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ComEd Resilience Metrics for Tracking Storm Restoration and Gray Sky Day Performance

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SUMMARY

Resilience improvements represent major strategic objectives of any critical infrastructure sector, including electric power. Prerequisites for success include a well-thought out strategic vision, well-executed action plans, an effective mechanism for allocating capital and prioritizing investment options under financial constraints. Storm events are one of the major causes of substantial disruption to electric utility infrastructure, which affects the continuity of power supply. Since resilience investments directly affect the number and duration of outages in the aftermath of an adverse event, the avoided cost of restoration needs to be considered in assessing the cost-benefit of investments. Investments and improvements to the restoration process are complementary to, and at times an alternative to, investment in grid hardening, and for that reason they must be considered as they are directly correlated to the cost and duration of the restoration process. However, it is important to develop metrics that can capture the utility's performance during each of these events. At ComEd, performance during a storm can be measured by percentage of customers restored within 12 hours of losing power and performance during a gray sky day can be measured by percentage of gray sky days with fewer than 12,000 customer interruptions. The 12 hours is based on storm restoration process shift schedule. The 12,000 customer interruptions is based on a median of five years of historical gray sky day performance.

In this paper, we define ComEd's resiliency and lay out how we measure the resilience of the ComEd system, establishing a cutting-edge approach to quantifying resilience that the broader industry has yet to develop.

KEYWORDS

Resilience, Metrics, SAIFI – System Average Interruption Frequency Index, CAIDI – Customer Average Interruption Duration Index, Customer Interruptions, Outage, ACI – Avoided Customer Interruptions, DA – Distribution Automation

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1. INTRODUCTION

A resilient power grid ensures an uninterrupted supply of electricity to citizens and interdependent lifeline systems even during extreme weather and other threats to the system. The power grid continues to evolve as the needs and demands from society continue to change. In addition, grid operators are constantly faced with an emerging risk landscape. Changing power demand, increased reliance on renewable and distributed energy resources (DERs) and increasing penetration of smart technologies introduce additional layers of complexities to grid operations. In addition, the increasing frequency and severity with which natural disasters occur because of climate change [1], [2], as well as the potential for manmade disasters (e.g., 2014 physical attack on PG&E's substation) [3], and cyber-attacks (e.g., malware BlackEnergy) pose significant risks and challenges to the uninterrupted operation of the modern power grid.

Resilience as a concept has emerged as a strategic objective within the critical infrastructure community. According to Presidential Policy Directive 21 [4], resilience is defined as "the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents." Grid resilience is the power grid's capability to ensure continuity of service to communities during high-consequence disruptive events. While it may not be feasible to guarantee the continuity of the operations at nominal or pre-disruption levels, ensuring even a reduced service level can minimize the negative impacts of these events on communities.

For five consecutive years (2016-2020), ComEd achieved best-in-class SAIFI compared to benchmarking results of electric utility peer companies. With the evolution of customer expectations and the necessity of electricity in the 21st century economy, reliability is no longer enough. However, ComEd still must strive to anticipate and bounce back from natural or manmade threats. This was most evident during the August 2020 Derecho Storm, which struck the entire ComEd system with 13 tornadoes, winds reaching up to 110 mph, severe straight-line winds gusting up to 100 mph, golf ball sized hail and 4,300 lightning strokes. In total, the August 2020 Derecho knocked out power to approximately 800,000 customers. 540,000 customers were restored in 24 hours, which is the fastest restoration in ComEd's history for a storm of that magnitude. However, the storm did not meet the threshold of customers restored within 12 hours based on ComEd's storm resiliency metric (Metric 1).

ComEd's definition of a resilient system is a system that responds effectively to naturally occurring events, as well as potential physical and cyber incidents, by increasing the system's flexibility and robustness. A system's flexibility is described by its ability to respond, adapt, and recover from events that result in interruptions. Technology programs under our investment plan that enable flexibility include the following: Distribution Automation program, Bus Reconfiguration program, Community Energy Storage program, Reducing Substation Customer Count program, and a 4kV to 12kV Conversion program. A system's robustness is described by its ability to absorb event impacts without sustaining interruptions. Material condition programs under investment plan that enhance robustness in the system include: Very Important Feeders (VIF) program, Undergrounding / Targeted Resiliency program, Underground Cable Replacement programs (URD/Mainline), Distribution Wood Pole Replacement program, Transmission and Substation Modernization program, Flood Prevention. The current resilience metric focuses on weather-related events.

Commonly used reliability metrics, such as Customer Average Interruption Duration Index (CAIDI), System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index SAIDI), and Customer Average Interruption Frequency Index (CAIFI), measure the reliability of the system and ensuring preparedness for disruptions and expected outages that occur under relatively normal conditions. However, due to the changing risk landscape, there is a broad consensus among electric utilities across North America (other parts of the world) that these metrics do not adequately capture the impacts of many of the emerging risk exposures in the power grid [5]. The current dynamically evolving risk landscape, requires a new set of metrics and processes to assess the *resilience* requirements of the power grid.

2. RESILIENCE METRICS

To maximize the resilience of a system, ComEd has designed two metrics that will be aggregated into one overall resilience metric. The two metrics are (1) Storm Resiliency (Metric 1), which focuses on speed of recovery during the first 12 hours from customers losing power and (2) Gray sky day Resiliency, which focuses on robustness and the ability to withstand most weather events. The purpose of Metric 1 - Storm Resiliency is to assess the storm response process and determine solutions that can improve performance. The purpose of Metric 2 - Gray sky day Resiliency is to assess the robustness of the system based on various weather conditions and determine solutions that can improve performance. The methodologies for Storm and Gray sky day resiliency metrics were shared with the other Exelon utilities and IEEE taskforce. While the two Metrics focus on weather, there are metrics that would focus on cyber and physical events that are not captured in this paper.

2.1. STORM DEFINITION

ComEd's storm definition is weather events resulting in greater than 125 primary sustained interruptions or 25,000 sustained customer interruptions within a 24-hour period.

2.2. METRIC 1 – STORM RESILIENCY

This metric is focused on reductions in the number of storm related customers without power for more than 12 hours from the time the customer loses power. Metric 1 will factor in customer counts restored automatically, or not requiring human interventions, thus encouraging the utility to invest in new technology that minimizes customer impact. It will measure the number of storms where recovery is favorable to threshold values divided by total number of storms.

$$\frac{\textbf{\# of Storms where recovery is favorable to thresholds}}{\textbf{\# of Storms}}$$

Since all storms are not equal, to compare and gauge improvement, storms will be categorized into four categories:

1. Significant Storms: Defined as greater than 1500 storm interruptions (outages)
2. Large Storms: Defined as between 701 and 1500 storm interruptions (outages)
3. Medium Storms: Defined as between 251 and 700 storm interruptions (outages)
4. Small Storms: Defined as fewer than or equal to 250 storm interruptions (outages)

The baseline threshold for the four storm categories were derived by data analysis on 10-year historical storm data.

The Annual Average for each of the four storm categories is the baseline threshold values:

1. Significant = 24.1%
2. Large = 9.0%
3. Medium = 2.8%
4. Small = 0.8%

Calculation:

1. For each storm in a calendar year, calculate the ratio of customers without power for more than 12 hours and total customer interruptions (CI) including customers automatically restored (ACI) through smart switch operations (DA devices), community energy storage, and microgrids (does not include substation reclosing events) – measured in %.

$$\textbf{Storm Event: } x = \frac{\sum \text{Customers Without Power for More Than 12 Hours}}{\textit{Sustained CI+ACI Due to Distribution Automation}}$$

2. Based on number of interruptions (storm outages), categorize each storm event significant, large, medium, or small.
3. Determine if X is greater than or equal to the threshold value (Y) for the category.
4. If X < Y, storm met expectations. If X >= Y, storm did not meet expectations.

Sample of storm year:
1. Storm 1 – Small 0.5% without power for 12+ hours (favorable to 0.8% threshold).
2. Storm 2 – Medium 2.1% without power for 12+ hours (favorable to 2.8% threshold).
3. Storm 3 – Medium 6.5% without power for 12+ hours (unfavorable to 2.8% threshold).
4. Storm 4 – Medium 2.5% without power for 12+ hours (favorable to 2.8% threshold).
5. Storm 5 – Large 13.9% without power for 12+ hours (unfavorable to 9.0% threshold).
6. Storm 6 – Medium 0.9% without power for 12+ hours (favorable to 2.8% threshold).
7. Storm 7 – Small 0.1% without power for 12+ hours (favorable to 0.8% threshold).
8. Storm 8 – Significant 15.5% without power for 12+ hours (favorable to 24.1% threshold).

Based on the sample of the storms above, six of the eight storms (or 75% of storms) achieved the storm resiliency threshold based on percentages of customer interruptions with lengthy customer interruptions (≥12 hours) which factor in automatic restoration or avoided customer interruptions by distribution automation.

2.3. METRIC 2 – GRAY SKY DAY RESILIENCY

Metric 2 accounts for weather conditions (independent of storm definition) and sustained customer interruptions. Gray sky day is defined as any calendar day that meets any one of the following weather criteria:
1. ≥ 80˚F average temperature across the system.
2. ≤ 0˚F average temperature across the system.
3. ≥ 25MPH average sustained wind speeds across the system.
4. ≥ 25MPH average one-hour wind gust across the system.
5. ≥ 0.75” average rain across the system.
6. ≥ 3,000 lightning strokes across the system.

The criteria above was derived by identifying an exponential increase in outages based on weather conditions.

Figure 1 shows Gray sky day intensity which measures extremity of qualifying weather conditions. Three color codes (yellow, orange, red) account for average daily temperature, wind speed, rainfall, and lightning strokes. These color codes can be used to evaluate reliability performance on a given Gray Sky Day.

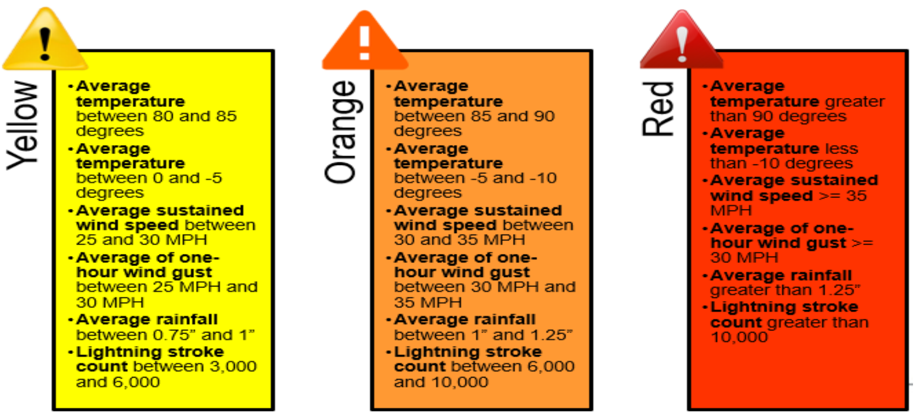

Figure 1: Gray Sky Day Intensity

Calculation:

1. Metric 2 is measured in percentage of gray sky days that do not exceed the target value. The target value is set at 12,000 customer interruptions (CI).

   # of Gray sky days < 12,000 CI / Total # of Gray sky days = % of Success

2. Five year historical performance on each gray sky day was evaluated and the target of 12,000 customer interruption was selected based on the median of the data set.

2.4. RESULTS AND BENEFITS OF RESILIENCE METRIC TRACKING

Benefits of Storm Resiliency (Metric 1) include insights and guidance on performance of storm restoration efforts; highlights the similarities and outlines the differences between two similar category storms. Through data analysis, improvements in infrastructure and operational enhancement efforts can be recommended. Deep dive analysis was performed by comparing two storms that occurred in 2021 to understand why the goal was missed. The selection was based on similar storm size, outages, customer interruptions, avoided customer interruptions by distribution automation, and regional impact.

Storm 1 and Storm 2 have a similar outage range, as seen in the Table 1. However Storm 1 occurred at 8 PM and had a second storm wave, while Storm 2 occurred at 1 PM. Distribution automation restored 26,511 customers for Storm 1 storm whereas it restored 30,872 for Storm 2.

Table 1: Storm Details

#	Start Storm Date Time	End Storm Date Time	Sustained Outage Count	Sustained Customer Interruption	CAIDI (Min)	Max Outage (HR)	DA ACI	Restored >12Hrs (w/ ACI)
Storm 1	6/20/2021 20:18	6/21/2021 17:34	540	54,131	331	93.1	26,511	8.00%
Storm 2	9/7/2021 13:02	9/8/2021 6:13	420	40,946	231	39.4	30,372	3.70%

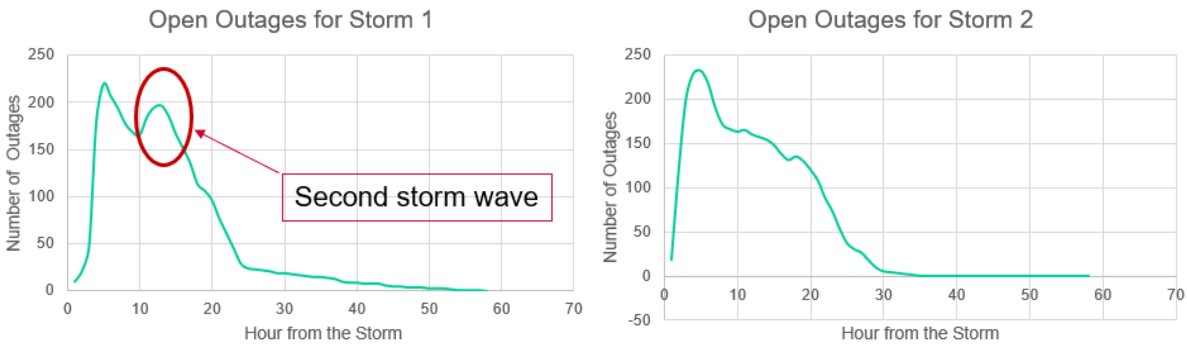

Figure 2: Storm 1 and Storm 2 Comparison

Figure 2 shows the open outages at any hour of the storm that the utility needs to restore. As soon as the storm hits, there are customer outages, and during the initial few hours (typically first 5 hours) the outage count increases. Either there are more outages due to some tripping, fuse blowouts, trees falling onto the line, or there is a new wave of storm. Typically, the former phenomenon is seen. However, **Figure 2 – Storm 1** shows the latter phenomenon where we see a substantial rise in open outages after 10 hours. This is another round of storm that hit the territory during the ongoing restoration process. This phenomenon affects the restoration process, crew deployments, and resource management.

Based on the analysis performed, it is observed that the timing of the storm played a major role with the recovery process. In other words, a faster resource deployment in the initial 12-hour window of a storm helps achieve the ComEd storm resiliency metric target (Metric 1). Additionally, a high percentage of customers restored with distribution automation devices typically results in favorable performance versus the metric target.

Gray sky day Resiliency (Metric 2): At the end of 2021, 67% (or 45 out of 67) Gray sky days had fewer than 12,000 customer interruptions. The target was set at 58% based on five year historical average. 2021 performance is favorable to target which indicates system improvement. Customer interruptions and gray sky days result are tracked using interruption reporting system (IRS), qlikview dashboard, and key performance indicator (KPI) as shown in Table 1. KPI creates visibility on monthly and year-to-date performance and allows us to perform deep dive analysis to determine areas for improvement and system investments.

Table 2: 2021 KPI Metric 2 monthly and year-to-date (YTD) performance

Gray Sky Day Resiliency (YTD)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Actual (%)	100	100	85	87	86	78	74	69	69	66	69	67
Target (%)	71	67	67	73	68	61	57	58	57	56	57	58
# of Gray Sky Days Favorable to Target	6	14	22	27	30	31	31	34	35	35	41	45
Total Number of Gray Sky Days	6	14	26	31	35	40	42	49	51	53	59	67

Gray Sky Day Resiliency (Month)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Actual (%)	100	100	67	100	75	20	0	43	50	0	100	50
Target (%)	71	60	67	88	40	29	44	60	50	50	60	75
# of Gray Sky Days Favorable to Target	6	8	8	5	3	1	0	3	1	0	6	4
Total Number of Gray Sky Days	6	8	12	5	4	5	2	7	2	2	6	8

ComEd’s resiliency metrics can be expanded beyond weather conditions. For this reason, ComEd is leading the IEEE Distribution Resiliency Taskforce to develop the 'Distribution Resiliency Guide' by rallying a team of over 60 utilities, universities, National Labs and Industry across the world. The framework requires a set of inputs, models, and outputs to facilitate a systematic, risk-informed, data-driven, resilience-focused decision-making process. The guide is to be completed by end of 2024.

3. CONCLUSION

ComEd has developed Storm and Gray sky day resiliency metrics to track storm performance. ComEd has invested significantly in system infrastructure improvements. ComEd analyses the storm performance using these metrics, and can focus investments and planning based on the system performance (resilience). The ComEd resiliency metrics provides clear picture of storm restoration (speed of recovery) and gray sky day (system robustness) performance.

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