Impacts on Underground Transmission Assets due to Flooding Caused by Major Storms

Introduction: Why underground cables get a bad rap when flooding is involved

Many may think that while underground transmission and distribution is great for normal storm resiliency it fails when flooding is involved, and the cables are rendered inoperable. However, contrary to this belief, PDi^2 in conjunction with Burns & McDonnell recently completed a survey where we reached out to utilities that have been impacted by storms including flooding to assess the performance of underground transmission cable systems during these storm events. Based on this data, the performance of the underground cable systems was found to be exceptionally high. While the flooding events did cause outages on the transmission systems, including circuits with underground components, it was not impacting the cables themselves but rather the equipment that the cables were connected to.

While this data may be surprising to some, it supports the cable manufacturers efforts to design cable systems capable of withstanding complete submersion without operational impacts. Nearly all modern cable systems being manufactured today are designed and tested to withstand the rigors of flooding events. These robust cable systems, along with storm hardening improvements to critical connected equipment (relays, switchgear, transformers, etc.) can yield a system capable of continuous operation of the transmission circuit(s) in the most challenging of storm conditions, including flooding.

Many utilities are updating to new equipment or instituting resiliency plans.

The Study

Overview of the types of impacts from flooding on underground transmission assets and methods developed to mitigate future impacts

Objective

Power Delivery Intelligence Initiative (PDi^2) tasked Burns & McDonnell to solicit data on underground transmission asset performance from utilities located in areas impacted by major weather events. The weather events used for this evaluation were Superstorm Sandy (northeast US) and Hurricane Irma/Harvey (southeast US). The data analyzed was used to create a report providing a summary of the subsequent findings (Report). The objective of this initiative is to identify not only the mechanisms of failure, but also identify the mitigation techniques deployed by utilities who may have been impacted by the aforementioned major weather events.

The following report highlights the methods in which the data has been acquired, a summary of the findings, and a conclusion based on the data received.

Methodology

Before the data could be solicited, a list of potential utilities in areas which may have been impacted by major weather events was created. The areas considered for this study were coastal areas impacted by either one of two major storms. The first area considered is the northeast US, which has been impacted by Superstorm Sandy, and the second area is the southeast US coastal areas, which were impacted by Hurricane Irma/Harvey. See Table 1 for the complete list of utilities solicited in areas impacted by Super Storm Sandy. See Table 2 for the complete list of utilities solicited in areas impacted by Hurricane Irma/Harvey.

Table 1: Utilities Solicited in Areas Impacted by Superstorm Sandy

Utility	Service Area
Con Ed	NYC/Westchester County
PSEG	New Jersey
PSEGLI	Long Island, NY
United Illuminating	Connecticut
Eversource	New England
National Grid	New England
First Energy	New England

Table 2: Utilities Solicited in Areas Impacted by Hurricane Irma/Harvey

Utility	Service Area
Duke Energy Florida	Central Florida
AEP	Florida
TECO	Tampa Bay, FL
Entergy	TX, LA, MS
CenterPoint Energy	TX, LA, MS
Florida Power & Light	Eastern/Southern Florida

Upon developing the list of utilities according to the areas impacted, the Burns & McDonnell Underground Transmission group coordinated to identify known contacts at each utility. Ultimately each utility was assigned a contact and the list was completed.

Develop Survey

A survey titled *Underground Transmission Circuit Performance During Flooding due to Major Weather Events* (Survey) was developed to be transmitted to each contact listed within the list of utilities. The Survey was developed such that the responses received would provide enough data to complete a high-level overview of the impacts. Upon developing the survey questions, Google Surveys was utilized to create the survey for soliciting data from the utilities. Once the Survey was created, it underwent a collaborative review process (by Burns & McDonnell and PDi^2) and was modified per the results of the review before being transmitted to each of the utilities and their respective contact.

The completed Survey consists of two sections as outlined below.

The first section of the Survey utilized multiple choice questions to acquire data on the circuits. These questions were intended to discover the following:

- How many circuits were in operation at the time of the storm
- How many circuits were impacted by the storm
- If the circuit(s) impacted utilized a solid dielectric cable system
- If the circuit(s) impacted utilized a pipe-type cable system
- The mechanism(s) of failure

The second section of the Survey utilized written responses to acquire additional data on the impacts to the circuits. These questions were intended to discover the following:

- A description of the impacts on the circuits
- Ancillary system impacts
- Design or operational changes implemented to mitigate future impacts

See the attached Appendix for an example of the completed Survey.

Results

The following sections highlight participation of the utilities solicited, the results of the surveys completed, and the conclusions inferred from the completed survey data.

Participation

In total there were 13 contacts within the list of utilities created, with one contact per Utility on the list. A breakdown of the participating utilities is shown in Table 3.

Table 3: Percentage of Utilities Participated in Survey

Number of Utilities Surveyed	Number of Utilities Participated	Percentage of Participation
13	4	30%

Results of the Survey – Superstorm Sandy

Of the four participating utilities in the survey (30%), two service the Superstorm Sandy area. Because of the survey confidentiality, the utilities which completed the Survey and provided the data to be used in this Report will remain anonymous.

Results of the Survey – Hurricane Irma/Harvey

The two remaining utilities participating in the survey service the areas impacted by Hurricane Irma/Harvey. Because of the survey confidentiality, the utilities which completed the Survey and provided the data used in this Report will remain anonymous.

Summary of Results

The summary of results is intended to show all data received collectively and is not dependent on the area impacted. See Table 4 for individual survey results.

Table 4: Summary of Survey Results

	# CIRCUITS IN OPERATION	# CIRCUITS IMPACTED	SOLID DIELECTRIC SYSTEM IMPACTED	PIPE-TYPE SYSTEM IMPACTED	MECHANISM OF FAILURE SOLID DIELECTRIC	MECHANISM OF FAILURE PIPE-TYPE
SURVEY RESPONSE 1	70	5	1	0	TERMINATIONS	NONE
SURVEY RESPONSE 2	5	0	0	0	NONE	NONE
SURVEY RESPONSE 3	20	5	0	1	NONE	PUMPING PLANT, SUB EQUIPMENT
SURVEY RESPONSE 4	100	5	0	1	NONE	FLUID LEAK

Summary of Results – First Section

The first section of the survey included multiple choice questions allowing insight into the quantity of operational circuits, the type of cable system utilized by the impacted circuits, and the mechanisms of failure. The data points collected from the survey's first section are shown in Table 5.

Table 5: Summary of Data Points Collected

ITEM	DATA POINT
1	PERCENTAGE OF SURVEYED UTILITIES IMPACTED 75%
2	PERCENTAGE OF CIRCUITS IN OPERATION IMPACTED* 8%
3	PERCENTAGE OF SYSTEMS IMPACTED WHICH ARE SOLID DIELECTRIC 33%
4	PERCENTAGE OF SYSTEMS IMPACTED WHICH ARE PIPE-TYPE 67%
5	PERCENTAGE OF SOLID DIELECTRIC SYSTEMS IMPACTED WHERE FAILURE AT TERMINATION** 100%
6	PERCENTAGE OF SOLID DIELECTRIC SYSTEMS IMPACTED WHERE FAILURE AT SPLICE 0%
7	PERCENTAGE OF SOLID DIELECTRIC SYSTEMS IMPACTED WHERE FAILURE AT CABLE 0%
8	PERCENTAGE OF PIPE-TYPE SYSTEMS IMPACTED WHERE FAILURE AT TERMINATION 0%
9	PERCENTAGE OF PIPE-TYPE SYSTEMS IMPACTED WHERE FAILURE AT SPLICE 0%
10	PERCENTAGE OF PIPE-TYPE SYSTEMS IMPACTED WHERE FAILURE AT CABLE 0%

*Total percentage of circuits impacted out of number of total circuits in operation; includes utilities surveyed which reported impacts to circuits only

**Percentage of failure type based only on type of system impacted

Per the data received, 75% of the surveys completed revealed some degree of impact to underground transmission assets (Item 1). Of the circuits in operation during the storms, the data shows only 8% of those circuits were impacted (Item 2). Extrapolating this data, it is likely the utilities not participating in the Survey may report similar findings.

The data shows that of the circuits impacted, 33% were solid dielectric cable systems and 67% were pipe-type cable systems (Items 3 and 4, respectively).

Of the circuits impacted utilizing solid dielectric cable systems, the data shows 100% of the failures happened at the terminations only and not at the splice or on the cable. Of the circuits impacted utilizing pipe-type cable systems, there was no data showing failure at the termination or splice. Per the data received, there was a fluid leak in a pipe-type system, although the data shows the leak was caused by a fault in an overhead line rather than in the cable itself and is therefore not considered as an impact on the cable.

Summary of Results – Second Section

The second section of the survey included written responses, allowing further insight into the failure mechanisms and methods used to mitigate future impacts. The responses received from the second section of the completed Surveys are shown in the following figures.

*Figure 1: Results of Second Section of Survey, Part 1****

Written Responses**

**Please note that as the response is being typed, the response box will expand to display the full text. There is no character limit to these responses.

Please provide a brief description of the impact(s).

Salt contamination on the terminations and lightning arrestors.

Please describe any ancillary system impacts due to the storm.

No issues due to flooding.

Please describe any design and/or operational changes which have been implemented to mitigate future impacts to underground transmission systems due to major weather events.

Upgraded lightning arrestors

*Figure 2: Results of Second Section of Survey, Part 2****

Written Responses**

**Please note that as the response is being typed, the response box will expand to display the full text. There is no character limit to these responses.

Please provide a brief description of the impact(s).

Pumping plants were damaged when flooded by the storm surge during Hurricane Ike. Damaged pumping plants were replaced and installed to a higher elevation based on area study.

Please describe any ancillary system impacts due to the storm.

69kV substation equipment damaged due to storm surge and replaced with 138kV equipment. Associated 69kV pipe-type cable was de-energized indefinitely.

Please describe any design and/or operational changes which have been implemented to mitigate future impacts to underground transmission systems due to major weather events.

Install critical equipment to higher elevation based on area study. Install nitrogen back-up system in pumping plants.

*Figure 3: Results of Second Section of Survey, Part 3****

Written Responses**

**Please note that as the response is being typed, the response box will expand to display the full text. There is no character limit to these responses.

Please provide a brief description of the impact(s).

A fault in an OH line caused a pipe leak

Please describe any ancillary system impacts due to the storm.

ground water remediation required

Please describe any design and/or operational changes which have been implemented to mitigate future impacts to underground transmission systems due to major weather events.

none

***Each Part represents distinct responses from different utilities which reported impacts to underground transmission assets

As shown in the responses to the Survey's second section, there were other mechanisms of failure within ancillary systems not reported in the first section. Per the data received, one of the surveyed utilities reported salt contamination on the terminations and lightning arresters, while a different survey reported impacts to pumping plants caused by flooding. It can be deduced from this data that not only ancillary systems, but also other above grade components were impacted and those impacts were associated with flooding due to storm surge. This data coincides with other reporting of impacts from public information provided by other utilities in areas affected by these storms.

Per the data received regarding methods of mitigating future impacts due specifically to flooding, one utility upgraded the lightning arresters which were contaminated with salt during the storm. Another utility installed critical equipment at higher elevations and installed backup systems. The remaining utility reported flooding but did not provide any methods for mitigating future impacts.

Additional Research Data

To supplement the data received from those utilities participating in the Survey, additional research has been analyzed to better form a conclusion on the performance of underground transmission assets during storms. This research primarily involved the impact on electric power transmission circuits in New York, both overhead and underground, as this area was one of the hardest hit from Superstorm Sandy. Consolidated Edison, Inc (Con Ed) services the New York City and Westchester County areas of New York State.

Con Ed stated:

> 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 devasted by wind and tree damage leaving nearly 70 percent of those served by the overhead systems without power.[1]

This supports the conjecture that underground transmission circuits are more resilient to the impacts of major storms than overhead, as only the overhead transmission circuits are noted for taking significant damage during the storm. This is further supported if considering that during Superstorm Sandy (2012), Con Ed reported only 438 miles of overhead circuits compared to the 750 miles of underground circuits[2]. In summary, although there is almost twice the distance in underground transmission circuits than that of the overhead transmission circuits, the majority of damage reported involved the overhead circuits only.

In addition to the survey and research data, feedback regarding impacts to underground transmission assets has been solicited through conversation with engineers working with, or employed by, utilities within the areas mentioned in this Report. A summary of the impacts is as follows.

- Damage to critical equipment
    - Debris hitting and damaging lightning arresters, terminations, etc.
- Issues related to soil stabilization due to flooding
    - Foundations and structures displaced slightly
- Mud and silt containing corrosive properties left over after storm surge and flooding
    - Corrosive to steel and concrete impacting foundations, structures, etc.

Conclusion

Of the participating utilities in the Survey, a high percentage reported impacts to underground transmission assets. However, per the data received, the ratio of circuits impacted to the total number of circuits in operation is very low. Therefore, because of the low ratio of underground circuits impacted to underground circuits in operation, it is reasonable to assume underground transmission assets are unlikely to experience impacts caused by flooding due to major weather events. However, the data received shows that any failures as a result of flooding would likely be within the ancillary equipment and other above grade cable components.

Per the data received and additional research conducted on this topic, the recommendations for the mitigation of impacts to underground transmission assets are primarily focused on methods deployed to prevent damage to ancillary systems and above grade components caused by flooding and debris. The installation of new equipment, relocating existing equipment to higher elevations, replacing non-submersible equipment with submersible equipment[3], and the implementation of back-up systems are all possible methods used to mitigate future impacts from flooding due to major storms.

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[1] Consolidated Edison Company of New York, Inc., Report on Preparation and System Restoration Performance, 2013

[2] Consolidated Edison, Inc., 2012 Annual Report, 2012

[3] NERC, Hurricane Sandy Event Analysis Report, 2014

APPENDIX: SURVEY QUESTIONS

Underground Transmission Circuit Performance During Flooding due to Major Weather Events

Burns and McDonnell (BMcD) and Power Delivery Intelligence Initiative (PDI2) seek industry leaders from across the nation to share knowledge and expertise to improve existing infrastructure and to ensure the best practices are being implemented on every project. In an effort to better understand the impacts of major weather events such as Super Storm Sandy, Hurricane Harvey, and Hurricane Irma, BMcD has created a short survey to gather feedback which can be used to identify the best practices available.

Through this online survey, BMcD will gather the results and analyze the feedback provided regarding the types of impacts that major weather events may have on underground transmission systems, and if there were indeed impacts, identify the mechanisms of failure and understand any design changes which have been implemented to mitigate future failures.

All responses will be kept strictly confidential. Your input will only be used in combination with the responses of others participating in the survey. Your individual responses will not be published.

pdi² Power Delivery Intelligence Initiative

BURNS McDONNELL.

Description of Circuits*

*For the purpose of this study, the term "circuit" refers to a complete circuit which can be made up of one or more lines. If more than one line within a circuit has been impacted, the entire circuit should be considered as impacted and counted only once, regardless of the number of lines included within it.

How many circuits were in operation at the time of the storm? If choosing other, please write the number of circuits in operation.

- ☐ 1-5
- ☐ 6-10
- ☐ 11-15
- ☐ 16-20
- ☐ 21-25
- ☐ 26-30
- ☐ 31-35
- ☐ 36-40
- ☐ 41-45
- ☐ 46-50
- ☐ Other:

How many circuits were impacted by the storm? If choosing other, please write the number of circuits impacted.

- [ ] 1-5
- [ ] 6-10
- [ ] 11-15
- [ ] 16-20
- [ ] 21-25
- [ ] 26-30
- [ ] 31-35
- [ ] 36-40
- [ ] 41-45
- [ ] 46-50
- [ ] Other: ____________________

Does the circuit(s) impacted utilize a solid dielectric insulated cable system or a pipe-type cable system? Please select all that apply.

- [ ] Solid dielectric
- [ ] Pipe-type

If a solid dielectric insulated cable system, please check all applicable boxes indicating the item(s) which were impacted by the storm. If other, please explain.

- [ ] Cable
- [ ] Splices
- [ ] Terminations
- [ ] Other:

If a pipe-type cable system, please check all applicable boxes indicating the item(s) which were impacted by the storm. If other, please explain.

- [ ] Cable
- [ ] Splices
- [ ] Terminations
- [ ] Other: ____________

Written Responses**

**Please note that as the response is being typed, the response box will expand to display the full text. There is no character limit to these responses.

Please provide a brief description of the impact(s).

Your answer

Please describe any ancillary system impacts due to the storm.

Your answer

Please describe any design and/or operational changes which have been implemented to mitigate future impacts to underground transmission systems due to major weather events.

Your answer