Electric System Reliability Indices

Introduction

The electric utility industry is moving toward a deregulated, competitive environment where utilities must have accurate information about system performance to ensure that maintenance dollars are spent wisely and that customer expectations are met.

To measure system performance, the electric utility industry has developed several performance measures of reliability. These reliability indices include measures of outage duration, frequency of outages, system availability, and response time.

System reliability is not the same as power quality. System reliability pertains to sustained interruptions and momentary interruptions. Power quality involves voltage fluctuations, abnormal waveforms, and harmonic distortions. An interruption of greater than five minutes is generally considered a reliability issue, and interruptions of less than five minutes are a power quality concern.

This course explains the reliability indices used to measure distribution system reliability, how to calculate the indices, and discusses some of the factors that influence the indices.

I. Distribution Indices

The Institute of Electrical and Electronic Engineers (IEEE) defines the generally accepted reliability indices in its' standard number P1366, "Guide for Electric Distribution Reliability Indices". IEEE-P1366 lists several important definitions for reliability including what are momentary interruptions, momentary interruption events, and sustained interruptions.

Momentary Interruption -

A single operation of an interrupting device that results in a voltage zero.

Momentary Interruption Event -

An interruption of duration limited to the period required to restore service by an interrupting device. This must be completed within five minutes.

Sustained Interruption –

Any interruption not classified as a momentary event.

The most common distribution indices include the System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), System

Average Interruption Frequency Index (SAIFI), Momentary Average Interruption Frequency Index (MAIFI), Customer Average Interruption Frequency Index (CAIFI), Customers Interrupted per Interruption Index (CIII), and the Average Service Availability Index (ASAI). We will review each of these indices with an example of how to use them.

A. System Average Interruption Duration Index (SAIDI)

The most often used performance measurement for a sustained interruption is the System Average Interruption Duration Index (SAIDI). This index measures the total duration of an interruption for the *average* customer during a given time period. SAIDI is normally calculated on either monthly or yearly basis; however, it can also be calculated daily, or for any other time period.

To calculate SAIDI, each interruption during the time period is multiplied by the duration of the interruption to find the customer-minutes of interruption. The customer-minutes of all interruptions are then summed to determine the total customer-minutes. To find the SAIDI value, the customer-minutes are divided by the total customers. The formula is,

$$\mathbf{SAIDI = \Sigma(r_i * N_i) / N_T}$$

Where,
SAIDI = System Average Interruption Duration Index, minutes.
Σ = Summation function.
r_i = Restoration time, minutes.
N_i = Total number of customers interrupted.
N_T = Total number of customers served.

Consider the following example. What is the SAIDI for the 28th of the month where five outages were recorded? The table shown below shows each outage, the duration of the outage, and the customer-hours. The utility has a total of 50,000 customers.

As you can see from the table, the first outage was at 9:53 in the morning and 10 customers where out of service for 90 minutes (1.5 hours). Therefore, the customer hours are 10 * 1.5 or 15 hours.

///Table 1

Table 1
Calculation of Customer-Hours

Date	Time	Customers	Duration	Customer-hours
28th	9:53	10	90	15.00
28th	11:02	1,000	20	333.33
28th	13:15	2	175	5.83
28th	20:48	1	120	2.00
28th	22:35	1	38	0.63

		1,014	443	356.80

The customer-hours are calculated for each outage and then summed for a total of 356.80 customer-hours. Since we want to know the SAIDI calculation in minutes the customer-hours must be converted to customer-minutes by multiplying by 60. The result is 356.80 * 60 = 21,408 customer-minutes.

The SAIDI is,

SAIDI = 21,408 / 50,000

SAIDI = 0.428 minutes.

This says that the average customer was out for 0.428 minutes on the 28th of the month. If the SAIDI is calculated for each day, the monthly SAIDI is found by summing the daily values.

B. Customer Average Interruption Duration Index (CAIDI)

Once an outage occurs the average time to restore service is found from the Customer Average Interruption Duration Index (CAIDI). CAIDI is calculated similar to SAIDI except that the denominator is the number of customers interrupted versus the total number of utility customers. CAIDI is,

$$\textbf{CAIDI} = \Sigma(r_i * N_i) / \Sigma(N_i)$$

CAIDI = Customer Average Interruption Duration Index, minutes.
Σ = Summation function.
r_i = Restoration time, minutes.
N_i = Total number of customers interrupted.

From our previous example, what is the CAIDI for the 28th?

The customer-minutes are 21,408 and 1,104 customers were interrupted on the 28th (See Table 1). Therefore, the CAIDI is,

CAIDI = 21,408 / 1,014

CAIDI = 21.1 minutes.

On average, any customer who experienced an outage on the 28th was out of service for 21.1 minutes.

C. System Average Interruption Frequency Index (SAIFI)

The System Average Interruption Frequency Index (SAIFI) is the average number of times that a system customer experiences an outage during the year (or time period under study). The SAIFI is found by divided the total number of customers interrupted by the total number of customers served. SAIFI, which is a dimensionless number, is,

SAIFI = $\Sigma(N_i) / N_T$

Where,
SAIFI = System Average Interruption Frequency Index.
Σ = Summation function.
N_i = Total number of customers interrupted.
N_T = Total number of customers served.

From our previous examples, on the 28^{th} there were 1,104 customers interrupted during 5 separate events and the total number of customers served by the utility is 50,000 so the SAIFI is,

SAIFI = 1,014 / 50,000

SAIFI = 0.020

This says that on the 28^{th} of the month, the customers at this utility had a 0.020 probability of experiencing a power outage. SAIFI can also be found by dividing the SAIDI value by the CAIDI value,

SAIFI = SAIDI / CAIDI

With a SAIDI of 0.428 minutes and a CAIDI of 21.1 minutes the SAIFI is,

SAIFI = 0.428 / 21.1 = 0.020

D. Customer Average Interruption Frequency Index (CAIFI)

Similar to SAIFI is CAIFI, which is the Customer Average Interruption Frequency Index. The CAIFI measures the average number of interruptions per customer interrupted per year. It is simply the number of interruptions that occurred divided by the number of customers affected by the interruptions. The CAIFI is,

CAIFI = $\Sigma(N_o) / \Sigma(N_i)$

Where,
CAIFI = Customer Average Interruption Frequency Index.
Σ = Summation function.
N_o = Number of interruptions.
N_i = Total number of customers interrupted.

From our previous examples, on the 28th there were 1,104 customers interrupted during 5 separate events and the total number of customers served by the utility is 50,000 so the CAIFI is,

CAIFI = 5 / 1,014

CAIFI = 0.005

This says that the average number of interruptions for *a customer who was interrupted* is 0.005 times.

E. Customer Interrupted per Interruption Index (CIII)

The Customer Interrupted per Interruption Index (CIII) gives the average number of customers interrupted during an outage. It is the reciprocal of the CAIFI and is,

$$\mathbf{CIII = \Sigma(N_i) / \Sigma(N_o)}$$

Where,
CIII = Customer Interruption per Interruption Index.
Σ = Summation function.
N_o = Number of interruptions.
N_i = Total number of customers interrupted.

A total of 1,104 customers were interrupted during five separate events and the total number of customers served by the utility is 50,000, so the CIII is,

CIII = 1,014 / 5

CIII = 203 customers

This says that, on average, 203 customers were interrupted on the 28th. Of course, on a detailed look at the outages on the 28th, it is clear that one outage contributed to the vast majority of the customer outages.

F. Momentary Average Interruption Frequency Index (MAIFI)

The MAIFI is the Momentary Average Interruption Frequency Index and measures the average number of momentary interruptions that a customer experiences during a given time period. Most distribution systems only track momentary interruptions at the substation, which does not account for pole-mounted devices that might momentarily interrupt a customer. MAIFI is rarely used in reporting distribution indices because of the difficulty in knowing when a momentary interruption has occurred. MAIFI is calculated by summing the number of device operations (opening and reclosing is counted as one event), multiplying the operations by the number of customers affected, and dividing by the total number of customers served. MAIFI is,

$MAIFI = \Sigma(ID_i * N_i) / N_T$

Where,
MAIFI = Momentary Average Interruption Frequency Index.
Σ = Summation function.
ID_i = Number of interrupting device operations.
N_i = Total number of customers interrupted.
N_T = Total number of customers served.

Assume the system had six momentary substation breaker operations on the 28th. One breaker operated twice affecting 1,015 customers and four other breakers operated once affecting 867, 2,005, 1,500, and 1,330 customers. The utility serves 50,000 customers. What is the MAIFI?

The sum of the breaker operations times the number of customers affected is,

$\Sigma(ID_i * N_i) = (2* 1{,}105) + (1 * 867) + (1 * 2{,}005) + (1 * 1{,}330)$

$\Sigma(ID_i * N_i) = 6{,}412$ customer-interruptions

Therefore the MAIFI is,

MAIFI = 6,412 / 50,000

MAIFI = 0.128

On average, the customers experienced 0.128 momentary interruptions on the 28th.

G. Average Service Availability Index (ASAI)

The Average Service Availability Index (ASAI) is the ratio of the total number of customer hours that service was available during a given time period to the total customer hours demanded. This is sometimes called the service reliability index. The ASAI is usually calculated on either a monthly basis (730 hours) or a yearly basis (8,760 hours), but can be calculated for any time period. The ASAI is found as,

$ASAI = [1 – (\Sigma(r_i * N_i) / (N_T * T))] * 100$

Where,
ASAI = Average System Availability Index, percent.
Σ = Summation function.
T = Time period under study, hours.
r_i = Restoration time, hours.
N_i = Total number of customers interrupted.
N_T = Total number of customers served.

In this calculation, the restoration time, r_i, is in hours instead of minutes.

What is the ASAI value for the 28^{th} based on the outage data reported in Table 1?

From Table 1, the customer-hours are 356.80. Since only one day, the 28^{th}, is under study the study period is 24 hours. So, the ASAI is,

$$ASAI = [1 - (356.80 / (50{,}000 * 24))] * 100$$

$$ASAI = 99.97\%$$

Another way of looking at ASAI on an *annual* basis is,

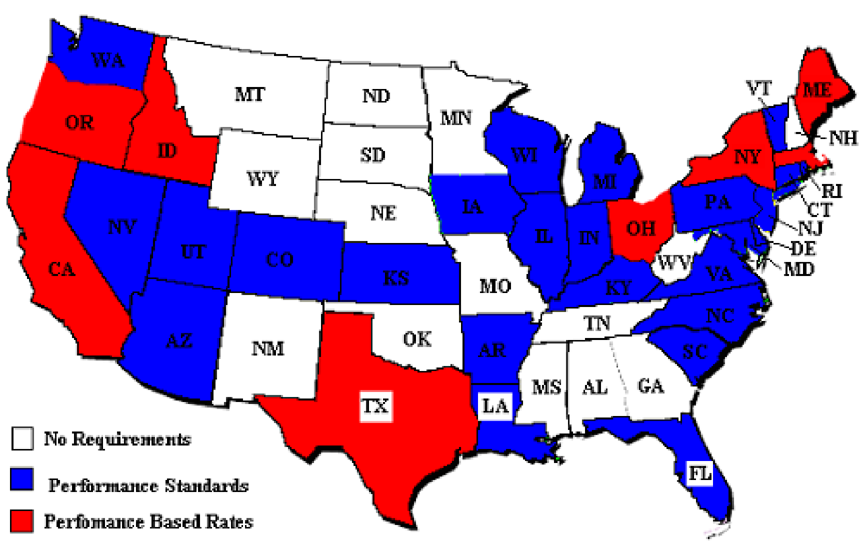
ASAI = [(8,760 – SAIDI) / 8760] * 100

From the ASAI, we see that the system has an average availability of 99.97% for the 28^{th}. Some utilities have set an ASAI goal of “four-nines” or 99.99% reliability. A “four-nines” reliability value translates into a SAIDI of 52 minutes per year.

II. Major Events

The indices presented herein are used by utilities to measure their present performance against past history and to compare their performance to other utilities. In some states the public utility commissions are mandating reliability standards based on the indices and attaching revenue incentives to performance. The adjacent map of the United States shows the status of public utility commission regulatory requirements for distribution reliability.

Regulatory Requirements for Reliability



For the indices to have meaning there must be a standardized method of recording data. Applying the indices to routine outages is straightforward. The issue is how do utilities separate major events from routine occurrences? Almost all regulators allow utilities to separate major events from routine outages. But, what is a major event?

Traditionally utilities have used rather simple measures to define major events. One such measure is "a major event is any event that has more than 10% of the utilities customers out of service for 24 hours." Another definition is "15% of the customers for the duration of the storm." Because regulators want to tie performance to reliability, utilities are looking for an approach that better defines when an anomaly has occurred on the system.

An IEEE working group has proposed a statistical approach to the problem to define Major Event Days or MEDs. Their recommendation, known as the Beta Method, works like this,

- A Major Event Day (MED) is any day that exceeds a daily SAIDI threshold called T_{MED}.
- Daily SAIDI values for the past five years are used to calculate T_{MED}.
- The natural log (ln) of each SAIDI value is found and the log-average (α) is found.
- The standard deviation of the logarithms is found (β).

From this data, T_{MED} is,

$$\mathbf{T_{MED} = e^{(\alpha + 2.5 * \beta)}}$$

Where,
T_{MED} = Major Event Threshold, minutes.
e = Exponential function, 2.718.
α = Log-average of the data.
β = Log-standard deviation of the data.

For an example, consider the following chart (which only has one month's data instead of the recommended 60 months.)

///Table 2

Table 2 SAIDI Values for March						
Date	SAIDI	ln(SAIDI)		Date	SAIDI	ln(SAIDI)
03/01/04	0.00176	(6.34244)		03/16/04	0.19419	(1.63892)
03/02/04	0.00065	(7.33854)		03/17/04	0.13260	(2.02042)
03/03/04	7.59645	2.02768		03/18/04	0.27269	(1.29942)
03/04/04	0.00148	(6.51571)		03/19/04	0.03015	(3.50157)
03/05/04	0.14035	(1.96362)		03/20/04	0.03733	(3.28796)
03/06/04	0.30691	(1.18120)		03/21/04	0.00891	(4.72058)
03/07/04	0.26691	(1.32084)		03/22/04	0.05419	(2.91526)
03/08/04	0.01264	(4.37089)		03/24/04	0.01052	(4.55448)
03/09/04	2.21194	0.79387		03/25/04	0.00530	(5.24005)
03/10/04	0.00400	(5.52146)		03/26/04	0.00311	(5.77313)
03/11/04	0.03646	(3.31154)		03/28/04	0.00482	(5.33498)
03/12/04	0.20081	(1.60540)		03/29/04	0.00115	(6.76799)
03/13/04	0.00128	(6.66090)		03/30/04	1.17312	0.15967
03/14/04	0.00871	(4.74328)		03/31/04	0.23627	(1.44278)
03/15/04	0.05203	(2.95593)				
				Total =	13.01	(99.348)

From the data in table 2, we see that the total of the natural logarithms of the data is – 99.348 and with 29 days the log average is -3.4258. Using an Excel spreadsheet and the standard deviation function (STDEV) the log-standard deviation is 2.4413. With this data, T_{MED} is,

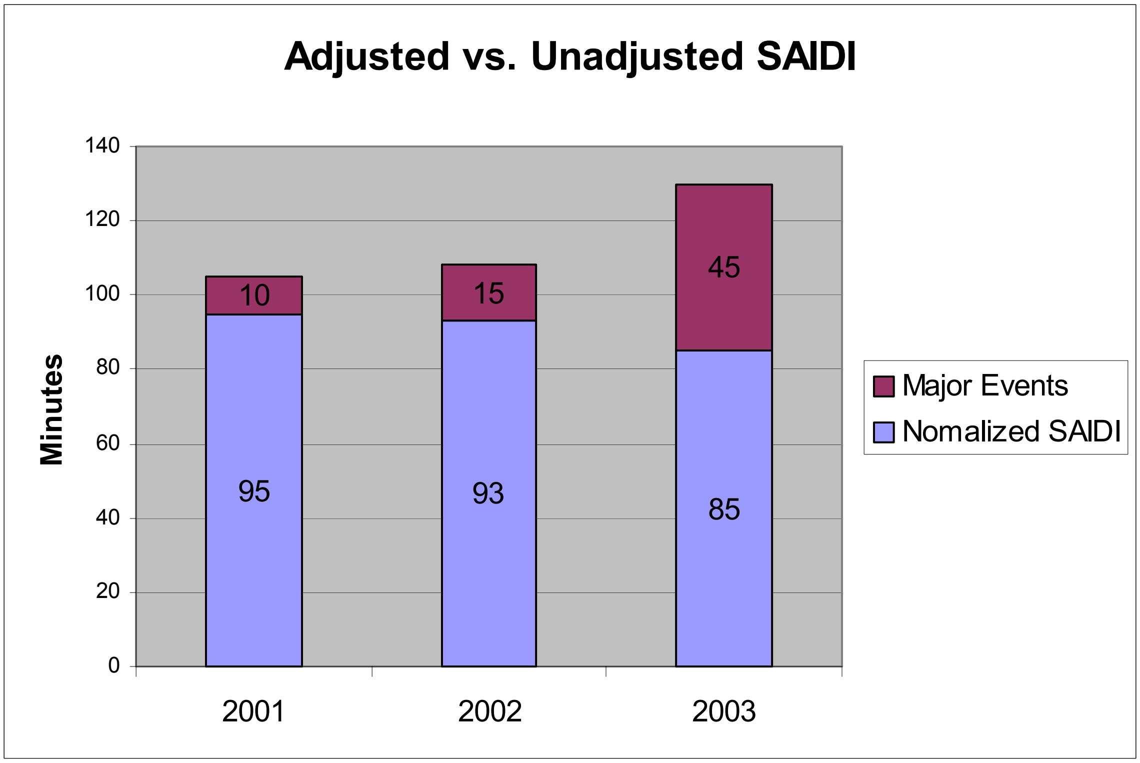
$$T_{MED} = e^{(-3.4258 + 2.5 * 2.4413)}$$

$$T_{MED} = 14.55 \text{ minutes.}$$

From this data, the utility should only consider an event as major if the daily SAIDI exceeds 14.55 minutes.

One of the reasons to factor out major events is to normalize the SAIDI information to ensure that the utility is responding to real changes in its reliability indices and is not "chasing" variances caused by major events such as hurricanes, tornadoes, and floods. The following graph is a good example of why the major event days should be used.

///graph of impact of MEDs////

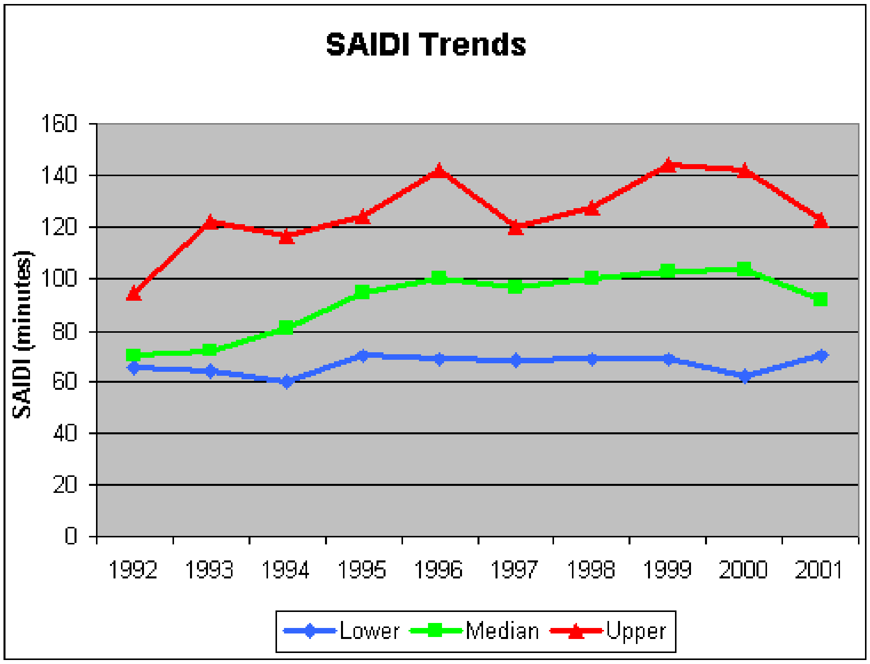


From this graph we can see that 2003 was the worst year for SAIDI, but 45 minutes of the SAIDI was due to a major event. Removing the major events, the SAIDI data is fairly consist over the past three years and even 2003 shows some improvement in reliability.

III. Reliability Trends

There has not been much change in the reliability of the electric distribution systems during the past few years. The chart below, which is based on data from the Electric Power Research Institute (EPRI) shows the SAIDI values over a ten-year period including the median value, and the upper and lower quartiles. The average SAIDI value has hovered around 100 minutes per year while the top quartile has been slightly under 70 minutes.

///SAIDI Trends



With the advent of performance-based rates, utilities are taking a closer look at their reliability data and working to improve their indices. Studies have shown that reliability is greatly affected by lightning, circuit length, circuit density, and system voltage. There is an almost direct correlation between lightning and reliability (the more lightning flashes, the lower the reliability), as well as circuit length, with longer circuits have more interruptions. Some data also suggests that utilities with higher system voltages tend to have more outages, but this may be related to the length of the circuit more than the voltage.

Circuit configuration also has an impact on system reliability. Simple overhead radial systems have the worst reliability. Auto-looped overhead systems and underground systems have an about equal degree of reliability, and a well-coordinated overhead system with multiple protective devices usually results in the highest degree of reliability. Of course, network systems provide a level of service reliability that is an order of magnitude better than any standard distribution configuration.

Conclusion

Understanding how to correctly apply the IEEE standard reliability indices is the first step in measuring the reliability of an electric distribution system. Major events must be removed from the base data so that reliability measures are not distorted and to help the utility track improvements to the electric system.

The most difficult part of using reliability indices is knowing how to interpret the data and understanding what the performance indices are really saying about the system performance.