Assessing I-Grid™ Web-Based Monitoring for Power Quality and Reliability Benchmarking

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Introduction

It has been said that the U.S. electricity system is among the most reliable in the world. Yet, there is no comprehensive body of information that would allow one to make such a comparison authoritatively. Data collected by utilities on the actual reliability of service is neither collected consistently, nor readily available to make these comparisons. Worse, information on a key aspect of electricity reliability when viewed from the customer's point of view, power quality, is rarely collected at all [Warren, Pearson, Sheehan 2002].

The I-Grid power quality and reliability monitoring system provides a cost effective way to benchmark power quality and reliability on a regional and nation-wide basis [Divan, Brumsickle 2002]. A pilot program, sponsored by the DOE and in collaboration with SoftSwitching Technologies and the Silicon Valley Manufacturers Group, was begun in mid-2002 to assess the I-Grid concept. The program results will form the basis for planning a national power quality and reliability benchmarking effort, in collaboration with DOE and industry stakeholders.

This paper presents preliminary findings from DOE's pilot program. The results show how a web-based monitoring system can form the basis for aggregation of data and correlation and benchmarking across broad geographical lines. A longer report describes additional findings from the pilot, including impacts of power quality and reliability on customer's operations [Divan, Brumsickle, Eto 2003].

Description of the I-Grid Power Quality and Reliability Monitoring System

The I-Grid system, developed by SoftSwitching Technologies,[1] 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 10-minute min/max and average rms voltages and data on grid events,

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

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.[2]

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. In addition, web-based forms capture customer observations on the cause of the event, if known, and the effect of the event on company processes, including cost of downtime, if known.

SoftSwitching's power monitors significantly lower the cost of network connection and communication to $200-300 per device and offer targeted, highly specific functionality.[3] 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 methodologies by replacing monitor-centric thinking with a system-centric approach, providing access to real-time as well as historical data on site-specific power quality and reliability, as well as the ability to correlate events recorded at geographically dispersed locations. More importantly, the low cost per node means that broad-based deployment of monitoring across the 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.

Description of DOE Silicon Valley Pilot Project

SoftSwitching Technologies and the U.S. DOE's Lawrence Berkeley National Laboratory, in conjunction with the Silicon Valley Manufacturer's Group (SVMG), initiated a pilot project for the I-Grid in 2002. The purpose of the pilot was to:

- Demonstrate the correlation of power quality events with process downtime occurrences;
- Develop, at a proof-of-concept level, several types of advanced data analysis utilizing the array of event data the I-Grid will make available;
- Field test the Beta I-Grid system;
- Provide the basis for a more extensive follow-up project.

Recruitment of participants was facilitated by the SVMG. Participants were asked to install and register a small number of I-Sense monitors at an appropriate site within their facilities.

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[2] EPRI-PEAC has recently completed a comprehensive test report sponsored by EPRI confirming the accuracy of the power quality information collected by I-Sense monitors. [EPRI 2003].

[3] 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. From a network perspective, the voltage is the relevant and unifying parameter. Current is typically associated with individual points of consumption but does provide fault magnitude and directionality information, when available.

Typically, service delivery points and panels serving sensitive loads were selected. Participants were also asked to respond to notifications of power quality events by completing an on-line form regarding downtime occurrences coincident with the event (note that all process-related information will be purged of company identity). In return, participates received email notification of events after they were recorded, and access to the I-Grid website for additional diagnostic information on the events.

Seven firms/institutions agreed to participate in the pilot and installed a total of 30 I-Sense monitors. Figure 1 shows the approximate locations of the monitoring sites.

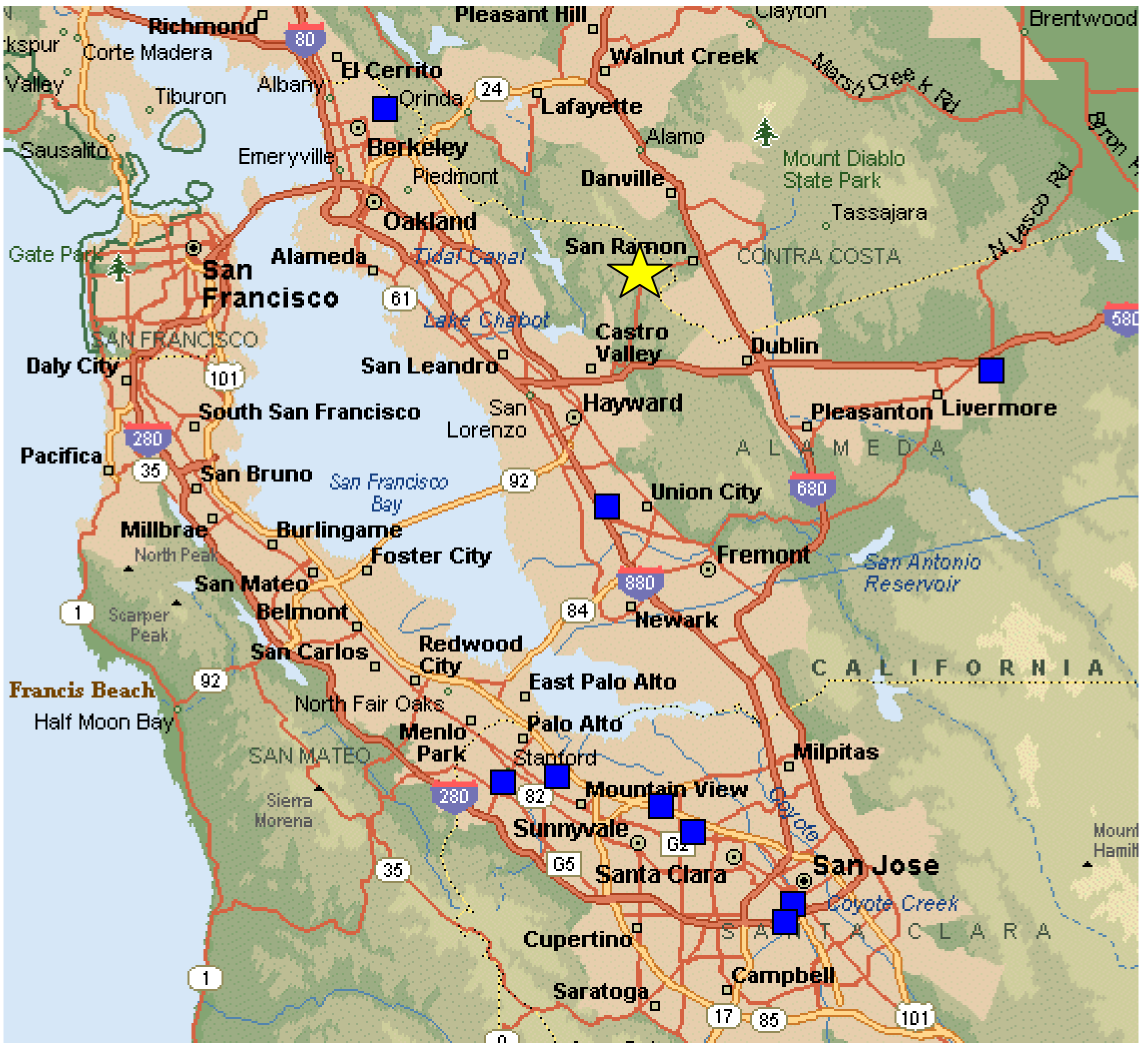

Figure 1. DOE Silicon Valley area pilot study monitor locations (blue boxes). Feb. 2, 2003 earthquake epicenter (yellow star).

Review and Analysis of Power Quality and Reliability Events Recorded

The first participant monitors were installed in late May 2002. Figure 2 shows a summary of the PQ events recorded up to mid-April, 2003. In all, 478 voltage sag events and 56 interruptions were recorded.[4] No voltage swells were recorded in this period.

It is notable that voltage sags with more than 50% remaining voltage predominate and that all but two of the voltage sag events were less than 2.0 seconds (120 cycles) in duration.

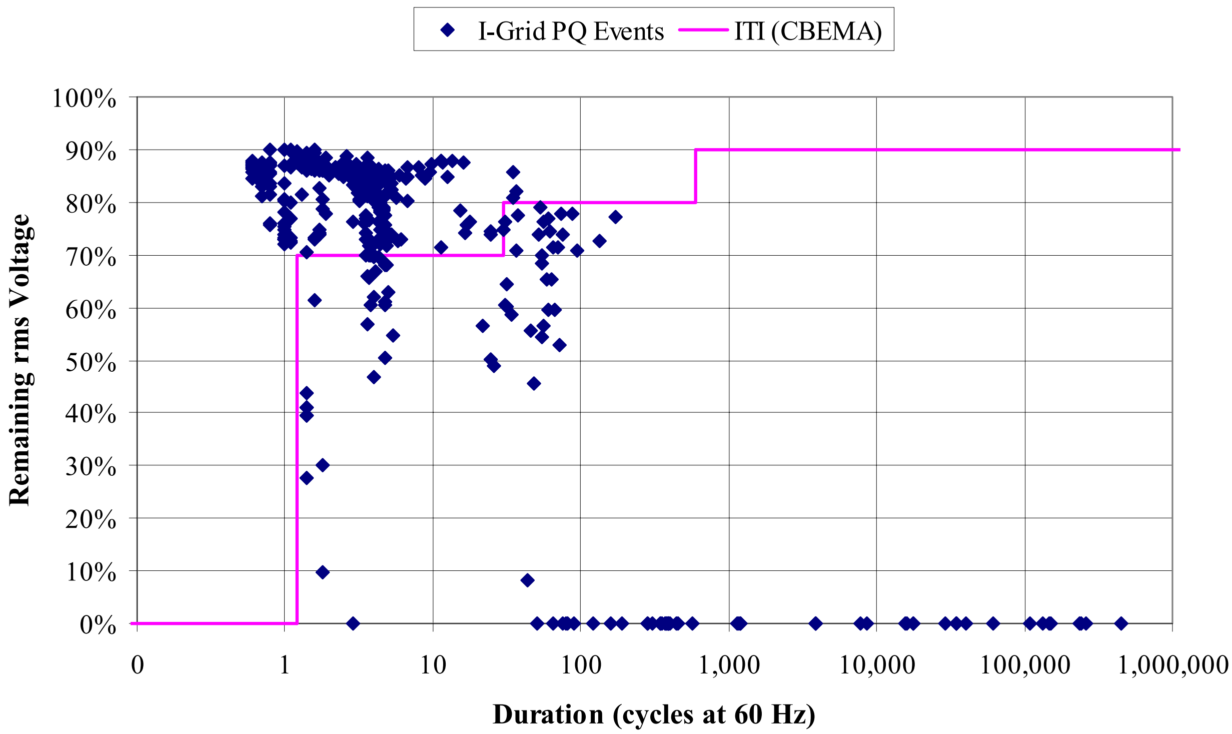

Figure 2. Magnitude-Duration summary of all significant Silicon Valley events, 5/23/02 to 4/24/03

To maintain the anonymity of participants, the participant companies and institutions are numbered Firm 1 through Firm 7 in the discussion below. Further description of the monitor locations is provided in the project report [Divan, Brumsickle, Eto 2003].

Several recorded event case studies are discussed in the remainder of this section.

[4] It is believed that the recorded interruptions (i.e., the points along the x-axis indicating 0 voltage) include a small number of cases where the monitor was purposely disconnected or a scheduled interruption of internal facility power occurred. To the extent possible, these events will be removed from the data set after completion of participant interviews.

July 1, 2002 Car-Pole event near Firm 1

Firm 1 installed six I-Sense monitors at one manufacturing site. The plant electrical loads are approximately evenly divided between two utility transformers and these transformers connect to separate utility distribution "blocks." Three monitors were installed on each bus within the plant.

On July 1, 2002, the three monitors on bus "Block 2" reported a 9.6 minute interruption event (outage) at 10:54 a.m. The three monitors on bus "Block 1" did not report an event. No other I-Sense monitors in the SV area reported events at this time.

In a subsequent interview, the facilities manager stated that a car had hit a utility pole near the site and that the utility line crew were forced to de-energize the line to extricate the car. The distribution bus "Block 1" was not affected.

This is a clear example of an externally caused event that affected only the local distribution system. Firm 1 has not provided a cost estimate for the process interruption caused by this event, but has reported that the restart time for some manufacturing processes can be three days and that the plant revenue is approximately $500,000 per day at full operation.

October 19, 2002 Short voltage sag event at Firm 1

On October 19, 2002, all six monitors at Firm 1 reported a short duration voltage sag at 8:27 a.m. Event voltage waveforms from two monitors on buses Block 1 and Block 2 are shown in Figure 3 on the next page. The nearly identical waveform signatures, together with the knowledge that the plant buses are not inter-tied, indicates that this event was externally caused and was propagated on the distribution grid. No other I-Sense monitors in the SV area reported events at this time, which further suggests that the root cause occurred on the distribution or sub-transmission grid, not on the transmission grid.

Firm 1 has not reported a process interruption associated with this event.

Figure 3a: 10/19/02 event voltage waveform, Block 1 (event 50182). 480V L-L monitor.

Figure 3b: 10/19/02 event voltage waveform, Block 2 (event 1632). 480V L-L monitor.

November 7, 2002 Region-wide wind storms

A major windstorm swept through California on November 7, 2002. Voltage sags were reported by monitors across the Silicon Valley area. The chart below summarizes one widespread event recorded at 11:41:28 p.m. by twelve different monitors.

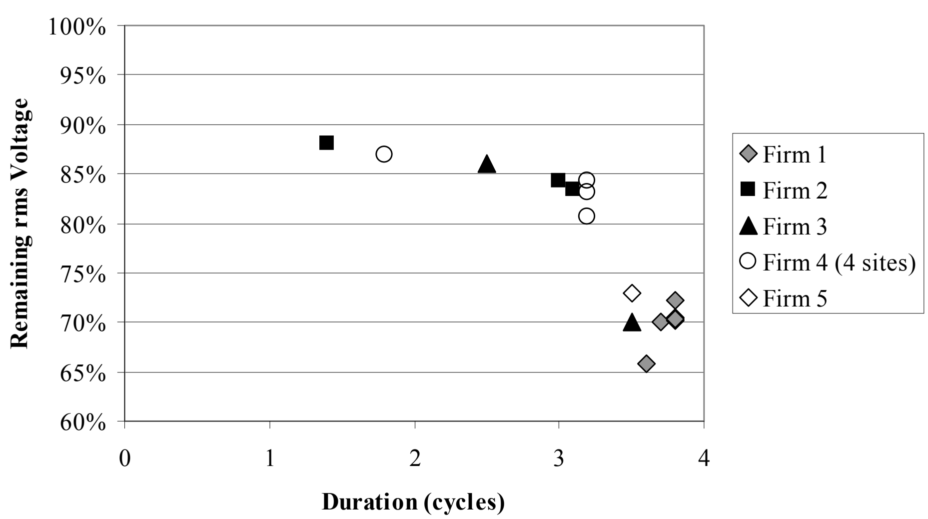

Figure 4. Summary of voltage sag event reported by 12 monitors, Nov. 7, 2002, 11:41:28 p.m.

Example rms voltage profiles captured at each location are shown in the figure below.

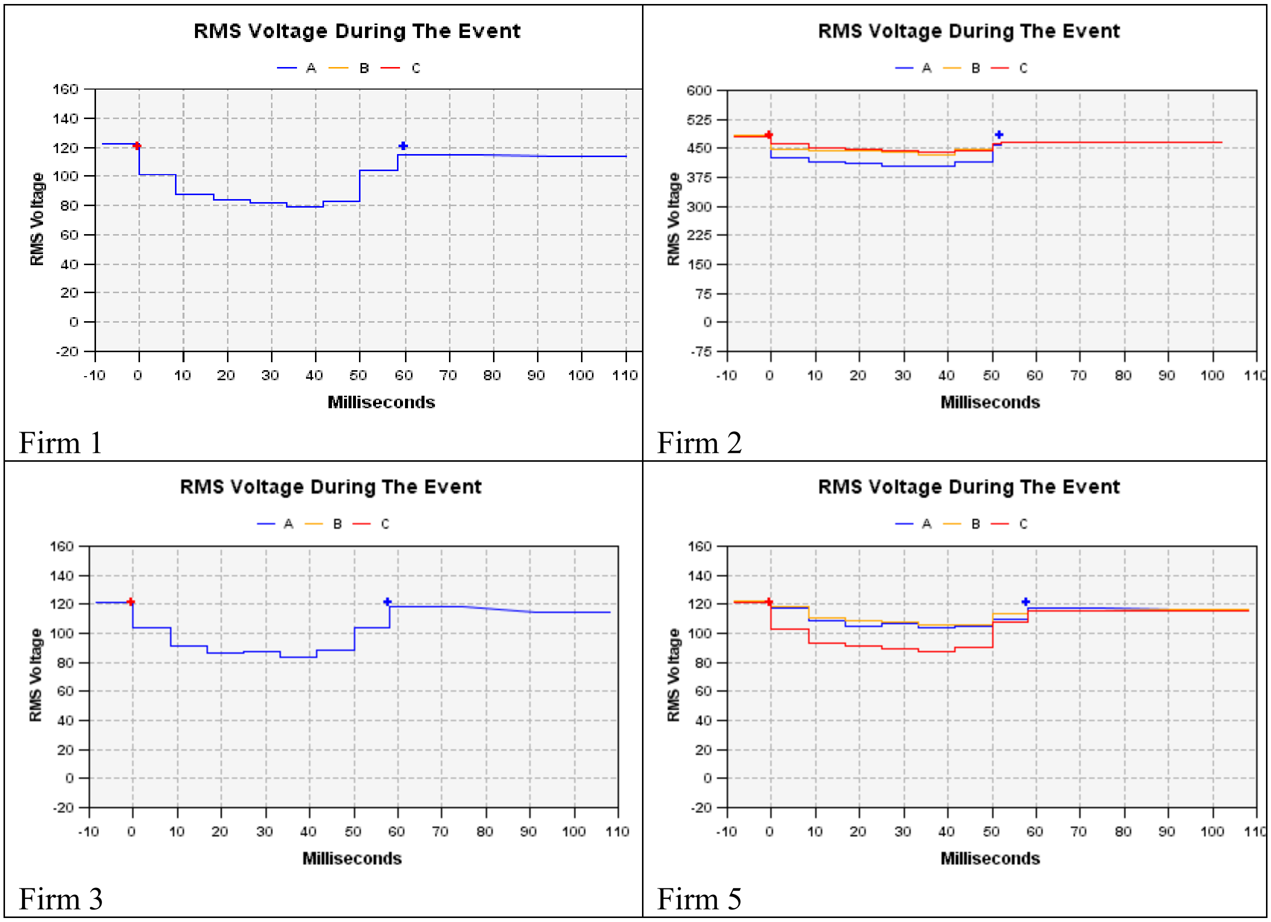

Figure 5. 11/7/02 example event rms voltage profiles

This event was felt across the Silicon Valley region, at all monitored locations, except one. A likely conclusion is that a weather-related transmission-level fault caused the voltage sag event.

December 27, 2002 campus distribution transformer failure

Firm 3 installed single-phase I-Sense monitors in two separate building on a single campus. On the evening of December 27, 2002, one of the two monitors reported a 1 minute interruption followed 22 minutes later by a 67 minute interruption. In a subsequent interview, the site facilities manager reported that a distribution transformer (owned by Firm 3) had failed at that time. At least one campus building was without power for several days until a replacement transformer could be located.

Firm 3 is served directly at 115kV. No other monitors in the area recorded significant events around the same time period. This case demonstrates an internally-caused power quality event that did not affect the regional power grid.

January 23, 2003, airplane hit 500kV transmission line.

A Cessna Cirrus SR20 crashed in the Evergreen Foothills northeast of San Jose on January 23, 2003. NTSB officials said the airplane dropped from radar around 5 p.m. PG&E said the plane hit the 500 kV transmission line that feeds the San Jose area. PG&E reported that the plane damaged seven spans of wire and destroyed five or six cross-arms but did not cause any power outages.

At 4:53 p.m., all four three-phase monitors at Firm 1 recorded a 3-cycle duration voltage sag to 80-84% remaining rms voltage. One of two single-phase monitors at Firm 3 and a monitor at Firm 4 recorded similar voltage sags with the same timestamp. Less than one second later, both monitors at Firm 3 reported interruptions: one monitor saw a 1.0 minute interruption while the other saw a 42 minute interruption. No other monitors in this study recorded an interruption or further voltage sags. Six minutes after the time that the 42 minute interruption ended, the other Firm 3 monitor (which had earlier seen only a 1 minute interruption) reported a 2 cycle interruption.

Firm 3 has cogeneration in place that provides 80-85% of campus power requirements during on-peak hours. In this case, a relatively insignificant transmission-level PQ event may have been exacerbated at Firm 3 by local switching practices associated with the distributed generation.

February 2, 2003 Earthquake

An earthquake, followed by multiple aftershocks struck the SV region on February 2, 2003. The quake epicenter was 5 km SE of San Ramon, California. The USGS classified shaking as "severe" throughout the area of this study.[5] Two separate PQ events, 15 seconds apart, were detected at 5:19 p.m. by 14 monitors in the SV study area, as well as by other I-Sense monitors in South San Francisco and 70 km (45 miles) east of Livermore in the California Central Valley. The two figures below show three phase monitor data from two sites approximately 20 km (13 miles) apart in the western SV area. Apparently, a single-line voltage sag was propagated on the transmission network. Of the monitors that did not record these two events, all were single-phase monitors that may be connected to a phase voltage that was not affected by the events.

The actual cause of the transmission-level PQ events is not known to the authors; the coincidence of the events with the earthquakes is suggestive of a correlation.

[5] Source: http://quake.usgs.gov

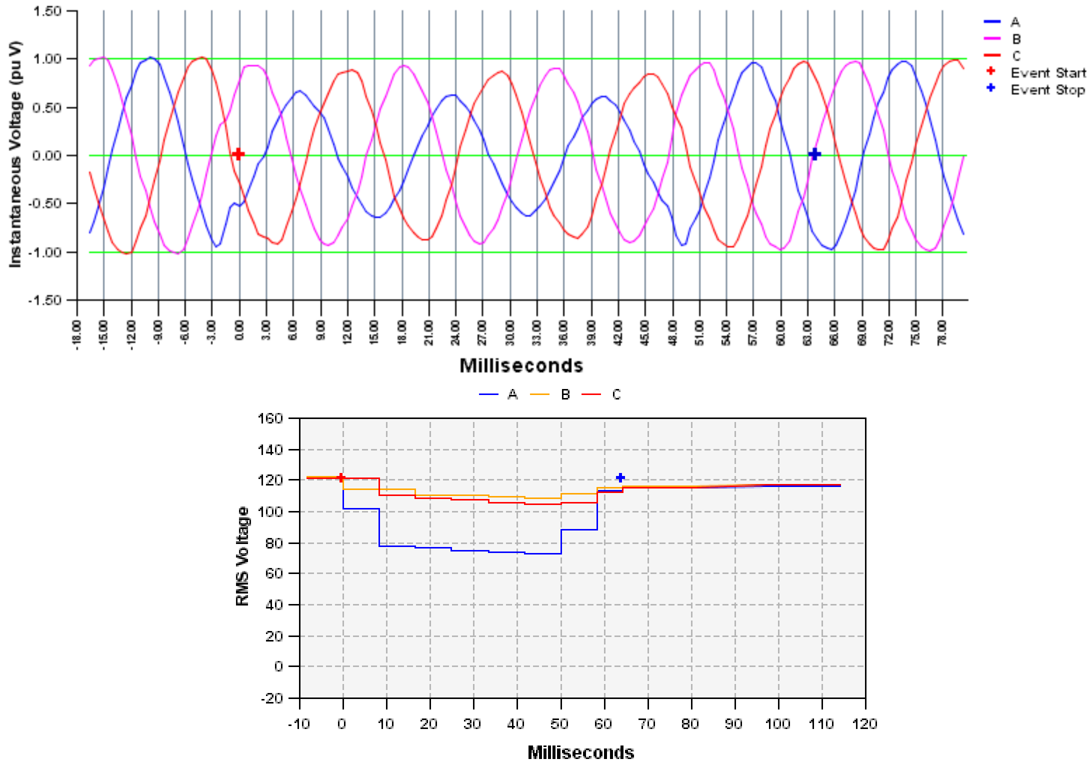

Figure 6a: 120 volt L-N monitor

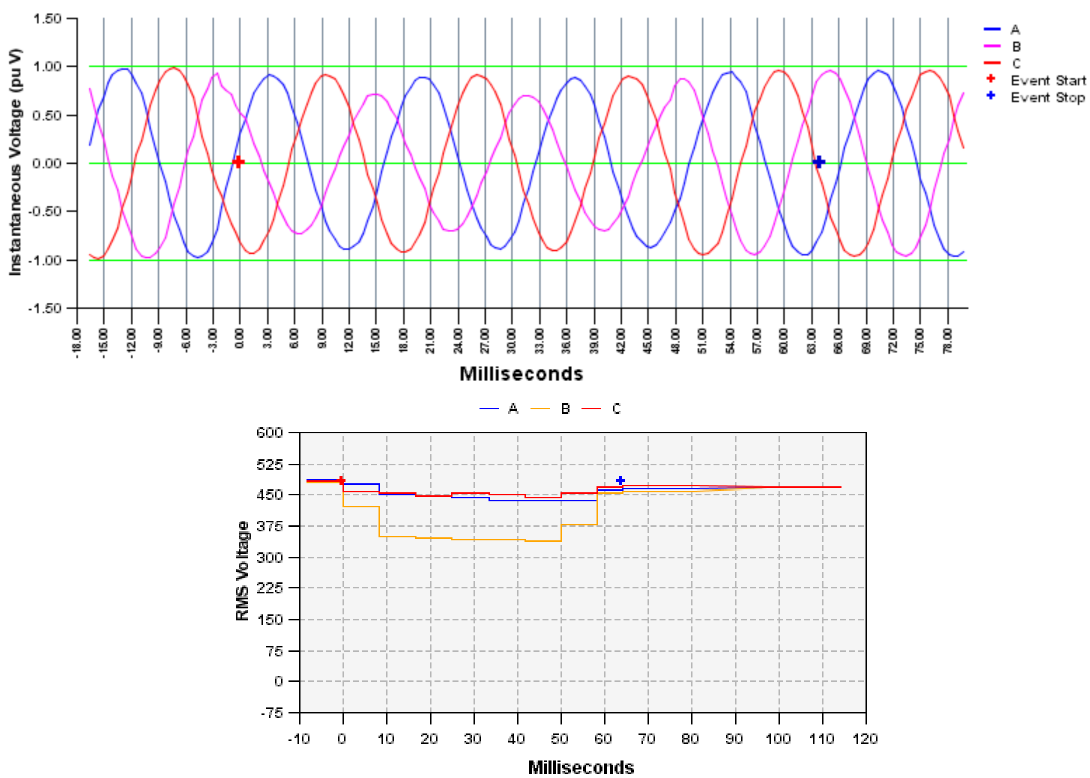

Figure 6b: 480 volt L-L monitor

Conclusions

This paper has described a new approach for collecting information on power quality and reliability. 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 according to EPRI 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.

Preliminary results from a pilot evaluation of the I-Grid system conducted in the Silicon Valley 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. The full report from this study [Divan, Brumsickle, Eto 2003] will be used to assist in planning for a living, national public domain database of power quality and power reliability information to better inform public and private decision-making on reliability policy and investments.

Acknowledgments

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