NERC

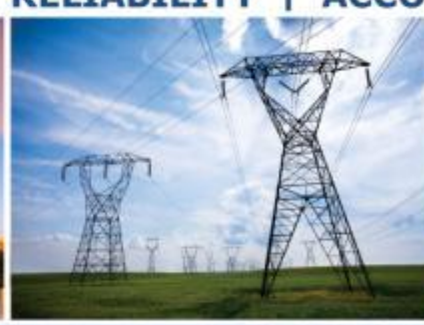
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Hurricane Sandy Event Analysis Report

January 2014

RELIABILITY | ACCOUNTABILITY



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Objective

The purpose of this report is to provide an analysis of Hurricane Sandy's impact on the bulk power system (BPS) to ensure a complete, coherent review and documentation of the event and restoration efforts. The report focuses on three main areas: 1) preparation, 2) operations during the event, and 3) restoration (to include consideration of the November 2012 Winter Storm Athena). The report is from the perspectives of the Reliability Coordinators (RCs) and summarizes the event for the entire storm area. Any questions about the contents of this report including corrections, improvements, and any suggestions please contact NERC.EventAnalysis@nerc.net.

Executive Summary

Hurricane Sandy slammed into the eastern seaboard on October 29, 2012, with massive winds and record-breaking storm surge. This inflicted massive disruptions on the electric power system in New York, New England, and the Mid-Atlantic states.

On October 22, the National Weather Service forecast that Hurricane Sandy could track up the East Coast and make landfall on the New Jersey, New York City, Long Island, or Connecticut coasts and that wherever landfall occurred, it had the potential to majorly impact the Northeast and Mid-Atlantic states. Projected impacts included significant coastal flood threat, damaging wind, and heavy rains, with the most significant effects forecast from October 29 to October 30.

NERC Regional Entities (REs), Independent System Operators (ISOs), and the potentially affected registered entities continually monitored weather developments and exchanged projections with each other. Lines and generators on maintenance were returned to service. Unit commitment and generator dispatch decisions were made to posture the system to withstand the impact of the storm and recover promptly afterward. Equipment status and capabilities were confirmed. Transmission Owners (TOs) reported several local load networks were preemptively shut down in a controlled fashion to prevent damage to equipment and speed restoration. The TOs reported that some low-lying generating units were placed into preemptive "shut-downs" to further protect assets from long-term damage from the forecast storm surge.

Hurricane Sandy made landfall on the New Jersey shore Monday, October 29, at approximately 8:00 p.m. Eastern as a post-tropical cyclone with winds of 80 MPH. The leading edge of the storm began to inflict transmission system outages on the BPS as early as 4:00 p.m. that day. As the main body of the storm progressed over the New York power system from 4:00 p.m. on the 29th through noon on the 30th, approximately 264 transmission assets tripped. These included 765, 500, 345, 230, 138, and 115 kV transmission lines, transformer banks, and Phase Angle Regulators (PARs), as well as High-Voltage Direct Current (HVDC) and Variable Frequency Transformer (VFT) interconnections. The TOs reported that due to the storm surge being so extensive, low-lying stations were flooded and became completely inoperable. Generating facilities over a very wide footprint were either forced or tripped off-line, and some generators were rendered unavailable due to the loss of interconnecting transmission. Over the course of the event, 20,007[1] MW of generation capacity was rendered unavailable. The distribution system was also severely damaged. By late Monday, October 29, approximately 8.35[2] million electric customer outages were reported across the impacted area.

The recovery effort was initiated by the transmission, distribution, and generation asset owners. The initial recovery consisted of inspections and asset assessments. The equipment owners' initial assessments were greatly hampered by flooding and the unavailability of roads. The priority, as communicated by the utilities, was to the restore transmission assets to generating facilities needed for distribution load recovery. While there was sufficient generation capacity available to meet the load as restoration progressed, there were some cases where customer restoration was hindered by local area transmission outages. This includes instances in which substations were so severely damaged, they did not allow power to be delivered to the distribution system. Most entities returned 95 percent of their customers to service between November 1, 2012, and November 9, 2012. Only the Long Island area of New York, which was one of the hardest-hit areas, reported having restored fewer than 95 percent of customers by November 9, 2012.

[1] This includes 8,121 MW lost from NYISO, 9,586 MW from PJM, and approximately 2,300 MW from ISO-NE.

[2] This consists of 4.78 million customers in PJM, 2.22 million in NYISO, and 1.37 million in ISO-NE.

Background

Pre-existing System Conditions

Pre-existing conditions for all areas were considered normal for late October, which is generally considered an off-peak season for the Mid-Atlantic and New England areas of the United States. During these times, asset owners typically try to take advantage of the seasonal temperatures and the corresponding lower system demands to perform system maintenance and upgrades.

Affected Areas

Hurricane Sandy affected many entities in New England and the Mid-Atlantic states. In PJM, these areas included northern and central New Jersey and eastern Pennsylvania (Bucks, Montgomery, Chester, and Philadelphia Counties in the southeast, as well as Allentown, Easton, Stroudsburg, Wyoming, Limerick, and Scranton). To the west, areas affected by Hurricane Sandy's devastation included Ashtabula and West Akron, Ohio. Areas affected farther south stretch from Maryland to Kentucky, specifically Rising Sun, MD; Mt. Storm, VA; Clayton, Beckley, Princeton, Wise, Charleston, and Huntington, WV; and Pine Mountain, Paynes Gap, Jenkins, and Elko, KY.

In the NYISO footprint, the following service areas had significant impacts: New York City, Long Island, and portions of the Hudson River Valley (including portions of the service territories of Con Edison, Central Hudson, Orange & Rockland, and NYSEG/RGE).

Finally, ISO-NE reported impacts to the following local control centers (LCCs): Central Maine Power, Connecticut Valley Electric Exchange (Convex), NSTAR, New Hampshire REMVEC, and VELCO.

Time Frame for Outage and Restoration

None of the generator or transmission losses required load curtailments to maintain BPS security. Despite the catastrophic nature of the storm and the high number of transmission line outages, the hard-hit areas of Long Island and New York City remained connected to the Eastern Interconnections. Throughout the storm and during the recovery period, utilities were able to operate within power transfer limits.

Table 1: Restoration Times Reported by NYISO, ISO-NE, and PJM

Member	Restoration Start Date	Restoration End Date	Length of Restoration
PJM	10/29/2012	11/28/2013	31 days
NYISO	10/29/2012	11/09/2012	12 days
ISO-NE	10/29/2012	11/04/2012	7 days

Weather

Weather Alerts

Weather Systems and Notifications

The utilities and ISOs of the Mid-Atlantic and ISO-NE areas all use various weather tools to monitor current and forecast weather. The most often used tools or services are TELVENT (seven entities), NOAA (seven entities), staff meteorologists (four entities), AccuWeather (three entities), and private vendors (two entities). Other weather services in use are MDA EarthSat, Earth Networks, Send Word Now, Weather.gov, Murray & Trettel, Meteorlogix, PJM SOS-T calls, Weather Underground, The Weather Channel, and ImpactWeather. Various control centers also use local and national television and radio forecasts.

Table 2 is a summary of the methods used by the various utilities and ISOs. Weather services that have only one user in the affected area are accounted for in the "other" category.

Table 2: Weather Services Used by Utilities and ISOs

Entity	TELVENT	NOAA	AccuWeather	Staff Meteorologists	Private Vendor	Other[3]
PJM	X	X				XX
PPL/UGI	X					
First Energy		X			X	
AEP				X		
Linden VFT						XX
EP Rock Springs		X				X
DLC			X			
PECO	X	X				XXX
BGE					X	
Constellation Nuclear Group		X				XXX
Exelon Nuclear				X		
Dominion				X		
PSE&G	X		X			
ACE, Delmarva, and Pepco	X	X				XX

[3] Some companies use more than one "other" source for weather information. The number of X's in the box represents the number of other sources used. Services represented by "other" include MDA EarthSat, Earth Networks, Send Word Now, Weather.gov, Murray & Trettel, Meteorlogix, PJM SOS-T calls, Weather Underground, The Weather Channel, and ImpactWeather, as well as local and national news services.

Table 2: Weather Services Used by Utilities and ISOs						
Entity	TELVENT	NOAA	AccuWeather	Staff Meteorologists	Private Vendor	Other[3]
NYISO	X	X				
ConEd				X		
ISO-NE	X	X				

Timing of Warning Systems and Action Taken

Initial information regarding the potential threat of Hurricane Sandy was received on October 22, 2012; the majority of entities were actively monitoring the storm by October 25, 2013. As a result of these warnings, the following actions occurred:

- Senior management was informed and updated on the situation;
- Conference calls were held daily or more frequently with both weather services and other entities to discuss Sandy’s track and forecast path;
- Conference calls and all-calls were held daily or more frequently to keep members up to date and effectively plan coordination;
- Communication and coordination with LCCs was increased to prepare for storm impacts;
- Facilities were secured for heavy weather;
- The status and readiness of generation and transmission resources were determined;
- Emergency Response Organizations were activated;
- Employees were provided with the incoming weather and changes to daily schedules;
- Plans for supplemental operations and support staffing were developed and/or implemented;
- Predicted wind speeds and directions were monitored to determine most critical time frames;
- Procedures and checklists were reviewed;
- Outages were postponed;
- Data were shared and Regional Mutual Assistance groups were engaged; and
- More frequent forecasts were issued to employees to assist in their storm preparation plans.

Entities continued to monitor the storm in the days leading up to landfall. Table 3 provides a record of the development of the severity of the hurricane as projected for time of landfall, magnitude of surge, impact of tides, and wind speed projections. The staffs of the various ISOs also took steps to prepare the system for the storm impact and the recovery effort that was sure to follow. Please see the storm preparation actions in Section 5: “Preparation and Results Achieved” for more detail.

Table 3: Hurricane Sandy NYISO[4] Storm Advisory Report Timeline								
Forecast Date Time	**Land Fall**	**Max Sust. Wind**	**Max Wind Gust**	**Storm Surge NYC (60/40)**	**Storm Surge NYC (90/10)**	**Storm Surge Long Island (60/40)**	**Storm Surge Long Island (90/10)**	**Timing of Max Wind and Surge**
10/26 2:00 PM	30 Oct., midnight–8:00 a.m., Southern NJ	75 MPH	95 MPH	N/A	N/A	N/A	N/A	N/A
10/27 8:00 a.m.	30 Oct., midnight–8:00 a.m., Southern NJ	75 MPH	95 MPH	High tide coastal flooding concern	High tide coastal flooding concern	High tide coastal flooding concern	High tide coastal flooding concern	30 Oct., early morning
10/27 11:00 a.m.	29 Oct., 2:00 p.m.–midnight, Southern NJ	65 MPH	85 MPH	High tide coastal flooding concern	High tide coastal flooding concern	High tide coastal flooding concern	High tide coastal flooding concern	30 Oct., early morning
10/27 2:00 p.m.	29 Oct., 2:00 p.m.–midnight, Southern NJ	65 MPH	85 MPH	7–9 ft	13–15 ft	7–9 ft	13–15 ft	29 Oct., afternoon and evening
10/27 5:00 p.m.	29 Oct. 4 pm - midnight in Southern NJ	65 MPH	85 MPH	7–9 ft	13–15 ft	8–10 ft	14–17 ft	29 Oct., afternoon and evening
10/27 8:00 p.m.	29 Oct. 4 pm - midnight in Southern NJ	65 MPH	85 MPH	9–11 ft	17–19 ft	8–10 ft	16–18 ft	29 Oct., afternoon and evening
10/28 8:00 a.m.	29 Oct. 6 pm - midnight in Southern NJ	65 MPH	85 MPH	9–11 ft	17–19 ft	8–10 ft	16–18 ft	29 Oct., afternoon and evening
10/28 11:00 a.m.	29 Oct., 6:00 p.m.–midnight, Southern NJ	75 MPH	90 MPH	9–11 ft	17–19 ft	10–15 ft	16–18 ft	29 Oct., afternoon and evening

[4] As reported from NYISO_Hurricane_Sandy_EAR Pg. 5

Table 3: Hurricane Sandy NYISO[4] Storm Advisory Report Timeline								
Forecast Date Time	**Land Fall**	**Max Sust. Wind**	**Max Wind Gust**	**Storm Surge NYC (60/40)**	**Storm Surge NYC (90/10)**	**Storm Surge Long Island (60/40)**	**Storm Surge Long Island (90/10)**	**Timing of Max Wind and Surge**
10/28 2:00 p.m.	29 Oct., 6:00 p.m.–midnight, Southern NJ	75 MPH	90 MPH	9–11 ft	17–19 ft	10–15 ft	16–18 ft	29 Oct., afternoon and evening
10/28 5:00 p.m.	29 Oct., 6:00 p.m.–midnight, Southern NJ	80 MPH	90 MPH	9–11 ft	17–19 ft	10–15 ft	16–18 ft	29 Oct., afternoon and evening
10/28 8:00 p.m.	29 Oct., 6:00 p.m.–midnight, Southern NJ	80 MPH	90 MPH	9–11 ft	17–19 ft	10–15 ft	16–18 ft	29 Oct., afternoon and evening
10/29 5:00 a.m.	29 Oct., 6:00 p.m.–midnight, Southern NJ	75 MPH	85 MPH	14–16 ft	18–20 ft	12–14 ft	17–19 ft	29 Oct., 8:00 p.m. high tide
10/29 10:00 a.m.	29 Oct., 6:00 p.m.–midnight, Southern NJ	75 MPH	85 MPH	14–16 ft	18–20 ft	12–14 ft	17–19 ft	29 Oct., 5:00–10:00 p.m. 2–4 ft surge at 10:00 a.m. in NYC
10/29 11:00 a.m.	29 Oct., 6:00 p.m.–10:00 p.m., Southern NJ	85 MPH	100 MPH	14–16 ft	18–20 ft	12–14 ft	17–19 ft	29 Oct., 5:00–10:00 p.m. 2–4 ft surge at 10:00 a.m. in NYC
10/29 2:00 p.m.	29 Oct., 7:00 p.m.–10:00 p.m., Southern NJ	85 MPH	100 MPH	14–16 ft	18–20 ft	12–14 ft	18–20 ft	29 Oct., 8:00 p.m. high tide. 4–6 ft surge at 10:00 a.m. in NYC
10/29 4:00 p.m.	29 Oct., 8:00 p.m.–10:00 p.m., Southern NJ	85 MPH	100 MPH	14–16 ft	18–20 ft	12–14 ft	18–20 ft	29 Oct., 8:00 p.m. high tide. 4–6 ft surge at 10:00 a.m. in NYC

Table 3: Hurricane Sandy NYISO[4] Storm Advisory Report Timeline								
Forecast Date Time	**Land Fall**	**Max Sust. Wind**	**Max Wind Gust**	**Storm Surge NYC (60/40)**	**Storm Surge NYC (90/10)**	**Storm Surge Long Island (60/40)**	**Storm Surge Long Island (90/10)**	**Timing of Max Wind and Surge**
10/29 8:00 p.m.	Landfall around 7:30 p.m.	75 MPH	100 MPH	14–16 ft	18–20 ft	12–14 ft	18–20 ft	Occurring
10/29 11:00 p.m.	Last update storm dissipating	75 MPH	85 MPH	Receding	Receding	Receding	Receding	Improving in next 4–8 hrs

Benefits of On-site Meteorologists

All entities that have on-site meteorologists reported it as beneficial because it allows forecasts to be more narrowly tailored for the entity's particular areas of interest. One entity that stated it was beneficial to have a meteorologist on staff further commented as follows:

> Our meteorologist relates the various weather forecast data into actionable information the company can use to prepare and respond to a weather event.
>
> Weather forecasts and meteorological data received from outside sources are technical and require training to interpret. Often, there are varying solutions for one specific weather event resulting in disagreement between various weather forecasts. The in-house meteorologist provides insight into what the variances are and how they could impact the Company. Additionally, most of the weather information is not company-specific. The forecasts can be for a broad area that is bigger than [our] territory. Our in-house meteorologist uses his weather expertise combined with the knowledge of the Company to customize the weather forecasts for our specific need.
>
> Our meteorologist also conducts research and performs analyses on weather events that help the company to become more aware of its weather tolerances so that it can prepare and mitigate when appropriate.[5]

Storm Weather Updates During Event

In general, the various ISOs and utilities continued to broadcast and communicate critical information to crews, neighbors, and other impacted systems throughout the event. Some of the various methods used were:

- Conference calls
- Information broadcasts
- Emailed and paged alerts
    - Alerts were sometimes supplemented by videos or graphic clips that provided more detail.

While the frequency of these updated calls varied by entity from four to 12 hours, all members felt the frequency of updates to crews, neighbors, and ISOs was sufficient to keep all parties informed of the critical information.

[5] NYISO_Hurricane_Sandy_EAR Pg. 6

Storm Weather Updates Following Event

Various ISOs and utilities continued to monitor the weather after Hurricane Sandy. Of particular interest was the potential of another major weather system that ended up developing into Winter Storm Athena. Entities dealt with this information in various ways, including twice-a-day conference calls, updates upon request, and continued monitoring of weather forecasts.

Weather Impacts on Restoration Efforts Gleaned from Comparable Storms

Entities have learned from previous events that sites with a history of flooding need to be monitored. For example, FirstEnergy monitored sites that had a history of flooding from Irene. PPL, DPC, CENG, and others learned about similar issues—and potential vulnerabilities, such as what might be useful if a water main were to break during a major storm—from Hurricane Irene, Tropical Depression Lee, and Hurricane Ivan.

Storm Severity

In New England, Hurricane Sandy severely impacted many regions with record wind and storm surge, resulting in a 14 foot storm surge in Manhattan at the Battery monitoring station, and high winds, coastal flooding, and heavy rain throughout the region. The most significantly impacted regions were southern New England, New York City, Long Island, and New Jersey. Hurricane Sandy was an intense storm, as detailed by this excerpt from the National Weather Service's report, *New England Effects from the Hurricane Sandy Hybrid Storm*:

> Sandy, a hybrid storm with both tropical and extra-tropical characteristics, brought high winds and coastal flooding to southern New England. Easterly winds gusted to 50 to 60 mph for interior southern New England; 55 to 65 mph along the eastern Massachusetts coast and along the I-95 corridor in southeast Massachusetts and Rhode Island; and 70 to 80 mph along the southeast Massachusetts and Rhode Island coasts. A few higher gusts occurred along the Rhode Island coast. A severe thunderstorm embedded in an outer band associated with Sandy produced wind gusts to 90 mph and concentrated damage in Wareham early Tuesday evening, a day after the center of Sandy had moved into New Jersey. In general, moderate coastal flooding occurred along the Massachusetts coastline, and major coastal flooding impacted the Rhode Island coastline. The storm surge was generally 2.5 to 4.5 feet along the east coast of Massachusetts, but peaked late Monday afternoon in between high tide cycles. Seas built to between 20 and 25 feet Monday afternoon and evening just off the Massachusetts east coast. Along the south coast, the storm surge was 4 to 6 feet and seas from 30 to a little over 35 feet were observed in the outer coastal waters. The very large waves on top of the storm surge caused destructive coastal flooding along stretches of the Rhode Island exposed south coast.

Challenge of Wind and Flooding (Coast) and Snow and Ice (Inland)

The safety of personnel, fallen or damaged trees, salt water damage, impassable roads, and damage that delays or prevents access to stations are all challenges of wind, heavy snow, and flooding. Some safety practices restrict what can be done in adverse conditions. For instance, work from insulated aerial lifts or work from poles or structures should be discontinued during adverse weather (e.g., sustained winds exceeding 40 MPH or 30 MPH if material handling is involved); flooding will delay response until the waters have receded to a safe level.

Snow caused delays to helicopter aerial patrols until October 31, 2012. Severe icing on transmission lines delayed the re-energizing of those circuits. Heavy snowfall in mountainous areas required additional effort and equipment to restore downed power lines and poles.

Exelon Nuclear required load reductions at LGS because of high winds. Further power reductions were required at LGS due to excessive leaf accumulation on cooling tower screens and service water pump suction strainers. High winds caused the loss of off-site power and resulted in a block wall separating voltage regulators in the switchyard to fall at Oyster Creek. The emergency plan at Oyster Creek was activated by a high water level at the intake structure.

Other Storm Severity Issues

The high winds caused many problems, including significant damage to distribution facilities. Roads became impassable as a result of snow and downed trees. The barrier islands were initially inaccessible to responding crews because of concerns for biohazards and leaks. Delivery of material and services was delayed by road closures. Wires, poles, road closures, substations, and other devices on systems were compromised.

Additionally, ConEd Reported:

> The toll the storm took on our electric systems was astounding. We lost five transmission substations and 4,000 MW of generation. In total, 14 Manhattan networks, one Brooklyn network, and three Staten Island area substations were shut down. Our overhead systems were devastated by wind and tree damage leaving nearly 70 percent of those served by the overhead systems without power. The overhead distribution system suffered a loss of nearly 1000 utility poles, more than 900 transformers, and approximately 140 miles of cable. In comparison to Hurricane Irene, we lost 10 times as many poles, more than five times as many transformers, and more than four times as many miles of cable.
>
> Overall, the storm caused more than one million Con Edison customers to lose electric power – five times the previous largest storm of 204,000 customer outages during Hurricane Irene. We also isolated roughly 30 miles of steam mains to prevent catastrophic damage, causing roughly a third, or 561, of our steam customers to lose service. Another 4,200 customers experienced gas outages as a result of the storm.[6]

Storm Comparison

Comparison of Sandy to Other Storms (Customer Outages, Extent of Outages)

The Northeast has experienced several other recent significant storms, including Hurricane Irene in August of 2011 and the late October Snowstorm of 2011, and all have had significant yet different impacts on the transmission system. The storms, including Sandy, had varying levels of intensity, different types of precipitation, and different geographical trajectories. Hurricane Irene hit the region as a high-impact tropical storm with a track crossing through Connecticut and Western Massachusetts. Hurricane Sandy made landfall in New Jersey as post-tropical cyclone that tracked into central Pennsylvania. The most comparable storms, in terms of type of precipitation experienced, were Hurricane Irene and the 2012 Derecho.

ConEd Reported:

> Superstorm Sandy was the largest tropical cyclone ever observed in the Atlantic Ocean, with a diameter extending approximately 820 miles. Approximately 8.5 million customers throughout the eastern U.S. lost power during Sandy. The storm's impact on our service territory was twofold: powerful wind gusts up to 90 miles per hour brought down trees and power lines, and an unprecedented 14-foot storm tide breached shorelines and available flood-protection measures, inundating facilities and underground equipment.

[6] NYISO_Hurricane_Sandy_EAR Pg. 7

> Sandy's actual storm surge of 14.06 feet exceeded all official forecasts, surpassing a reported historical record set in 1821 by nearly three feet. More recently, the 1992 Nor'easter brought the worst flooding we had experienced up to that time, with a storm surge that was 4.5 feet lower than Sandy.[7]

Some entities in PJM, particularly those that were not on the coast, such as Allegheny Power and AEP, experienced greater damage in other storms, such as the 2012 Derecho storm. However, the damage that Jersey Central Power & Light Company, ConEd, PPL, and others experienced from Hurricane Sandy exceeded that caused by both Hurricane Irene and the Derecho storm. In fact, PPL reported that Sandy was the most damaging storm to PPL since record keeping began.

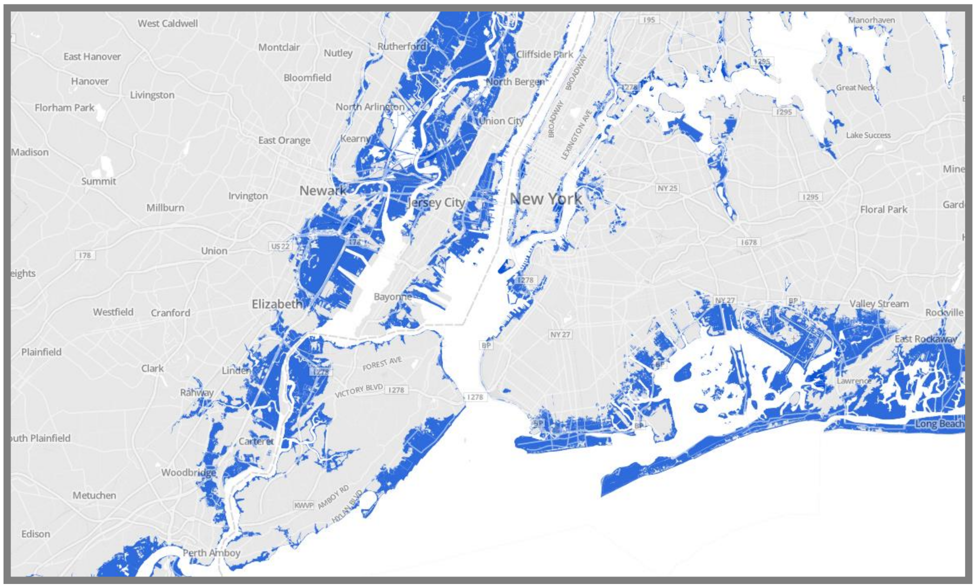
Table 4: Outage Comparisons

Member	Sandy Outages (Oct. 2012)	Irene Outages (Aug. 2011)	Derecho Outages (June 2012)
PJM	4,778,905	3,520,451	3,853,162
NYISO	2,222,337	177,187	N/A
ISO-NE	1,370,000	2,100,000	N/A

[7] NYISO_Hurricane_Sandy_EAR Pg. 7-8

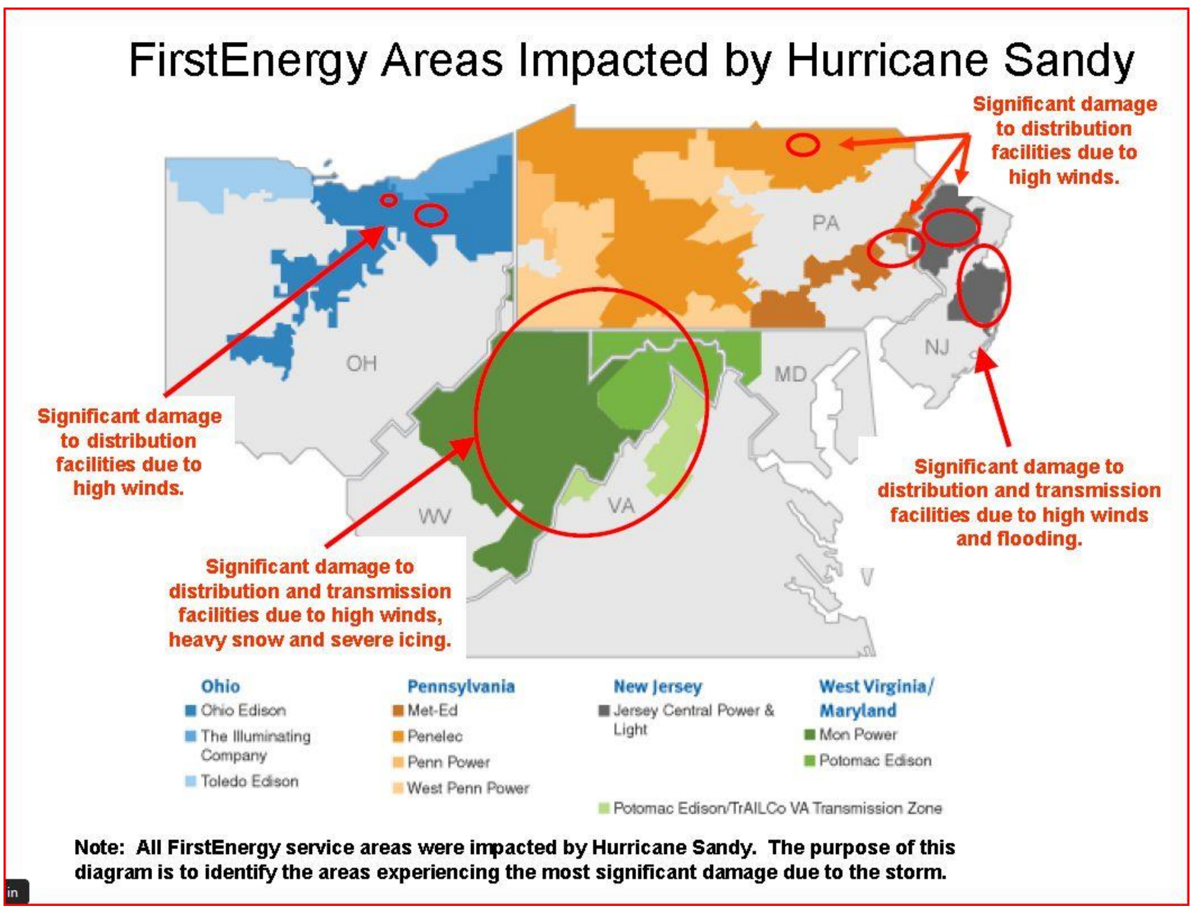
Maps of Impacted Areas

Areas that Flooded

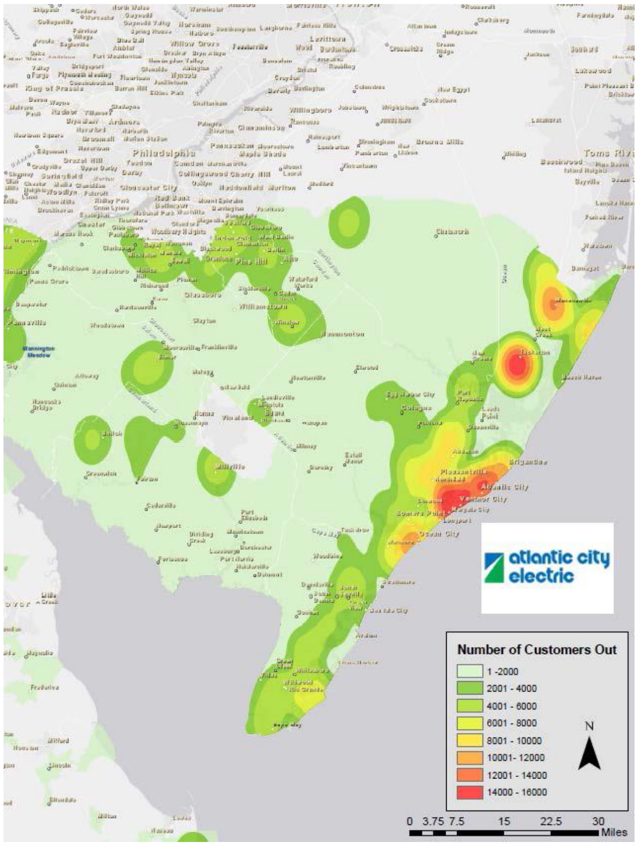


Source: http://project.wnyc.org/flooding-sandy-new/index.html#11.00/40.6846/-74.0224 1

conEdison ON IT



First Energy Impacted Area


atlantic city electric
Number of Customers Out
1 -2000
2001 - 4000
4001 - 6000
6001 - 8000
8001 - 10000
10001- 12000
12001 - 14000
14000 - 16000
N
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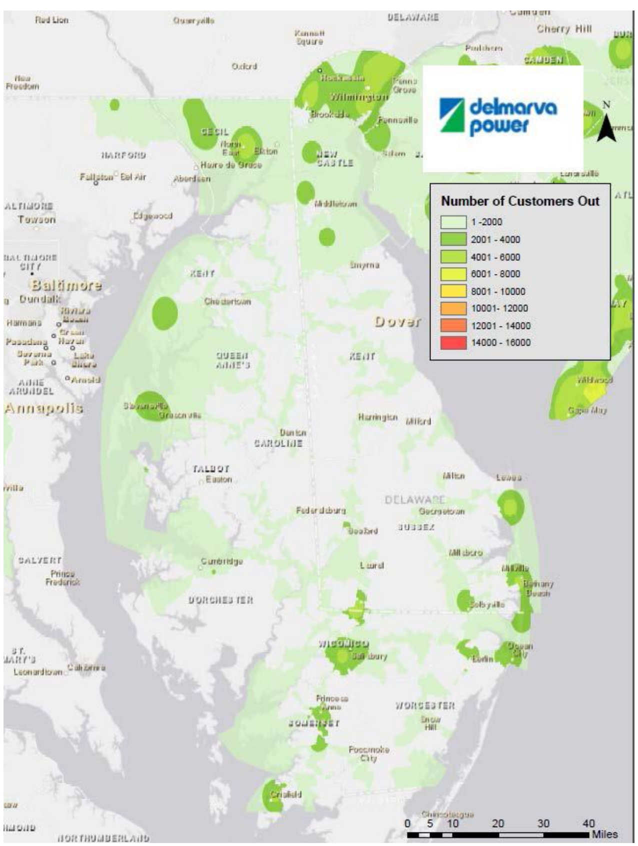
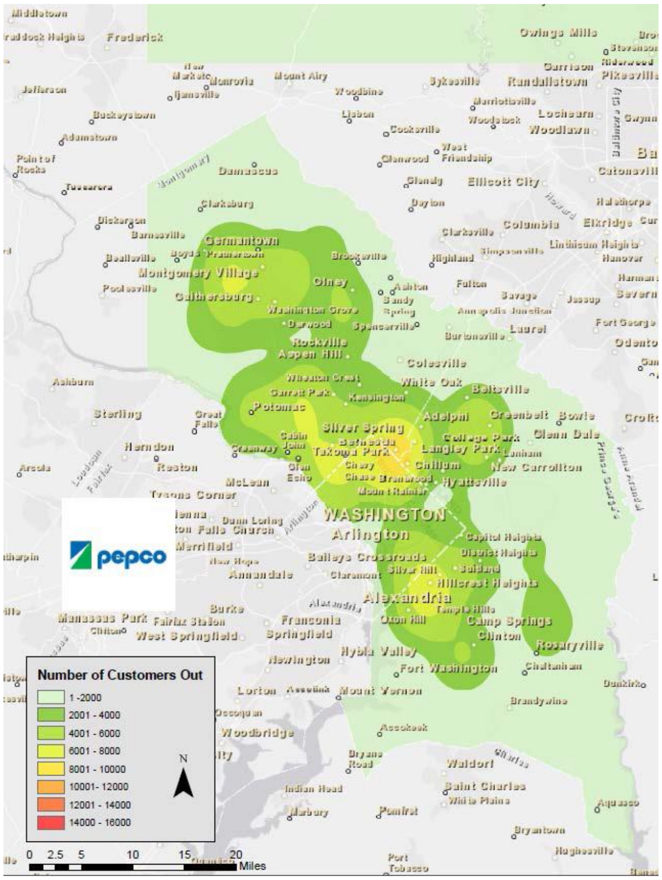
Miles


delmarva power
N
Number of Customers Out
1 -2000
2001 - 4000
4001 - 6000
6001 - 8000
8001 - 10000
10001- 12000
12001 - 14000
14000 - 16000
0 5 10 20 30 40
Miles


pepco
Number of Customers Out
1 -2000
2001 - 4000
4001 - 6000
6001 - 8000
8001 - 10000
10001- 12000
12001 - 14000
14000 - 16000
N
0 2.5 5 10 15 20
Miles
WASHINGTON
Arlington
Alexandria
Silver Spring
Rockville
Germantown
Gaithersburg
Columbia
Ellicott City

Preparation and Results Achieved

ReliabilityFirst, Northeast Power Coordinating Council, NYISO, ISO-NE, and PJM, in conjunction with NERC Situational Awareness, coordinated storm preparation plans with the Transmission Owners, Generation Owners, Balancing Authorities, and other registered entities within the area forecasted to be impacted. Entities worked to ensure that sufficient numbers of additional field operation crews were scheduled and available to respond to the expected storm disruptions.

Where possible, previously scheduled outages were postponed to ensure that facilities would be available over the next several days; generators were advised of expectations during the storm, which included the potential for abnormal dispatch instructions. Blackstart units were also contacted to confirm that the units had fuel sufficient and available to run for an extended duration.

Concerns regarding potential impacts of the coming storm included:

- The unpredictable nature of the impending load loss
- The potential for high voltages due to the load loss
- The potential for Minimum Generation Emergency conditions due to the load loss
- The potential for substation flooding along the Connecticut shoreline
- The potential for post-storm restoration efforts that would be aided by having generators in a ready, or "hot," condition
- The need for fuel diversity across the system
- The potential for restrictions on flows across major flowgates to limit the ability to import emergency power

Preparation and Effectiveness of Forecasted Hurricane Force Winds and Unprecedented Storm Surge

Entities across the impacted area made the following special preparations:

- Existing storm preparation plans activated
- Helicopters staged inland for aerial patrols
- Sandbags and barriers deployed to substations
- Debris in substations inspected and removed
- Operational status of roof and sump pumps inspected and confirmed
- Loose equipment and materials in substations inspected and secured
- Substations manned with qualified personnel to provide situational status to emergency operations center
- Plans made to de-energize barrier islands to minimize equipment damage and allow for quicker restoration
- Labor, equipment, and materials acquired to allow for a quicker start at restoration
- Critical mobile equipment moved to the mainland to protect against damage
- Service vendors contacted
- Additional field resources scheduled

- All available transmission and generation outages returned to service
- NYISO requested information from coastal generating stations regarding the level of surge that would necessitate that the plants be forced to shut down and developed a capacity-at-risk table based on that surge level (see Table 4).
- Status of Special Protection Systems (SPS) in eastern New York confirmed
- Dynamic re-ratings implemented for key facilities in the Hudson Valley
- Thunderstorm Alert implemented
    - Thunderstorm Alert expanded the contingency list that the NYISO dispatch used to include select N-2 contingencies. The Thunderstorm Alert had the effect of bringing additional units on-line in southeastern New York, unloading transmission and increasing downstate reserves.

While the above were for the most part effective, the below preparation did not have the desired impact:

- Aqua Dams deployed in the ConEd system were generally ineffective against the unprecedented storm surge.

Special Preparations for Areas Expecting Snow and Ice

Entities that were in the forecast impact area for Winter Storm Athena all brought on additional labor, material, and equipment to quickly begin assessment and restoration.

Communications with Neighbors

Entities convened or participated in numerous conference calls and broadcasts. They also communicated with the mutual assistance groups to which they belonged. These calls began October 27, 2012, and continued through the restoration effort, with some lasting though November 9, 2012.

Regional and Inter-regional Calls

On Sunday, October 28, the first in a series of NPCC daily conference calls began. On the initial Sunday conference call, ISO-NE reported scheduling 3,100 MW of off-economic dispatch generation commitments for reliability purposes. This was done in anticipation of the loss of coastal generation stations. PJM reported scheduling 4,000 MW of reliability generation commitments for the possible loss of coastal nuclear stations. These regional conference calls were an important means of monitoring and communicating events with adjacent Reliability Coordinators, and they continued daily throughout the storm.

In addition, gas pipelines were contacted and notified of the impending storm and the implementation of M/LCC 2 (Abnormal Conditions Alert); they were requested to advise ISO-NE of any special procedures or anticipated abnormal conditions. All gas pipelines implemented their hurricane preparedness plans for the Northeast Region, which included checking on-site generators for compressor stations and reviewing staffing plans and facility flood plans.

Additional Staffing (RC, TOP, and TO Levels)

Entities resourced various staff to address additional requirements before, during, and after the storm. Some of these included:

- Using unassigned personnel and training shift personnel
- Assigning additional operators and supervisors to shifts
- Assigning director-level management to control locations

- Assigning qualified personnel to substations
- Requesting and receiving assistance from mutual assistance crews from approximately 100 companies representing 34 states and Canada
- Requesting and receiving substation support from various manufacturers and contractors
- Placing limits on IT maintenance, cancelling all scheduled maintenance on critical IT systems, and ensuring that critical computer maintenance issues were approved by operations personnel prior to being implemented

The majority of increased staffing was in the restoration area (vegetation management crews, substation crews, and line crews). Additional areas that received increased staffing were operations centers, primary control centers, backup control centers, and customer service centers.

Manning Substations

Many of the entities assigned qualified personnel to normally unmanned substations prior to the storm. Others assigned personnel to substations if communications were to be lost during the storm. Their tasks included providing situational status reports to operations centers and monitoring and patrolling substations that had previously experienced high water. For unmanned stations, operators were typically located at other nearby substations that could be easily redirected if necessary.

Sandbagging Facilities in Storm Surge Zone

In some areas, the combination of sandbagging with other flood remediation equipment, such as flood doors, etc., was effective; in others, the heavy storm surge overwhelmed many of the sandbag levies. In particular, the Aqua Dams installed by ConEd were ineffective. ConEd described the dams as large, polyethylene, water-filled berms that act as a dam to contain and control surrounding water. The berms were filled to a height of 4 feet and were interconnected around the critical facilities. The heavy storm surge eventually dislodged the berms, making them ineffective in protecting the equipment.[8]

Pre-positioning Storm Transmission System Equipment

In general, only a few companies pre-positioned restoration equipment. Others took stock of inventory, reviewed current materials designated to other projects, and determined which would be diverted for storm restoration.

Pre-positioning Storm Restoration Crews from Foreign Systems

While equipment was generally not pre-positioned, most entities did pre-position restoration crews when possible. When restoration crews are positioned at pre-planned locations—usually close to the places most likely to be hardest hit—the restoration process becomes streamlined and more efficient. Much of this pre-positioning of crews, though, only refers to an entity's own system. Mutual assistance is typically deployed once a storm passes and impacted companies have completed their damage assessment. This approach allows the supporting utilities to equitably divide the available resources based on the needs of the requesting companies. This also allows entities to request specific needs, such as digging crews, damage assessors, line crews, vegetation management crews, etc. to allow for the best use of these resources during the restoration effort.

It is also important to keep in mind that flexibility and assessment are needed for situations like this, especially when there is heavy damage in unexpected areas. Some entities that pre-positioned crews found that they needed to redeploy those crews to other harder-hit areas.

[8] NYISO_Hurricane_Sandy_EAR pg 15

Damage to BPS

Overview

Damage to BPS Facilities Due to Wind, Snow, Ice, and Flooding

Several companies, including American Electric Power, FirstEnergy, PPL, Linden VFT, UGI, Exelon Nuclear, and Public Service Gas and Electric, reported significant damage to BPS facilities and subtransmission facilities. This damage also extended to the distribution level. Examples of the types of damage include:

- Conductor and static wire damage
- Broken poles and crossarms
- Damage from trees being blown into the right-of-way
- Flooding of Variable Frequency Transformers
- Salt water intrusion damage
- Broken or damaged insulators

Damage to BPS Reliability

Each of the Reliability Coordinators (NYISO, ISO-NE, and PJM) asserted that the damage caused by Sandy was significant, but that at no time did Sandy impact the overall reliability of the BPS.

Affected Transmission Facilities

Affected Transmission Facilities (by voltage class[9]):

- 765-kV lines (1)
- 500-kV lines (10)
- 345-kV lines (31)
- 230-kV lines (33)
- 138-kV lines (127)
- 115-kV lines (16)
- 345/138 & 345/115-kV transformers (17)
- 230/115-kV transformers (4)
- 138-kV Phase Angle Regulators (7)
- 230-kV substations (8)
- 138-kV substations (10)

Affected Generation Facilities

Nuclear Generation

The following units were affected by the storm:

- Limerick Generating Station (Exelon Nuclear) experienced reduced power during the storm but remained online.
- Nine Mile Point, Unit 1 (CENG) experienced loss of transmission exits from the plant. The unit did not, however, experience any storm damage. Offsite power was maintained.

[9] These are best estimates of outages as provided by NYISO, PJM, and ISO-NE.

- Indian Point, Unit 3 (Entergy) experienced loss of transmission exits from the plant. The unit did not experience any storm damage. Offsite power was maintained.
- While not impacted directly by Sandy, the following nuclear plants were offline for refueling prior to the storm:
  - Oyster Creek
  - Beaver Valley 2

Damage

Exelon Nuclear's Limerick Generating Station plant is the only nuclear station that was damaged by Hurricane Sandy. It experienced a temporary loss of condenser vacuum and service water and, due to the loss of transmission system load, experienced high voltage. The Oyster Creek plant had a temporary loss of off-site power due to switchyard damage and a bushing on a voltage regulator associated with the Bank 6 transformer.

Identified Nuclear Safety Issues (Inc. Loss of Off-Site Power)

During loss of off-site power at Exelon Nuclear's Oyster Creek, the reactor shutdown cooling and spent fuel cooling was temporarily lost but was restored when emergency diesels started and loaded.

Lessons Learned from Storm Preparation or Operations

Five potential lessons learned were identified for generation stations during the storm:

- Communication:
  - ISOs/RCs need to improve communication with generation plants during major events.
  - ISOs/RCs should develop or document alternate communications methods when normal methods are lost.
- More comprehensive weather preparation procedures need to be developed.
- Improvements can be made for managing personnel who remain on-site.
- Development of anticipated generation reductions is necessary for the loss of one or more nearby transmission elements.

Wind Generation Damage

No damage was reported, but some wind units tripped due to the high winds, resulting in 323 MW of unavailable wind capacity.

Fossil Generation

Flooded Stations

Fossil units were forced off both pre-storm (in anticipation of potential flooding) and as the stations flooded. A total of 16,738 MW of generation capacity became unavailable as a result. Because of the amount of load preemptively off or unavailable to the distribution system, this loss did not result in any capacity issues.

Generation Taken Off-line in Preparation of Storm

NYISO declared approximately 546 MW[10] of generation unavailable in anticipation of the storm.

[10] NYISO included 300 MW of preemptive generation reduction in their report on pg. 26 of the NYISO report. However, after consultations with NPCC, it was concluded that the 546 MW of preemptive generation reduction as reported on in table 4A on pg. 19 of the NYISO report was the correct amount.

Generation Tripped During Storm

A total of 16,738 MW[11] of generation capacity became unavailable as a result of the storm. This loss did not result in any capacity issues.

Hydro Generation

According to a supplemental update from RFC and PJM, there was 36 MW of hydro capacity. Neither NYISO nor ISO-NE experienced any capacity loss.

DCS Events Related to the Storm

There were two NPCC Disturbance Control Standard (DCS) criteria events related to the storm. At 21:03 on October 29, Reserve Pick Up (RPU) and Shared Activation of Reserve (SAR) were initiated for the loss of Nine Mile 1, loaded at 622 MW. ACE crossed zero and the RPU was terminated at 21:08; SAR was terminated at 21:20. At 22:43 on October 29, RPU and SAR were initiated for the loss of Indian Point 3 plant, loaded at 1050 MW. ACE crossed zero and the RPU was terminated at 22:47; SAR was terminated at 22:55. In both cases the system response was within criteria.

Generator Returns (Inhibition by Reduced Load, Transmission Damage)

Several units were delayed from returning to service or needed to operate at reduced power due to transmission or load pickup. This resulted in 11,681 MW[12] of unavailable power due to transmission damage.

Generation Operation Risks During Storm

Several generation operation risks were identified during the storm. These include:

- Increased potential for Loss of Off-site Power (LOOP) to nuclear facilities.
- Possibility of LOOP due to switchyard damage, or loss of normal condenser cooling and loss of availability of service water due to high water.
- Precipitator fly ash buildup and higher gas flow pressure due to operating without auxiliary feeds.
- Curtailments due to wet coal, which is normal with any significant precipitation.
- Danger from the loss of building siding.
- Potential lack of fuel due to damage to the fuel provider's facilities.

[11] Includes 6,449 MW from NYISO, 2,300 from ISO-NE and 7,989 MW total from Fossil, Combustion Turbine, and Combined cycle units
[12] This is a combination of 3,560 MW of generation in PJM and 8,121 from NYISO.

Operations

Conservative Operations and Operational Challenges

Conservative Operations Mode or Emergency Procedures Implemented During Storm

Due to the overwhelming power of Hurricane Sandy, many of the entities affected by the storm implemented emergency procedures or entered a conservative operations mode sometime during the event. In planning for Sandy, entities scheduled additional generation to mitigate loss and cancelled or postponed generation and transmission maintenance work when possible. When entities experienced pre-storm high system voltages that were exacerbated by the loss of load in eastern load zones, they switched out transmission lines and took other control operations, such as removing capacitors from service, to manage the conditions. Finally, entities initiated Minimum Generation Alerts due to loss of load and high voltage.

Some entities implemented severe weather plans and continually reviewed conditions to determine if additional actions were necessary. Finally, some entities imposed alerts that required operating the system to withstand N-2 contingencies as opposed to the normal method of operating to N-1 contingencies.

Challenges Associated with High-Voltage Issues

Some entities experienced high voltage as a result of:

- Open-ended high-voltage transmission facilities
- Significant loss of distribution load
- Lightly loaded extremely high-voltage facilities, such as 500-kV lines

Actions Taken to Maintain High Voltages

Entities that experienced high voltage de-energized equipment, removed lines from service, removed capacitor banks from service, operated reactors, brought on pumped storage units in pump configuration, and had generators lower their VAR output.

System Control

Challenges in Maintaining Load/Generation Balance During Storm

The largest challenge for PJM was coordinating load lost on the distribution systems with lost generation—in particular, the loss of entire generating stations or the loss of multiple units within close temporal proximity. This at times forced ACE to go either high or low for extended periods of time. It was also challenging to maintain load/generation balance during restoration as generation and/or load was added back into the system.

Post-Storm Operations

Long-Term Effects that Could Impact Serving Firm Load in 2012–2013 Winter

There were no long-term effects from Sandy with regard to transmission. There was however, one generation station that may be forced into early retirement by the flooding brought on by Sandy. The Danskammer plant, while not operating at the time, may be forced into retirement by Hurricane Sandy. Units 1 through 4 at the facility flooded due to high water; Units 1 through 4 have been in a forced outage status since that time. Units 5 and 6 were not exposed to flood water, but the power transformer for these generators was damaged by flood water. During the intervening period, Dynegy retained contractors to assess the full extent of the damage at the facility. Their assessment indicates that the flooding damaged approximately 90 percent of the motors and 60 percent of the switchgear in the facility. Based on this assessment, the estimated cost to repair the Danskammer facility is significant.

On January 3, 2013, Dynegy Danskammer, LLC announced its intent to retire all six generation units from service and to dismantle the facility.   In Nov 2013, Helios Power purchased the plant from Dynegy and has requested the ability to delay filing the final retirement notice until they complete their assessment of the condition of the units and the ability to return them to operation.

Danskammer is located within NYISO, which is a summer-peaking system. NYISO did not expect, nor did it experience, any reliability issues associated with this generation station's retirement in the 2012–2013 Winter season.

Restoration

Timeline

Amount of Load Lost (MW)

While utilities can determine the number of customer outages, they can only approximate the amount of load lost. Based on these approximations, ISO-NE reported 1,366 MW of load lost based on forecast load versus actual load for October 30; NYISO reported that 2,222,337[13] customers experienced outages, which translates to approximately 5,200[14] MW of load; and PJM reported a total amount of load loss of 11,680 MW. This comes to a total approximate loss of 18,246 MW of load as reported to NERC.

Duration Load Lost

Most entities returned 95 percent of their customers to service between November 1, 2012, and November 9, 2012. Only the Long Island area of New York, which was one of the hardest-hit areas, reported having restored fewer than 95 percent of customers by November 9, 2012.

Challenges

Restoration challenges included loss of power to a control facility as well as impeded accessibility to substations and transmission lines because of snow, flood-damaged areas, and fallen trees. Additional challenges in the general services area included the need to secure food, lodging, and fuel for the work crews. As is the case for many large events, management faced challenges in effectively utilizing resources needed to safely restore or maintain power. There was also equipment damage from salt water and flooding.

Some utilities have expressed concern regarding the fuel situation in the New York/New Jersey areas following Hurricane Sandy. In particular, even though security teams were able to ration and distribute gasoline, some entities are considering purchasing fuel tanks for gasoline or diesel, or storing surplus fuel onsite during emergencies.

Isolated or remote areas experienced issues associated with the operation of (isolated) generating units. Because of their location and the lack of additional supporting generation available online, two units online in Long Island faced problems with grid instability. Rapid, frequent fluctuations of feeder voltage, frequency, VARs, and load made it difficult to maintain the generation in a stable condition.

Finally, salt water damage and flooding resulted in significant challenges to restoring the bulk power system. One entity reported the following:

> *After the flooding of stations, a proactive approach to washing and cleaning equipment affected by salt water was undertaken, and items such as metal-clad switchgear and breakers were sent to repair companies for cleaning, testing and part replacement. Where equipment could not be cleaned, repaired, or replaced, mobile units were implemented or system configurations were modified to support consumer load.*[15]

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[13] NYISO reported 2,222,337 customers in table 4A on pg. 19 of the NYISO report. Table 5 on pg. 32 of the NYISO report states there were 2,105,943 out as of 10/30/2012. This number reflects some restoration that occurred from the peak earlier in the day.

[14] Additional information gathered from NPCC on August 27, 2013 via email. The NYISO report did not specifically state the MG load lost, only the number of impacted customers.

[15] NYISO_Hurricane_Sandy_EAR pg. 35.

Considerations, Statistics, and Lessons Learned

Lessons Learned

The following good industry practices and lessons learned were identified:

- Pre-staging of equipment, when possible, makes the restoration process more effective.
- De-energizing facilities in flood-prone areas was effective in speeding repair and restoration.
- Some entities are considering water-tight doors for facilities in flood-prone areas.
- Improvements can be made in the areas of public communications, outreach, and emergency planning.
- In places where cell phone coverage is spotty, field personnel were able to maintain contact via text messages.
- Installation of additional sectionalizing switches better isolates flood-prone areas.
- In some instances, water dams in lieu of sandbags can be used to prevent flooding.
- Increase feeder supply options where possible.
- For underground equipment, replace non-submersible equipment with submersible equipment.
- Create long-term plans for operating flood-prone substations.

Entities Comparing Notes on Weather Forecast

For the most part, entities do share weather information. In particular, those within a similar geographic region tend to share information with their neighbors as this provides the entities a way to determine if and why their forecasts are out of sync with each other. While sharing of forecast data is helpful in that each entity uses a different source for its forecasts, sometimes the forecasts are not consistent with one another. Entities could use a common recognized model for forecast comparisons to help reduce the possibility of conflict. On the other hand, NERC recognizes that weather forecasting, while improved, is as much an art as a science. For that reason, many different models are used and compared with one another, because no one model will be correct 100 percent of the time. Having and using multiple models helps to identify outliers: what one forecast may miss, another may catch.

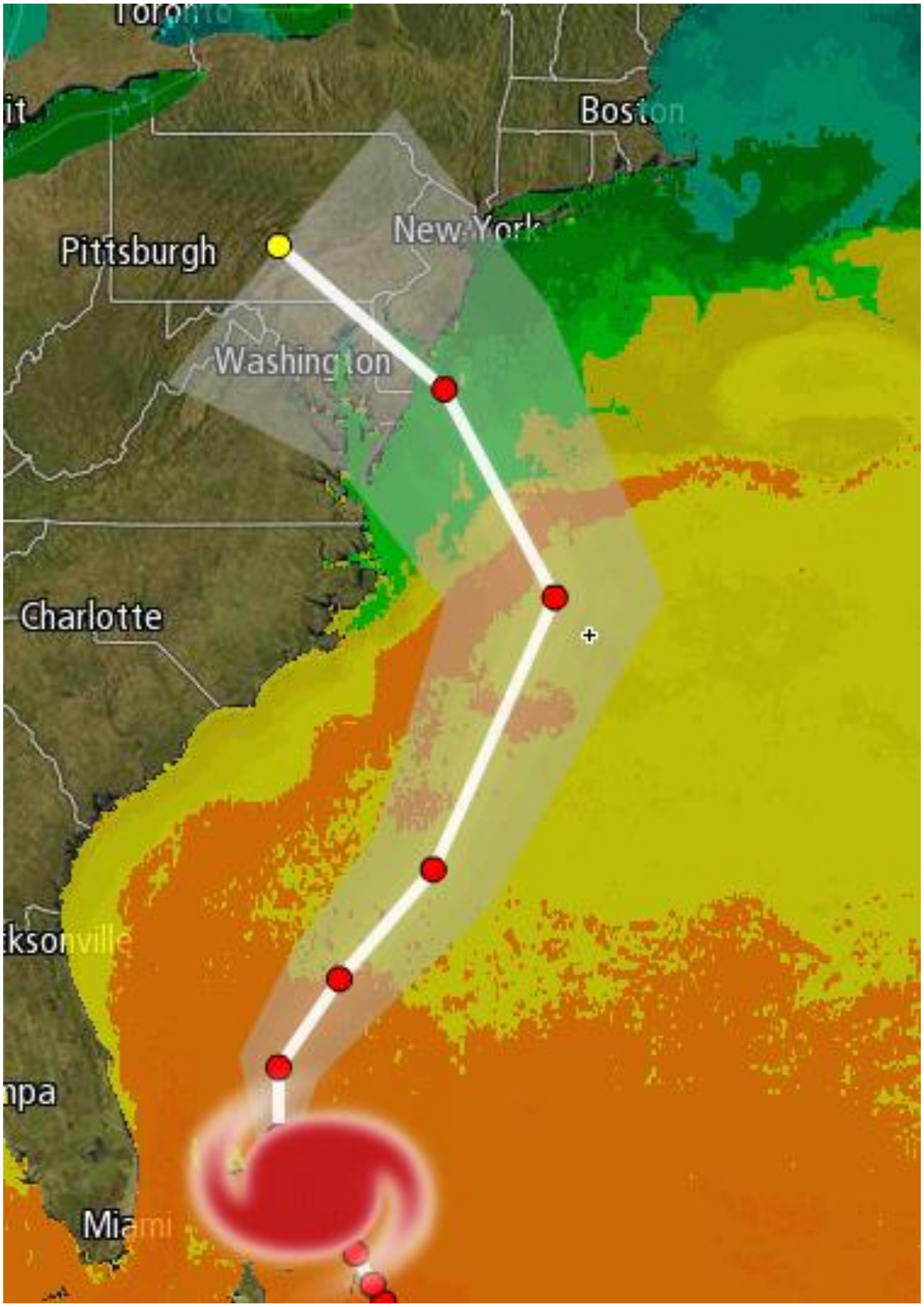
Summary of Findings and Conclusion

The coordination of preparations for the storm with our Transmission Owners, the recall of transmission from maintenance, the recall of generation from maintenance, the commitment of additional units for voltage control, and additional reserve maintained, all contributed to the BPS preparedness for this exceptional storm.

From the Reliability Coordinator perspective, procedures and tools allowed the BPS to be secured for all megawatt flow-related limits through the event and recovery.

Storm and Restoration Photos

Hurricane Sandy Path



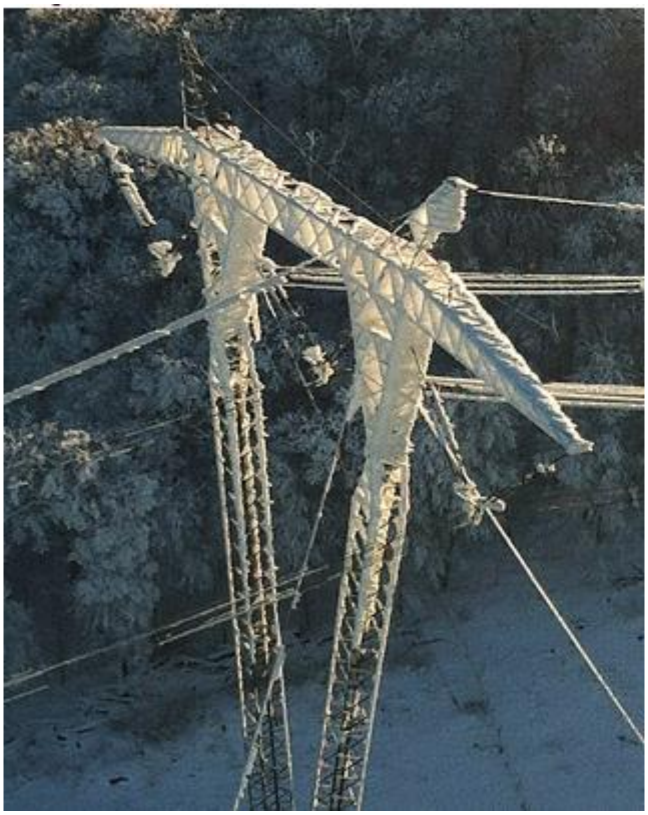
Path of Hurricane Sandy

Damage and Restoration Photos

Damaged substation equipment

Damaged high voltage transmission line

Damaged high voltage transmission line



Aerial inspections revealed a snow-covered tower in West Virginia.

An AEP Transmission line mechanic walks through deep snow ahead of a plow to reach a switching structure.

Crews had to clear more than three miles of road through remote terrain to access and repair a line.

Workers hooked a crane truck to a bulldozer and pulled it more than seven miles past the nearest road to reach this transmission structure on top of East River Mountain near Bluefield. The then used the crane to place a downed static wire back on top of the snow-covered structure.

Examples of the Damage Sustained by the Distribution System

Follow-up Actions

Entities are using the following actions to improve reliability following the analysis of issues and challenges identified in this event:

- Evaluate pre-staging of personnel, materials, equipment and services.
    - Ensuring that critical needs such as fuel availability and transfer equipment for vehicles, availability of restoration crews, and strategic placement of equipment depots of commonly needed materials such as poles, wire, fuses, etc. can help decrease restoration times after a storm event.
- Consider plans to de-energize facilities prior to their being exposed to flooding.
    - Identifying equipment in flood prone or other areas that may be at risk for water intrusion prior to major storms will allow entities to take pro-active steps to minimize equipment damage, potentially speeding restoration.
- Plans to manage high-voltage during periods of significant load loss due to the storm should be considered.
    - Ensuring procedures and equipment are in place to help reduce high-voltage challenges will reduce the burden on operators during major storms and protects again equipment damage. This may reduce the impact to the system and/or help to speed restoration by preventing the need for lengthy repairs to equipment before it can be placed back in service.
- Plan for outside assets such as helicopters and other equipment to help patrol and inspect for storm damage.
    - Ensuring early access to inspection equipment will help to effectively prioritize restoration resources.
- Incorporate lessons learned from Hurricane Sandy into existing training and procedures as appropriate.
    - Reinforcing the lessons learned during Sandy can help to reduce major storm impacts and to sustain efficient restoration in the future.

Contributions

Acknowledgements

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