ORGANISATION OF CARIBBEAN UTILITIES REGULATORS

16th Annual Conference

"Regulating for Sustainability in a Disruptive Environment"

Electricity Grid Resilience in the Face of Extreme Weather Events:

Tropical Storms & Hurricanes

Victor Rodriguez

Standards Engineer
Regulated Industries Commission

The views expressed in the following document are solely those of the author and not the views of the Regulated Industries Commission (RIC).

All monetary values are stated in United States Dollars unless otherwise indicated.

Abstract

In 2017, hurricanes devastated several islands in the Caribbean and caused severe damages in parts of Texas, USA. A large section of Puerto Rico was without electricity for several months after being impacted by Hurricane Maria, with some parts of the country still not restored after almost a year. The damage to the grid forced many to rely on portable generators and canned foods for survival. In Trinidad and Tobago, a minor tropical storm, reaching mere speeds of 41 miles per hour, was able to down trees and damage power lines, leaving some customers without an electricity supply for periods, spanning from a few hours to several days. The extent of the impacts of these outages highlights the need to make electricity grids more resilient to weather impacts within the region. It is also important to take into account the rate of recovery of the entire country from weather events when considering mechanisms for addressing the resilience of the network.

This paper discusses the challenges and mechanisms for addressing network resilience in the Caribbean when being affected by extreme weather events such as hurricanes and tropical storms. It presents an overview of existing regulations of grid resilience and reliability, the need for grid hardening in the electricity transmission and distribution industry, a case study of Florida Public Service Commission's analysis of the effect of the grid's resilience after "hardening" measures have been implemented and the lessons learnt from implementation.

Contents

1 Introduction

Electricity grids are susceptible to damages due to extreme weather events. In the Caribbean and surrounding tropical region this is usually hurricanes and storms. Every year, climatic activities in the Atlantic Ocean bring the hurricane season, which officially begins in June and ends in November. The past few decades have seen an increase in the frequency and intensity of these extreme weather activities. Studies[1][2] have been conducted to examine these changes, and to project future trends in intensity and frequency, and these indicate that hurricanes are likely to both intensify and become more frequent.

The hurricane seasons of 2016-2017 was very active, with several hurricanes of category 3 and higher making landfall in the Caribbean and U.S. territories. The 2018 season is also showing signs of significant activity. In 2017, Hurricane Maria devastated several islands in the Caribbean. Most of these countries experienced widespread power outages. In Dominica, the cost of damages to the electricity grid was estimated at US$ 66 million. The cost to rebuild is expected to be much greater, with an estimate cost of US$ 80 million. Given the difference in these costs, it may have been more cost effective if investments were made in reinforcing the network to resist damage compared to rebuilding a completely new electricity system after devastation. Indeed, this would the case for the region as a whole, and prevention is a far more prudent, that is less costly option, than recovery.

Extreme weather events not only hinder the performance of utilities, but also negatively impact the economic and social wellbeing of the affected countries. The impact of these on the electricity grids has highlighted the need to make them more robust to counter adverse weather effects and to operate safely. The need for action is apparent, as these events result in several negative impacts such as damages to infrastructure, buildings and property, loss of communications, health and safety risk, and loss of life. Therefore, there is a need for utilities and regulators across the region to develop and incorporate grid resiliency measures within the electricity networks.

[1] Chang, H.-R. et al. 2005. *Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment*. Science Magazine, Vol 309.
[2] Dobson, I. et al. 2014. *Impact of Extreme Weather on Power System Blackouts and Forced Outages: New Challenges*. ResearchGate.

Discussion of grid resilience has been ongoing over the years. However, recent events have brought it into greater focus as a critical aspect that electric utilities and regulators must consider. Some utilities within the Caribbean have undertaken activities that could contribute to some degree of grid resilience. However, these have been very limited, and not coordinated or targeted to achieve specific outcomes. This rest of this paper gives a broad definition of resilience, briefly examines some of the causes behind the increased intensity and frequency of hurricanes and storm. It goes on to examine in detail some of the core components of resilience such as prevention, recovery and survivability, reviews the approach utilised by the Florida Public Services Commission and there after presents some brief findings. Thereafter some conclusions and recommendation are outlined.

2 Resilience

Resilience is the ability to reduce the magnitude or duration of the impact of disruptive events. Therefore, the effectiveness of a resilient infrastructure depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event (NIAC, 2010).[3] This issue is particularly important to ensure that the electricity grid can reasonably withstand disruptive events such as tropical storms and hurricanes and continue to deliver electricity to the customers in the quantity and quality required. In this context, resilience focuses on the notion that disruptions can happen regularly and systems should be designed to tolerate these disruptions to resume normal operations in the least possible time. For example, the use of more resilient electricity poles is becoming more important in the Caribbean region in the face of more intense hurricanes and storms. These poles are different in design and construction to conventional wooden or steel poles. The re-design may consider the added stresses associated with strong winds and force of impact from flying debris etc.

[3] National Infrastructure Advisory Council, 2010

2.1 Storms and the Electricity Grid

2.1.1 Cause and Impacts of Storms

The Caribbean experiences a hurricane season, typically occurring during months of June to November. This period poses the greatest risk to the electric utility as the region can be adversely impacted by extreme weather events such as, tropical depressions, storms and hurricanes. According to the National Oceanic and Atmospheric Association (NOAA) for 2018, there is approximately a 70 percent chance of 10 to 16 named storms developing into tropical storms. Five to nine of these tropical storms can achieve hurricane status and one to four developing into hurricanes of category 3 or higher.[4] Though these numbers may seem high, it is important to note that not all of these weather events will either actually occur or make landfall.

A recent study on weather trending revealed a strong correlation between the path of storms and local rainfall. This data went on to show that the year with the least annual rainfall coincided with the least active hurricane season and conversely, the highest annual rainfall coincided with the most active hurricane season.[5] Analysis of hurricanes and storm formation in the North Atlantic shows that there has been an increase in hurricane frequency and intensity since 1995.[6] There is also a relationship between increased hurricane intensity and frequency and increasing sea surface temperatures (SST). Studies have shown that SST greater than 26 degrees Celsius are necessary for the formation of tropical cyclones. An increase in SST has been observed in recent years due to the emission of greenhouse gases from industrial activities.[7] This is a fundamental example of the part climate change (CC) plays in the increasing severity of extreme weather events.

In 2017, Hurricane Maria affected several islands in the Caribbean. For example, the destruction in the island of Dominica was so severe that officials declared it uninhabitable and required its citizens to be evacuated. Power outages occurred due to the extensive damages to the electricity grid from both heavy winds and flooding while telecommunications disruptions prevented the majority of the country from contact with foreign entities. Estimated damages and losses to the

[4] Ghose, T. 2018. *Hurricane Season 2018: How Long It Lasts and What to Expect*. Life Science

[5] Burn, M & Palmer, S. 2015. *Atlantic hurricane activity during the last millennium*. Nature: Scientific Reports

[6] Webster, P.J. et al. 2005. *Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment*. Science Magazine. http://science.sciencemag.org/content/309/5742/1844

[7] International Energy Agency. 2017. *Global Energy & CO_2 Status Report*

electricity infrastructure, as previously stated, was in the amount of US$ 66 million, and the amount needed for recovery was estimated to be US$ 80 million. Ninety percent of transformers on the island were damaged beyond repair leaving only twenty-five percent of the network operable. The country's electricity infrastructure damages was second only to its transport sector which required US$ 815 million to recover.[8] This gives a good perception of the overall damages sustained.

Hurricane Maria also impacted Puerto Rico resulting in immense damage to its electrical infrastructure. The damages were so extensive that a proper estimate of the cost was not determined until months after. It is reported that, a total of US$ 1.9 billion has been spent so far to rebuild the nation's electric grid.[9] Reports also stated that 80 percent of the nation's electricity grid was damaged, leaving the entire island without power.[10] This event caused many of its residents to resort to purchasing portable generators for survival, and were still awaiting restoration of a reliable power supply almost a year later.

In 2017, St Maarten was impacted by Hurricane Irma, leaving an estimated 90 percent of the country's infrastructure damaged and US$ 1.8 billion in physical damages. Damages to both electricity and water utilities were evident after the hurricane passed. While 80% of the St Maarten's electrical distribution network is located underground, roughly 40% of its distribution grid was impacted because of severed high voltage cables in several areas. [11] This relatively low degree of damage to the distribution network can be used to display how efficient undergrounding is as a grid resiliency method.

Whilst this paper focuses on the impacts of hurricanes and storms on the electricity grid, it should also be noted that other impacts stem from the disruption of electricity supply. While facilities are sometimes designed with redundancy to accommodate short term power outages, long term outages can pose a risk to health and safety. These include the prevention of the safe operation of basic systems such as traffic lights and water supply systems.

[8] The Government of the Commonwealth of Dominica. 2017. Post-Disaster Needs Assessment Hurricane Maria
[9] Ferris, D. 2018. *Puerto Rico's grid recovery, by the numbers*. E&E News.
[10] Berg, R. et al. 2018. *National Hurricane Center Tropical Cyclone Report – Hurricane Maria*. National Oceanic and Atmospheric Association.
[11] Workgroup, 2017. *National Recovery Plan – Interim Report October 2017.* Workgroup

Another critical impact is the loss of communications system due to a lack of power. This can hamper recovery, hinder routine activities and engender feelings of uneasiness. The public can begin to think that they have been forsaken if communication is not established. Communication is needed to provide public information and directives to facilitate the transition back to normalcy.

Lastly, the loss of power can impact on the functioning of systems that are essential for life and wellbeing. Loss of life can occur when vulnerable persons are exposed to adverse conditions when special devices become inoperable after losing power. One such case occurred at a nursing home in the Florida, United States of America, when eight elderly patients died from exposure to excessive temperatures, after Hurricane Irma knocked out power, leaving the facility without air-conditioning for several days.

3 Electricity Grid Resilience

3.1 The Elements of Grid Resilience

The Electrical Power and Research Institute (EPRI) has identified three elements that define the concept of grid resilience:

1. Prevention;
2. Recovery;
3. Survivability.

3.1.1 Prevention

Prevention is the protection of the grid from damages. This is done through competent engineering designs to harden the transmission and distribution system to limit damages that may lead to disruptions. From inception, planners have the ability to design the system with advanced technology to allow maximum distribution during instances of major power outages that can disable entire communities. The system can be designed to allow alternative pathways for transmission and/or distribution to communities to operate normally preventing major power outages. Transmission and/or distribution can be supplied from unaffected areas of the grid to the area affected by the major power outage. This element will be dependent on the nature of the distribution system and its working environment. Thus, system designers must be prudent to ensure cost effectiveness of the design when considering the feasibility of hardening activities.

Prevention of damage can include several actions that the utilities can undertake. These include:

- Vegetation Management
  - The trimming of tree branches and/or removal of overgrowth of vegetation from transmission and distribution lines
- Undergrounding of targetted distribution lines
  - The burying of cables as an alternative to overhead lines. The buried cables would be used strategically in areas deemed higher risks for overhead lines
- Overhead distribution reinforcement

- Reviewing the structural integrity of electrical facilities and providing additional support by use of guying wires, specialized bolts and replacing of wooden poles with steel or concrete
- Security (Smart Grid)
    - The use of an Advanced Metering Infrastructure (AMI) to remotely monitor the performance of transmission and distribution facilities for early detection and repair of faults.

3.1.2 Recovery

Recovery is the rate at which the grid is restored. It involves mechanisms that enable swift redistribution of electricity to limit the duration of power outages, and to restore supply to the largest number of consumers in the shortest time. The recovery of the system requires quick damage assessments, rapid deployment of repair crews and the availability of key components in inventory. Recovery can be hampered by several factors such as the inability to identify fault location or lack of access to areas damaged by fallen debris or flooding.

The United States Department of Energy has argued that recovery is more appropriately deemed a reliability issue, and not a resilience.[12] The definition of resilience mentioned before, includes the ability of the system to withstand disruptions and return to normal operations. However, reliability would be a measure of system behavior once resilience is compromised. Electric utilities and regulators commonly measure reliability of the system in two categories: frequency of outages (CAIFI and SAIFI)[13] and duration of outages (CAIDI and SAIDI)[14].[15] The frequency of outages presents an indicator of the number of instances that the system's resilience has been compromised. Therefore, the argument holds some merit and can be discussed further. This is important to note when projects are being proposed to enhance grid resilience.

[12] Taft, J. 2017. *Electric Grid Resilience and Reliability for Grid*. U.S. Department of Energy
[13] Customer Average Interruption Frequency Index and System Average Interruption Frequency Index
[14] Customer Average Interruption Duration Index and System Average Interruption Duration Index
[15] Taft, J. 2017. *Electric Grid Resilience and Reliability for Grid*. U.S. Department of Energy

3.1.3 Survivability

The survivability refers to the ability to provide an essential level of electricity service to allow communities to continue functioning in instances where the normal power sources are disrupted. This allows critical institutes (hospitals, prisons, emergency services), cellular networks, and other vital systems to use distributed generation (DG), such as micro grids.

Current regulations in some jurisdictions do not allow for the use of micro-grids, or the interconnection of renewable energy (RE) power into the grid. This makes it difficult for utilities to develop mechanisms that can aid survivability in the event of natural disasters and catastrophic failures. The onus will be on utilities and regulators to use innovative technologies and legislative tools to increase survivability levels. Historically, survivability has been the responsibility of the customer. Institutions, such as banks and hospitals, have had to assume the responsibility of ensuring their operations are not interrupted by events. This has caused these customers to invest in generators, back up battery supplies, and in rare cases, where available, alternative electricity distribution feeds from the electric utility.

3.2 Benefits of Grid Resilience

Grid resilience has tangible benefits for all stakeholders. Utilities benefit financially, and their reputations are enhanced when grid resilience portrays them as innovative leaders in their industry. Customers on the other hand, continue to enjoy the benefit of being supplied with electricity during conditions which would have otherwise downed their power lines had it not been for a grid resiliency programme.

The United States of America was affected by three (3) major hurricanes during the 2017 season – Maria, Irma and Harvey – with estimated costs of US$ 52 billion, US$ 65 billion and US$ 199 billion respectively.[16] Utilities stand to lose a significant amounts of revenue each day a community is without electricity. When outages occur due to damaged transmission or distribution circuits, electric utilities cannot sell electricity to the customers who are supplied by these circuits.

[16] 2017 Hurricane Season Recap and 2018 Implications for Utilities, Scott Madden Management Consultants

This is further compounded by the fact that they may still be required to pay for the supply of power from the generators, depending on the arrangement. Grid resiliency can sometimes ensure that the network is not compromised and therefore maintain a consistent flow of revenue.

Customers today have a greater expectation of the quality of service they should receive, given the advances in technologies. Customers assume that lengthy outages should be a thing of the past and believe they are entitled to an improved quality of electricity service. Improved grid resilience can lead to increased levels of customer satisfaction. This increased level of customer satisfaction is beneficial to both the utility and the regulator. Based on jurisdiction and regulations, a utility can be penalized for substandard quality of service. This can in turn enhance the reputation of the regulator as the performance of the utility is reflective of the regulator's efforts to improve performance within the sector.

Positive results from a grid resiliency programme can increase customer confidence in the utility. Grid resiliency programmes have the potential to significantly impact customer, and as such, when customers experience quick recovery during times of harsh weather, it can increase their satisfaction.[17] Successful implementation of a grid resiliency project can increase customers willingness to pay for other projects the utility and/or regulator may propose. The increased buy-in from customers on other projects will have reduce opposition to change and allow the utilities to attempt new ventures to increase long term profits.

During periods of adverse weather, the public sometimes depends on a reliable supply such as in hospitals and special institutions. Some persons have medical conditions and require a reliable power supply for survival such as patients on respirators. Other situations can arise such as electricity required for other items e.g. water pumps and electric stoves. Long term power outages can impact individuals who depend on electricity for survival. While institutes have a role as consumers to ensure some level of redundancy in event of power failure, electric utilities have a responsibility to provide a consistent supply. In addition to the impact on physical health, power outages can also jeopardize safety. Customers can become isolated or traffic lights may cease to

[17] Warren, C. 2017. *How Utilities Can Avoid Complacency and Boost Customer Satisfaction*. Greentech Media.

operate at times during rush hour. The social effects of power outages can be mentally straining to individuals causing withdrawal and depression.[18]

In an economic outlook, grid resilience can be beneficial by preventing power outages to productive sectors of the economy. As long term power outages can in turn have negative impacts in stock markets. Power outages for these industries can have devastating effects in mere hours. Organizations have the possibility of incurring huge losses due to loss of business.

Figure 1 below graphically compares the recovery time from a resilient and less resilient system. It shows that the recovery time for the resilient system is much shorter as opposed to a less resilient system.

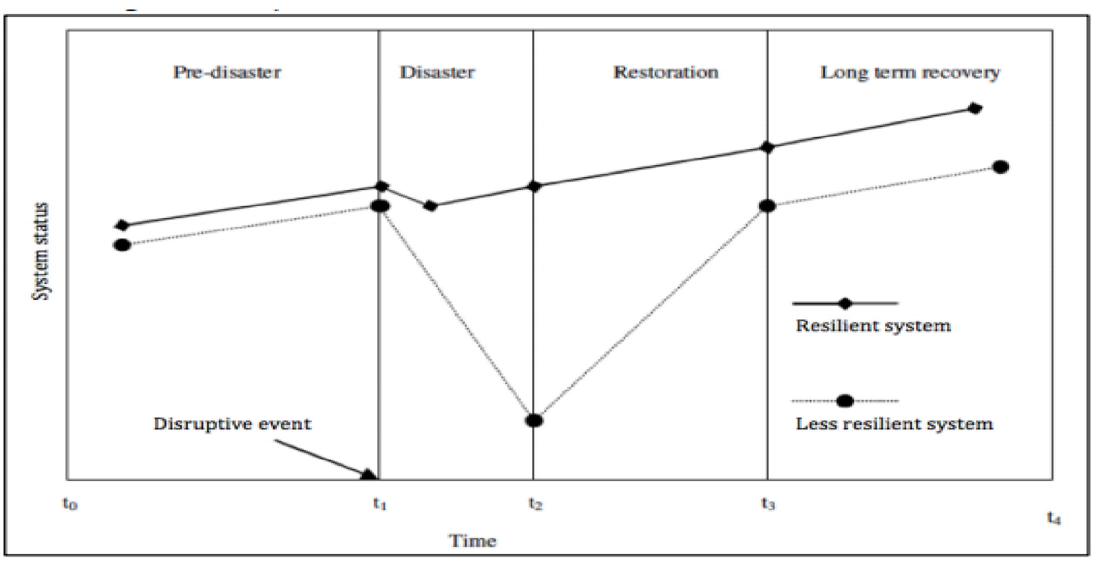

Fig 1. A resilient system vs a less resilient system. (Source: Clark-Ginsberg, 2016)

[18] Sifferlin, A. 2017. *How Power Outages Can Affect Mental Health*. Time Health.

4 Case Study: Grid Resilience in Florida

This case study focuses on an overview of the state of Florida and the use of grid resiliency methods and technology to improve the ability of the investor owned utilities (IOU) operating within that jurisdictions to adapt and recover. Florida Public Service Commission (PSC) is the utility regulator for the state of Florida in the United States of America. Florida PSC is responsible for economic regulation, regulatory oversight and consumer assistance. Florida PSC is the regulator of the electricity sector as well as natural gas, telephone and water sectors. They are responsible for regulating the five (5) investor owned electric utilities within the state of Florida.

The Florida PSC decided on several key directives which was the basis for enhancing the electricity grid's resilience. These directives were:

1. Utilities were required to provide a Hurricane Preparedness Briefing. This briefing would include the preparation of documented plans and protocols for potentially disruptive events.
2. Utilities were required to develop plans inclusive of methodology and estimated implementation costs for continuously enhancing storm preparedness initiatives.
3. These utilities were also required to adopt rulemaking for distribution construction standards that were stricter than the minimum safety requirements of the National Electric Safety Code.
4. The use of rulemaking would be used to identify circumstances where distribution facilities should be required to be constructed underground.

4.1 Storm Order

Following lengthy power outages during the 2004 and 2005 hurricane season, Florida PSC began the process to mandate electricity utilities under its jurisdiction to enhance the resilience of their electricity grids.[19] The process began by conducting workshops to discuss the issue of grid resilience with all major stakeholders. Stakeholders included the utilities, government

---

[19] Arriaga, I et al. 2006. *Notice of Proposed Agency Action Order Requiring Storm Implementation Plans*. Public Service Commission. http://www.floridapsc.com/library/filings/2006/08605-2006/08605-2006.PDF#search=storm%20order%20060198

organizations, technical consultants, academics and the public. These stakeholders provided feedback to the regulator, giving opinions on the workshop. Follow up meetings were conducted to examine the feedback and the regulator was responsible for recommending the actions for the electric utilities to perform.

Proposals from the regulator were scrutinized by stakeholders and feedback provided was used to aid the regulator in creating a set of items that would be cost-effective and practical. From the feedback, several items were brought forward as agreements. These agreements included the standards of distribution construction to meet minimum safety requirements of local electrical inspectorate, classification of locations and instances where undergrounding of electrical facilities should be strategically implemented, Hurricane Preparedness Briefings be conducted prior to the start of hurricane seasons and each electric utility provides a business plan for ongoing storm preparedness initiatives.

A storm Order was issued on April 25, 2006 as Order No. PSC-06-0351-PAA-EI.[20] This Order provided a roadmap for utilities to harden the electricity transmission and distribution grids. It presented a constructive method by which the utilities could implement procedures and track its performance to enhance accountability for improving the service provided to the consumers. The Order aimed to reduce the amount of outages faced by the electricity grid as Florida, due to storms and other similar weather activity.

4.2 Network Grid Resilience Programme & Activities

The Storm Order indicated that the implementation plans proposed by utilities were to include continuous activities to ensure the grid's resilience improved significantly against potential storm damages. The Order instructed that the grid resiliency plan to include a ten-part initiative programme. The electric utilities were responsible for preparing plans and implementation costs for each initiative to be reviewed by the regulators. Plans were required to be of equivalent to, or

---

[20] Arriaga, I et al. 2006. *Notice of Proposed Agency Action Order Requiring Storm Implementation Plans*. Public Service Commission. http://www.floridapsc.com/library/filings/2006/08605-2006/08605-2006.PDF#search=storm%20order%20060198

greater than, the required standard of the regulator while still allowing the utility to perform the activities in a cost effective approach. The business plans for these initiatives were to include a timeline, methodology, budget and expected rate impacts. The initiatives of the grid resiliency programme included the following but were not limited to:

1. A Vegetation Management Cycle for Distribution Circuits
2. An Audit of Joint-Use Attachment Contracts
3. A Transmission Structure Inspection Program
4. Hardening of Existing Structures
5. A Geographic Information System
6. Post-Storm Data Collection and Forensic Analysis
7. Data Collection of Outages Differentiating Between Reliability Performance of Overhead and Underground Systems
8. Utility Coordination with Local Governments
9. Collaborative Research on Effects of Hurricane Winds and Storm Surge
10. A Natural Disaster Preparedness and Recovery Program

These initiatives are examined in detail below.

4.2.1 Vegetation Management Cycle for Distribution Circuits

While most transmission lines are typically located higher than distribution lines and above tree heights, transmission facilities vegetation management activities are carried out more frequently as damages to these facilities can result in major power outages. In addition, utilities are able to better manage transmission structures' vegetation as some distribution structures can be beyond the utilities' rights of way[21]. This is due to the utilities' responsibility ending at a certain point because of legislation.

While electric utilities already engage in vegetation management activities, more stringent practices were to be adopted by all electric utilities, especially those that were prone to storm damage. Intervals for inspections and tree trimming was to be performed in three year trim cycles

[21] The legal right, established by usage or grant, to pass along a specific route through grounds or property belonging to another.

however the initiative was to be prudent on the cost. Performance indicators for power outages were to be used to determine areas where vegetation management could be improved on the distribution network. Metrics such as duration since last inspection/tree trimming, number of power outages during high winds and distance of vegetation from structures were the indicators for a vegetation management cycle.

4.2.2 Audit of Joint-Use Attachment Contracts

In the state of Florida, like many other jurisdictions, utility poles are often shared between electricity and telecommunications providers. These utility poles are either wooden or steel poles and can often be overloaded by non-electric utility attachments. The structural integrity of these poles were required to be inspected as they can be subject to failure during harsh conditions caused by hurricanes and storms. While inspections were performed, the need for a proper inspection cycle is required. The inspection cycle was to be completed in eight year intervals. It aimed to reveal the poles that had weakened integrity and prevented failures by preparing for future storms.

An auditing of the electric utility poles was also required for the ease of identifying and replacing or upgrading poles. Information on the pole such as location, construction material, number and type of attachments present aided the utilities in decision making for upgrades or replacements. This information was used to identify a potential funding mechanism for a pole replacement scheme.

4.2.3 Transmission Structure Inspection Program

Inadequate inspection and repairs to damaged transmission structures can cause major power outages with devastating effects. The transmission inspection procedures have been found to widely vary among the utilities however, identical to vegetation management and pole inspections, periodic inspections have been mandated to utilities. In addition to frequency of inspections, other issues arise such as the particulars of items inspected by the utilities on the transmission structure was not properly defined. Thus potential causes for failure were overlooked. The programme mandated of the utility was to identify the apparatus on the transmission poles and towers that required inspection such as insulators, guying, grounding, conductor splicing, cross-braces and arms, bolts, etc.[22]

4.2.4 Hardening of Existing Structures

Historically, wood has been the material used for the construction of both transmission and distribution structures. After storms caused damages, requiring replacement or reinforcement by guying, the use of these wooden structures have been reconsidered intensely. While wooden poles continue to be a justifiable option, structures incorporating a relatively durable material were to be considered such as concrete, steel or other non-wooden options. This initiative set about a replacement programme that increased the hardness of structures such as replacement of wooden structures. Utilities were to provide methodology, barriers and selection criteria for transmission structure upgrades and replacements.

4.2.5 A Geographic Information System

The implementation of a Geographic Information System (GIS) was used to identify the locations and performance data of facilities on the electricity transmission and distribution grid. This system, coupled with an Advanced Metering Infrastructure, could locate faults in the network for quick restoration. GIS systems are becoming the norm in the electricity sector to aid utilities and improve operational efficiency. For example, in densely populated areas, where distribution lines are sometimes perplexing, technical personnel are able to easily identify source of damage and acquire information on the type of equipment that may require repairs. Data collected using the GIS can be used to conduct forensic reviews, compare the performance of underground systems to overhead systems, determine where maintenance has been performed and evaluate storm hardening options.[23]

Gulf Power implemented a transmission and distribution geographic system that improved their storm restoration process. While GIS systems are very effective in identifying faults, the implementation of a system can be very lengthy and affluent. Florida PSC instructed utilities to

---

[22] Arriaga, I et al. 2006. *Notice of Proposed Agency Action Order Requiring Storm Implementation Plans*. Public Service Commission. http://www.floridapsc.com/library/filings/2006/08605-2006/08605-2006.PDF#search=storm%20order%20060198

[23] Arriaga, I et al. 2006. *Notice of Proposed Agency Action Order Requiring Storm Implementation Plans*. Public Service Commission. http://www.floridapsc.com/library/filings/2006/08605-2006/08605-2006.PDF#search=storm%20order%20060198

develop proper business plans including a methodology that reflects a certain degree of efficiency and cost-effectiveness that was to be at the forefront of this initiative.

4.2.6 Post-Storm Data Collection and Forensic Analysis

Data collected from inspections on electrical facilities after hurricanes and storms can be used to determine if appropriate maintenance or additional storm hardening options are required. One aspect of grid resilience is the ability to adapt to ensure the grid is not compromised or recovery from the disturbances without impacting the service provided. After Hurricane Wilma, the data presented to the regulator from the electric utilities was insufficient to allow analyses to determine cause, effect and solutions for faults to the grid. KEMA, a consultant hired to assess damages, relied mainly on interviews with staff. An analysis provided indications to source of damages to the facilities and allowed the utility to focus on these items, therefore targeting specific areas to prevent reoccurrence. The regulator required all utilities to develop a plan for data collection for the purpose of forensic analysis. The utilities were instructed to develop the plan to be flexible to propose a methodology that was cost effective and efficient but still provided the ability to collect sufficiently detailed data for forensic reviews to better evaluate storm hardening options.

4.2.7 Data Collection of Outages Differentiating Between Reliability Performance of Overhead and Underground Systems

While parts of the transmission and distribution grid are located underground, they are not invincible to the effects of adverse weather. Facilities located underground are susceptible to the additional problems associated with this weather such as flooding. Though it can be very effective against high wind gusts and vegetation, undergrounding can be a very expensive and labour intense task to install and repair.

Outage data has not always been provided by utilities to differentiate whether the outage was caused by underground or overhead facilities. The use of this data would have aided the utilities in addressing hardening options for damages, associated costs and service interruptions. The collection of this data was to be used to assess the performance of overhead versus underground facilities. Further evaluations of performance of differing technologies and methods was to be done in each case. Comparisons can be done on direct bury cable versus cable-in conduit or wooden poles versus concrete poles. The utility should provide a plan for this initiative ensuring it extracts sufficient data such as location, costs and if possible, a performance index.

The utilities were mandated to develop data collection plans for the performance data differentiating between overhead and underground facilities. The utilities had the ability to integrate this plan with a geographic information system. However, it was required to be similar to forensic analysis data collection by being cost effective and efficient.

4.2.8 Utility Coordination with Local Governments

Communication between the utilities and government services is an important factor. It allows the utilities to have greater input by continuously addressing issues in communities instead of during storm recovery. Cooperation between government services can aid the electric utility in planning grid hardening projects. Examples of this cooperation being helpful are when local services provide information to the utility such as mapping of locations with dense vegetation and flood-prone areas. This communication can aid the utility for effective planning to reduce delays and use improved hardening technologies in designated areas. In addition, services can coordinate with the utilities to plan for critical institutions. It is important that the distribution grids feeding critical institutions be resilient during hurricanes and storms.

Utility coordination and communication with government services has been a continuously on-going process. The utility regulator directed utilities to develop programmes to increase coordination with government agencies. The was required to be implemented to have continuous dialogue and conversation with representatives of each party to keep abreast of projects the other is preparing to undertake and allowed for agreements of how these agencies would work together with utilities to address mutual concerns. Coordination was done to prioritize needs, considered the time and financial constraints associated with given actions.

4.2.9 Collaborative Research on Effects of Hurricane Winds and Storm Surge

Research must be done by utilities on weather trends and evolving technologies which are more resilient to the threats of caused by hurricanes. While it is not the primary service of the utility to perform research on weather trends, collaboration can be done with other institutions such as meteorological offices and universities. These institutes can provide the necessary information to the utility to improve on their plans for network resiliency upgrades. The information provided can aid in forecasting the likelihood of inclement weather frequency and intensity.

Electric utilities were given the directive to develop programmes to provide funding to increase collaborative research, identify objectives and promote cost sharing. The utilities were required to request the participation of other utilities in addition to the available education and research organizations thus expanding their knowledge bank.

4.2.10 A Natural Disaster Preparedness and Recovery Program

An important factor to recovery is the incorporation of a natural disaster preparedness and recovery plan. This aids the utility by developing sets of procedures to follow in the event of the different types of natural disasters. The procedures will document the necessary actions for the utility to perform to ensure the electricity grid can be put back into operation as soon as possible to prevent the occurrence of negative effects. The utilities were mandated to produce disaster preparedness and recovery plans outlining disaster recovery procedures and updating any existing plans to ensure they can improve the efficiency.

5 Funding Mechanisms

Grid resiliency projects can be very costly, depending on the nature of the existing electricity network. Factors influencing the cost of a grid resiliency projects are age of infrastructure, location of facilities and environmental conditions. The costs of these upgrades indirectly finds its way down to the consumers. Regulators must be prudent in reviewing business plans for grid resiliency projects to ensure they are cost-effective and ultimately affordable for consumers.

Hence, in addition to being mindful of the cost of grid resiliency projects, customer willingness-to-pay (WTP) must be taken into consideration. Outreach programmes, customer surveys and interviews will aid the regulators and the utilities in determining the customers' WTP. Customers' WTP will increase with the more information provided to them. A transparent overview of a grid resiliency programme detailing all the initiatives, actions and protocols including the expected outcomes and performance indicators will give the customer a sense of relief and satisfaction that they are paying for a service that will be beneficial. The utility must be conscious of public scrutiny should their initiatives perform poorly.

It was evident that the Florida PSC was flexible in allowing the electricity utilities under its purview to utilize various means of cost recovery. The independent owned utilities (IOU) were to include their cost recovery as part of the base rates and would be recovered in capital expenditures during general rate case/price review. On investigation of sample bills from Florida Power and Light (FPL), a surcharge was implemented for funding of grid resiliency projects. While the utilities were given a degree of latitude in choosing the funding mechanisms used, final approval had to be granted by the Florida PSC to ensure prudent cost recovery.

Although two funding mechanisms uses mainly by the utilities, several were identified for the implementation of the activities, with the intention of allowing customers to adapt to incremental changes in bills. These mechanisms are:

1. Storm Reserve Accounts
2. Cost Deferral
3. Rate Adjustment
4. Securitization
5. Formula Rates
6. Lost Revenues and Purchased Power Adjustment

7. Customer Funding Contributions
8. Government Funding
9. Insurance

5.1 Storm Reserve Accounts

A storm reserve account is a method of savings for the event of storm related impacts to the grid. These funds are acquired in advance to use in cases of storm damages. This savings can be made by the utilities taking a fixed amount from its earnings and placing it in the account. This account is then used to help pay for the damages to the grid. While this may not be able to pay for the entire cost of damages to the grid, it acts as a buffer and thereby lessens the financial impact borne by the utility. In instances when the storm reserve is completely depleted due to repair works, the utilities, with the approval of regulatory commissions, can apply a surcharge to customers in order to recoup the amounts required to replenish the reserve.

5.2 Cost Deferral

While the cost of hardening to increase resilience or recovery from damages due to storms may be excessive in one clean swoop project, the costs borne from the utility to the customer can be deferred. The costs borne can be placed on a balance sheet as an asset or liability. The costs on the balance sheet are then charged or credited to the customers when required. This cost recovery method defers the decision to recover the cost until the next price/rate review process. In this process, the deferred costs can be recovered through a multi-year rate plan and thus the customer will not experience the brunt of the increases in one year.

An issue that arises with cost deferral is the carrying cost to the consumer is linked to the asset. This cost is important to note as delaying the cost recovery negatively impacts the utilities' finances. Consideration must be given to the fact that the present value of cash is higher than the future value of cash.

5.3 Rate Adjustment

The rate adjustment mechanism includes a customer surcharge to recover the costs of an item, such as a grid resiliency plan, apart from base rates. This surcharge may be permanent or temporary, fixed or varying and must be approved by the regulatory commission. These types of surcharges are due to unforeseen circumstances in previous price/rate reviews, costs imposed to the utility based on situations beyond its control or costs that are substantial and distinctive events. The rate adjustment mechanism has been more prevalent as it allows control of specific cases without frequent rate reviews and provides transparency.

Since the rate adjustment is a temporary surcharge, it is a useful mechanism of cost recovery for storm response projects. This mechanism can be used to apply charges to selected customers and be seasonal. This mechanism can also be used by other agencies and is not limited to use by the utilities and regulators. It can also be used to implement special programmes such as universal water metering projects in the water sector.

5.4 Securitization

The securitization mechanism is a tool that purchases bonds linked to secure revenue streams, advocated by legislation, and then selling them on the market. The use of securitization ensures investments from the proceeds of the bonds have a high chance of being repaid, thus offering much lower interest rates than obtainable by the utility from financing the investment solely. Lower interest costs to the utility translates to lower costs to the customers through surcharges.

While securitization seems like a simple process, it is not always the preferred tool for storm recovery as it requires legislations in most cases and satisfactory consent from regulating authorities.[24] Another negative issue with securitization is that utilities are sometimes unable to earn revenue from the investments. An example is a utility using securitization to finance a pole replacement project and not being able to earn on the investment which leads to a reduced rate base. This process of securitization also carries hefty administrative costs.

5.5 Formula Rates

Formula rates allow utilities to adjust rates between price/rate review periods to recover costs for unexpected circumstances such as storm damage, permitting them to acquire the allowed returns. While utilities require approval from regulating authorities to change rates in these events, the price/rate review includes changes in cost for storm-related expenses, the formula rates can be used for immediate recovery of costs such as to recoup finances after storm damage has been done.

[24] Edison Electric Institute. 2014. *Before and After the Storm – A compilation of recent studies, programs, and policies related to storm hardening and resiliency.* Edison Electric Institute. http://www.eei.org/issuesandpolicy/electricreliability/mutualassistance/Documents/BeforeandAftertheStorm.pdf

5.6 Lost Revenues and Purchased Power Agreements

When utilities lose revenues due to damages on the grid, a rate adjustment may be required to sustain operational expenditure from the forecasted revenues as these forecasts set the rate. If the utility loses revenues from customers due to lack of consumption for long periods after a storm, a mechanism can be used to recoup the costs. In some instances, a lost revenue adjustment clause can be applied to allow utilities to recover these costs, once approved by the regulating authority.

Likewise, for the generation structures of the electricity grid, storm damages can occur and make generators inoperable. If power must be purchased from an alternative generator at a higher rate than forecasted, the cost can be borne to the customers. While the regulator and utility must be prudent when adjusting costs, the purchased power adjustment may not always recover the full amount incurred by the utility, it can still recover some of the additional costs.

5.7 Customer Funding Contributions

Due to customers' interest in technologies to improve grid resilience against storm damage though undergrounding or hardening of facilities, a mechanism can be used to acquire additional funding. Since the cost of a grid resiliency project can be quite high, customers funding programmes are able to aid the utility in providing this service. This allows the customers to pay for the service of hardening the grid such as a customer paying the difference between undergrounding and overhead line installation. An analysis of the cost is done and the utility provides the cost to the customer. The customer can pay the full amount or the utility can attempt to match the customer's contribution. In situations for hardening transmission facilities, these would affect a large scale of customers and carry substantial costs. Transmission facility hardening and customer funding contributions would need regulating authority approval for including the costs in the rate base.

While customer contributions are one aspect of this mechanism, the electricity utilities can share costs with other service provides that use techniques which may be applicable to electricity such as undergrounding. The electricity utility can share the cost of undergrounding with a gas or water utility to take advantage of the situation where the cost of undergrounding will be much less. Another example is sharing of utility poles. Electricity distribution and telecommunication lines can share the cost responsibility of expanding the network when installing utility poles.

It is important to note that contributions such as this can be classified as a contribution in aid of construction (CIAC). In varying jurisdictions, these types of contributions may not be recovered in the utility's rate base and can be considered as taxable income to the utility.

5.8 Government Funding

Funding by government agencies can aid the electricity utilities in providing technologies that can be used to harden the grid. Governments aim to increase the resilience of the utilities' network as this allows the system to operate during storms or recover from damages quickly. The greater the resilience of the system the greater the likelihood that the country or state can recover quickly and operate during periods where natural disasters can have crippling longer term effects.

Utilities can either apply for funding or governments can make it their mandate to improve infrastructure through funding initiatives. While this type of funding is available, it is important to note that other avenues are also available to apply for funding such as international development banks and organizations. These institutes play a pivotal role in developing countries as they are able to partner with governments to allow utilities to afford projects such as grid resiliency programmes. Utilities can apply for this funding and present its costs in Capital Expenditures during Price/Rate Review periods. This provides transparency and allows regulators to make carefully informed decisions on projects to include.

5.9 Insurance

Similar to motor or health insurance, utilities are able to acquire insurance policies to protect themselves and their network in the event of natural disasters such as extreme weather events. Proceeds from these policies can be used to repair the grid after incidents have occurred however they have been known to be difficult to obtain. Due to changes in weather patterns, it is not practical for insurance firms to use data beyond five to ten years to predict risks.[25] Insurance firms also calculate risk based on location and storm prone areas. The combination of these risks reduces the likelihood of being accepted. In addition, coverage is usually done in small amounts with high deductible values such as the case of Connecticut Light and Power (CLP). CLP had an insurance policy of US$ 15 million. However, its deductible was US$ 10 million. This in turn would only

[25] Frye, E. et al. 2005. *Insurance and the Nation's Electrical Infrastructure: Mutual Understanding and Maturing Relationships*. U.S. Department of Energy/National Energy Technology Laboratory. https://cip.gmu.edu/wp-content/uploads/2016/06/CIPHS_Insurance-and-the-Nations-Electrical-Infrastructure_White-Paper.pdf

grant CLP a net total of US$ 5 million for repairs to damages when claims are being made through insurance. Utilities will still require approval from the regulatory authorities to use this mechanism.

While insurance firms are a funding mechanism to recover costs after weather events have occurred, storm reserve accounts can be a method of self-insurance for utilities as is does not rely on a third party. Unlike insurance firms, storm reserves can have an upper limit or can be continuously used to improve the grid's resilience.

6 Outcomes

In 2018, a review of the Florida's electricity grid resilience and reliability was done by the Florida PSC. This review was done recently because there was no significant storm activity in the state of Florida since the events of its 2004-2005 hurricane season which prompted the utilities and regulator to undertake the grid resiliency programme. The review highlights the responsiveness of the electric utilities' actions before, during and after hurricanes during the hurricane seasons of 2016-2017 and aims to display the effects of an aggressively improved resilience plan.

During the preparation period for the hurricane seasons, the Florida PSC's role was clearly defined. As the regulating entity, they were responsible for facilitating workshops for electric utilities to exhibit hurricane preparation and restoration plans to better coordinate with local governments. They were responsible for preparing support to emergency operations to ensure integrity of power supply systems were maintained during events. In addition, as the regulatory authority, Florida PSC was responsible for the communication of information to consumers regarding disaster preparedness for the impact of storms and power outage preparedness.

Many notable improvements were revealed by the review done by Florida PSC. These findings showed that the duration of outages were significantly reduced since the 2004-2005 hurricane season, hardened distribution facilities performed better than un-hardened distribution facilities, the majority cause of outages was due to vegetation management not being done due to being out of the rights of way of the utility, underground facilities performed better than overhead facilities and very few transmission structure failures causing major outages were reported.[26] These improvements were noted by Florida PSC after comparisons were done among utilities under their purview against hurricanes which affected the electricity grid in Florida before and after the Order was implemented.

During the 2017 hurricane season, Hurricane Irma made direct impact with the state of Florida as a category 4 before weakening to a category 3 and left several counties with almost entire power

---

[26] Florida Public Service Commission. 2018. *Review of Florida's Electric Utility Hurricane Preparedness and Restoration Actions 2018.* Florida Public Service Commission. http://www.floridapsc.com/Files/PDF/Publications/Reports/Electricgas/UtilityHurricanePreparednessRestorationActions2018.pdf

outages. Table 1 below provides information of the five counties most affected by power outages due to Hurricane Irma.

Table 1. List of Counties with Highest Number of Power Outages

	Max. No. of Outages	Max. % of Outages
Hendry	18,750	100.0%
Highlands	62,010	99.3%
Nassau	43,740	97.6%
Hardee	11,976	97.4%
Okeechobee	21,990	96.5%

Source: Florida Public Service Commission 2018

While this data reveals the amount of counties most affected by Hurricane Irma, the peak percentage of customer without power in the state of Florida was 62 percent.[27] The southern counties in Florida received the most amounts of storm surge and rainfall due to the path of the hurricane. Counties in Florida within the hurricane's outer bands felt the high winds and some storm surges.

In the aftermath of Hurricane Irma, Florida PSC reported more than 27,000 service crews were deployed by Florida's electric utilities to quickly restore power to customers. This was possible through mutual aid from neighboring states and collaborative work efforts to prepare for such extreme weather events. As previously mentioned, Florida PSC would have been responsible for providing support to emergency coordination and as such data was recorded of customers affected by the outages. Figure 2 below provides a graphical view of the percentage of customer affected by power outages. The data also includes the various electricity utilities that fall under the purview of the electricity regulator. From the graph, the maximum amount of customers affected by power outages occurred on September 11th 2017. It can be inferred the most amount of customers being

[27] Florida Public Service Commission. 2018. *Review of Florida's Electric Utility Hurricane Preparedness and Restoration Actions 2018.* Florida Public Service Commission. http://www.floridapsc.com/Files/PDF/Publications/Reports/Electricgas/UtilityHurricanePreparednessRestorationActions2018.pdf

affected, over 6.5 million customers, was reduced to less than one percent of the maximum number affected within 10 days.

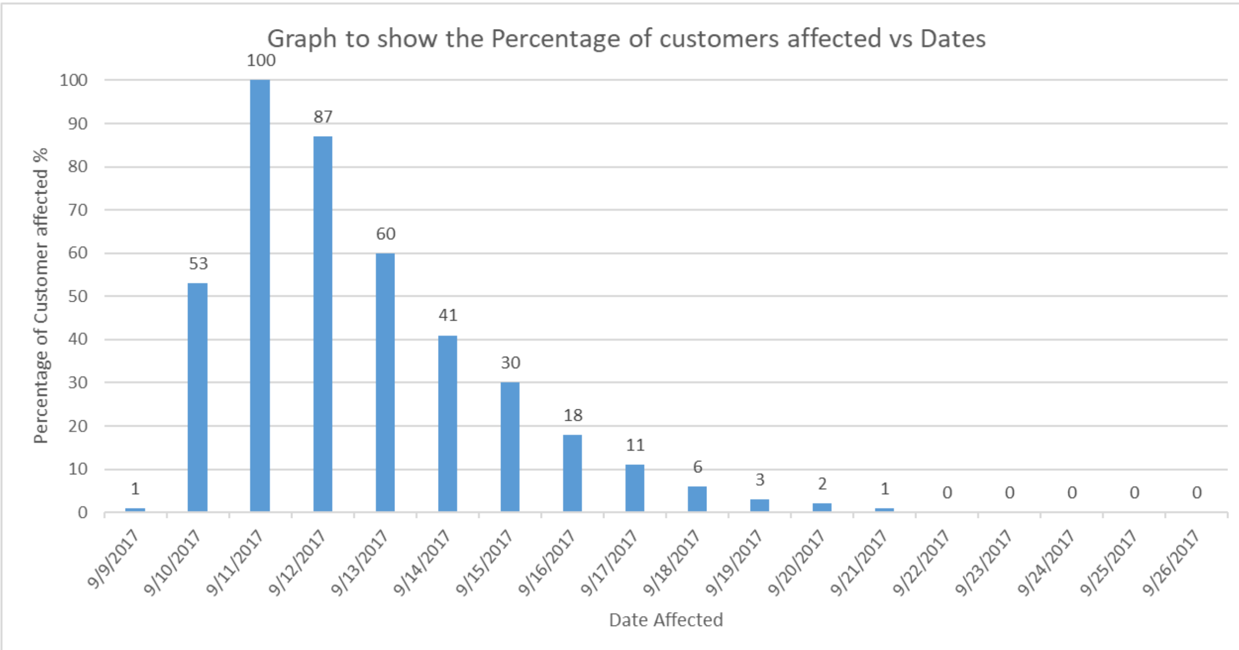

Fig 2. Graphical view of number of power outages due to Hurricane Irma.
(Source: Florida Service Commission 2018)

A comparison was done between the effects of Hurricanes Wilma and Irma for customers of Florida Power and Light (FPL). This comparative data is a clear indicator of the responsiveness of the utilities with respect to hurricane and storm related outages. The data provided shows that for the 2017 hurricane season (after the Storm Order issued and the directives implemented which improved grid resilience) the restoration time for customer drastically decreased while the number of customers on the grid had increased. The number of customer increased by more than one million whilst there was a decrease in a total number of days for Hurricane Irma to 10 days in comparison to Hurricane Wilma which took 18 days. Furthermore, the rate at which restoration was done was provided as a percentage restored per day, showing the grid resiliency programme to increase the rate by five times. This reveals how successful a grid resiliency programme can function.

Table 2. Comparative Analysis of Hurricanes Wilma and Irma

	Wilma (2005)	Irma (2017)
Customer outages	3.2M	4.4M
% Restored/day	50% / 5	50% / 1
Days for complete restoration	18	10
Average days to restore	5.4	2.1

Source: Florida Power and Light 2018

Additional information was collected to review and compare the differences experienced by Hurricane Irma throughout areas of the electricity grid. Due to Hurricane Irma having a large footprint that expanded to various counties in Florida, the data allowed for comparisons between different locations that experienced similar conditions. The information was collected by FPL and comparison was done for hardened overhead, non-hardened overhead and underground lines. Table 3 shows that the rates of outages for hardened overhead lines were noticeably less than those of non-hardened overhead lines. Notably, while limited underground distribution lines were damaged during the hurricane, underground electricity transmission lines were not. Thus, the decision to underground portions of the electricity grid, while it can be costly, is one that can be considered due to its resilience in the event of hurricanes. Consideration must be given to the effects by floods and uprooted vegetation to underground lines.

Table 3. Comparative Analysis of hardened vs non-hardened facilities during Hurricanes Irma

	Transmissions	Distribution feeders	Distribution laterals
Non-hardened overhead	20%	82%	24%
Hardened overhead	16%	69%	N/A
Underground	*	18%	4%

Source: Florida Power and Light 2018

Further to FPL's data collected, two other large-scale electric utilities presented performance data for their systems during the passing of Hurricane Irma. These two utilities were Duke Energy Florida (DEF) and Tampa Electric Company (TECO). The data provided by these utilities was the number of reported repairs to damages caused by Hurricane Irma. The information from the three electric utilities were tabulated for ease of comparison and shows pole/tower repairs.

Table 4. Comparative Analysis of hardened vs non-hardened facilities during Hurricanes Irma

		Hardened Overhead Total	Hardened Overhead Replace/Repaired	Non-hardened Overhead Total	Non-hardened Overhead Replace/Repaired
FPL	Transmission	60,694	0	5,991	5
	Distribution	124,518	26	1,063,684	2,834
DEF	Transmission*[28]	30,594	0	23,625	142
	Distribution**[29]	N/A	N/A	N/A	N/A
TECO	Transmission	19,447	2	5,834	15
	Distribution	63,120	20	199,880	145

Source: Florida Power and Light 2018

From the data provided, the results show the percentage of hardened overhead lines resulted in fewer replaced/repaired in comparison to the numbers of non-hardened overhead lines that required replacement or repair. Due to less transmission poles requiring replacement or repair, there were considerably less major power outages caused by the hardened transmission facilities.

[28] Summation of transmission poles and towers replaced and/or rebuilt.

[29] DEF did not provide records of distribution poles as this electric utility does not record information to differentiate between hardened and non-hardened poles. After the hurricane passed, a study was done on 2,130 replaced poles and none were determined to be hardened.

7 Conclusion & Recommendations

A review of the Storm Order by the Florida PSC showed that it was effective, in that it allowed the utilities to adapt their networks to better withstand adverse weather events and recover quickly. Given the similar experiences with hurricanes and tropical storms between Florida and the Caribbean, utility regulators within the region can learn from the experiences of the Florida PSC. Regulators can utilize similar strategies to implement electricity grid resilience measures, while considering differences that may limit what is transferrable, such as the difference in terrain. For example, by taking an aggressive approach to hardening the grid against hurricanes and storm damage, Caribbean utilities can be better prepared for the hurricane seasons.

Several key findings include the following:

- The directives from Florida PSC were able to improve the level of grid resilience, allowed the network to adapt to adverse weather events and enable the utilities to recover quickly after storm damage;
- Hardened facilities operated more efficiently against hurricane and storm damages; and
- Undergrounding of facilities carry high costs to install and maintain thus strategic locations should be selected

From the outcomes of FPSC's Storm Order, the following lessons were learnt:

- Regulators need to be proactive in developing mechanisms that can aid utilities in becoming more efficient. Developing a proactive approach can be more cost effective in minimizing the impact of extreme weather. Florida PSC saw the need to enforce grid resilience after sustaining hurricane damage in the 2004-2005 hurricane seasons. While the damages may not have been prevented completely, the electricity grid would have been able to recover from the impacts with less effort.
- The principles and methodology used by Florida PSC to create a solution to their grid resilience issue must be adapted to suit the environment in which it is being executed. The PSC understood they were not initially equipped with the knowledge to derive a solution and, therefore, included all key stakeholders in the process. The process was iterative to provide a level of transparency and engage stakeholders at various levels.

- Regulators and utilities need to re-examine existing initiatives and enforce them accordingly as many utilities already perform the tasks set in the initiatives of Florida PSC. However, most are not reviewed in detail. Reviewing in detail would allow the regulators to develop performance indicators to hold utilities accountable.
- Since the Caribbean shares similar climate to Florida, utility regulators can follow the example set by Florida PSC in becoming the champion to promote grid resilience.
- The aggressive approach taken by the Florida PSC to enhance grid resilience can be adopted in the Caribbean as the frequency and intensity of hurricanes are expected to rise.

Implementation of a grid resiliency programme can be enhanced by the following recommendations:

1. A post-project assessment should be done to measure the success of a grid resiliency project.
2. Suitable performance indicators should be established to monitor and assess the performance of grid hardening measures. This would require the implementation of appropriate data collection and reporting mechanisms. This can also be used to demonstrate the practical benefits of the investment made by the utility.
3. When considering activities to be performed for a grid resiliency programme, regulators and utilities must be mindful of the terrain and the conditions that may be faced when executing these tasks.
4. Communication between electric utilities and customers on power outages after storms can give customers a sense of relief that they have not been forsaken and can take appropriate measure to ensure their survivability.
5. A review of legislation for vegetation management outside of the utilities' rights of way can be done to reduce outages and prevent high restoration costs. Furthermore, an educational awareness programme can also be launched to inform customers of the right tree for the right place to aid in vegetation management.

Electricity grid resiliency has garnered less attention in the past. With the trend of severe weather showing increased frequency and intensity, the need for grid resilience is more important now than ever and needs to become an area of greater focus for regulators.