Distribution system versus bulk power system: identifying the source of electric service interruptions in the US

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Abstract: This study reports on the results from efforts by the Institute of Electric and Electronics Engineers (IEEE) Distribution Reliability Working Group (DRWG) and the U.S. Energy Information Administration (EIA) to improve the usefulness of reliability metrics by developing and then applying consistent, yet distinct measures of the continuity of supply based on the portion of the electric power system from which power interruptions originate: the lower voltage distribution system versus the high-voltage bulk power system. The modified metrics better support reliability planning in the US because they separately measure the effectiveness of actions to improve reliability made by the two distinct groups of firms (and their regulators or oversight bodies) that are responsible for planning and operating each portion of the US electric power system. The authors then present for the first time quantitative information on the reliability of each portion of the US electric power system. When reliability is measured using the system average interruption duration index and the system average interruption frequency index, they find that the distribution system accounts for at least 94 and 92%, respectively, of all interruptions. They also find that these relationships have been stable over the recent past.

1 Introduction

As with most developed countries, the electric power system is a complex network of electric components designed to generate, transport, and deliver electricity across two distinct yet integrated systems – the high-voltage bulk power and the lower voltage distribution systems. In the US, while the electric power system is operated on an integrated basis, oversight of and responsibilities for ensuring the reliability of the bulk power system is distinct from that for ensuring the reliability of the distribution system.

In most countries, the most common measure of the reliable performance of the electric power system is whether customers experience interruptions in power delivery. Electric utilities have long assessed the reliability of their systems by recording the frequency and duration of power interruptions to their customers [1, 2]. Standardised metrics, such as the System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI), are widely used for this purpose [3–5]. Distribution utilities, in particular, have long relied on these metrics to target investments and develop operating procedures to improve reliability.

SAIDI and SAIFI metrics as traditionally reported in the US, however, have neither regularly nor consistently distinguished between interruptions due to factors affecting the bulk power system and factors affecting the distribution system. Thus, as traditionally reported, these metrics do not support evaluation of the reliability performance of a distribution system as distinct from the reliability performance of the bulk power system. In other words, the most basic and widely reported measures of continuity of service in the US cannot, in their present form, be used meaningfully to assess or prioritise efforts to improve the distribution versus bulk power system reliability because they mask the source of power interruptions.

The absence of comprehensive, unambiguous, and consistently defined measures of continuity of service taking into account the sources of power interruptions has led to misleading assessments of the reliability of US electric power system. For example, some researchers have drawn conclusions on trends in reliability based on emergency reports submitted on large power system events [6–10]. Fisher *et al.* [11] assessed the reports upon which these studies were based and found that they, in fact, represent a small fraction of the power interruptions because emergency reports are only submitted for the very largest power interruptions (when, in fact, the vast majority of power interruptions are local and short-term in duration). Moreover, they found that the data sources relied on by these researchers were incomplete and inconsistent with respect to one another. Finally, they found that trends in worsening reliability derived from these reports could also be attributed to greater compliance with reporting rules (which were made mandatory during the middle of the period over which trends had been assessed), not only to increases in power system events. Findings, such as these, underscore the need for complete and precise information on power system reliability.

This paper reports on recent efforts by the Institute of Electrical and Electronics Engineers (IEEE) Distribution Reliability Working Group (DRWG) and the U.S. Energy Information Administration (EIA) to improve the usefulness of reliability metrics by developing and applying consistent, yet distinct measures of the continuity of supply based on which part of the vertically integrated electricity power system power interruptions originate: the lower voltage distribution system or the high voltage bulk power system. Using these measures, we present for the first time quantitative information on the reliability of the U.S. electricity distribution system, as distinct from reliability of the U.S. bulk power system.

This paper is intended to complement and add to the body of worldwide reliability reporting efforts. For example, in Europe the Council of European Energy Regulators (CEER) for nearly two decades has produced a periodic report that monitors the quality of electricity supply for up to 30 EU countries [12]. The report is intended to identify best regulatory practices that could be adopted elsewhere in Europe. A study by McDaniel *et al.* 2015 [13] highlights the efforts to annually report a benchmarking of reliability, comparing the North American and European efforts. In Asia, the Pacific Power Association in 2015 released their third report on utility performance for year 2012 for 21 utilities across roughly the same number of smaller Pacific island countries/ territories [14]. In Australia, the Australian Energy Regulator in

2015 issued its second annual benchmarking report including reliability performance for the 14 distribution network service providers in the country, acknowledging use of the IEEE standard for estimating the average duration and frequency of ‘off’ supply [15].

In this work, we focus on information that enables separate evaluation of the reliability performance of the lower voltage distribution systems separate from the reliability performance of the high-voltage bulk power system, including sub-transmission, bulk transmission, and, in principle, generation. As a final aside, it is important to recognise the planning and operation of the bulk power system is based on an expectation of continuous operation in the face of the loss of major components, such as a large generator. So, while loss of generation can be a source of customer power interruptions, these occurrences are rare and it is more useful from the standpoint of continuity of supply, to equate the reliability of the bulk power system with essentially the reliability of the transmission portion of the electric power system. The bulk power system is operated in accordance with mandatory reliability rules that require the system to be operated in such a manner that the loss of one or two elements (either generation or transmission) will not lead to an interruption in power delivery to customers. Consequently, loss of supply generally refers to the loss of a radial portion of the transmission system that is supporting a single group of customers within a distribution circuit (or group of such circuits). Only on rare occasions when multiple generation and transmission elements (beyond the number of elements addressed by mandatory reliability rules) are forced out of service due to, for example, severe weather would generation shortages be a contributing cause to the loss of supply to customers within a distribution system.

We organise this paper as follows:

- In Section 2, we describe the activities of the DRWG, including the formal definitions for SAIDI and SAIFI articulated in industry standards they developed and the annual benchmark survey they conduct. We also discuss two important caveats affecting the interpretation of the bulk power system as a source of interruptions using these data.
- In Section 3, we present SAIDI and SAIFI data from the DRWG benchmark survey for the year 2014 disaggregated by the following sources: unplanned distribution, planned distribution, and the bulk power system. We then expand the analysis to review trends in interruptions originating in the bulk power system over time for years 2008 through 2014.
- In Section 4, we compare the data from the DRWG benchmark survey to similar data collected by EIA for the year 2014. We also examine additional information collected by EIA on the voltage at which the bulk power system is defined, a common metric used abroad.
- In Section 5, we conclude with a summary of findings and the importance of this work for future energy policy as well as some suggested next steps.

2 Reliability metrics and reliability data collection activities of the IEEE distribution reliability working group

The IEEE DRWG is a voluntary industry organisation dedicated to improving and sharing information on utility reliability practices, starting with reliability metrics.

2.1 Reliability metrics

The DRWG sponsors the development of IEEE Standard 1366, which articulates consensus-based definitions for key reliability concepts [3, 4, 16]. Included in this Standard are definitions for SAIDI and SAIFI, which are the most well-known metrics for characterising sustained interruptions and the focus of this paper. IEEE Standard 1366-2012 defines a momentary interruption as an interruption of 5 min or less and a sustained interruption as any interruption that is not a momentary interruption; effectively, this refers to interruptions lasting longer than 5 min.

SAIDI measures the total number of minutes each customer, on average, is without electric service for a given time period. It is defined as follows:

$$\mathrm{SAIDI} = \frac{\sum \text{Customer Interruption Durations}}{\sum \text{Total Number of Customers Served}} \tag{1}$$

Higher values of SAIDI correspond to more minutes of interruption experienced by all customers, on average, and therefore indicate that the reliability of the utility is lower than the reliability of a utility with lower values of SAIDI.

SAIFI measures the number of times each customer, on average, experiences a power interruption. It is defined as follows:

$$\mathrm{SAIFI} = \frac{\sum \text{Total Number of Interruptions}}{\sum \text{Total Number of Customers Served}} \tag{2}$$

Analogous to SAIDI, a higher value of SAIFI corresponds to more interruptions experienced by all customers, on average, and therefore indicates that the reliability of the utility is lower than the reliability of a utility with lower values of SAIFI.

2.2 Annual benchmarking survey

Each year, the DRWG conducts a survey where utilities voluntarily provide daily SAIDI and SAIFI information for analysis and review [17]. The DRWG calculates a variety of reliability metrics using the IEEE Standard 1366 and presents and discusses the findings at annual committee meetings.

In 2012, the DRWG recognised that it would be useful to its members to identify what the source of interruption events impacting customers would be and began asking utilities to submit their data along with information on the source of each interruption. In 2012 and 2013, many data submittals that differentiated the source of the interruption had certain data issues requiring substantial data scrubbing; however, in 2014 the DRWG and benchmark participants retooled the benchmark survey to augment edits, resulting in a high quality dataset which identified the source of interruptions on a daily basis.

Specifically, they asked utilities to report whether interruptions were:

- caused by unplanned factors from within the distribution system;
- planned (and affecting only the distribution system); or
- due to the loss of power supplied to the distribution system (or bulk power system).

2.3 Use of bulk power information as a proxy for transmission

SAIDI and SAIFI originating from the bulk power system refer to factors that are outside (i.e. upstream) of a distribution system. To a first approximation, they can be thought of as factors associated with the operation of the transmission system. However, there are two caveats to bear in mind.

First, the dividing line between the bulk power system and a distribution system is not uniform. In common parlance, voltages are used to distinguish between transmission (e.g. 69 kV and above), sub-transmission (e.g. 35–69 kV), and distribution (e.g. <35 kV) systems. Alternatively, other classifications might consider the dividing line based on the function they serve. And more recently, 100 kV has been established as the voltage at which FERC's authority for regulation of transmission reliability begins. In 2010, FERC Order 743 revised the definition of the ‘bulk energy system’ to include all facilities operating at or above 100 kV with the exception of those necessary for operating an interconnected electric transmission network. FERC also recognised that certain lines operating at higher than 100 kV could functionally act similar to distribution lines and therefore could be excluded from consideration as part of the bulk energy system. Note, however, that facilities operating at lower voltages are subject to FERC authority if the reliability of these facilities has a material effect on

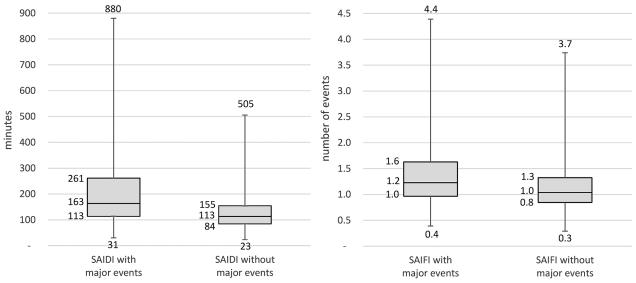

Fig. 1 *SAIDI (left) and SAIFI (right) with and without inclusion of major events in year 2014*

Fig. 2 *Map of IEEE DRWG regions*

the reliability of the higher voltage systems to which they are interconnected [18].

Second, the information collected by the DRWG does not include the voltage at which interruptions originating from the bulk power system is measured, nor other distinguishing characteristics of individual distribution systems. As a result, we do not have information from the utilities submitting their data to the DRWG on how they have defined the distinction between the bulk power system and distribution systems. Note that EIA does provide this information as discussed in Section 4. Nonetheless, the results presented here provide new information regarding interruption sources, which may benefit stakeholders as they evaluate investments and programs designed to improve reliability for customers.

3 Information from the DRWG benchmark survey on the source of electric service interruptions

Our analysis is based on annual SAIDI and SAIFI information provided by 90 utilities that contributed data to the DRWG benchmark survey and agreed to allow their data to be used for our analysis. The data were collected by the DRWG for performance years 2013 and 2014, but we obtained data going back to year 2008 (because the data submissions require at least five historic years of data). The calculation of major events requires submission of daily SAIDI and SAIFI values for the previous five years of the reporting year [19–21]. Data reported to the DRWG for performance year 2014, therefore, includes daily values from 2009 to 2013. In Section 4.1, we summarise overall features of the data focusing on the year 2014. In Section 4.2, we segment the data by source of interruption for 2014 and then examine trends in the percentage of interruptions attributable to events originating from the bulk power system for the years 2008–2014.

3.1 SAIDI and SAIFI for 2014

In this subsection, we summarise overall features of the data for the year 2014. We discuss the composition of utilities whose data are included in our analysis and present descriptive statistics, both nationally and by region.

The 90 utilities included in our analysis represent nearly half of total US electricity customers (45%) and slightly less in total US electricity sales (43%). More than one-quarter are large in size (i.e. <1 million customers). Sixty percent are medium in size (i.e. between 100 thousand and 1 million customers). The remaining, almost 15% is small in size (i.e. <100 thousand customers). The vast majority are investor-owned utilities (84%) with a much smaller share from municipals (12%).

Fig. 1 describes the distribution of SAIDI and SAIFI values, both with and without major events included, in box-and-whisker form. The IEEE Standard 1366-2012 defines a major event as follows: *a major event day is a day in which the daily SAIDI exceeds a Major Event Day threshold value. For the purposes of calculating daily system SAIDI, any interruption that spans multiple calendar days is accrued to the day on which the interruption began. Statistically, days having a daily system SAIDI greater than TMED are days on which the energy delivery system experienced stresses beyond that normally expected (such as during severe weather). Activities that occur on Major Event Days should be separately analysed and reported.* The top and bottom horizontal lines of each box represent the 75th and 25th percentiles, respectively. The median is indicated by a horizontal line that divides the box into an upper and lower half. The end points of the vertical lines extending above and below the boxes indicate the maximum and minimum values, respectively. These plots illustrate the variability in values across all utilities, as well as the impact of including major events.

Fig. 1 shows that not including major events removes a noticeable amount of annual variability as illustrated by both the shorter lines extending above and below the box representing the maximum and minimum values and a shorter box height showing a narrower inter-quartile range. The box-plot shows the 25th and 75th percentiles as the bottom and top limits of the box with the median value in the middle and the vertical lines extending to the minimum and maximum values. As expected, not including major events reduces SAIDI proportionally more than SAIFI. During major events this measure increases substantially and results in major events having a more significant impact on SAIDI than SAIFI.

The DRWG uses the groupings of states and provinces shown in Fig. 2 to organise reporting by region. Table 1 provides the supporting and descriptive statistical information for each of these regions. In this and subsequent tables or figures, '*n*' represents the number of utilities. The median, mean, and coefficient of variation (COV) are shown. The COV is defined as the standard deviation divided by the mean. As expected, the COV is larger when major events are included.

Fig. 3 shows the box and whisker plots of SAIDI with major events for each region. This plot suggests that when major events are included, reporting utilities from the Mid-Atlantic region, on average, experience more minutes of interruption than other regions. The trends are similar when major events are not included and also for the frequency of interruptions. This plot shows that some regions (e.g. Mid-Atlantic and Northeast) exhibit wider ranges than others (e.g. Southeast). The range in the minimum and maximum values for the Southeast region is also narrower than it is for other regions, but this is due to the very small number of utilities who contributed data for use in this study.

3.2 SAIDI and SAIFI segmented by source of interruption

Figs. 4 and 5 present box and whisker plots for SAIDI and SAIFI, respectively, by source of interruption.

The following findings emerge from review of SAIDI in Fig. 4:

- Unplanned distribution interruptions represent a much larger proportion of SAIDI than unplanned supply interruptions.
- Unplanned distribution interruptions without major events generally appear to represent a larger proportion of SAIDI than unplanned distribution interruptions from major events alone.

Table 1 Regional SAIDI and SAIFI by IEEE DRWG region in year 2014

IEEE region	*n*	SAIDI						SAIFI					
		With major events			Without major events			With major events			Without major events		
		Median	Mean	COV, %	Median	Mean	COV, %	Median	Mean	COV, %	Median	Mean	COV, %
Northeast	10	168	234	105	105	109	43	1.2	1.2	95	1.0	1.0	38
Mid-Atlantic	24	197	318	76	123	158	74	1.4	1.4	95	1.1	1.2	34
Southeast	3	243	234	45	197	178	27	1.9	2.5	75	1.5	2.2	62
Midwest	20	145	198	93	84	98	67	1.1	1.1	97	0.9	0.9	45
Southwest	11	105	139	81	92	105	60	1.0	1.1	89	0.9	1.0	32
South	11	170	248	85	136	147	45	1.6	1.7	96	1.4	1.4	24
Northwest	11	219	218	61	134	143	42	1.3	1.4	93	1.1	1.1	40
All regions	90	163	237	85	113	130	63	1.2	1.4	44	1.0	1.1	44

Note: *n* represents the number of utilities in each region.

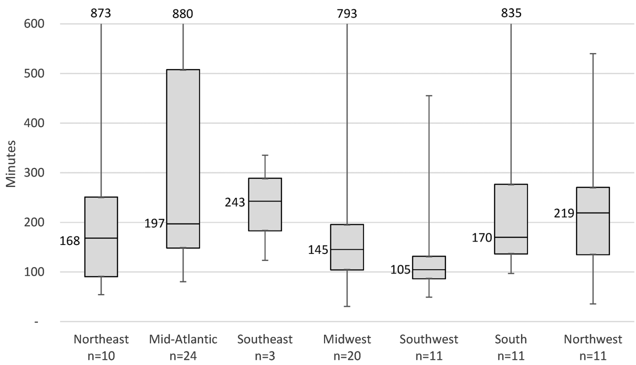

Fig. 3 *Regional SAIDI with major events in year 2014, n = number of utilities*

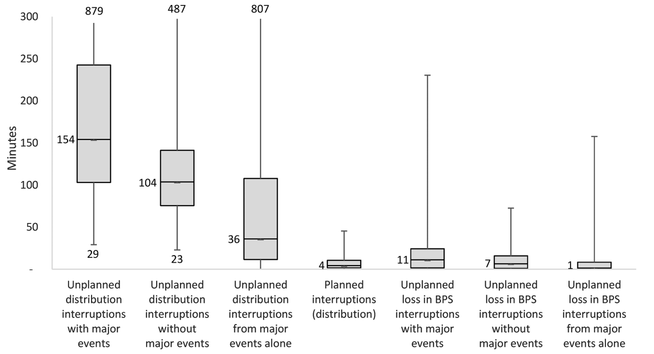

Fig. 4 *SAIDI by source of interruption in year 2014. Note: BPS refers to bulk power system*

- Planned distribution interruptions are small in comparison to both unplanned distribution interruptions and unplanned interruptions originating from the bulk power system.
- Unplanned supply interruptions without major events are generally, but not always, a larger proportion of SAIDI than unplanned supply interruptions from major events.

The following findings emerge from review of SAIFI in Fig. 5:

- Unplanned distribution interruptions represent a larger proportion of SAIFI than unplanned supply interruptions.
- Unplanned distribution interruptions without major events account for a larger proportion of SAIFI than unplanned distribution interruptions from major events alone.
- Planned distribution interruptions are small in comparison to unplanned distribution interruptions.
- Unplanned supply interruptions without major events are a smaller proportion of SAIFI than unplanned supply interruptions from major events alone.

Table 2 presents information on the percentage of SAIDI associated with interruptions originating from the bulk power system. In addition to the mean and median, we also present the customer-weighted mean.

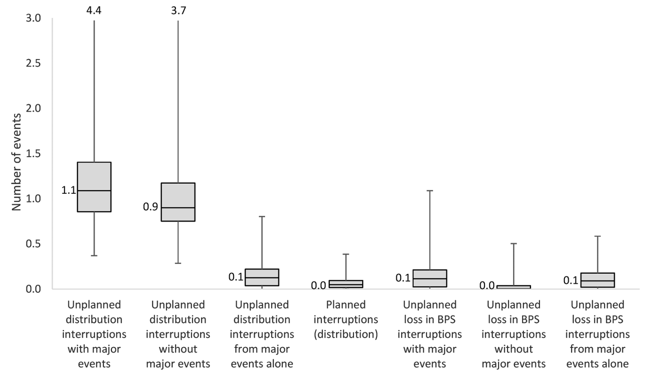

Fig. 5 *SAIFI by source of interruption in year 2014. Note BPS refers to bulk power system*

Table 2 Proportion of SAIDI due to interruptions originating from the bulk power system in year 2014

	SAIDI with major events, %	SAIDI without major events, %	SAIDI major events alone, %
mean	8	7	14
median	4	6	3
customer weighted mean	6	6	8
number of utilities (*n*)	90	90	80

Generally speaking, the mean, median, and customer-weighted mean values are almost always <10%. They are also within one or two percent of each other when comparing SAIDI with major events, SAIDI without major events, and SAIDI for the major events alone. One exception is the mean for SAIDI from major events alone, which is significantly larger than the mean for SAIDI with and without major events.

Table 3 presents information on the percentage of SAIFI due to interruptions originating from the bulk power system. In addition to the mean and median, the customer-weighted mean is also presented.

Overall, the percentages of SAIFI due to interruptions originating from the bulk power system are uniformly higher than the comparable percentages for SAIDI. In other words, compared to interruptions originating from within distribution systems, interruptions originating from the bulk power system are more frequent but shorter in duration. This makes sense intuitively given the level of redundancy that is designed into the operation of the upstream bulk- and sub-transmission systems. Bear in mind, however, that the dominant source of interruptions for SAIDI and SAIFI remain interruptions due to factors originating from within and whose effects are limited to the distribution system.

Table 3 Proportion of SAIFI due to interruptions originating from the bulk power system in year 2014

	SAIFI with major events, %	SAIFI without major events, %	SAIFI major events alone, %
mean	12	11	17
median	10	8	6
customer weighted mean	8	8	10
number of utilities (*n*)	90	90	80

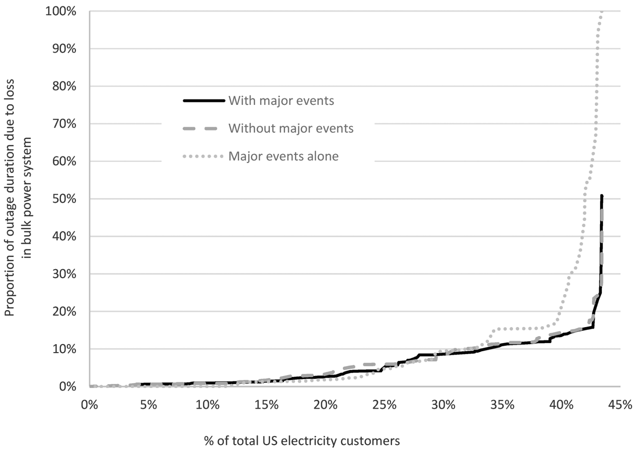

Fig. 6 *Proportion of SAIDI due to loss interruptions originating from the bulk power system as share of total US electricity customers in year 2014*

Figs. 6 and 7 present information, for each utility, on the interruptions originating from the bulk power system as a proportion of total SAIDI and SAIFI, respectively, with and without major events, as well as for major events alone. The percentage of interruptions originating from the bulk power system over total SAIDI and SAIFI for each utility is rank ordered from lowest to highest. In addition, information on the cumulative proportion of total US electricity consumers represented by each utility is indicated across the *x*-axis. The result is a series of upward slope curves.

Figs. 6 and 7 tell similar stories. For major events alone, interruptions originating from the bulk power system can exceed 20% and up to nearly 100% of SAIDI and SAIFI. For SAIDI and SAIFI with and without major events, interruptions originating from the bulk power system very rarely exceeds 50% and is generally <20%.

For SAIDI with and without major events, interruptions originating from the bulk power system account for less than about 15% of SAIDI for the vast majority of customers (>90%). For SAIFI with and without major events, interruptions originating from the bulk power system accounts for <15% of SAIFI for nearly 75% of the customers in our sample.

Fig. 8 examines trends in SAIDI and SAIFI, both with and without inclusion of major events over time. The customer-weighted mean is provided for the 73 utilities that reported data for all years 2008–2014.

Several patterns emerge:

- The trends in percentages due to interruptions originating from the bulk power system are fairly stable over time. SAIDI with major events is generally between 6 and 7%. SAIDI without major events is generally <6%.
- Consistent with findings for 2014, the percentages are higher for SAIFI than they are for SAIDI. SAIFI with major events is generally between 8 and 10%. SAIFI without major events ranges from <8% to nearly 11%.
- Percentages with major events included are generally larger than they are when major events are not included.

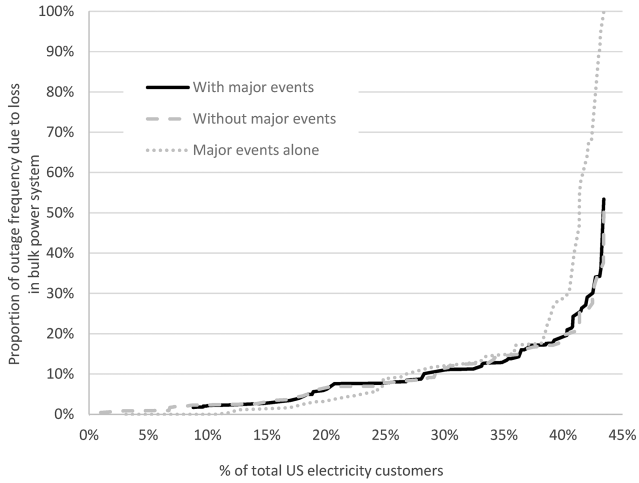

Fig. 7 *Proportion of SAIFI due to interruptions originating from the bulk power system as share of total US electricity customers in year 2014*

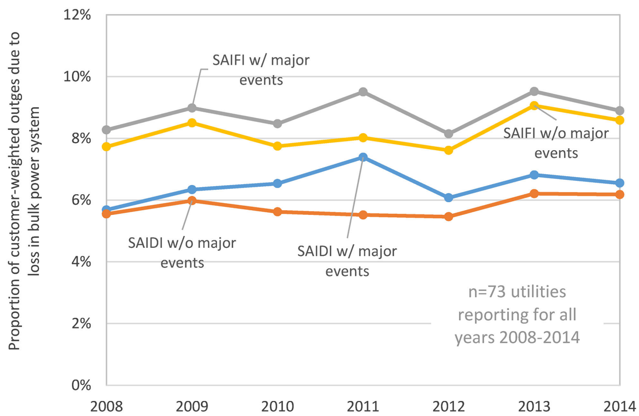

Fig. 8 *Customer-weighted proportion of SAIDI and SAIFI due to interruptions originating from the bulk power system from 2008 to 2014, n = 73 utilities*

4 Initial comparison of information on the source of electric service interruptions from EIA form 861 and the DRWG benchmark survey

Starting with reporting year 2013 (i.e. data collected in 2014 for performance during the year 2013), EIA has required utilities to report SAIDI and SAIFI both with and without major events on Form 861 [22]. Additionally, EIA collects information on the method used to classify major events (namely, whether they use IEEE Standard 1366) and also on the voltage at which the transition from the distribution system to the bulk power system is measured. We compared both overall reported values of SAIDI and SAIFI and percentages of SAIDI and SAIFI due to interruptions originating from the bulk power system reported to EIA and DRWG. We then explore the relationship between the percentage of SAIDI and SAIFI accounted for by interruptions originating from the bulk power system and the voltage at which transition from the distribution to the bulk power system is measured.

In terms of reporting by source of interruption, EIA only collects information on interruptions originating from the bulk power system for SAIDI and SAIFI with major events. Furthermore, not all utilities reported information on interruptions originating from the bulk power system to EIA. For 2014, there were 446 utilities that both reported SAIDI and SAIFI using IEEE Standard 1366 and reported the portion originating from the bulk power system. Together, these utilities account for >60% of total US customers. The data were filtered to remove seemingly erroneous entries, i.e. utilities reporting 100% of outages due entirely to interruptions originating from the bulk power system.

Table 4 compares the share of SAIDI and SAIFI with major events due to interruptions originating from the bulk power system from EIA and DRWG for 2014. In general, the mean values are

Table 4 Proportion of SAIDI and SAIFI with major events due to interruptions originating from the bulk power system in year 2014

	SAIDI with major events (EIA 861), %	SAIDI with major events (IEEE DRWG), %	SAIFI with major events (EIA 861), %	SAIFI with major events (IEEE DRWG), %
mean	12	8	15	12
median	4	4	8	10
customer weighted mean	5	6	7	8
number of utilities (n)	446	90	446	90

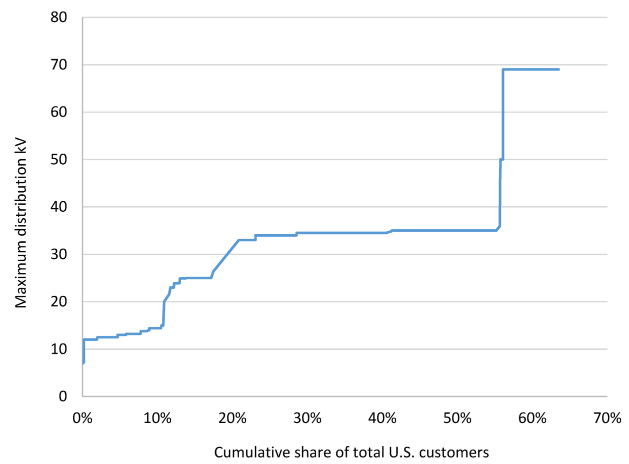

Fig. 9 *Distribution voltage at which interruptions originating in the bulk power system is measured, as reported to EIA in year 2014*

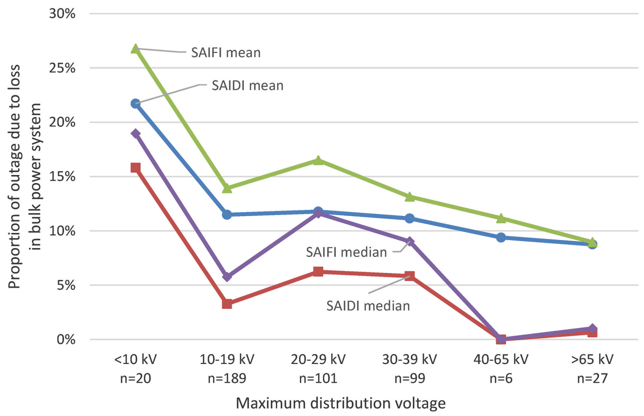

Fig. 10 *Proportion of SAIDI and SAIFI due to interruptions originating from the bulk power system as a function of the maximum reported distribution voltage for year 2014, n is the number of utilities*

higher in the EIA data. The median values and the customer-weighted means are much closer to one another.

EIA Form 861 also collects information on the lowest distribution voltage at which the transition from the distribution to the bulk power system is measured. Fig. 9 sorts this information from highest to lowest reported voltage. Values are weighted along the x-axis by the percentage of total US customers served by each utility. Taken together, EIA collects this information from utilities that together serve >60% of total US customers.

Fig. 9 indicates that utilities serving nearly 10% of customers measure the transition to the bulk power as deliveries from voltages >65 kV (generally at 69 kV). Utilities serving almost 40% of customers measure the transition to the bulk power system as deliveries at or in excess of 35 kV. Utilities serving the remaining 10% of customers measure the transition to the bulk power system as deliveries at or in excess of voltages <35 kV, with some measuring it as deliveries as or in excess of <10 kV.

Fig. 10 begins to explore how the voltage at which loss of supply is measured is related to the percentage of SAIDI and SAIFI due to loss of supply. In this figure we show the mean and median proportion of interruptions originating from the bulk power system as a percentage of total SAIDI or SAIFI versus the voltage at which the transition to the bulk power system is measured.

This plot indicates that the proportion of SAIDI and SAIFI due to the interruptions originating from the bulk power system tends to increase as the voltage at (or above) which the transition to the bulk power system is measured decreases. This is not a surprising finding, but it is one that can now be documented using data from a large sample of US utilities and suggests that more consistent methods for distinguishing the transmission and distribution systems are needed.

With respect to the proportion of interruptions originating from the bulk power system that is due to transmission, it is instructive to focus on the higher distribution voltages. For the 27 utilities that measure loss from the bulk power system at the highest voltages (generally, 69 kV and above), the mean SAIDI with major events is slightly <10%, but the median is on the order of 1 or 2%.

5 Conclusion

Better assessments of electric reliability require more complete, accurate, and detailed reliability data. This paper offers an improved assessment of reliability that distinguishes explicitly between the transmission and distribution systems. This paper presents newly available information collected by the IEEE DRWG and EIA, which confirms that the vast majority of reliability events experienced by US customers are due to causes that originate from within distribution systems. Using a consistent methodology, IEEE Standard 1366, the reporting entities in this study can be directly compared and assessed without concern for calculation bias, a challenge often faced and mentioned earlier in this paper when comparing electricity reliability for a broad geographic region or continent. Based on our analysis, when reliability is measured using SAIDI (the average minutes of interruption per year), we find that the distribution system is responsible for 94% or more of all minutes of interruption. When reliability is measured using SAIFI (the average number of interruptions per year), we find that the distribution system is responsible for 92% or more of all interruptions. Based on information collected by IEEE, we find that these trends have been fairly stable over the past 5 years.

The percentages reported generally overestimate the contribution from the transmission system to unreliable power because the dividing line between distribution and transmission varies and some local transmission voltages are functionally serving as bulk distribution sources. Based on information collected by EIA, we find that the proportion of interruptions originating from the bulk power system decrease as the voltage at which the transition to the bulk power system is measured increases. For a handful of utilities that report loss of supply at voltages approaching the FERC definition of the bulk electric system (i.e. 100 kV and above, with inclusion of lower voltages on a case-by-case basis), we find that the proportion of interruptions originating from the bulk power system is closer to 1% or 2% for both SAIDI and SAIFI.

To the author's knowledge, this is the first paper to assess the overall distinction in reliability using actual data, providing policymakers with the necessary information to make more informed decisions in the future. Identifying where the unreliable power is coming from has an immensely important role in improved decision making. For example, removing the transmission or generation component of reliability enables a utility to focus on the source of reliability improvement needed in the distribution system, e.g., vegetation maintenance, equipment upgrades. Knowing that most power interruptions originate in one part of the electric power system can help guide energy policy toward the areas of the grid that potentially require more attention and resources.

This work is not intended to suggest that more investment is needed to improve distribution system reliability or that less investment is warranted for maintaining transmission system reliability. Rather, the purpose of this work is to facilitate dialogue among utilities and their regulatory agencies and state or local governments who are charged with making these determinations by providing them with more accurate information on the actual reliability performance of past (and future) efforts to maintain or improve reliability.

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