabel on September 6^{th}, 2003 as a tropical depression off the Southern Cape Verde islands (almost two weeks before landfall). As they continued to track and monitor the storm, they maintained contact with mutual aid partners. On Monday September 15^{th}, based on the storm's intensity and forecasted track, BGE initiated its Severe Impact

Storm (SIS) procedures and premobilized 300 external, overhead construction crews and 85 external tree crews. On Thursday, September 18th, Isabel made landfall as a category-2 hurricane on the Outer Banks of North Carolina with sustained winds of 100 mph. The size of the hurricane stretched more than 300 miles in diameter. By late Friday, September 19th, almost 2 million customers were without electricity including more than 790,000 in BGE territory. Because of preemptive action and advanced warning, BGE was able to mobilize the largest workforce in its 200-year history, and restored power to the last customer who was able to receive power on Friday, September 26th, only one week after the storm.

One key point that this and other cases in the storm report illustrate is the inherent difficulty in predicting and forecasting certain storm events. Some storms have very short lead-times, while other events afford greater latitude for planning and mobilizing. In a survey, DSTAR members were asked to provide their average advance warning time (in hours) for various types of storms such as hurricanes, snowstorms, ice storms, wind storms, thunderstorms, lightning, heatwaves, and tornadoes. As expected, utilities generally have a much longer lead-time for hurricanes than for any other type of storm, and a much shorter one for tornadoes, but it was interesting to see how the lead times varied by geographical location and utility type/size.

Predicting Storm Damage

The goal of storm damage prediction is to forecast the amount of damage a storm will produce, the resources required for restoration and the approximate time to restore service; it is an essential part of the storm management process, providing triggers for levels of storm center activation and crew mobilization.

Storm prediction is based on accurate weather forecast of elements that can damage the electric distribution system. This could be inches of ice accumulation on trees and overhead equipment for ice storms, peak wind speed and gust durations for hurricanes, and stroke proximity and frequency for lightning. Based on the history of storm damage, operational capability, and the susceptibility of the current design, expected damage and approximate crew requirements can be predicted. Damage prediction for a substation area or feeder might include the location and extent of the following:

- Poles broken
- Transformers damaged
- Primary conductor down (miles or spans)
- Secondary conductor down (miles or spans)
- Customers out
- Trees down/damaged

Prediction tools range from simple storm classification tables, based on current data and past information, to more sophisticated computer models that take into account other system variables like topology, system design and layout, customer density and vegetation. In the DSTAR storm survey, over 50% of respondents report using some in-house tool or process for storm damage prediction.

Activation and Mobilization

The first step in responding to a storm emergency is to activate the storm organization. A best practice is to provide mobilization triggers for various stages of advanced planning. The DSTAR storm report recommends that utilities develop a categorization method that prescribes levels of activation based on storm characteristics. These Categorization methods and activation levels can vary greatly from utility to utility based on factors like geographic location, size, customer base, etc. The table below shows one example of storm activation levels from a mid-sized utility commonly exposed to winter storms.

1. **Level Zero** (normal conditions)
   - Dispatching from Central Dispatch Center
2. **Level One** (more than normal, less that 6 hours) –
   - Dispatching from Central Dispatch Center with added resources
3. **Level Two** (more than 6 hours, less than 12 hours) –
   - Storm site mobilized for resource management
   - Dispatching continues from Central Dispatch Center with added resources
4. **Level Three** (more than 12 hours, less than 24 hours) –
   - Storm site mobilized for resource management
   - Nearest Regional Dispatch Site is mobilized for dispatch of the storm site.
5. **Level Four** (more than 24 hours) –
   - Storm site mobilized for resource management
   - Regional Dispatch site is mobilized for dispatch of the storm site or Storm Site assumes dispatching functions with resource assistance.

Once the storm center is activated, appropriate personnel are mobilized to staff the various command functions. The level of activation also provides triggers for resources, both in terms of materials and crews. Other key decisions in the mobilization timeline are when to secure line and crew contractor commitments, when to request mutual aid support from other utilities, and when to release resources.

Materials Management and Logistics

Materials management and logistics form the backbone of a utility's restoration effort. During the course of the event, the utility must ensure that personnel are properly fed, visiting crews have lodging, workers have access to materials and tools, trucks and other equipment are maintained and fueled, security is in place, transportation, water, ice and laundry and bathroom facilities are all available, and scores of other details without which work would grind to a screeching halt.

The storm report examines best practices in materials and inventory control, staging and positioning, lodging and meals distribution, and security and safety. One of the key findings, as obvious as it sounds, is "*you can't work more people than you can logistically house and feed*." More crews may speed up the restoration process, but the ability to care for the crews will always be a bottleneck. During Hurricane Rita in 2005, Entergy Gulf States learned this lesson the hard way. A report by the Texas PUC stated, "*EGSI learned that its logistical support was a bottleneck. Facilities to house restoration workers were either not available or very limited.*

Inventory levels were very low for both the utility and suppliers. EGSI concluded that its contractor and vendor lists need to be updated each year before the hurricane season."

STORM RESTORATION - RESPONSE

After all the planning, preparation, training, activation, mobilization, and logistical arrangements are completed, the only thing left to do is execute the plan … meaning, restore the system. In some ways, this is the most familiar aspect of the entire operation, as it simply calls on line workers to do what they have been trained to do – construct, repair and maintain electrical infrastructure. This section of the report discusses the various restoration activities that take place after a storm and draws on numerous storm experiences to highlight industry best practices and lessons learned.

Storm Restoration Priorities

Restoration activity is generally guided by the utility's restoration priorities. This is a high-level guide to the order in which systems should be restored, based on importance and criticality. The survey of DSTAR member utilities reveals that restoration priorities are very similar across the utilities (as expected), with a few caveats. The general order is listed below. Note that some of these tasks may be performed in parallel where separate crews/skill sets are required.

1. Large transmission lines
2. Substations
3. Public safety calls
4. Main or three-phase backbone feeders.
5. Emergency services, priority and high profile
6. Single-phase lines serving large blocks of customers.
7. Lines serving neighborhoods and multiple customers.
8. Individual customers

As far as possible, supervisors and field crews follow the utility's restoration process, but in practice it is always supplemented with good judgment.

Damage Assessment

The time to restore a distribution system following a major event is highly dependant on a quick and accurate assessment of system damage. In terms of the process flow, this assessment follows staging and positioning (which should already be in motion before the storm), and should precede crew deployment and the performance of actual restoration activities.

Damage assessment scouts, also called field checkers, or spotters, evaluate storm damage before line crews are dispatched. Ideally assessors are personnel specifically selected for their knowledge of the system and geography, who have been put through a training program before the storm season. The role of a damage assessor is to patrol the feeders to identify trouble spots, evaluate the extent of the damage, and develop initial estimates of resources needed for restoration. The assessment generates critical information that helps to define the scope of the work, prioritize efforts and assign resources. The typical damage assessment process is:

- Scores of damage evaluators or damage assessment teams are sent out to survey all the feeders and taps.
- Assessors record and tally the number of broken poles, spans of wire down, damaged transformers, etc., and the location of the damage.
- Upon returning to the dispatch location (usually at the end of the day) the information is passed on to someone to prioritize the trouble and dispatch crews to perform the repairs.

Damage assessment is effectively a bottleneck in the storm restoration process. Since crews will not typically be dispatched until assessment results are analyzed, foreign and local crews are idle while waiting for their assignments. This wait time can be quite expensive, so the speed and accuracy of data transfer to the operations center impacts the length and cost of the overall restoration effort. *A decision error during this period carries through the entire restoration process and can have a major impact on restoration time*. One of best practices encountered and discussed extensively in the study is the use of processes and technology such as mobile communication and smart meters to efficiently collect and transfer damage data to the operations center.

Public Safety Processes

The goal of the public safety process is to protect the public and make as many hazardous situations safe in the shortest possible time. The most common public safety hazard on overhead systems is from arcing or downed wires. Other public safety concerns include open neutrals from secondary damage, contact voltages from energized underground facilities, and flooded metering equipment. A leading practice among utilities is to have safety functions proceed in parallel with damage assessment. This is best done in three stages (although in practice some or all stages may be combined):

Stage I – Public safety patrollers respond to wire down calls from customers and public safety officials to assess the threat to public safety. An initial inspection is performed to determine if the downed wire is from the electric utility or another utility (telephone, cable). Safety patrollers are primarily responsible for communicating information back to the operations center, not performing repairs.

Stage II – Public safety standby personnel or wire watchers are dispatched to the scene to set up barriers and monitor the situation to protect the public. They are not responsible for assessing threats or performing repairs, but should have basic safety awareness training.

Stage III – Cut and clear crews are dispatched to the locations where standby personnel are guarding downed wires to make the situation safe. These crews are qualified overhead personnel assigned to the safety function. Their main goal is secure the situation by switching off, cutting and clearing energized down wire, but they may also restore power if the repair is not time-consuming.

One particularly cogent observation about the safety patrol process, from a utility's experience is that "*you have to communicate clearly when down-wires are left as-is because they are CATV or telephone wires, so customers are not anxious and angry*."

Crew Deployment

Crews are dispatched to repair damage and restore service after the damage assessment data is analyzed to determine the best deployment strategy. This is not an exact science. Local personnel are typically deployed in their home regions. Mutual aid and contract personnel are deployed based on various strategies, but utilities should strive for equitable deployment, so that no region is disadvantaged to benefit another. Some factors that should go into making deployment decisions include:

- Proximity of area to incoming mutual aid crews
- Number of customers out
- Number of critical facilities damaged
- Severity or extent of damage
- Ease of repair or access to damaged areas
- Geography and customer density
- Logistical support available

Taking all these factors into consideration and making logical deployment decisions, still does not guarantee that there will be equitable restoration or that some customers will not feel that they were intentionally neglected. The DSTAR storm report discusses a few observations from a utility's storm experience that would help in this area.

Clearing, Repairing and Switching

Clearing lines, repairing damage and switching customers are core activities of the restoration process. Once damage assessment is complete, coordinators in the storm center have a fairly good idea of the size and extent of the damage and the resources required. Crews are then assigned (dispatched or deployed) to specific areas to restore the system. One of the best practices discussed in the storm report and supplemented by utility experiences is to c*oordinate switching and clearance activities to achieve best maximum efficiency*. There is a wide range of opinions as to what the proper balance is between allowing crews to work autonomously to speed up restoration, and controlling and coordinating crew activities to ensure safety and efficiency. Whenever a crew works on a circuit, they need clearance to lockout the circuit for repair, and switch it on when the repair is completed. All switching can be controlled from the operations center (centralized) or switching responsibility can be decentralized to the districts, substation areas, feeders, or even to the field crews. The manner in which clearances and switching requests are handled can have a huge impact on the overall effort.

COMMUNICATIONS AND TECHNOLOGY USE

Effective communication, both internal and external, is a key component of any successful restoration effort. It goes without saying, that internal communications are essential to manage and coordinate restoration activities, but external communications are equally important to create public trust and reinforce the perception of a successful effort. Good communications makes it much easier to bolster and maintain the perception of a successful restoration effort and well run utility. On the other hand, regardless of how statistically and logistically successful the restoration effort, poor external communications can doom it in the eyes of consumers, the media, officials, regulators and shareholders.

External Communications

External communications comprises of all contact outside of the utility, with customers, government officials, community leaders, the media, public safety organizations, other utilities and emergency management organizations. Within the EOC, the Communications Coordinator is responsible for all external communications with stakeholders. External communication is important for many reasons, most importantly public safety. But poor communications can lead to unwanted attention from regulators and government officials. *A review of recent regulatory audits shows that the outcome is often a function of how well the utility communicates during the event*. From a purely business perspective, communications drives customer satisfaction, which in turn affects the perception of the utility; and as we all know, perception impacts the bottom line, especially for publicly traded companies.

When the power goes out, customers typically what to know three things: Does the electric company know my power is out? When will the power be back on? What caused the outage? Failure to provide adequate information can lead to frustration, disillusionment and a dissatisfied, complaining customer. In particular, customers often express frustration when they cannot get an estimated time of restoration (ETR) or the time is so long as to be meaningless. In some cases, utilities have found that it may be better to avoid providing specific ETRs if they are not reliable.

Internal Communications

Internal communications is communications within the utility enterprise needed to manage and coordinate the storm response – one of those things that’s often taken for granted and critically missed when it’s gone. Poor or no internal communications can potentially hobble the entire effort. During a storm, many modes of communication are used to report emergencies, keep families and off-duty personnel up-to-date, maintain contact with customers and suppliers, and coordinate response actions. These systems include cell phones, beepers/pagers, radios, telephones and faxes and computer networks. The DSTAR member survey shows that the primary means of communication with crews and other responders are by two-way radios, cell phones, remote data terminals, and in some cases satellite phones. Not surprisingly, there is more reliance on private networks than on public or commercial services during emergencies, because experience has shown that private networks are more reliable during major storms.

Technology Use

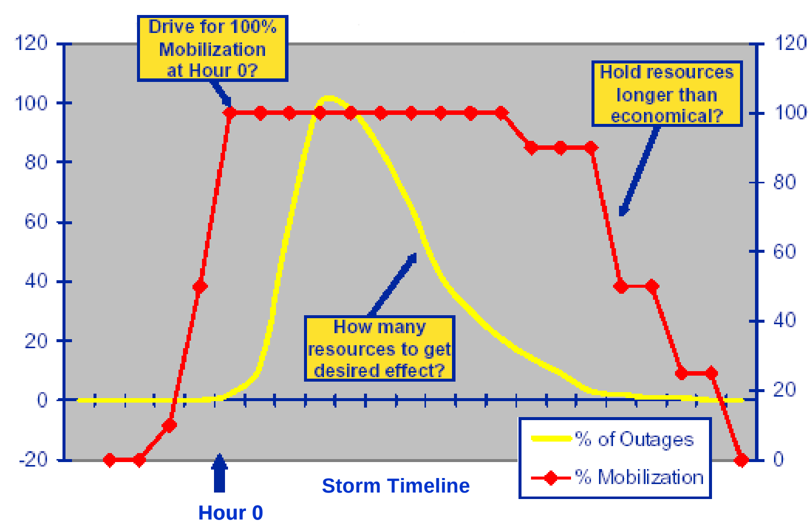
There are many other applications and networks, that are built on, and enabled by the core communication layers that have also become indispensable tools in outage response. As utilities realize their potential to improve efficiency and reduce cost, various applications are becoming a more common part of the storm restoration process. Some of the more common ones identified by DSTAR members as being useful for storm response include interactive voice response units (IVR/VRU), outage management systems (OMS), automated meter reading and advanced metering infrastructure (AMR/AMI), mobile computing, geographic information systems (GIS), mobile workforce management (MWFM), work management systems (WMS) and automated vehicle location (AVL). The greatest potential, however, lies in the integration of these applications to seamlessly move data between the field, operations and back office.

AFTER THE STORM – RECOVERY

When the intense activity and frenzy of actual restoration is nearing an end, a sense of accomplishment and finality may set in. But this could be misleading, because as every utility that has been through a major storm knows, there is still a tremendous amount of work to be done, and typically with less resources than during the actual system restoration. The post-event period can be broken into three phases: ramp-down, clean-up and review.

Ramp-Down

During the ramp-down phase of post-storm recovery, resources must be demobilized in a rational, intelligent way to complete outstanding tasks and not incur unnecessary costs. It may not be economical to hold onto external resources during this period, but if they are released too soon, some outages and clean-up may be prolonged, and customer satisfaction may be affected. To illustrate this point, the graphic below shows an example of the Southeastern Electric Exchange mobilization timeline. The chart shows that as the percent of outages nears zero, the number of resources should be stepped down accordingly. Crews that are not actively clearing or repairing lines can be dedicated to clean up and verification of the system. Obviously, this proceeds faster if more resources are available, but it is also more expensive if external resources are used. The point at which it is prudent to release foreign crews is a judgment call that is dependent on many situational factors.



Clean-Up

Clean up is one of the more underestimated activities of storm recovery. After storms that cause widespread damage, it is not uncommon for utilities to be cleaning up downed trees, broken limbs and debris, and making facilities repairs for months after actual system restoration. The following excerpt from the Kentucky PSC report after a major ice storm in February 2003 illustrates the point. "*Nearly all of the affected utilities continued to work jobs associated with the ice storm well into the summer months. Lines that were "temporarily" fixed in order to restore service had to be permanently repaired. Poles that may have been "spliced" were replaced. During restoration, lines are often cleared just enough to restore service, and vegetation management practices take a back seat to getting power back on. This speeds up repair, but it is essential that utilities document and return to areas that need further trimming. Danger trees, which are those with hanging limbs, dead sections, etc., still pose a threat to electric lines even months after the storm, especially in windy conditions*."

Review

Every storm is unique and there are important lessons to be learned from each experience. The post-event phase provides the perfect opportunity for self-assessment, peer review and sharing of lessons-learned. Shortly after the storm, findings need to be assembled and documented for the benefit of future storm responses, for response to regulatory requests, and for public dissemination. Some industry practices that are helpful in post-storm review are: survey mutual-aid utility personnel and off-system contractors; conduct Town-hall meetings in various locations and survey customers on their storm experience; and prepare or commission a comprehensive assessment report on every major event with issues and recommendations.

CONCLUSIONS

Recently, DSTAR commissioned a comprehensive report to examine the practices, procedures and experiences of U.S. utilities during major storm occurrences with the goal of understanding and conveying what went right and what went wrong during the build-up, restoration and ramp-down phases. This includes appreciating how utilities harden their systems to withstand storm elements, how they prepare, train and drill storm-duty personnel, available tools and processes for storm tracking and damage prediction, how they organize and manage response activities, procedures for assessment, repairing and switching, communications and technology use.

The investigation included: a detailed survey of DSTAR member utilities on a wide range of storm response issues; interviews with utility personnel, vendors, manufacturers, researchers and consultants; extensive review of relevant literature including industry publications, conference proceedings, whitepapers, utility storm reports and public commission assessments; and examination of utility, vendor and manufacturer websites. The result is comprehensive discussion of many important aspects of storm restoration with an emphasis on best practices and lessons-learned from past experiences. The DSTAR report concludes with 144 recommendations based on utility experiences with major storms in the U.S. This summary paper has discussed the overall focus of the report and presented a few of the key discussion points and findings from the study.