Moving Beyond Average Reliability Metrics

Executive Summary: Reliability matters to all stakeholders. While the most used metrics for reliability have changed relatively little since the 1970s, technology and customers' use of electricity is evolving, placing ever-growing importance on electricity distribution reliability. There is often a disconnect between the average systemwide performance metrics, such as SAIFI, SAIDI, and MAIFI, and the performance experienced by individual customers.

This piece lays out S&C's conclusions that a broader suite of reliability metrics should be used, placing more weight on customer-centric metrics that include Customers Experiencing Long Interruption Durations (CELID), Customers Experiencing Multiple Interruptions (CEMI), and Customers Experiencing Multiple Momentaries (CEMM). There is also another underused metric that should get more focus: Customers Experiencing Multiple Sustained and Momentary Interruptions (CEMSMI). Looking to the future, as we transition toward an energy system with integration of much greater volumes of distributed generation and the electrification of transportation, distribution system stability metrics will likely become useful.

Introduction

Reliability is a key aspect of utility performance. It matters to the utilities themselves, to regulators, and to electricity users (the utilities' customers). The most used reliability metrics, such as the System Average Interruption Frequency Index (SAIFI), the System Average Interruption Duration Index (SAIDI), and the Momentary Average Interruption Frequency Index (MAIFI), date back to the late 1960s and early 1970s. There have been important developments since then, including new rules for identifying major event days and the inclusion of some additional measures, but the core metrics and how they are applied haven't fundamentally changed.

By contrast, in recent years there have been growing expectations of reliability from electricity distribution grids as well as key changes in how electricity is both generated and used. As electricity users become more reliant on electricity for digital services and transportation, the importance of reliability is growing, and these customers increasingly expect to never be interrupted. This has been highlighted during the COVID-19 pandemic as people who are sheltering and working from home place a high reliance on the reliability and resilience of electricity supplies.

There are also new classes of customer, such as distributed generation (DG) owners, owners of energy storage, and aggregators, each of which have their own requirements from the grid. Despite the improvements already made to the energy system through distribution automation and investment in smart grid technologies, customer satisfaction is on the decline.[1]

There is often a disconnect between the average systemwide performance metrics such as SAIFI, SAIDI, and MAIFI, and the performance experienced by individual customers. Investment and incentives based solely on these broad system measures may encourage utilities to focus on making good performance better rather than addressing the needs of worst-served customers at the grid edge.

[1] ACSI Energy Utilities Report 2018-2019, https://www.theacsi.org/news-and-resources/customer-satisfaction-reports/reports-2019/acsi-energy-utilities-report-2018-2019

While electricity users place high value on system resilience during storms, average reliability metrics often exclude those major event days. Ironically, this is when homes and businesses are most impacted by outages.

To get a more complete picture of utilities' reliability performance, it's important to consider a broader range of metrics and to use existing metrics differently. Fortunately, there are examples of best practice in terms of reliability reporting and using enhanced metrics that give a more complete picture of utilities' performance, which can help drive investment in reliability and improved customer satisfaction.

This paper will discuss the history of the reliability metrics, how the industry landscape is changing in ways that affect the appropriate metrics and how they are used, and key steps or best practice that can be followed in achieving a more balanced picture of reliability that aligns with what customers need.

History Of The Reliability Metrics

There has been a long history of work to understand the causes of outages on electricity distribution grids and levels of reliability, as shown in **Figure 1**. The most used reliability metrics, developed in the late 1960s and early 1970s, include SAIFI, SAIDI, and MAIFI. In many cases, the presentation of these metrics is done with major event days excluded, a move that provides a better look at day-to-day reliability but that can also mask problems with system resilience. Two key developments have been new rules for identifying and separating out major event days and the inclusion of two new measures for Customers Experiencing Long Interruption Durations (CELID) on both an individual outage basis and cumulatively. Recently, regulators in some areas have begun using the measure of Customers Experiencing Multiple Interruptions (CEMI) as part their reporting requirements.

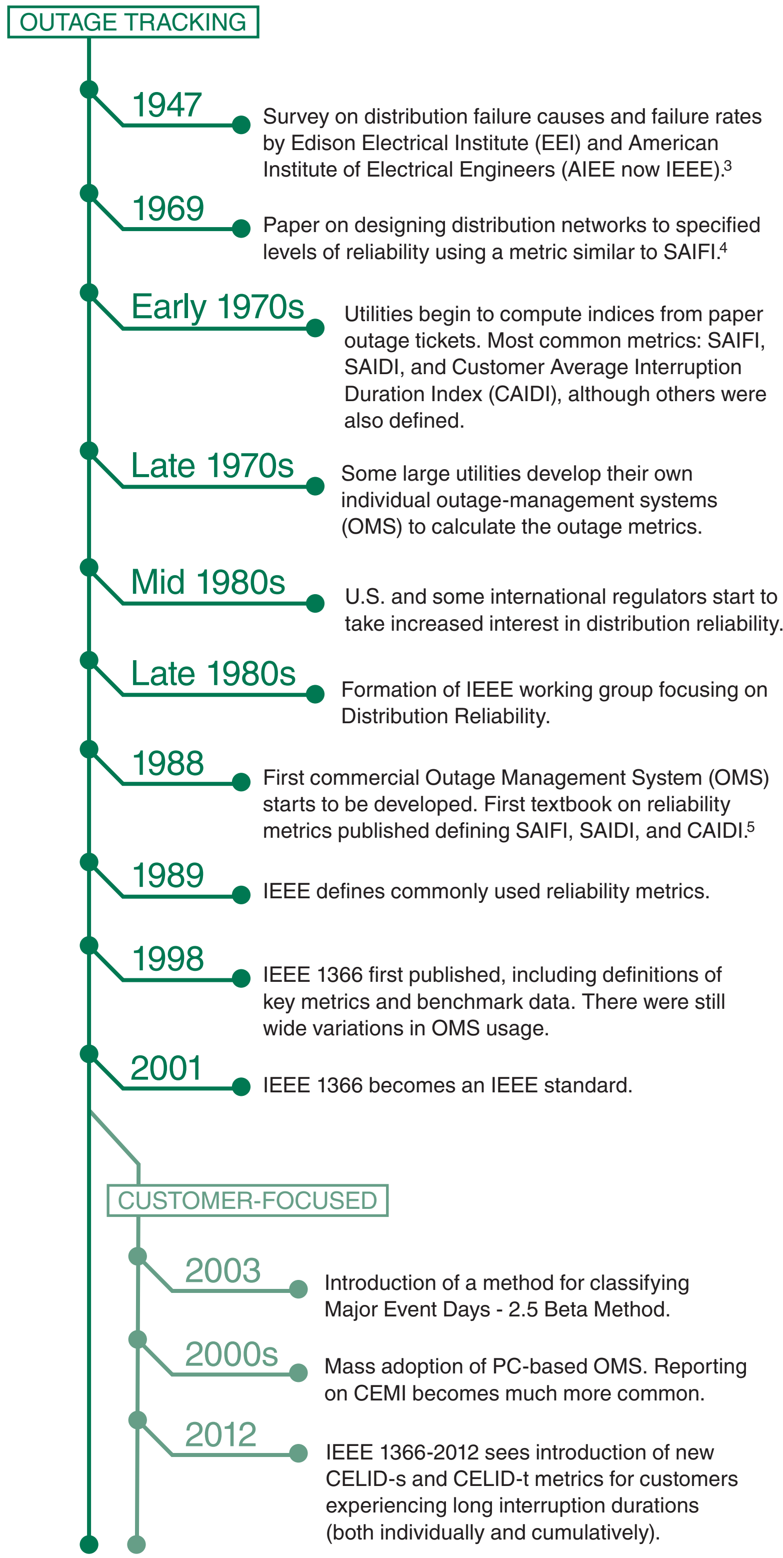

Figure 1. History of reliability metrics.[2]

[2] Based on Table 2 in Richard E. Brown, Electric Power Distribution Reliability, CRC Press, 2009 and additional research.
[3] Electrical Transmission and Distribution Reference Book (formerly the Westinghouse Electrical Transmission and Distribution Reference Book), ABB Power T&D Company, Inc.,1997.
[4] R.L. Capra, M.W. Gangel, and S.V. Lyon, "Underground Distribution System Design for Reliability", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-88, No. 6, June 1969, pp.834-842.
[5] R. Billington and R. Allan, Reliability Assessment of Large Electric Power Systems. Kluwer Academic Publishers, 1988.

While the Customer Average Interruption Duration Index (CAIDI) has in the past been a popular metric with utilities and regulators, it is increasingly seen as problematic as a measure of reliability. Brown (2009)[6] notes that "reliability could be improving in both frequency and duration [SAIFI and SAIDI falling], but CAIDI could be increasing." Investment in technologies such as distribution automation or lateral protection can drive significant improvements in both SAIFI and SAIDI and, therefore, improving the reliability experienced by customers, but if SAIFI falls more rapidly than SAIDI, CAIDI will still increase, giving the false impression of worsening performance.

Otherwise, most developments in reliability metrics have focused on improvements in gathering data and in computing the metrics with relatively little change in the core metrics used. The key metrics are now typically calculated automatically with computerized Outage Management Systems (OMS) that remove the risk of manual errors that existed when these metrics were calculated from paper outage tickets. Also, an OMS includes reliability calculations for mid-line devices, which was an improvement over statistics that were largely substation-based.

The Changing Energy Landscape

While there has been limited change in the core metrics used to assess distribution reliability, there have recently been rapid changes in the energy landscape. There is a consensus that human activities are causing climate change, and policymakers are taking steps to address this, including through Renewable Portfolio Standards (RPS), which require minimum proportions of renewable generation by target dates, and net zero emissions targets. These changes will create increased requirements for more advanced, flexible, and reliable electricity grids that integrate considerable amounts of distributed energy resources. Technological and manufacturing innovations in the areas of information technology (IT), consumer electronics, renewable energy, energy storage, and electric vehicles are also leading to rapid changes in both the way we use and produce electricity.

A wide range of devices are now used by residential and commercial customers that are sensitive to short interruptions and power-quality issues. This impacts a wide range of stakeholders:

- Residential customers are increasingly irritated at the loss of Internet access and video streaming when their routers take several minutes to reset following a momentary outage.
- Retail businesses are upset at the cost and loss of sales while their equipment reboots.
- Factories make increasing use of digital interfaces, smart sensors, and alarms that are all affected by momentaries, leading to lost production and waste.

The expansion of non-wires alternatives such as DG, energy storage, and demand response will make distribution system reliability increasingly vital. This means there are new types of customer, such as owners of DG and energy storage, that depend on this reliability. Renewable generation makes up 19% of the U.S. generation mix. In its Annual Energy Outlook 2020 Reference Case, the U.S. Energy Information Administration forecasts that this could grow to at least 38% by 2050, with most of the new generation coming in the form of solar and wind power.[7]

Much of this new generation will be connected to distribution feeders. This increasing volume of distributed generation dramatically increases the impact a momentary outage would have on the energy system. Even a momentary outage lasting five seconds will knock distributed generation offline. IEEE Standard 1547-2018[8] requires the generation resources to remain offline for 5 minutes after they have been disconnected. Reconnecting customers to a grid that is now missing 20%-40% of its generation will put additional stress on the grid and reduce resilience.

Even after a 5 minute window, different types of generation have different recovery times. Some recover quickly, within a few minutes. Others, however, may be subject to manual intervention of complex start-up sequences, meaning they are offline for a longer period, even though the service is restored to the feeder and the load is fully present. Taken in scale (such as during a large storm with many scattered outages), this is bad news for the distribution grid because a growing portion of the generation may not be available when it is most needed. This can aggregate from a small local problem to a larger distribution network problem as generation availability is shifting on and off.

We are also seeing a broader range of flexible resources being connected to electricity distribution networks, including energy storage and demand response systems. These flexible resources will be connected to distribution feeders, so they will depend on distribution system reliability to provide services when they are needed. These systems cannot provide

[6] Richard E. Brown, Electric Power Distribution Reliability, CRC Press, 2009
[7] EIA Annual Energy Outlook 2020, EIA, January 2020, page 62, https://www.eia.gov/outlooks/aeo/pdf/AEO2020%20Full%20Report.pdf
[8] 1547-2018 IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

services to transmission or distribution grids, or to peer-to-peer services to other customers, if the grid isn't available.

Finally, the transportation sector is heading toward electrification over the next few decades. This will happen at different rates in different states and countries around the world. It matters because more electric vehicles will mean more load on the grid, and distribution system reliability will now affect the transportation sector.

As our network of energy sources and loads becomes more complex, a stable, reliable grid is increasingly important as the platform on which these solutions operate. In this context, understanding the dimensions of reliability performance will only become more important.

Network Reliability Is A Localized Problem With Localized Solutions

While utility reliability is typically reported and published at a systemwide level, each customer's experience of reliability is unique to their location. Average systemwide performance measures can mask wide differences in reliability and create a disconnect with what utility customers are experiencing.

Figure 2 shows an example of the spread of medium-voltage (MV) overhead line performance for a British utility. While the average SAIDI from MV overhead lines is 45 minutes, 8% of circuits are experiencing 3 times the average level of performance.

Outage impacts will depend on the types of customer. For example, when residential customers lose power, they want to get their Internet connection, television, and air conditioning back on right away. Factories are affected by production stoppages, leading to work-in-progress being scrapped. With complex machinery, it may take a long time to resume production. Pharmaceutical companies may experience a loss of inventory if appropriate refrigeration can't be maintained. Retailers and restaurants can't process transactions when registers go down and, if the outage is for too long, some of the perishables can go bad. Delays in restoring power can cost businesses dearly.

The local and customer-specific aspects of reliability mean it's important to look beyond the average systemwide performance metrics focused on today, as shown in Figure 3 on page 5. There are several dimensions in which the system averages for SAIFI, SAIDI, and MAIFI can be unpacked to get a more granular and complete understanding of reliability performance, including the level of the impact and the duration of the outages.

How granular should reporting be?

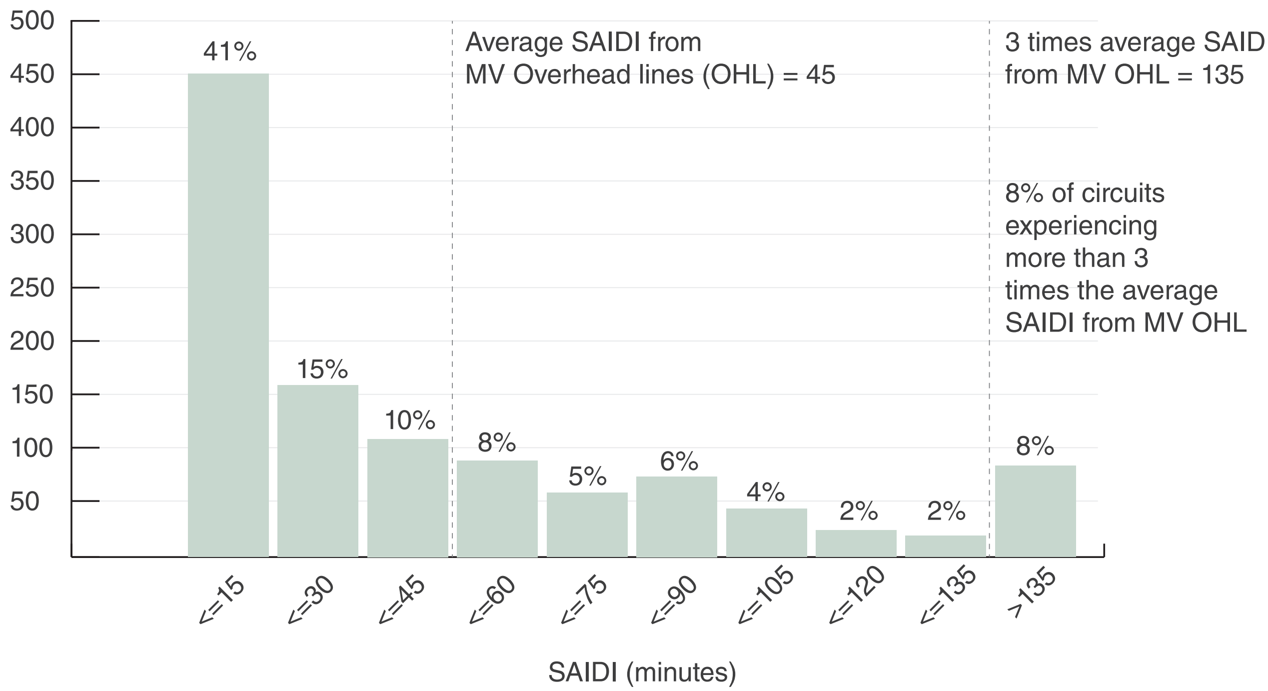

Figure 2. SAIDI performance of medium-voltage overhead lines.

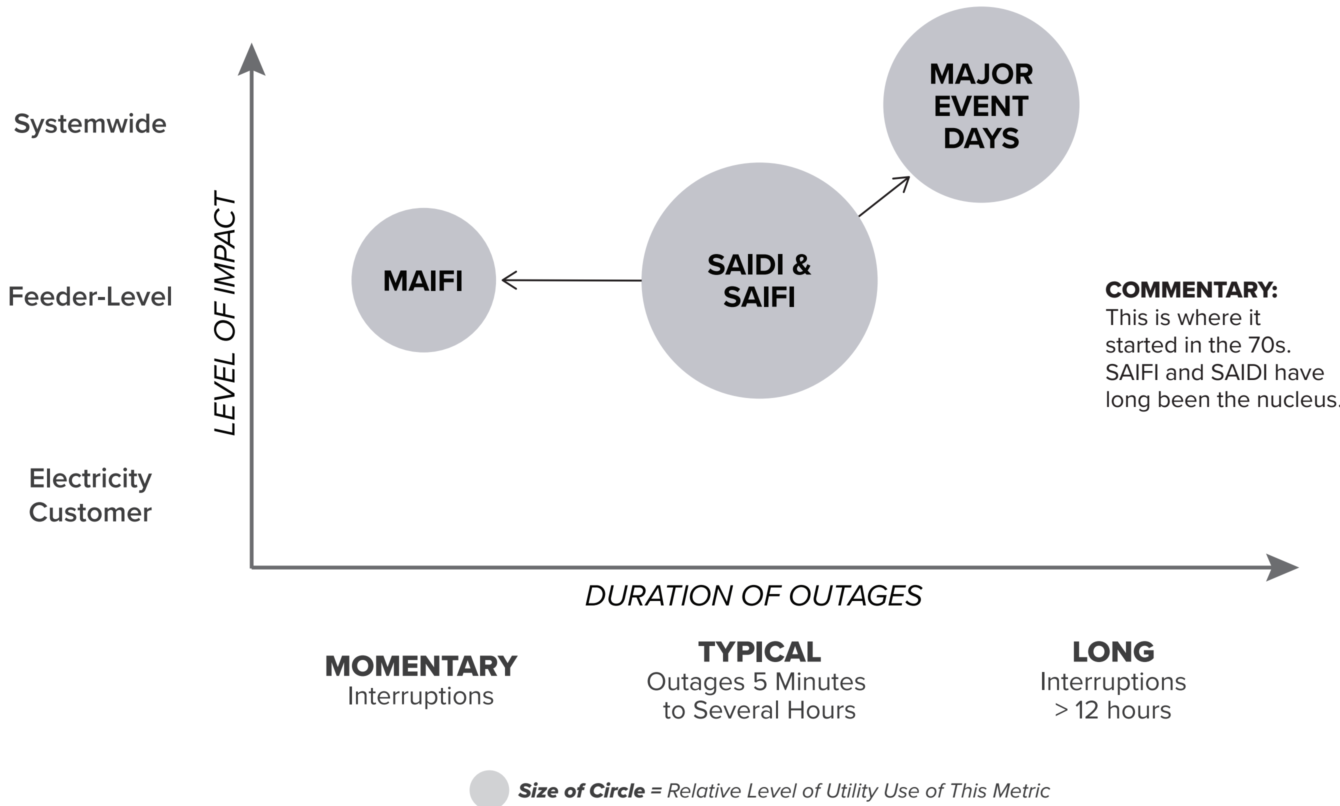

Figure 3. S&C's interpretation and illustration of key reliability metrics—where it started.

More Customer-Centric Metrics Provide A More Complete Picture Of Reliability

The average reliability metrics, such as SAIFI, SAIDI, and MAIFI, are utility-centric. They focus on performance of one entire feeder or even the utility's whole distribution grid. The inclusion of more customer-centric metrics as part of a suite of reporting can provide a more complete picture that includes reliability experienced by the worst-served customers. Table 1 shows several U.S. states and utilities have now adopted the CEMI reporting. This metric captures the number of customers experiencing more than a defined number of sustained interruptions in a year.

Table 1. CEMI Reporting in the U.S.

STATE	*CEMI REPORTING*
California	Requirement to report CEMI-12
Connecticut	Requirement to report CEMI-3 to 10
Delaware	Requirement to report CEMI-8
DC	Requirement to report CEMI-8
Florida	Requirement to report CEMI-5 for utilities > 50,000 customers
Maryland	Requirement to report CEMI-2, 4, 6, and 8
Michigan	DTE Energy Reporting CEMI-1 to 10
New Jersey	Atlantic City Electric reporting CEMI on a company and district basis
North Dakota	Northern States Power reporting on CEMI-4 to 6
Washington	Avista reporting on CEMI-0 to 6

Florida Power and Light (FPL) and Gulf Power are using a new metric of Customers Experiencing Multiple Momentaries (CEMM) to drive performance improvements for customers worst affected by momentary interruptions.[9] They are achieving major improvements in performance during both normal conditions and major storms by targeting this measure.

The CELID metric in IEEE Standard 1366-2012 captures another important aspect of performance, where customers are experiencing long interruption durations either in aggregate or from a single event. This metric allows the utility and regulators to see how much performance differs for the worst-served feeders versus the system average.

However, this is not yet a widespread regulatory reporting requirement. The Delaware Public Services Commission requires utilities to report on the total number of customers that have experienced a cumulative total of more than eight hours of outages (CELID-8).[10] Reporting of long-duration interruptions is also popular in other parts of the world, such as Britain and Scandinavia. The British Energy Regulator, Ofgem, requires reporting of the number of unplanned and pre-arranged customer interruptions by duration bands under both normal conditions and as part of exceptional events.[11] The Swedish Energy Markets Inspectorate and the Finnish Energy regulator, Energiavirasto, require reporting on the number of interruptions longer than 12 and 24 hours as part of their arrangements for compensation for long duration outages.[12] [13]

Figure 4 shows S&C's interpretation of how regulators and utilities are moving toward more customer-centric measures.

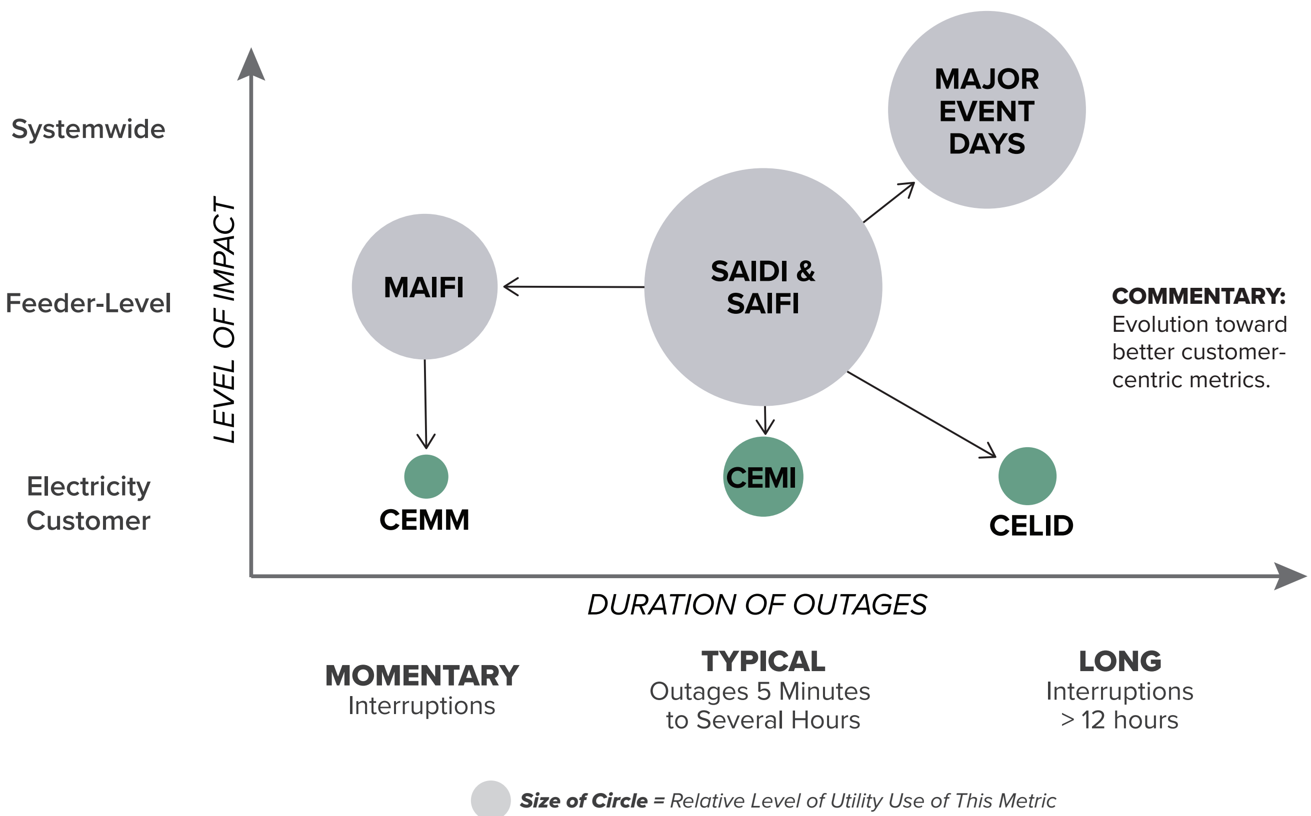

Figure 4. S&C's interpretation and illustration of key reliability metrics—evolution toward customer-centric metrics.

[9] FPL annual reliability filing to the Florida PSC, p.84, http://www.floridapsc.com/Files/PDF/Utilities/Electricgas/DistributionReliabilityReports/2019/2019%20Florida%20Power%20and%20Light%20Company%20Distribution%20Reliability%20Report.pdf#search=FPL%20distribution%20reliability%20report

[10] Delaware Administrative Code: Title 26: 3007: Electric Service Reliability and Quality Standards, https://regulations.delaware.gov/AdminCode/title26/3000/3007.shtml

[11] Regulatory Instructions and Guidance for RIIO-ED1, Ofgem April 29 2020, https://www.ofgem.gov.uk/publications-and-updates/direction-make-modifications-regulatory-instructions-and-guidance-rigs-riio-ed1-version-60

[12] C.J. Wallnerström, E. Grahn, G. Wigenborg et al, The Regulation of Electricity Network Tariffs in Sweden from 2016, Swedish Energy Markets Inspectorate, 2016, https://ei.se/Documents/Nyheter/Nyheter%202016/Artikel%20Ei%20till%20SAEE2016%20final%20version.pdf

[13] Finnish Competition and Consumer Authority, https://www.kkv.fi/en/facts-and-advice/defects-and-delays/power-cuts/

Customer centricity is growing in importance as the customer expectations of distribution reliability increase. CAIDI is not a good customer-centric metric. The issue with CAIDI is it is a ratio of outage duration divided by outage frequency for individual customers. If reliability-improvement initiatives reduce outage frequency more than the duration, CAIDI appears to be deteriorating when in reality reliability has improved.

However, IEEE 1366-2012[14] contains another important, though underused, metric capturing worst-served performance: Customers Experiencing Multiple Sustained Interruptions and Momentary Interruptions Events (CEMSMI). This metric covers the number of customers that experience more than a certain number of interruptions a year, including both momentaries and sustained interruptions. Therefore, it gives a more rounded view of performance versus the system average. As the distinction between momentary and sustained outages loses importance over time – because all outages matter, regardless of duration in the digital and connected world – CEMSMI may emerge as a key index for measuring the individual electricity user experience, as shown in Figure 5.

This information can help utilities target their investments where it matters most. To date, we've identified two utilities that are reporting this: Rocky Mountain Power (Pacificorp) in Idaho and Avista in Washington State.

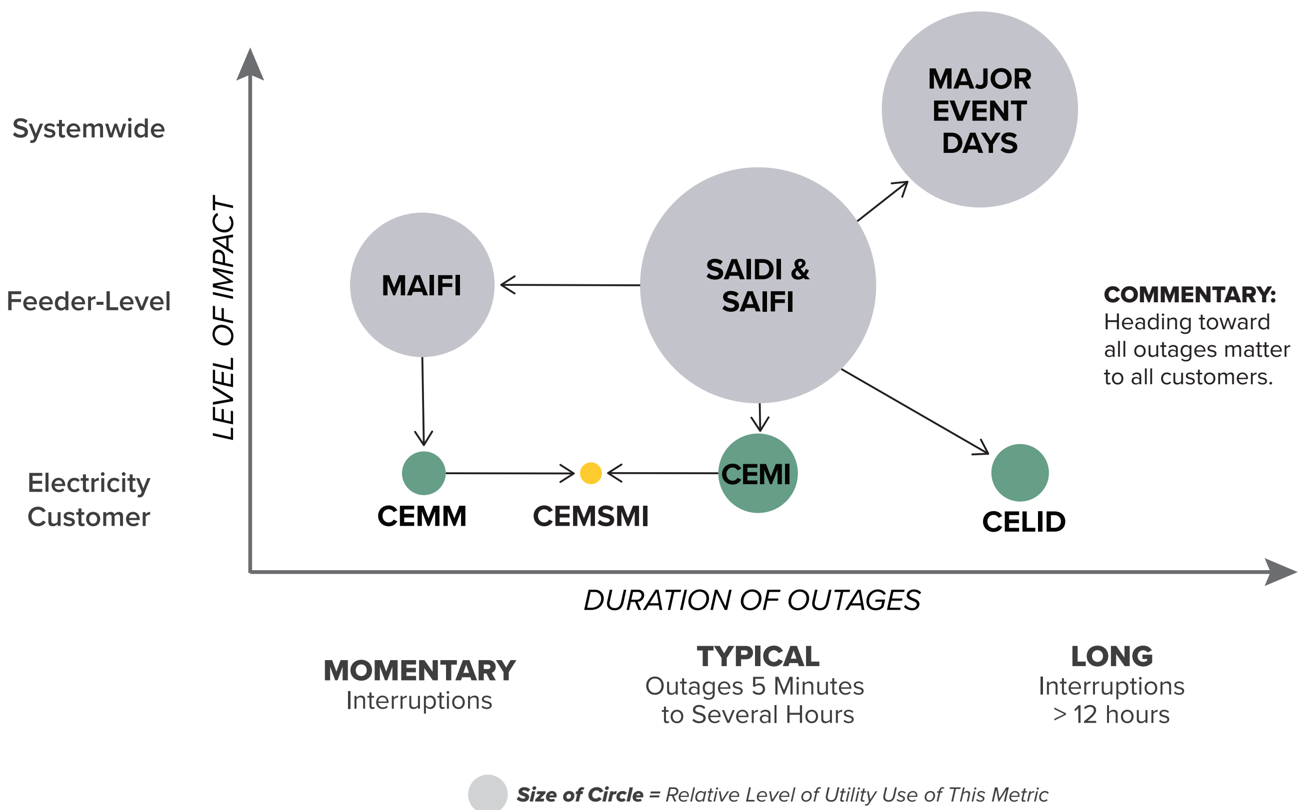

Figure 5. S&C's interpretation and illustration of key reliability metrics—heading toward all outages matter.

[14] 1366-2012 - IEEE Guide for Electric Power Distribution Reliability Indices

The Performance For Different Types Of Customer Matters

Most utilities report reliability using average systemwide indices. However, the typical average reliability metrics don't shed much light on reliability performance for commercial and industrial (C&I) customers because the number of residential customers far outweighs them.[15] These C&I customers consume much more power and have more to lose when there are outages. Despite reliability being a key area of focus for utilities, large U.S. C&I customers aren't seeing an improvement in reliability. S&C's 2020 State of Commercial and Industrial Reliability Report[16] finds reliability is stagnant for these customers, yet they expect it to improve. Figure 6 shows outage duration has remained relatively constant over the three years, while Figure 7 shows customers expect significant improvements in performance.

There are also new categories of customers, such as DG and energy storage, not captured in the traditional metrics that should be considered as their penetration increases. They depend on the distribution grid being reliable to export their energy or to provide services to the grid or on a peer-to-peer basis to other users. New metrics could be adopted that capture the impact of unplanned interruptions on these types of customer, such as measuring the DG Average Interruption Frequency or DG Average Interruption Duration, similar to the SAIFI and SAIDI metrics for demand customers.

There would be benefits in reporting new measures, such as CELID and CEMSMI, for different categories of customer, including residential, C&I, and DG.

What Will Come Next?

As the transition toward the energy system of the future continues with the integration of much greater volumes of DG and the electrification of transportation, distribution-system stability is likely to become much more of a challenge. Prior to the blackout in Great Britain on August 9, 2019, there were indications of issues with system stability a few weeks ahead of the event. As of 2020, there is no visibility of utilities tracking metrics related to distribution-level stability, but this seems a plausible evolution in the years to come. This would provide a more complete picture covering both reliability and distribution-system stability, as shown in **Figure 8**.

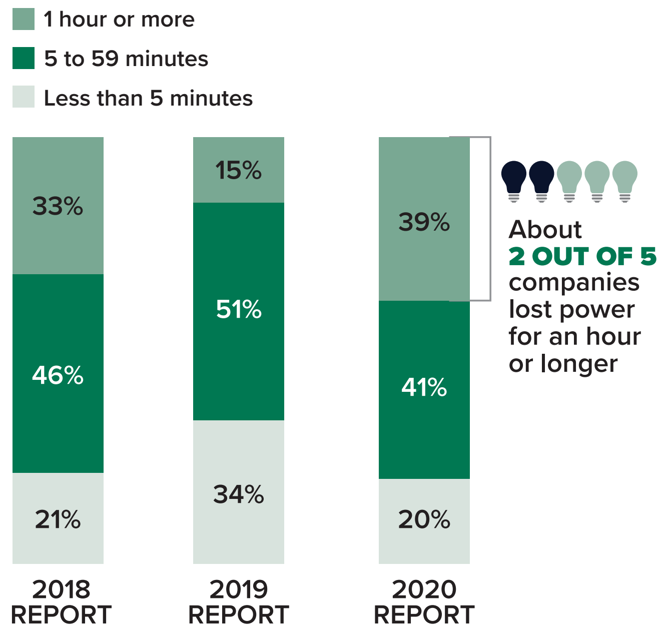

Figure 6. Typical C&I customers' outage duration.

Base: Comparable groups for 2018, 2019, and 2020 State of Commercial and Industrial Reliability reports (same industry and company size representation)

Question: What was the duration of the typical power outage that you experienced in the past 12 months?

Source: Frost & Sullivan

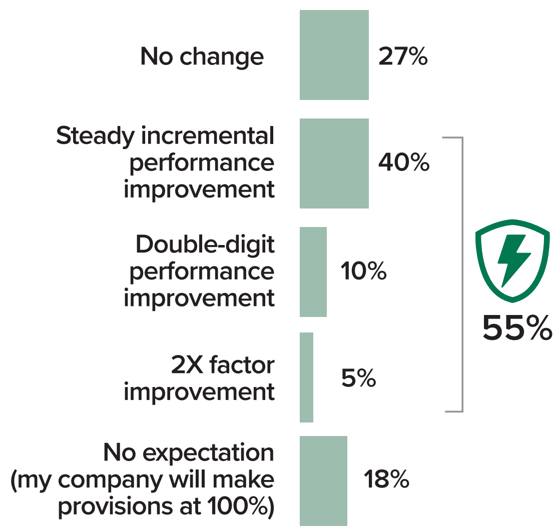

Figure 7. C&I customer expectations for power reliability in the next 2-3 years.

Base: All respondents (n=255)

Question: How do you anticipate the state of power reliability to change in the next two to three years? Select one answer only.

Source: Frost & Sullivan

[15] R. Schueberger, R. Arno and N. Dowling, Why Existing Utility Metrics Do Not Work for Industrial Reliability Analysis.

[16] State of Commercial and Industrial Reliability Report, S&C Electric Company and Frost and Sullivan, March 2, 2020

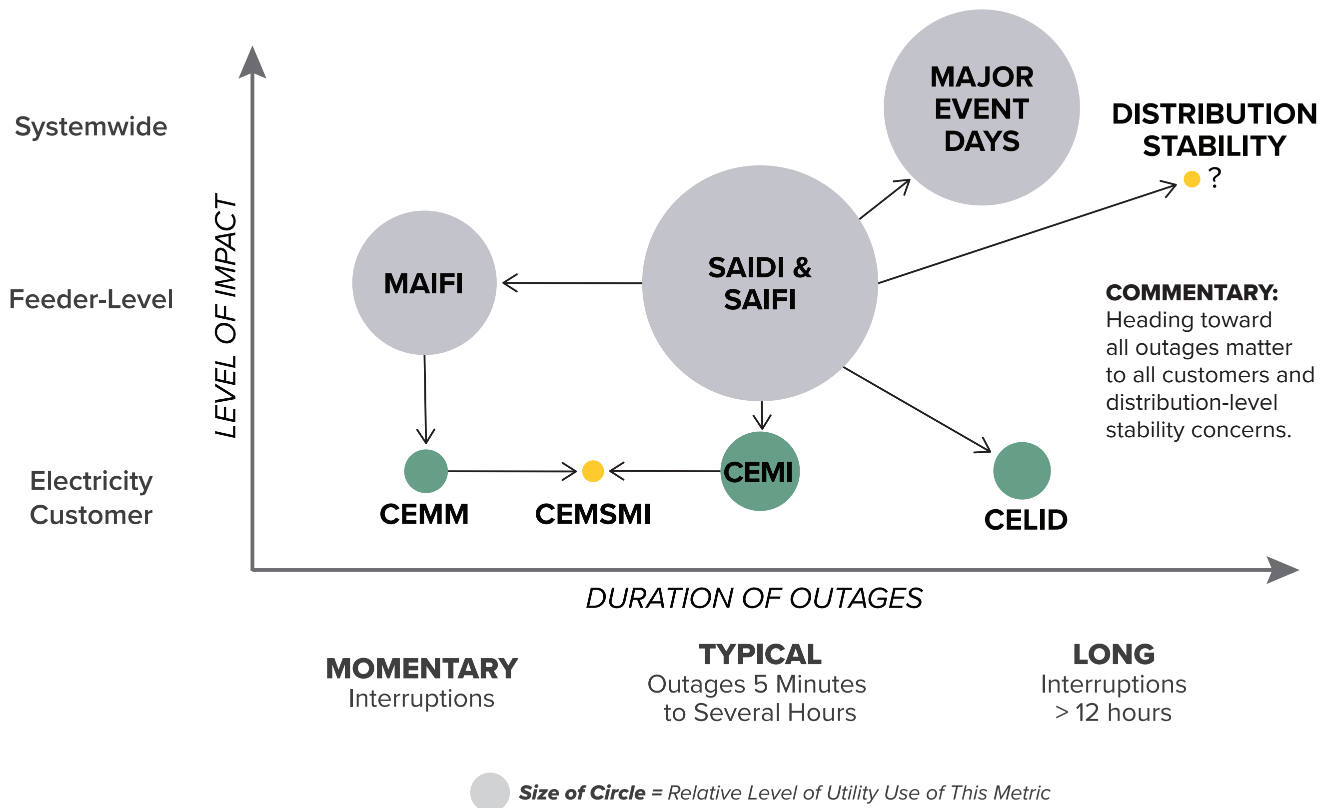

Figure 8. S&C'S interpretation and illustration of key reliability metrics—including distribution-level stability concerns.

Conclusions

Changes in technology are driving changes in expectations as customers place more reliance on the grid. The electrification of transport will continue this trend. To address this and to get a more complete picture of reliability performance that helps focus utility investment appropriately, it is important to look beyond average systemwide reliability metrics. More customer-centric measures, such as CEMSMI, CEMI, CEMM, and CELID, are useful and can help target improvements in reliability for worst-served customers and should be used more widely in the future. Looking to the future with much higher levels of intermittent renewables and electrification of the transportation system, distribution-level stability metrics are likely to be a new area of focus.

S&C Support For Clients

While S&C is primarily known for its equipment and engineering work, the company also has a regulatory team tracking and analyzing trends in electricity policy. This team has worked with utilities on performance-based regulation, advised regulatory commissions, and spoken at international conferences on the coming changes in electricity regulation. If your team is looking to model how regulatory changes could affect your planning, S&C's regulatory team is available to work with you on that front.

About the Authors

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