Reliability of U.S. Electric Utilities

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Executive summary

Reliable electric power plays a critical role in communities around the world. With a focus on safety and sustainability, UL's experts have recently completed an analysis of reliability data made available by the U.S. Energy Information Administration. This work indicates:

- The current reliability indices for duration and frequency of interruptions enable, with detailed analysis, many insights into the operation of the electric distribution infrastructure.
- The 2020 U.S.-customer weighted average interruption duration was 117 minutes, with an interruption frequency of 1.0.
- The underlying reliability in the U.S. distribution system has shown (correcting for underlying drivers) some improvement (reduced duration and frequency) between 2013 and 2020. All utilities have not registered the improvements, but approximately 20% show clear improvements. Additional focus on good practice transfer between peer benchmark utilities would likely accelerate the improvements.
- Correlation analyses indicated at the utility/state level that the major drivers of the recorded reliability were the methodology of interruption capture and the level of tree cover. Impacts due to location and utility size were also observed.
- Increasing the proportion of the distribution infrastructure installed underground is seen to correlate with improved reliability and reduced operation and maintenance costs. Any increase in undergrounding needs to be accompanied with improvements in the quality and performance of the underground components.

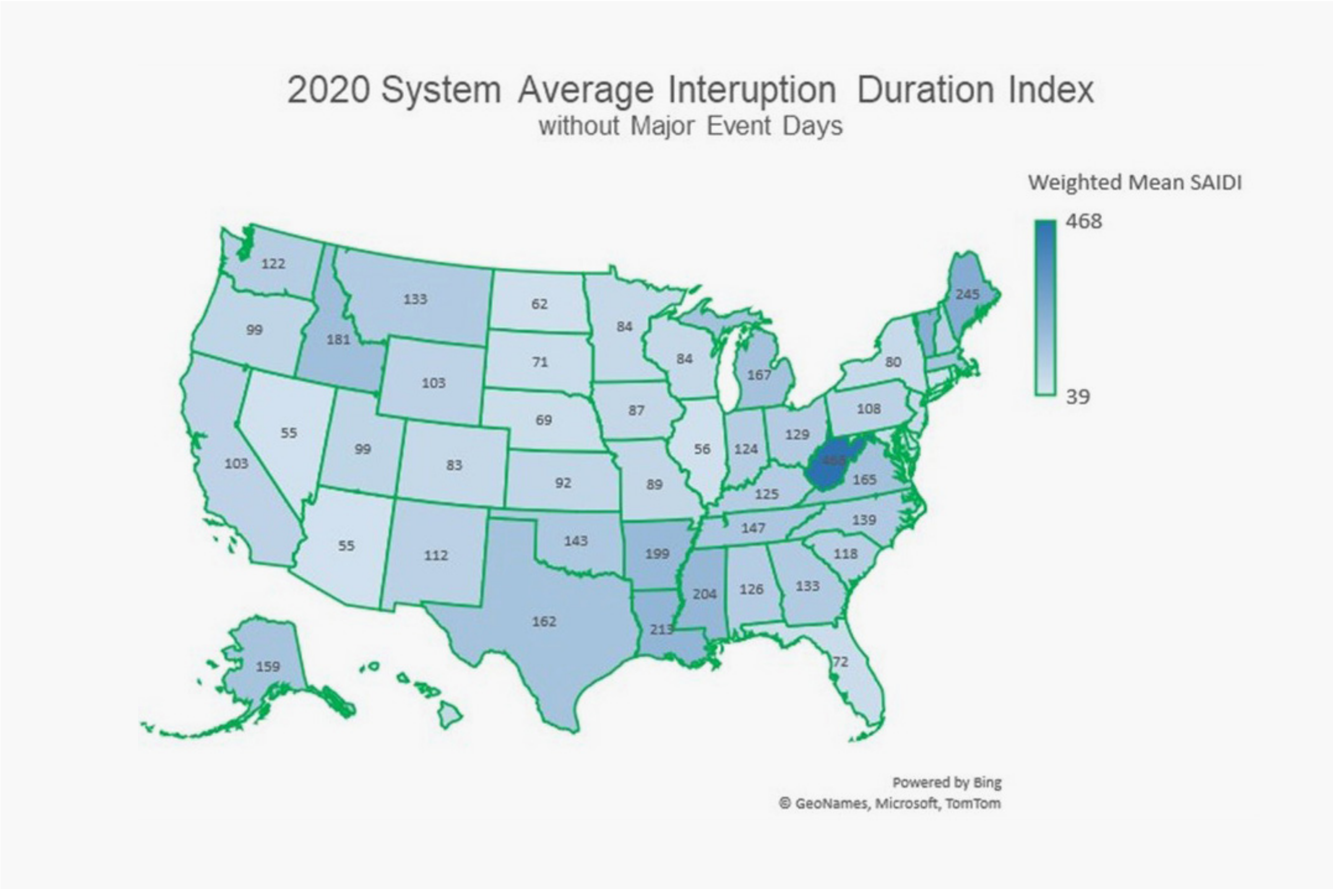
Introduction

Reliable electric power is central to the safety and sustainability of our communities. Power outages disrupt many elements of our lives. Outages happen to the power system for a variety of reasons, from accidents and aging equipment to inclement weather. Since electric power plays a critical role in our lives, freedom from these outages is critical, and utilities work hard to minimize their frequency and length. The system average interruption duration (SAIDI) and frequency (SAIFI) indices describe the way users experience these outages. These reliability indices detail the electric service reliability at the distribution level. They are the basis for many reliability goals and benchmark performance against peer utilities. Moreover, they can help a utility and the public track the tangible benefits of their investments.

Several bodies, including the U.S. Energy Information Administration (EIA) and the Institute of Electrical and Electronics Engineers (IEEE), develop and publish reliability indices such as SAIDI and SAIFI annually. To improve the usefulness of these data, this document details some of the recent work undertaken to understand the drivers of utility reliability.

2020 data

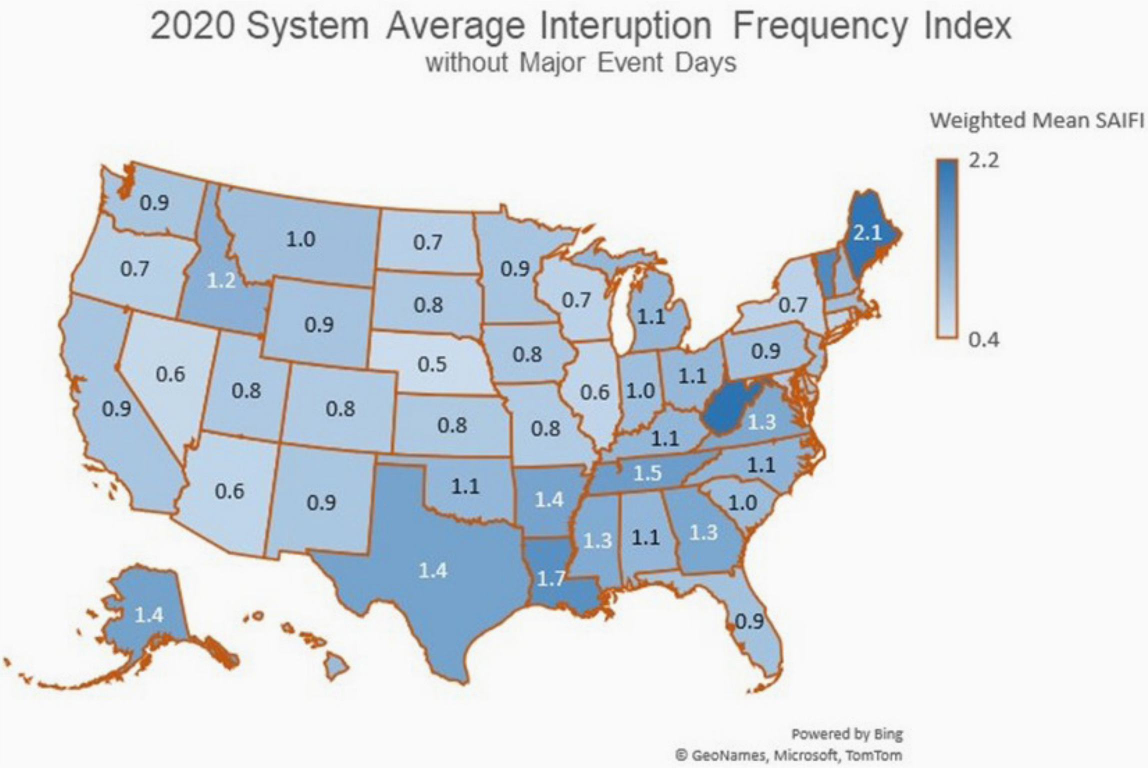
The 2020 data, released in 2021, from EIA contained over 900 individual reliability records for 148 million electric customers. It is well established that unusual weather patterns impact electric outages and can obscure the underlying performance of the infrastructure. To estimate, and then adjust for, the weather impact, a well-established procedure is used to define major event days (MED). Thus, the reliability data are reported by EIA both with and without MED.



The maps display the 2020 durations (above) and frequency (next page) for each state with MED removed. These data adjust for the different numbers of customers served by the participating utilities: 76%, 11% and 9% served by investor-owned, cooperative and municipal utilities.

Power interruptions, excluding MED, were longest in West Virginia and occurred most often in Maine. Nevada and New Mexico had the shortest and least frequent interruptions.

Overall, for the U.S., weighted by the number of customers in each utility and without MED, the average duration (SAIDI) for 2020 was 117 minutes with a frequency (SAIFI) of 1.0. MED increased these indices by 81 minutes and 0.36 occurrences. Adding MED to the underlying reliability indices provides a sense of the overall experience of electricity consumers.



The tabulated U.S. data for 2020 (on the next page) shows the impact of data outliers and utilities entering the survey since 2013 (consistent participants have completely reported every year since 2013). In this analysis, unlike in the maps, all utilities are counted equally with no weighting for the size of a utility. The table indicates that omitting the outlier data tends to reduce (improve) the reliability indices.

2020		All data included	Outliers omitted	Outliers omitted, consistent participants only
Unweighted mean	SAIDI + MED	376	325	349
	SAIFI + MED	1.58	1.44	1.41
	SAIDI – MED	135	111	105
	SAIFI – MED	1.21	1.09	1.05
% of records used		100%	94%	53%

Methodology

Large collations of industry data will, by their nature, contain mistakes in data entry. After examining the data retrieved from EIA, standard statistical tests on both SAIDI and SAIFI flagged the outlier data. The analyses reported here omit the outliers to enhance the accuracy. The analyses retained 94% of the data.

Where practical, nonparametric analytic methods (such as analysis using medians) were used to better identify the underlying trends that may be applied to all of the data.

The EIA data contain, in addition to the reported reliability indices, certain metadata (e.g., number of customers, state, system voltages). These were augmented by additional metadata from EIA and external sources (see Bibliography) to enable more detailed insights of the underlying factors.

These extra metadata included mean elevation, service territories (counties), degree of forestation (state based) and location (latitude and longitude).

Additional features, such as long-term changes and consistent responders, were calculated from the reliability data to facilitate the analyses.

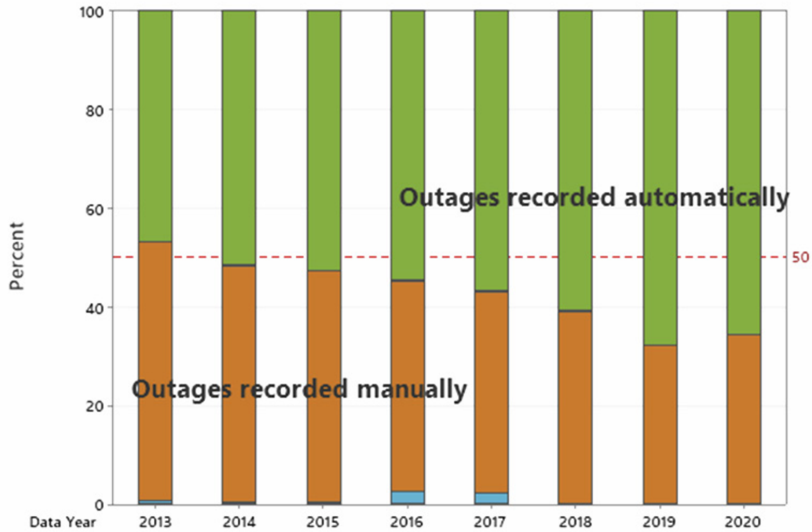
Context

IEEE and EIA provide reliability indices data on a voluntary basis. This means the number and composition of participants can vary from year to year.

Care must be exercised in the use of simple yearly comparisons of indices and rank positions as apparent changes can contain contributions due to who participated rather than underlying performance. The magnitude of this consistency of reporting issue can be recognized by looking at the participant codes, as approximately 10% and 85% of the 2020 entries have participated throughout all the surveys for IEEE and EIA collations, respectively.

Additionally, how utilities collect the individual interruption data has evolved over time, thereby making trending that much trickier, especially if the method of collection impacts the magnitude of the indices. The adjacent chart shows a consistent trend in the EIA data away from manual collection and toward the automated collection of data as time progressed. Automatic data collection is now the typical method for utilities in 2020, with 65% of participants using this, compared with only 45% at the start of EIA collection in 2013.

Thus, more utilities were reporting to EIA in 2020 than at the start, and approximately 20% of these have changed methods and now collect their data automatically.



Long term trends

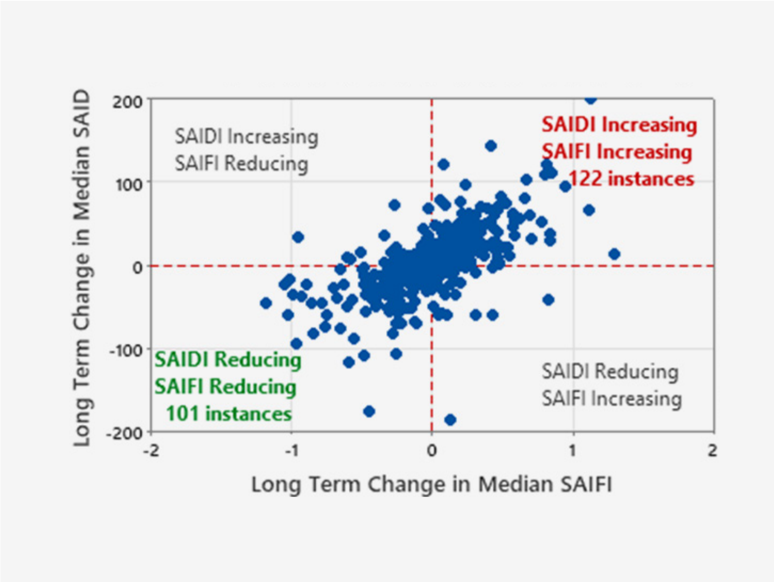
Major event days

A study of MED associated with each of the reports indicated that MED typically added 81 minutes and 0.36 outages to the average disruptions experienced in 2020. Exploratory analyses of the data back to 2013 indicate increases in both the duration and frequencies ascribed to MED. This increase (2013 - 2020) may be due to either an increasing number and length of extreme events or to the improved accuracy of reporting associated with the increased use of automated systems or improved estimates of MED with the availability of more years of data.

Underlying reliability

Reliability data (SAIFI and SAIDI) are reported annually, and it is common to make a basic comparison of utility performance or rank position on a year-on-year basis. Such short-term comparisons, although convenient, are prone to impacts due to annual effects such as weather patterns, changes in participants and changes in methodologies. A longer-term approach based on the general performance of a few years will be less susceptible to the errors of the year-on-year approach. This study has taken a non-parametric trending approach and compares the changes in median SAIFI and SAIDI between 2013 to 2016 and 2017 to 2020. This trend analysis has not controlled for the change in reporting method (automatic vs. manual) from 2013 to 2020.

The chart shows the changes for utilities and the states of operation reporting without MED data for the whole eight-year period. The dot histograms of the data (blue dots) indicate that most of the changes are grouped around the origin, i.e., indicating that no long-term change was observed within the data. This would seem to suggest that there has not been a sustained long-term improvement or negative changes (smaller SAIFI or SAIDI). However, further examination suggests that a fraction of the degrading reliability (blue dots in the top right quadrant) can be ascribed to the changing methods of data collection described earlier, i.e., manual to automatic collection that we know increases the reported SAIFI and SAIDI. It is expected that a correction for this effect would suggest that the center of the mass of data shifts towards the bottom left (improving reliability) somewhat.



This analysis also shows that consistent improvements in reliability with the current approaches are likely to be of the order of <0.25 SAIFI/yr and <25 SAIDI minutes/yr. Thus, the experience of the last years is that, with current practices, it is difficult to make a large, sustained impact on the underlying reliability indices.

Reliability drivers

Reliability practitioners often seek to explain the differences between durations and frequencies reported by utilities in terms of geography, system architecture, etc. In this study, a number of analyses were undertaken to see if these hypothesized explanations could be correlated with the reported data without MED.

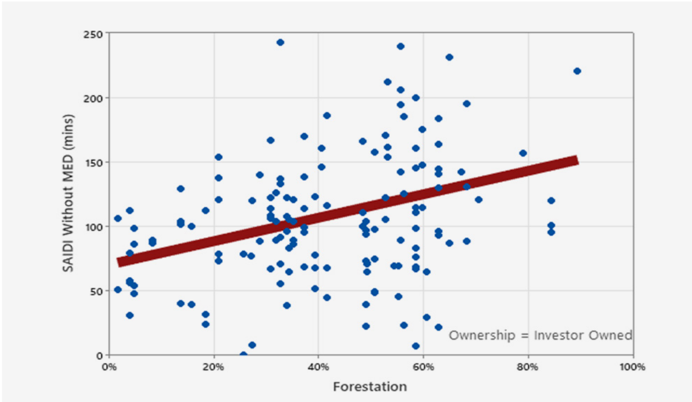
	SAIDI - MED	SAIFI - MED
Utility ownership	1st	2nd
Outage measurement	5th	1st
Mean tree cover	2nd	4th
Utility size (customers)	3rd	3rd
Mean elevation	4th	5th
Mean latitude	3rd	5th
Mean longitude	3rd	5th

The outcomes in terms of the magnitude of the correlations in this investigation are tabulated on the left, and the magnitudes are represented by ranking. As an example, the size of utility had the third-largest effect on both SAIDI-MED and SAIFI-MED, whereas outage measurement was the largest impact for SAIFI but fifth for SAIDI. Most of the correlations in the table were at least 95% significant. The impacts of the number of extreme events and customer mix (residential and commercial) were not found to be large or significant.

This analysis suggests that many of the hypothesized explanations for differences do have an impact; however, the reality is quite nuanced, and it is difficult to generalize about many explanations. Other drivers may be hypothesized (system vintage, percent underground, maintenance and replacement practices, etc.), for which data are not yet available. The fit of the model suggests that additional drivers such as these could improve the accuracy of the modeling and be equally effective drivers for reliability.

Forestation

The analyses show that tree cover has a strong correlation with the frequency and duration of outages, with higher levels of forestation leading to poorer reliability (higher SAIFI and SAIDI).



However, as the figure and the table indicate, this feature is not able to explain all the variations observed between utilities. This impact of forestation is observed for all types of utility (IOU and Co-Op) and did not depend on whether the data collection was manual or automatic.

Measurement approach

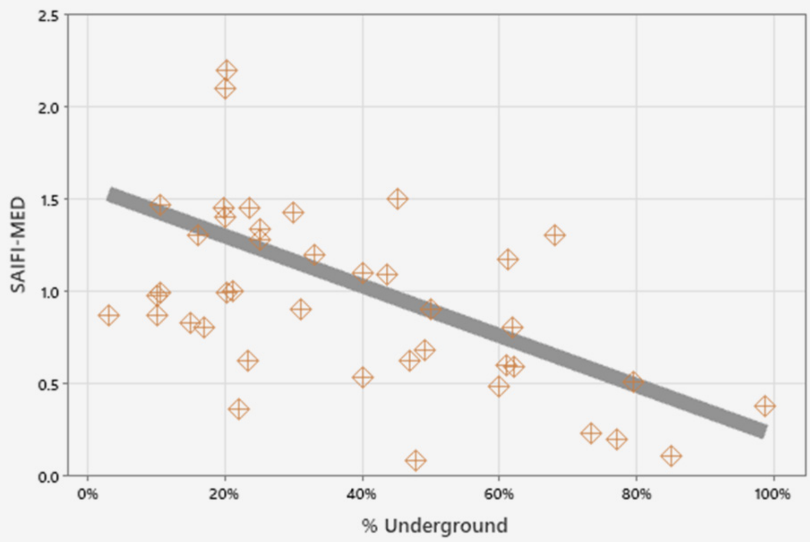
The reported statistics are derived from all the individual interruptions recorded by a utility in a year for specified locations and then collated by EIA. The customers impacted and the duration can either be determined from reports received from customers (manual) or from the distribution automation devices and systems (automatic). In these analyses, it was observed that, for both frequency and duration, the large and significant impacts were correlated with the way (automatic or manual) the utility collected the data. Utilities collecting data automatically reported higher values of SAIDI and SAIFI (see the tabulated data for 2020, not corrected for other effects). This difference is not because the monitoring devices decrease reliability, but because the initiation and restoration times are captured more accurately than in the manual case.

2020		Outliers omitted consistent participants only	
		Automatic	Manual
Unweighted mean	SAIDI + MED	371	289
	SAIFI + MED	1.49	1.19
	SAIDI – MED	110	89
	SAIFI – MED	1.11	0.87
Records		39%	31%

Undergrounding
Only a portion of any distribution system will be installed underground. The precise amount will depend upon geography, grid architecture, financial resources, etc. However, engineers generally view the process of increasing the percentage of the system undergrounded as a good way to improve the underlying reliability of the medium voltage (MV) grid compared to the traditional bare overhead construction. The impact of undergrounding has been studied using both the Council of European Energy Regulators (CEER) and the EIA reliability data. The figure below demonstrates a correlation in improved reliability with the extent of undergrounding. This lends experimental correlation to the approach of improving reliability by increasing the portion of the distribution grid installed underground. A similar reduction in the average duration of the outages is seen in SAIDI: as the percentage underground increases, the average duration decreases. When considering the duration data, it is useful to recognize that SAIDI measures the restoration of service, not the ultimate repair of the fault. Obviously, if unrepaired faults accumulate, recovery from subsequent faults becomes significantly more difficult and longer.

It is also important to recognize that just as an overhead system is more than wires (including poles, insulators and connectors), the underground system comprises terminations and elbows, cables, and joints that all contribute to the reported SAIDI and SAIFI data. Furthermore, most of the failures reported by utilities are associated with the accessories and, more specifically, with the workmanship. However, the larger concern is the backbone cables which, as distributed devices, are more difficult and costly to address. This is especially important as cables from earlier generations still make up a large portion of the utility system and were installed in mature areas where excavations are difficult and expensive. Consequently, the quality and robustness of the new underground components need to be enhanced to sustain the benefits in reliability with the older components.

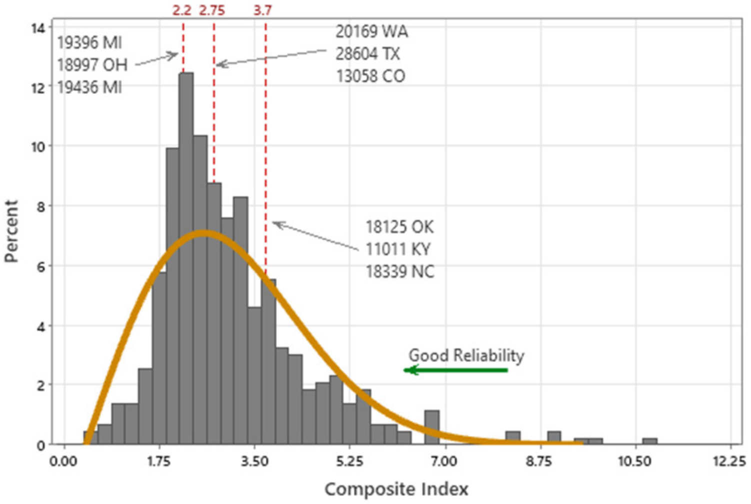
Location
The impact of the geographical location of utilities has been investigated using the mean latitude and longitude associated with the counties in which utilities provide service. This analysis resulted from a hypothesis that central desert and plain locations were less prone to disruptions. Analyses of these types are difficult because other factors, such as population, forestation and ocean weather systems, correlate with latitude and longitude. An example of this is the level of forest cover which tends to be higher in the East than in the West (forest cover correlates with location). Nevertheless, the data does suggest that the coastal nature of a utility (within three degrees latitude or longitude of the coast) does not impact the underlying reliability (SAIDI and SAIFI without MED). However, MED are increased by proximity to the coast, even when adjusting for forestation and customers. In 2020, coastal utilities experienced MED 200 minutes longer and 0.13 times more often than non-coastal utilities.



Thought topics

Composite indices for reliability

In this note, the reliability is characterized by separate annually reported SAIDI and SAIFI. These traditional approaches are not well suited for accounting of both outage frequency and duration and long-term trends at the same time. Practitioners will often select a single index that is believed to be particularly relevant and use that single metric for their decisions. An example of this is the utility ranking used within the Distribution Reliability Working Group of IEEE (Benchmark Year 2021 Results for 2020 Data).

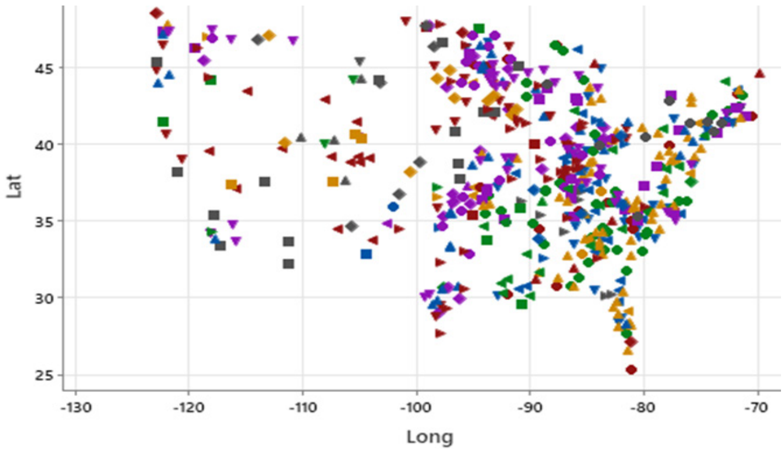


A useful approach developed by the authors considers the data structure itself to create a single reliability vector for each utility. This vector is based on the current indices and the long-term trends. In this representation, utilities with low levels and negative long-term gradients (reductions with time) are recognized as being well-performing utilities from the reliability standpoint. The analysis used more than 300 of the consistent participants (eight years) of EIA survey. The reliability vector approach is effective for data either with or without MED. The dimensionality of the data was reduced to three principal components, or features, that define a reliability vector based on the actual SAIDI and SAIFI value and the long-term trend. In this representation, low values represent high reliability and high values lower reliability. The histogram of the reliabilities enables one to make a robust ranking of performance. Moreover, the figure shows that ranking utility performance and trends is possible. The chart identifies the EIA utility codes and state of service at the first, second and third quartiles.

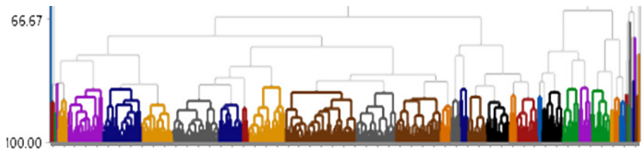
Although the example shows the positions at the utility level, the same approach can be used for areas and regions within a utility. This provides a data-driven way to determine the most appropriate locations for future investments in reliability. Additionally, it is a way to assess the reliability impact of the investments.

Benchmarking

Practitioners of reliability studies often compare SAIDI and SAIFI or rank positions to peer utilities. Selection of peer utilities for benchmarking activities based on geography, i.e., selection of neighbors, is not uncommon. However, this locality approach may not account for the actual reliability performance or the metadata (size, utility characteristics, etc.) of the utilities involved. The authors have refined a methodology that enables a data-driven approach to peer selection by identifying clusters within which utilities have a minimum level of similarity using an unsupervised machine learning algorithm.



This concept was proven using approximately 500 utilities from a collation of the EIA submissions of 2013 to 2020. A principal component approach similar to that for reliability assessment was used to develop four features for the reliability (current levels and long-term trends) and metadata. Peer groups are formed by agglomerative clustering utilities with similar attributes. The colored dendrogram (next page) shows the different clusters when a similarity of 85% or less is selected. Lower similarities would result in fewer clusters defined by the groups of the grey limbs of the tree. Moreover, on the left, the gold, purple and navy groups are similar but different. The gold and purple groups are more similar as they connect to the same node.



The analysis in the dendrogram has identified approximately 25 significant utility peer groups (shown on the map of the previous page), arranged based on utility location: the same symbol and color represent the members of the same group. Members of the same cluster would be good benchmark partners. This representation shows that geographically close utilities do not always make appropriate partners.

Costs of outages

Customer interruption costs are important considerations when planning reliability-based investments. Although the reliability durations and frequencies are important, they are not the only inputs to the cost estimation process because an important element is associated with the impacts of the loss of supply. Lost supply cost will depend on location, time of year and the type of customer (residential or industrial), leading to considerable diversity of costs for an outage. However, the cost is clearly more than just the cost of repair by the utility and the loss in revenue. The Department of Energy and Berkeley National Labs have developed an Interruption Cost Estimator (ICE) that provides an indication of costs for selected inputs. The data underlying this tool were developed from a series of detailed surveys completed by electricity consumers.

In this example, the ICE tool estimated the costs for an average-sized utility with an average split between residential and commercial and industrial loads for selected states. In the calculations, the 2020 averages (see the maps) of the SAIFI and SAIDI are used. These examples also show:

- Customer costs per event can be quite large.
- Although the individual indices may indicate cost (large indices correlate with large costs), calculations are required to obtain a good estimate.

	NE	NM	ME	LA	CA	WV
Cost per Event ($)	189	197	247	343	368	641
SAIFI	0.6	0.6	2.1	1.3	0.9	1.3
SAIDI	55	55	245	204	105	468
SAIDI and SAIFI are weighted means						

Why UL?

One of the major strands of improving reliability and resiliency is to harden the grid infrastructure by identifying the critical parts of the system. Other improvements include:

- Moving overhead lines underground
- Replacing aging equipment
- Using more covered conductors on overhead lines

Our long history in quality and standards development makes us a trusted and independent thought leader in the wire and cable arena. Comprehensive factory and technical assessment programs for all underground components help to ensure that utilities are building a robust infrastructure.

Field testing by our experts for commissioning and asset health helps ensure the optimal performance of distribution assets. As the supply chain diversifies and lengthens, our global presence aids successful deployment, helping reduce your risks. Our global advisory service teams work with you to analyze the reliability landscape of utilities to ensure that upgrade programs are optimally targeted and deliver the value intended.

Contact UL's experts to see how an analysis of the 2020 reliability data can help your utility.

Our goal is to help the swift deployment of safer, superior products that meet the requirements of a changing world.

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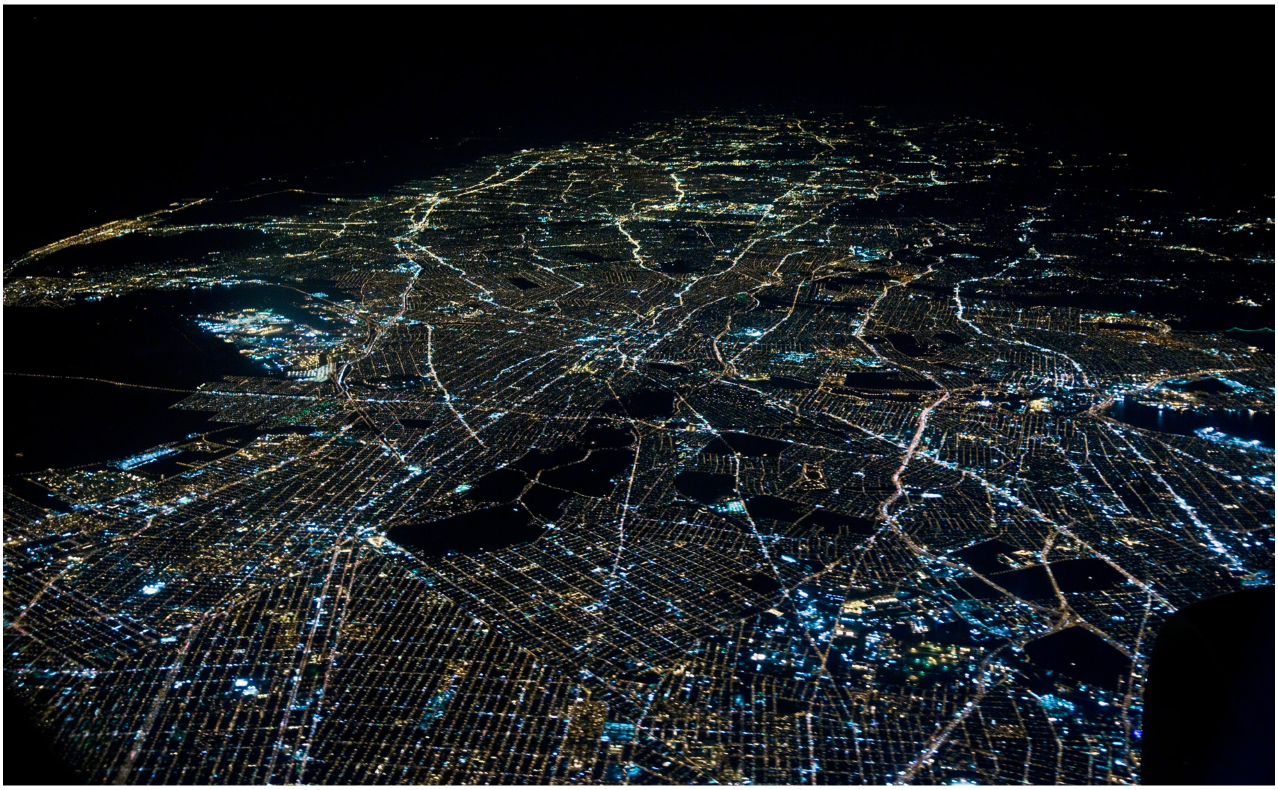

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