The Economic Value Of Electricity Reliability And Power Quality

Joseph Eto, Lawrence Berkeley National Laboratory[1]
Deepak Divan and William Brumsickle, Softswitching Technologies

Public interest in electricity reliability is at an all time high. Underlying these interests is a growing recognition of the critical role that electricity reliability plays in our daily lives and in our nation's economic health. Clearly, a key consideration in discussions of what can and should be done to ensure reliability ought to be the value we place as a society on reliability. In reviewing what is currently available, however, we find that data on the reliability of electric service and, more importantly, on its impacts on consumers and businesses are neither collected consistently, nor readily available to make these assessments. Information on a key aspect of electricity reliability when viewed from the customer's point of view, power quality, is rarely collected at all. We submit that a better understanding these costs should figure prominently in assessing alternatives for the future organization, regulation, and management of the electricity industry. This paper presents interim findings from a recent DOE-sponsored project that is intended to improve the quantity, quality, and availability of public information on the economic significance of electricity reliability and power quality.

Silicon Valley Manufacturers Group Pilot Demonstration Of I-Grid

The project was conducted in collaboration with the Silicon Valley Manufacturers Group (Eto, Divan, Brumsickle 2003). The overall objective is to assess a web-based electricity reliability and power quality monitoring system that is based on deployment of a small network of sensors deployed within geographic region, called I-Grid (Divan, Brumsickle, Eto 2003). The I-Grid consists of a network of low-cost monitoring devices and a web database and analysis capability that is 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. Customers and others can then view and analyze the event on a secure website.

Our pilot study involved installing 22 monitors at seven customer sites throughout the southern portion of the San Francisco bay area (known as "Silicon Valley" because of the large number of high-technology firms there). Data were collected from June 2002 through July 2003. We field-tested the capabilities of the I-Grid system, including its ability to detect grid-level events through a network of sensors deployed at individual customer sites. In this paper, we report findings from a secondary objective, which is to better understand the impacts of power quality and reliability on customers. The findings were developed through interviews with pilot program participants.

The interviewees were generally lead staff members from the facilities departments of each firm. One participating firm has outsourced its management of utility services, including treatment of reliability and power-quality issues, so we were granted permission to interview the third-party firm handling these services. Another participating firm provides power-quality consulting services; we interviewed the president of this firm. Another firm sells electrical supplies, including power-quality mitigation products; we interviewed the principal sales engineer for these products.

Participants granted interviews based on the understanding that their responses would be confidential. To respect this agreement and to assemble the information we gathered in a coherent presentation, we identified several thematic issues addressed in the interviews and organize our findings around these topics:

- The economic cost of power-quality and electricity-reliability problems
- Perceptions regarding electricity reliability and power quality, including utility relations
- Steps taken to address power-quality and electricity-reliability issues, including paybacks on investments
- Barriers to implementing solutions to electricity-reliability and power-quality problems

1 jheto@lbl.gov

The Economic Cost Of Electricity-Reliability And Power-Quality Problems

The participants in the pilot study generally place a very high premium on ensuring power quality and electricity reliability. Their participation in this pilot is a direct reflection of their business interest in this topic. Therefore, it was no surprise that they were readily able place a quantitative value on these aspects of electricity service. The quantitative values given by our study participants are shown in Table 1. We believe that this level of understanding is likely to be limited to sophisticated electricity users such as those who participated in our project.

The first key observation is that, from the customer's point of view, the costs associated with an electricity-reliability or power-quality event depend more on the manufacturing or process downtime that results from an event, not necessarily on the duration of the event. That is, when asked about the value or economic costs of electricity reliability and power quality, the interviewees generally responded with cost information linked to downtime, not the duration of the event. One participant observed that "Customers do not make distinctions about the causes of machine downtime; all they know is that their machinery has stopped functioning. We also believe this sentiment results, at least in part, from that participant having had relatively rare experiences with extended outages (events lasting more than a few minutes) and relatively frequent experiences with power-quality events and short-duration interruptions (events lasting a few minutes or less).

Table 1. The Economic Costs of Electricity Reliability and Power Quality

Business Type	Event Description	Economic Cost ($)
Manufacturer of silicon-chip fabrication equipment	Voltage sags and short-duration voltage interruptions	$350,000 per event
Silicon-chip fabrication	Even an outage of a few minutes can lead to 1-1.5 days of downtime	Up to $500,000 per day in lost revenue
Automotive manufacturing	From a few seconds to one half-hour of downtime	Less than $1,000,000
	More than 1 hour of downtime	In the millions
Financial clearinghouse	30 minutes of downtime because of a lightning strike	$12,000,000

Several participants offered supporting information to help place the monetary values in perspective. For example, one offered valuable insight on the often-cited statistic that an outage costs silicon-chip fabricators $1 million per event. He said that this value depends largely on whether the chips have already been sold and the plant is currently operating at full capacity. The determining factor is whether the downtime results in the firm missing a deadline for delivery of chips that have already been sold. He pointed out that, in 2003, many firms were running at less than full capacity. Under these conditions, lost production from an outage could be made up through overtime (which is not possible when a plant is running at full capacity) and that the costs of materials lost as a result of the outage were minimal in comparison to the financial penalties that would be associated with missing shipping delivery dates. The chip fabricator participating in our study reported that outages of even a few minutes could sometimes lead to 1 to 1.5 days of downtime, causing the firm to forego $500,000 per day in revenues.

Traditionally, business-cycle issues such as those noted by this participant are not well-accounted for in studies of reliability costs. A related example was provided by the manufacturer of silicon-chip fabrication equipment. As a final step before delivery of a new piece of fabrication equipment to a customer, the manufacturer must conduct a continuous, 1,000-hour factory test, which takes about six weeks. Any interruption during this period requires restarting the entire test from the beginning. The cost of an interruption during this period is, consequently, much greater for this firm than the cost when a new piece of equipment is not undergoing factory testing. This firm reported that it had recently made a $2.5-million investment in equipment to improve electricity reliability that paid for itself in nine months, which translates into an implied cost per outage of $350,000 per event. (We discuss the high returns on electricity-reliability and power-quality technology investments in the subsection below on steps taken to address reliability and power-quality issues.)

The monetary penalties for missing deliveries are especially high in the financial services industry. For these firms, "missed" deliveries refer to financial transactions that cannot be executed. Financial clearinghouses, for example, provide written guarantees for maximum allowable downtimes in the contracts they sign with their customers (e.g., banks that offer credit cards). Stringent financial penalties, based in part on the value of foregone or inaccurate transactions, result from exceeding pre-specified limits. As a measure of the great value placed on reliability by this type of firm, we were told that: "These customers never ask how much it's going to cost to fix the problem; they only want to know how quickly the solution can be implemented." We were told of a financial clearinghouse in Texas that had experienced a $12-million loss as the result of a 30-minute outage caused by a lightning strike.

We also heard that the costs of downtime have been growing over time for participants. One participant reported that "Problems that used to cost $2-300,000 per event now cost in the millions per event." We explore some of the reasons for this increase in vulnerability to reliability and power-quality problems in the next subsection.

Perceptions Of Power Quality And Electricity Reliability, Including Utility Relations

Customer awareness of electricity-reliability and power-quality problems and understanding of the root causes of these problems are critical factors in evaluating the actions that customers have and have not taken to address these problems.

Among the individuals we interviewed, awareness of electricity-reliability and power-quality issues is fairly high. Many had received professional training on the subject.
However, it is important to recognize that awareness of power-quality issues, in particular, is not widespread. To be aware of the problem, a customer must have equipment that is sensitive to power-quality problems, and this sensitivity must have a material effect on operations. One participant indicated that he was not specifically aware of power quality as an issue in operations at his firm mainly because the firm does not have much susceptible equipment, and, more importantly, because he has not received complaints that could be traced to power-quality problems.

Power-quality problems manifest, as noted earlier, in faulty operation of equipment; however, power-quality problems are only one possible cause of equipment malfunction and are also difficult to observe, so it is not a simple matter for a customer to definitively determine that a power-quality event has caused an equipment problem. One participant in our study said that his primary clue that a power-quality event was to blame for equipment problems was the simultaneous failure of multiple pieces of equipment. His participation in the pilot study was motivated by the desire to confirm when power-quality issues are the sources of manufacturing problems. He noted that regular maintenance of equipment (to avoid downtime) was currently a bigger issue for his firm than power quality (in part because power-quality solutions had already been incorporated in the most critical of his company's processes). Another participant indicated that a key measure of the success of his firm's training programs is whether students can correctly identify power-quality problems (versus software problems) as the cause of an equipment fault.

Interestingly, the emergence of industry standards, such as SEMI F47 (for semiconductor manufacturers) and ITI/CBEMA (for office PCs), may have indirectly contributed to reducing awareness of the possibility that power-quality problems may affect operations. That is, some argue that specifying equipment that is in compliance with these standards means that power-quality problems have been adequately addressed. In fact, both standards only articulate thresholds above which equipment is expected ride through power disturbances; disturbances below these thresholds will still cause faulty operation or failure of equipment.

Understanding of the root causes of electricity-reliability and power-quality problems was mixed among our study participants. Some view "power quality" as an "internal" problem on the customer side of the meter and "reliability" as an "external" problem on the utility side of the meter. Yet in reality, power-quality problems may emerge from actions arising on either side of the meter.

More than one participant perceived the majority of power-quality problems to result from improper or poor grounding practices, which is an internal problem; one participant stated that up to 95 percent of all power-quality problems could be attributed to grounding problems within a customer's premises. Participants suggested that proper grounding practices, as prescribed by the National Electric Code in part to prevent power-quality problems, are often not implemented. Renovation and expansion of existing facilities were noted as frequently leading to grounding problems and thus to power-quality problems.

Other participants were aware that power-quality problems could emerge from actions and events on the utility side of the meter. Many had implemented power-quality solutions based on careful assessments of the frequency of power-quality events coming from the utility side of the meter. At least one large customer had worked successfully with his utility to change the schedule for a routine utility operation that regularly disrupted his plant's operations.

Participants' experiences with utility power-quality and reliability issues varied widely. We have already cited the experience of one participant who was not specifically aware of power-quality events significantly affecting his operations. Others had detailed recollections. Among industrial electricity consumers, we found the number of power-quality-related experiences were, by and large, correlated with the voltage at which each customer took service from the utility. On the low end, the one participant with service at transmission voltage recalled four to five voltage sags during the past five years or about one sag per year on average. On the high end, one participant with service at distribution voltage based his decision to invest in a power-quality solution on a desire to avoid an average of nine events per year based on data taken during three years.

Perceptions of utility responsiveness to power-quality problems were neutral to slightly positive. More than one participant noted that the utilities had made efforts to be responsive to power-quality concerns. As noted earlier, more than one participant cited their utility's willingness to modify its operations to eliminate recurring voltage sags that took place during a critical time for the customer's operations. It is important to bear in mind that several of the participants are very large electricity consumers, so it is not surprising that utility service representatives are very responsive to these customers.

Apparently, utilities in the recent past offered power-quality consulting services to customers. However, these efforts have been dropped as a result of changing corporate priorities at utilities and customers' preferences for third-party assistance in identifying and addressing power-quality problems.

Steps taken to address electricity reliability and power quality, including payback on investments

Each of the participants in our study has taken action to address reliability and power-quality issues. These actions have mostly been highly cost effective – often more cost-effective than standard investment criteria (e.g., less than a two-year payback). Hardware solutions have tended to dominate. We will explore some of reasons for this bias in the final subsection on barriers, below.

Perhaps the most common theme of the strategies undertaken by participants to address electricity-reliability and power-quality issues was reliance on a "bottom-up" approach. Insulating or hardening individual equipment or, in some cases, the controls for equipment, was the most common approach selected by participants. Typically, a dedicated uninterrupted power supply (UPS) was installed. In one case, constant-voltage transformers were installed to protect the controls for each piece of equipment in a manufacturing process.

Increasingly, equipment manufacturers are addressing reliability and power-quality issues in response to customer demands. Specifying equipment that is in compliance with SEMI F47 or CBEMA is now a common practice. Many manufacturers offer power conditioning systems embedded in their machines as the means of ensuring compliance.

Where susceptible processes were or could be co-located, we found more systematic solutions. These solutions typically involved UPS integrated with back-up generation serving multiple machines or processes. Data-processing facilities were commonly centralized and hardened in this manner.

Recognition that most power-quality events were the result of routine operations on the utility's distribution system has led some customers take utility service at a higher voltage. This strategy has been expensive but highly effective for some participants in our study.

We asked participants about recent heightened concerns in California over rolling blackouts and the trend toward outsourcing of operations. We speculated that moving operations out of the SV area might be perceived as an effective strategy for addressing reliability and power-quality concerns. By and large, the typical response was that the economic forces driving firms to move manufacturing (including power-quality-susceptible processes) out of the SV area were related to larger-scale concerns than power quality. One participant observed that moving manufacturing to Southeast Asia simply amounted to trading vulnerability to Silicon Valley power-quality problems for vulnerability to the power-quality problems of Southeast Asian utilities. Only one participant cited reliability and power quality as a consideration in a corporate decision to move data processing to a central facility in another part of the U.S. where the firm's new facility had been specifically designed to insure higher levels of resilience to reliability and power-quality problems (among other features that were incorporated into its design).

Most of the actions taken by the firms we interviewed to reduce vulnerability to electricity-reliability and power-quality problems have been highly cost effective. Payback periods that were disclosed for specific investments were generally shorter than two years. It was noted that in the electronics industry, investments with payback periods longer than two years longer are simply not considered. One participant said his firm's payback criterion was 18 months.

With respect to paybacks, it appears that there is much low-hanging fruit. One participant cited a recent $2.5-million investment that paid for itself in nine months. Another investment paid for itself in six months by preventing a single shutdown; shutdowns had previously been occurring once or twice a year.

Back-up generation was a subject that drew mixed reactions. Fears of rolling blackouts had led many firms to make substantial investments in back-up generation during 2001 and 2002. However, few firms actually experienced rolling blackouts. Some firms are served by municipal utilities that were not affected by the rolling blackouts of 2000 and early 2001. Several firms joined PG&E's Optional Binding Mandatory Curtailment program, which allowed them to avoid subsequent rolling blackouts in return for immediately dropping load in response to a call from the utility.[2] But, most important of all, there were no calls for rolling blackouts during the summer of 2001 or 2002. At least one participant indicated that there was some bitterness among firms that had invested in back-up generation to protect against rolling blackouts that did not materialize.

Barriers To Implementing Electricity-Reliability And Power-Quality Solutions

In an earlier subsection, we touched broadly on the lack of awareness and understanding as barriers to implementation of electricity-reliability and power-quality solutions. In this final subsection, we address barriers specifically by focusing on the roles of education/training, company organizational structure, and corporate practices and decision making.

[2] An interesting anecdote we heard was that many firms found that they could easily shed 30 percent of load with little or no impact on operations. Some recognized these as energy-efficiency opportunities (i.e., as evidence that this load could be reduced all the time, not just in response to system emergencies); nonetheless, these opportunities to save energy were not usually implemented. It was never suggested that these low-cost opportunities to save energy were passed up to maintain a higher baseline.

Education/Training

Participants involved in the pilot project had all received modest to significant professional training in electricity-reliability and power-quality issues. One had authored a standard industry textbook on power-quality monitoring. These participants, in our opinion, are not representative of the majority of staff in firms addressing electricity-reliability and power-quality issues in the industry today.

Several participants mentioned education and training as the key to improving businesses' ability to address electricity-reliability and power-quality issues in an economically efficient manner. One participant proposed that the current bias toward hardware solutions was a direct result of the poor understanding among many facilities staff members of the root causes of most power-quality problems (namely, grounding problems within facilities).

One participant opined that, "Generally, approaches to addressing reliability problems are reactionary and made hastily; they are often not well thought-out. The result is to try to fix what appears to be hurting without determining the real underlying problems. This lack of understanding often leads to overspending on expensive hardware solutions when a much less expensive solution would be equally (or more) effective. For example, rotating machinery can ride through a momentary loss of power, so protecting the controls alone, rather than sizing a UPS to carry the load of the entire machine, would be a much cheaper solution."

Organizational Structure

As we learned more about how firms addressed electricity-reliability and power-quality problems, we gained a greater understanding of how firms' organizational styles affected their ability to address these problems. Most participants in the pilot study were staff from the facilities engineering departments of their firms and were generally responsible for all utility services, including electricity, gas, and water. Facilities staff typically become involved in addressing electricity-reliability and power-quality problems when these problems are raised by production staff ("something is not working; please fix it now.")

As noted previously, we were led to believe that facilities staff generally do not have extensive training in electricity-reliability and power-quality issues. At one participating firm, we interviewed a third party that had been hired specifically to provide specialized expertise in addressing electricity-reliability and power-quality issues. In this instance, expertise was brought in house by outsourcing this aspect of the firm's facilities maintenance and operations.

In some firms with highly specialized equipment, facilities staff share responsibility with production engineering staff for identifying and addressing electricity-reliability and power-quality problems. Production engineering staff typically propose solutions for individual equipment; facilities staff may be able to take a more systematic view of solutions to the problems. In these collaborative settings, ensuring good communication and coordination between these two staffs is critical to addressing problems effectively.

One participant suggested that neither facilities nor production staff was the appropriate organizational entity to address electricity-reliability and power-quality issues. In his opinion, quality-control staff were the appropriate entity to recommend solutions to these problems because these staff members are in the best position to assess solutions from the standpoint of the net impact on a firm's productivity.

Corporate Practices and Decision Making

A final set of barriers to addressing electricity-reliability and power-quality issues is corporate practices and decision making. To some extent, we believe this barrier to be the most fundamental and challenging. That is, addressing both of the types of barriers discussed above, education and training and organizational structure, depends ultimately on corporate recognition of and motivation to address electricity-reliability and power-quality problems.

One participant observed that a major challenge for firms addressing power-quality and electricity-reliability problems is that traditional accounting systems make it difficult to quantify the full dollar impact of these problems. If these cost impacts are not reliably accounted for, economic justification of actions or investments to address them is very difficult.

Even with reliable accounting, capturing the attention of senior management is an ongoing challenge. More than one participant noted that the attention of senior management is a scare commodity. Problems must rise to a significant level to gain attention. And, although focused attention may be devoted to solving a problem that is perceived as significant, attention is often easily diverted, if a solution is not found quickly, to other, newer problems that appear more pressing. In this regard, heightened public awareness of electricity issues in California has likely had a positive effect on firms' effectiveness in addressing electricity-reliability and power-quality issues. According to one participant: "Deregulation moved electricity, as an issue, to the board room."

Related to this observation, another participant offered "Power quality has always been a tough sell from the beginning. No one wants to buy insurance. The motivators are the usual ones: fear, uncertainty, and doubt." He went on to relate "Executive interest is directly related to the time since the most recent bad experience: today, no one is buying gen-sets. I call this the "half-life" of pain."

Even with awareness and attention to electricity-reliability and power-quality problems, idiosyncrasies of corporate decision making sometimes take precedence. One participant recounted an anecdote in which a power-quality solution with a 7.5-*hour* payback was passed up because, if installed, it would take up space that would require reducing the number of machines that could operate in the facility. With the power-quality solution, the throughput of the remaining fleet of machines would have more than compensated for the lost output of the machine that would have been displaced.

Conclusion

This paper has summarized findings from interviews conducted with participants in a pilot demonstration of a novel approach to collecting electricity-reliability and power quality data from a network of sensors installed at customer's premises. The interviews focused on customer's views on the economic cost of power-quality and electricity-reliability problems; perceptions regarding electricity reliability and power quality, including utility relations; steps taken to address power-quality and electricity-reliability issues, including paybacks on investments; and barriers to implementing solutions to electricity-reliability and power-quality problems. In presenting these findings, we hope to contribute to DOE's goal, as outlined in the National Transmission Grid Study (DOE 2002), to improve the quantity, quality, and availability of public information on the economic significance of electricity reliability and power quality.

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

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