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Reliability Metrics for the Perfect Power Seal of Approval

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1 Introduction

While price is usually the obvious concern for consumers when thinking about their utility, reliability quickly becomes priority number one once the power goes out. In addition, utilities and regulatory commissions have cited reliability and safety as two specific objectives for electricity improvement. Though many states track reliability indices, and some states have set reliability targets the U.S. average reliability performance lags other developed countries and pockets of poor reliability plague many U.S. cities[14].. Some studies, estimate that the U.S. economy loses nearly $190 billion each year due to power outages, not counting the impact of poor reliability.[1]

Country	SAIDI	SAIFI
United States	240	1.5
Austria	72	0.9
Denmark	24	0.5
France	62	1.0
Germany	23	0.5
Netherlands	33	0.3
UK	90	0.8

As electricity becomes more and more entwined with every aspect of day-to-day life, the issue of reliability becomes increasingly important. An outage – or even a slight variation in power quality – can cause fatalities, injuries, days of lost productivity and thousands of dollars in production losses and equipment repairs. Power outages present a significant safety and economic threat to the public especially senior citizens and lower income consumers.

Utilities today strive for perfection in terms of worker safety while paying little attention to the safety impacts of electricity system interruptions and interactions on consumers. At Gridweek 2010 one utility executive was quoted as saying, "Utilities have a tradition of pursuing perfect employee safety, but we haven't turned that thinking toward the customer experience. "

To ensure greater focus on power reliability and quality which will ensure the well-being of the public are not compromised, safety and reliability metrics need to be improved and trended. The purpose of this paper is to define a comprehensive set of performance metrics that can be used to benchmark and compare reliability and safety performance over time (e.g. trends) and for benchmarking or comparative use.

The benchmarks set forth in this paper have been culled from the many regulatory agencies that oversee utility operations in this country as well as some of the exemplary standards from overseas. Reliability metrics include safety, reliability, and power quality.

The metrics outlined in this paper are part of the Perfect Power Seal of Approval (PPSA) program developed by the Galvin Electricity Initiative. The purpose of this program is to assess the performance of microgrids and rate them accordingly. Similar to the Leadership in Environment and Energy Design (LEED) system, the PPSA will create a voluntary rating system that others (e.g., municipalities and investor-owned utilities) can use to compare the performance of various suppliers across these metrics. The rating system also can be utilized by consumers to specify performance requirements in purchase agreements.

Reliability is only one of four microgrid performance areas that will be evaluated to rate overall electricity system performance. The others are cost, environment/efficiency and consumer empowerment. When combined, these four performance areas provide a comprehensive assessment of performance and a roadmap for putting the microgrid owner/operator on the path to Perfect Power.

2 The Case for Metrics

The electric industry uses several indices to measure electric reliability and power quality. However, the Lawrence Berkeley National Laboratory (LBNL) and others have pointed out that there is a lack of consistency in reporting, and there is no national comparison or rating system that would hold utilities accountable for their performance. For example, some utilities report reliability metrics with major outages, while others do not. Many utilities and/or the commissions that regulate them have different definitions of what constitutes a major outage. More to the point, many utilities don't even agree on the exact definition of an outage. Sustained outages, as defined by IEEE 1366, are those that last more than five minutes, and momentary outages are those that last less than five minutes. Unfortunately, not every utility or utility commission uses IEEE 1366.

Some states allow certain events to be excluded from these indices, which can introduce other inconsistencies from state to state. When major events are excluded from these calculations, for example, the System Average Interruption Duration Index (SAIDI) tends to decrease more dramatically than the System Average Interruption Frequency Index (SAIFI).

As our society becomes increasingly dependent on technology, we also become increasingly dependent on the electricity that powers life support devices, key business systems, heating/cooling and refrigeration for food. Consequently, the economic damage and human health impacts that can be caused by a power outage are intreasing. The metrics that historically have been used to measure outages and their impact are no longer sufficient to express the true scope of the damage that can be caused by an interruption in electricity.
According to a study sponsored by the Electric Power Research Institute's (EPRI) Consortium for Electric Infrastructure to Support a Digital Society (CEIDS), "The U.S. economy is losing between $104 billion and $164 billion a year to outages and another $15 billion to $24 billion to power quality phenomena."[1] This is equivalent to 3 to 5 cents per kilowatt hour based on the total U.S. electricity consumption of 3,733 million megawatt hours per year.[2]

As disconcerting as this number is, the Lawrence Berkeley National Laboratory makes a compelling case that this number is, in fact, too low because of the potential cost omissions of residential customers. Most of this nationwide estimate ends up in the cost of goods and services produced in the United States. More importantly the electricity sector is not tracking the impact of outages on customer health and life safety.

After speaking with many city managers, the Galvin Electricity Initiative discovered the additional costs of human health and safety impacts, dispatching police and fire, of evacuating and securing senior citizens and from ancillary damage, such as the kind caused by loss of power to sump pumps , also add to the total cost for residential customers. As such, the Initiative suspects that the LBNL-estimated cost per residential customer is much too low.

At this point, only estimates can be made because the electricity sector does not measure or track the costs incurred by customers due to a loss of electricity. Without knowing precisely the cost of interruptions, utilities cannot justify investments needed to reduce interruptions and their associated costs. Figure 1 provides a glimpse of the hidden costs of electricity interruptions, which include economic losses and the impact of interruptions on regional economic development. Cities and utilities today are competing for people and business, and the electricity system can be a marketing asset or liability.

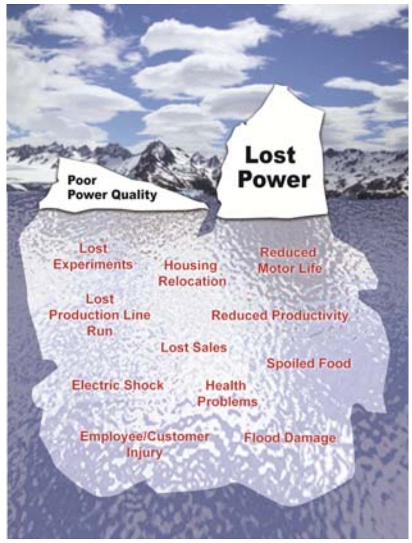

Figure 1: Quality Hidden Costs

3 System Boundary and Interface with Other Rating Systems

Microgrids typically serve a specific constituent or set of constituents, establishing a boundary for which metrics can be reported. This boundary could be a university, a large development, a neighborhood or a city. In some cases, the microgrid is served by one or more local substations or area substations, and the cost system boundary is drawn or set at the supply meters or breakers at the site/area substations. In other cases, the site is served by one or more circuits that come from remote substations. In such cases, the system boundary would be extended to the breaker at the remote substation. The other system boundary would be drawn at the facility meter. Costs inside the meter, including sub-metering, would be assigned to the building.

Established metrics for electricity reliability have been around for several years, especially for sustained outages. Reliability metrics should be measured for all measured substations. Distributed generation that can also be used to mitigate outages should also be tracked.

4 Discussion of Performance Metrics

Before the proliferation of computer systems, the negative impact of power outages and power quality events on a business' financial performance was fairly easy to calculate, with loss of productivity typically being the largest casualty. But when a power outage shuts down network systems or complex machinery, the true cost can be thousands of dollars in lost data or equipment damage.

The private sector is also inextricably entwined with the grid and dependent upon it to run life-saving equipment. From specialized care, such as dialysis machines, to a simple air conditioner, the impact of a power outage on the public can be devastating in terms of both safety and economics.

The metrics outlined in this paper are designed to reflect the complexity of our technological environment and the following myriad ways that an outage can affect our lives:

- Safety (consumer injuries and deaths)
    - Consumer T&D interactions
    - Power outage injury and mortality
- Reliability and power quality
    - Sustained outages
    - Momentary outages
    - Power quality events

As a result of the discussion above, the Initiative developed the scoring methodology in Table 1. Some of the metrics are attributes, and others are performance metrics.

Table 1: Reliability Metrics and Scoring

Performance Categories		Specific Metrics	Max Points	Scoring
Consumer T&D Interaction		Points for tracking T&D-related deaths and injuries	10	
Power Outage Injuries and Mortality		Points for tracking and trending deaths and injuries	10	
Sustained Outages		(Outage duration of two minutes)	30	
SAIDI		Points based on national averages and quartiles		10
SAIFI		Points based on national averages and quartiles		10
CEMI-3		Points for tracking		5
CEED-8		Points for tracking		5
Momentary Outages		(Outage duration less than two minutes)	30	
MAIFI		Points for tracking		20
CEMMI-X-Y or other metric		Points for tracking momentary outage durations at durations less than two minutes in a finer level of detail		10
Power Quality			20	
Voltage swells		Points for tracking		5
Voltage dips		Points for tracking		5
Harmonics		Points for tracking		5
Phase imbalance/ lost phase		Points for tracking		5
Total Possible Points			**100**	

4.1 Safety

Safety can have many meanings for a utility company. When dealing with a potentially hazardous product like electricity, it is even more crucial to consider all aspects of safety. For example, safety for most utility companies usually means tracking injuries to their own employees—an important statistic that is carefully monitored under the Occupational Safety and Health Act (OSHA) of 1970. In addition, the public is at risk not simply from the dangers of fallen power lines, but also from interruptions in service, which can lead to injuries or even fatalities in numerous forms. The Perfect Power Seal of Approval is suggesting safety performance criteria that will measure all injuries and deaths to consumers resulting from the transmission and distribution system (T&D). These criteria will include deaths and injuries due to consumer interactions with the T&D system, such as car accidents, as well as those resulting from storm damage or other external events—including deaths and injuries that are a direct result of a power outage, such as critical care equipment at homes, nursing homes and hospitals. Hurricane Katrina in 2005, for example, provided a compelling example of the importance of electricity to life safety.

4.1.1 Consumer T&D Interaction

While most electrical injuries are work related, direct contact with electricity wires by consumers has resulted in a range of injuries and even death. According to a 2009 study by DRC Consulting for the Institute of Electrical and Electronics Engineers:

> Over 130 fatalities attributed to contact with overhead power lines are reported each year. This does not include injuries caused by inadvertent contact with overhead or fallen power lines. Injures can include burns, heart attacks, respiratory injuries, and injuries resulting from being thrown by an electrical discharge. The number of incidents and fatalities related to contact with overhead power lines has not changed over the last 10 years.[3]

The study also quotes David Wallis, director of OSHA's Office of Engineering Safety, as saying the most important thing the electrical community can do to increase safety is to focus on reducing consumer contact with overhead power lines. Microgrids will be evaluated based on the number of injuries and deaths resulting from consumer contact with power lines or those attributed to a loss of power/outage, which will require the collection and tracking of injuries and deaths reported to hospitals and police.

Measurement methods – Data on injuries and deaths from consumer exposure to the T&D system can be collected from emergency reporting and liability suits.

Benchmark – Injury and deaths resulting from contact with overhead power lines are not currently being reported. Initially the PPSA will award points to grids that record and report this important data.

Precedence – Provision 3204 of the Colorado Public Utilities Commission's "Rules Regulating Electric Utilities" states that, "Each utility shall inform the Commission of all incidents that occur in connection with the operation of its property, facilities or service and that result in death, serious injury or significant property damage within two hours (120 minutes) of learning of the incident."[4]

4.1.2 Power Outage Injury and Mortality

The Associated Press reported in 2009 that roughly 2 million people are using residential electricity-dependent oxygen machines, and at least 10,000 more breathe with home ventilators. Many more people depend on electricity to power their at-home heart pumps, dialysis machines, nebulizers and IV

pumps—all of which are at risk of shutting down during power outages, which can also stop elevators that are critical to the egress of impaired consumers.[5]

Reliable electricity is as critical to life safety as it is essential in the heating and cooling of homes during severe weather. The massive heat wave and power outages in Chicago in 1995 caused more than 700 deaths,[6] and the National Weather Service reports that about 20 percent of winter storm fatalities occur in the home due to lack of heat.[7] In addition, power outages cause dangerous hazards that put the public at risk. For example, when lights go out, consumers resort to candles, creating a significant fire hazard. Power outages also can cause traffic signal failure, increasing the chances of traffic injuries.

While these numbers are sobering, they have largely gone unreported in the past. Typically, when a power outage causes critical care equipment to fail, the death certificate or injury report may not capture the fact that contact (or lack thereof) with electricity was the primary cause.

Measurement methods – Deaths and injuries related to power outages can be tracked by reviewing police reports, hospital emergency room records and insurance reports.

Benchmark – Injuries and deaths resulting from power outages are not currently being reported. Initially the PPSA will award points to grids that record and report this important data.

Precedence – Utilities in every state already keep lists tracking customers whose lives depend on electric power due to at-home medical equipment. These lists imply an understanding that power outages can result in injuries and possibly deaths.

4.2 Reliability and Power Quality

Reliability, as it applies to a utility industry, refers to the quality of power delivered to its customers in terms of interruptions, surges and other factors. This section will outline standards for performance monitoring, which include the following:

- Sustained outages
- Momentary outages
- Power quality

Sustained Outage Duration

The LBNL study concluded that the definition of "duration" for a sustained outage had only a small impact on SAIDI and SAIFI indices. However, the range of duration that was evaluated was from three to five minutes.

The Initiative considered reducing the definition of a sustained outage down to as little as one second, but thought MAIFI is intended to measure instantaneous outages. The Initiative is still weighing the pros and cons of going to a very short duration for sustained outages.

4.2.1 Sustained Outages

Outages are the most noticeable example of a change in the quality of service from the utility company. We've already discussed how damaging power interruptions can be from a safety and economic standpoint, which would naturally make finding an acceptable level of outages a key concern for any regulatory agency. Unfortunately, the industry definition of an outage can vary dramatically across the United States.

- Some utilities include major outages in their reporting, while others don't.
- Many utilities use different minimum outage durations ranging from one minute to five minutes before an outage is counted.

The PPSA will be based on best practices while drawing heavily from the Institute of Electrical and Electronic Engineers (IEEE) Standard 1366[8] for outage metrics and the European Norm 50160[9] for power quality metrics. Two notable exceptions to the IEEE standard include:

- The inclusion of major events in reliability ratings, which are required by many U.S. states
- A sustained outage will be defined as any interruption lasting more than two minutes. Texas has set a new best practice by defining an interruption as any event where the voltage is reduced to zero. Wide variations in the definition of an interruption make it difficult to benchmark reliability performance.

The GGR will evaluate reliability using the following common indices:

SAIDI – System average interruption duration index represents the sum of customer-sustained outage minutes per year divided by the total customers served.

SAIFI – System average interruption frequency index represents the number of customer interruptions divided by the total customers served.

CEMI-3 – Customers experiencing multiple interruptions index represents the percentage of all customers that have experienced more than three interruptions.

CEED-8 – Customers experiencing extended outage durations longer than eight hours. The Initiative suggests using this metric to assess time to restoration.

Measurement methods – Reliability indices are calculated with information from individual power interruptions, such as their duration and size. System indices are then calculated from the information of all the individual interruptions that occur in a system during a reporting period.

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Benchmarks – The 2008 IEEE Benchmarking Survey[10] lists the following reliability benchmarks for sustained outages:

Table 2: Reliability Benchmarks

Quartile	Percentile	SAIDI IEEE, minutes of outage duration	SAIFI IEEE, number of outages per year
Min	0	20.47	.321
1	25th	102.06	1.060
2	50th	154.78	1.340
3	75th	195.65	1.580
Max	100th	493.26	3.220

Table 2 categorizes SAIDI and SAIFI values of 31 utilities into statistical quartiles. The best performing utilities fall in the first quartile, which is the top 25 percent. The worst performing unities would fall into the last quartile, which is the bottom 75 percent. The SAIFI and SAIDI columns show the cut-off values for each quartile. These quartiles will be used for scoring SAIDI and SAIFI metrics.

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Table 2

Precedence – According to the 2008 LBNL report, there are 35 public utility commissions that require reliability information be reported routinely:

> All 35 states require reporting of SAIFI. Thirty states require reporting of SAIDI, and 18 states require reporting of the Customer Average Interruption Duration Index (CAIDI). However, the definitions of SAIDI, SAIFI and CAIDI are interrelated. SAIDI can be calculated from SAIFI and CAIDI, and CAIDI can be calculated from SAIDI and SAIFI. Therefore, for all intents and purposes, SAIDI and SAIFI are either directly reported or, if SAIDI is not directly reported, it can be derived from SAIFI and CAIDI, which are reported.[11]

4.2.2 Momentary Outages

For a growing number of customers, especially industrial customers, even one-minute interruptions can cause significant equipment loss and damages. Therefore, there is a need for information to be collected on short interruptions.

The PPSA will evaluate short interruptions using the following indices:

MAIFI – Momentary average interruption frequency index represents the system-wide average number of momentary outages per year and is determined by dividing the number of momentary customer interruptions by the total customers served. A momentary outage as defined in this document is any time the voltage goes to zero for less than two minutes. The duration of a MAIFI event could range from an instant or very small fraction of a second or cycle to as long as two minutes. Outages longer than two minutes are classified as sustained outages. The scoring system will give more credit to entities that measure MAIFI in levels of finer detail, such as outages lasting less than one second and outages lasting longer than one second.

Measurement methods – While measuring MAIFI does not necessarily require advanced metering infrastructure (AMI), it helps significantly in the process. What is required, however, is a supervisory control and data acquisition (SCADA) system that at least detects outages down to the circuit level of each substation and is fast enough to measure events that may happen in small factions of a cycle.

Benchmark – There has not been enough momentary outage data collected in the United States to establish a rating system. Europe has not set benchmarks for momentary outages, either, but most countries are collecting separate data for momentary outages. Initially, the PPSA will award points to grids that record and report this data.

Precedence – Currently, only two states require MAIFI reporting, and those that do only require reporting for circuits that are monitored by a SCADA system. Most countries in Europe collect data, also using SCADA systems, for momentary outages.

CEMMI-X-Y – Customers experiencing multiple momentary interruptions index represents the percentage of all customers that have experienced more than X interruptions under Y cycles. This could be a metric used for measuring momentary outages in a finer level of detail than just MAIFI in scoring. The Initiative is very interested in tracking momentary outages in a finer level of detail.

4.2.3 Power Quality Events

Power quality (PQ), in today's digital economy, is an emerging issue for the industry due to the increasing demand for higher-quality power and recognition that power quality events cost American businesses significant amounts of damage and waste. An EPRI study claims the U.S. economy is losing as much as $24 billion a year to PQ phenomena.[12] Some may argue that these costs only affect business,but businesses that experience these outages frequently pass the costs on to consumers. Power quality events include the following:

- **Supply voltage variations –** These are variations in the voltage level above or below the nominal voltage under normal operating conditions. This power quality phenomenon reduces the efficiency and life of electrical equipment. When the variation is under voltage, electrical equipment may shut down, and over voltage can cause overheating and damage.
- **Rapid voltage changes (RVC) –** A rapid voltage change is a fast change in a voltage between two steady conditions and is caused by switching large loads on or off. This phenomenon is commonly caused when a large motor is started. When rapid voltage change exceeds thedip/swell threshold, it is considered a dip or swell.
- **Voltage swells –** This is an increase in voltage above 110 percent of nominal for one-half cycle to one minute. Swells are typically brief in duration and do not cause significant damage to equipment. They can, however, cause light bulbs to burn out, which may cause safety problems.
- **Voltage dip –** This brief reduction in voltage in a system, typically between one-half cycle to one minute, is also called voltage sag. Voltage drop can cause problems in the operation of electrical equipment and is particularly damaging to motors.
- **Flicker –** The perception of change in light intensity due to some deviation in the voltage that supplies lighting circuits is a flicker. This deviation can be very small and rarely causes major operating problems for electrical equipment. Even the slightest deviation, however, can irritate human eyes, causing headaches and making ordinary tasks difficult.
- **Voltage imbalance/Lost phase –** The utility transmits power in three phases, but only sends one phase to typical residential customers. A lost phase means that the voltage of one of the phases goes to zero for one reason or another, such as a severed wire or blown fuse on one of the phases. The impact of this is different depending on whether the customer is a single-phase or a three-phase customer. Most residential customers are only supplied a single phase, and when the utility loses a phase, only customers that are connected to the lost phase experience an outage.

  However, the act of losing a phase will most likely cause some type of power quality event for other customers. For instance, other single-phase customers will likely experience variations in voltage and possibly frequency variations when a phase is lost. Industrial customers and many commercial customers are supplied three-phase power. If they lose a phase, the effect can be more devastating. These customers tend to have motors that are designed to operate on three phases, so when a phase is lost, the other two phases can be overloaded, causing damage to the motor due to overheating. Industrial customers have reported motor failures due to PQ events.

- **Harmonics –** This is recurring distortion of the waveform. Harmonic distortion can cause operating problems, as well as overheating, in electrical equipment.

Measurement methods – As with MAIFI, measuring power quality does not necessarily require AMI, though AMI would again be helpful in gaining these measurements. A SCADA system is required, however, that can measure attributes of power quality down to the circuit level of each substation.

Benchmark – There has not been enough PQ data collected in the United States to establish a rating system. The PPSA will draw heavily from European power quality standard EN 50160, as illustrated in Table 2.

Table 3: European Power Quality Standard EN50160

Quality aspects	EN 50160		
Voltage level	[0.1] kV	<1.35> kV	[35 > kV
Supply voltage variations	Nominal Voltage ± 10% (10 min mean 95% of the week) Nominal Voltage ±10/-15% (all 10 min mean values)	Contractual Voltage± 10% (10 min mean 95% of the week)	None
Rapid voltage changes (RVC)	Indicative: Generally <5% up to 10%	Indicative: Generally < 4% up to 6%	None
Voltage swells	Indicative: < 1.5kV (phase to earth)	Generally < 1.7 x U_c (earthed) Generally <2.0 x Contractual Voltage (isol./resonant.)	None
Voltage dips	Indicative: few tens up to one thousand	Same as Low Voltage (up to 1kV)	None
Flicker	Long Term Flicker (Plt) ≤ 1 (95% of the week)	Same as Low Voltage (up to 1kV)	None
Voltage imbalance	≤ 2% (10 min mean 95% of the week) ≤ 3% occur in some areas	Same as Low Voltage (up to 1kV)	None
Harmonic voltage, THD (total harmonic distortion)	THD ≤ 8% (10 min mean 95 % of the week)	Same as Low Voltage (up to 1kV)	None
Harmonic voltage individual	EN 50160 Table 1 (10 min mean 95% of the week)	Same as Low Voltage (up to 1kV)	None

From the Council of European Energy Regulator's Fourth Benchmarking Report on Quality of Electricity Supply[13]

Precedence – In Europe, EN 50160 is used to regulate power quality, though some individual countries maintain even higher standards. Several countries, including France, Italy, the Netherlands and Spain, are requiring all new smart meters to continuously monitor and collect power quality information.[14]

5 Issues and Limitations

In regard to safety metrics, proper reporting of injuries and deaths related to contact with overhead power lines will require interface with police and hospitals to collect data, which may make the data reporting difficult.

For the purposes of this rating system, the Initiative has decided to use two minutes for the basis of determining a sustained outage—a decision that was based on a discussion with industry experts who believe that most automated power restoration equipment should be able to restore power within this time frame. The opinion of these experts was that one minute may not be quite enough time for the automated equipment to restore power. Additionally, MAIFI is intended to track momentary outages. The Initiative advocates increased emphasis on MAIFI, especially for a microgrid, as it is often the outage itself, not the length of the outage, which causes the most damage.

Some regulating agencies include major events in the reporting of sustained outages, and others do not. The reason some utilities do not include major events in the recording and reporting of sustained outages is that a dramatic major event where power is lost for hours or even days can radically affect their SAIDI statistics and create a skewed picture of their overall reliability. Furthermore, the definition of a “major event” is also open to interpretation. However, the recording of major events is necessary to determine a fair reliability rating. For example, if the increased demand from a heat wave shuts down the electric grid every summer, there is clearly a predictable pattern that must be addressed by the utility. To avoid ambiguity on this issue, the PPSA is including all events but using a three-year average of the service quality indices to dampen the impact of annual changes in weather patterns. A one-time major event like Hurricane Katrina would not appreciably increase the three-year average or indicate poor performance.

Overall, wide metrics can cover up pockets of poor reliability. Finer levels of analysis are required to uncover these areas. Worst performing circuit analysis may not reveal unreliable areas. In some states, the circuit has to be on the worst performing list for three consecutive years to earn the title. This means the circuits that make the list two years in a row and then skip a year before falling back on the list again will not be identified.

The primary barrier to setting benchmarks for momentary outages is a lack of data. The cause of this shortage of information is that currently many electricity distributors do not have the systems capability that enables them to measure MAIFI. The introduction of AMI could theoretically help rectify this problem provided that the meters are configured to do so. Low cost nano sensors are under development to help provide the required information.

Additionally, many electricity distributors do not have the ability to continuously monitor and collect power quality information. Once again, the introduction of AMI should rectify this problem.

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