Lawrence Berkeley National Laboratory
Lawrence Berkeley National Laboratory

Title

A new approach to power quality and electricity reliability monitoring-case study illustrations of the capabilities of the I-GridTM system

Permalink

https://escholarship.org/uc/item/2w85j5zz

Authors

Divan, Deepak
Brumsickle, William
Eto, Joseph

Publication Date

2003-04-01

eScholarship.org Powered by the California Digital Library
University of California

LBNL-52048

A New Approach to Power Quality and Electricity Reliability Monitoring – Case Study Illustrations of the Capabilities of the I-Grid™ System

Prepared for
Imre Gyuk, Energy Storage Research
Distributed Energy and Electric Reliability Program
Energy Efficiency and Renewable Energy
U.S. Department of Energy

Prepared by
Deepak Divan and William Brumsickle,
SoftSwitching Technologies Corp.

&

Joseph Eto
Energy Analysis Department
Environmental Energy Technologies Division
Ernest Orlando Lawrence Berkeley National Laboratory
University of California Berkeley
Berkeley, CA

April 2003

The work described in this report was funded by the Assistant Secretary of Energy Efficiency and Renewable Energy, Distributed Energy and Electric Reliability Program of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Abstract

This report describes a new approach for collecting information on power quality and reliability and making it available in the public domain. Making this information readily available in a form that is meaningful to electricity consumers is necessary for enabling more informed private and public decisions regarding electricity reliability. The system dramatically reduces the cost (and expertise) needed for customers to obtain information on the most significant power quality events, called voltage sags and interruptions. The system also offers widespread access to information on power quality collected from multiple sites and the potential for capturing information on the impacts of power quality problems, together enabling a wide variety of analysis and benchmarking to improve system reliability. Six case studies demonstrate selected functionality and capabilities of the system, including:

- Linking measured power quality events to process interruption and downtime;
- Demonstrating the ability to correlate events recorded by multiple monitors to narrow and confirm the causes of power quality events; and
- Benchmarking power quality and reliability on a firm and regional basis.

Acknowledgments

The authors thank Tina Kaarsberg[1] and Imre Gyuk, DOE Energy Storage research for their support of this project. A draft of this report benefited greatly from reviews provided by Joseph Hoagland and staff, TVA, Steve Wisenant and Patrick Chaney, Duke Energy, Dale Krummen and staff, AEP, and John Boyes, Sandia National Laboratories. All errors and omissions remain the responsibility of the authors.

---

[1] Ms. Kaarsberg is currently staff to the Energy Subcommittee of the Committee on Science, U.S. House of Representatives.

Acronyms

CAIDI	customer average interruption duration index
CAIFI	customer average interruption Frequency index
DOE	U.S. Department of Energy
DUR	duration
EPRI	Electric Power Research Institute
MAG	magnitude
MAIFI	momentary average interruption frequency index
R&D	research and development
SAIDI	system average interruption duration index
SAIFI	system average interruption frequency index
SEMI	Semiconductor Equipment and Materials International

Table of Contents

Figures and Tables

1. Introduction

Public interest in electricity reliability is at an all-time high because of recent negative experiences associated with electricity industry restructuring: rolling blackouts, inadequately designed and policed electricity markets, and resulting unacceptably high wholesale electricity prices. The recent National Transmission Grid Study (DOE 2002) observes that "as a cornerstone of restructuring, we should allow consumers to pay for a higher level of reliability than that provided by the current electricity system." It then goes on to note that "[a] critical barrier to informed consumer decisions about reliability, which includes power quality, has been the lack of public data on the subject."

This report describes a new approach for collecting information on power quality and reliability, and making it available in the public domain. Making this information readily available in a form that is meaningful to electricity consumers is necessary for enabling more, informed private and public decisions regarding electricity reliability.

One part of the problem associated with current information on electricity reliability is that utilities collecting this information use different definitions of reliability "events" or apply these definitions differently; e.g., what might be counted as an outage by one utility would not be counted as an outage by another (Warren, Pearson, Sheehan 2003). If basic phenomena are measured inconsistently among utilities, meaningful comparisons are not possible. Another part of the problem is that utilities do not consistently report the information they collect, and public access to this information is limited in any case. Finally and most importantly, information collected and reported by utilities typically does not account for the impact of power quality events on customers. Routine grid operating events that, in past, were un-noticeable by customers, can now cause lengthy downtimes due to the increased sensitivity of customer's equipment to these events. In other words, there is a growing disconnect between traditional measures of reliability used by utilities and the actual impact of the system's operation on customers.

Assessment of power quality involves looking at electromagnetic deviations from the ideal service that the U.S. electricity distribution system is designed to provide: a pure 60-cycle per second alternating current at a designated voltage (120 volts for residential customers or 480 volts for many commercial or industrial customers). Any deviation from this standard that causes customers' equipment to fail or malfunction is considered a power quality "event." Sustained interruptions (blackouts), which occur when voltage falls to zero for more than one minute (typically, 5 minutes or more), are the power quality problem with which most individuals have the greatest direct experience and are the key phenomena represented in utility reliability statistics (with the limitations described in the previous paragraph).

For many customers, subtle deviations in power quality pose a far more significant reliability problem than outages. The most common small deviation is a voltage "sag" – a drop in (but not complete loss of) voltage for a short period of time (i.e., from a few cycles to a few seconds).[2] Voltage sags can be caused by natural events (e.g., trees falling on power lines or lightning

---

[2] EPRI's landmark study of power quality found that voltage-related power quality events accounted for 90% of all power quality events (Electrotek 1996).

striking lines or transformers), utility activities (e.g., routine switching operations or human error), or customer activities (e.g., starting of large motors).

Although in the past most electricity-consuming devices could “ride through” voltage sags (e.g., a light bulb might dim momentarily), many of the electricity-consuming devices associated with today’s digital economy (e.g., equipment controlled by programmable logic chips) cannot tolerate a partial drop in voltage for even a fraction of a second. Voltage sags may cause this equipment to shut down and remain off even after service is restored to normal levels. Voltage sags are rapid and not easily detectable by an untrained observer, and so consumers may not realize that a power quality ‘event’ caused their equipment to fail or stop operating. They are not included in reliability statistics reported by utilities (e.g., SAIFI, SAIDI, CAIDI, CAIFI, MAIFI).

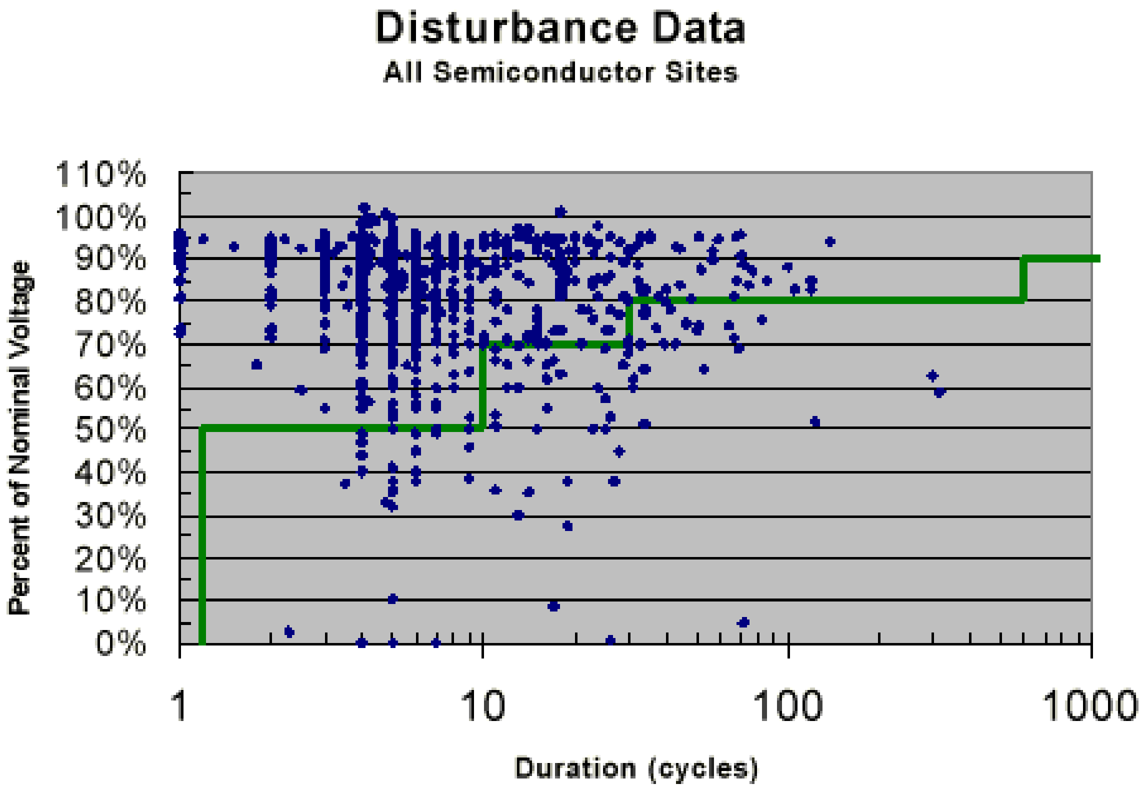


Figure 1. Representative Power Quality Data and the SEMI F47 Standard

Figure 1 illustrates the relationship between voltage sags and equipment performance. The figure plots individual recorded power quality events by their duration and magnitude. Superimposed on the figure is the SEMI F47-0200 standard (SEMI 2000), which is a standard for voltage tolerance for sensitive equipment. Equipment that meets the SEMI F47 standard should be able to tolerate voltage sags of durations and magnitudes above the curve. As indicated by these data, a significant number of recorded events fall below the curve, indicating that these events would cause the equipment to fail or mis-operate.

Increased reliance on devices susceptible to power quality problems means that the U.S. economy's vulnerability to electricity supply interruptions in general, and momentary supply deviations in particular, has increased. Thus, the disconnection noted above -- between the statistics that utilities collect about power quality and the actual power quality effects that are important to consumers -- has great economic significance. In some cases, it may be most cost-effective to harden customer's equipment to be more tolerant of power quality events; in other cases, it may be more cost-effective to implement changes to the grid and its operation.

The absence of consistent and geographically comprehensive information about the prevalence and impact of power quality problems on the nation's economy presents a challenge for private market participants as well as for public policy. From the perspective of electricity consumers, challenges to collecting power quality data include the complexity and high cost of power quality monitoring devices and a general lack of awareness of power quality as an issue that may reduce productivity. Power quality monitoring devices typically cost $2,000-10,000+ and are sold to be used by technicians with specialized training. These devices are necessary because, as noted above, most power quality problems are not noticeable to the untrained observer. Manufacturing processes may stop for many reasons other than power quality events, including mechanical failures, impurities in feedstock, and poorly calibrated operations.

From the public policy perspective, reliable information is needed to inform both private and public decision-making on reliability and power quality issues. The grid was never designed to provide perfect power quality; it may be more cost-effective for society as a whole to improve the tolerance of certain types of equipment to power quality events, rather try to reduce the frequency of power quality events originating from the grid. As noted above, without consistent information, it difficult to assess and make trade off among these and other alternatives. The last systematic information published on power quality was developed by the Electric Power Research Institute (EPRI) seven years ago and addresses only selected regions of the country (Electrotek 1996). These data are now very outdated and difficult to obtain except for members of EPRI.

This report describes the capabilities of a new power quality monitoring system that addresses both private and public interests in improving the accessibility of power quality information. The system, called the I-Grid^{TM}, consists of very low-cost monitoring devices ($300 each) and a web data base and analysis capability that is separate from the devices and easy to use without specialized training. When an I-Grid monitoring device detects a voltage sag or interruption, it time-stamps and precisely records the data; after voltage returns to normal, the device automatically dials up and uploads information on the event to a web server.[3] Customers and others can then view and analyze the event on a secure website.

The system dramatically reduces the cost (and expertise) needed for customers to obtain information on the most significant power quality events: voltage sags and interruptions. The system also offers widespread access to information on power quality collected from multiple sites and the potential for capturing information on the impacts of power quality problems, together enabling a wide variety of analysis and benchmarking to improve system reliability.

---

[3] The I-Grid, however, does not monitor all power quality phenomena; it only monitors voltage sags and interruptions, which according to EPRI, account for 90% of power quality events.

This report is the first of two documents describing initial U.S. Department of Energy (DOE) work to assess the I-Grid concept. In this report, we describe the concept and illustrate it with examples of power quality information from current installations of the monitoring devices. A second report describes findings from a case study installation of a small number of sensors in which we focus on the impact of power quality on selected manufacturers' operations based on information provided by the monitoring system, supplemented by on-site interviews (Eto, Brumsickle, Divan 2003).

The remainder of this report is organized as follows:

- Section 2 describes the I-Grid monitoring system.
- Section 3 illustrates some of the system's key functionalities based on six case studies of current installations.
- Section 4 summarizes our findings.
- Appendix A summarizes findings from a recent EPRI report that assessed the technical performance of the sensors used in the I-Grid system.

2. The I-Grid Power Quality and Reliability Monitoring System

The I-Grid system, developed by SoftSwitching Technologies,[4] offers the potential for a web-based power quality and reliability monitoring and alarm system for key aspects of U.S. electricity grid performance. The system relies on widespread deployment of a large number of ultra-low-cost "I-Sense"™ power monitors throughout a geographic region of the grid. The monitors capture data on grid events, including outages, blackouts, brownouts, interruptions, and short-duration power quality disturbances or events such as voltage sags and swells, which, as noted in the previous section, can pose significant reliability concerns from the customer's point of view.[5]

The monitors transmit data via the Internet to a central data base and website. Information on grid events is displayed at the website, and near-real-time notification of events is sent to designated individuals or groups. With these functions, the website can act like a live "web cam" for areas of the electricity grid.

Most providers of power quality monitoring equipment[6] have focused primarily on data collection from single sensors or a group of sensors for a particular plant, facility, or customer. Emphasis has been on developing "smart" sensors that support their own web sites with full notification and reporting services. Although sensor costs have drifted downward, the focus has been on increasing performance rather than reducing cost. Costs for individual sensors have consistently stayed in the range of $2,000 to $10,000 per node although there has been some movement downward into the $500 range in recent years. Solutions at the lower end of the cost spectrum are typically linked with monthly charges of $50 to $200 per month per node. This prevailing high cost per node dramatically limits the deployment of power quality monitors. Almost no attempts have been made to date to introduce ultra-low cost monitors that could enable massively distributed arrays of correlated power sensors.

SoftSwitching's power monitors significantly lower the cost of network connection and communication to $200-300 per device and offers targeted, highly specific functionality.[7] The monitors utilize low-cost digital signal processors and electronics, communication via the Internet, centralized data processing and aggregation. Reliance on standard web browsers eliminates the need for the significant investment in software and hardware infrastructure that is typically required for other monitoring systems.

The I-Grid differs from other power quality monitoring approaches in providing real-time as well as historical data on site-specific power quality and energy consumption patterns. More importantly, the low cost per node means that broad-based deployment of monitoring across the

---

[4] SoftSwitching Technologies is a spin-off from the University of Wisconsin that designs and manufactures power electronics technology for power quality applications.

[5] EPRI PEAC has recently completed a comprehensive test report confirming the accuracy of the power quality information collected by I-Sense monitors. The findings from this report are summarized in Appendix A.

[6] For example, Dranetz/BMI, ABB, GE, Square D, Smart Synch, Silicon Energy, and Tridium.

[7] The I-Grid system, in its present configuration, does not monitor all possible power quality phenomena; it monitors only voltage-related power quality events, which according to EPRI (Electrotek 1996), account for 90% of all power quality events.

electricity grid is more financially feasible. A large number of monitors along with appropriate analysis software could allow data clustering and aggregation over large geographic areas to assess power quality and reliability for individual customers as well as grid-wide measures of the state of the electricity system.

3. Case Studies of I-Grid Capabilities

The six case studies summarized in this section demonstrate selected functionality and capabilities of the I-Grid system, including:

- Linking measured power quality events to process interruption and downtime;
- Demonstrating the ability to correlate events recorded by multiple monitors to narrow and confirm the causes of power quality events; and
- Benchmarking power quality and reliability on a firm and regional basis.

The features described in these case studies directly address the growing national interest in understanding the economic impact of power quality events on the U.S. economy and on identifying and prioritizing public interest policies and R&D to address these costs.[8] Because the system includes a mechanism for capturing end-user feedback about the process impact of individual power quality events, it offers the possibility for accurate assessment of the economic costs of power quality problems.[9]

All of the functionalities of the system assessed in these case studies could be provided with conventional technologies. However, the high labor and material costs of these conventional alternatives means that pursuit would be limited to a small group of industries or users with the highest economic interest in mitigating power quality problems. Widespread deployment, which would allow grid-wide monitoring across multiple sites, would be highly unlikely except in very specialized locations. The I-Grid promises to lower these cost barriers significantly, thereby enabling widespread deployment. The public benefits of this technology increases dramatically with the analysis capabilities that are enabled by widespread deployment.

The case studies illustrate selected physical monitoring capabilities or analyses that are enabled by the I-Grid system. The case studies do not address the economic impacts or assess the severity of the power quality and reliability events captured. Additional information collected from customers experiencing power quality events is required. As noted in the introduction, this topic is developed more fully in a companion report (Eto, Brumsickle, Divan 2003).

For each case study, the analysis methodology and key conclusions are summarized.

---

[8] The National Transmission Grid Study recommendations include: “DOE will work with FERC, state PUCs, and industry to ensure routine collection of consistent data on the frequency, duration, extent (number of customers and amount of load affected), and cost of reliability and power quality events, to better assess the value of reliability to the nation’s consumers.” (DOE 2002)

[9] This aspect of the monitoring system is not examined in this report.

Case 1: Power Quality at a Major U.S. Automobile Assembly Plant with Dual Utility Feeds

Background

For many customers who require highly reliable power, utilities provide dual feeds; i.e., service to a facility comes from two independent transmission lines. Under normal conditions, the plant load is shared by the two transmission lines. When a problem arises on one of the lines, plant loads are switched nearly instantaneously to the other line. In other words, the two lines provide redundant paths to ensure near continuous electric service to a customer.

Description

A large automobile assembly plant (over 3,000 workers) is supplied from a dedicated substation that is fed from two separate transmission lines. An I-Sense monitor was located on each transmission line. See Figure 2.

A grid event occurred during which the monitor on one line recorded a voltage sag of 4.8 cycles (0.09 seconds) followed immediately by a complete interruption that lasted 9.8 seconds; the other monitor recorded a similar voltage sag followed by return to normal voltage and no subsequent interruptions. These data indicate that a fault occurred on the first transmission line, and a voltage sag was propagated from one line to the other. See Figure 3.

The physical cause of the event was later reported: a windstorm caused a line-line fault at the point of entry of Transmission Line #1 into the substation. The fault was initially fed by both transmission lines, causing a voltage sag on all downstream load buses. Circuit breakers subsequently disconnected the faulted transmission line, leaving all plant loads connected to the remaining Transmission Line #2.

Discussion

This case study demonstrates the operation of a dual feed when a fault occurs: an automatic transfer is initiated from the faulted feed to the unfaulted feed. This strategy allows automatic restoration of power to the facility, permitting a restart of interrupted processes. The dual-transmission-feed infrastructure meant that this company experienced only a four-cycle (0.07-second) voltage sag rather than a several-hour interruption of service. Nevertheless, the voltage sag was sufficiently severe to cause some process interruptions. Commercially available voltage sag mitigation equipment would have kept all critical processes running during this event; 68 percent of voltage remained during the sag, and sag correctors can compensate down to 50 percent remaining voltage.

This example shows how highly reliable power can be provided with two utility feeds but also that use of dual feeds does not eliminate the short-duration voltage sags that can also cause process downtime.

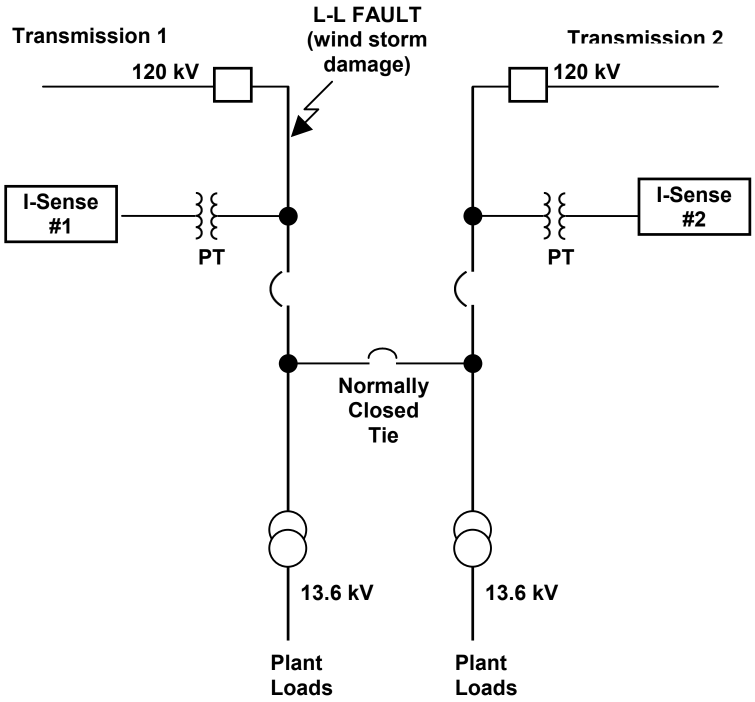


Figure 2. Line Diagram for Case #1

Events recorded on Feeder #1: A two-line sag for four cycles, followed by nominal voltage for one cycle, followed by complete interruption for 9.8 seconds, followed by return to normal.

(I-Sense #1)

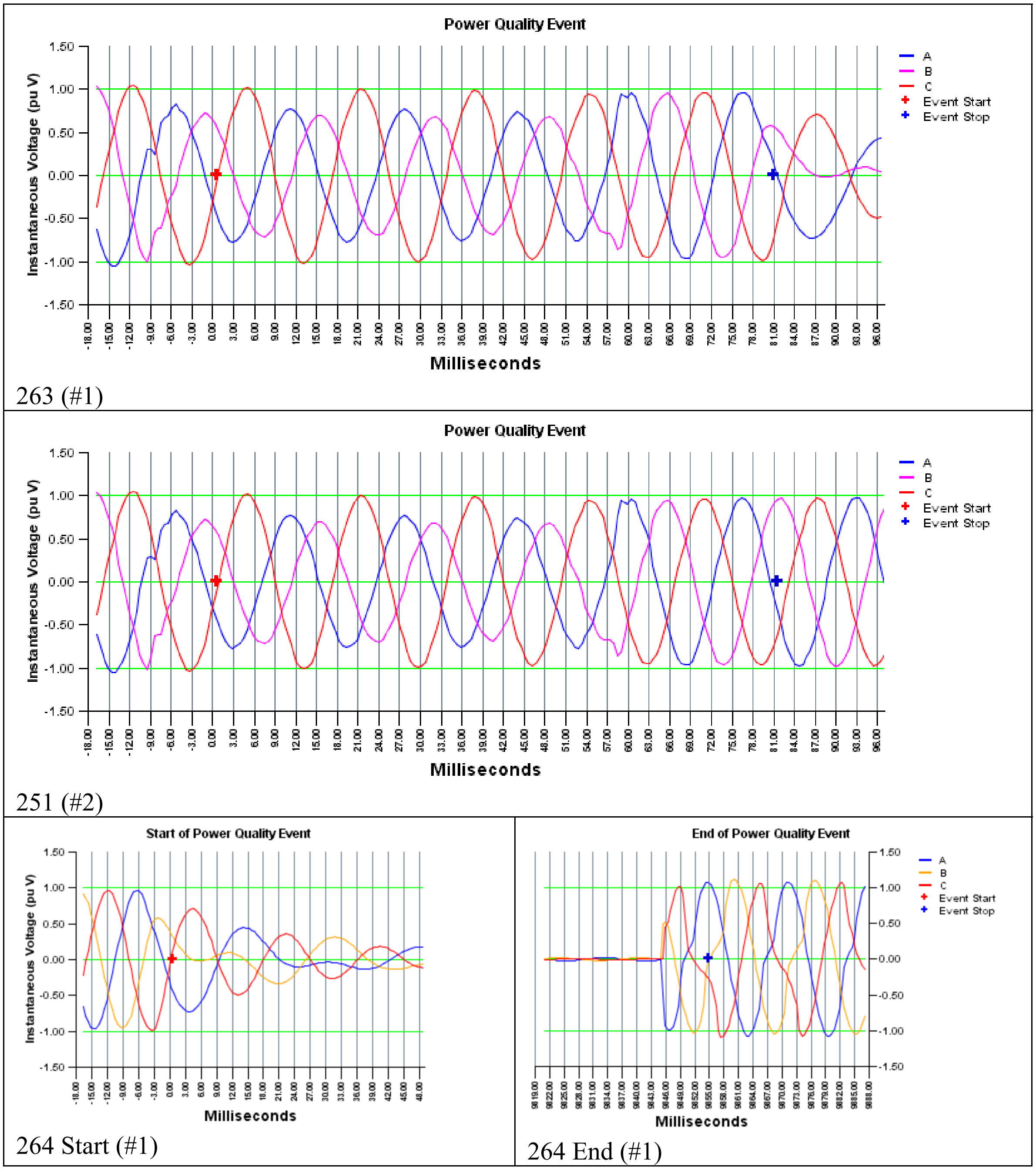
event#	Date	time	classification	duration	depth
263	6/26/2002	06:25:29.242 PM	Instantaneous Sag	4.8 Cycles	67%
264	6/26/2002	06:25:29.324 PM	Temporary Interruption	9.8 sec.	0%

Events recorded on Feeder #2: A two-line sag for four cycles, with no subsequent interruption.

(I-Sense #2)

event#	Date	Time	Classification	duration	depth
251	6/26/2002	06:25:29.283 PM	Instantaneous Sag	4.9 Cycles	67%

Event waveforms are shown below. Note that the plots of events 263(#1) and 251(#2) are of exactly the same total duration. Note also that the beginning of event 264 is visible in the plot of event 263.



263 (#1)

251 (#2)

264 Start (#1)

264 End (#1)

Figure 3. Case #1 Event Waveforms

Case 2: Establishing Correlations Among Power Quality Events to Determine Their Source

Background

Power quality events may be caused by the utility supplying the customer or by equipment operations within a customer's or a neighboring customer's plant. Comprehensive monitoring is required to pinpoint the source.

Description

In an industrial neighborhood in a small city in the Midwest, a crow flew into medium- voltage switchgear at a utility substation. The event caused a fault from the utility line to ground. Voltage sags and momentary loss of utility voltage resulted on the grid for several miles around the substation and were felt by more than 200 customers.

Four I-Sense monitors distributed throughout the neighborhood recorded the effects of this power quality event, as shown in Figure 4. Accurate time stamps permitted post-processing to cluster the recorded data and present them as one physical event (Figure 5). By clustering the data in this fashion, we hypothesized that the event was propagated on the distribution grid – that is, that this was a "grid" event rather than a set of uncorrelated events, each initiated from within a distinct customer's premises.

The hypothesis that the recorded data all represented a single, utility-caused event was confirmed when utility company records revealed a relay operation on a parallel feeder with the same time stamp as the power quality events recorded by the sensors. Analysis of the waveforms clearly indicates a single-line-to-ground fault, which is the most common type of utility system fault. (Note that monitor #1 recorded line-line voltage, and the other monitors recorded line-neutral voltage.)

A customer at one monitored location experienced a 13-hour process shutdown as a result of this event.

Discussion

The ability to discriminate between grid and internal events is vital. An event originating from within a customer's premises is the responsibility of the individual customer. An event originating from the utility, which affects multiple customers, is the utility's responsibility.[10] This case study validates the assumption that grid events are experienced by all utility customers in a geographical region and that every single customer does not need to be monitored to assess the power quality for a region. Grid-wide power quality and reliability monitoring would require deployment of sensors for only a small percentage of customer facilities.[11]

---

[10] The exact nature of this responsibility is dictated by the conditions of service offered by the utility as determined through regulatory (or other) oversight of the utility's operations.

[11] Knowledge of the topology of the distribution grid could further enhance the effectiveness of information from a network of monitors.

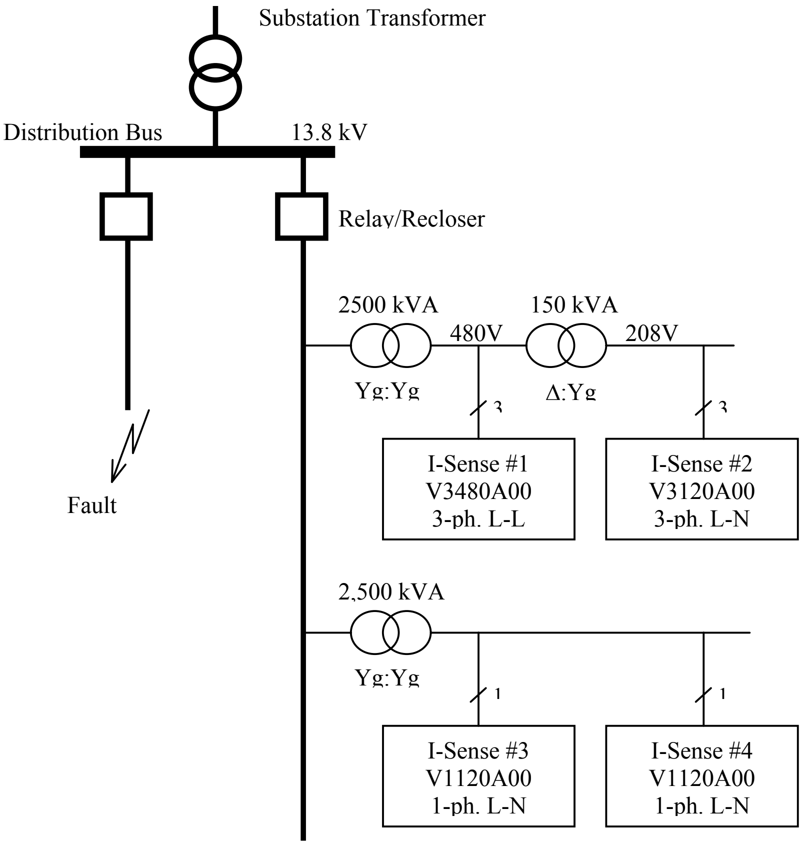
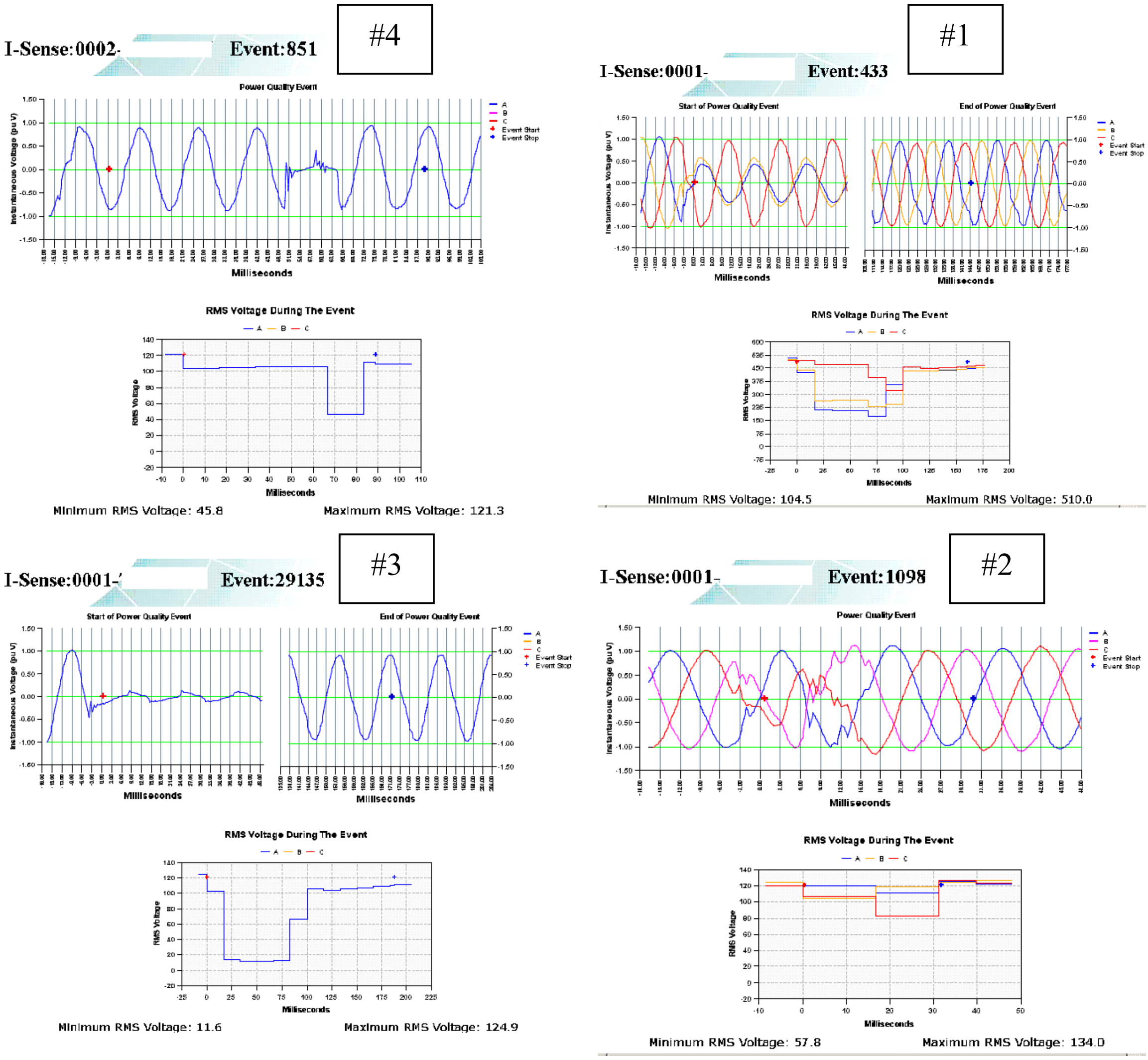


Figure 4. Single-line Drawing for Case #2

Waveforms from this event show that commercially available voltage sag mitigation equipment would have protected customer equipment from this event in all four monitored locations.



I-Sense:0002- Event:851

Minimum RMS Voltage: 45.8 Maximum RMS Voltage: 121.3

I-Sense:0001- Event:433

Minimum RMS Voltage: 104.5 Maximum RMS Voltage: 510.0

I-Sense:0001-' Event:29135

Minimum RMS Voltage: 11.6 Maximum RMS Voltage: 124.9

I-Sense:0001- Event:1098

Minimum RMS Voltage: 57.8 Maximum RMS Voltage: 134.0

Figure 5. CASE #2 Event Detail Pages

Case 3: Documenting the High Reliability of a Meshed Utility Distribution Grid

Background

One approach to solving power quality problems on a grid-wide basis is to build a highly meshed rather than a traditional, radial distribution grid. A highly meshed grid with fast transfer switching and advanced communications means that any equipment that meets SEMI F47-0200 (SEMI, 2000) voltage sag susceptibility requirements should (almost) never experience a power-related interruption. Although highly meshed grids almost never experience outages, they can experience more frequent voltage sags than radial grids.

Seven utilities are participating in DV2010, a program that is examining the use of meshed grids, among other alternatives, to deliver high-reliability power and will require many end users to install power quality solutions to "ride through" voltage sags.[12]

Description

Two single-phase I-Sense monitors were installed five miles apart in the service territory of one of the participating investor-owned utilities in the Midwest. The two monitors recorded power quality events at the same time on several occasions, providing strong evidence that the events were propagated on the distribution grid.

The example shown in Figures 6 and 7 are typical of the meshed grid's five-cycle fault-clearing capability, which permits equipment meeting SEMI F47 requirements to ride through the events.

Discussion

The waveforms during these events are typical of faults on very high-reliability (typically highly meshed) distribution grids. This example demonstrates the grid's capability to limit the severity of a voltage sag and permit equipment that meets voltage sag susceptibility requirements to ride through an event. This case study indicates that there could be a standard approach to distribution grid architecture that, coupled with mitigation/process equipment specifications, would almost completely eliminate the economic impact of power quality and reliability events.

A. Tabular Event Log

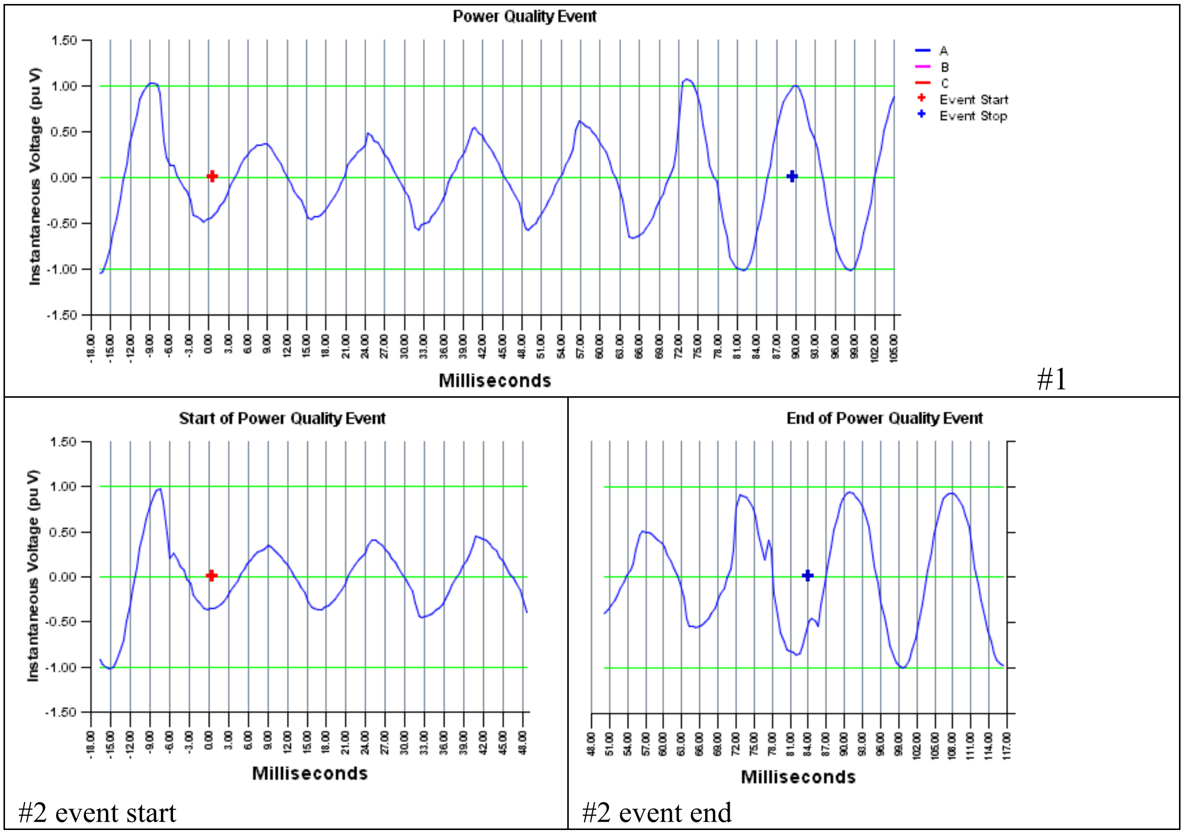
Monitor	event#	Date	Time	classification	Duration	depth
#1	588	6/1/2002	07:39:15.774 PM	Instantaneous Sag	5.3 Cycles	40%
#2	2236	6/1/2002	07:39:16.665 PM	Instantaneous Sag	6 Cycles	34%

B. Voltage Waveforms

In this example, the voltage waveforms captured by the two monitors are very similar in shape. (The time scales in the plots shown here are identical.)

---

[12] The participating companies include (as of August 2002): AEP/EmTech LLC, Alliant Energy, Ameren, BC Hydro, OG&E Electric Services, Public Service Electric and Gas, and WE Energies.



Power Quality Event

#1

Start of Power Quality Event

#2 event start

End of Power Quality Event

#2 event end

Figure 6. Case 3 Voltage Waveforms

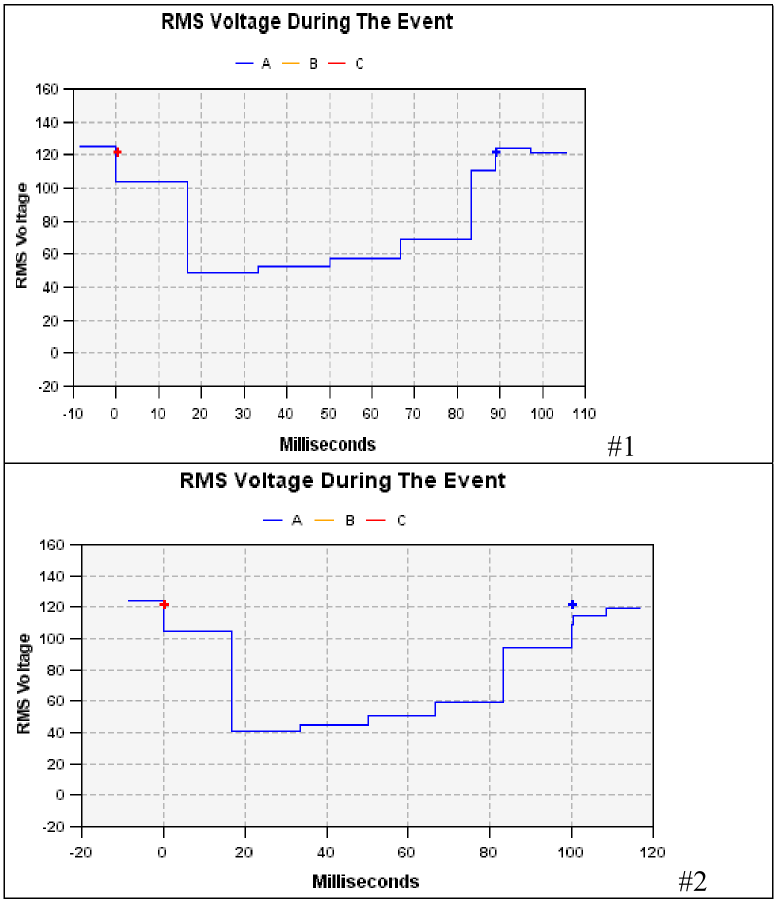


Figure 7. Case 3 RMS Voltage Profiles

Case 4: Severe Weather Can Cause Localized Outages and Grid-Wide Power Quality Problems

Background

Most electricity customers are familiar with the correlation between severe weather and sustained interruptions of power. Customers without power quality monitoring equipment may, however, be unaware that such severe weather can also cause short-duration voltage sags that are sufficient to shut down sensitive processes even if there is no discernible loss of power.

Description

A lightning and dust storm in a southwest city caused power lines to go down. Part of the city was without electricity for a few hours.

I-Sense monitors in two locations recorded five separate voltage sags (but not interruptions or outages) during this event. Some were detected at only one location; others were detected simultaneously at both locations. This pattern indicates that each of the five faults (the root causes of the voltage sags) occurred in different locations on the grid.

One location, an electronics manufacturer, has two three-phase line-to-line monitors installed; one records raw grid voltage (INPUT), and the other records the OUTPUT of a voltage sag corrector. The sensitive production equipment that was protected by the voltage sag corrector rode through these voltage sag events, but unprotected process equipment shut down.

One of the events, a 13.3-cycle voltage sag (see Table below), caused several large semiconductor/electronics manufacturers to lose an entire shift of production.

Discussion

This case study demonstrates the unavoidable nature and geographic scope of severe power quality events. Here, localized weather-related faults caused wide-ranging voltage sags. The data also clearly show that the disturbance that disrupted production at all of the manufacturing sites involved would not have been readily perceived by human senses; specialized instruments like the power monitoring sensors in use were needed to detect the events. Without such instrumentation, it would be difficult to correlate the manufacturing downtime with a power quality event.

Because manufacturing processes can involve numerous machines, controllers, and support equipment such as pumps for water and air, all linked in a complex sequence of functions and activities, even a short interruption can mean hours of time will be necessary to reset and restart the process.

On the surface, power quality solutions needed to ride through a subtle disturbance like the one described in this case study (in contrast to an extended outage) are much lower in cost than a system that relies on substantial energy storage. However, more information is needed on the frequency, nature, and impacts of poor power quality on their operations so that manufacturers can fully assess the tradeoffs among various power quality solutions.

Tabular event data (3 monitor locations):

Event ID	**Local TIME**	**DURATION**	**MAGNITUDE**	**LOCATION**
3656	8:17:37 PM	**3.9 Cycles**	**82%**	DYSC INPUT
1788	8:17:37 PM	1 Cycles	88%	DYSC OUTPUT
3662	8:20:49 PM	**13.3 Cycles**	**40%**	DYSC INPUT
1793	8:20:51 PM	1.5 Cycles	76%	DYSC OUTPUT
35701	8:24:17 PM	4.9 Cycles	82%	OFFICE
35702	8:24:19 PM	8.8 Cycles	83%	OFFICE
3666	8:32:56 PM	**5.2 Cycles**	**63%**	DYSC INPUT
1798	8:32:56 PM	1.5 Cycles	82%	DYSC OUTPUT
35706	8:32:56 PM	5.3 Cycles	64%	OFFICE
3675	9:50:10 PM	**4.7 Cycles**	**68%**	DYSC INPUT
1804	9:50:10 PM	1.3 Cycles	83%	DYSC OUTPUT
35715	9:50:10 PM	3.9 Cycles	85%	OFFICE

Case 5: Benchmarking Power Quality Across Sites within a Region

Background

Statistics on power quality events at point of use are important from the customer's viewpoint. Tracking changes in power quality statistics can provide early indicators of equipment mis-operation or failure. Benchmarking among similar facilities can also make significant differences clear and lead to overall performance improvement.

Description

Power quality events with nearly identical time stamps were captured within the same region of Michigan at different facilities. Several power quality monitors were involved:

- Monitors #1 and #2 are located in the same manufacturing plant;
- Monitor #4 is in an office building in the same city; and
- Monitor #3 is in a manufacturing plant in a different area of the same region.

Statistics were compared at the three facilities during a one-month period. The table below reports information reported at nearly the exact same time. This example suggests that the source of the power quality problem originated from the utility distribution system, not from within any one of the four locations monitored. Waveforms are shown in Figure 8.

Monitor	Local Time	Event Type	Duration	Worst Case RMS Voltage
#1	6/15/2002 8:26:59	Instantaneous Sag	3.6 Cycles	81.4%
#2	6/15/2002 8:26:59	Instantaneous Sag	4 Cycles	81.5%
#3	6/15/2002 8:27:00	Instantaneous Sag	4.3 Cycles	58.3%
#4	6/15/2002 8:27:01	Instantaneous Sag	8.3 Cycles	82.5%

Discussion

This case study demonstrates that power quality events throughout a region can be correlated using the data collected by I-Sense monitors in combination with facility operators' data on process interruptions. Combining these data could permit assessment of the wide-scale economic impact of individual power quality events.[13]

Correlation of events throughout a region could justify large-scale power quality solutions or transmission infrastructure investments.

---

[13] Additional information on the topology of the distribution and transmission network would further enhance these analyses.

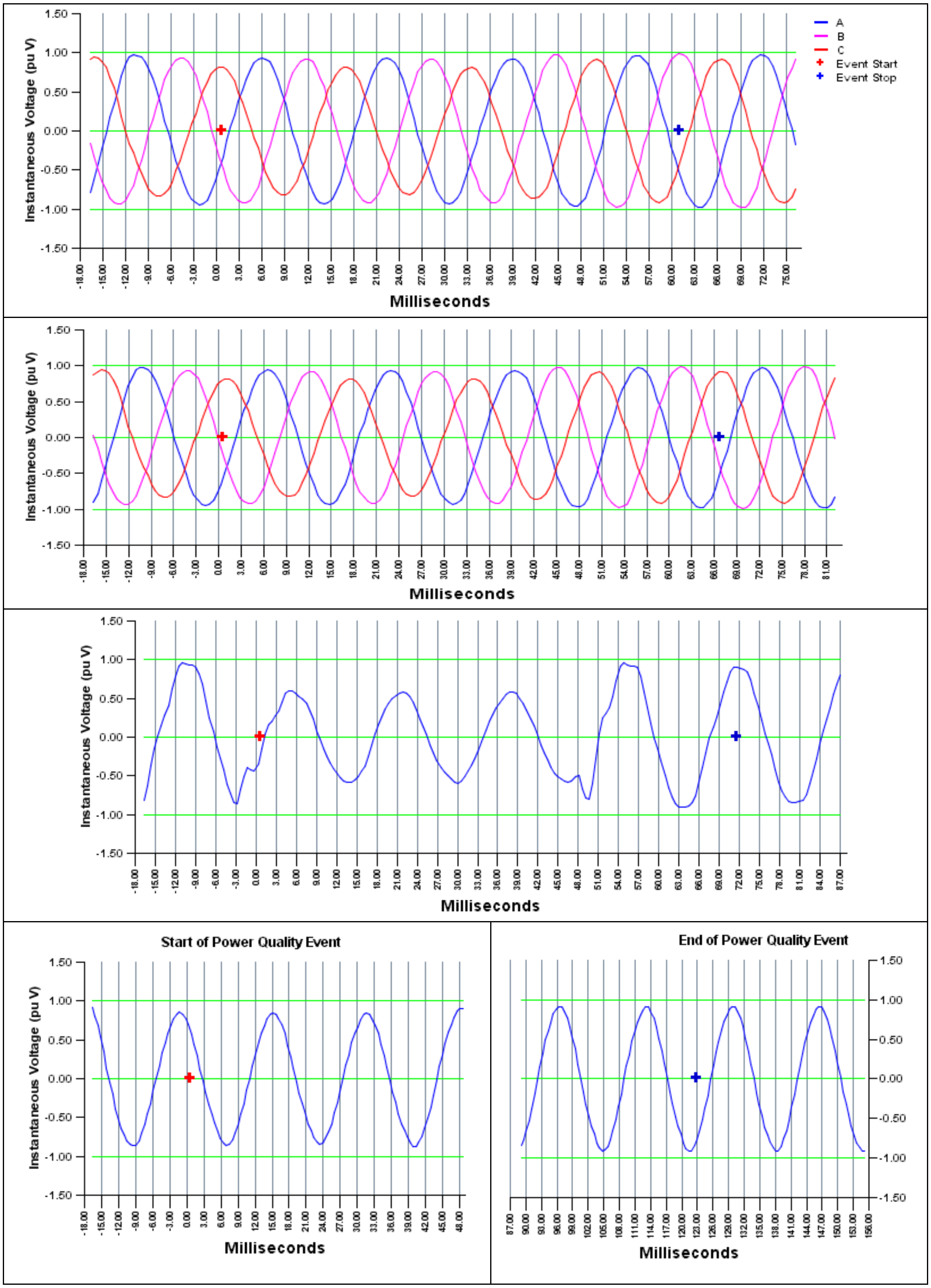


Figure 8. Case 5 Voltage Waveforms (top to bottom: monitor #1, 2, 3, 4)

Case 6: Benchmarking Power Quality Across Regions

Background

Better information on the nature, frequency, and impact of power quality and reliability on customers is needed to inform private and public decisions on appropriate measures to address these issues. Comparative information on benchmarking power quality across or within regions should be an essential input to these decisions.

Description

Several states have installed significant numbers of I-Sense monitors. In this case study, several monitors were located in both rural residential and industrial locations in Wisconsin, and all monitors in Michigan were in commercial or industrial locations. The data presented here were collected between May 1, and July 1, 2002.

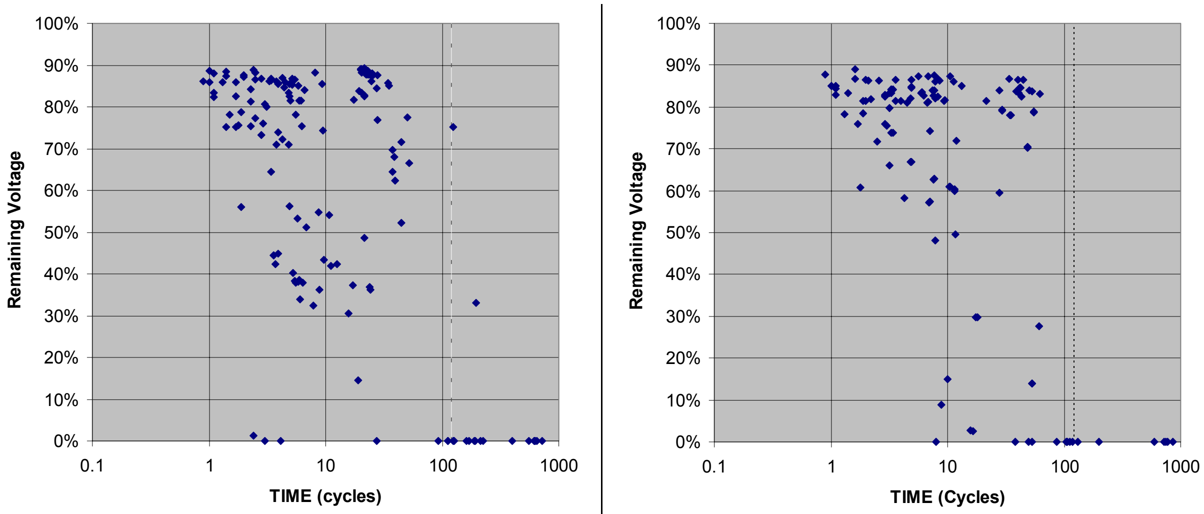
Discussion

With data from all I-Sense monitors residing in the common I-Grid database, the potential for statistical analysis is limited only by the number and density of deployed monitors and the completeness of the dataset. Figure 8 presents un-adjusted power quality data collected in each state plotted using magnitude vs. duration (MAG-DUR) charts. Each power quality event is represented by a single point. A simple statistical summary is also shown: the density of power quality events of varying severity is normalized to a per-monitor basis

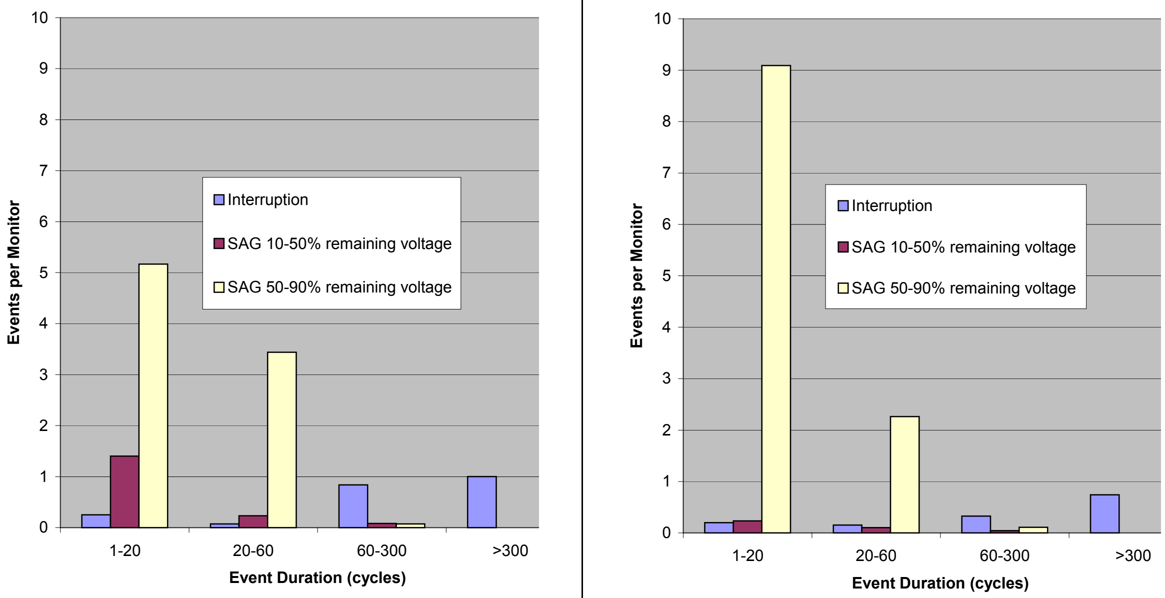
This example illustrates both the potential value of widespread data collection and the feasibility of use of the I-Grid approach for collecting these data. It also illustrates the importance of careful analysis and presentation to avoid misinterpretation. Power quality problems may be experienced across the distribution grid, or may be confined to—and originate in—a single facility. A large sample of monitored sites and observed events is needed to provide reliable information on regional power quality. Further, these data must be jointly analyzed in order to establish the source and extent of disturbances. The analysis must compare where and when power quality events are detected, as well as their severity.

It is important to note that this case study is intended only as an illustration. The results are not a statistically meaningful comparison of power quality between these two states. As noted, a number of statistical adjustments and enhancements would be required in order to support this type of analysis, including:

1. Normalization for number of monitors;
2. Separation by user type (industrial, commercial, or residential); and
3. Normalization for short-duration/season of monitoring period.



Wisconsin MAG-DUR (raw data) Michigan MAG-DUR (raw data)



Wisconsin normalized data Michigan normalized data

Figure 9. Comparison of Statewide I-Grid Data, for the Period of May 1 to July 1, 2002

4. Conclusion

This report describes a new approach for collecting information on power quality and reliability and making it available in the public domain. Making this information readily available is necessary for enabling informed private and public decisions regarding electricity reliability. The importance of national leadership on this issue is highlighted by increased public concerns over electricity reliability issues and increased vulnerability of a growing segment of the U.S. economy to power quality problems.

The system, called the I-Grid, consists of very low-cost monitoring devices ($300 each) and a web database and analysis capability that is separate from the devices and easy to use without specialized training. When a monitoring device detects a voltage sag, which is the most significant power quality problem, it time-stamps and precisely records the data; after voltage returns to normal, the device automatically dials up and uploads information on the event to a web server. Customers and others can then view and analyze the event on a secure website.

Six case studies were described that illustrate how the I-Grid is being used today and could be extended in the future to serve a variety of private and public interests related to the importance of electricity reliability and power quality. This report, along with a companion report examining specific impacts of power quality and reliability events on customers (Eto, Brumsickle, Divan 2003), has been prepared as input to planning discussions for activities to increase the availability of power quality and power reliability information in the public domain.

References

Eto, J., W. Brumsickle, and D. Divan. 2003. *Pilot Evaluation of Power Quality and Reliability Monitoring in California's Silicon Valley with the I-Grid System.* Forthcoming.

Electrotek, Inc. 1996. *An Assessment of Distribution System Power Quality; Volumes 1-3*. EPRI TR-106294-V1-3. Palo Alto, CA.

EPRI. 2003. *Power Quality and Energy Measurement System Independent Evaluation Center: Test Results of Five Power Quality Monitors.* EPRI, Palo Alto, CA: 2003. 1001651.
SEMI. 2000. *Standard SEMI F47-0200*, *Specification for Semiconductor Processing Equipment Voltage Sag Immunity.*

U.S. Department of Energy (DOE). 2002. *National Transmission Grid Study.* May. Washington, D.C.

Warren, C., D. Pearson, and M. Sheehan. 2003. "A Nationwide Survey of Recorded Information Used for Calculating Distribution Reliability Indices*."* *IEEE Trans. on Power Delivery*, vol. 18, no. 2, Apr. 2003, 0885-8977/03, IEEE.

Appendix A.

In mid-2002, EPRI PEAC Corporation conducted an independent evaluation of the I-Grid and I-Sense.[14] The evaluation consisted of 9 different tests including: three-interruptions, three-phase sags to 50% of nominal, three-phase sags to 80% of nominal, single-phase sags to 50% of nominal (on phase B), three-phase swells to 120% of nominal, combination events; simulated recloser operation, faulted feeder, simulated recloser operation, unfaulted feeder, and capacitor switching transient. According to report authors, "Overall, the I-Grid/I-Sense system performed very well. With few exceptions, the I-Sense unit captured all of the events that were imposed on it. By working with the manufacturer of the I-Sense unit, all of the discrepancies were addressed and have been resolved or will be resolved."

---

[14] EPRI. 2003. *Power Quality and Energy Measurement System Independent Evaluation Center: Test Results of Five Power Quality Monitors.*