Economics of Different Plant Ride-Through Improvement Solutions for Power System Problems

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Introduction

Many industrial and commercial electric customers now require a higher level of power quality due to increasing sensitivity of sophisticated process controls and the growing reliance on computers. These customers are especially sensitive to momentary voltage sags (Figure 1) caused by remote faults on the transmission system or on parallel feeder circuits.

Determining the optimum supply system and customer electric system characteristics for these sensitive customers requires an economic evaluation of different alternatives. Power quality can be improved through system-side solutions, customer service entrance solutions, power conditioning for selected equipment within a facility, or improved specifications and equipment design. All of these alternatives have costs and associated benefits.

This paper describes a procedure for performing economic evaluations of different power quality improvement alternatives. The alternative technologies for improving power quality are identified and evaluated in terms of the expected performance improvements that can be obtained with each technology. The improved performance is then translated into economic benefits for customers based on the expected costs of the different types of power quality variations (in this case, voltage sags of different severity). With the costs of the different technologies and the expected benefits, benefit/cost ratios can be calculated to compare the alternatives.

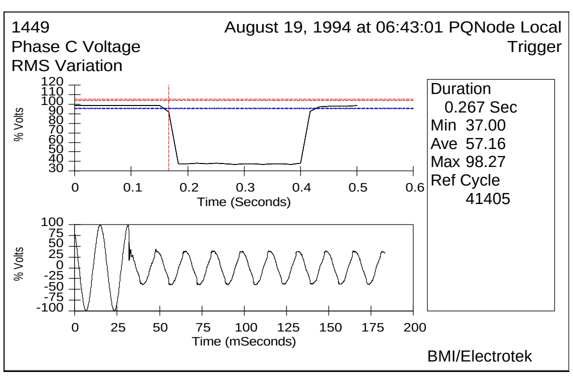

Figure 1. Example of Voltage Sag that will cause process to shut down

The Example System

The example system used for this evaluation involves a plastics manufacturer supplied from a 13 kV distribution system. The plant has four step down transformers to supply various plant loads (see Figure 3).

The facility has a primary feeder and another feeder that can be used as an alternate in the case of problems with the primary feeder. There is one other feeder from the bus at each of the substations that supply the plant.

The most critical loads in the plant are extruder process machines used to produce plastic bags. Figure 2 is a simplified block diagram of the overall machine.

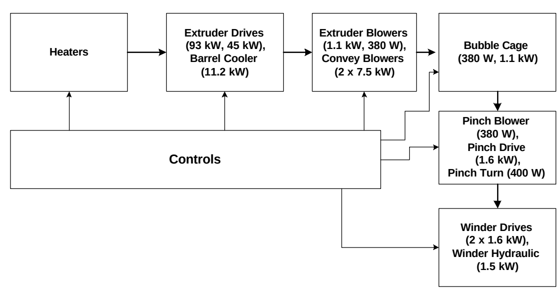

Figure 2. Diagram of Extruder Process Machines

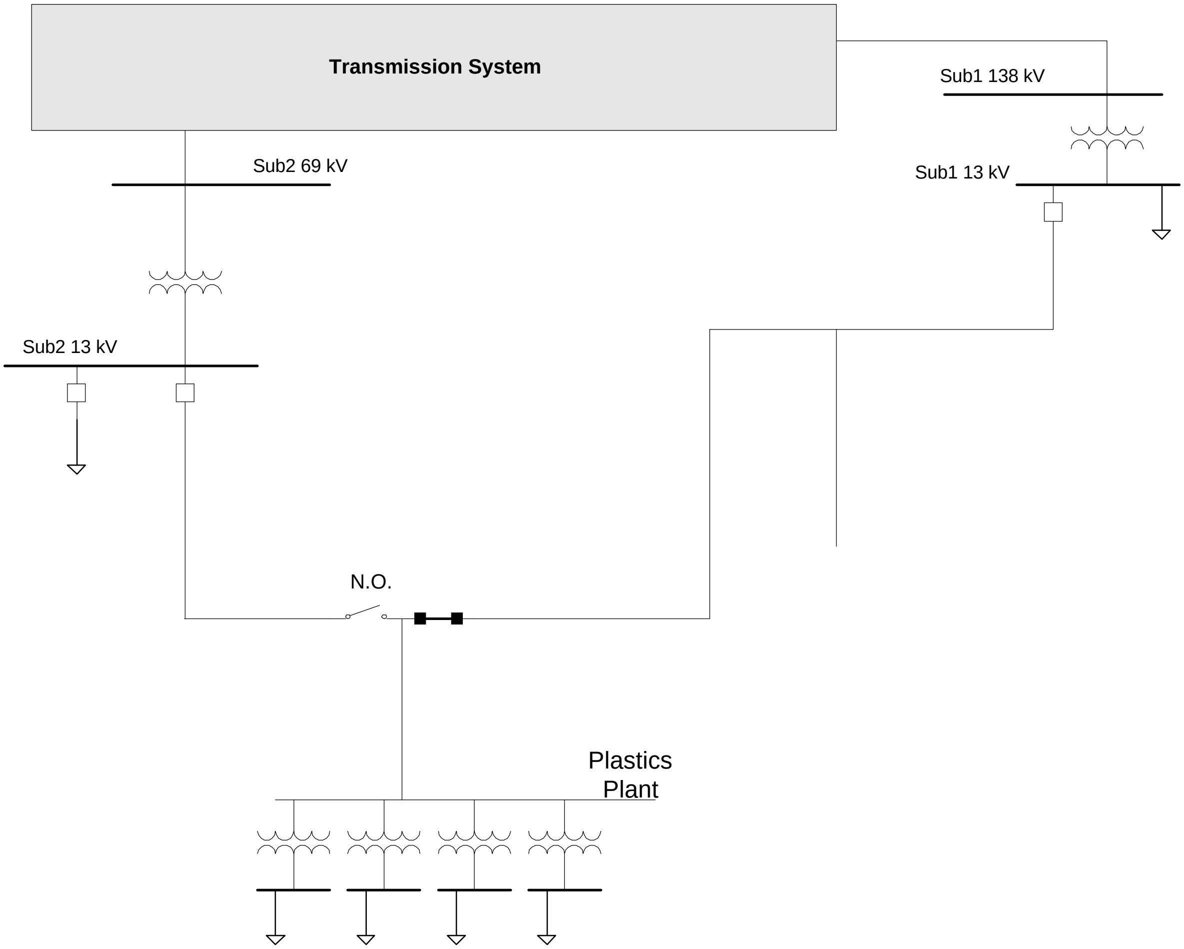

Figure 3. Simplified One Line Diagram of Example System

Characterizing System Performance

The first step in the evaluation is to characterize the performance of the system. The most important disturbances affecting the facility are voltage sags and momentary interruptions which occur when there is a fault on the supplying power system. The voltage sags can be caused by faults on the distribution system or the transmission system.

The expected system performance is characterized through monitoring efforts and calculations that can be made by the supplying utility using historical fault performance information. Figure 4 is an example of the expected performance broken down by severity of the sags and the cause of the voltage sag (transmission or distribution). This expected performance is in line with national average statistics determined by EPRI over a two year monitoring period with approximately 300 sites across the country. Note that in this case the less severe sags are dominated by faults on the transmission system but all actual interruptions to the plant are caused by distribution faults.

Characterizing Equipment Sensitivity

The voltage sags are not a concern unless they cause equipment to misoperate. This depends on the equipment sensitivity to disturbances (ride through characteristics). The dc drives, ac drives, and controls that make up these machines can be particularly sensitive to voltage sags. The sensitivity can be determined by logging impacts to the machines and correlating them with monitored voltage sag characteristics. Both the magnitude and duration can be important, as indicated by this plot of events that caused extruders to trip at another plastics plant.

If voltage sags where the voltage goes below 80% cause equipment to misoperate, the example facility would experience 20 events per year that cause problems according to the performance estimates in Figure 4.

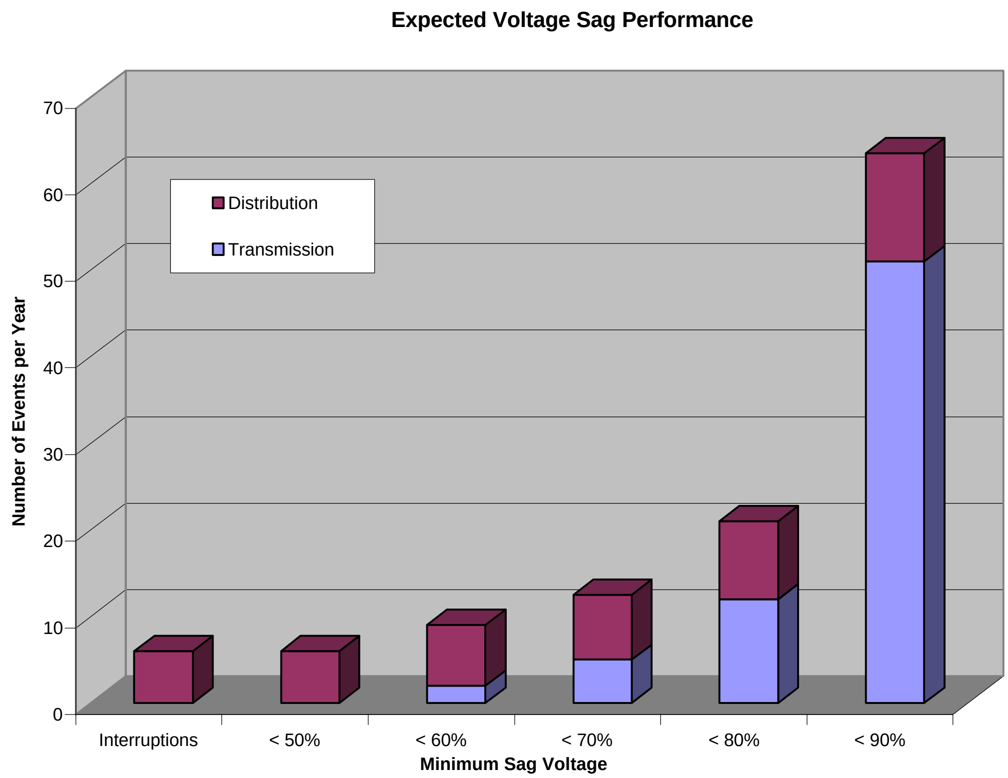

Figure 4. Expected Voltage Sag Performance.

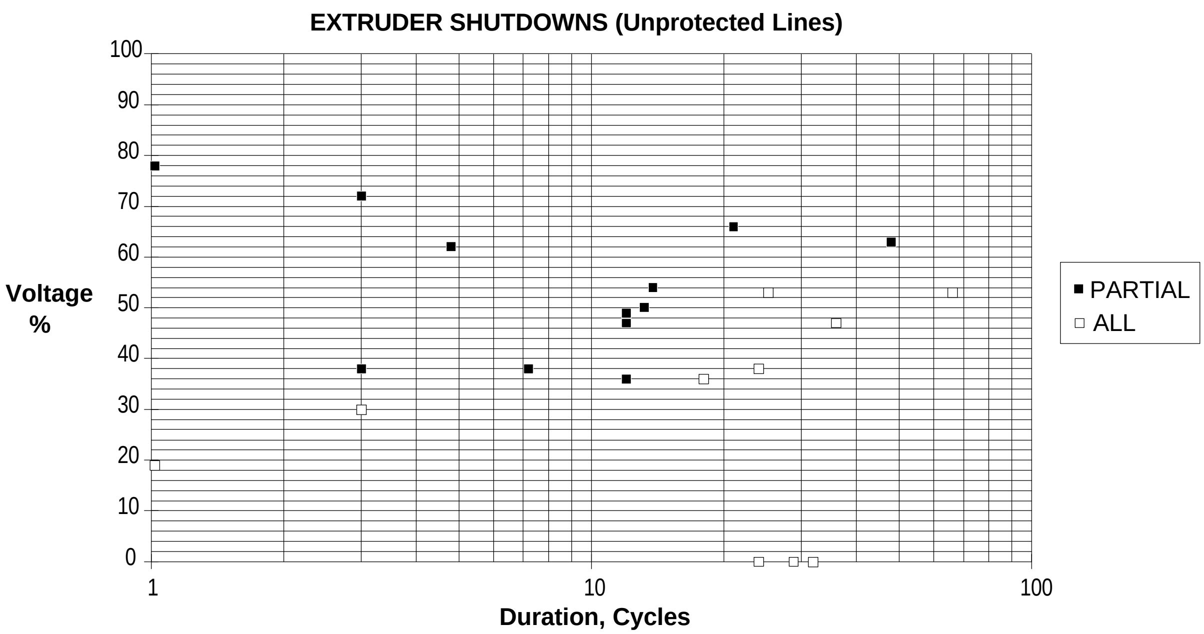

Figure 5. Example of Extruder Sensitivity to Voltage Sags.

Power Quality Improvement Technologies

A variety of different options for power quality improvement can be considered, ranging from power conditioning at sensitive loads to energy storage technologies on the distribution system. The most important categories for the power quality improvement options are discussed briefly here.

End Use Equipment Power Conditioning

It is almost always best to evaluate the potential to improve the performance of the end use equipment itself first. This can be accomplished through the specification stage if ride through characteristics are considered before the equipment is purchased. After installation, various retrofit alternatives can also be available. These may include protection of controls, PLCs, and starters with constant voltage transformers or other small ride through technologies. Sometimes, the modifications to the controls or relay settings are possible, such as adding a delay to prevent tripping for very short voltage sags (e.g. less than a half second).

This option involves understanding the design and installation of each machine and its controls. There may be some significant engineering effort involved to identify specific loads for protection, size the protection, and coordinate with the overall process. However, this effort is usually very worthwhile and economically justified.

Technologies for Service Entrance Application

For plants that have critical loads making up a large portion of the total plant load or when it is possible to segregate the loads in the plant so that all the critical loads can be supplied from a common service, service entrance protection may be appropriate. This takes advantage of the economies of scale associated with protection of larger loads. The most obvious choice for protection at the service entrance is still UPS systems. They can be obtained with individual unit sizes up to 1000 kVA and they can be paralleled to obtain much larger installations.

Although conventional UPS systems (static or rotary) are applicable for protecting large loads at the service entrance, many other options are available. They may have significant advantages in terms of lower operating costs, improved efficiency, and reduced maintenance. Usually these alternative technologies involve some type of energy storage technology configured as a standby power supply. A static switch is used to switch over to the backup supply in the event of a disturbance. Figure 6 is a general block diagram for a wide range of these technologies.

In this case, the economic evaluation involves a 2 MW energy storage system that can provide ride through support for 10 seconds. This is not enough to protect the entire plant but it is sufficient to protect the extruder machines themselves.

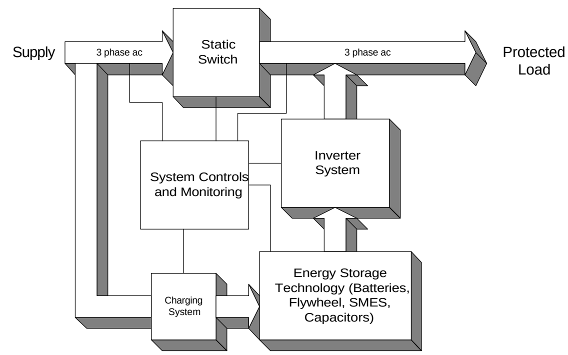

Figure 6. General configuration for standby energy storage technologies.

Technologies for Supply System Application

A number of different supply-side options are available for improving the voltage sag and interruption performance at customer facilities over a portion of the distribution system.

The first and most obvious solution is to eliminate faults on the power system. Of course, it's not feasible to completely eliminate faults. Measures that help include improving tower grounding, applying arresters, using animal guards, tree trimming, and preventive maintenance practices.

When system maintenance and protection practices have been improved as much as possible and additional performance improvement is needed, there are a few new technologies that can be employed. These include the distribution voltage restorer (DVR) which can be series connected to compensate for voltage sags and distribution static switches to instantaneously switch to a backup feeder in the event of a disturbance.

For this example, a static switch is evaluated because there is an alternate feeder available that can be used for the backup.

Economic Analysis of Alternatives

Weighting Factors for Different Power Quality Variations

The actual dollar impacts of the different types of disturbances are often not known or may be confidential for a customer operation. However, it is clear that power interruptions are generally more severe than momentary voltage sags. It is often possible for a customer to estimate the economic impacts for a power interruption because all unprotected equipment will trip and the impact to the process can be determined. Different costs will be associated with less severe voltage sags because not all unprotected equipment will trip (some equipment can ride through the voltage sags) and not all processes will be interrupted. The procedure developed here uses the concept of weighting factors for different power quality variations.

The weighting factors are developed using the cost of a momentary interruption as the base. Usually, a momentary interruption will cause a disruption to any load or process that is not specifically protected with some type of energy storage technology. These base costs associated with a momentary interruption will be designated as C_i. Voltage sags and other power quality variations will always have an impact that is some portion of this total shutdown. The weighting factors used for the example case are given inTable 1 and they are used to calculate an equivalent number of momentary interruptions (from an economic point of view) for the facility. In this case, the facility experiences the economic impact equivalent to 15.2 momentary interruptions per year. If one interruption event costs the plant $20,000, then the annual impact of these disturbances is approximately $300,000.

Evaluating the Performance Improvement for Each Technology

Each individual technology needs to be evaluated in terms of the performance improvement that can be achieved with the technology. For instance, a primary static switch will provide support for all events that are caused by distribution faults but will not help with the voltage sags caused by transmission faults. Technologies like ride through support for controls on individual machines will not help the whole machine ride through actual interruptions

Table 1. Assumed weighting values for voltage sags of different severities and application of the weighting factors to the expected system performance.

Category of Event	Weighting for Economic Analysis	Expected Number per Year	Equivalent Interruptions per Year
Interruption	100%	6	6.0
Sag below 50%	100%	0	0.0
Sag between 50% and 70%	50%	6.5	3.3
Sag between 70% and 80%	20%	8.5	1.7
Sag between 80% and 90%	10%	42.5	4.3
TOTAL		**63.5**	**15.2**

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Table 2 compares four different ride-through improvement technologies in terms of the expected performance improvement for the overall process in the plant. The economics of these different alternatives are then compared in Figure 7 assuming a cost of $20,000 for a momentary interruption. Note that the most benefit per dollar spent is achieved by improving the performance of individual machines by protecting controls. However, the primary static switch is also potentially an economically attractive solution in this case and combining the static switch with protection of machine controls is very attractive.

Table 2. Performance Improvement Estimates for Different Technology Alternatives

Type of Condition Affecting Customer	Weighting	Base Performance (events/year)	Reduction with Controls Protection	Reduction with Service Entrance Energy Storage	Reduction with Primary Static Switch	Reduction with Static Switch and Controls Protection
Interruptions	1	6.0	0%	60%	100%	100%
Sags below 50%	1	0.0	0%	90%	90%	90%
Sags 50-70%	0.5	6.5	50%	90%	50%	70%
Sags 70-80%	0.2	8.5	80%	95%	30%	90%
Sags 80-90%	0.1	42.5	90%	95%	10%	92%
TOTAL EVENTS AFFECTING PLANT		**63.5**	**15.2**	**5.6**	**47.45**	**6.2**
Total Events Weighted for Severity		**15.2**	**8.4**	**3.0**	**6.6**	**1.5**

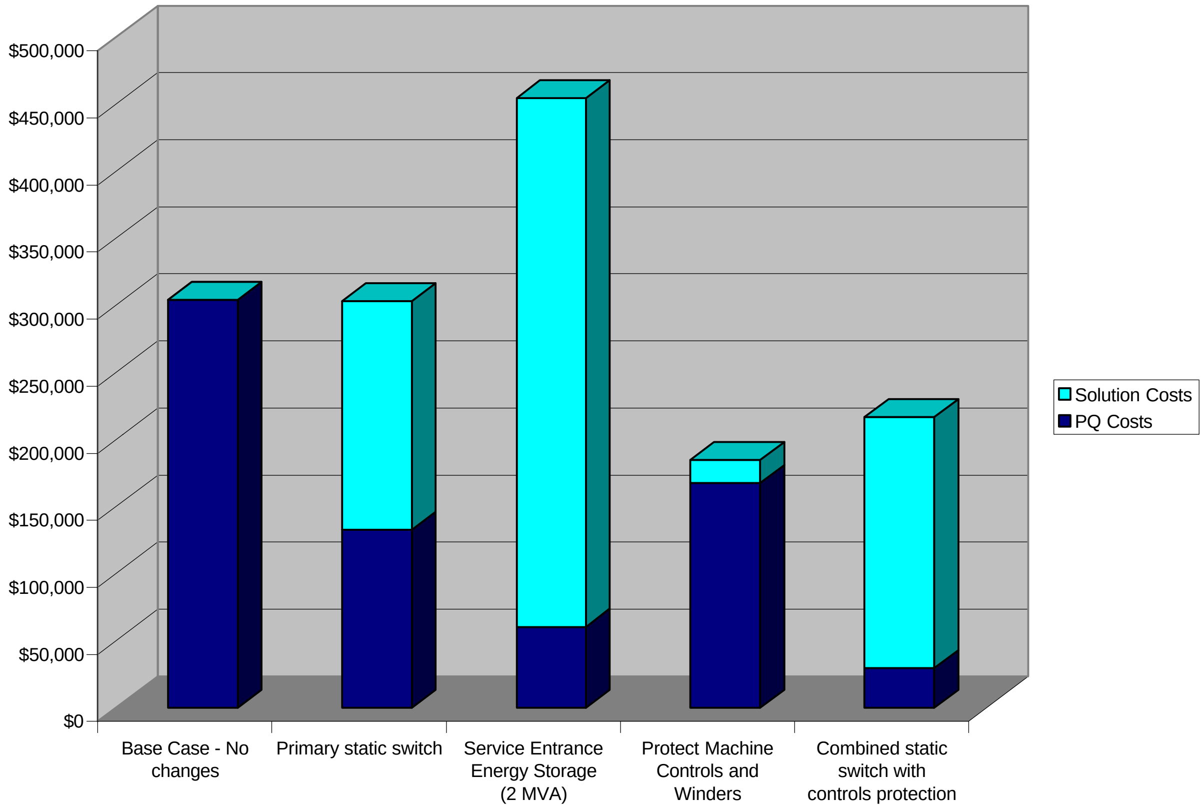


Figure 7. Economic Comparison of Ride Through Improvement Alternatives (chart shows the total annual costs of the power disturbances plus the annual costs of the solution – lower total bar heights are better).

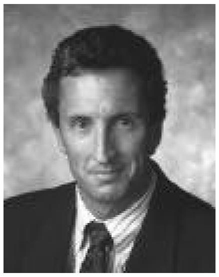
Summary

The economic evaluation procedure described provides a systematic method for evaluating a range of alternatives that could be used to improve the reliability of plant operations during power system disturbances. The technologies can be applied at the end use equipment, at the customer service entrance, or on the utility supply system.

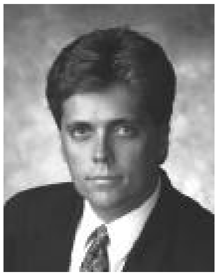
The procedure is based on characterizing the expected number of power quality variations in a number of different categories. The impacts of variations in each category are characterized by a weighting factor that expresses the economic costs associated with the variation in per unit of the costs associated with an interruption. The total impacts to a customer are determined by summing the costs associated with the events in each category (number of expected events times the weighting factor).

The different technologies are then evaluated by estimating the improved performance that can be expected after the technology has been applied. The cost savings are calculated for each technology along with the costs of applying the technology. The economics are compared in terms of the annual cost associated with the power quality variations and the costs of the power conditioning technology use to improve the performance.

Authors



Mark McGranaghan manages the Power Systems Engineering Group at Electrotek Concepts (www.electrotek.com) in Knoxville, TN. They provide consulting services, seminars, software, and research and development projects for the electric power industry, especially in the areas of distribution system planning and operations and power quality. Mark has been studying power system problems and solutions for 20 years. He has been involved in developing advanced monitoring equipment and the most advanced software for analyzing and managing power quality available in the industry. He has recently been involved in defining the indices that can be used to characterize system power quality performance. Along with Roger Dugan and others at Electrotek, Mark is a co-author of the book Electrical Power Systems Quality. He has authored numerous technical publications and magazine articles over the years. He has been active in IEEE and is currently the Chairman of IEEE 519Am a Task Force developing a "Guide for Applying Harmonic Limits on the Power System."



Chris Melhorn is the Manager of Utility and Industrial Studies at Electrotek. Chris is responsible for developing marketing strategies, coordinating industrial and commercial proposals and studies, and developing and supporting seminars. Since joining Electrotek in 1990, he has been involved in numerous projects that have involved monitoring, simulating, and analyzing power quality phenomena. Some major projects include the EPRI Distribution Power Quality project (RP-3098-1), power quality case studies for PG&E, Con Edison, Arkansas Power & Light. He is currently project manager for the power quality monitoring effort at Consolidated Edison Company of New York. Chris is also involved in software development efforts at Electrotek. Chris is secretary for the IEEE P1100 working group, "The Emerald Book," a member of the IAS Power Quality Subcommittee, and a member of IEEE P1346, "Electric Power System Compatibility with Electronics Process Equipment". Chris has written over 20 technical papers for organizations like the IEEE, CIRED, PQ/PCIM, and PQA. He has presented over 50 talks and seminars on power quality that include tutorials and workshops on power quality monitoring and analysis.