Hardening Transmission and Distribution Systems
Against Extreme Weather Events

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Asset Management

Introduction
The frequency of severe weather events (floods, droughts, wildfires, hurricanes, tropical cyclones, wind and ice storms), and their associated damage, has increased over the last 20 years, and is projected to be on the rise according to many sources. Hundred-year storms now happen every year, according to a Senior Vice President of a large utility.

Regulatory bodies from Florida, Texas and other states, following the extensive damage from hurricanes in the early 2000’s, asked their utilities either to adopt or investigate hardening options for their systems. In response to this, a number of utilities have performed hardening studies and have implemented some hardening measures. Based on these studies, about half of the utilities have either received, or are expecting to receive, approval to recover some or all associated costs through a regulatory process.

This article summarizes some of hardening initiatives that utilities have and are implementing.

System Hardening… A Science Not an Art
Following the hurricanes of 2004/2005, the Florida Public Service Commission (PSC) ordered the affected utilities to investigate the types of facilities that failed and why they failed in the numbers they did (and whether age had any bearing on the failure) and look into means to harden their systems against them. Other hardening programs were initiated in Texas, Oklahoma, Kentucky and others. Table 1 shows some salient points of some of these programs.

<table>
<thead>
<tr>
<th>Focus Area</th>
<th>Florida</th>
<th>Texas</th>
<th>Kentucky</th>
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<tbody>
<tr>
<td>Start Date</td>
<td>2007</td>
<td>2010</td>
<td>2009</td>
</tr>
<tr>
<td>Vegetation Management</td>
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<td>x</td>
<td>x</td>
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<tr>
<td>Construction Standards</td>
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<td>x</td>
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<td>Undergrounding</td>
<td>x</td>
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<td>Forensic Inspections</td>
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<td>Expanded Reliability</td>
<td></td>
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<tr>
<td>Reporting</td>
<td>x</td>
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<tr>
<td>Third-Party Pole Attachments</td>
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<td>x</td>
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Table 1: Selected Storm Hardening Programs

Hardening programs today include activities across the country that look at ways to protect utility systems against all types of weather events, not only hurricanes.
Infrastructure Hardening Options
The National Electric Safety Code (NESC) is the foundation upon which many utility standards are built. Recent damage from hurricanes and wind storms has shown that building to such standards alone may suffice for normal weather, but not necessarily for some of the severe weather events resulting in some catastrophic failures and subsequent extended outages.

Tree Trimming and Vegetation Management
A major component of hardening for extreme weather is tree trimming. Revisiting in-place vegetation management programs is vital to minimize the effects of wind and winter storms on power lines. For these vegetation management programs to be effective, it is important to recap some of the salient points collected from different wind and winter storms, such as:

- Utility actions typically include expansion of existing right-of-way (ROW), clearance of overhang in urban areas and removal of dead or dying trees (hazard trees).
- Inspections of damage from wind storms and hurricanes have revealed that distribution pole failures were principally a consequence of fallen trees (secondary failures) and not due to the impact of the wind on the power delivery system directly (primary failures).
- For distribution systems, there is a direct correlation between the proximity of trees to distribution lines and the vulnerability of the lines to severe wind and winter storms.
- Tree-related failures increase exponentially when wind speeds are over 60 mph.
- In high wind situations, risk from airborne debris from trees outside the right-of-way (ROW) can exceed the risk of trees within the ROW by factors as much of 3- or even 4-to-1.
- Increasing the intensity of the hazard tree program would not noticeably improve electric system performance during major storm events. Some assessments have shown that even if all hazard trees are removed from areas around power lines, outages could not have been avoided. This is because sometimes over half of the trees causing outages have no visible defect (not hazard trees).
- Line outage frequency is highly correlated to the number of trees per mile edge of the line, and weakly correlated to variables such as line and tree heights and clearance between the trees and the line.
- Reductions in wind-related outage rates can be achieved by reducing the span length and increasing the number of poles per mile for the cases where the majority of the damage is due to power line (poles, hardware, etc.) failures (primary damage). However, if secondary damage to the power is more prevalent for most pole failures, then this approach could result in more pole failures rather than fewer and the time needed to restore service could be prolonged.

The single largest risk factor for distribution infrastructure for wind storms is vegetation-caused outages.
Hardening Against Flooding
Flooding is a most significant extreme weather event because of the long-term effects of flood water damage. Floods can be most broadly grouped as either flash floods or river floods with the main difference being the onset of the flooding. Flash floods are usually the most damaging with heavy downpours which can lead to surges of water that turn dry flood plains into raging torrents in minutes. With flash floods, there is often little warning that flooding will occur and infrastructures in the water's path can be destroyed quickly and roads can become impassable. Storms, tropical cyclones and other maritime extreme weather can also produce deadly storm surges, as in the case of Hurricane Katrina in 2005, Cyclone Sidr in November 2007 and Cyclone Nargis in May 2008.

Flooding affects many aspects of the power system, but is a major concern to substations. Flooding becomes a problem for substations when the amount of water reaching the drainage network exceeds its capacity. Flooding can cause severe damage to substation equipment and may lead to interruptions in service continuity and widespread outages. Large amounts of water, rust and mud left trapped behind a flood in a substation can make repair of the equipment a sizable and lengthy restoration task.

Certain measures can help diminish the risk of power interruptions in substations due to flooding, such as:
- Ensuring that all substation drawings and prints are stored in a location that will remain dry.
- Cleaning the grounds in and around the substation from debris and materials so that water runs off freely.
- Consolidating load on the minimum number of energized transformers (to minimize damage from through faults) during the event.
- Removing relays which are not in use.
- Sealing and waterproofing equipment as much as possible when practical.

Heat Waves and Dry Spells
Lessons learned on preparing for heat waves and summer peaks include:
- Inspection of substations for peak load readiness and identification of load relief projects with projected overloads.
- Identification of potential thermal overloads and low voltages.
- Development or updating of emergency load transfer and contingency switching plans.
- Verification of the availability of capacitor banks.

Upgrading of Poles and Towers
The most common hardening practice for electric T&D systems is upgrading poles and structures with stronger materials. This typically comprises upgrading wooden poles to steel, concrete or a composite material. It may also include and installing guys and other structural supports. Transmission structures are usually upgraded from aluminum to galvanized steel lattice or concrete. Materials are typically upgraded to meet certain grade and wind
loading criteria as defined NESC. The NESC specifies three grades for pole material strength: Grades B, C and N, of which B is the highest, see Table 2.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
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<tr>
<td>B</td>
<td>More conservative installation with higher safety factors and lower potential load applied to the structure. Highest grade typically corresponds to crossings (highway and railroad) and lines carrying variable voltage levels.</td>
</tr>
<tr>
<td>C</td>
<td>Less conservative installation with a lower safety factor and higher potential load applied to the structure. Lower than Grade B and typical for power or joint telecommunications/power distribution pole applications.</td>
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<tr>
<td>N</td>
<td>Lowest grade of construction; typically used in telecommunication applications.</td>
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Table 2: Selected Storm Hardening Programs
Source: Institute of Electrical and Electronics Engineers (IEEE), National Electrical Safety Codes (NESC)

**Strengthening Poles with Guy Wires**

Strengthening poles and towers by installing guy wires and upgrading crossarm materials are common hardening methods.

- Adding guy wires can increase the strength of a pole without the need for full pole replacement.
- Upgrading crossarm material allows for the strengthening of a structure with minimal material replacement.
- Industry practices are: transmission towers (minimum of two to four anchors/guys) and distribution poles (two anchors).

T&D poles subject to storm surges and flooding require guying. Costs and procedures for installing guy wires vary according to the height of the pole or structure, soil characteristics, assembly configuration, and design wind speed. For example, if lines pass through marshes, it may be necessary to dig as much as 100 feet deep to install anchors for the guy wires, substantially increasing cost. The most expensive guying involves pole installation in sand and silt soils.

**Undergrounding**

Placing utility lines underground, "undergrounding", eliminates their susceptibility to wind, ice and lightning damage. In the USA, undergrounding has been proposed many times as a way of hardening, but been set aside as a serious solution based on cost issues. Undergrounding of overhead lines costs about a million dollars per mile, and would lead to hefty rate increases. Though undergrounding of existing overhead infrastructure is not economically feasible, some utilities have considered targeted undergrounding projects, especially for lines serving critical infrastructure and selected backbone circuits. Undergrounding facilities, though immune to wind related damage, are prone to flooding issues, and which would also require higher costs than overhead lines. Undergrounding presents significant challenges: longer repair time and much higher installation and repair costs. Investor-owned utilities in North Carolina compared five years of underground and overhead reliability data, and found that the frequency of outages on underground systems was 50% less than for overhead systems, but the average duration of an underground outage was 58% longer.
Facility Relocation
Facility relocation can be costly and should be reserved for priority areas that require a high degree of resiliency.

Reducing the Span Length
Sometimes shortening the span length can improve the hardening of distribution lines. The span length can only be shortened by adding more poles to an existing line. The number of attachments cannot be reduced on existing lines, at least not without high cost.

Small Wire Replacement
Some older distribution lines have old small copper wire (e.g., #6 and #4 Cu) or copper-clad wire and aluminum wire with corroded steel core, and replacing them with larger sized wire could avoid some outages during major storms. Small wire replacement is currently part of the electrical hardening initiative at a number of U.S. utilities.

Aging Infrastructures
As extreme weather has become more and more common over the past few years, aging power infrastructures and equipment, which have not been designed to such extremes, will be expected to see relentless attacks. Assets are aging with many critical assets operating well beyond design service life causing wide spread damage and outages. As electrical equipment and systems get older, they deteriorate, causing many to fail, or more often, to yield to forces leading to higher failure rates and rendering them unable to perform as needed during periods of high stress, such as extreme summer temperatures and winter storms. They would have been able to withstand when new. Such failures cause interruptions in service to the utility’s customers, and require expensive emergency repairs and system restoration work. Aging infrastructure is at risk from extreme conditions making the power systems more vulnerable to failures that place human health and safety at risk.

Role of the Smart Grid
The promises of the Smart Grid may offer some significant advantages in reducing the footprint of some weather related outages, as well as enhancing and speeding up restoration efforts. The improved robustness of the Smart Grid, as compared to current grid systems, makes it better equipped to detect and correct supply problems in extreme weather. The Smart Grid enables the detection and pin-pointing of disruptions and facilitates actions (automatic or manual) to correct them. Where severe weather events themselves create safety and security problems, Smart Grid sensors, communication and automated operation can considerably rectify the issue.

Putting it all Together
To develop a hardening initiative needs a study. While some initiatives may be common to many different utilities, others are specific to each. Each utility must analyze the performance of its assets during the extreme weather event, and perform cost benefit analysis for hardening the system for future extreme weather events. Both capital and operations and management (O&M) costs need to be included in such analysis. Hardening alternatives should also be prioritized to ensure that the measures provide the greatest benefit.

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