Extreme Weather Effects on Power Systems

N.C. Abi-Samra, *Senior Member, IEEE* W.P. Malcolm, *Senior Member, IEEE*

***Abstract*-- Extreme weather events have resulted in widespread damage to the power infrastructure and have caused severe outages, affecting significant numbers of customers. These weather events include floods, high winds, ice storms, hurricanes and heat waves.**

***Index Terms*—Blizzards, floods, freezing rain, heat storms, ice storms, wind storms, winter storms and Smart Grid.**

I. Introduction

Extreme weather encompasses climatic variables that have sudden and sometimes destructive impacts that are especially severe, unseasonal, or at the extremes of historical distributions. Extreme weather is relative to both the historical weather record and to the regional design basis of the electric utility infrastructure. These include: floods, wind storms, winter storms, hurricanes and heat waves.

Throughout the world, electric utilities have developed special expertise in dealing with extreme weather on power systems. Because many parts of utility systems have not been designed to withstand such events, to be proactive, electric utilities spend a large amount of effort in preparation for weather that may adversely impact their systems and, after such an event, focus on learning how to respond more efficiently and effectively in the future to similar events. Such events have the importance of striking a balance between preventive and restorative measures.

This paper discusses some such lessons learned to increase system resilience, enhance the ride-through of the power grid and achieve quick restoration from such natural disasters.

II. 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.

III. Wind Storms

Wind storm occurrences throughout the world resulted in

N.C. Abi-Samra is with Accenture San Diego, California (Nicholas.Abi-Samra @Accenture.com).
W.P. Malcolm is with Accenture San Francisco, California (e-mail: Wade.p.Malcolm@Accenture.com)

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major damage to the power grid and/or led to extended disruptions in power. These included both synoptic winds as well as high intensity winds, such as small-scale downdrafts.

Examples of lessons learned from previous wind storms include:

- Localized weather effects can result in winds much stronger than those recorded at nearby weather stations. Also, records for high intensity winds need to be segregated from other wind storm records and processed independently.
- Certain grid design concepts/approaches (such as meshing and interconnection of lines) can increase system resiliency to wind storms.
- Introducing design changes to towers for hardening them before they are built is much more economical than retrofitting them later.

Tree-Related Damage

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:

- 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[1] 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.

IV. Tropical Storms (Hurricanes)

A hurricane is a storm system that produces strong winds and floods; hence, lessons learned from floods and wind storms can be applied. Although hurricanes typically lose their strength if they move over land, some, like hurricane Ike, reach locations well away from the coast but are still able to cause severe damage.

Two of the major lessons learned from the Hugo, Rita, Katrina and Ike hurricanes are that coordination and mutual assistance between utilities are of prime importance to any speedy recovery.

Other lessons learned from dealing with some major hurricanes include:

- Coordination with local fire, police and communication bodies is essential.
- Structured, ongoing communications with utilities across the region to secure assistance is irreplaceable.
- Advanced staging, as well as having detailed plans, can reduce restoration times significantly and real-time outage information, such as on-line outage maps and other tools have proven to be very important for dealing with major storms.

V. Heat Waves And Dry Spells

The World Meteorological Organization defines heat waves as a period of at least five consecutive days with a maximum temperature at least 5°C higher than the climatological norm for the same calendar day over the period

[1] A hazard tree is a tree that, due to disease or other factors, is more susceptible to falling in windstorms, or having parts of the tree fall.

1961-1990. Heat waves and dry spells are also typically talked about in the context of “climate change” and “extreme weather trends” which may impact planning and maintenance practices.

Reference [1] covers the impact of heat waves on distribution transformers and underground cables.

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.

Effects of Droughts and Heat Waves on Generators

In the past few years, faced with heat waves and droughts, a number of power plants in the United States had to curtail power generation. Solutions which have been adopted by generating stations to combat the effects of droughts include:

- Renting modular cooling towers
- Using helper towers
- Altering location or elevation of intake elevation
- Use of hybrid cooling

VI. Climate Change Considerations

Climate change is by definition a long-term change in the statistical distribution of weather patterns. It may lead to a change in the average weather conditions or a change in the distribution of weather events with respect to an average, for example, greater numbers of extreme weather events. If this involves warmer summer days, this can increase the peak load at summer-peaking utilities. More frequent warm days and, equally or even more importantly, warm nights, can stress power system components such as transformers. If components are not derated to allow for this, they may age faster and fail more frequently. As indicated in [1], distribution transformers being unable to cool at night have failed during heat waves. If more extreme wind storms occur, they can lead to more power line damages and more tree-related faults and damage.

Extreme weather events associated with climate change can impact the power system, but a true assessment of such impacts requires quantifying the rate of change of the weather extremes and comparing this to the rate of change of the power system infrastructure itself, which is typically measured in decades (e.g., ten years to plan and build a new transmission, 30 to 50 years life expectancy of a transformer, etc.). Hence, if substantial changes occur in a timescale of decades, the power system, for example, needs to address the “new normal” of extreme weather ranges through changes in planning and maintenance practices.

VII. Blizzard Of 2011 (Ground Hog Day Blizzard)

In the first week of February, 2011, ERCOT[2] reported that severe weather led to the loss of 50 generation units amounting to 7,000 MW of capacity. Initial reports at the time of writing this paper (five days after the event) described something closely resembling a “perfect storm”: *coincident loss of generation and increased load*. Some salient points from this event can be summarized as follows:

- ERCOT’s electricity demand reached 56,334 MW between 7-8 pm, a new all-time record for winter peak demand. ERCOT’s previous record for all time winter peak demand is 55,878 MW, which occurred on Jan. 8, 2010. Summer usage is higher, but winter also can bring strong demand because about two-thirds of Texas homes are heated with electricity.
- A few large coal plants failed after water pipes burst causing some power outages.
- The power outages affected some stations for compressing natural gas, leading to their unavailability to pump natural gas. This led to some gas fired power plants to go offline.
- Due to the cold weather, there was a high demand for natural gas to heat a good percentage of homes. Hence, some gas plants saw their supplies curtailed due to natural gas supply restrictions[3]. Natural gas supplies originating from Texas to other States were also affected.

[2] The Electric Reliability Council of Texas (ERCOT) manages the flow of electric power to 22 million Texas customers - representing 85 percent of the state's electric load and 75 percent of the Texas land area. As the independent system operator for the region, ERCOT schedules power on an electric grid that connects 40,000 miles of transmission lines and more than 550 generation units. ERCOT also manages financial settlement for the competitive wholesale bulk-power market and administers customer switching for 6.5 million Texans in competitive choice areas.

[3] Rules regarding “curtailment” of natural gas (last revised in 1972) give priorities to other customer classes when supplies run short.

- A larger than usual amount of generation was off-line for scheduled maintenance (~ 12,000 MW).

On the wind generation side, there were some isolated issues with a few machines because of the cold air affecting the nitrogen in the hydraulic system that helps run the turbines. The combination of very high demand and reduced supply left the ERCOT grid scarily short of reserves, which required the implementation of rotating outages to initially shed 4000 MW of load, which was then reduced to 3000 MW.

So far, this blizzard has highlighted some salient points such as:

- Emergency actions by ERCOT prevented the generation outages from causing the entire system from failing. ERCOT's emergency operations seemed to work satisfactorily, given the difficult situation.

- It is necessary to study peak load conditions during heat waves as well as severe cold events during the winter.

- ERCOT isolation from surrounding power systems prevented power companies within ERCOT from accessing excess power capacity in neighboring states and some utilities in Texas.

- There seems to be a need for better generator preparation for the extreme cold (and the hazards that the weather brings with it) in places where severe cold weather is not the norm.

- Perhaps most importantly, the blizzard has highlighted the importance of interdependences between the power system and other infrastructure. For example, some of the controlled outages idled natural gas pipeline compressor stations, reducing pipeline pressure and hampering the ability of natural gas generation plants to get fuel they needed. On the consumer side, one cable company reported intermittent loss of service after its battery backup system was drained from repeated loss of power from the grid. While the linkages between the electric power system and the utilities can't be severed, actions can be taken to make each system more resilient to problems with the other.

Finally, it is yet to be determined if the significant investment in wind power capacity in Texas over the last few years may have discouraged some added investment in natural gas infrastructures or coal powered plants. Potential reliability impacts could be seen from such scenarios as identified by NERC [6].

VIII. Is There A Role For The Smart Grid To Combat Some Of The Effects Of Extreme Weather Events?

Although this paper is not about Smart Grid, a brief mention of it is needed in the context of extreme weather events.

The complexities and uncertainties surrounding our current knowledge of climate science and occurrences of extreme weather events call for a risk management approach in dealing with the grid reliability under such conditions. For that, 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.

Of the many advantages Smart Grid has to offer, is that during heat waves, the Smart Grid can have a major impact on how to level peak demand for electricity with, for example, the help of smart appliances. Smart appliances are programmed to dial down energy usage when the grid is threatened with an overload, and are able to reconfigure the distribution system if some of its elements are lost to heat-related outages.

IX. Conclusions

Lessons learned from extreme weather events highlight the importance of improving certain design practices and emergency preparedness. An electric utility may not be as prepared for a rare weather event simply because the focus has been directed toward the weather events experienced in recent years. A utility that rarely experiences a certain type of the extreme weather can learn from other utilities that see the same weather occurrence more frequently.
To be proactive, some electric utilities spend a tremendous amount of effort in preparation for weather that may adversely impact their system and, after such events, focus intently to reflect on experiences and learn how to respond more efficiently and effectively in the future. Experience has also shown that a good emergency response is needed for quick restoration and, in addition to spare material stocks; this emergency response must include a solid emergency organization structure, agreements for mutual and regular training and mock drills of extreme weather emergencies. Because utilities can never be fully protected against extreme weather, a balanced approach is needed between prevention and restoration. Further, an incident investigation capability allows a utility to learn form a recent event and improve response for future events.

Finally, the Smart Grid will have pronounced benefits in dealing with and containing the impacts of extreme weather and enhancing the restoration of the system.

X. References And Further Readings

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XI. Biographies

Nicholas Abi-Samra (M’1977, SM’1985) Nick is a Senior Manager with Accenture’s Utilities Client Service Group. Before joining Accenture, he was a Senior Technical Executive with the Electric Power Research Institute (EPRI). He was the principal EPRI investigator into most of the major blackouts, and root-cause analysis efforts of major components failures, in the USA and abroad. Prior to EPRI, he spent 20 years at Westinghouse Electric in increasingly responsible positions including Management of the Engineering Studies Group. He managed the Electric Design Section for the US Navy Nuclear ships and submarines, and was a Westinghouse Fellow and Operations Manager of the Western Consulting Services. He has over fifty publications and is Registered Professional Engineer in California.

Wade P. Malcolm (M’1982, SM’1990) is the Global Director of Smart Grid Operations Technology for Accenture. He is actively involved in a number of intelligent networks and advanced metering initiatives. He has over 25 years of experience involving consulting, technology development and delivery, and utility operations. He is a former officer of the Electric Power Research Institute (EPRI), Powel Group, Inc. (now Powel ASA), UTILITY.COM, a former executive of SRI Consulting (formerly the Stanford Research Institute) and was previously employed by Exelon/PECO Energy. Wade is a Senior Member of the IEEE and is a Registered Professional Engineer in the Commonwealth of Pennsylvania. He earned both his Bachelor of Science in Electrical Engineering and his Master of Science in Electrical Engineering from Drexel University.