Lesson Learned

Weathering the Storm – System Hardening

Primary Interest Groups
Transmission Owners (TO)
Transmission Operators (TOP)
Generator Owners (GO)
Generator Operators (GOP)
Distribution Providers (DP)

Problem Statement
The electric system requires additional system hardening in coastal areas to reduce the cost of impact from hurricanes. This is necessary because population growth and infrastructure concentration along the coast has greatly increased the cost of damage from extreme weather events in North America over the last 20 years. Some system hardening has already occurred in Florida and has reduced restoration times there.

In 2004 and 2005, a string of hurricanes made a huge impact on the Southeastern United States. Florida took the brunt of the impacts from four Category 3[1] or higher hurricanes (Charley, Frances, Ivan, and Jeanne) during six weeks in 2004. The 2005 Atlantic hurricane season was one of the most active in history and included Wilma, which hit as a Category 3 storm, causing over 3.2 million outages in Florida–a record at the time. The estimated impact of the 2004 season on the United States was $61 billion; the 2005 season more than doubled that at $170 billion. An even more severe Atlantic hurricane season came in 2020.[2]

Details
After the highly active seasons of 2004–2005, it was apparent that something needed to be done to ensure Florida would be able to rebound quickly from a major hurricane. In 2006, the Florida Public Service Commission (FPSC) held a workshop to discuss electric utility lessons learned during the past hurricane seasons. The workshop led to the development of the electric infrastructure storm hardening initiatives, and[3] three main recommendations drove these initiatives. The first recommendation was for Florida to continue to maintain a high level of storm preparation regardless of the recent hurricane activity. The second was to strengthen Florida's electric infrastructure to better withstand the impacts of severe weather events, including a wide range of hardening activities that takes years to complete. Finally, there was a need to establish additional comprehensive planning tools to enable the FPSC and utilities to identify existing overhead electric facilities that warranted converting lines and other equipment to underground as a means of storm hardening.[4]

Following the passage of the Florida storm statutes, Florida utilities began replacing wood transmission structures with steel and concrete structures (which are rated for higher wind speeds), installing substation

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1 https://www.nhc.noaa.gov/aboutsshws.php
2 2020 had 31 tropical and subtropical storms, 30 named storms, 14 hurricanes, and 7 major hurricanes.
3 http://www.psc.state.fl.us/Files/PDF/Publications/Reports/Electricgas/stormhardening2007.pdf
4 http://www.leg.state.fl.us/statutes/index.cfm?App_mode=Display_Statute&Search_String=&URL=0300-0399/0366/Sections/0366.96.html#:~:text=(b)%20%E2%80%9CTransmission%20and%20distribution,distribution%20facilities%2C%20and%20vegetation%20management

flood monitoring, adding smart devices for mapping outages, performing vegetation management exceeding NERC standards, and burying many distribution lines and service drops. Hurricane Irma in September 2017 was the first test of those improvements made after Hurricane Wilma in 2005. Irma was reported as the strongest Atlantic Basin hurricane ever recorded outside the Gulf of Mexico and the Caribbean Sea and resulted in more than 100 high-voltage transmission lines forced out of service and over 4 million customer outages.

Had this hardening effort not started in Florida over the decade prior to Irma, the number of outages would have been significantly higher, and restoration times would have been extended due to more structural damage. Refer to the *Hurricane Irma Event Analysis Report*[5] for more detail.

System hardening efforts greatly increased the speed at which the system recovered from the hurricanes. This work began after Hurricane Wilma. Even though the system hardening work was incomplete when Hurricane Irma occurred, the recovery was substantially faster as a consequence. System hardening efforts were more advanced by the time Hurricane Ian hit, and dramatically improved system restoration speed (see **Table 1**). Note that Ian and Charlie had very similar storm tracks and were equivalent in strength, making for a close comparison. Florida's largest utility lost no transmission structures during Ian, and restoration after Ian proceeded much more rapidly than that for Charlie or Wilma despite the fact that flooding was more severe during Ian (see **Figure 1**).

Table 1: Hurricane Information

	Customer Outages in Florida	Time to 95% Restoration in Days
Hurricane Charlie (2004)[6]	600,000	13
Hurricane Wilma (2005)[7]	3,200,000	18
Hurricane Irma (2017)	4,000,000	6
Hurricane Ian (2022)	2,600,000	3.8*

**Restoration was already 2/3 complete by the end of the first day*

[5] Hurricane Irma Event Analysis Report: https://www.nerc.com/pa/rrm/ea/Hurricane_Irma_EAR_DL/September%202017%20Hurricane%20Irma%20Event%20Analysis%20Report.pdf
[6] See 2004 System Disturbance Report: https://www.nerc.com/pa/rrm/ea/System%20Disturbance%20Reports%20DL/2004SystemDisturbance.pdf
[7] See 2005 System Disturbance Report: https://www.nerc.com/pa/rrm/ea/System%20Disturbance%20Reports%20DL/2005SystemDisturbance.pdf

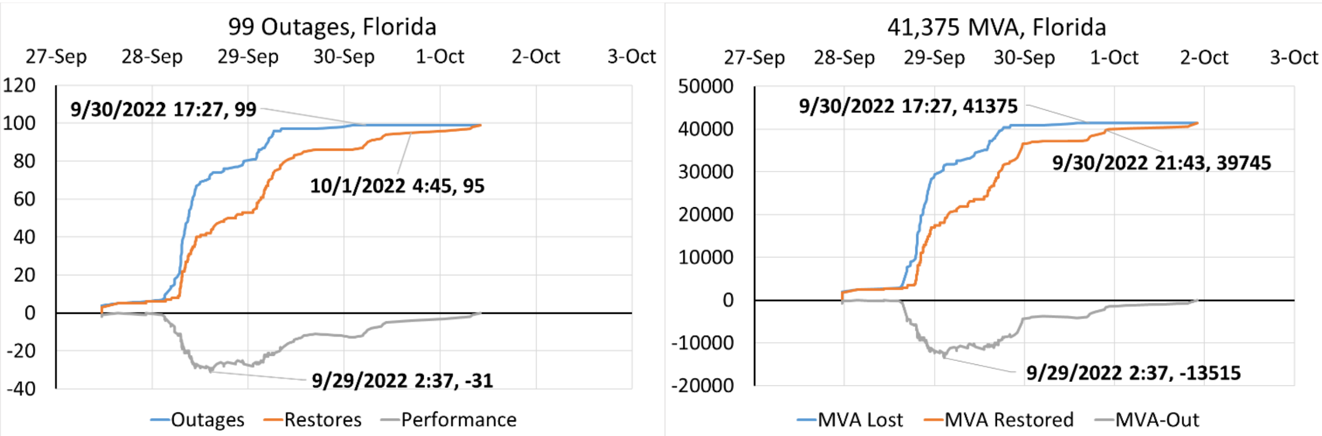

Figure 1: Transmission Element and MVA-based Outage, Restoration, and Performance Curves for Florida–Hurricane Ian

Corrective Actions

- Hardening and resiliency programs that included replacing wood transmission structures with higher wind-speed-rated steel and concrete structures, and burying many distribution lines implemented prior to hurricanes Irma and Ian significantly reduced the storm damage sustained from high winds and storm surge.
- Staging equipment outside the projected path of the hurricane made the restoration process more effective.
- Preemptively removing generation from service prior to the landfall of the hurricane protected equipment from damage and significantly shortened restoration times.
- Continuous communications between the RC, TOPs, and BAs ensured coordinated efforts throughout the event and the subsequent restoration.
- Advanced meters and intelligent grid devices were effective in pinpointing outages, operating equipment remotely, and increasing efficiency.
- Installation of flood monitors in substations located within the 100-year flood plain resulted in the ability to de-energize substations upon notification of rising water, reducing potential damage to sensitive station equipment.
- Leveraging social media enabled the first ever communications with Facebook live and other platforms, providing customers with the most current outage and restoration information.
- Aerial drones[8] were effective in assessing damage, evaluating work conditions, and enabling real-time situational awareness. Infrared capabilities helped identify equipment that needed further inspection.

[8] See NERC Lesson Learned LL20190201 "Current Drone Usage" https://www.nerc.com/pa/rrm/ea/Lessons%20Learned%20Document%20Library/20190201_Current_Drone_Usage.pdf

Lesson Learned

Entities that are at risk of storm systems, such as hurricanes, nor'easters, derechos, or tornadoes, should review their transmission and distribution systems (with higher priority on transmission systems) to understand their systems' ability to withstand high wind speeds and handle flooding. Hardening can increase the ability to withstand strong storm systems. Lines may still trip, but structures will likely sustain no or very little damage, allowing faster restoration. The following actions can help harden a system against storm damage:

- Where Public Utility Commissions and states provide requirements and incentives to harden against storms, multi-year structure replacement programs have been successful at improving performance.
- Utility Emergency Response programs with formal command and control organizations[9] have been in place for decades. Training, working through tabletop scenarios, and annual drills (including communications with other entities) for these organizations are important tools for ensuring organizational readiness and familiarizing new workers with the process.
- Take opportunities following smaller storm events to provide practical hands-on transmission and distribution restoration training for new personnel, both operations and field. This will translate into skills needed to prepare for large events.
- Periodically review wind speed and flooding potential maps for updates and update internal engineering standards for new construction and damaged structure replacements accordingly.
- Have a defined inspection program for replacing structures based on the condition and likelihood of higher speed winds occurring in those locations.
- Burying lower voltage distribution lines reduces the number of wind storm induced faults and thus the number of customer outages, and burying reduces challenges to protection and control systems (misoperations on distribution systems sometimes result in impacts to transmission-level equipment). Note that high water table or flooding potential in a location may make relocating facilities underground impractical. Also note that it is generally cost-prohibitive to bury higher voltage transmission lines.
- Store storm response equipment and replacement parts outside of areas known for major historical storm impacts but still within reasonable transport times of these areas.[10] If hardened storage is available within areas known for major historical storm impacts, it can help ensure that equipment is delivered to impacted areas much faster.
- Preemptively removing from service generation in the path of high wind speeds may protect equipment from electrical damage and shorten restoration times. This is already the practice at nuclear power plants for preset wind speeds documented in their technical specifications and

[9] See https://www.fema.gov/emergency-managers/nims
[10] Also see recommendations for near-term pre-staging for a storm's projected path: LL20220701, "Forecasted High Winds" https://www.nerc.com/pa/rrm/ea/Lessons%20Learned%20Document%20Library/LL20220701_Forecasted_High_Wind_Speeds.pdf

procedures. Wind generators have design wind speed automatic cut-outs, but may also be removed from service manually (often remotely) when high speed winds are in the forecast.[11]

- Keep mutual assistance agreements[12] and emergency supplier contracts up to date to speed recovery. Negotiate agreements with local and geographically remote partners in case of widespread local impacts.
- Apply previous NERC Lessons Learned on substation flooding.[13]

NERC's goal with publishing lessons learned is to provide industry with technical and understandable information that assists them with maintaining the reliability of the bulk power system. NERC is asking entities who have taken action on this lesson learned to respond to the short survey provided in the link below.

Click here for: Lesson Learned Survey

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For more Information please contact:

NERC – Lessons Learned (via email)

[11] Again, see LL20220701, "Forecasted High Winds"
https://www.nerc.com/pa/rrm/ea/Lessons%20Learned%20Document%20Library/LL20220701_Forecasted_High_Wind_Speeds.pdf

[12] Such as those available through the Southeastern Electric Exchange: https://www.theexchange.org/committees.html,the North American Transmission Forum: https://www.natf.net/docs/natf/documents/natf-restore-program-overview.pdf, and Edison Electric Institute: https://www.eei.org/en/issues-and-policy/reliability-emergency-response

[13]LL20220404, "Substation Flooding Events Highlight Potential Design Deficiencies":
https://www.nerc.com/pa/rrm/ea/Lessons%20Learned%20Document%20Library/LL20220404_Substation_Flooding_Events_Highlight_Potential_Design_Deficiencies.pdf