The Role of Distributed Generation in Power Quality and Reliability

Final Report

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Prepared for:

New York State Energy Research and Development Authority
17 Columbia Circle
Albany, New York 12203-6399

Prepared by:

Ken Darrow
Bruce Hedman
Energy and Environmental Analysis, Inc
1655 North Fort Myer Drive
Arlington, VA 22209

Thomas Bourgeois
Daniel Rosenblum
Pace Energy Project
78 North Broadway
White Plains, NY 10603

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Table of Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

The nature of business and power consumption has changed considerably over the last two decades. Facilities of all kinds now make widespread use of sensitive electronic components, computers and programmable logic controllers. There is also a growing need for reliable and continuous communications with customers, suppliers, and financial institutions. Many businesses suffer economic losses when electric power interruptions occur or even when there are voltage or current abnormalities present in the power delivery. While the performance of the U.S. and New York electric utility industries is extremely good, even this level of performance is not sufficient to protect customers with highly sensitive loads from economic losses. These customers must invest in on-site equipment to ensure higher levels of reliability and power quality than is delivered from the electric grid. This report explores the power quality sensitivity of the power market in New York and examines the value of integrating distributed generation into an overall customer power quality and reliability solution. The basic premise for this study is that distributed generation can be used to support customer's power quality and reliability needs and by so doing the value of distributed generation is increased.

Power Quality Issues and Frequency[1]

The ability of the electric system to deliver electric power without interruption is termed 100% *reliability*. The ability to deliver a clean signal without variations in the nominal voltage or current characteristics is termed high *power quality*. Higher or lower than normal voltage or current can damage or shut down certain types of electrical equipment. Such variations in the normal signal occur on the typical power delivery circuit multiple times per year. **Figure ES1** shows the results of a prior study that monitored 300 sites on 100 distribution feeders at 24 utilities throughout the U.S. The average number of events per site, per year, is given in 18 bin groupings (incremented by 5% from 0 to 85%) representing the reduction in voltage that occurred at the site. Minor voltage excursions, within 10% are considered normal. There were nearly 75 events per customer per year. Most of the recorded events were minor sags, though the average site also experienced 8.5 momentary or longer service interruptions per year.

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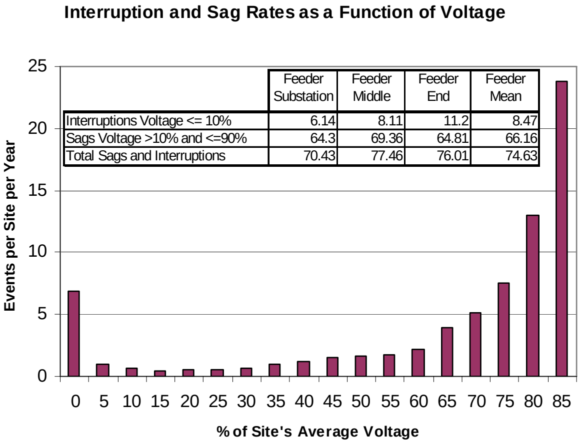
[1] The source for power quality technology and market information in this report unless otherwise noted comes from a series of reports prepared for EPRI and provided under a single use license agreement for this study:
Markets for Distributed Resources: Business Cases for DR Applications, EPRI Report TR-109234-V2, November 1997.
Distributed Resources Premium Power Solutions, EPRI Report 1004451, January 2003.
Understanding Premium Power Grades, EPRI Report 100406, November 2000.
Information to Support Distribution Resources (DR) Business Strategies, EPRI Report TR-114272, December 1999.



	Feeder Substation	Feeder Middle	Feeder End	Feeder Mean
Interruptions Voltage <= 10%	6.14	8.11	11.2	8.47
Sags Voltage >10% and <=90%	64.3	69.36	64.81	66.16
Total Sags and Interruptions	70.43	77.46	76.01	74.63

Figure ES1 Average Voltage Sags and Interruptions per Site per Year

Power Quality Markets

Power quality sensitive customers can be grouped into three areas as follows:

- **Digital Economy** – Firms that rely heavily on data storage and retrieval, data processing, or research and development:
  - **Mission Critical Computer Systems** – banks, depository institutions, other financial companies, stock markets, investment offices, insurance companies, computer processing companies, airline reservation systems, and corporate headquarters need to protect computers, peripherals, and computer cooling equipment.
  - **Communications Facilities** – telephone companies, television and radio stations, internet service providers, cellular phone stations, repeater stations, military facilities, and satellite communication systems need to protect their computers, peripherals, antennae, broadcasting equipment, and switches.
- **Continuous Process Manufacturing** – Manufacturing facilities that continuously feed raw materials, often at high temperatures, through an industrial process. These industries include paper; chemicals; petroleum; rubber and plastic; stone, clay, and glass; and primary metals. Large centralized photo-finishing centers need to protect their computers and photo-finishing equipment.
- **Fabrication and Essential Services –** This sector includes other manufacturing industries plus utilities and transportation facilities. Hospitals, nursing homes and other health care facilities need support for critical life support systems, medical equipment, and maintenance of critical HVAC environments. Other essential services include other manufacturing industries, utilities and transportation facilities such as railroads and mass transit, water and wastewater treatment, and gas utilities and pipelines.

Generally, within these power quality sensitive markets, not the entire load at a facility is sensitive. Therefore, the type and scope of the mitigation measures employed at a facility will depend on the size of the sensitive load with respect to the entire load.

Power Quality Costs

Industries and individual facilities vary widely in the costs imposed by power quality problems. Measured in terms of costs per kVA per event, costs range from $3-$8 per kVA for the textile industry to $80-$120 per kVA event for sensitive process industries. Downtime can cost a cellular communications facility $41,000 per hour; while, a brokerage house would experience several million in damages if it were shut down for an hour. These costs can include:

- Damaged plant equipment
- Spoiled or off spec product
- Extra maintenance costs
- Cost for repair of failed components
- Loss of revenue due to downtime that cannot be made up.
- Additional labor costs.

Those customers who cannot afford to be without power for more than a brief period usually have on-site standby generators that can pick up all or a part of their load. There are also customers for which any disruption at all, either in loss of power or variation of power quality, can lead to severe economic loss. These customers generally require uninterruptible power supply (UPS) systems along with associated power control and conditioning equipment to correct surges, sags, harmonics, and noise.

In a prior EPRI study, 2 million business establishments were evaluated to determine the economic costs of power outages and power quality disturbances. The results of this analysis are shown in **Table ES1**. The estimated cost of outages for the three sectors is $45.7 billion per year. An additional $6.7 billion in costs result from power quality disturbances other than outages. The cost for all industry is estimated at $120 to $190 billion per year. According to the study, New York ranks third in the U.S. behind California and Texas with an estimated $8.0 to $12.6 billion in costs associated with outages and power quality phenomena.

Table ES1 Estimated Total U.S. Cost of Power Quality Disturbances per Year

	Outage Costs ($billions)	Power Quality Costs ($billions)
Digital Economy	$13.5	$1.0
Continuous-Process Manufacturing	$3.0	
Fabrication and Essential Services	$29.2	$5.7
Total PQ Sensitive Sectors	$45.7	$6.7
Estimate of All Business Sectors	$104-$164	$15-$24

Power Quality Control Techniques and Costs

A range of technologies can be used to improve the power quality at a site. These technologies can help to insulate the customer from variations in PQ in utility supplied power or to mitigate PQ disturbances emanating from the customer's own equipment. These technologies are often used as individual components of an overall PQ control strategy and include: transient voltage surge suppressors; VAR compensators; dynamic voltage restorers; isolation transformers; motor-alternators (motor-generators); and various types of UPS. A facility may choose to protect its entire load (at the electric service entrance), sensitive sub-facilities (individual circuit protection), or individual operations (controls or individual equipment protection.) The protection level depends on the size and type of critical load.

Small-scale equipment (up to 3 kVA) is 120-volt, single-phase PQ protection equipment for point-of-use applications protecting individual equipment such as personal computers or logic controls for larger equipment. This type of equipment includes:

- Uninterruptible power supplies (UPS) costing $200-500/kW
- Single-phase transient voltage surge suppressors (TVSS) at $10-$50 per circuit.
- Single-phase power conditioners, isolation transformers, and voltage regulators ranging from $100-500/kW.

Medium-scale equipment (3.1 to 100kVA) is used to protect the low voltage distribution system (240-600 V) within a facility. This equipment is typically located at the service entrance panel boards, or supplying a feeder or branch circuit. Typical equipment in this category includes:

- Single-phase UPS (3-18 kVA) and three-phase UPS (up to 100 kVA) ranging in price from $75-$225/kW.
- Three-phase TVSS except for revenue demand meter mounted units from $100-$200/circuit.
- Three-phase power conditioners: voltage line conditioners, isolation transformers, power distribution units, voltage regulators, motor generators, and active and static harmonic filters ranging in price from $50-500/kW.

Large scale equipment (greater than 100 kVA) is designed for use at the service entrance of the facility. This scale of equipment may be installed outdoors in pad-mounted enclosures or in a customer-owned substation. Large-scale equipment includes the following:

- Energy storage systems including battery energy storage, mechanical storage systems such as flywheels ($25-100/W-hour) with electrochemical capacitors.
- Large-scale UPS costing $250-400/kW
- Low voltage static transfer switches (less than 600 V) for $40-60/kW
- Medium voltage static transfer switches (4.16-34.5 kV) and customer power products such as static-series compensators/dynamic voltage restorers (DVR), static shunt compensators, and static circuit breakers ranging in cost from $28-32/kW.

Approximately 90% of the PQ equipment and services market is focused on small and medium scale equipment or services, and, therefore, has little synergy with DG systems. The remaining 10% of the market for facility-scale power quality control (greater than 100 kVA) represents a $450 to $900 million per year market in the U.S. It is this market for large-scale equipment that represents the greatest potential for integration with distributed generation systems.

Integration of Distributed Generation into Power Quality Solutions

The underlying requirements of a DG/power quality system include the following elements:

- Fast response from energy storage to protect the load from momentary voltage variations;
- Conversion of the stored energy into clean power;
- Control for synchronization and paralleling between systems;
- Seamless transfer (also called soft transfer) to the alternate power source and back again;
- Immediate isolation from any grid disturbance(s);
- Sufficient quantity of stored energy to ride through until primary or secondary power is restored; and
- Ability of the DG system to provide clean power to the critical loads.
- Dispatchability for varying local load
- High energy efficiency and low emissions

Figure ES2 shows a standby or secondary DG system that utilizes energy storage and a more sophisticated control system to provide not only protection from long-term outages but also from short-term and momentary disturbances as well. The on-site energy storage provides the ride through capability until the generator can start. The static switching and controls technology ensure that these changes from the utility source to the standby or secondary DG source are not detected by the load.

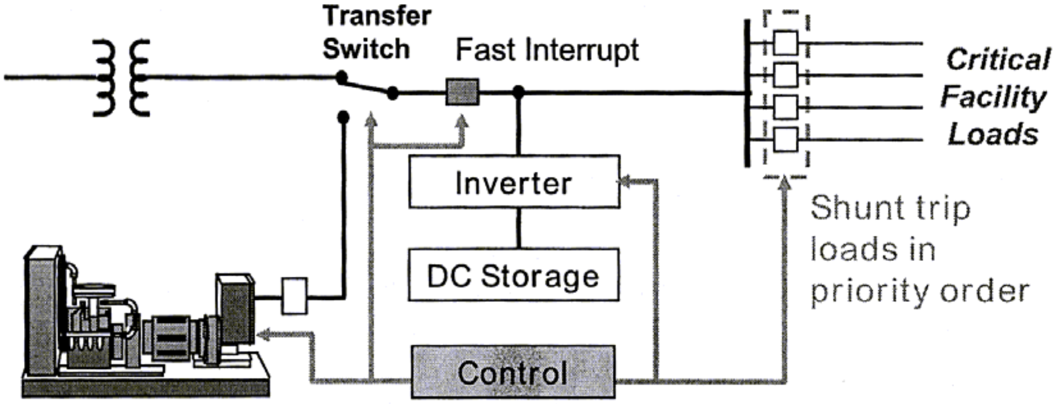


Figure ES2 Standby or Secondary DG System Offering PQ Support

This is a common configuration for PQ sensitive customers that utilize UPS supported by battery energy storage system and one or more standby generators. In very sensitive applications there are usually redundancies in some or all of the component parts of the system.

Economics of Power Quality and DG

A framework for evaluating PQ investments was developed based on a hypothetical utility and customer. The utility feed, typical of the type of service seen by a large commercial or industrial customer had 20 voltage sags throughout the year lasting only a fraction of second each, 2 momentary power interruptions per year, and one extended outage lasting 60 minutes every other year. The facility disruptions caused by these events, however, were assumed to be 50 minutes for a sag, 1.4 hours for a momentary interruption, and 5 hours for the extended outage. In this example the 22.5 disruptions per year (lasting a an average of only 30.2 minutes per year) causes 22 hours of facility downtime with only 16 hours mean time between forced outages.

Various combinations of mitigation measures were evaluated in terms of their cost and effectiveness as shown in Table ES2. A UPS system with standby generator would have an annual cost of $149/kW and reduce the facility downtime from 22.5 hours/year to only 15 minutes. Such an investment would be worthwhile for any customer whose annual outage costs were greater than or equal to $6.90/kW. A standby system alone is comparatively less cost effective because of its inability to deal with momentary sags and interruptions – the majority of events during the year.

Table ES2 Mitigation Effectiveness, Costs, and Break-even Value

	Facility Disruption	Annual Cost of Mitigation	Break Even PQ Value
	Hours/year	$/year	$/kW
No Mitigation Equipment	22.0	$0	NA.
UPS without Standby	2.7	$142,576	$4.93
Standby without UPS	20.3	$81,454	$31.76
Combined UPS/Standby System	0.25	$224,030	$6.90

While this configuration of UPS with standby generation is cost effective, the basic premise for this study is that distributed generation can be used to support customer's power quality and reliability needs and by so doing the value of distributed generation is increased. Two DG applications, peak shaving and combined heat and power, were evaluated in terms of the value of integration into a PQ/reliability framework. In both cases, integration results in a reduction in capital costs due to the avoidance of the investment in a diesel standby generator. For a simple, peak shaving system, the incremental investment for providing an environmentally acceptable gas-fired generator in place of the diesel standby unit is little more than half of what it would be in a straight peak shaving project. For a more complicated combined heating and power (CHP) system[2], the avoided cost of a diesel generator reduces capital costs by up to 40%.

In addition to this capital cost benefit, a CHP system operating continuously provides a greater level of protection for the customer against external voltage sags and other momentary disruptions. The CHP system is essentially a second feed for the customer. With static switching, 95% of PQ problems can be avoided even before the benefit of UPS is considered. With UPS added, the mean time between failures increases to 27 years. The UPS system with a standby generator had an MTBF of 4.4 years. For less sensitive customers that are not heavily invested in UPS, the reduction in PQ disruptions just from having CHP operating could be significant.

In hypothetical economic examples for peak shaving and CHP, the advantages of integration with power quality were very important. The paybacks were reduced from 6.9 to 3.7 years for the peak shaving analysis and from 12.2 to 6.6 years for the CHP case. In both cases, the integration of the DG cost savings function with the PQ support for power quality helped to move the projects into an economic acceptance range. In other words, integration of DG and PQ functionality can move a project from *no-go or on the edge* to *go*.

New York Utility Industry Focus on Power Quality

Since 1991, the New York Public Service Commission (PSC) has required that utilities file power quality and reliability (PQR) reports. The requirements involve the establishment of

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[2] Combined heat and power systems, also known as cogeneration, recapture the heat lost in power generation to provide heating and cooling to the process or building.

minimum acceptable (Minimum) and desirable (Objective) levels of reliability. Reliability is gauged utilizing indices for both the frequency and duration of service interruptions. The recommended reliability levels are customized for each of the utility operating areas in the State. The Order also includes criteria for identifying, ranking, and developing appropriate improvement plans for the worst-performing circuits in each operating area. In addition, the utilities are required to develop programs for responding to customers' power quality problems.

These reports have created a common set of metrics for defining the issue in terms of average interruption frequency, average interruption duration, and average service restoration time. Review of the PQRs from the major investor-owned utilities in the state shows that high/low voltage excursions ranged from 160 to 281 incidents per year by region for one utility. Voltage quality issues occurred thousands of times per year within each service region. Utilities have also engaged in case studies and customer interviews in an attempt to better quantify the issues and improve operations.

New York Customer Views of Power Quality and Utility Response

The project team spoke with nine facility managers in sensitive industries throughout New York State about their power quality and reliability issues. While, the very dramatic extended Northeast blackout of 2003 created problems for most of them, this once in 25 year event is not as important as the more subtle and more frequent disturbances these facilities experience every year, every summer, and, in some cases, nearly every day. Problems arise with computers, microprocessors, fluorescent light ballasts, sensitive medical imaging equipment, variable speed drives, computer directed design and manufacturing, critical communications equipment, nuisance trips on circuit breakers, overheating of equipment, etc. Some facilities don’t know what is causing their equipment to break, go off-line or lose data, they just go in and fix it to their systems get back up and running. Other facilities have become very sophisticated in monitoring their power signal and in diagnosing problems.

Still, from the perspective of the customers contacted for this study, utilities were generally not helpful in identifying and diagnosing power quality problems. Consequently, to get to the root of PQ related problems, customers had to install monitoring equipment and identify and diagnose the problems themselves. Armed with such investigative data, some customers were then able to get the utility to act to correct persistent low voltage or phase imbalance conditions.

All of them have made some level of power quality/reliability enhancing investments to protect their operations. Both centralized and equipment level UPS systems were used. Power factor correction, harmonic filters, isolation transformers, and other equipment were also used to support specific facility issues. Most included standby generation as part of their protection scheme. Two facilities had in-place and operating combined heat and power facilities and a number of others had done CHP feasibility studies. Of the two operating CHP systems, one was an integral part of the facility power-quality protection system. In the other case, the facility manager was very interested in this issue but had been unable to install a system capable of running independently of the grid due to restrictive utility interconnect requirements. He was continuing to push the utility for addition of that capability to his DG system. One facility, in

New York City, uses its standby diesel generators to participate in the ICAP demand reduction program. This facility was thus fortuitously operating on its own generators under an ICAP demand reduction when the blackout hit in 2003.

Research, Development and Demonstrations needs

There are a number of issues that need to be addressed before DG/PQ integrated projects become more widespread:

- ☐ Both standby and other types of distributed generation can themselves insert PQ disruptions (especially fault contribution for rotating or generator type DG versus inverter type) into both the customer and the utility system, and there are specific issues, especially harmonic voltage magnification, of compatibility between customer generation and UPS and capacitor banks. It is very important to address the issue of power quality in designing and building a DG system. Design, demonstration, and monitoring projects could help to eliminate potential problems and also to provide a database of correct practices and rules of thumb for future installations.
- ☐ Interconnect rules that restrict the ability of DG systems to provide onsite back-up power during grid outages should be re-examined from both a technical and economic perspective. They are being required to tripped off when they are most needed to support local voltage and power.
- ☐ The design and implementation of emergency demand response programs should allow or even encourage participation by customers with DG systems.
- ☐ Current tariffs make customer sited DG generally unprofitable for utilities. In order to encourage customer DG, a mechanism for monetizing benefits to the utility system and other stakeholders needs to be developed.
- ☐ Alternative technical approaches could enhance the opportunities for growth in this market such as dual-fuel (diesel and gas) engine technology that permits clean operation for economic dispatch with full emergency functionality, development of integrated packages that can integrate the power electronics from DG with the power electronics packages for UPS.
- ☐ More cost-effective and packaged protection systems are needed to provide all of the necessary protection functions that local utilities are requiring for the interconnection of DG.
- ☐ *Best Practices* guides need to be developed for DG operation in a premium power environment.

The Role of Distributed Generation in Power Quality and Reliability

1. INTRODUCTION

Modern electric power supply and delivery systems consist of a complex grid of multiple electrical components including power generation supply, transmission, voltage control, and power delivery with multiple points of supply and use. The complicated interaction of components of the grid leads to temporal variations in the characteristics of the power that an individual customer sees at its service panel. These variations range from nearly instantaneous to extended periods of outage or abnormal power characteristics. Taken as a whole, the presence or absence of such variations is termed low to high *power quality*. The degree to which power is provided with and without interruptions is termed low to high (such as 99%) *reliability*. The nature of business and power consumption has changed over time with the introduction and widespread use of sensitive electronic components, a greater reliance on computers, programmable logic controllers for controlling industrial processes, and a need for constant communications with customers, suppliers, and financial information. As a result of these changes, some businesses and even some residential customers experience economic losses and/or make investments in custom power systems that can both condition and supplement purchased power so that sensitive systems are not harmed or interrupted. The manufacture, distribution, sale, and installation of this equipment and the businesses that utilize it are referred to as the *premium power market.*

The basic premise for this study is that distributed generation can be used to support customer's power quality and reliability needs and by so doing the value of distributed generation is increased; hence, the purpose of this report is to identify the economic value of using distributed generation (DG) to mitigate power quality and reliability problems. DG refers to modular power generation at or near the customer site and loads. The placement and use of DG can potentially provide an economic value to the customer as well as to the overall electric power grid. The economic values, or value propositions, that can be provided by DG are as follows:

- Combined Heat and Power (CHP) – An important benefit of DG is that the thermal energy that is not usually used when backup generation is implemented can be utilized for process heat requirements. This dual use of thermal and electrical energy can make CHP more cost effective for customers than separately buying electric power and fuel or steam for thermal needs.

- Low Cost Energy – If there are no or low fuel costs (waste energy systems, bio-energy systems, photovoltaic systems) or if the customer is remote from or not connected to the central power grid, a DG system can provide lower energy costs than central station generation even without heat recovery.

- Peak Shaving –DG can be used to reduce "demand" charges by the local utility by operating only during peak periods. This application can both reduce the customer's overall energy costs by reducing peak demand and contribute to increasing the capacity of the central power system to serve other customers although no utility that we are aware of is compensating the DG owner for this benefit.

The following two DG value propositions are directly related to power quality and reliability issues and are the focus of this study.

- ☐ Stand-by Power – DG can support customer operations during periods of extended outage of the electric grid. Actually, the most common kind of customer generation is in the form of stand-by diesel generators (*gen-sets*.) These systems have only one function, to take over emergency loads during grid outages. They often are permitted for use only for this purpose, as they are usually installed without environmental controls and with extremely limited use restrictions. The focus of this report, however, is to define how a DG system that supports one of the three economic functions described above can also support the function of meeting stand-by power requirements. The use of the term DG in this report, therefore, will be understood not to include stand-by diesel gen-sets

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- ☐ Premium Power – The nature and extent of this application will be defined in this report. As a rule, customers with extreme sensitivity to power quality who invest in uninterruptible power systems (UPS) and other power conditioning equipment also require a standby power system that supports operations during longer outages. As previously described, this report identifies and characterizes DG solutions rather than the use of stand-by diesel generators.

This report is organized into the following sections:

- ☐ **Integration of Distributed Generation and Power Quality** – specific uses and configurations of DG to support power quality
- ☐ **Power Quality Issues in New York State –** an evaluation of power quality disturbances that occur in New York and a discussion of customer perspectives
- ☐ **Economic Analysis of Integrated Power Quality and DG Solution**s **–** characterization of DG/PQ integrated systems and definition of economic values
- ☐ **Conclusions –** an overall evaluation of the role of DG in supporting power quality needs in New York State including an assessment of research and evaluation needs.

There are appendix sections including:

- ☐ **Summary of Power Quality Issues, Markets and Solutions –** including a definition of power quality issues and their occurrence, the nature and size of power quality sensitive markets, the adverse economic costs associated with power quality disturbances, and the type of power quality control equipment that is used to provide customers with premium power service
- ☐ **Customer Interviews –** describing site-specific power quality issues and solutions.
- ☐ **Glossary of Terms**

2. INTEGRATON OF DISTRIBUTED GENERATION AND POWER QUALITY

This section describes the use of DG to provide reliability and support PQ solutions for the premium power market. The basic premise for this study is that distributed generation can be used to support customer's power quality and reliability needs and by so doing the value of distributed generation is increased. A description of underlying power quality issues, markets and solutions is provided in **Appendix A**. The underlying requirements of a DG/PQ system include the following elements:

- ❑ Fast response from energy storage to protect the load from momentary voltage variations
- ❑ Conversion of the stored energy into clean power
- ❑ Control for synchronization and paralleling between systems
- ❑ Seamless transfer (also called soft transfer) to the alternate power source and back again
- ❑ Immediate isolation from any grid disturbances
- ❑ Sufficient quantity of stored energy to ride through an outage until primary or secondary power is restored
- ❑ Ability of the DG system to provide clean power to the critical loads.

A standby generator provides protection from long-term outages. **Figure 2.1** shows the standard configuration for a standby generator (as described in the National Electric Code) connected to building loads by means of an automatic transfer switch (ATS). A utility outage is automatically sensed by the system control logic that disconnects the load from the grid by means of the ATS and starts the generator. Typically, a diesel generator can start and assume load within 10 seconds. The control logic may also be programmed to prioritize loads so that the generator is not overloaded and the most critical loads are protected.

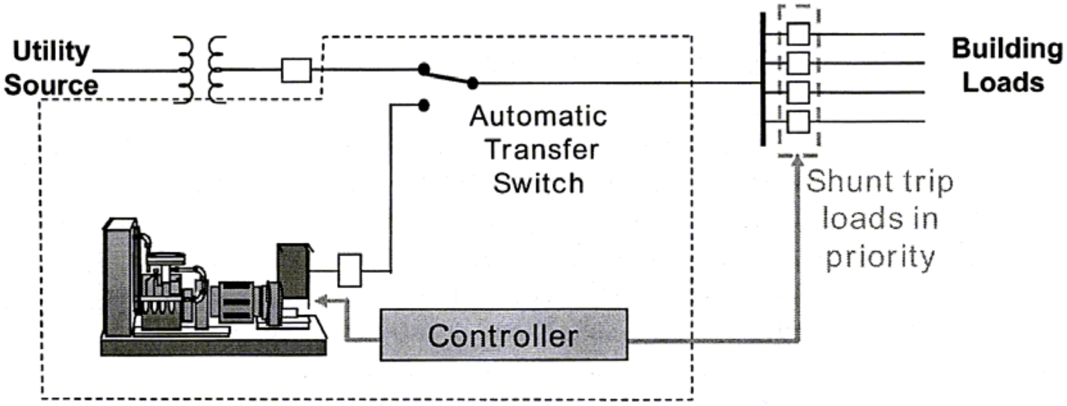

Figure 2.1 Typical Standby Generation Configuration

While the system protects from long-term outages, there is no protection from short duration voltage disturbances. The customers that would utilize such a system have either an economic or a health and safety need to avoid extended outages but are relatively insensitive to short-term PQ issues. Customers that are sensitive to short-term PQ fluctuations would derive very little benefit from this configuration.

There are a large number of standby systems in place. There have been some attempts made to harness this large resource of "cold iron" for providing indirect electric system peak load support. These schemes are hampered by the air pollution emissions associated with uncontrolled diesel power generation and also by the restrictive nature of the switching, control, and load connections. Generally, additional engine permitting, emissions clean-up often by alternative fuel capability, and more sophisticated switch-gear are needed to support this DG function.

Figure 2.2 shows a standby or secondary DG system that utilizes energy storage and a more sophisticated control system to provide not only protection from long-term outages but also from short-term and momentary disturbances as well. The on-site energy storage provides the ride through capability until the generator can start. The static switching and controls technology ensure that these changes from the utility source to the standby or secondary DG source are not detected by the load.

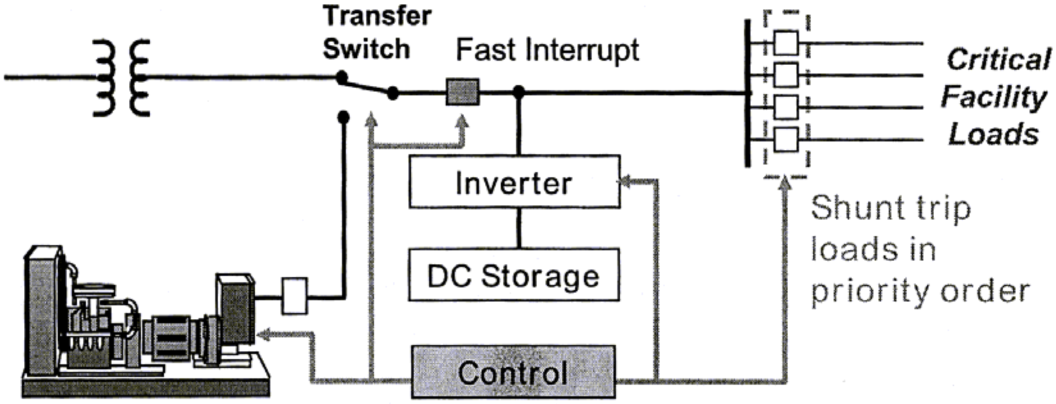

Figure 2.2 Standby or Secondary DG System Offering PQ Support

This is a common configuration for PQ sensitive customers that utilize UPS supported by battery energy storage system and one or more standby generators. In very sensitive applications there are usually redundancies in some or all of the component parts of the system. The same (or very similar) level of reliability and power quality protection can be provided by this type of system with an upgraded generator and permitting to run for economic rather than emergency reasons. Emissions control, dual-fuel conversion, or replacement with gas-fired technologies could be used to make the system available for peak shaving. A customer could reduce his own peak demands by operating 1500-3500 hours per year. However, a more mutually beneficial application for the customer and the utility is to operate only during system-wide peak events – generally 75-400 hours per year. This type of application requires an automatic notification or dispatching system as part of the control package. An alternative is for the utility to provide a price signal that could trigger the turn-on of the DG systems.

Figures 2.3 and 2.4 show alternative configurations for combined heat and power systems. In the first case, the system operates in parallel with the utility to provide low cost electric and thermal energy. The generator type, controls, and switch-gear need to be specially configured to operate during a grid outage. **Figure 2.4** shows a system capable of operating independently of the grid with anti-islanding protection. Such a system could provide the reliability of a standby generator. With the addition of UPS system and energy storage media, a full premium power system could be available.

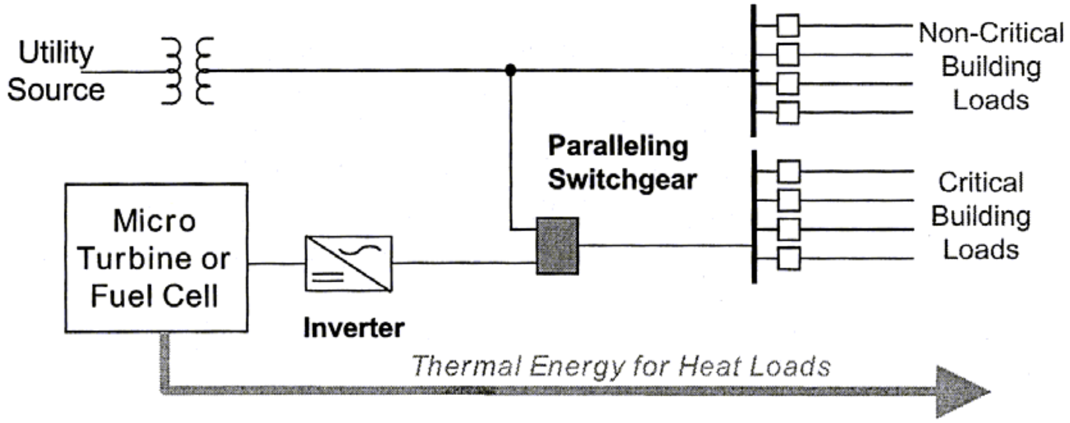

Figure 2.3 Primary DG System with PQ Responsibility for Critical Loads

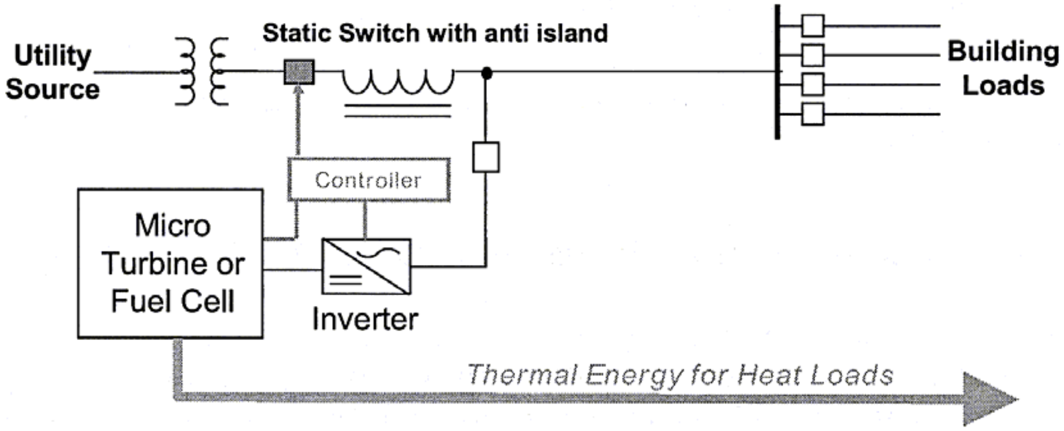

Figure 2.4 DG with Soft Grid Connection Supporting Critical Loads

Figures 2.5 and 2.6 show how renewable DG with intermittent supply characteristics, such as a wind turbine generator or a photovoltaic array, can be configured to supplement energy consumption and support onsite power quality requirements.

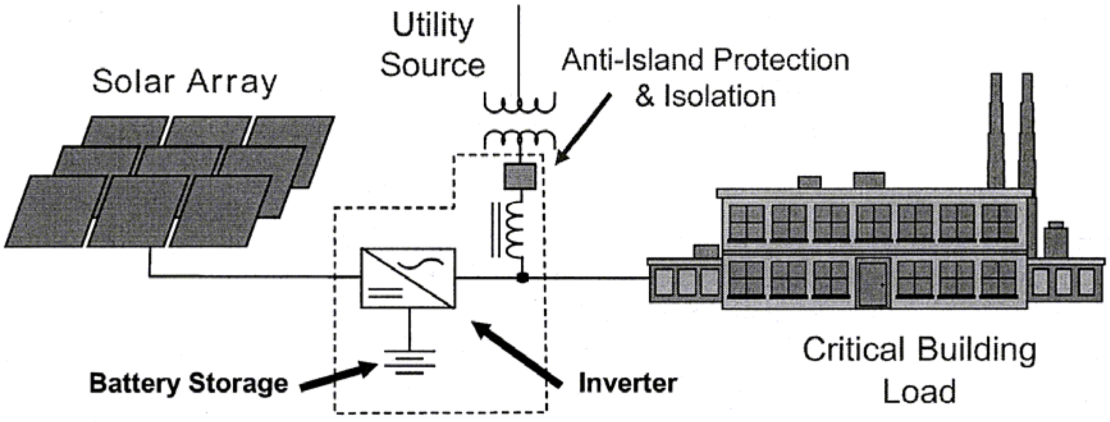

Figure 2.5 Use of Intermittent DG within PQ Environment (Solar PV)

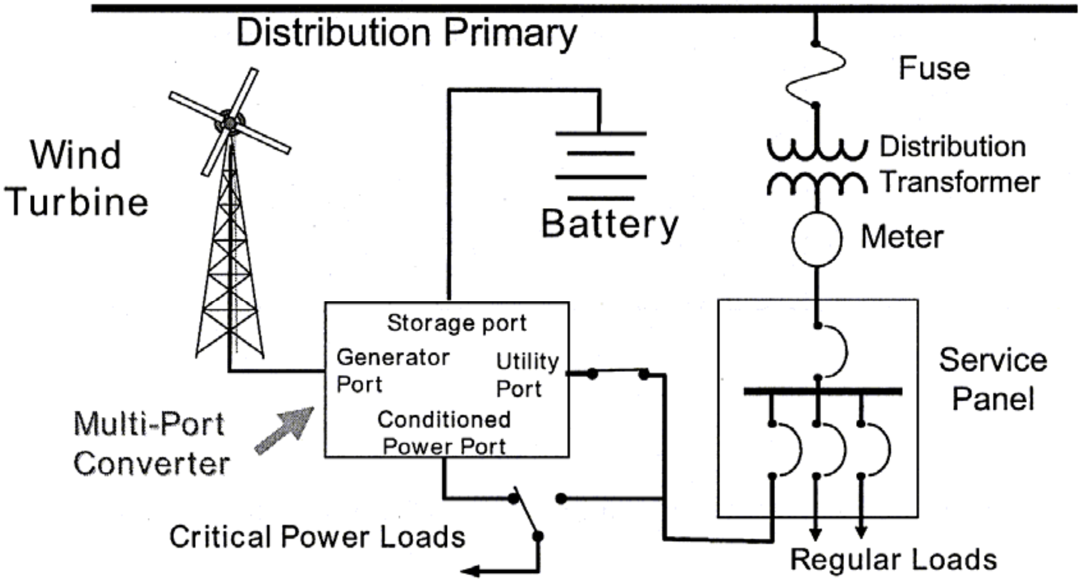

Figure 2.6 Use of Intermittent DG within PQ Environment (Wind)

Figure 2.7 shows an ultra-high reliability system with a unique architecture.[3] The system is designed to supply computer grade electricity at 99.9999% availability over 20 years. The system is designed to operate independently of the utility grid indefinitely. The system integrates on-site power generation, rotary UPS, and flywheels on a DC power bus. Multiple redundancies allow for maintenance or change-out of individual system components without affecting overall availability and power quality. Unlike other UPS systems incorporating standby power generation, this system utilizes DG as the primary energy source. Grid power is used as the back-up. During normal operation, the system is not interconnected with the grid. This design feature avoids interconnection issues of grid stability, synchronization, and pass through of unwanted variations in PQ. The DC power link allows for each generator to operate independently and for DC/AC power conversion via DC/AC motor generators to be provided redundantly to each load center. For 48 VDC telecom loads, a DC-DC converter plant reduces the high-voltage DC output to the required voltage. Flywheels protect against a DG unit outage or a step load change. Waste heat from the continuously operating DG system is used to provide cooling for the sensitive electronic load centers.

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[3] Whit Allen and William E. Cratty, *Very High Availability (99.9999%) Combined Heat and Power Systems for Mission-Critical Applications*, Sure Power Corporation, Danbury, CT.

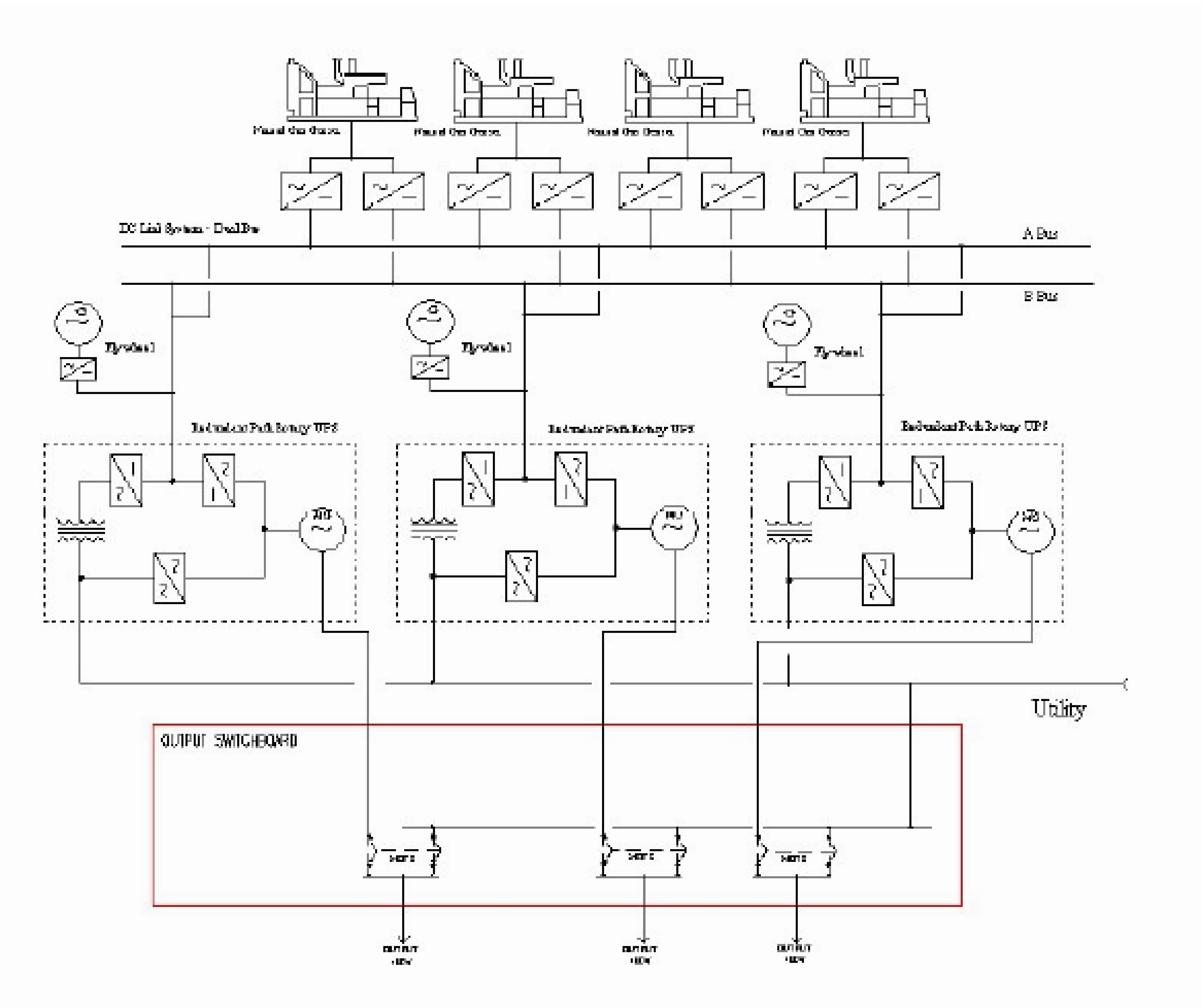

Figure 2.7 Ultra High Reliability System Using DC Bus (SurePower)

The advantages of this configuration as defined by its developers are as follows:

- Source voltage and throttle failures don't draw power from other sources
- Critical load faults are isolated to one motor generator, with fault clearing being superior to a static UPS
- Control system failures do not result in system failure
- There are no interdependencies on the operation of multiple generators

- ❑ There are no reverse power or directional relays
- ❑ The potential for synchronization or cascade failures is eliminated.

When integrating DG with a UPS or other premium power solution, there are a number of compatibility issues that must be considered for correct operation.[4]

- ❑ The on-site energy storage capacity must be sufficient to allow start up of the generator before the storage capacity is exhausted. For BESS, storage time might be up to 15 minutes. For a flywheel system, typically the storage provided is less than thirty seconds. A diesel generator capable of starting and assuming load within 10 seconds would be compatible with a flywheel energy storage system but a microturbine that might require 90 seconds to start and assume load, might not.
- ❑ The ability of the DG system to support the critical load independently of the grid must be carefully considered. The equipment must be sized so that motor starting and other large step loads can be handled without loss of voltage control. In addition, certain types of DG such as fuel cells or microturbines have less ability to handle step loads than a diesel generator.
- ❑ Systems operating in parallel with the grid must have the required interconnection protections for positive disconnect, voltage and current regulation and system protection. The DG system logic fault sensing and disconnect/reconnect could be incompatible with distribution feeders using fast reclosing technology for fault clearing.
- ❑ There are many serious compatibility issues for a standby generator or DG system operating with UPS
  - ♦ Constant temperature HVAC controls used for computer rooms use pulsed heating that creates many load pulses per second. This pulsating load on the gen-set alters frequency faster than the engine and governor can adjust. This can result in the gen-set failing to come on when needed or fail to synchronize.
  - ♦ The use of static filters on UPS may create excess capacitance at light load conditions leading to a leading power factor with respect to the gen-set. Such a condition may lead to the generator losing voltage control. Oversizing of the gen-set and/or modification of the standard control logic can solve generator/DG incompatibility problems, but the issues must be carefully addressed where DG is to support a PQ function.

Power quality/reliability systems need to include important design criteria that relate to “system hardening.” First, it is important to understand the business mission and the tolerance for outages. For critical systems requiring 100 percent availability, there are a number of requirements:

- Redundant systems are specified including generator capacity, control systems, paralleling boards to link the DG systems together, and automatic transfer switches where paralleling is not used.

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[4] Gary L. Olson (Cummins Power Generation), “UPS Systems and Gen-Sets: Better, But Still a Potential Problem,” *Electrical Construction & Maintenanc*e, February 1, 2004.

- Systems need to be separated from each other into secure rooms with fire rated walls. The system must remain working even if every component in a single room is knocked out, as in a fire.
- There are not many special requirements for the DG systems in standby mode (other than extra capacity) although dual starters, special fuel filters, and high quality hoses are required.
- Systems must run off the standby DG power reliably during extended tests of switchgear and battery systems. When diesel generators are used, sometimes this testing protocol is constrained by the limited hours of the diesel-operating permit.
- For DG systems that are used for prime power, all aspects of power quality from the DG system are very important.

3. CUSTOMER PERSPECTIVE ON POWER QUALITY ISSUES

The project team conducted a series of interviews with large commercial, industrial and institutional electricity consumers in New York State. The composition of the interviewees varied markedly from refrigerated warehouses, to plastics and other continuous and batch manufacturing processes, to hospitals, and the communications and financial services industries.

The interviewees that participated in the surveys are not representative of the customer mix of New York State or its regions; they were selected to represent sectors of high sensitivity to power quality disturbances and areas that had experienced, in their view, a high level of such disturbances. In addition, there was a high rate of non-responses among the businesses contacted. Therefore, the information that has been derived from the interview process is best viewed as a qualitative compilation of the perspective of customers who view power quality as an important issue. As the market characterizations in **Appendix A** showed, this high sensitivity market is a small share of the total commercial and industrial power markets.

A detailed summary of each of these interviews is provided in **Appendix C**. Within this section the project team distills some of the common elements that arose out of the entire set of interviews. The discussion is structured around these themes:

- ☐ Power Quality & Reliability Problems Encountered at the Site,
- ☐ Costs Incurred Due to Power Quality and Reliability Problems,
- ☐ Mitigation Measures Taken to Reduce the Costs of Incidents, and
- ☐ Site Analysis, if Any, of a CHP Solution

3.1 Power Quality & Reliability Problems Encountered at the Site

If there was a common theme among a disparate group of interviewees, it was this that tolerances to power quality problems have been decreasing over time. Whether it is in manufacturing, the institutional sector, or banking, finance and communications, new equipment and processes are increasingly sensitive to poor power quality. Interviewees across the spectrum referred to the sensitivity of equipment to power quality.

In plastics manufacturing utilizing computer numerical controlled (CNC) equipment and computer-aided design (CAD) stations, momentary interruptions can be very costly. If the machines shut down, it takes hours to reprogram and re-start. Shutdown of the CNC machine could damage the work-in-progress resulting in significant costs due to lost materials and days to rework. Equipment at the plastics manufacturing site was being tripped due to voltage sags and a frequent phase voltage imbalance problem.

Another manufacturer reported that voltage and current sags caused machine tripping due to the sensitivity of controls on the machines. For example, under voltage relays will be tripped, circuit boards with fixed voltage sensing will trip on phase loss, and alternating current induction motors will draw excessive current and trip the overloads. Long duration over- and undervoltage situations have a significant impact on production and require manual corrections to optimize capacity.

A second plastics facility reported a similar story, in a different utility service region. They never lost all of their power, but would lose one phase (typically L3). Motors would trip when there was a phase drop off. The utility denied the problem at first, but later made the necessary repairs. The cable under the street was upgraded and voltage is now consistent, except when the facility attempted to bring on a new machine.

A hospital reported that flickering lights, surges, spikes and transients have become more frequent. The local utility does not warn the site when maintenance and testing of feeders is scheduled. On the contrary, a communications facility noted that the local utility did give them advance notice of testing and maintenance procedures and warned them of plans for voltage drops (brownouts).

The tolerances to power quality variations and the amount of losses involved vary greatly across the interviewees. In a couple of instances we interviewed businesses that required extremely high grade power. These businesses made huge investments in preventative measures. One of these businesses experiences approximately 15-20 incidents (spikes, transients) on any given day that could affect their operations, but the business has invested in a system of protections that minimize the impacts of these problems.

3.2 Costs Incurred Due to Power Quality and Reliability Problems

The diverse group of customers interviewed as part of this study experienced a variety of costs due to power quality and reliability problems. The costs included the value of lost production, increased labor costs, damage to work-in-process with resulting reduced value or costs of reworking, value of lost materials, equipment damage, revenue (opportunity) loss due to failure to perform contracts, transaction processing losses and the need to ration services to customers.

The costs of disruptions are not typically quantified, with a few exceptions. In one instance a plastics business reported that when its machines were down due to power quality problems, it suffered the indirect cost of lost production but also incurred the direct cost of paying all line workers even though no product was being made. Another plastics business reported documenting $16,500 in equipment damage costs in a single month. This figure was said to be quite conservative as it only included the direct costs to repair damaged equipment that could be directly linked to poor power quality. The company did not document and account for “softer,” though no less real costs, such as the value of lost production, losses to work-in-progress and other costs.

In another continuous manufacturing process costs incurred due to poor power quality included losses when a machine trips out while raw materials are on the line. This would require re-processing the materials input, could require overtime pay premiums of $35 to $40/hour, might involve damage to the machinery that was working the input material, down time and regrounding in the machine shop. It could lead to loss of goodwill from missed delivery dates and at worst an incident could mean a total cost of $60,000 to $70,000.

In the communication sector one business stated that the costs of downtime could be huge. Its contracts provide that a precise amount of advertising time be delivered or the buyer is not required to pay. Depending on the duration and the timing of the downtime, the losses could run into millions of dollars. Other losses that are incurred with momentary power losses were equipment damage and replacement costs. This business requires that equipment be running continuously, perhaps for a couple years at a stretch. When a power loss occurs a certain percentage of continuously operating equipment, in the range of 2% to 3%, will not power back up. The company incurs losses due to early replacement of equipment, equipment repair and the labor time to necessary to identify all malfunctioning equipment and quickly change it out.

The hospital interview uncovered a different assessment of power quality and reliability costs. The hospital noted that with every test of its emergency backup generators, there is a "$10,000.00 hit to equipment." The hospital incurs significant costs to replace ballasts, bulbs and computers damaged by surges, sags, spikes and transients. Specialty machines, such as MRIs and Catscans, are vulnerable and could be heavily damaged by a transfer of power. The hospital tries to give 30 minute warning to operators of CAT-scans and cardiac catheters, something that is obviously impossible in an emergency.

3.3 Mitigation Measures Taken to Reduce the Costs of Incidents

Measures taken by a financial services company, for which cost was not a major consideration, included: all critical loads strictly connected to a UPS system sensitive to frequency range; each generator has two separate power panel feeds, with three 750 kVA modules in each feed; more than one control room; special specification for the generators, with the cooling capacity increased so they are primary rated; weekly, monthly and annual testing of generators; ATS has its own chillers, air conditioning and ventilation with a battery room; fuel tanks are physically separated using two diverse paths; and UPS units are physically separated on separate floors, with inherent fire barriers and separate "bathtubs" with drains to take water away from systems.

A paper mill also has UPS for its computers, a hospital for its computer room and medical equipment; a university for its computer systems; a metal manufacturing plant for its boilers, phone system and augmentation of its switchgear; a company making "superalloys" for its main computer facility, satellite computer servers and computer controls in the manufacturing area: a manufacturer of precision plastic parts for its microturbines controller and for its computer servers; and a major network television and radio broadcasting center for all critical systems.

The major network television and radio broadcasting center, with a critical need for reliable and high quality power, also installed four emergency generators to back up its critical systems and UPS system and fitted its UPS system with transient filtering/suppression capability. The active, on-line system will always put power out at the correct voltage, or will go to battery backup and emergency generation. In extreme situations, the equipment will shut off to prevent damage.

The hospital might also seriously consider CHP, were it not for financial and siting constraints. The metal manufacturing plant also attempts to purchase equipment that can withstand less than ideal power quality, varied operation to try to “catch” harmonics, sized motors and adjusted overheads to protect against voltage/current sags, added isolators and power conditioners in problem areas to avoid transient related problems and shifted some production to the night shift to avoid power quality problems that are more likely to occur during summer days and evenings. The “superalloy” manufacturer has installed a transformer substation to isolate internal plant power quality from the surrounding distribution system, a standby generator with an automatic transfer switch, other gas-fired emergency generators dedicated to emergency lighting circuits and a 9,200 kVAR filter bank to deal with harmonic problems and power factor correction. A temperature controlled (very cold) warehouse company sharing a building with a manufacturer of plastic items installed a CHP system as well as a series of capacitors. A manufacturer of precision plastic parts implemented one of the most comprehensive measures, installing a hybrid onsite power system with both wind turbines and microturbines.

3.4 Site Analysis of DG/CHP Solutions

Of the nine firms interviewed:

- Two firms have active on-site CHP facilities. One, an upstate plastics manufacturer, cited ongoing power quality and reliability problems as a major factor impelling it to consider and ultimately install CHP.
- For the facility incorporating CHP as part of an overall strategy to improve power quality and reliability, the situation has improved. The upstate plastics manufacturer has indicated that phase imbalance problems that had repeatedly damaged microprocessor-driven equipment and ruined product have been resolved by virtue of its deployment of a microturbine/wind hybrid system.
- An upstate copper and alloy manufacturer, faces a number of power quality issues, ranging from voltage sags causing machines to trip; long duration over- and under-voltage impacting the copper melting process; and harmonic noise. However, DG/CHP is not considered to be an attractive option because: the company receives inexpensive NYPA “Power for Jobs and Economic Development” making it more difficult to undercut the cost with a CHP unit; the local utility’s standby tariff eliminates most of the benefits of a system optimally sized to steam load; and the CHP system oversizing necessary to avoid the utility standby charges requires excessive capital costs and would result in less than optimal utilization factor.
- A hospital in Queens faces power quality issues ranging from relatively minor (blown ballasts and computers when emergency generators run) to the life threatening (such as when the back-up generator supplying life safety equipment was lost during the 2003 blackout). Financial resource constraints appear to be the major factor precluding the hospital from pursuing CHP at this time. Difficulty finding a sufficiently large and properly located site is another problem.
- Two other traditional manufacturing firms have indicated that external power quality problems and reliability have not had a material impact on plant operations. One, a forge

plant specializing in superalloys for jet and rocket engine rotors, experiences few external power quality problems confined mainly to transients caused by lightning strikes. The other, a paper mill located near the Canadian border, is fortuitously located right on a 115 kV line; loss is confined to relatively minor (less than $10,000) and occasional (once every couple years) damage to equipment, product in process being rendered “off-grade” and costs of cleaning and restarting equipment. Both firms have installed UPS to support critical computer load. While both firms suggested that a CHP application might offer some power quality and reliability benefits, these would be secondary considerations to potential energy cost savings. In each case, however, utility standby charges and exit fees undercut the economic viability of CHP. CHP might become more attractive in the future as new standby tariffs are phased in.

- Two “new economy” firms, though highly sensitive to power quality and reliability issues, have not actively considered CHP for this purpose. Each firm has recently taken steps to structure its operations to minimize business disruption, instituting, among other things, state-of-the-art on-line UPS systems with back-up generation to support critical load. Management’s confidence in the robustness of the assets currently devoted to providing continuous, high quality power limit the prospects for near-term deployment of CHP, except perhaps in the context of a cost-effective alternative to refurbishment of older back-up generation. Other factors cited as working against CHP include the lack of on-site hot water or steam requirements; space considerations; concerns about natural gas price volatility; and uncertain economic benefits.

4. ECONOMIC ANALYSIS OF INTEGRATED POWER QUALITY DISTRIBUTED GENERATION SOLUTIONS

Typically, power quality investments and DG investments are evaluated separately by a facility. This section provides a framework for evaluating the costs and benefits of investments in power quality/reliability control equipment based on the expected frequency and types of power quality events, the economic cost of those events to the facility, and the capital and operating costs of power quality mitigation equipment. The separate economic benefits of distributed generation investments (CHP and peak-shaving) will be overlaid onto this framework. The value will be determined both in terms of the overall value of the combined systems to the facility and also in terms of the incremental power quality value of the DG investment.

4.1 Economic Performance Model

Table 4.1 provides a hypothetical example of the power quality disturbances seen by a large commercial or industrial customer on an 11-kV distribution circuit. It is assumed that there are 20 voltage sags throughout the year lasting only a fraction of a second each. These sags trip sensitive equipment off-line resulting in a 50-minute loss of productivity for the facility for each occurrence. Only two momentary interruptions are experienced per year of about 2-seconds each, but these interruptions disrupt the facility for 1.4 hours each time. As shown in Appendix A (Figure A4) about 12% of customers are this sensitive to voltage sag or momentary interruption and about 2% of customers are much more sensitive. Finally, about every other year the customer can expect an outage of about one hour or more. Recovery from such a long duration outage requires 4-hours plus the time of the outage or 5-hours in total. In this example, there are 22.5 events during the year with a mean time between forced outage (MTBF) of 16.2 days. The approximately 30 minutes of voltage abnormalities during the year result in about 22 hours of facility disruption.

Table 4.1 Assumed Power Quality Events and Customer Sensitivities

Power Quality Disruptions	Occurrences per Year	Duration per Occurrence	Facility Disruption per Occurrence	Total Annual Facility Disruption
Voltage Sags	20	0.14 Seconds	50 Minutes	16.7 Hours
Momentary Interruptions	2	5.3 Seconds	1.4 Hours	2.8 Hours
Long-Duration Interruptions	0.5	60 Minutes	5.0 Hours	2.5 Hours
Total Events	22.5	30.22 Minutes		22.0 Hours

Voltage Availability	99.99425%
Customer Availability	99.74924%
MTBF	16.2 Days

An economic cost for the facility disruption is then determined. For an actual project evaluation, these values would come from an assessment of the facility performance over a period of time. For this analysis, we will first look at costs reflecting the sensitive market segments as defined in Section 2 and then look at the break-even costs that would economically justify each level of power quality protection. The costs for specific facility types have been estimated on a unit cost basis for process industries and commercial businesses:

- A 15,000 kW metal processing firm with a cost sensitivity of $15 per unserved kW would have an annual power quality cost of nearly $5 million (22 hours of facility downtime at $15/kW for 15,000 kW.)
- A 1,500 kW plastics manufacturer with a cost of $3/kW would have an annual power quality cost of close to $100,000 per year.
- A 5,000 kW financial institution with a cost of $150/kW would have an annual power quality cost of $16.4 million. Of course, it is inconceivable that such a facility would not, therefore, invest in redundant UPS to insure that such costly disruptions do not occur.

This is a simplified view of the costs. Many facilities react differently to short-term versus long-term disruptions. In addition, when considering mitigation investments it is important to determine what percentage of the load is sensitive to the disturbance and therefore needs protection. The average costs of a power quality disruption shown above are derived from the overall facility load, even though only a portion of that load may actually need protection.

4.2 The Costs and Benefits of Power Quality/Reliability Mitigation

Using this simple framework, it is possible to evaluate alternative configurations to strengthen reliability and power quality. This analysis serves to define a baseline cost and value for such systems to which distributed generation can be added. The basic components to be considered are a standby generator to handle long duration disturbances and a UPS system with short-term energy storage to provide ride-through capability for short-term disturbances. **Figure 4.1** shows a system consisting of a UPS system, energy storage, a standby generator, and static switch gear to provide seamless transfer of power from the utility feed to the generator.

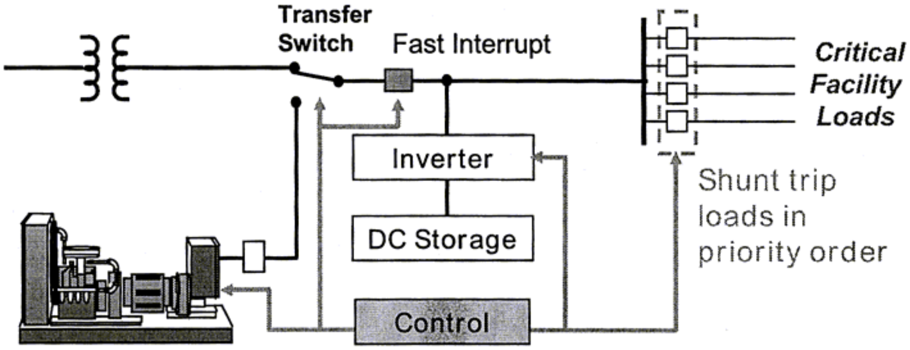

Figure 4.1 Typical System for PQ and Reliability Support

The estimated costs of a hypothetical system of 1,500 kW is shown in Table 4.2. A single 1,500 kW diesel gen-set with basic switch-gear and installation costs $375/kW. This does not include costs for a separate building for the generator which would require an additional $200/kW. A basic UPS system with battery storage and necessary switch-gear to tie into the service, the load, and the generator would cost $460/kW for a total system capital cost of $835/kW. The annual carrying charges for the equipment was based on a 10% annuity assuming 15 year life for the generator and switch-gear and 7-year life for the UPS. Generator maintenance adds about $5/kW year. The operation of the double conversion UPS is assumed to consume about 1% of the energy input of the system which at an average power cost of $0.08/kWh results in an additional $5/kW-year. Therefore, the total annual costs for the system approaches $150/kW or $224,000 per year to support the 1500 kW installation.

Table 4.2 Estimated Capital and Annual Costs of a UPS System with Standby Generator

	Capital Cost	Annual Carrying Charges	Annual O&M Costs	Total Annual Costs	
	$/kW	$/kW	$/kW	$/kW	$/year
Standby Diesel Generator and Switchgear	$375	$49.30	$5.00	$54.30	$81,454
UPS with Battery Energy Storage	$400	$82.16	$5.00	$87.16	$130,743
Additional Switch-gear	$60	$7.89	$0.00	$7.89	$11,833
Overall System Cost	$835	$139.35	$10.00	$149.35	$224,030

The system described above can then be characterized in terms of its impact on the number of voltage sags, momentary interruptions, and long-duration interruptions. For this analysis it was assumed that the UPS system had an availability of 99% and the diesel generator had an availability of 95%. The UPS eliminates 99% of all voltage sags and momentary interruptions. The standby generator eliminates 95% of long-duration interruptions, or more accurately, converts them to momentary interruptions that are then eliminated by the UPS. **Figure 4.3** shows this result. Facility disruptions are reduced from 22 hours/year to 0.2 hours. The mean time between forced outages (MTBF) has increased from 16.2 days to only one event per 4 years. To justify this improvement in reliability/power quality, the customer must have an economic benefit that offsets the $224,000 annual cost of the system. This break-even cost for the customer is $6.86/kW. ($224,000 / 1500kW / 21.8 hour reduction in disturbances)

Table 4.3 Power Quality Disruptions for System with UPS and Standby Generator

Power Quality Disruptions	Occurrences per Year	Duration per Occurrence	Facility Disruption per Occurrence	Total Annual Facility Disruption
Voltage Sags	0.2	0.14 Seconds	50 Minutes	0.2 Hours
Momentary Interruptions	0.02475	5.3 Seconds	1.4 Hours	0.0 Hours
Long-Duration Interruptions	0.00025	60 Minutes	5.0 Hours	0.0 Hours
Total Events	0.225	0.02 Minutes		0.2 Hours
Voltage Availability		100.00000%		
Customer Availability		99.99769%		
MTBF		1622.2 Days		

Given the nature of the PQ disturbances at this site, the majority of incidents are short-term fluctuations that are handled by the UPS. The standby generator only handles the single long-term outage that occurs about once every other year. The facility availability can be evaluated separately for the UPS and the standby generator with the incremental break-even costs to the facility calculated. **Table 4.4** summarizes this calculation. A UPS without back-up is economically justified for customers whose avoided costs of facility disruption is $4.93 per kW or higher. A standby generator is comparatively more expensive for the additional protection provided with a break-even cost of $31.76/kW. The standby system, however, controls against the possibility of a potentially devastating long-duration outage, so, in that sense, the system provides an insurance value. A facility operator would prefer a known annual cost to one that is highly variable and uncertain.

Table 4.4 Mitigation Effectiveness, Costs, and Break-even Value

	Facility Disruption	Annual Cost of Mitigation	Break Even PQ Value
	Hours/year	$/year	$/kW
No Mitigation Equipment	22.0	$0	NA.
UPS without Standby	2.7	$142,576	$4.93
Standby without UPS	20.3	$81,454	$31.76
Combined UPS/Standby System	0.25	$224,030	$6.90

4.3 Distributed Generation Economic Benefits and Integration with PQ/Reliability

Separate from the need to avoid power quality and reliability disruptions, a facility may seek to reduce its energy costs by installing a distributed generation project. In this section two DG projects, a peak shaving installation and continuous combined heat and power system, are evaluated strictly in terms of their energy savings and then the power quality benefits are considered and the improvement in the DG economics is shown.

4.3.1 Peak-Shaving

New York State has instituted several emergency demand response programs to help the regional utility system control the need for expensive peaking power. A utility or regional grid often needs 20% or more of its total capacity for less than 100 hours per year. This “slice” of power is extremely expensive to generate or to purchase on the wholesale market. Therefore, utilities and independent system operators are motivated to develop, at least in part, solutions that involve customer demand reduction or activation of customer-sited distributed generation. With so much imbedded capacity at customer sites in the form of standby diesel generators, it would seem to be a good fit for both customers and the utility system to use this capacity for demand reduction. However, in some areas, diesel generators cannot participate in these programs because they are permitted only for emergency operation and testing, not for economic use. In addition to the environmental and permitting issues, many in-place diesel generators are not connected optimally to the customer’s peak loads.

In this example, a gas-fired generator is designed from the start to provide both the economic benefit of peak load reduction and it also serves as the facility’s standby generation. This configuration would not be appropriate for certain health and safety applications that require on-site fuel storage and rapid start up, but for many applications in which the need for standby is economically derived, a gas-fired generator would be acceptable.

The assumptions for this system are as follows:

- The facility configuration would be as shown previously in Figure 4.1. The generator is assumed to be a 1500 kW lean burn gas-fired reciprocating engine instead of the diesel gen-set that would ordinarily be installed strictly for standby duty.
- The gas engine meets applicable emissions requirements without the use of SCR. Its unit capital cost is $795/kW. Where the unit doubles as the standby generator, a credit of $375/kW is applied representing the avoided capital cost of diesel generator.
- The system would not need to be interconnected with the utility; it could work using an automatic or static transfer switch.
- Because of the limited duty cycle, no heat recovery is used.
- The average industrial electricity cost for industrial customers of investor owned utilities varies from a low of 5 cents/kWh at Niagara Mohawk to a high of 14.4 cents/kWh for Consolidated Edison. The simple average of industrial prices paid by the customers of the five major investor owned utilities is 8 cents/kWh. 150% of this average or 12 cents/kWh was assumed to be the avoided energy cost during peak load “emergencies.”
- Gas costs for the generator are assumed to be $6.50/MMBtu.

- ❑ A demand reduction payment, with penalties for nonperformance, of $120/kW is assumed. This payment reflects the New York ISO ICAP special case resource payment for the metropolitan New York area.
- ❑ Because this is a cooperative program, there is no utility imposed standby charges, though there are penalties for nonperformance of the generator during programmed interruptions. Any penalties that are part of the demand reduction program for non-performance are assumed not to be triggered in the example.

The characteristics, costs, and paybacks for this system are shown in **Table 4.5.**

Table 4.5 Comparison of Peak Shaving System Paybacks with and without Integration with Power Quality and Reliability Function

	Peak Shaving	Peak Shaving with Reliability
System Characteristics and Assumptions		
Generator Capacity (kW)	1500	1500
Electric Heat Rate (Btu/kWh HHV)	10,035	10,035
Electrical Efficiency (%)	34.0%	34.0%
Net Installed Cost (2003 $/kW)	$795	$420
O&M Costs ($/kW)	$3.00	$3.00
Fuel Input (MMBtu/hr)	15.05	15.05
Economic Life Years	15	15
Annual Hours of Operation	25	25
Program Payments ($/kWh)	$120	$120
Generator Availability	97%	97%
Thermal utilization Factor	none	none
Average Gas Cost	$6.50	$6.50
Peak Period Power Cost ($/kWh)	$0.120	$0.120
Annual Power Production (kWh)	36,375	36,375
Program Benefits		
Annual Program Payment	$174,600	$174,600
Avoided Power Costs	$4,365	$4,365
Generator Costs		
CHP Fuel Costs	$2,446	$2,446
Annual O&M Cost	$4,500	$4,500
Net Operating Savings	$172,019	$172,019
Capital Cost	$1,192,500	$630,000
Payback	6.9 Years	3.7 Years

The results show a significant increased benefit to the consumer by designing the DG system for the dual function of peak load reduction and emergency standby. Paybacks for the system are reduced from 6.9 to 3.7 years for the dual function system. In addition, the use of customer dispatched DG as a demand response measure during peak summer periods helps improve the reliability of the system for all customers.

The ability of this system to avoid power quality and reliability disruptions should be the same or slightly better than the one already examined using UPS and a standby diesel generator. The only exception to this is that gas-fired DG systems generally take longer to start up and pick up load than does a diesel generator. This is generally not a problem for integration with a UPS that has battery storage of 15 minutes. However, some newer systems based on only 15-20 seconds of flywheel storage would not be compatible with a gas-fired generator that might take a minute or so to reach necessary fuel pressure and a stable operating condition.

As already mentioned, some facilities with health and safety requirements for standby may not be able to substitute a gas-fired system for a diesel system. However, there has been work on dual fuel conversion of diesel engines that would preserve all aspects of the diesel engine’s functionality in an emergency, i.e., rapid deployment on 100% diesel fuel. This same system would also provide cleaner and cheaper fuel burning characteristics using primarily natural gas for economic applications such as peak shaving.

Dedicated DG facilities of the type suggested by this analysis are not widely used for utility demand reduction programs. Generally, the utility payments are not high enough to justify the investment in single-purpose generating capacity. In addition, utilities often will restrict customer participation to demand response only or to existing generation and will not allow new generation to be put in specifically for the program. More work needs to be done to demonstrate the benefits of this type of system for the utility system, the customer, and for non-participants as well.

4.3.2 Combined Heat and Power

Combined heat and power systems can also support power quality and reliability if they are appropriately configured and are capable of operation both in parallel with the grid and separately in the case of grid fault. **Figure 4.2** shows such a configuration. This configuration provides a different level of support to the facility power quality that is more like a dual feed than a stand-by system because the CHP system is designed to operate nearly continuously with a percent availability factor in the high 90%s. Consequently, the DG system itself is providing more of the short duration ride-through capability than would a standby generator because it is always operating. Grid power effectively becomes the back-up for the facility.

As shown in **Table 4.6,** a continuously operated DG system with careful control of the quality of its power output can reduce the power quality disturbances at a site even before UPS is added. From 22.5 disturbances per year with a MTBF of 16.2 days, the customer reduces disturbances to 1.1 per year with a MTBF of 324 days. This improvement can either be a specific objective of the project or a supplementary benefit that the customer would not otherwise pay to achieve.

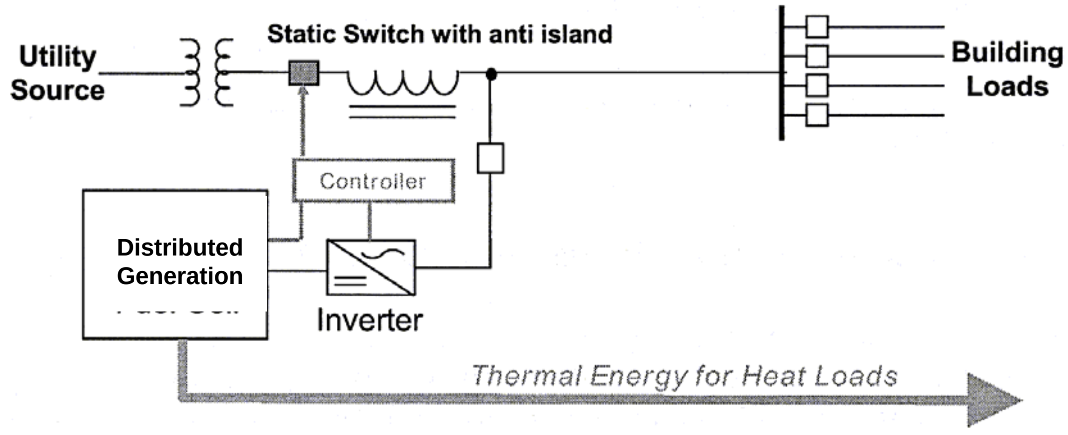

Figure 4.2 CHP System with Power Quality Functionality

Table 4.6 Impact of CHP System on Power Quality Disturbances at the Site

Power Quality Disruptions	Occurrences per Year	Duration per Occurrence	Facility Disruption per Occurrence	Total Annual Facility Disruption
Voltage Sags	1	0.14 Seconds	50 Minutes	0.8 Hours
Momentary Interruptions	0.1	5.3 Seconds	1.4 Hours	0.1 Hours
Long-Duration Interruptions	0.025	60 Minutes	5.0 Hours	0.1 Hours
Total Events	1.125	1.51 Minutes	1.1 Hours	

Voltage Availability	99.99971%
Customer Availability	99.98746%
MTBF	324.4 Days

When coupled with UPS, the MTBF increases to only one occurrence in 27 years compared with a frequency of one occurrence in 4 years for the UPS system with a standby generator.

The economics of a CHP system with and without integration into a power quality reliability function is shown in **Table 4.7**. The assumptions of this analysis are as follows:

- The same size and type generator was selected for analysis as in the peak shaving case.
- The addition of a heat recovery system and paralleling switchgear increases the capital costs by $150/kW.
- The same average power and gas costs as were described in the peak shaving case were used ($6.50/MMBtu for gas and $0.08/kWh for electricity.)

- ☐ The system has a 90% load factor (with a 95% availability factor) and 80% of the recovered thermal energy is used to displace gas purchased for an 80% efficient boiler.
- ☐ Utility standby costs, a serious issue in New York State, were approximated as 25% of the average industrial rate or 2 cents/kWh.
- ☐ The incremental power quality value was based on the comparison to the UPS with standby generator. Facility disruption was reduced by 11.5 minutes, valued at $50/kWh.

Table 4.7 CHP Value with and without Power Quality Integration

	CHP	CHP PQ Integrated
Generator Capacity (kW)	1500	1500
Electric Heat Rate (Btu/kWh HHV)	10,035	10,035
Electrical Efficiency (%)	34.0%	34.0%
Installed Cost (2003 $/kW)	$945	$570
O&M Costs ($/kWh)	$0.009	$0.009
Fuel Input (MMBtu/hr)	15.05	15.05
Total Heat recovered (MMBtu/hr)	5.55	5.55
Economic Life Years	15	15
Load Factor	90%	90%
Thermal Utilization Factor	80%	80%
Average Gas Cost ($/MMBtu)	$6.50	$6.50
Average Power Cost ($/kWh)	$0.080	$0.080
Annual Power Production (kWh)	11,826,000	11,826,000
Gas Use Avoided (MMBtu/hr)	6.9	6.9
Program Benefits		
Avoided Utility Power Costs	$946,080	$946,080
Avoided Gas for Process Use	$284,415	$284,415
Incremental Power Quality Value		$14,344
Annual Running Costs		
CHP Fuel Costs	$771,380	$771,380
Annual O&M Cost	$106,434	$106,434
Utility Standby Charges	$236,520	$236,520
Annual Operating Savings	$116,161	$130,505
Capital Cost	$1,417,500	$855,000
Payback	12.2 Years	6.6 Years

The payback period for a CHP investment that also supports a UPS system and provides facility backup in case of an outage is almost half that of a CHP system that does not support those functions. The reduced payback period is primarily from the reduction in power cost due to the avoidance of the need for a diesel standby generator. The incremental power quality value is comparatively minor in this example because both systems being compared are also being supported by a UPS. Some facilities that do not have UPS because of lower costs associated with power quality disturbances would see a greater power quality benefit from having a continuos DG system operating compared to a standby generator, though these benefits are still minor in comparison to the thermal and electric cost savings.

5. CONCLUSIONS

The project team spoke with nine facility managers in sensitive industries throughout New York State about their power quality and reliability issues. While, the very dramatic extended Northeast blackout of 2003 created problems for most of them, this once in 25 year event is not as important as the more subtle and more frequent disturbances these facilities experience every year, every summer, and, in some cases, nearly every day. Problems arise with computers, microprocessors, fluorescent light ballasts, sensitive medical imaging equipment, variable speed drives, computer directed design and manufacturing, critical communications equipment, nuisance trips on circuit breakers, overheating of equipment, etc. Some facilities don't know what is causing their equipment to break, go off-line or lose data; they just go in and fix it to get back up and running. Other facilities have become very sophisticated in monitoring their power signal and in diagnosing problems.

All of them have made some level of power quality/reliability enhancing investments to protect their operations. Both centralized and equipment level UPS systems were used. Power factor correction, harmonic filters, isolation transformers, and other equipment were also used to support specific facility issues. Most included standby generation as part of their protection scheme. Two facilities had in-place and operating combined heat and power facilities and a number of others had done CHP feasibility studies. Of the two operating CHP systems, one was an integral part of the facility power-quality protection system. In the other case, the facility manager was very interested in this issue but had been unable to install a system capable of running independently of the grid due to restrictive utility interconnect requirements. He was continuing to push the utility for addition of that capability to his DG system. One facility, in New York City, uses its standby diesel generators to participate in the ICAP demand reduction program. This facility was thus fortuitously operating on its own generators under an ICAP demand reduction when the blackout hit in 2003.

The Public Service Commission (PSC) has required that utilities file power quality and reliability (PQR) reports. These reports have created a common set of metrics for defining the issue in terms of average interruption frequency, average interruption duration, and average service restoration time. Review of the PQRs from the major investor-owned utilities in the state shows that high/low voltage excursions ranged from 160 to 281 incidents per year by region for one utility. Voltage quality issues occurred thousands of times per year within each service region. Utilities have also engaged in case studies and customer interviews in an attempt to better quantify the issues and improve operations. Still, from the perspective of the customers contacted for this study, utilities were generally not helpful in identifying and diagnosing power quality problems. Consequently, to get to the root of PQ related problems, customers had to install monitoring equipment and identify and diagnose the problems themselves. Armed with such investigative data, some customers were then able to get the utility to act to correct persistent low voltage or phase imbalance conditions.

The basic premise for this study is that distributed generation can be used to support customer's power quality and reliability needs and by so doing the value of distributed generation is increased. A number of configurations for enhancing power quality, with and without on-site generation, were defined. Two DG applications, peak shaving and combined heat and power, were evaluated in terms of the value of integration into a PQ/reliability framework. In both cases, integration results in a reduction in capital costs due to the avoidance of the investment in a diesel standby generator. For a simple, peak shaving system, the incremental investment for providing an environmentally acceptable gas-fired generator in place of the diesel standby unit is little more than half of what it would be in a straight peak shaving project. For a more complicated CHP system, the avoided cost of a diesel generator reduces capital costs by up to 40%.

In addition to this capital cost benefit, a CHP system operating continuously provides a greater level of protection for the customer against external voltage sags and other momentary disruptions. For customers that are very sensitive to PQ disruptions and therefore require complete UPS protection anyway, this improvement is small. However, for less sensitive customers that are not heavily invested in UPS, the reduction in PQ disruptions could be significant.

In hypothetical economic examples for peak shaving and CHP, the advantages of integration with power quality were very important. The paybacks were reduced from 6.9 to 3.7 years for the peak shaving analysis and from 12.2 to 6.6 years for the CHP case. In both cases, the integration of the DG cost savings function with the PQ support for power quality helped to move the projects into an economic acceptance range. In other words, integration of DG and PQ functionality can move a project from *no-go* to *go*.

There are issues that need to be addressed before DG/PQ integrated projects become more widespread:

- Both standby and other types of distributed generation can themselves insert PQ disruptions into both the customer and the utility system, and there are specific issues of compatibility between customer generation and UPS and capacitor banks. It is very important to address the issue of power quality in designing and building a DG system. Design, demonstration, and monitoring projects could help to eliminate potential problems and also to provide a database of correct practices for future installations.
- Interconnect rules that restrict the ability of DG systems to provide site back-up power during grid outages should be re-examined from both a technical and economic perspective.
- The design and implementation of emergency demand response programs should allow or even encourage participation by customers with DG systems.
- Current tariffs make customer sited DG generally unprofitable for utilities. In order to encourage customer DG, a mechanism for monetizing benefits to the utility system and other stakeholders needs to be developed.
- Alternative technical approaches could enhance the opportunities for growth in this market such as dual-fuel (diesel and gas) engine technology that permits clean operation for economic dispatch with full emergency functionality, development of integrated packages

that can integrate the power electronics from DG with the power electronics packages for UPS.

- More cost-effective and packaged protection systems are needed to provide all of the necessary protection functions that local utilities are requiring for the interconnection of DG.
- *Best Practices* guides need to be developed for DG operation in a premium power environment.

APPENDIX A
SUMMARY OF POWER QUALITY ISSUES, MARKETS, AND SOLUTIONS

This section provides an overview of power quality issues and their impact on customers. The types of equipment that are used to control power quality are characterized along with the size of the market.[5] A glossary of typical electric and power quality terminology and their definitions are provided in **Appendix D**.

A.1 Normal Power Conditions

Electric utility systems generate power in the form of alternating current (AC.) The decision to use AC versus direct current or DC was made in the very early days of the electric power industry because AC generators were lighter, safer, and more robust than early DC generators. Most importantly, AC power can be stepped up or down in voltage using transformers to allow efficient transmission of power over long distances at high voltage while being able to deliver power to customers at much lower voltages. AC generators typically work by using shaft power to rotate coils within a magnetic field. The amount of power generated depends on the angle of the coil motion within the field with the field reversing polarity every 180° of rotation within the field.[6] Consequently, AC power generation takes on a sinusoidal waveform as shown in **Figure A.1**. The speed of rotation and the number of magnetic poles in the generator determine the frequency of the sine wave. In addition, large generators and large customers employ 3-phase power with power being generated or used in three phases 120 ° apart. In North America the standard frequency or wave period for power generation is 60 cycles per second – called 60 Hertz (Hz). In other parts of the World, such as in Japan, Europe, and parts of South America the standard is 50 Hz.

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[5] The source for the information in this section unless otherwise noted comes from a series of reports prepared for EPRI and provided under a single use license agreement for this study:
Markets for Distributed Resources: Business Cases for DR Applications, EPRI Report TR-109234-V2, November 1997.
Distributed Resources Premium Power Solutions, EPRI Report 1004451, January 2003.
Understanding Premium Power Grades, EPRI Report 100406, November 2000.
Information to Support Distribution Resources (DR) Business Strategies, EPRI Report TR-114272, December 1999.

[6] Photovoltaic Arrays and Fuel cells produce DC power which is then passed through an inverter to create AC. Microturbines generally produce a very high frequency AC power which is first rectified to DC and then converted by an inverter to 60 Hz AC power.

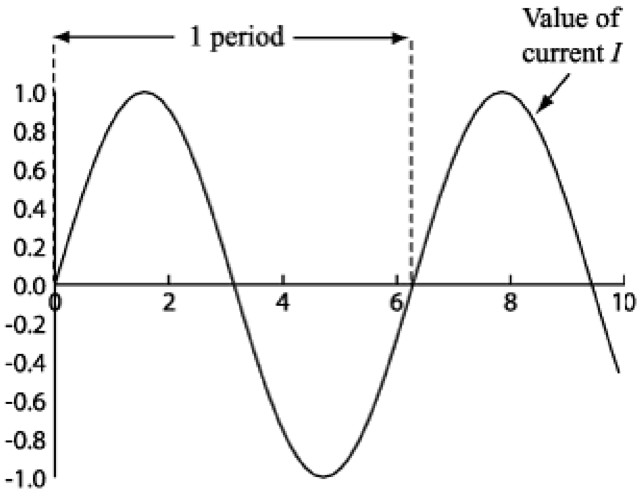

Figure A.1 Sinusoidal Waveform of Alternating Current

When there are disturbances in the power system as will be defined in the next section, this ideal waveform becomes distorted or the voltage and current get out of phase with each other. When these distortions exceed certain levels, equipment outages or damage may result. The Information Technology Industry has published a curve that defines the region in which electronic equipment can operate.[7] The ITI Curve is shown in **Figure A.2.** The curve shows that electronic equipment have steady state voltage tolerances of 90-110% of nominal voltage. Equipment can operate normally with an 80-110% voltage excursion of less than 10 seconds, 70-120% for less than half a second. Systems can operate normally with a complete loss of voltage lasting for only one or two cycles. Equipment can tolerate surges of 200% or more in voltage that last 1 millisecond or less, though such extremely short duration effects are not typical of power system disturbances.

The nature of power disturbances that cause power characteristics to fall outside this normal operation zone and the associated protection equipment that can be used to protect customers from their effects are described in the next section.

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[7] *ITI (CBEMA) Application Note*, Information Technology Industry Website http://www.itic.org/technical/iticurv.pdf

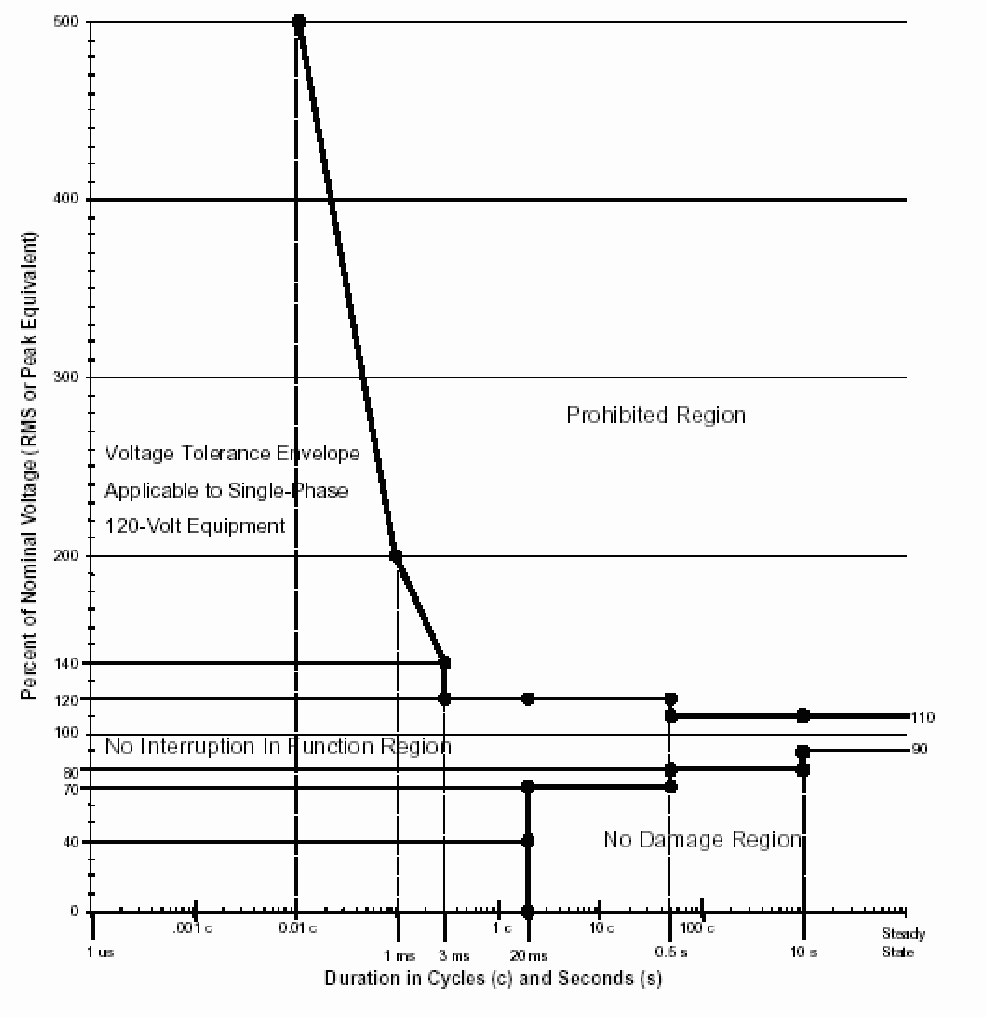

Figure A.2 Normal Operating Region for Electronic Equipment

A.2 Definitions of Power Quality Disturbances

Power quality (PQ) issues arise when certain variations, such as extreme voltage drop or sag, in the power signal create problems for a customer. Analysis of power quality disturbances necessarily encompasses the nature and frequency of the power variations themselves, the types of customers most affected by PQ variations, the sensitivity of customer owned power-using equipment to these variations, and the types of control responses utilized by the customer.

Table A.1 Category Of Power Quality Disturbances With Respect To Spectral Content, Typical Duration, And Typical Magnitude.

Table A.1 Power Quality Variations[8]

Categories	Spectral Content	Typical Duration	Typical Magnitudes
1.0 Transients			
1.1 Impulsive			
1.1.1 Voltage	> 5 kHz	<200 µs	
1.1.2 Current	> 5 kHz	<200 µs	
1.2 Oscillatory			
1.2.1 Low Frequency	< 500 Hz	<30 cycles	
1.2.2 Medium Frequency	300 Hz – 2 kHz	30-120 cycles	
1.2.3 High Frequency	> 2 kHz	2 sec. to 2 min.	
2.0 Short-Duration Variations			
2.1 Sags			
2.1.1 Instantaneous		0.5-30 cycles	0.1 – 1.0 pu
2.1.2 Momentary		30-120 cycles	0.1 – 1.0 pu
2.1.3 Temporary		2 sec – 2 min.	0.1 – 1.0 pu
2.2 Swells			
2.1.1 Instantaneous		0.5-30 cycles	0.1 – 1.8 pu
2.1.2 Momentary		30-120 cycles	0.1 – 1.8 pu
2.1.3 Temporary		2 sec – 2 min.	0.1 – 1.8 pu
3.0 Long-Duration Variations			
3.1 Over-voltages		> 2 min.	
3.2 Under-voltages		> 2 min.	
4.0 Interruptions			
4.1 Momentary		< 2 sec.	0
4.2 Temporary		2 sec. – 2 min.	0
4.3 Long-term		> 2 min.	0
5.0 Waveform Distortion			
5.1 Voltage	0-100th harmonic	steady-state	0-20%
5.2 Current	0-100th harmonic	steady-state	0-100%
6.0 Waveform Notching	0-200 kHz	steady-state	
7.0 Flicker	<30 Hz	intermittent	0.1 – 7%
8.0 Noise	0-200 kHz	intermittent	

Transients

Transient disturbances are caused by the injection of energy by switching or by lightning. These are subcycle (a cycle is 1/60 of a second or 16.67 milliseconds long) disturbances with a very fast voltage change. They typically have frequencies of tens to hundreds of kilohertz, with some even into megahertz. The voltage excursions range from hundreds to thousands of volts.

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[8] IEEE Standard 493-1997 *The Gold Book* (cited by EPRI)

Transients are also called spikes, impulses, and surges. The disturbance may be either *impulsive(a step change)* or *oscillatory (swing from high to low with or without damping).* Lightning, electrostatic discharge, load switching, or capacitor switching may cause an impulsive transient. Oscillatory transients are characterized by frequency content and may be caused by switching operations such as energizing a capacitor bank, distribution line or cable, or interruption of current to an inductive load.

The most destructive cause of transients is lightning. Transients generated from direct strikes have the greatest potential for damaging equipment—both for the utility and the customer. However, even a strike in the vicinity of the lines can induce enough energy in them to cause a significant transient.

Other transient sources include large reactive loads such as power factor correction capacitors. This transient, although less powerful than a lightning strike, still transmits enough energy to cause problems. The same is true when load transfer switching is done whether by the utility or by the customer. Adding or removing a large bulk of the load will often create significant transients. Capacitor banks also can create resonant circuits which cause magnify voltages due to harmonic sources. Basically capacitor in combination with line and load inductance can create a tuned circuit for harmonic (multiples of 60Hz) circuits and thus magnify the voltage.

Solutions to equipment upsets caused by transients include the following:

- A properly installed lightning arrestor system with a separate ground;
- Transient voltage surge suppressors (TVSS) should be installed at the service entrance or smaller systems protecting individual equipment may be more cost effective; and
- For the most sensitive equipment additional protection equipment is used such as computer grade power conditioners and ferro-resonant line conditioners.

Voltage Sags and Swells

Voltage sags and swells are variations in the RMS (root mean squared) voltage from about one half cycle to several seconds. RMS rather than peak-to-peak is how the voltage is measured on an AC system. Sags and swells are characterized by decreased/increased changes in the RMS voltage value, respectively. Sags refer to a reduction in the voltage, while swells deal with a voltage increase. A voltage swell occurs when a single line-to-ground fault on the system results in a temporary voltage rise on the unfaulted phases. Removing a large load or adding a large capacitor bank can also cause voltage swells, though typically of longer duration.

Equipment used in modern industrial plants, such as process controllers, PLCs, adjustable speed drives, and robots are affected by sags and swells. When a sag occurs, the power supply inside electronic devices uses some of its stored energy to compensate for the loss of input voltage. If enough energy is lost due to the sag, then the power supply may lose its ability to maintain an exact DC voltage to all the active components, such as integrated circuits, inside the device — even for a few milliseconds. This is long enough to corrupt data in microprocessor-based electronics and to cause malfunctions of digital equipment. Swells can damage device power supplies and/or cause resets to occur.

Overvoltages and Undervoltages

When sags and swells last for longer than 2 minutes they are classified as over or under voltage conditions. Such long duration voltage variations are most often caused by unusual conditions on the power system. Out of service lines or transformers sometimes cause undervoltage conditions usually lasting less than one or two days. Voltage can also be reduced intentionally in response to a shortage of electric supply. These *brownouts* have occurred in New York during peak summer periods. Brownouts can cause overheating in constant speed motors due to the increase in current density as well as the problems with electronic equipment that occur with short-term voltage variations. Most utility voltage regulation problems are the result of too much impedance in the power system to supply the load; customers at the end of feeders suffer the most from low voltage. Under heavy load conditions, the voltage can drop. Longer-term variations can usually be corrected by changing the tap settings on a load tap changing transformer.

Problems on the utility grid can cause higher than nominal voltages long enough to adversely affect facilities. This situation might happen because of problems with voltage regulation capacitors or transmission and distribution transformers. The utility does have overvoltage protection, but at times these devices do not respond fast enough to completely protect all equipment downstream.[9]

There are two basic solutions to utility-based overvoltage problems, each represents a different philosophy. The first philosophy is to protect the facility from these disturbances at the expense of uptime. In other words, if an overvoltage occurs, shut down the power. This is done through devices that sense the voltage level, and if they exceed a preset limit, they operate, opening the circuit. The second philosophy is to protect the facility, or at least sensitive parts of it. This approach maintains uptime while providing controlled voltage regulation. Voltage Regulators are employed to stabilize the voltage under an assortment of power disturbances including overvoltage. Many times, voltage regulation is only one part of a device's capability. An uninterruptible power system, or UPS, is one example. When utility power is available, the UPS regulates the voltage to sensitive loads. Should the source power fail, the UPS provides back up power.

Voltage regulators, or devices that incorporate voltage regulation, may be used at key distribution sites within the facility such as the service entrance, the main distribution panel, or the computer room panel. The most common types of voltage regulators, however, are small, portable units used to protect one piece of equipment or one sensitive system. Utilities also use voltage regulators on the distribution lines to maintain the voltage drop from substation to the end of the circuit feed.

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[9] Utility power systems are designed to maintain voltage with the +10% to -10% voltage range for the most part. Over and under voltage and frequency equipment is designed to protect equipment for disturbances that result in voltage excursions outside of this range.

Voltage Interruptions

Voltage interruption is the complete loss of voltage – also referred to as an outage. Interruptions can be a short duration (less than 2 minutes) or a longer duration. An interruption is caused by the opening of a circuit breaker, line recloser, or fuse, or a physical break in the line caused by a storm or accident. If there is a fault (short-circuit) in the electric line, such as a tree contacting an overhead line, a circuit breaker or recloser will open in an attempt to clear the fault. Customers located on the faulted feeder will experience one or more interruptions, depending on the type of fault and reclosing practices of the utility. For a temporary fault, one or two reclosings may be required before the fault is cleared and normal power is restored. Line reclosing occurs usually within one second; some utilities are experimenting with faster reclosing times – 0.3 to 0.5 seconds. For a permanent fault, the breaker locks out after a set number of reclosing attempts, resulting in a sustained outage on that line. Customers on that line will experience one or more interruptions. Customers on parallel lines will experience voltage sags during the fault and subsequent reclosing attempts.

Voltage interruptions can be corrected by UPS systems involving battery storage and power conditioning equipment. Storing mechanical energy in large, high-speed flywheels represents an alternative to battery storage.[10] Facilities can also be protected from voltage interruptions by having multiple feeds to the facility. However, a static source transfer switch (SSTS) is required for protection from momentary interruptions.

Protection from interruptions longer than the energy storage capability of the UPS can be provided by on-site generation. Typically, this has taken the form of emergency standby diesel generators. However, this study explores the integration of other kinds of distributed generation, particularly those types that have far lower emissions of criteria pollutants and are thus more suitable for continuous operation than diesel generators.

Harmonic Distortion

If the voltage or current wave shape is not sinusoidal (as shown previously in Figure A.1), it is considered distorted. Harmonic distortion implies that there are higher frequencies than just the 60 Hz frequency that defines the power flow. These higher frequencies can disrupt, degrade, and damage equipment. Some possible problems include overheating of distribution transformers, adverse effects on electronic equipment, and system resonance with power factor correction banks. Potential sources include computers, lighting ballasts, copiers, and variable frequency drives.

Equipment used in controlling harmonics includes 12-pulse input transformer configuration, impedance reactors, passive or trap filters, and active filters. Other countermeasures include

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[10] In a flywheel system, a motor generator is connected to a large rotating mass or flywheel. Under normal power conditions, the electric motor keeps the flywheel spinning. When an outage occurs, the flywheel energy is used to power the generator to provide line power for a period of time, usually 15 to 20 seconds.

transformers with higher K-factor ratings[11], other filtering techniques, and phase shift transformers for powering different adjustable speed drives. [12]

Voltage Notching

When silicon-controlled rectifiers (SCRs) are used in electrical controls, line voltage distortion in the form of "notches" occurs in the waveform. Line notches are an irregularity in the voltage waveform that appears as a notch.[13] They are typically present in the waveform during SCR commutation or when a one-phase SCR is turned off and the next one is turned on. During this small amount of time, a short circuit exists between the two phases. This results in the current going high and the voltage going low. In the most severe cases, the notch touches the zero voltage axis. This type of notch typically causes the most problems. The types of equipment that frequently use SCR control schemes and thus experience notching include DC motor speed controls and induction heating equipment.

In a normal cycle of sinusoidal voltage, the voltage crosses the x-axis, or zero, at 0° and again at 180°. Under normal operating conditions, there are two zero crossings in each cycle. Some manufacturers design electronic equipment to be triggered on the zero crossing or when the voltage is zero, allowing equipment to activate without the surge currents or inrush currents that would be present if you switched it on while voltage was present. Some equipment, like digital clocks, use the zero crossing for an internal timing signal. When notches exist, particularly in 3-phase equipment, it is possible to have additional zero crossings. Instead of two zero crossings in each cycle of voltage, there can be four.

Sensitive equipment connected to the same voltage source as the equipment producing the notching can be protected by the installation of an impedance reactor. A 3% impedance reactor solves most 3-phase voltage notching problems. Reducing the notch voltage at the point of common connection with other sensitive equipment by approximately 50% or less of its initial value (depth) is normally sufficient. This eliminates the multiple zero crossings and typically solves the interference problems with neighboring equipment.[14]

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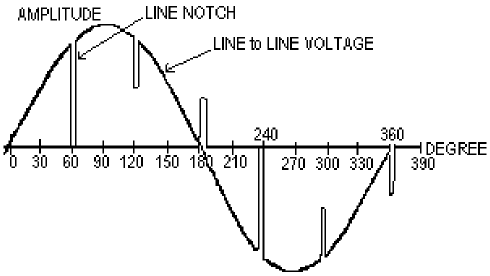
[11] The K-Factor rating assigned to a transformer is an index of the transformer's ability to supply harmonic content in its load current while remaining within its operating temperature limits.

[12] Cory J. Lemerande, "Harmonic Distortion: Definitions And Countermeasures—Part 3," *Electrical Construction & Maintenance*, Jul 1, 1998 (Online archive ecmweb.com).

[13] A view of waveform notching is shown in the figure:



[14] John A. Houdek, "Solving SCR Line Voltage Notching," *Electrical Construction & Maintenance*, September 2000. (Online archives ecmweb.com)

Flicker

Flicker is a modulation of waveform voltage at frequencies of less than 25 Hz. This frequency modulation is detectable to the human eye as a variation in light output from standard bulbs – hence, the name, *flicker*. Voltage flicker is caused by arcing on the power system, such as from a welding machine or an electric arc furnace. Voltage step changes of greater than 3% caused by the starting of large motors may also cause complaints of light flicker, though these events are not characterized by frequency modulation of the voltage amplitude.

Flicker problems can be corrected with the installation of filters, static VAR (Volt-Amperes reactive) systems, or distribution static compensators.

Noise

The last category is *Electrical Noise* or electromagnetic interference (EMI). EMI consists of high frequency, low voltage signals coupled onto the power lines. Frequencies may vary from the kilohertz to the megahertz range, and magnitudes may be up to 10 or 20 volts. EMI can adversely affect telecommunications and other communications processes, hence the term, *noise*.

Noise can come from a variety of natural and manmade sources. Natural sources include lightning, static electricity, and solar radiation. Manmade sources include power lines, automobile ignition, power electronics devices with high frequency switching, and fluorescent lights. Equipment that is adversely affected by EMI, termed EMI receptors, include computers, industrial process controls, electronic test equipment, biomedical instruments, communications media, and climate control systems.[15]

Radio frequency line filters, capacitors, or inductors can be installed at the equipment level to lessen susceptibility to EMI.

A.2 Frequency of Power Quality Disruptions

The impact of power quality disruptions on customer operations depends not only on the type of electricity using equipment in place but also on the frequency of occurrences throughout the year. **Figure A.3** shows the results of monitoring 300 sites on 100 distribution feeders at 24 utilities throughout the U.S.[16] The average number of events per site, per year, is given in 18 bin groupings (incremented by 5% from 0 to 85%) representing the reduction in voltage that occurred at the site. Minor voltage excursions, within 10% are considered normal. The totals for outages and sags as shown in the inset table average nearly 75 events per customer per year. Most of the recorded events are minor sags, though the average site experienced 8.5 momentary or longer service interruptions per year.

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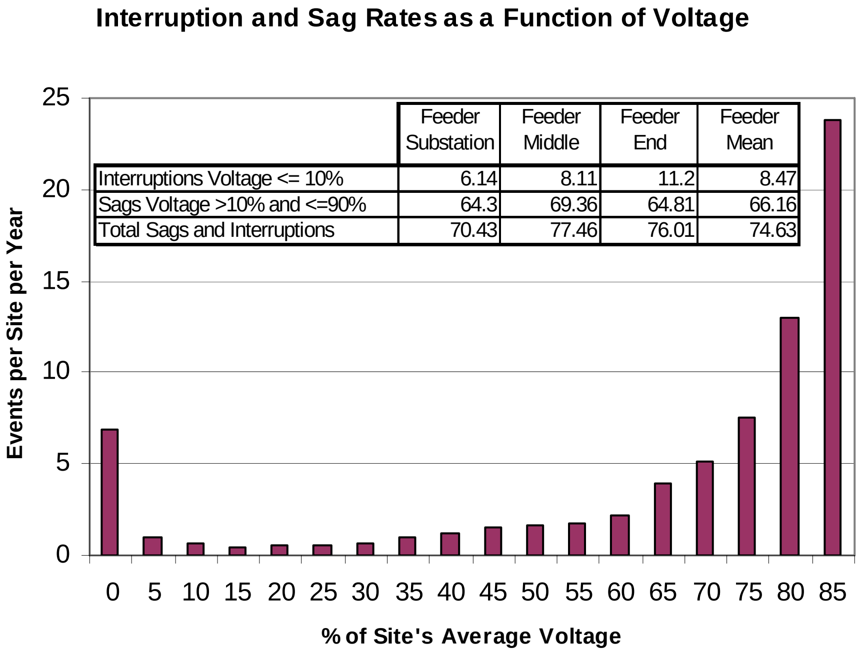
[15] Eushiuan Tran, "Environment/EMC/EMI", *18-849b Dependable Embedded Systems*, Carnegie Mellon University, Spring 1999.

[16] *An Assessment of Distribution System Power /quality: Volumes 1-3*, TR-106294 (V1,V2, V3), EPRI, Palo ALto, CA, 1995.



	Feeder Substation	Feeder Middle	Feeder End	Feeder Mean
Interruptions Voltage <= 10%	6.14	8.11	11.2	8.47
Sags Voltage >10% and <=90%	64.3	69.36	64.81	66.16
Total Sags and Interruptions	70.43	77.46	76.01	74.63

Figure A.3 Average Voltage Sags and Interruptions per Site per Year

A dimension not shown on the previous figure is the length of time for each power quality disturbance. **Figure A.4** shows the average length of power quality disturbances. Over 60% of the PQ disturbances last for only 1-second or less. Over 80% of the disturbances last for less than 10 seconds. Only about 4% last for more than 30 minutes. Based on the average of 75 sags or interruptions per year at a site, this amounts to three occurrences per year.

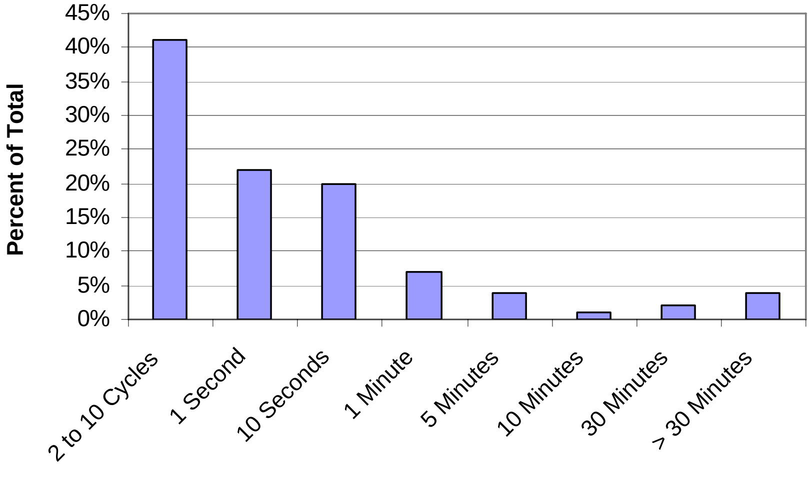


Figure A.4 Distribution of Sags/Outages per Site per Year

While the typical voltage sag or interruption is very brief, the impact on customers varies widely. Many customers experience little or no impact, but the most sensitive customers may be adversely affected for several hours. **Figure A.5** shows the duration of facility outage following a 1-second power interruption. More than a quarter of the facilities are affected for one minute or less. However, about 14% experience process disruptions for a half-hour to more than four hours.

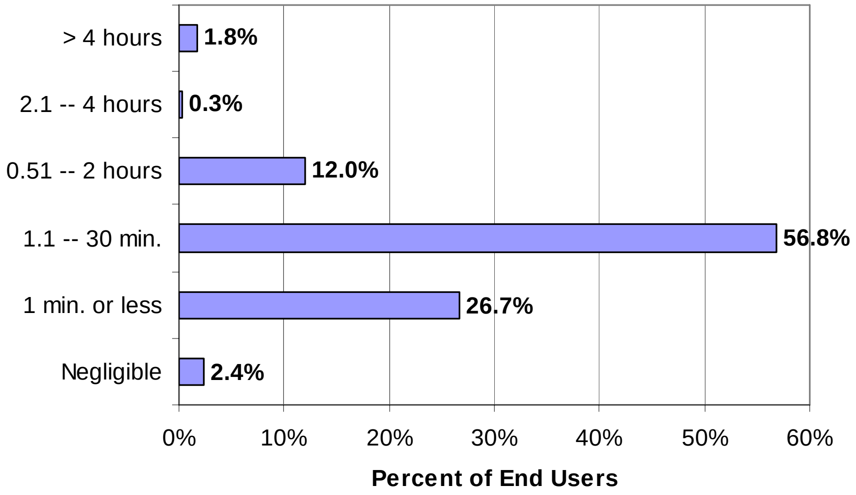


Figure A.5 Duration of Facility Outage Following a 1-Second Power Interruption

Over a 10-year period, utilities working with EPRI's Power Electronics Applications Center (this is their old designation, now know as EPRI-Solutions) have provided information on over 500 investigations of customer power quality problems. These investigations covered a broad spectrum of commercial and industrial business activity. **Figure A.6** shows the characterization of causes of power quality complaints. Almost half of the complaints come from voltage sags/swells. The next most common problem is harmonic distortion followed by wiring/grounding problems at the facility. It should be noted that many of the power quality problems do not emanate from the utility system practices *per se* but may be the result of the facility's own power using equipment or the power use of a neighboring customer.

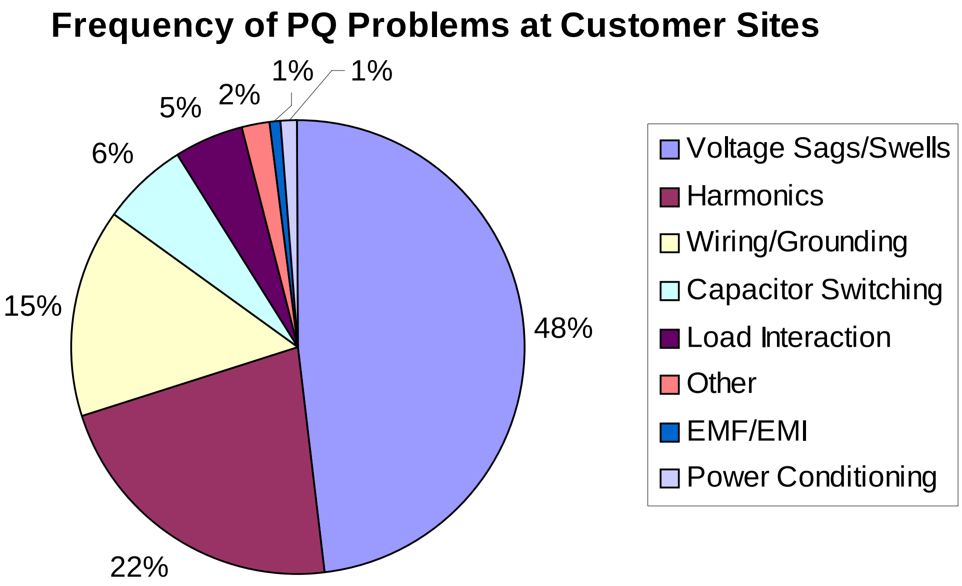


Figure A.6 Distribution Causes of PQ Complaints to Utilities

A.3 Premium Power Markets

Variations in power quality are not in and of themselves a problem. Whether a problem occurs depends upon the interaction of these variations with specific end-use equipment, the use of which is concentrated in certain sensitive business applications herein defined as the premium power market. This section categorizes the market and defines both the costs of PQ disturbances and the current expenditures in control equipment.

A.3.1 Power Quality Sensitive Customers

As described in the previous section, there are a variety of occurrences in which utility supplied power fails to conform to the ideal of a perfectly in-phase (with the current waveform) sine wave of constant voltage amplitude and power. The most obvious of these occurrences is an extended outage in which power is cut off for a period of a few seconds to several hours. The economic affect of these outages varies widely by customer class, sometimes even by individual customer. Those customers who cannot afford to be without power for more than a brief period usually have on-site standby generators that can pick up all or a part of their load (critical loads). There are also customers for which any disruption at all, either in loss of power or variation of power quality, can lead to severe economic loss. These customers generally require uninterruptible power supply (UPS) systems along with associated power control and conditioning equipment to correct surges, sags, harmonics, and noise.

Customers with a need for true premium power systems include the following:

- ❑ Mission Critical Computer Systems – banks, depository institutions, other financial companies, stock markets, investment offices, insurance companies, computer processing companies, airline reservation systems, and corporate headquarters need to protect computers, peripherals, and computer cooling equipment.

- Communications Facilities – telephone companies, television and radio stations, internet service providers, cellular phone stations, repeater stations, military facilities, and satellite communication systems need to protect their computers, peripherals, antennae, broadcasting equipment, and switches.
- Hospitals and Nursing Homes – hospitals, nursing homes and other health care facilities need support for critical life support systems, medical equipment, and maintenance of critical HVAC environments.
- Large Photo-finishing Labs – large centralized photo-finishing centers need to protect their computers and photo-finishing equipment.
- Continuous-Process Manufacturing – paper; chemicals; petroleum; rubber and plastic; stone, clay, and glass; and primary metals
- Fabrication and Essential Services – all other manufacturing industries plus utilities and transportation facilities such as railroads and mass transit, water and wastewater treatment, and gas utilities and pipelines.

A.3.2 Costs of Electric Power Quality Problems

Power quality problems can lead to a number of costs to industrial and commercial facilities. These costs can include:

- Damaged plant equipment
- Spoiled or off spec product
- Extra maintenance costs
- Cost for repair of failed components
- Loss of revenue due to down-time that cannot be made up.
- Additional labor costs.

About two million business establishments in three critical sectors were evaluated by EPRI in terms of the costs of power quality disturbances. This evaluation grouped the power quality sensitive businesses, as described above, into three areas as follows:

- **Digital Economy –** Firms that rely heavily on data storage and retrieval, data processing, or research and development. **Table A.2** shows examples of the high costs of power outages in these sectors.
- **Continuous Process Manufacturing –** Manufacturing facilities that continuously feed raw materials, often at high temperatures, through an industrial process. **Table A.3** shows average costs by industry per disruption (both voltage sags and outages.)
- **Fabrication and Essential Services –** This sector includes other manufacturing industries plus utilities and transportation facilities.

Table A.2 Example Outage Costs for Sensitive Customers[17]

Business Activity	Outage Costs $/hour
Cellular Communications	$41,000
Telephone Ticket Sales	$72,000
Airline Reservations	$90,000
Credit Card Operations	$2,580,000
Brokerage Operations	$6,480,000

Table A.3 Average Costs per PQ Event for Sensitive Process Industries[18]

Industry	$/kVA per Event
Semiconductors	80 - 120
Glass	10 - 15
Automotive	6 - 10
Plastics	4 - 7
Textile	3 - 8

The 2 million establishments analyzed account for 17% of the total number of business establishments and 40% of the U.S. gross domestic product. **Table A.4** shows the annual costs that were estimated for the three power quality sensitive sectors with an extrapolation to all business facilities in the U.S.

The estimated cost of outages for the three sectors is $45.7 billion per year. An additional $6.7 billion in costs result from power quality disturbances other than outages. The cost for all industry is estimated at $120 to $190 billion per year. According to the study, New York ranks third in the U.S. behind California and Texas with an estimated $8.0 to $12.6 billion in costs associated with outages and power quality phenomena. It should be noted that problems in the digital economy and fabrication and essential services sectors have an immediate impact on the rest of the economy as well.

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[17] Keith Davidson, Ken Darrow, Teresa Bryson, and Bill Major, *Advanced Microturbine System (AMTS) Market Study*, prepared for DOE and Capstone Turbine Corporation, prepared by Onsite Energy Corporation, April 2001.

[18] Gerhard Linhofer, Philippe Maibach, and Francis Wong (ABB Switzerland), “Power Quality Devices for Short term and Continuous Voltage Compensation,” *International Power Quality Conference 2002*, Singapore, October 21-25, 2002.

Table A.4 Estimated Total Cost of Power Quality Disturbances per Year

	Outage Costs ($billions)	Power Quality Costs ($billions)
Digital Economy	$13.5	$1.0
Continuous-Process Manufacturing	$3.0	
Fabrication and Essential Services	$29.2	$5.7
Total PQ Sensitive Sectors	$45.7	$6.7
Estimate of All Business Sectors	$104-$164	$15-$24

To evaluate the costs and benefits of mitigating power quality problems, one must look at the costs for PQ problems within industry groups or even at individual facilities. The costs incurred by a site as a function of its capacity (kW) and unserved energy use (kWh) provide a benchmark for evaluating control strategies. **Tables A.5 through A.7** show some average costs for industrial facilities and commercial buildings.[19]

Table A.5 Average Cost of a Single Power Interruption for Industrial Plants

All Plants	$6.43/kW + $9.11/kWh
Plants > 1000 kW max. demand	$3.57/kW + $3.20/kWh
Plants < 1000 kW max. demand	$15.61/kW + $27.57/kWh

Table A.6 Average Cost of a Single Power Interruption for Commercial Buildings

All Commercial Buildings	$21.77/kWh not delivered
Office Buildings Only	$26.76/kWh not delivered

Table A.7 Cost of Power of a Single Power Interruption as a Function of Duration for Office Buildings with Computer Centers.

Power	Sample	Cost/Peak kWh Not Delivered		
Interruptions	Size	Maximum	Minimum	Average
15 min. duration	14	$67.10	$5.68	$26.85
1 hour duration	16	$75.29	$5.68	$25.07
duration > 1 hour	10	$204.33	$0.48	$29.63

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[19] Table 2.5, 2.6 and 2.7 are from EPRI 1004451 (op cit.), the original source cited is *IEEE Standard 493-497: IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems*, IEEE, 1997.

A.3.3 Estimated Size of the U.S. Power Quality Market

A detailed study performed for EPRI in 2000 evaluated the size and nature of the market for power quality equipment and services.[20] This study projected a market of $8 billion in 2003 with 13% growth throughout the forecast period as shown in **Figure. A.7**.

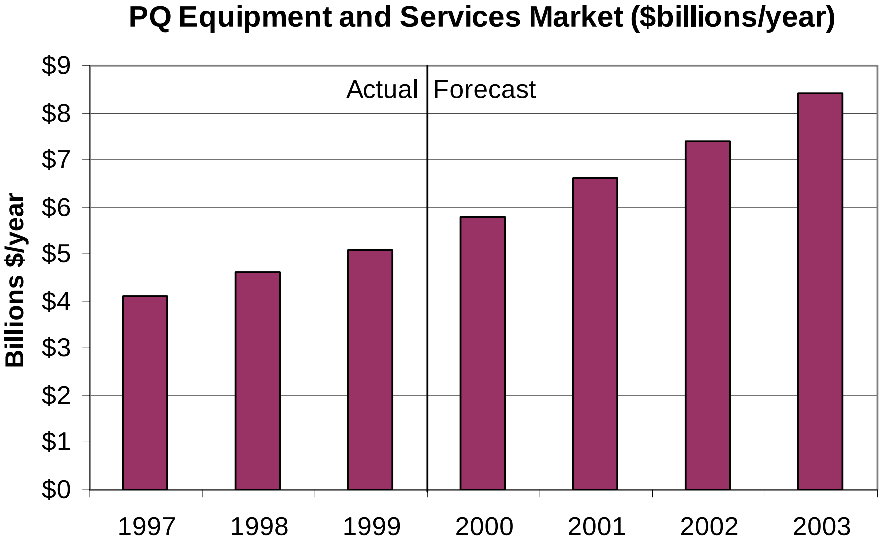

Figure A.7 Estimated Annual U.S. PQ Equipment and Services Market

Figure A.8 shows the market breakdown in the final forecast year, 2003. Over 60% of spending for premium power equipment is in the commercial sector, with annual growth at 13% per year. About 30% of the market is in the industrial sector which is also the slowest growing sector at 10% per year. The remaining 9% is for residential applications, though this is experiencing 22% per year growth.

The largest single component of the premium power market is for PC-sized UPS. These small systems account for approximately $2 billion in annual sales. Other small equipment such as TVSS and power line filters and power quality services take up the bulk of the remaining market. Approximately 90% of the PQ equipment and services market is focused on small and medium equipment or services, and, therefore, has little synergy with DG systems. The remaining 10% of the market for facility-scale power quality control (greater than 100 kVA) represents a $450 to

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[20] Power Quality Equipment & Services: Selected industrial & Commercial Market Segments of Interest to Electric Utilities, EPRI ReportTR-1000202, Frost & Sullivan, June 2000 (Results summarized in EPRI 1004451 previously cited.)

$900 million per year market in the U.S. It is this market for large-scale equipment that represents the greatest potential for integration with distributed generation systems.

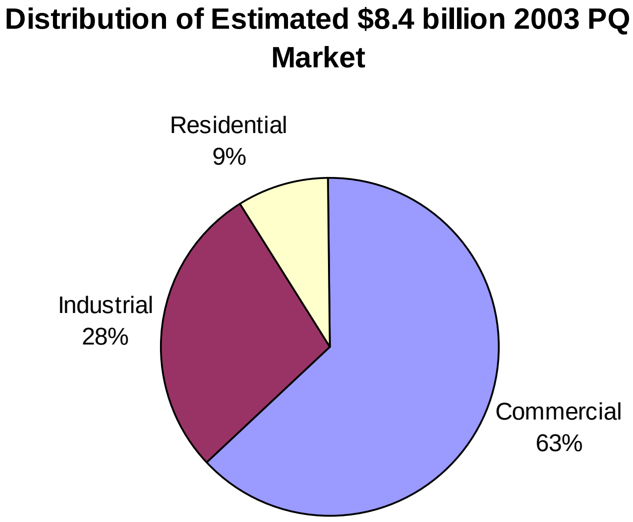

Figure A.8 Market Distribution of Total Estimated PQ Market for 2003

Two other related markets are relevant to the consideration of the overall premium power market:

- DC Power Systems – This market is oriented toward communications and cellular applications. The market for DC power equipment was $3.5 billion in 2000 and growing at about 20 percent annually.
- Standby generation – This market equals $3.5 billion per year. Diesel generators are the primary technology for this market.

A.4 Power Quality Technologies

Power quality can be controlled or strengthened at any point in the power system from system-wide measures undertaken by the utility all the way down to the design devices for individual equipment. Generally speaking, a PQ sensitive customer has only indirect and limited ability to exert control over utility operations or the design of end-using equipment required for their own operations. This discussion focuses on the measures that a facility operator can take on his side of the meter to minimize any adverse effects of variations in power quality or reliability.[21] A facility may choose to protect its entire load (at the electric service entrance), sensitive sub-

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[21] Discussion in this section derived from *Distributed Resources Premium Power Solutions*, EPRI Report 1004451, January 2003.

facilities (individual circuit protection), or individual operations (controls or individual equipment protection.) The protection level depends on the size and type of critical load.

Small-scale equipment (up to 3 kVA) is 120-volt, single-phase PQ protection equipment for point-of-use applications protecting individual equipment such as personal computers or logic controls for larger equipment. This type of equipment includes:

- ❑ Uninterruptible power supplies (UPS) costing $200-500/kW
- ❑ Single-phase transient voltage surge suppressors (TVSS) at $10-$50 per circuit.
- ❑ Single-phase power conditioners, isolation transformers, and voltage regulators ranging from $100-500/kW.

Medium-scale equipment (3.1 to 100kVA) is used to protect the low voltage distribution system (240-600 V) within a facility. This equipment is typically located at the service entrance panel boards, or supplying a feeder or branch circuit. Typical equipment in this category includes:

- ❑ Single-phase UPS (3-18 kVA) and three-phase UPS (up to 100 kVA) ranging in price from $75-$225/kW.
- ❑ Three-phase TVSS except for revenue demand meter mounted units from $100-$200/circuit.
- ❑ Three-phase power conditioners: voltage line conditioners, isolation transformers, power distribution units, voltage regulators, motor generators, and active and static harmonic filters ranging in price from $50-500/kW.

Large scale equipment (greater than 100 kVA) is designed for use at the service entrance of the facility. This scale of equipment may be installed outdoors in pad-mounted enclosures or in a customer-owned substation. Large scale equipment includes the following:

- ❑ Energy storage systems including battery energy storage, mechanical storage systems such as flywheels ($25-100/W-hour) with electrochemical capacitors.
- ❑ Large-scale UPS costing $250-400/kW
- ❑ Low voltage static transfer switches (less than 600 V) for $40-60/kW
- ❑ Medium voltage static transfer switches (4.16-34.5 kV) and customer power products such as static-series compensators/dynamic voltage restorers (DVR), static shunt compensators, and static circuit breakers ranging in cost from $28-32/kW.

A.4.1 Alternative Power Supplies and Switching Technology

Customers can increase their reliability of service and in some cases their quality of power by having an alternative source of power. This power source can be a second utility feed, a standby generator, or a DG system. The way in which this second power source is connected determines the customer's improvement in PQ/reliability. The types of switching technology are as follows:

- ❑ **Manual Transfer Switch –** As its name suggests, this type of switching requires facility personnel to manually switch from one source of power to the next. This protects facilities from long-term outages only as it takes several minutes at a minimum for the manual switch to be made.

- **Automatic Transfer Switch –** This switch senses a fault in the primary feed and automatically switches to the secondary feed. In cases where the secondary feed is from an unaffected utility feeder, the successful switch causes a momentary disruption of power to the facility. Where a standby generator is the secondary source of power, the transfer would require more time depending on the start-up capability of the equipment. A common specification for diesel generators is to start and pick up load within 10 seconds and transfer power to the critical loads by means of an automatic transfer switch. A DG system that was already operating would pick up load in a similar fashion as a secondary utility feed although it may take a few cylcles or seconds to dispatch the DG to the correct setting for the load demand. As in the first case, this option protects against long-term outages only and does nothing to protect sensitive customers from sags and momentary outages.
- **Static Source Transfer Switch –** The SSTS uses solid-state switches to provide an almost seamless transfer from one power source to another. The transfer time is from ¼ to ½ cycle or about 4 milliseconds. Obviously, this rapid switching requires that the secondary power source be ready to pick up the facility load. A standby generator would not benefit from connection to a SSTS unless there were an intervening source of power such as a UPS. A second utility feed would provide protection from all distribution level utility faults but would not protect the customer in the event that the transmission system goes down.

A.4.2 Power Conditioning Technologies

A range of technologies can be used to improve the power quality at a site. These technologies can help to insulate the customer from variations in PQ in utility supplied power or to mitigate PQ disturbances emanating from the customer's own equipment. These technologies are often used as individual components of an overall PQ control strategy.

Transient Voltage Surge Suppressors

Protection against lightning strikes and other voltage surges can be provided by a transient voltage surge suppressor. Plug-in equipment available for personal computers and other small electronic equipment is widely used, though manufacturers of larger facility protection TVSS equipment question the capability of individual plug outlet surge suppressors. Larger scale equipment is available for protection of an entire facility or critical circuit. This type of equipment consists of modular metal oxide varistors (MOV). (See Glossary Appendix A for definition of MOV.)

VAr Compensators

Uncompensated reactive power leads to unstable grid conditions that can cause voltage dips, sags and swells. Utilities must keep the voltage very close to the rated value, because otherwise this can in the longer term lead to damages due to high currents and therefore overheating in the applications. Voltage fluctuations also have a great influence on the lifetime of components.

There are several options to provide the needed reactive power:

- Reactive power provided directly by generators (synchronous condenser)
- Banks of fixed capacitors (close to big inductive loads)
- Fixed and Switched capacitor banks
- Static VAr Compensator (SVC)
- Active VAr compensation.

Dynamic Voltage Restorer

One means for a customer to ride through transients and momentary conditions is through the use of a *Dynamic Voltage Restorer* (DVR). For voltage transients (dips, sags and swells) the DVR provides the required buffering to ride through such disturbances without noticeable effect on the production line. Connected in series between the grid and protected load, it compensates for transients caused by faults in the transmission or distribution system, thus a securing a safe power supply to the load. The DVR can be sized to virtually any voltage and load requirement but is best suited for medium voltage (MV) or high voltage (HV) applications. The DVR stabilizes the voltage directly at the facility level, which normally is MV in the distribution system. Energy storage for up to a 300 to 500 millisecond sag is provided by capacitor banks. **Figure A.9** shows the system schematic of operation and a prefabricated trailer installation available from ABB.[22]

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[22] Gerhard Linhofer, Philippe Maibach, and Francis Wong (ABB Switzerland), "Power Quality Devices for Short term and Continuous Voltage Compensation," *International Power Quality Conference 2002*, Singapore, October 21-25, 2002.

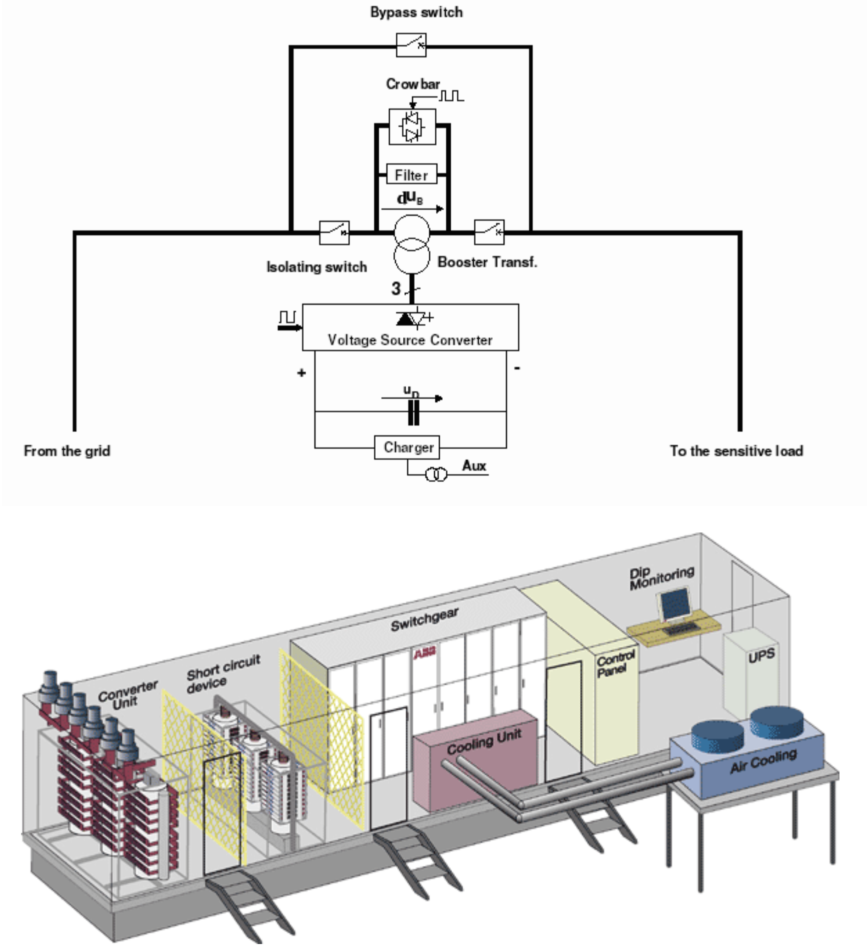

Figure A.9 Dynamic Voltage Restorer Schematic and Physical Layout

Isolation Transformer

Electric circuits must be separated from the network using isolation transformers in installations for environments with special problems, such as medical and surgical rooms. Statically shielded isolation transformers shield sensitive loads from electromagnetic interference. In fact, they provide protection against indirect contacts without it being necessary to interrupt the circuit upon an initial ground fault. They are consequently used, in particular, in installations where a sudden interruption in service could cause serious problems and automatic interruption is therefore prohibited.

Motor-Alternator (Motor-Generator)

Motor-alternator technology consists of an electric motor driving a generator or alternator. This technology is used as a very high-grade "line conditioner," which by definition consists of a voltage stabilizing product combined with a noise rejection technology. It not only rejects common-mode noise, but also, by virtue of the shaft or belt connection, stops any line-to-line noise from entering the output. A rotary UPS system uses a motor-generator set, with its rotating inertia, to ride through brief power interruptions. Power goes to critical loads by means of a generator driven by an AC or DC motor. The generator provides true isolation of the power so no abnormalities pass through the UPS (other than some slight harmonics due to the characteristics of the generator's windings).[23]

A.4.3 Uninterruptible Power Supplies

The premium UPS topology is the true on-line or *double-conversion* product shown in **Figure A.10**. Incoming AC power is rectified to DC power to supply the internal DC bus of the UPS. The output inverter takes the DC power and produces regulated (60-Hz) AC power to support the critical load. Batteries attached to the DC bus are float charged during normal operation. When the input power is out of spec, the batteries provide power to support the inverter and critical load.[24]

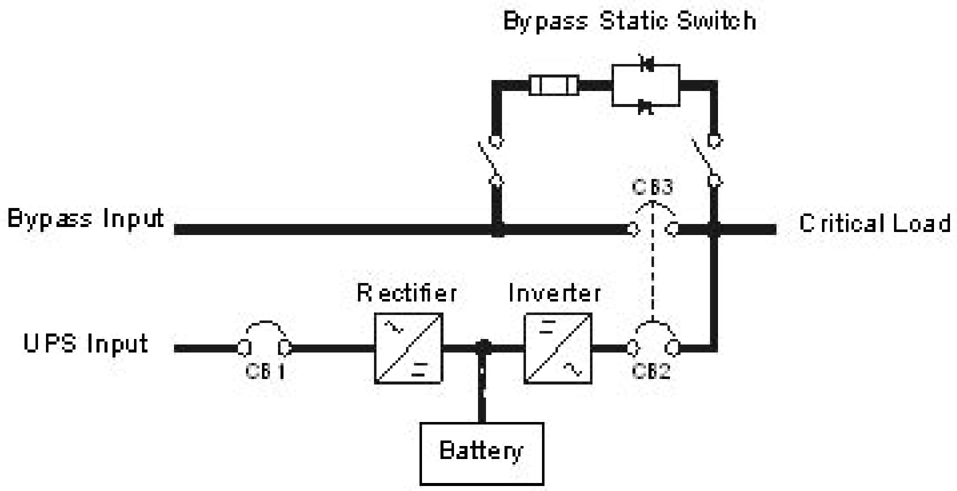

Figure A.10 Schematic of a Double Conversion UPS

The UPS system consists of the following subsystems:

- **System Controls**: The system control logic automatically manages critical bus operation and monitors performance of the UPS module. Microprocessor technology and dedicated firmware provide advanced logic control and a comprehensive display of information. The system includes ports for communicating with external devices.

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[23] Ray Waggoner, “The How, What, and Where of Power Conditioning, Part 4”, Electrical Construction & Maintenance, September 1, 1996. (online archives)

[24] “The Basics of UPS Technology: A Liebert White Paper,” Liebert Corporation Website (www.liebert.com)

- **Rectifier/Charger**: The rectifier/charger converts utility power from AC to DC to charge the battery and provide the DC input to the inverter. Its design limits reflected harmonic current distortion to source power and provides low ripple DC power for charging batteries.
- **Inverter**: The inverter converts DC power into the precise AC power required to supply a sensitive critical load. The inverter converts DC power into a pulse-width-modulated (PWM)/six-step waveform that is easily filtered into a clean sine wave output. The PWM/stepwave also minimizes the harmonic voltage distortion caused by typical switching power supplies and other non-linear load components used in computers and related electronics.
- **Static Bypass Switch**: The static (solid-state) bypass switch immediately transfers the load from the inverter to the bypass AC power source in the event of a severe overload on the system or a failure within the UPS. This transfer takes place without any interruption of the power supplied to the load. The system includes redundant circuits to detect and isolate shorted SCRs in the static switch.
- **Fuses** are installed in series with the static bypass circuit to ensure reliable overload protection in the unlikely event of a catastrophic output condition (for example, a dropped wrench) electrically close to the output of your UPS system. The static switch SCRs themselves are rated to easily handle the fuse-blowing current.
- **Bypass Circuit**: The bypass circuit consists of a motor operated circuit breaker in parallel with a solid state (static) switch and associated synchronizing and control circuitry to transfer the load to/from the bypass source.
- **Battery Energy Storage System:** The battery is used as the alternate source of power to supply DC power to the inverter if the AC supply voltage is outside the acceptable range. The battery supplies power to the inverter until the utility power is restored or until an alternate power source is available. If AC source power is not restored or an alternate power source is not available, the battery can be sized to provide power long enough for an orderly shutdown of the load.

Some advantages of this configuration include:

- The critical load is completely isolated from the incoming AC input power.
- The critical load is always being supplied by the output inverter, which is always being supplied from the internal DC bus. When input power fails, there is no transitional sag in the output voltage because the inverter is already operating on DC input.
- The input voltage and frequency may fluctuate, but the double-conversion UPS doesn't see it, since the rectifier is only making DC power to feed the DC bus. The UPS can operate and even continue to recharge its batteries with input voltage at 15% below nominal. It can continue to operate, without discharging the batteries, through voltage sags of 20% below nominal. Likewise if input frequency is fluctuating in and out of specification, the rectifier will continue to make DC power and the output inverter will continue to make 60 Hz power without using the battery.
- The output inverter usually contains an isolation transformer that can produce a separately derived neutral. This enables the UPS to be electrically isolated and provide common mode noise protection for the load.

- The double-conversion UPS is inherently dual-input, meaning that it has separate inputs for the rectifier and bypass circuits.
- A fault on the input line causes the UPS to go to battery power, but the UPS rectifier will not allow power from the DC bus to flow upstream.
- This is a very well understood design with a long track record of proven performance.

Though battery energy storage is the most common form of storage used in a UPS, other forms of energy storage are being used and/or developed for commercial use. These emerging systems include flywheels, super capacitors, and superconducting electromagnetic storage.

APPENDIX B: REVIEW OF NEW YORK POWER QUALITY EVENTS AND UTILITY ACTIONS

Under statutory authority to require “safe and adequate service”[25], the New York State Public Service Commission (PSC) adopted service reliability and quality standards applicable to in-state electric utilities (Order) in 1991.[26] The case was established in response to a 1989 Department of Public Service (DPS) policy initiative to establish service standards for electric, telephone, gas, and water service. By order issued December 18, 1990, a proceeding was initiated to comment on a draft prepared by DPS staff for that purpose. Comments on staff's proposal were sought from consumer groups, other state agencies, the electric utilities, and other interested parties.

The PSC Order, adopted on July 2, 1991, requires electric utilities to develop programs that detail specific actions to ensure that adequate service is provided. The requirements involve the establishment of minimum acceptable (Minimum) and desirable (Objective) levels of reliability. Reliability is gauged utilizing indices for both the frequency and duration of service interruptions. The recommended reliability levels are customized for each of the utility operating areas in the State. The Order also includes criteria for identifying, ranking, and developing appropriate improvement plans for the worst-performing circuits in each operating area. In addition, the utilities are required to develop programs for responding to customers' power quality problems.

The Order defines reliability as “[the degree to which electric service is supplied without interruption”, and includes definitions to measure it, as follows:[27]

- System Average Interruption Frequency Index (SAIFI): This index is the average number of times that a customer is interrupted during a year. It is determined by dividing the total annual number of customers interrupted by the average number of customers served during the year. A customer interrupted is considered to be one customer interruption. This is the same as one customer affected.

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[25] Public Service Law § 65 (1) & 66 (1).

[26] PSC Case 90-E-1119, Proceeding on motion of the Commission to consider establishing standards on Reliability and Quality of Electric Service, Order adopting standards on reliability and quality of electric service (issued July 2, 1991). Note: As a result of pending cases, Case 02-E-1240 - Proceeding on Motion of the Commission to Examine Electric Service Standards and Methodologies - and Case 02-E-0701 - In the Matter of a Petition by Orange and Rockland Utilities, Inc. to Update the Company's Customer Average Interruption Duration Index (CAIDI) Target Levels for the Central and Western Operating Divisions -, new service reliability and quality standard for electric utilities would be adopted. The comment period closed earlier this year.

[27] Id. at Appendix 1 § 2 (a) & (e). Power Quality was defined as: **“**In general, the characteristics of electric power received by the customer, with the exception of interruptions. Characteristics of electric power that detract from its quality include momentary interruptions, waveform irregularities and voltage variations - either prolonged or transient. Power quality problems shall include, but not be limited to, disturbances such as momentaries; high or low voltage; voltage spikes and transients; flickers and voltage sags, surges and short-time overvoltages; and harmonics, noise and "dirty" waveforms.” *Id.* at Appendix 1 § 2 (b).

- SAIFI = total number of customer interruptions/total number of customers served or CA/CS = total number of customers affected/total number of customers served

- Customer Average Interruption Duration Index (CAIDI): This is the average interruption duration time for those customers that experience an interruption during the year. It approximates the average length of time required to complete service restoration. It is determined by dividing the annual sum of all customer interruption durations by the sum of customers experiencing an interruption over a one-year period.

- CAIDI = sum of customer interruption durations/total number of customers interrupted or CH/CA = sum of customers affected hours/total number of customers affected.

Each utility is required to set operating area reliability performance levels and establish procedures to meet the service reliability. To that end, the utilities were asked to file with DPS detailed electric service reliability programs that included goals and procedures. The programs' goals are to "improve reliability where it can be improved cost-effectively and to sustain that reliability over time. Special emphasis should be given to the worst-performing circuits in each operating area."[28]

Two levels of performance are determined for each utility:[29]

Objective Level: This level represents the fully adequate level of electric service that each utility should strive to achieve and maintain. A utility reaches this level when both the SAIFI and CAIDI indices of each of its operating areas are equal to or better than the SAIFI and CAIDI values established as the Objective Level set forth by the PSC.

Minimum Level: This level represents the lower threshold of adequate service below which further review, analysis and corrective action may be required. A utility reaches this level when the SAIFI and CAIDI indices of each of its operating areas are equal to or better than the Minimum SAIFI and CAIDI values set forth by the PSC.

Performance below the Minimum Level is considered unacceptable when either the SAIFI or the CAIDI index of an operating area falls below the Minimum Level SAIFI and CAIDI values established by the PSC for the calendar year. When a utility's calculations show that an operating area has fallen below the Minimum Level for the calendar year, the utility must prepare a report to be submitted to the DPS which analyzes the interruption patterns and trends, as well as the operating and maintenance history of the affected operating area, describes the problems causing unacceptable performance, and the actions the utility is taking to resolve them. The report must contain target dates for completion of the corrective action.

Further, each utility is required to consider power quality in the design of its distribution power-delivery system components and "strive to avoid and to mitigate, to the extent feasible and cost-

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[28] *Id.* at Appendix 1 § 3.

[29] *Id.* at Appendix 1 § 5. (The SAIFI and CAIDI indices of each operating area shall be calculated at the end of each calendar year for the previous 12-month period).

effective, power quality disturbances under its control that adversely affect customers' properly designed equipment."[30] Each utility was asked to file a power quality program with the DPS that includes its performance objectives and procedures. The programs must be designed to respond promptly to customer reports of power quality problems and to avoid, mitigate, or resolve such problems to the extent cost-effective and practical.

The Order also required an annual report on power quality and reliability (PQR Report) that includes at least the following information:[31]

> (a) An overall assessment of the reliability performance, in each of the company's operating areas, in relation to the Objective and Minimum Levels for interruption frequency and duration, as set by the Commission.
>
> (b) An analysis of the worst-performing circuits per operating area for the calendar year. This section of the report was required to describe the actions that the utility has taken or will take to remedy the conditions responsible for each listed circuit's unacceptable performance so that it can improve to the Minimum Level or above. Target dates for corrective actions were to be included in the report. The utility may determine that actions on its part are unwarranted - in those cases, its report was to provide adequate justification for such a conclusion.
>
> (c) A listing of plans and schedules for improvements, as indicated by the above assessments, and estimated cost of those improvements.
>
> (d) A report on the accomplishment of the improvements proposed in prior reports for which completion has not been previously reported.
>
> (e) A description of any new reliability or power quality programs and changes that are made to existing programs.

In Case E-02-1240 *Proceeding on Motion of the Commission to Examine Electric Service Standards and Methodologies*, the Commission is evaluating whether the electric service standards currently in place properly reflect current industry conditions, demographic conditions, and customer expectations. In August 2003, as a result of this effort, staff proposed Service Reliability and Quality Standards Applicable to Class A Electric Corporations[32]

The Power Quality Objectives proposed by staff are as follows:

SECTION 4: POWER QUALITY OBJECTIVES[33]

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[30] *Id.* at Appendix 1 § 4.

[31] *Id.* at Appendix 1 § 7 ("Each utility shall file a report with the Department by June 30 of every year").

[32] PSC CASE 02-E-1240, NOTICE REQUESTING COMMENTS, Issued August 14, 2003

[33] ibid., pg. 3.

> (a) Each utility shall consider power quality in the design of its distribution power-delivery system components. It shall strive to avoid and to mitigate, to the extent feasible and cost effective, power quality disturbances under its control that adversely affect customers' properly designed equipment.
>
> (b) Each utility shall maintain procedures to meet allowable voltage levels. The program shall be designed to satisfy the service and utilization voltage ranges as specified by the American National Standards Institute’s C84.1-1995 or later unless otherwise directed by the Commission (Case 28914, Conservation Voltage Reduction). For minimum service voltage levels not addressed by these requirements, the program shall be designed using a lower limit of 5% below the nominal service voltage.
>
> (c) Each utility shall, as a minimum, maintain a power quality program that includes its performance objectives and procedures. The program shall be designed to respond promptly to customer complaints of power quality disturbances.
>
> (d) Each utility shall record the number of power quality complaints received, the number of investigations conducted during the year, and the results of the investigations. The results of the investigations shall indicate if the origin of the disturbance was the responsibility of the utility or customer and be categorized as follows: momentary interruptions, over voltage condition, under voltage conditions, voltage sags and swells, transients, harmonics and noise, or unknown.
>
> (e) Each company shall develop and maintain a program for recording the number of momentary interruptions where practical and feasible. The data should be arranged by voltage class and compiled on a company-wide and operating division basis.

The Staff’s Proposal did not call for the adoption of electric service standards for voltage. In Initial Comments, some parties addressed voltage surges and sags, some supporting and others opposing specific standards[34]. In its initial comments an association representing large customers in New York, Multiple Intervenors (MI), put forth two and a half pages of specific incidents where their members were adversely affected by voltage irregularity.[35]

On the other hand, a review of the most recently filed power quality and reliability reports from the utilities indicated that few complaints reach the level of the PSC. For example, New York State Electric and Gas Corporation (NYSEG) reports that customers made a total of 6 complaints to the PSC regarding interruptions and PQ problems during 2002.[36] Likewise Niagara Mohawk Power Corporation (NMPC) reported a total of 4 PSC Complaints in 2002[37]

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[34] PSC Case 02-E-1240 Reply Comments Submitted By Eliot Spitzer Attorney General of New York, pg. 1. January 10,2003

[35] Ibid., pg. 2

[36] New York State Electric and Gas Corporation 2002 Annual Reliability Improvement Report. March 31, 2003, page. 126.

[37] Niagara Mohawk: Power Quality 2002 Annual Report. Power Quality Investigation Management System Power Quality Statistics. March 2003. Page 12

The Project team reviewed the 2002 PSC's required power quality and reliability (PQR) reports from three in-state utilities: the NYSEG, Central Hudson Gas and Electric Corporation (Central Gas) and NMPC. In addition, the team evaluated information provided in a brief report related on the power quality program by the Consolidated Edison Company of New York (Con Edison).

The reports by NYSEG and Central Hudson provide information on PQ and reliability indexes and PQR programs and activities. Information on PQR indexes includes: CAIDI, SAIFI, and SAIDI, which represents a combination of the first two indices resulting in the average outage time (hours) experienced by a customer in the study year.

The reports by NMPC and Con Edison on power quality do not address these indexes. NMPC's report focuses on data from the Power Quality Momentary Interruption Tracking System (PQ-MITS). This report provides a detailed listing of NMPC's momentary interruption statistics for all circuit classes and from a variety of perspectives. The statistical information that is provided is used in part to derive and track the results of the 2002 Power Quality Penalty Avoidance Targets. Con Edison's reports simply summarized activities and programs by its Power Quality Service Center (CEPQSC). Therefore, the data found in these reports is helpful to understand PQ issues in the state, but is not sufficient to provide comparisons or synthesize the information in a comprehensive way. Accordingly, the following section highlights the most relevant information provided in the PQ reports for the purposes of this study.

B.1 New York State Electric and Gas Corporation

NYSEG's 2002 Annual Reliability Improvement Report

The information provided below is based on NYSEG 2002 Annual Reliability Improvement Report (NYSEG 2002 Reliability Report) on the reliability of electric service provided by the corporation in 2002.

Reliability measurements were compared to minimum and objective levels of CAIDI and SAIFI that were set for each division in PSC Case 96-E-0979. SAIDI was compiled to represent a combined measure of both frequency and duration together, and to yield one overall metric.

The NYSEG 2002 Reliability Report also provides a description of internal procedures that result in the identification and analysis of reliability problem areas around the NYSEG distribution system. This is termed the NYSEG Reliability Program and describes the corporate procedures/practices that identify, analyze and correct problem areas (including a few samples). Finally, the document includes a Power Quality Section, which is a general overview of NYSEG's power quality program including accomplishments, discussions of 2002 data and objectives for 2003.

NYSEG suffered adverse weather patterns in 2002 and consequently reliability measures showed poor performance as compared with longer term trends. Some reliability information for 2002 compared to the years 1992 through 2001, including all interruptions are as follows:

1. The highest number of interruptions with 14,460.
2. The highest SAIFI of 1.74.
3. The 3rd highest customer hours of interruption with 4,781,151.
4. The highest number of weather events to qualify as a major storm.

Major storms are defined by the PSC. Utilities categorize reliability data as storm related and non-storm related.

NYSEG Reliability Performance

The reliability measurements for 2002 are shown in the table below.

NYSEG CORPORATE-WIDE RELIABILITY PERFORMANCE (Without Storms)

	2002	PSC Minimum Goals	2001	2000	1999	1998
CAIDI	1.87	2.08	1.76	2.00	1.93	1.91
SAIFI	1.14	1.20	1.02	1.05	0.90	0.95
Interruptions	10,660		9,424	8,592	8,489	8,178
Customer Hours	1,786,631		1,500,522	1,731,874	1,418,632	1,470,652
Customers Interrupted	956,846		851,380	866,610	736,230	770,700
Avg. Outage Duration (min)	158		151	166	168	161

In 2002, interruptions were 1236 higher then in 2001. Non-storm outages accounted for approximately 74 percent of total interruptions in 2001. Within the non-storm category, the most frequent causes for interruption were: tree contact (38 percent); equipment problems (18 percent): lightning (14 percent); and accidents (14 percent).

The PSC is concerned with measuring power quality and reliability at the division or operating area level. The Objective and Minimum levels for reliability indices are set at division level as shown below.

NYSEG CAIDI MEASURES 1999 – 2002 WITHOUT STORMS

DIVISION	Obj. / Min.	2002	2001	2000	1999
Auburn	CAIDI obj.=1.26 min=1.73	2.88	1.65	1.57	1.76
Binghamton	CAIDI obj.=1.75 min=2.00	1.64	1.58	1.73	1.55
Brewster	CAIDI obj.=1.75 min=2.50	1.57	2.07	1.75	1.91
Elmira	CAIDI obj.=1.75 min=2.40	1.99	2.10	2.47	2.09
Geneva	CAIDI obj.=1.50 min=1.85	2.24	2.08	1.62	2.00
Hornell	CAIDI obj.=1.60 min=1.97	1.97	1.97	1.88	1.85
Ithaca	CAIDI obj.=1.75 min=2.40	1.67	1.65	2.23	1.78
Lancaster	CAIDI obj.=1.48 min=1.71	1.63	1.39	1.78	1.80
Liberty	CAIDI obj.=2.00 min=2.50	2.18	2.33	2.66	2.66
Mechanicville	CAIDI obj.=1.50 min=1.70	1.78	1.58	1.97	1.98
Oneonta	CAIDI obj.=1.80 min=2.50	2.28	1.83	2.83	2.25
Plattsburgh	CAIDI obj.=1.21 min=1.70	1.67	1.32	1.61	1.81

NYSEG Distribution Circuit Reliability Program

One part of NYSEG's effort to maintain highly reliable energy systems is the Worst Performing Distribution Circuit Reliability Program. The program consists of monitoring the performance level of all NYSEG circuits on a regular schedule, identifying the under-performing circuits and the factors contributing to their poor performance, scheduling corrective measures to address poor performance and tracking the effectiveness of corrective actions. Below is a chronology of the steps taken to complete the process.

- ☐ Establish specific ranking criteria (factors and weighting).
- ☐ Compile data and rank the performance level achieved by NYSEG distribution circuits over the previous 3 years (July 1-June 30). The listing ranks reliability performance so that worst performers can be addressed along with other factors such as numbers of customers served and energy delivered by the circuit. (Circuit Reliability Ranking Lists are included with each division in this report).
- ☐ Select the circuits (from the circuit ranking list) that will be analyzed in detail to identify the factors leading to a performance failure. The selection process follows these analytical criteria:
    1. Highest weighted customer hours of interruption over last three years with storm, by circuit, with the following circuit statistics factored in: SAIDI, SAIFI, Load, Interruptions/Circuit Mile and Number of Customers connected. Customer Hours of Interruption are weighted to emphasize degrading trend.
    2. CAIDI is considered in final circuit selection.
    3. Adjustments may be made for poor reliability not recognized in the ranking process, such as high numbers of interruptions.
    4. Recent reliability improvements not reflected in ranking are also factored in, as well as significant single events not likely to repeat.
    5. Large amount of energy interrupted or special situations.

- ☐ Analyze newly selected circuits for performance failure causes and recommend corrective actions.
- ☐ Discuss selected circuits and recommended corrective action with respective operating divisions.

Finalize selections and distribute circuit analyses with committed actions list to operating divisions for implementation of high priority corrective reliability measures for *at least* 5% of worst performing circuits. Where corrective actions may require capital improvements to add or replace equipment or make circuit design changes, divisions submit project proposals to the Reliability Achievement Council (RAC) for funding.

- ☐ Divisions submit overall reliability plans for review by the RAC and corporate technical departments.
- ☐ Analyze prior year corrective action circuits for associated improvement in reliability performance.
- ☐ Prepare and submit the annual Reliability Improvement Report for PSC.

Power Quality

A section of the 2002 NYSEG Reliability Report contains a discussion of the corporation's PQ Program for 2002. It includes a review of accomplishments and an analysis of the power quality problem data obtained.

NYSEG's objectives for its PQ Program for 2002 include the following:

- ❑ Continue training NYSEG's Division personnel as needed in the following modules:
- ❑ Operation and use of PQ instruments and the evaluation of PQ data obtained.
- ❑ Safety considerations and customer hardware involved in making PQ audits.
- ❑ Complete the first survey of industrial customers to characterize NYSEG's power quality.
- ❑ Evaluate extending this survey to additional customers.
- ❑ Identify and evaluate more capable revenue meters with PQ monitoring capability.
- ❑ Complete the evaluation of voltage regulator applications on motor control circuits at Sanmina(?).
- ❑ Make further improvements to PQ problem reporting in TMS. Provide training as needed to ensure reporting accuracy.
- ❑ Continue with the implementation of the Storm Safe Program in all Divisions to sell meter-base and plug-in surge suppressors to NYSEG's customers.

Interestingly, the result of the power quality survey of industrial customers, from data obtained from August 2001 through December 2002, revealed the following results:

- ❑ The survey was initiated to establish typical power quality problem occurrence rates at NYSEG's industrial customer’s facilities. Data was obtained using ABB'S Alpha Plus PQ revenue meters that include power quality parameter measuring capabilities. These meters were installed for customers that signed up for the EPO (Energy Profiler On-line) service offered by NYSEG. They include a telephone line connection that permits downloading data remotely.

- ❑ Report results are based on data from 22 customers across the NYSEG system obtained from August 2001 through December 2002. They provide typical occurrence rates for power quality problems including high and low voltage, sags, momentary interruptions and harmonic distortion. These occurrence rates show that both transmission and distribution systems experience disturbances, incidents, or events although the distribution system experiences them more frequently.

The company indicated that this data would be used by operating and engineering departments to identify circuits where performance improvements may be needed. Also, NYSEG's customer service representatives could find this data helpful in making customers aware of the typical level of power disturbances they can expect to help them plan accordingly. The survey would continue into 2003.

Another program, NYSEG PQ program, is the PQ Database. In 2001, several improvements were made to NYSEG's TMS (Trouble Management System) for recording power quality incidents in 2002. These included; the addition of a "Momentary Interruption" trouble type to the Trouble Entry screen; provision of information to Division personnel clarifying the difference between momentary interruptions and flickering light problems; provision of instructions for Division personnel to ensure PQ incidents related to another problem such as a no power or to a PQ problem affecting more than one customer are not entered; and completing PQ incidents without codes that are related to storms. Comments regarding the impact of these changes on the number of PQ incidents reported are provided in the data discussion below.

NYSEG's general comments on PQ Problem Data for 2002 can be summarized as follows:

Data obtained for 2002 as for previous years are primarily power quality problems reported by residential customers. The 2002 year's breakdown by customer type is similar to previous years and is as follows:

Residential	93.2%
Commercial	4.9%
Industrial	0.4%
Other - (Churches, Gov't. (Facilities, Schools)	1.5%
TOTAL	100%

Out of the 2,633 problems reported. 1,226 problems were determined to be NYSEG's responsibility. Low voltage and flicker were the two most frequently reported problems. Out of the 2,633 problems reported, 767 were considered to be the customer' responsibility. Low voltage and flicker were again the most common problems.

Table B1 2002 NYSEG Power Quality Problems by Type

PROBLEM TYPE	NOS. OF OCCURENCES
Momentaries	106
Low Voltage	798
High Voltage	303
Harmonics	1
Sags	13
Swells	9
Flicker	1,392
Transients	11
TOTAL OCCURENCES	2,633

Loose or bad connections were the leading causes for PQ problems on NYSEG's side of the meter. These connections include the taps on the primary, transformer connections, and service drop splices at the house. Tree interference is the second most frequently occurring cause. Faulty or defective equipment was the third most frequent cause for PQ problems. On NYSEG's side of the meter, these include transformer failures, broken or faulted conductors, insulator failures, load tap controller or voltage regulator malfunction or failure. Faults occurring on the NYSEG system were the fourth most frequent cause for PQ problems. These faults are caused by animals and by weather related events such as wind, snow and ice. They occur primarily on NYSEG's side of the meter.

B.2 Central Hudson

Reliability Group at Central Hudson

The Electric Distribution Section has the responsibility in the Engineering group to closely monitor the Central Hudson electric system and to analyze and develop plans to improve the performance and the reliability of electric service to all Central Hudson customers. The 5 Customer Services operating areas of Central Hudson have SAIF1 and CAIDI goals to guide the efforts to improve electric service reliability. Monthly meetings are held between the Engineering group and the Customer Services group, focusing on reliability performance, in order to exchange information and stimulate discussions that result in methods to reduce the frequency and/or the duration of service interruptions.

The 2002 Reliability Performance Report of the Central Hudson System

Central Hudson prepared a Reliability Performance Report of the Central Hudson System for 2002 (2002 Central Hudson Reliability Report). The report details the 2002 reliability performance of the Central Hudson System and an assessment of the five operating areas' performance. This assessment includes a five-year history of performance, listings of the three indices, and a synopsis of current power quality programs.

Central Hudson’s Enhanced Reliability Program

The Enhanced Reliability Program was outlined in Central Hudson's Settlement Agreement with the Public Service Commission issued and effective on October 25, 2001. The objective of this Enhanced Reliability Program is to improve electric service reliability to customers through reduced electric outages on poor performing distribution circuits. This new program is funded up to a total of $20 million until June 30, 2004 from the Central Hudson Benefit Fund. Enhanced Reliability Program projects are prioritized and constructed based on the lowest project cost per customer outage avoided ($/COA).

Some of the types of projects identified thus far by the Electric Operations Engineers include:

1) Enhanced line clearance on distribution circuits to increase the buffer zone between the overhead distribution wires and the surrounding trees and vegetation by removing some or all of the overhanging tree branches and removing all of the surrounding danger trees;

2) Replace line fuses with reclosers and sectionalizers on distribution circuits to minimize outages which may be momentary in nature from resulting in permanent long term outages;

3) Install additional reclosers, sectionalizers, and fuses on distribution circuits to increase the number of protection zones on the circuit, thus, minimizing the number of customers affected during an outage;

4) Install additional lightning arresters on distribution circuits to minimize outages caused by lightning;

5) Replace problematic porcelain cutouts with polymer cutouts to reduce outages caused by cutout failures;

6) Install Automatic Load Transfer (ALT) switches on the distribution system to quickly (within a minute) restore electric service to customers for outages occurring upstream of the ALT switch;

7) Reconductor bare overhead conductors with covered conductors on distribution circuits and/or relocating off-road distribution circuitry on-road to reduce outages caused by momentary tree contact with the phase conductors.

Continued efforts utilizing the maintenance program and issues targeted by the reliability committee are expected to further reduce the number of interruptions.

Central Hudson System Reliability Performance Report

Year	SAIFI (Without Storms)	CAIDI (Without Storms)	SAIDI (Without Storms)	SAIDI (With Storms)
2000	1.021	1.845	112.98	426.89
2001	1.064	1.812	115.6	135.42
2002	1.226	1.889	138.99	255.32
% Change (2001 to 2002)	15.2%	4.2%	20.2%	88.5%

SAIFI/SAIDI:

The system SAIFI index (without storms) increased by 15.2% in 2002 and is higher than the five-year average of 1.08 (1.23 in 2002). According to Central Hudson, this increase is a result of the increase in the number of customers affected, excluding major storms, from 290,157 customers affected in 2001 to 344,235 customers affected in 2002. Central Hudson also explains this increase is a result of the system improvements the company made in the first 12 months (July 2001 thru June 2002) of its Enhanced Reliability Program to improve the total reliability (with and without storms) of electric service to its customers.

The SAIDI (with storm) index showed a significant decrease from 426.89 in 2000 to 255.32 in 2002 as a result of the system improvements made through the Enhanced Reliability Program. However, looking only at the SAIFI and SAIDI indices (without storms) from 2000 to 2002 would lead to the erroneously conclusion that the reliability of the Central Hudson electric system is deteriorating.

Another reason for this increase in the system SAIFI index (without storms) is because of the improved accuracy in outage reporting. This improved accuracy is a result of using a new Outage Management System (OMS) to double check and correct the outage data that either are manually recorded on paper and later entered into the Transmission & Distribution System (TDS) on the mainframe computer or are recorded via pen computers and uploaded into the TDS.[38]

Central Hudson states that its programs are focused on reducing the number of interruptions through predictive failure detection by performing distribution line patrol and infrared survey of the electric system to identify damaged or deteriorating equipment that have a high probability of causing an outage. Completion of repairs on these equipment and other action items that originate from the monthly reliability reports is a company priority to prevent possible future outages. In 2002, Central Hudson started performing outage analysis and equipment failure analysis to develop proactive plans to eliminate the root causes to these outage problems and prevent these outages and equipment failures from recurring.

CAIDI:

The system CAIDI index (without storms) increased by 4.2% in 2002 and is slightly above the five-year average of 1.87 (1.89 in 2002). Emphasis is given to significant numbers of interruptions involving off-road lines, necessitating long patrol times that affect large numbers of customers. In response to these interruptions and to enhance the response to all interruptions, the Electric Operations Engineers concentrate their efforts on the installation of fault indicators, the installation of ALT switches, and the creation of stronger or additional circuit ties for switching.

Improvements made to OMS have reduced the time required to process the interruption information and to identify the most likely sectionalizing devices that have operated. By reducing the time required to process the interruption information, quicker and more informed decisions are made during the initial moments of the outages to reduce the interruption duration. Also, OMS has provided Central Hudson Customer Service Representatives with valuable information to address customers' question when receiving calls in response to electric outages.

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[38] As indicated in a Central Hudson's March 2003 filing with the Public Service Commission (PSC) on the affects of the improved accuracy in Central Hudson's outage reporting after implementing the OMS, the system SAIFI index for 2002 would have been 0.95 under the previous manual system of recording outage events instead of the 1.226 value reported to the PSC based on the improved accuracy in the 2002 outage reporting. This 0.95 SAIFI index would indicate an improvement in the Central Hudson electric system in comparison to the 2001 SAIFI index of 1.064.

Power Quality program - 2002 Activities:

During 2002, Central Hudson reports, the Customer Services and the Engineering groups met with residential, commercial, and industrial customers to assess their power quality needs. The team worked with several of these customers in identifying and resolving power quality problems regardless of whether the root cause was the customer's or Central Hudson equipment. As part of this program, Central Hudson distributed the brochure entitled "Understanding & Avoiding Commercial Power Disturbances". Many of the visits made to commercial and to industrial customers' facilities were informational in nature and required no additional follow-up.

The following is one of the typical power quality problems that Central Hudson reported on during 2002:

- One of the customers the Poughkeepsie Operating Area worked with, in 2002, to resolve a power quality problem is RJM Plastics in the Town of Millerton. RJM Plastics is a small plastic bag manufacturing company that is served from the Millerton 7081 circuit. Often on a daily basis in early 2002, there were multiple operations of the Central Hudson's protection equipment in response to momentary outages on the electric system. These operations would cause problems for the RJM manufacturing equipment because they were very sensitive to both momentary and sustained outages on the Central Hudson electric system. After some investigation, it appeared that the reclosers just south of the RJM facility were the cause behind these multiple operations due to the tree conditions on the 7081 circuit.

- Therefore, Central Hudson performed some tree trimming on the 7081 circuit to solve the reclosers' nuisance operations. Furthermore, Central Hudson relocated these reclosers to just north of the RJM facility so that RJM would no longer be exposed to the operations from these reclosers for momentary outages on the 7081 circuit that are downstream from the RJM location. RJM's power quality problem was thought to have been solved until a few months later when some unfortunate circumstances arose causing RJM to see voltage dips and momentary outages as a result of a multitude of small problems occurring on both the Central Hudson distribution and transmission systems. Central Hudson then decided to go one step further by hiring EPRI (Electric Power Research Institute) to provide RJM with a "Power Quality Walkthrough Audit". Central Hudson engineers worked with an EPRI engineer at the RJM facility to investigate options in which critical electrical components at the RJM facility could "ride through" small voltage dips and momentary outages, thus, preventing the RJM production line from coming to a rather messy and costly halt. The EPRI walkthrough at the RJM facility took approximately half of a day. Critical RJM systems were identified with the assistance of RJM maintenance personnel. Diagrams and schematics were obtained to allow a complete and comprehensive examination of the entire facility. The EPRI engineer is currently putting together a report on possible remedies to RJM's power quality problem. After this report is issued, Central Hudson plans to meet with RJM to discuss the possible remedies recommended by EPRI. This information will also help RJM in the future design and procurement of equipment for their facility.

B.3 Niagara Mohawk

Power Quality 2002 Annual Report

In May 2003, NMPC reported on the details, statistics, and overall status of the Corporation's Power Quality Program for the period January 1, 2002 through December 31, 2002 as required annually by the PSC Case 90-E-1119 of July 2, 1991. It included, as attachments to the annual report the "2002 Transmission and Distribution Momentary Interruption Reports", which provide a comprehensive and detailed listing of NMPC's momentary interruption (MI) statistics for all circuit classes, from a variety of perspectives. The report provided the statistical information used to derive and track the results of the 2002 Power Quality Penalty Avoidance Targets.

The report discusses the NMPC's abilities to address present day PQ issues facing the electric utility industry and its customers. The company acknowledges its commitment to provide a comprehensive proactive approach in their response to the growing number of customer concerns regarding the quality of power delivered by the electric utility.

The results are summarized below:

1. NMPC's circuit performance exceeded the necessary criteria for avoiding penalties associated with the 2002 Power Quality Avoidance momentary interfernce (MI) Targets for all circuit classes. The year-end results were:

Circuit Class	2002 Target	2002 Actual
115kV	200	135
23-69kV	725	490
Distribution	2,000	1,890

2. Fixed Power Quality Penalty Avoidance Targets were established in July 1999. Beginning calendar year 2002, the Company will file annual performance reports in compliance with the Joint Proposal approved by the Commission in Case No. 01-M-0075. NMPC's exposure concerning these Power Quality Penalty Avoidance Targets for 2002 is $2.2M dollars.

   The fixed targets are:

   115kV < 200 MI's
   23-69kV < 725 MI's
   Distribution < 2000 MI's

   Note: The fixed targets are only for MI's that occur at the Substation breaker level and do not include pole-top recloser operations.

3. The Company’s power quality program is outlined in Electric System Bulletin (ESB) #320, titled Electric Power Quality Program. The “Beyond the Meter” program has been incorporated into ESB#320 to better comply with NMPC’s commitment to deregulation of the electric utility industry. Briefly, the “Beyond the Meter” program is defined in ESB #320 Exhibit 3, titled PQ Pricing Guideline. Implementation of the new PQ Pricing Guideline commenced in March 2000 and is ongoing.

4. A one-day Stray Voltage/Long Day Lighting Seminar developed by Dltech, Inc and Pro-Dairy was jointly sponsored by NMPC and New York State Electric and Gas. The first of these seminars was held on December 12, 2001 in Batavia. Three additional seminars were held in December 2002. (One in Johnstown, Richfield Springs, and Oneida New York). Additional seminars will be scheduled in 2003.

5. The PQ Work Order Tracking System was significantly enhanced in 2000 to support the Corporate Power Quality Program (ESB #320). This system provides a means of managing and tracking PQ investigations from start to finish on a system wide basis while maintaining detailed historical records.

6. No PSC complaints, that NMPC is aware of, have been left unresolved in 2002 based on the System Power Quality Parameters. The specifics of this year’s performance are provided in Attachment One – Power Quality Statistics. Following this table are bar graphs summarizing regional results.
7. NMPC continued to provide significant contributions to customers concerning Power Quality issues.

Examples of the information that is provided in the Power Quality 2002 Annual Report is illustrated by the graphs below. High/Low Voltage complaints are over-under voltage whereas Voltage quality complaints includes flicker, noise, surges, sags, swells, harmonics, and frequency

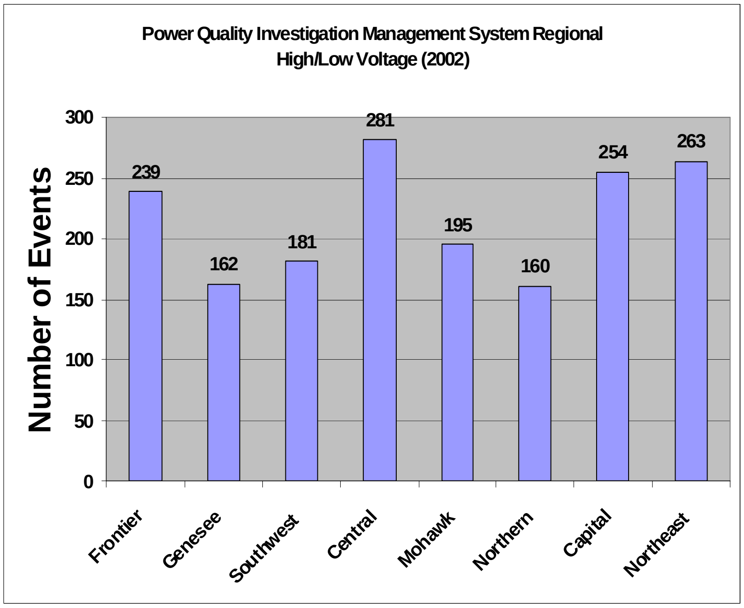

Figure B1 Niagara Mohawk High/Low Voltage Events by Region

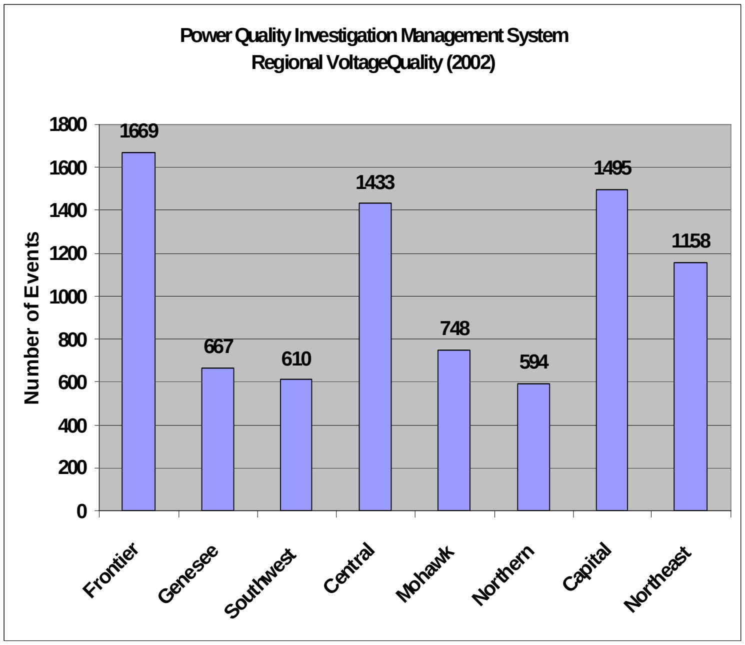

Figure B2 Niagara Mohawk Power Quality Events by Region

B.4 Con Edison

Con Edison Power Quality Service Center (CEPQSC)

Con Edison reported that its Power Quality Service Center (CEPQSC) has, since its inception in 1994, developed into a PQ-support center for its customers. The major objectives of the CEPQSC include maintaining a high level of PQ and maintaining presence as the region's leading source of power quality information and guidance for its customers.

The CEPQSC makes strategic alliances with the Electric Power Research Institute, the Power Electronics Application Center (PEAC), the Canadian Electric Association, and other utility power quality affiliations to aide in this effort. These alliances support the major objectives of the CEPQSC.

Con Edison acknowledges that PQ generates a high level of interest with its customers. Through expanded power monitoring, participation in industry developments and knowledge of technical trends, Con Edison is attempting to aid the customers with PQ concerns. In addition, through learning the needs of its customers, Con Edison has provided training seminars targeting specific topics by leaders in the industry.

Power Quality Information System

The Power Quality Information System (PQIS) serves as a key source of power quality information for the company and is the starting point for all customer assistance calls and studies. This information base is available to all Con Edison employees and is used to obtain detailed information pertaining to system events, power quality solutions and applications by many organizations. As well as an initial starting point this resource allows for us to be ready to supply immediate answers to customer calls.

Customer Contact and Support

Con Edison reported that the PQ group provided onsite assistance to 66 major commercial and industrial customers with power quality issues and concerns during 2002. In addition, the PQ group provided off-site assistance to 97 customers (general inquiries excluded) directly through telephone and email contact alone. During 2002, calls related to voltage quality were made throughout Con Edison’s service territory at a rate of 322 per 100,000 customers.

APPENDIX C
CASE INFORMATION BASED ON CUSTOMER INTERVIEWS

This section documents a series of interviews with large commercial and industrial customers regarding their experience with power quality problems. This is not a random sample of customers. Instead, these customers were chosen specifically because they were expected to have high power quality requirements and, in some cases, were known to have experienced power quality problems and/or had implemented distributed generation. The power quality issues reported by the customers were not independently verified, and the electric utilities involved were not contacted for a response.

Bear Stearns – March 3, 2004[39]

Background

Bear Stearns is the 7th or 8th largest banker and the largest clearing firm in the world. World headquarters is in Manhattan, another large office is in Brooklyn and there are other domestic and international offices.

The Manhattan office was completed and occupied in late 2001, designed by Bear Stearns (Mr. Kass directing) to maximize energy reliability and power quality. The building "won every single award for design." The Manhattan office has 5,000 employees, with eighty percent of employees working 8:00 to 5:00 five days a week. Power quality is essential at the Manhattan office in order to maintain communications for 1,800-2,000 traders and to complete a variety of work for which time is of the essence. The Brooklyn office is a back office operation, basically clerks and record keeping. The Brooklyn office has 1,800 employees in total, with 300 essential employees on UPS and generator. If there is an outage things will just back up.

Peak load is 8 MW at the Manhattan site occurring during the summer months, with a normal load of 5 ½ MW. Minimum load is in the 2 ½ to 3 ½ MW range. Back up includes four 1.8 MW primary rated generators, to run air conditioning and elevators. The company stores 40,000 gallons of fuel oil on site, or 48 hours, with contracts for deliveries on a daily basis.

Air conditioning is essential since equipment, including the average trader's six computers, generates a considerable heat. The company has 10,000 tons of air conditioning, with separate cooling for the generators and UPS. Little money is spent heating the building. If the building lost heat, circulating water would be sufficient to avoid pipes freezing.

Power Quality

Bear Stearns is very sensitive to power quality problems and has designed its new building and electrical system to minimize such problems.

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[39] Interview with Mel Kass, Managing Director responsible for physical plant operations worldwide.

The company experiences approximately 15-20 incidents (spikes, transients) on any given day that could affect their operations.

PQ Related Costs

PQ related costs could be enormous, including potential inability to complete time sensitive tasks and possible lost opportunities, justifying very expensive protections built into building and described below.

Blackout in August ’03

No problems in Manhattan, other than having to cut back generation because fuel deliveries were not being allowed into Manhattan. Brooklyn office was out from 4:00 p.m. on August 14 until 8:00 a.m. the next day. There were no real problems.

Measures to Increase Reliability

Power quality maximized by:

- Con Edison’s network system. If there is a break in one direction power is fed in from another.
- Three feeds coming in from the street bringing up 1308 KW, to five service transformers (only three are needed) and five 4,000 kVA service boards all in a common collector area? and in parallel to each other.
- All critical loads strictly connected to a UPS system sensitive to frequency range.
- Each generator has two separate strings with three 750 kVA modules in each string.
- The components of this system have static switches so the customers can switch from one to the other without any impact.
- There is more than one control room.
- Special specification for the generators, with the cooling capacity increased so they are primary rated. Primary costs much more to run, but don’t cost much more to put in. Business interruption insurance encourages primary rating and weekly, monthly and annual testing.
- ATS has own chillers, air conditioning and ventilation with a battery room.
- Fuel tanks physically separated using two diverse paths.
- UPS units are physically separated on separate floors, with inherent fire barriers. Built two “bathtubs” with drains to take water away from systems.
- N+2 (necessary plus 2) design.

It costs approximately $250,000 per year to maintain the ATS, static switching, UPS and generation. Capital costs of approximately $2.8 million, including items as small as outlets. Fuel tank cost $85,000, UPS cost approximately $1,300,000 and the generators $1,800,000 including installation. Diesel fuel consumption costs approximately $10,600 a year.

Considered Distributed Generation?

Bear Stearns is not a manufacturer and does not have a thermal load to utilize the waste heat. Company tries to use different sources (e.g. three electric and one steam absorption chiller connected to Con Edison system plus dedicated chillers for the UPS/generator system) and cannot have a redundancy with the Con Edison steam system. During the winter the company needs only one chiller, during the spring it needs two and during the summer three. It would be more expensive to run the steam system than the electric system.

Cellu-Tissue – March 9, 2004[40]

Background

The Natural Dam mill in Gouverneur, New York is owned by Cellu Tissue, a private management investment group that has bought Natural Dam and four other independent paper companies since 1998. Natural Dam produces specialty and color dry crepe tissues.

The mill operates 24/7, is a continuous process with a total of approximately 110 hourly and salaried employees on site. Presently there are more orders than production, so down time means lost sales and profits. When orders are down, rather than curtail operations the plant usually keeps running and produces low-profit products.

The company's peak demand is around 5 MW, with 4 MW from Niagara Mohawk and 1 MW from its own low-head hydro unit. Hydro generation is as high as 1 MW, but it is run of the river and as low as 300 KW when river flow is low. An average of approximately 18 percent of energy needs is self-generated. The hydro unit was built in 1928 and is tied to the grid. No major improvements are possible. One generator has been rewound and annual maintenance costs are approximately $20-$30k. The hydro unit runs all the time (takes about 20 minutes to start up) and can provide enough energy for the mill's lights and computers, but not enough to run the production equipment. The plant is situated right on a Niagara Mohawk 115 KV line.

On-site boilers for steam are necessary for production. Company has a 70,000 lbs/hr boiler that averages 50,000 lbs/hr. The company also has a package boiler for backup. Fuel consumption includes gas used every day for a boiler. Fuel oil is used for backup, including 8 days this year during a natural gas curtailment.

A 50 MW CHP plant had been certified and brought on line nearby, with Cellu Tissue's predecessor to get the steam. Niagara Mohawk never bought the power. It was mothballed in '93 and Niagara Mohawk bought out the contract. Now it's stripped down and a prior owner of Cellu Tissue sold off the benefits of the steam deal.

Key production costs are labor, energy and raw material. The company buys virgin pulp, often according to buyer specifications. It does not have a pulp mill and there is no real recycling. The only pulp mill left in area is in South Glen Falls, but the company does not buy from that mill.

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[40] Interview with Bruce Doxtater, Plant Engineer.

Power Quality

Power quality is not a major factor in site operations. Reliability is important but has not been a major problem.

It is hard to determine whether a problem is power quality, lightning, or just a problem with equipment. When one of 50 drives fails it's hard to pinpoint the cause. All interruptions are considered "electrical" – not necessarily a grid related problem. Company has about three interruptions a year. If these interruptions are more than a couple of seconds (approximately), problems result. Once one pump starter goes out, they all go out since they are interlocked in a chain.

PQ Related Costs

PQ costs consist of lost production and employee costs. When the plant goes down, everything shuts down. The company has to hose all the machines down before starting over. (The machines have to be hosed down periodically anyway, but usually at the end of a 45-minute roll.) It's an extra clean up when there is a shutdown.

After the plant goes down, product on the roll will likely be off-grade and the energy used to get it to that point wasted. Product on the roll will have to be taken off and maybe re-dyed. There is less cost if the roll being produced happens to be white. Production generally works in a sequence of white to darkest dyes, since machines get dirtier and that's less important to darker dyes.

Damage to equipment – pulp comes through on a screen with a slice lip just above. Loss of power can result in slice dropping onto wire and causing damage. This happens every couple of years because of a power loss. Repairing the wires is a six-hour job that costs about $10,000. The cost depends upon the life of the wire (how old it is and how long it would be expected to last).

Start-up – in sequence – can take an hour during which time off-grade product that has to be recycled is produced. The longer the plant is down, the longer it takes to start up since it takes longer to heat to the necessary level.

After about 4 hours the product cools, but this happens rarely because of the proximity of Niagara Mohawk's 115 KW line. Last time was the '97 ice storm.

Loss of critical data is not an issue, since the computers have UPS.

Blackout in August '03

The blackout in August '03 was not a big problem. Frequency went down to 58 hz for an hour or so. The company did not want to risk its new machine, but kept its old machine operating. If power is unstable, the company would rather keep the good machine off.

Measures to Increase Reliability

The company has UPS for main computer and individual packages for smaller computers that will last 15 minutes. Mainframe UPS will last under a couple of hours.

Considered Distributed Generation?

The company is looking into CHP. The economics are marginal, but it could make sense. Problem has been that standby rates are too expensive so it would be necessary to build a redundant system. Also, questions regarding what Niagara Mohawk would demand payment for the existing line which they could argue was put in for Cellu Tissue, although it was actually put in for the now stripped down CHP plant. Improvements to power quality from a DG system would not be an overriding concern.

Harbec Plastics – April 12, 2004[41]

Background

Harbec Plastics is located outside Rochester, NY in the town of Ontario. Harbec produces highly engineered, precision plastic parts for customers in medical, automotive, consumer goods and other industries.

Harbec has an onsite combined heat and power system – a hybrid system consisting of 250 kW wind and 750 kW of microturbines. The 750 kW microturbine system is comprised of 25 units of Capstone 30kW microturbines. Each set of two microturbines shares a heat recovery unit. The waste heat is utilized for both heating and cooling purposes.

The facility relies upon microprocessor driven, complex computer numerical controlled (CNC) processes. Power interruptions can create a disaster ruining work in process and damaging equipment and materials. Harbec had numerous problems with utility supplied power, primarily brownouts and continuing incidences of phase imbalance. At the time the company began seriously investigating a CHP system, they were a business with about 90 employees, today that figure is up somewhat to 110.

The site operates 5 days per week and 3 shifts per day. On weekends (Saturday) they run a half-day operation. In total they have 5 ½ days or approximately 5,000 hour of operation. The minimum load is 80 to 85 kW and the maximum load is 450 kW. The parasitic load is 70 to 75 kW. That is enough to meet the minimum thermal requirements as well. In that sense it’s a very nice fit

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[41] Interview with Bob Bechtold of Harbec Plastics.

Harbec has a weekend load of 75 to 80 kW. The microturbines provide the baseload heat and air conditioning requirements. That requires 4 to 5 microturbines to be running to meet the baseline need for thermal (heating or cooling).

Beyond this minimum requirement Harbec tries to meet as much load as it can from its wind power. That's a 250 kW system. If it's a very windy day, on the weekends, Harbec can push as much as 250 kW of free power out onto the grid. Energy not used internally is exported free to the grid.

Power Quality Concerns

Harbec had several conversations with its distribution utility regarding power quality problems and related business impacts. The utility's response was disappointing. The utility would come with a large contingent to the site for a review. Following the review the utility took months to prepare a response.

The final response was that utility would place a new step-up transformer on Harbec's side of the highway. The cost would be $100,000 and would be borne by Harbec. However, the transformer would be owned by the utility.

Prior to making the decision to purchase onsite generation the company began keeping a record of incidences. For the month of June it monitored and categorized interruptions. For that one month alone it documented $16,500 in damaged equipment. This is a serious problem to a small company. This estimate was very conservative: it only documented the cost to repair. It did not include any opportunity costs of lost product.

Nearby Harbec, in the same industrial park, is Optimax Inc., a precision optics company. Optimax produced 8 of the precision lenses that are part of the current Mars Excursion by NASA.

It continues to suffer constant losses due to poor PQ. If there is a trip, then the coding process goes wrong. This requires significant re-working, re-manufacturing of the precision optics.

The Company is working with an ESCO on a windpower/Microturbine or windpower/genset based onsite power solution with waste heat recovery.

Looking for a Solution

Harbec saw that the PQ problem was not going to be solved. There is a continuing high cost of grid connection. An objective was to never be impacted by the grid again, if need be. However, Harbec is still connected to the grid. Since installation of the Windpower/CHP hybrid systems it has operated for as long as 18 month period without taking any grid power.

Harbec was interested in a renewable energy solution. It first looked at a 1 MW project, later scaled back to 250 kW. There was a problem in banking it. Harbec knew that a renewable solution alone would not work. Its original conception was a wind/diesel combination. It later considered wind and natural gas engines, finally settled on wind coupled with microturbines. Harbec eventually settled on a hybrid system consisting of 250 kW wind and 750 kW Microturbines.

At one time Harbec contemplated a bio-diesel backup rather than the grid. The wind turbine needs to see either the onsite power or power from the grid. All wind turbine generators are asynchronous. It doesn't matter if it's the microturbines that they see or the utility grid. Also, the grid, whatever its source must be the greatest percentage. The wind turbine can not contribute 50% or greater, it must run under that 50% figure. The grid must take the majority share.

Harbec's preference is to use as much of the renewable energy as possible and use the microturbines to follow load. Now microturbines are dispatched in 30 kW increments. If Harbec expects load increases of 30 KW for more than 15 minutes it turns on a new unit. If a decrement is expected, it shuts one unit off. The microturbines can be dispatched within 3 – 5 minutes.

POWER QUALITY PROBLEM SOLVED

Harbec reports that following the installation of the hybrid CHP / windpower system the power quality problems have essentially been solved. It no longer has any phase imbalance disturbances, at least associated with the onsite power generation. The site is still taking 5% to 8% of its power from the grid. There remains a phase imbalance problem with this power. Harbec finds that 90% or more of the wind generator's down time is the result of utility side PQ problems. When the generator sees lower grade utility power it disconnects.

Harbec sees a variation of 6 volts from one line to another with utility supplied power. There is a company, MetaTech- working on software that will tell the equipment to re-start itself following a trip that is caused by phase imbalance. Three years later Harbec reports it is still facing poor power quality from grid power.

Cycle disturbances do not affect the microturbines. The CNC equipment is not affected. The microturbines run at 96,000 RPM, they exhibit great frequency control. Harbec finds no compatibility problems with the microturbines. It reports getting extremely high quality power from the microturbines.

Blackout in August '03

On the date of the August 14th blackout the surrounding area did not have a blackout. Power was 6 to 8 volts below normal. All equipment and lighting stayed on. The computers did drop off, and the microturbines dropped off. Harbec stayed in a low voltage situation for 4 to 6 hours. At that time it remained on the grid. This ended up costing the company $5,000 in utility charges. It was an expensive lesson. Beginning August 15th, whenever a similar situation occurs Harbec intends to disengage from the grid and go to isolated onsite power operation.

Other Measures to Increase Reliability

Harbec does have UPS on site. It has two large UPS systems; controller for the microturbines and one for the Servers. It does not want to have the computers drop off line. The company also had to guarantee 30 minute power backup as a requirement for cell phone tower on the building. When considering how to solve the power quality problems, Harbec knew that even a momentary outage was as damaging as a lengthy one, making standby generation alone an inadequate solution. A battery UPS may have improved power reliability but would have increased the already high electric costs. This led to the conclusion of seeking a distributed generation solution.

CHP / Distributed Generation Decision

When the decisions were made, it was really efficiency that mattered. Power quality put them over the edge, but it's the efficiency of the total system that is what its all about. Harbec is able to heat and air condition a plant for free. It can predict 25% to 30% of its power costs for 20 years out into the future. The microturbines are very low maintenance. They have one moving part and they require no lubricants or coolants. That is important to a company that is ISO 14000 certified.

Another objective in the decision-making process was the need to keep things simple. Harbec did not want to become involved in a situation requiring specialized staff and complex and costly operations and maintenance. The hybrid windpower/mictroturbine CHP system met that objective.

Harbec has just 3 electro-mechanical service technicians to service everything in the plant; including CNC's and microturbines. Harbec wanted to go with the least amount of maintenance possible. It felt that it was not in the power generation business and placed a premium on simplicity. Internal service people have handled all of the repairs after (a week?) training course. There has never been a Capstone service technician onsite. Harbec did have problems with premature engine failures and components burning out, but in general Capstone stood behind them in the sense that they kept sending free replacement parts as required. Replacing an engine is a simple process. Half dozen bolts and 2 igniters – it's a two hour job and its done.

Modification of Original Capstone Operation

The Capstone's originally ran in 4-packs. The system as structured was very inefficient. Harbec could not dispatch down to a single turbine within a pack. Harbec modified that with a PLC system that dispatches down to a single microturbine. Previously the set of microturbines would run very hot, become really heated up, unless they were all running together. There was a 300° increase in temperature. That problem has been solved.

Unifins were a great disappointment. Harbec has removed all of the original Unifins heat recovery units and substituted its own design. It received a NYSERDA grant to do the retrofits.

With the old Unifins, when they were running at 65% of rated capacity they would burn out within a month. With the new heat exchangers they run at 110% of rated capacity. The exhaust temperature is 10° over boiling and they now have excess cooling capacity

Harbec does stay connected to the utility grid. It is still able to go standalone within 3 to 5 minutes. This is the time that it takes for the microturbines to start up and to synch with the wind turbine. Harbec could go seamlessly to stand- alone but that would require purchase and installation of an automatic transfer switch. Now it relies on a manual transfer switch. The company has the procedures down and can be up and running within 3 to 5 minutes. It has a written protocol for switchover to standalone. The cost-benefit analysis of conversion to the automatic transfer switch does not yet seem to be an economic decision. The cost would be $30,000 to $40,000 for equipment and installation. The funds can be used elsewhere in the business and the need for transfer to standalone is rare.
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Jamaica Hospital Medical Center (JHMC)- April 13, 2004[42]

Background

Jamaica Hospital Medical Center (JHMC) created the MediSys Family Health Care Network, a network of ambulatory care networks throughout Brooklyn and Queens, which now includes: JHMC: Brookdale University Hospital and Medical Center; Flushing Hospital Medical Center; Trump Pavilion for Nursing and Rehabilitation; The Shchullman Schnachne Institute for Nursing and Rehabilitation; The James and Sarah Brady Institute for Traumatic Brain Injury and a network of 20 neighborhood-based family health care centers. JHMC is a 387 bed, not-for-profit teaching hospital with one of the busiest Level 1 trauma centers in New York.

MediSys has more than tripled in size and bought two other hospitals over the past ten years. It has serious financial constraints because the general patient population is decreasing: Brookdale has decreased from 800 to 50; Flushing was once bigger than Jamaica and is now down to 250: while Jamaica has stayed constant. Financial people target available cash to revenue producing investments and JHMC's medical equipment is state of the art.

The focus of the interview was on JHMC. JHMC has a 465 KW generator that provides service to "life safety" and a 615 KV generator that provides service to critical care (such as keeping ventilators operating). There are 11 transfer switches, six on one generator and five on the other. A wire connects the two generators, but due to danger it was never tested until the August '03 blackout. In addition, there is a 500 KW generator in another building that is connected physically, but not electronically, to the main building. There is also a 200 KW generator in the Trump Nursing Home building just across the street. JHMC has separate boilers for each building, the chilling water is connected and the 500 KW generator can be used for chilling. There is a ten-day supply of heating oil, plus 12,000 gallons of fuel oil for use in an emergency.

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[42] Interview with Hans Waldvogel, Director, Engineering, Jamaica Hospital Medical Center (JHMC).

Data on demand and energy consumption is being copied and sent to us. JHMC upgraded in 1994, but the backup power was not upgraded.

Power Quality

Light flickering, surges, spikes and transients have become more frequent. Con Edison doesn’t warn JHMC of maintenance on feeders and tests and problems occur. First problem when voltage sags is that elevator doors don’t open properly. Sometimes a computer will “blow.”

JHMC has a general problem caused by the fact that tolerances to power quality problem have been decreasing. For example, in the early ‘90s the entire hospital was retrofitted with energy efficient lighting using ballasts specified by Con Edison. They didn’t last long and were changed. The hospital then noticed that every generation test would result in the hospital losing about 30 ballasts. Part of the problem was that one of the generators did not have governors. Adding electronic governors improved matters, but the hospital continued to blow out ballasts and bulbs.

In addition, the emergency room is directly above the main service and the hospital experienced EKGs “jumping all the time.”

Also, expensive General Electric specialty machines, such as MRIs and Catscans, were vulnerable and would be destroyed by a transfer of power. Hospital had to give 30 minute warning to operators of CATscans and cardiac catheters, something that is obviously impossible in an emergency.

PQ Related Costs

JHMC incurs significant costs to replace ballasts, bulbs and computers damaged by surges, sags, spikes and transients. Every time a generator starts, something obviously necessary for reliability, there is a $10,000 hit to equipment.

Blackout in August ’03

Four hours into the blackout a piston blew and the 615 KW generator was lost. Some of the critical care load was shifted to the “life safety” generator. For the remaining 21 hours of the blackout, the hospital switched power back and forth using manual transfer switches under very dangerous conditions. JHMC was able to cycle ventilators, since some have twenty-minute packs and some have four-hour batteries that can be cycled. When the trauma center needed to have a CATscan, operational for example for two “shot in the head” patients, it required shutdown of other equipment.

JHMC only made it through the blackout because of overly cautious planning including the wire between the generators and Y2k planning. Blackout confirmed that hospitals are “stand-alone” and cannot depend upon Con Edison,, City or federal Department of Homeland Security for assistance.

Since the blackout, JHMC has not yet been able to replace the lost generator and has been renting one from a company in New Jersey. The replacement is expected to be delivered later this month.

Measures to Increase Reliability

UPS used for computer room and medical equipment. Computer room for JHMC and the two other hospitals has a 65 kVA UPS, with smaller UPS on each floor and for specialty medical equipment. A new cardiac catheter that was recently purchased requires a UPS twice as large as that for the computer room.

Considered Distributed Generation

JHMC and affiliated hospitals have looked at various possibilities ranging from a .6 MW plant to a 5 MW plant that would have sold into the grid. JHMC has considered the potential impact of CHP on power quality, particularly on reliability. There are two major impediments to installing CHP. First, the JHMC buildings are spread out and a proposed new nursing home will be taking what would have been the best site for a CHP unit. Second, JHMC's financial constraints mean that there are other more pressing needs for available funds.

New York Warehousing and Logistics - March 5, 2004[43]

Background

New York Warehousing and Logistics provides temperature controlled warehousing. Facilities manager, Dennis Lane developed an on-site power system both for his company and for Alpha Plastics, a company that manufactures plastic items and shares the 200,000 square foot building (most of the building used by Alpha Plastics). Alpha Plastics has 50 employees usually working three shifts.

Both New York Warehousing and Alpha need reliable and affordable power. New York Warehouse stores $30-40 million of seafood in its freezer. Alpha is beginning just in time contracts and penalties for failure to perform would exceed its profits.

Keyspan originally approached Lane in the last quarter of 2002 by one of their natural gas sales engineers, who subsequently introduced him to Con Ed Solutions and KeySpan Business Solutions for turnkey pricing on a DG/CoGen installation as his facility. Those two entities as well as various others then spent the next nine months just trying to agree on how to implement the project and get the correct equipment for the application. At Keyspan Gas Sales' urging, he finally agreed to do the installation himself, quickly put out RFP, and followed up with a purchase order in January of 2003, for the equipment. He then immediately began the

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[43] Interview with Dennis Lane of New York Warehousing and Logistics in Canarsie, Brooklyn.

installation of the required equipment and systems, and attempted to place the generation equipment in service in April 2003. Con Edison then notified him that even though he had properly filed for an interconnect with ConEd, that he must disconnect the on-site generation system because ConEd had not yet approved his interconnect request. The majority of the interconnect issues with ConEd were based on the equipment manufacturer's lack of documentary support in the usage of "Utility Grade" relays, software systems, etc., in the design and control of the system. Lane then designed his own interconnect control system and subsequently had it independently tested by a ConEd approved third party testing agency, and now the plant is consistently running in the 800-900 KW range. Final testing documents on Fault Current Studies, Harmonics and Full Coordination Studies have just been completed in the last two weeks and Lane will present them to ConEd Engineering within the next two weeks. The plant has been approved to run by ConEd at a 100% capacity during these final tests. Lane also had to comply with Con Edison policy prohibiting synchronous engines and requiring a short tap.

This is a very sophisticated customer who designed the generation, interconnection and monitoring system. First phase includes five 200 KW Hess engine (CHP) in first phase, limited to induction generation. Second phase will use all waste heat from the engine exhaust and engine jacket to indirectly fire absorption chillers for space ambient cooling as well as chilled water for Alpha's needs in their manufacturing machines. Alpha will also need cold water for spot conditioning and will use 75% of the waste heat just for its ambient space cooling load requirements. 180kW of Capstone Micro turbines with Black Start option are now in the design phase, and the waste heat from the turbines will drive a 100 ton absorption chiller for warehouse dehumidification and ambient cooling. New large capacity electric high pressure air compressors have also just been installed at Alpha, so the two Cat 3408 natural gas fired air compressors currently with air ends will each be converted to 250kW synchronous generator ends in the near future.

Power Quality

The company experienced consistent power quality problems. While New York Warehousing and Logistics never lost all of its power, it would lose one phase (typically L3). Alpha's motors would trip when there was a phase drop off. Con Edison denied they had any problems at first, but once Lane began tracking the power issues with his own monitoring equipment, and then knew the right questions to ask, Con Edison then made improvements and the necessary upgrades. Entrance cables in the cable vault were upgraded and incoming high voltage is now very consistent, with very few voltage drops of any significance, and those only occur when Alpha starts a large machine for a new run cycle.

Lighting is the biggest contributor to power quality problems. Anything with a ballast hurts power factor.

In addition to installing CHP, Lane also installed a series of capacitors, physically adjacent to each of the five 200kW generators, and tied them into the line side of the shunt breaker as well as the load side of the shunt breaker on each unit to maintain an even staging up or down of power factor quality correction and/or adjustment which allowed him to correct power factor to meet the ConEd Interconnect requirements, and to avoid problems and any potential penalty from the utility.

PQ Related Costs

New York Warehousing & Logistics had a huge amount of frozen seafood at risk. Alpha Plastics had 50 employees who had to be paid even if poor power quality/reliability meant their manufacturing machines were not operating.

Measures to Increase Reliability

As referenced above, black start generation is being installed for insurance purposes to prevent loss of frozen stored product. At the current time, New York Warehousing and Logistics has a contract with GE Portable Power to bring in a portable power supply generator if necessary.

Pace University– March 5, 2004[44]

Background

Pace University operates four campuses with 80 buildings, totaling 2.5 million square feet. Three of the campuses are in Westchester County; the other is located in the financial district in Manhattan.

Pace has a total of approximately 2 MW of emergency generation. Those on the Westchester campuses are diesel-fired units, and Pace Plaza, the downtown New York City campus, has a 250 KW natural gas fired unit. Each campus also has an emergency generator to back up its computing system as well as a battery backed-up UPS. There is also a backup computer system. In addition, the biology labs at the Pleasantville and Briarcliff campuses have small backup generators. The New York City campus uses the backup generator for its emergency lighting and one elevator only. Load shedding is required on all campuses to run the generators.

- Pleasantville has a 1250 KW tractor-trailer that provides power for the campus.
- Briarcliff has a 250 KW generator that provides partial backup.
- NYC – One Pace Plaza – has a 250 KW gas fired unit.
- White Plains has a 300 KW generator.

Pace buys high-pressure steam for two of its buildings in NYC for both heating and cooling. The steam is also used to produce the domestic hot water.

The other campuses have boilers producing low-pressure steam for reheating coils in air handling units. These campuses also have a mix of low temperature boilers that produce hot water for the peripheral convection heating system in most of the buildings. The smallest

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[44] An interview was conducted with Bill Batina, Energy Manager at Pace University.

buildings may receive the hot water from a nearby building or they may have small central air electric heat.

Most of the air conditioning is developed from gas absorbing chillers. The remaining electric chillers have been upgraded to the high efficiency models. Most of the dorms have window air conditioners with only two of the dorms using automatic controls on these window units.

Pace is always looking for ways to save energy. Most air conditioning units are controlled by building control systems. Pace monitors the outside temperatures and provides heating or cooling as needed depending on the season and the schedule. Pace also use the outside air for cooling when the humidity is low.

Pace has and will consider Peak Shaving, combined heat and power (CHP), microturbines and fuel cells.

Power Quality

Pace has not experienced significant power quality problems, except at a leased building downtown where there were complaints about computer monitors changing colors and being affected by lights. Two separate problems were discovered:

- Direct current magnetic fields from a nearby subway line produced changing colors in the monitors. There are large current spikes on the power lines within the building, presumably from subway switching equipment in a subbasement, which have not caused any noticeable effects.
- Alternating current magnetic fields from cubicle shelf lights caused the monitors to flicker.

Pace responded to the problems by changing monitors to LCD flat panels and shielded the larger monitors to prevent the magnetic fields from entering the monitors.

Pace has also had problems with ballasts “blowing” in new lighting. There is no power conditioning equipment, but the problem may have just been problems that have occurred recently with the ballasts from various manufacturers. The ballasts were replaced.

There have been some brownouts and “every once in a while” the lights go out because of a power outage.

PQ Related Costs

The only costs mentioned were to replace monitors with LCDs and to replace ballasts.

9/11 Attacks on the World Trade Center

Pace Plaza lost power, along with all of lower Manhattan, following the attacks of 9/11. Pace operated the emergency generator and then, later in the day, Con Edison delivered a 2 MW generator and 2 -2MW backup generators. Pace Plaza was designated an emergency center for the search and recovery effects due to the proximity to the World Trade Center, about three blocks away.

Blackout in August ’03

During the blackout on August 14, 2003., Pace was able to shed enough load to run its generators. At Pace Plaza, a downtown building facing the Mayors office, the emergency generator operates the hall lighting and one elevator. About five hours into the blackout, Mayor Bloomberg looked over at Pace Plaza, saw the lights were on, and exclaimed “ Hey Pace has power, How do they have power and we don’t?” He then realized the generator was running.

Measures to Increase Reliability

In addition to backup generators, Pace has a backup computer system and all computer systems are protected by surge suppressors and backed up by UPS. UPS responds very quickly – in less than 4 milliseconds.

UPS will last approximately 15 minutes. Within that time, the generator will kick in. Transfer switches for the computer generators are on automatic.

Considered Distributed Generation

Pace has talked to several interested vendors about CHP, which could be used for hot water in the dorms. Pace is also interested in peak load shaving and fuel cells.

Revere Copper - March 9, 2004

Background

Interview with Ron Edwards, Paul Pelton (electrical engineer) and Cliff Fike (finance and electric power billing) of Revere Copper Products in Rome, New York. Revere produces copper and alloy products and its manufacturing facilities includes melting, casting, hot rolling, cold rolling, extrusion, bar making and testing equipment. The Rome plant operates a batch operation 24/7 with 420 hourly and salaried employees on site.

The plant’s peak demand is 14,928 KW and it consumed 86,900,000 kWH/year and 520,300 mcf/year in 2000. Niagara Mohawk provides 115 KV volt power, transferred to 13.8 KV and 11.2 KV for own distribution.

The company has a 125 kW standby diesel unit, installed in the mid ‘80s, to serve as an emergency power source to; the combustion blowers; feed #6 fuel oil to the pre-heater and oil pump; hot water heater; air compressor; sewage pump; chemical mixer; feed water; boiler controls with metering and boiler room emergency lighting. A 2,000 kW (three phase) Caterpillar standby diesel generator, installed in the late ‘90s, is available primarily to serve four cast shop furnaces by barely meeting each furnace's minimum power requirements (just enough to keep furnace metal in a molten state during an extended outage). The unit would also be used for emergency related cast shop operations such as keeping overhead cranes and furnace hydraulics operable for emergency dump procedures and as an emergency feed to furnace inductors and MCC transformer.

In addition, there are two gas-fired generators in the cast shop for lighting and pumps. One is a 70 kW unit installed in the late 70s and used for emergency MCC including inductor cooling pumps, water relay panel, furnace controls, cast shop emergency lighting and tie-in breaker rectifier. The other is a 50 kW unit, installation date unknown, that provides emergency power to coil blower controls, sump pump and furnace auxiliaries.

The company also has dual fuel steam boilers using natural gas or No. 6 fuel oil.

The plant has UPS systems installed on its Rolling Mill and Bar Mill Inert Gas boilers. Installed in the 90s, the systems are necessary since the off gas from these boilers is used to maintain the annealing furnace atmosphere necessary so the metal in production will not oxidize and discolor. A power outage and resulting loss of the required atmosphere could require "repickling" to salvage. In addition, there is a UPS for the phone system and various augmentation of the switchgear.

Power Quality

Transients caused by lightening do cause metering and electronic board failures at Revere. Sometimes it is difficult to evaluate these failures and definitively state that lighting was the cause but that is certainly the case in most failures. Primary effect is on "environmental," since when a circuit board is "smoked" and has to be replaced, water can't be treated.

Voltage and current sags cause machine tripping due to the controls on machines. For example, under voltage relays will be tripped, circuit boards with fixed voltage sensing will trip on phase loss and alternating current induction motors will draw excessive current and trip the overloads. This is the "big hitter", especially during summer evenings. Problems became longer in 2002, lasting from 8:00 a.m. through 10:00 p.m., and more frequent. New solid state controls can adjust and newer devices can have overloads adjusted, but it is not possible to adjust circuitry on mid-80s drives.

Long duration over- and under-voltage situations have a significant impact on copper melting production and require manual corrections to optimize furnace melting capacity.

Noise on the power distribution is more apparent with lower quality drives with a high percentage of total harmonic distortion. Ability to withstand less than ideal power quality is a factor in purchasing equipment. Revere's old equipment can be hurt. It's looking for good incoming power circuits for power electronic equipment.

PQ Related Costs

Voltage/current sags can be very costly. When the company is hot rolling a cake into new bar and a machine trips out, 22 thousand pounds of cake (copper or brass) are lost and sent back to the melt shop. In addition, equipment such as the rolls that roll metal have been damaged. For example, skidding metal across a roll that isn't turning creates flat spots that need regrinding in the machine shop. Some operations are scheduled around times when problems might occur. So work might be done during the first shift (overnight) resulting in a $35-40/hour pay premium and more if overtime is required. Costs include scrap metal, impacts of broken promises, weekend work requiring overtime and, in worst case, $60-70,000 to replace a lost roll. Less costly, but still significant, voltage/current sags result in the need to reset air compressors, inert gas generating boilers for annealing, metal halide lights needed for task lighting (ten minutes to relight). It usually requires a half a shift to get a machine back up, with resulting productivity losses. Also there is no way to know that once a piece of equipment is knocked off-line by poor power quality if the problem will reoccur shortly again after startup.

With some blackouts, if part of an energy demand program, it is possible to adjust and receive payments for not taking energy. With a brownout it is hard to adjust and as costly or more so than a blackout. Each machine can be a bottleneck. Reduced production could result in Revere being perceived as having poor reliability and result in loss of market share.

Costs are incurred to purchase equipment that will be less but still vulnerable to power quality problems.

Longest outage has been an hour, other than a two-hour outage ten years ago when a helicopter hit a line. Long-term interruption could create a severe financial hardship. At three hours the company becomes very nervous (nervous at 2 hours). Company has lost all confidence after last summer.

Blackout in August '03

There was a power outage; lights went out a couple of times, followed by voltage sags. The mill was shutdown and the Friday evening shift was sent home. Many units were shutdown at the request of Niagara Mohawk and the company reduced its manufacturing operations for several days. The company benefited from the utility switching for a back feed of the 115 KV line. The annealing process could not be shutdown, since shutdown would have resulted in staining the product.

Costs included payment to employees even though they were sent home, some damage and material scrapped and 3-4 days of reduced production. At these reduced levels of production the company would typically lose $150,000/day.

Measures to Increase Reliability

Revere has taken many steps to increase reliability including; installation of generators; installation of UPS systems; sizing induction motors and adjusting overheads to protect against voltage/current sags; adding signal isolators and power conditioners in problem areas to avoid transient related problems; shifting operations off-peak to avoid voltage/current sag problems; and consultant's studies on power factor harmonics and other issues ("further study would be required" and a 6-8 year payback).

Considered Distributed Generation

Revere has considered distributed generation and completed a NYSERDA funded study. Distributed generation not considered to be attractive for company because of the application of stranded costs for maintaining a backup supply.

Special Metal Corporation - February 25, 2004[45]

Background

Special Metals Corporation has operations at an alloying plant in New Hartford, New York and a forge plant in Dunkirk, New York. The company specializes in "superalloys" for jet and rocket engine rotors. Approximately 250 employees work 24 hours five days a week. During peak times the plants would operate 24/7, but since the airline slump began after September 11, 2001, business is off to approximately one half of capacity.

The company has an electric demand of approximately 7 MW at the New Hartford plant and 2 MW at Dunkirk. Energy use at New Hartford is down to approximately 2 million kWh/month from approximately 4.5 million kWh/month prior to 9/11. Dunkirk is down to approximately 800-900 kWh/month from 1.3-1.4 million kWh/month prior to 9/11. The plants are served by Niagara Mohawk as the distribution utility, but buy their power directly from the New York ISO using Fluent Energy for paperwork. Special Metal owns its own substations and takes power at a high voltage level. The New Hartford plant is located on a small transmission line, close to a major substation, so there is limited exposure to trees.

Power Quality

The New Hartford plant experiences few external power quality problems and seldom has brownouts. Transients due to lightening affect the plant and approximately 2-3 times a year it is affected by momentary or extended outages that can cause a variety of delay and restart costs. Outages are usually caused by a severe storm, but can be a result of Niagara Mohawk switching to a different circuit.

Plant operations are a source of significant power quality problems for the plant itself and for the grid. The plant has a 4.5 MW induction power supply that generates high harmonics. Harmonics and flicker are created by the arc furnaces, power factor degradation from the induction melters, and voltage and current excursions from the starting and stopping of large rolling mill motors. The company has a high-speed press that uses six 1,250 hp motors that must

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[45] Interview with John Schoonmaker, Director of Engineering, Special Metals Corporation.

be started and stopped causing current and voltage excursions. The 4,000-ton press causes transients that reflect back on the system and led to a utility requirement that the company install a new substation and tale a higher incoming voltage.

The company can "ride out" any transients of a few cycles, but momentary or extended outages of several seconds or more cause problems with operations. For example, a power line circuit automatic reclosing for fault removal would cause approximately a 15 second outage. Any interruption of a few seconds triggers an automatic engineering review to make sure that material in process (especially the melters) is not compromised. Some of the melting cycles are 18 hours long. If the outage is very brief, then the processes are just restarted with primarily a loss of employee hours. If the outage is longer then processes would have to be started over leading to a loss of one day to one week.

PQ Related Costs

Special Metal hasn't explicitly quantified outage or power quality costs. For a brief power outage the cost would be relatively small – just employee hours. A power outage greater than a few minutes would result in costs upwards of tens of thousands of dollars. When the company is at less than 100 percent of capacity as it is now, this type of delay can be made up. When it is at 100 percent, any loss represents lost revenue.

Special Metal's biggest problem during a long-term outage is water flow. Pumps are needed to provide water flow to critical cooling systems and during an outage the company has to make sure that water flow continues. The company uses City water for emergency cooling and has thought about bigger generators to provide water so it would not have to rely upon the City water, but has decided not to do so.

The forging operation are not affected much by a momentary outage but a longer outage would result in scrap and lost time.

Blackout in August '03

The company lost power as it was closing down for the weekend. The company lost about six hours of operation and paid some employees that were sent home early, but did not lose much money because of the blackout.

Measures to Increase Reliability

Special Metal has taken the following steps to increase reliability:

- **115kV transformer** serving the entire plant load (for economics and to help isolate the internal plant power quality from the surrounding grid). Because of the nature of plant operations, Niagara Mohawk serves the company at primary voltage. In an effort to protect the surrounding distribution system from any power quality problems emanating from the plant. Special Metals has its own transformer substation. It receives power at 115kV and has 13.2 kV internal distribution circuits.

- **20 kVA UPS System –** protecting the main computer facility.

- **Distributed Small UPS Systems –** The plant has a number of smaller UPS systems that protect satellite computer servers and computer controls in the manufacturing area.
- **180 kW Onan Standby Generator and Automatic Transfer Switch –** This system provides longer term back up for the computers served by the main UPS system and also for critical product testing – mechanical stress rupture machines that are on a cycle lasting several days. All products must go through this testing before shipment. Any interruption backs up the testing, though apparently a 15-20 second interruption is not a significant problem so there is no UPS for the testing station.

- **50 kW Emergency gas-fired generators –** the plant has "a few" other generators that are dedicated to emergency lighting circuits.

- **9,200 kVAR Filter Bank –** located at the main distribution line (13.2kV) this system deals with harmonic problems and power factor correction. The system had both a power quality and an economic value. The plant was experiencing light flicker, computer problems, and premature motor failure. The cost of the system was paid back in less than a year by the elimination of reactive power charges from the utility. The company went from about 70 percent power factor to upper 90s now. Its contract threshold with Niagara Mohawk is 95 percent.

Considered Distributed Generation

The company evaluated an on-site peak shaving power system ten years ago, but could not make it pay off with the prevailing tariffs. It does have a 30,000 lb/hour high pressure boiler running the vacuum system, but it has a very intermittent duty cycle operating for only a half hour three times per day. The company does not have the year round steam load for CHP, though there is a large nursing home adjacent to the property (1/4 mile away). There is some large CHP in the area (Oneida Silver and Remington Arms – 65 MW and a larger Alcoa plant).

Special Metals has apparently not considered and did not respond positively to the idea of putting in additional standby capacity with the expectation that it would receive some benefit by dispatching the capacity for system-wide peak shaving. The company apparently sees the program in terms of load shedding (disrupting their operations) rather than as a supplementary value for standby generation

Case Study – Major Network Television and Radio Broadcasting Center [46]

New York is home to several global media firms. The Project Team interviewed the Director of Facilities Operations (DFO) of a major television and radio network broadcasting corporation to determine how power quality issues potentially impact key media sector firms.

Background

While the DFO has responsibilities for facilities nationwide, our discussion focused almost exclusively on the headquarters facility located in New York City. This facility is the media firm's principal place of business and, critically, serves as the"origination center" for all commercial broadcasts. Taped broadcasts and commercial rebroadcasts emanate from this point.

The company's most important revenue source is the sale of commercial time. This makes the New York City office the revenue generation point for the organization.

The company is a major consumer of electricity, with typical load of over 6 Mw. Load is very flat given the 24/7 nature of the business and equipment duty cycle.

Importance of Power Quality/Reliability to the Firm's Operations

Power quality and reliability are critical to the firm's profitable operations. Precise coordination and synchronization between the headquarters' operation and the company's over 200 radio and television satellite stations is essential if commercials and taped shows are to be aired simultaneously and for the expected duration. We were informed that commercials must be aired for a specific time down to the millisecond. "Every second contracted for must be aired" or the obligation to pay is voided.

Television stations need a good, clear signal to operate. Moreover, we were told that, other than for preventive maintenance, equipment runs continuously. The machines that are utilized are highly susceptible to power transients, low voltage, no voltage, etc. Transients also will shorten the lifetime of equipment, and require accelerated servicing which increases the risk of equipment fatality on power up/down. Voltage drops cause currents to rise in rotating machines, increasing heating and shorten lifespan.

Potential Economic Impacts of PQR

Loss of a few seconds air time due to a power outage, or equipment failure triggered by a disturbance, would cost the company millions of dollars and therefore cannot be tolerated.

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[46] The Project Team interviewed the Director of Facilities Operations (DFO) of a major television and radio network broadcasting corporation. The respondent did not wish for his company to be identified in this report.

Measures Taken to Mitigate Exposure to PQR Issues

The firm pursued an extensive power upgrade of its headquarters facility in 1999, as a result of the Washington Heights blackout. While the 1999 blackout did not affect this firm directly – being confined to a sector of the distribution network several miles away – it was a good “attention grabber” for management.

An on-line UPS system and 4 emergency generators now back up all critical systems. The firm considers 55-60% of its on-site load as “critical”. The system can support critical load for several minutes. The back-up generators are permitted to run for up to 700 hours annually, and have on-site fuel storage sufficient to run at full load for more than a day. Together, this system mitigates against business disruption under all but the most extreme contingencies.

The UPS system is also fitted with transient filtration/suppression capability. The active, on-line system will always put power out at the correct voltage, or will go to battery back-up an emergency generation. In extreme situations, the equipment will shut off to prevent damage.

Consideration of CHP

The firm has not actively considered CHP due to two factors. First, the DFO expressed concerns about space limitations. Typical of Manhattan, the company has nowhere to go laterally and any additional on-site generation would have to go somewhere within the existing footprint. Second, the DFO expressed concerns about natural gas price increases and the impact on system payback. Third, there is some question about whether the thermal energy can be effectively used on-site; the company has recently deployed a steam chiller for air conditioning load.

Three of the four emergency generators are new. The fourth is over 25 years old and the firm has hired an engineering firm to consider whether to replace or refurbish this generator. The DFO was not sure whether CHP was one of the alternatives being considered.

Conclusions

- The media firm is vitally concerned about power quality and reliability from an operational and financial perspective. Any, even fleeting disruption can cost the company millions of dollars in commercial revenue which is the lifeblood of the company.

- The media firm has taken a number of measures within the last 3-5 years to address both power quality and reliability issues. The Director of Facilities Operations seemed comfortable with the level of accepted risk given the reliance on both UPS and on-site generation to address short-duration and longer-term power quality and reliability issues.

- Power quality and reliability issues would not appear to be driving considerations when evaluating DG/CHP. Rather, CHP might be considered as a potential alternative to refurbishment or replacement of older, existing back-up generator if economics, space constraints, and fuel cost uncertainty could be addressed. Interested in dual-fuel capability as a further hedge against future fuel price increases.

APPENDIX D
POWER QUALITY GLOSSARY[47]

Alternating Current – A period current the average of which over a period is zero. The flow of electrical current increases to a maximum in one direction, decreases to zero, and then reverses direction and reaches maximum in the other direction and back to zero. The cycle is repeated continuously. The number of such cycles per second is equal to the frequency and is measured in "Hertz". U.S. commercial power is 60 Hertz (i.e. 60 cycles per second).

Ampere – A unit of measurement for electrical current or rate of flow of electrons (coulombs per second). If a group of electrons whose total charge is 1 coulomb passes a point in a conductor in 1 second, the electric current is 1 ampere. Its mathematical symbol is "I" the term is often shortened to "amps".

Apparent Power – The product of voltage and current in a circuit.

Arc – Sparking that results when undesirable current flows between two points of differing potential. This may be due to leakage through the intermediate insulation or a leakage path due to contamination.

Arrester – A nonlinear device to limit the amplitude of voltage on a power line. The term implies that the device stops overvoltage problems (i.e. lightning). In actuality, voltage clamp levels, response times and installation determine how much voltage can be removed by the operation of an arrester.

Autotransformer – A transformer used to step voltage up or down. The primary and secondary windings share common turns, and it provides no isolation.

Auxiliary Source – A power source dedicated to providing emergency power to a critical load when commercial power is interrupted.

Battery Reservoir – A combination of cells or batteries used to power a UPS's system inverter when it is in the emergency mode.

Blackout – A total loss of commercial power.

Branch Circuit – A division of a load circuit with current limited by a fuse or circuit breaker.

Break-Before-Make – Operational sequence of a switch or relay where the existing connection is opened prior to making the new connection.

Brownout – A low voltage condition lasting longer than a few cycles. "Brownouts" differ from "sags" only in duration.

Busbar – A heavy, rigid conductor used for high voltage feeders.

Capacitor – Two plates or conductors separated by an insulator. Applying a voltage across the plates causes current to flow and stores a charge. Capacitors resist changes in voltage.

Charger – An AC-to-DC converter which powers a UPS inverter and maintains the battery reservoir charge.

Common Mode (CM) – The term refers to electrical interference which is measurable as a ground referenced signal. In true common mode, a signal is common to both the current carrying conductors.

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[47] Compiled from online glossaries provided by Alliant Energy, Teal Electronics, and Computer Power and Consulting Corporation..

Common Mode Noise – An undesirable voltage which appears between the power conductors and ground.

Converter – A device which changes alternating current to direct current

Critical load – Devices and equipment whose failure to operate satisfactorily jeopardizes the health or safety of personnel, and/or results in loss of function, financial loss or damage to property

Current – The *flow* of electricity – Current is analogous to water flow in a pipe. Current is measured in amperes, or amps.

Delta – A standard three phase connection with the ends of each phase winding connection in series to form a closed loop with each phase 120 electrical degrees from the other.

Delta-Delta – The connection between a delta source and a delta load.

Delta-Wye – The connection between a delta source and a wye load.

Direct Current – Electrical current which flows in one direction only. Batteries and fuel cells produce direct current. Some industrial processes such as very large variable speed motors and electrochemical processes utilize direct current

Dropout – A discrete voltage loss. A voltage sag (complete or partial) for a very short period of time (milliseconds) constitutes a dropout.

Electromagnetic – A magnetic field cause by an electric current. Power lines cause electromagnetic fields that can interfere with nearby data cables.

Electromechanical – A mechanical device which is controlled by an electric device. Solenoids and shunt trip circuit breakers are examples of electromechanical devices.

Electrostatic – A Potential difference (electric charge) measurable between two points which is caused by the distribution if dissimilar static charge along the points. The voltage level is usually in kilovolts.

Electrostatic Shield – A metallic barrier or shield between the primary and secondary windings of a transformer which reduces the capacitive coupling and thereby increases the transformers ability to reduce high frequency noise.

EMF – Electromotive force or voltage.

EMI, RFI – Acronyms for various types of electrical interference: electomagnetic interference, radio frequency interference.

ESD – Electrostatic Discharge (static electricity). The effects of static discharge can range from simple skin irritation for an individual to degraded or destroyed semiconductor junctions for an electronic device.

Farady Shield – A grounded metallic barrier which can be used for improved isolation between the windings of a transformer. In this application, the shield basically reduces the leakage capacitance between the primary and secondary.

Feeders – Transmission lines supplying power to a distribution system.

Ferroresonant Transformer – A voltage regulating transformer which depends on core saturation and output capacitance.

Filter – A selective network of resistor, inductors, or capacitors which offers comparatively little opposition to certain frequencies or direct current, while blocking or attenuating other frequencies.

Fluctuation – A surge or sag in voltage amplitude, often caused by load switching or fault clearing.

Forward Transfer Impedance – The amount of impedance placed between the source and load with installation of a power conditioner. With no power conditioner, the full utility power is delivered to the load; even a transformer adds some opposition to the transfer of power. On transformer based power conditioners, a high forward transfer impedance limits the amount of inrush current available to the load.

Frequency – On AC circuits, designates number of times per second that the current completes a full cycle in positive and negative directions. See also "alternating current".

Frequency Deviation – A variation from nominal frequency.

GFI (Ground Fault Interrupter) – A device whose function is to interrupt the electric circuit to the load when a fault current to ground exceeds some predetermined value that is less than that required to operate the overcurrent protective device of the supply circuit.

Ground – The physical connection, whether intentional or unintentional, by which an electrical circuit or equipment is connected to the earth, or to some conducting body of relatively large extent that serves in place of the earth.

Ground Fault – Any undesirable current path from a current carrying conductor to ground.

Harmonic – A sinusodial component of an AC voltage that is multiple of the fundamental waveform frequency.

Harmonic Distortion – Regularly appearing distortion of the sine wave whose frequency is a multiple of the fundamental frequency. Converts the normal sine wave into a complex waveform.

Harmonic Neutralization – A cancellation process: harmonics at the output of a circuit are inverted and fed back in their opposite phase.

Hertz (HZ) – Unit of frequency, one hertz (Hz) equals one cycle per second.

I2R – The expression of power resulting from the flow of current through a resistance: P = I2R.

Impedance – Forces which resist current flow in A.C. circuits, i.e. resistance, inductive reactance, capacitive reactance.

Inductance – The ability of a coil to store energy and oppose changes in current flowing through it. A function of the cross sectional area, number of turns of coil, length of coil and core material.

Inductor – (Also called "choke") - A coiled conductor which tends to oppose any change in the flow of current. Usually has coils wrapped around ferrous core.

Inrush Current – The initial surge current demand before the load resistance or impedance increases to its normal operating value.

Inverter – A device used to change DC into AC power.

Isolation Transformer – A multiple winding transformer with primary and secondary windings physically separated and designed to permit magnetic coupling between isolated circuits while minimizing electrostatic coupling. See also "electrostatic shield".

KVA – (Kilovolt amperes) (volts times amperes) divided by 1000. 1 KVA=1000 VA. KVA is actual measured power (apparent power) and is used for circuit sizing.

KW – (Kilowatts) watts divided by 1000. KW is real power and is important in sizing UPS, motor generators or other power conditioners. See also "power factor".

KWH – (Kilowatt hours) KW times hours. A measurement of power and time used by utilities for billing purposes.

Lagging Load – An inductive load with current lagging voltage. Since inductors tend to resist changes in current, the current flow through an inductive circuit will lag behind the voltage.

The number of electrical degrees between voltage and current is known as the "phase angle". The cosine of this angle is equal to the power factor (linear loads only).

Leading Load – A capacitive load with current leading voltage. Since capacitors resist changes in voltage, the current flow in a capacitive circuit will lead the voltage.

Linear load – Equipment that has a proportional change in the voltage when current goes up or down. An incandescent light bulb is an example of a linear load.

Load – The driven device that uses the power supplied from the source.

Load Balancing – Switching the various loads on a multi-phase feeder to equalize the current in each line.

Load Fault – A malfunction that causes the load to demand abnormally high amounts of current from the source.

Load Regulation – A term used to describe the effects of low forward transfer impedance. A power conditioner with "load regulation" may not have voltage regulation. Removing the power conditioner altogether will improve load regulation.

Load Switching – Transferring the load from one source to another.

Load Unbalance – Unequal loads on the phase lines of a multi phase system.

Main Service Entrance – The enclosure containing connection panels and switchgear, located at the point where the utility power lines enter a building.

Make-Before-Break – Operational sequence of a switch or relay where the new connection is made prior to disconnecting the existing connection.

Metal Oxide Varistor (MOV) – A MOV is a voltage sensitive breakdown device that is commonly used to limit overvoltage conditions (electrical surges) on power and data lines. When the applied voltage exceeds the breakdown point, the resistance of the MOV decreases from a very high level (thousands of ohms) to a very low level (a few ohms). The actual resistance of the device is a function of the rate of applied voltage and current.

MTBF – (Mean Time Between Failure) the probable length of time that a component taken from a particular batch will survive if operated under the same conditions as a sample from the same batch.

Motor Alternator – (Also called a **motor generator**) A device that consists of an AC generator mechanically linked to an electric motor which is driven by utility power or by batteries. An alternator is an AC generator.

Negative Resistance – The characteristic of a circuit in which current varies inversely with applied voltage.

NEC – National Electrical Code.

Neutral – The grounded junction point of the legs of a wye circuit. Or, the grounded center point of one coil of a delta transformer secondary. Measuring the phase to neutral voltage of each of the normal three phases will show whether the system is wye or delta. On a wye system, the phase to neutral voltages will be approximately equal and will measure phase to phase voltage divided by 1.73. On a center tapped delta system, one phase to neutral voltage will be significantly higher than the other two. This higher phase is often called the "high leg".

Neutralizing Winding – An extra winding used to cancel harmonics developed in a saturated secondary winding, resulting in a sinusoidal output waveform from a ferroresonant transformer.

Noise – Unwanted electrical signals superimposed on the normal power system voltage or current pattern.

Nominal Voltage – The normal or designed voltage level. For three phase wye systems, nominal voltages are 480/277 (600/346 Canada) and 208/120 where the first number expresses phase to phase (or line to line) voltages and the second number is the phase to neutral voltage. The nominal voltage for most single phase systems is 240/120.

Nonlinear Load – A load in which the current does not have a linear relationship to the voltage. In a light bulb, the current is directly proportional to voltage at all times. In a nonlinear load such as switched mode power supplies, the current is not directly proportional to voltage.

Normal Mode (NM) – The term refers to electrical interference which is measurable between line and neutral (current carrying conductors). Normal mode interference is readily generated by the operation of lights, switches and motors.

Notch – Slang for a negative or subtractive impulse.

Ohm – The unit of measurement for electrical resistance or opposition to current flow.

Ohm's Law – The relationship between voltage (pressure), current (electron flow), and resistance. The current in an electrical circuit is directly proportional to the voltage and inversely proportional to the resistance. E=IR, or I=E/R, or R=E/I. Where E=voltage, I=current, and R=resistance.

Orderly Shutdown – The sequenced shutdown of units comprising a computer system to prevent damage to the system and subsequent corruption or loss of data.

Outage – An outage is a long-term power interruption. From the utility perspective, an outage occurs when a component of the distribution system is not available to provide its normal function (i.e., the generator cannot supply power). Normally, utility companies do not include short power interruptions (grid switching) in their classification of outage history and also may only count power interruptions with duration longer than 1 to 5 minutes. (see blackout)

Overvoltage – A voltage greater than the rating of a device or component. Normally overvoltage refers to long term events (several AC cycles and longer). The term can also apply to transients and surges.

Panelboard – A single panel or group of panel units designed for assembly in the form of a single panel; including buses, overcurrent protection devices (with or without switches) for the control of power circuits.

Parallel Operation – The connection of the outputs of two or more power conditioners for use as one unit. Paralleling for capacity means that the units are paralleled for the sum of their individual ratings, i.e. two 125 kVA systems paralleled for use as a single 250 kVA system. Paralleling for redundancy means using one or more additional units to maintain power even when one unit fails.

Peak Line Current – Maximum instantaneous current during a cycle.

Phase Compensation – Switching capacitors into or out of a power distribution network to compensate for load power factor variations.

Power – Electrical energy measured according to voltage and current (normally watts). Power in watts equals volts times amperes for DC circuits. For single phase AC circuits, watts equal volts times amperes times power factor.

Power Distribution Unit (PDU) – A portable electrical distribution device that provides an easily expandable and flexible electrical environment for a computer and its associated peripherals.

Power Factor – Watts divided by voltamps, KW divided by KVA. Power factor: leading and lagging of voltage versus current caused by inductive or capacitive loads, and 2) harmonic power factor: from nonlinear current.

Power quality – The method of powering and grounding sensitive electronic equipment.

Protector – A protector is another name for an arrester or diverter.

Real Power – Watts.

Reactance – Opposition to the flow of alternating current. Capacitive reactance is the opposition offered by capacitor, and inductive reactance is the opposition offered by a coil or other inductance.

Recloser – The automatic closing of a circuit-interrupting device following automatic tripping.

Rectifier – An electrical device used to change AC power into DC power. A battery charger is a rectifier.

Redundancy – The inclusion of additional assemblies and circuits (as within a UPS) with provision for automatic switchover from a failing assembly or circuit to its backup counterpart.

Reflection – The return wave generated when a traveling wave reaches a load, a source, or a junction where there is a change in line impedance.

Reliability – The statistical probability of trouble-free operation of a given component or assembly. Used principally as a function of MTBF and MTTR.

RFI – Radio Frequency Interference.

Ridethrough – The ability of a power conditioner to supply output power when input power is lost.

RMS – (Root mean square) used for AC voltage and current values. It is the square root of the average of the squares of all the instantaneous amplitudes occurring during one cycle. RMS is called the effective value of AC because it is the value of AC voltage or current that will cause the same amount of head to be produced in a circuit containing only resistance that would be caused by a DC voltage or current of the same value. In a pure sine wave the RMS value is equivalent to .707 times the peak value and the peak value is 1.414 times the RMS value. The normal home wall outlet which supplies 120 volts RMS has a peak voltage of 169.7 volts.

Rotating Field – The electrical field that develops in a multiphase generator. The varying currents of through pairs of stator winding cause the magnetic field to vary as if it was a single rotating field.

Safety Ground – An alternate path of return current, during a fault condition, for the purpose of tripping a circuit breaker. Also, the means of establishing a load at earth level.

Sag – A short-duration, temporary voltage drop lasting between 1/120th of a second and one minute.

Short circuit – The direct flow of electrical current, whether intentional or unintentional, from a power supply to a ground or the earth. Instead of current flowing to equipment, it is diverted directly or indirectly to a ground or the earth.

SCR – (Semiconductor, or silicon, controlled rectifier) an electronic DC switch which can be triggered into conduction by a pulse to a gate electrode, but can only be cut off by reducing the main current below a predetermined level (usually zero).

Semiconductor – An electronic conductor (ex., silicon, selenium or germanium) with a resistivity between metals and insulators. Current flows through the semiconductor normally via holes or electrons.

Service Factor – (Of a motor) a measurement of the motor's ability to operate under abnormal conditions. A 1.15 times its rated load continuously when operated at its rated voltage, frequency, temperature, etc. Therefore, a 125 horsepower motor could be operated as a 143.75 h.p. motor under normal conditions.

Shielding – Imposing a metallic barrier to reduce the coupling of undesirable signals.

Sine Wave – A graph, with the x axis for amplitude and the y axis for time, depicting AC voltage or current. The center line of the x axis is zero and divides polarity (direction).

Single Phase – (With a three phase source) one or two phase conductors. (Single phase source) A single output which may be center tapped for dual voltage levels.

Single Phase Condition – An unusual condition where one phase of a three-phase system is lost. It is characterized by unusual effects on lighting and other loads.

Soft-Start Circuit – Circuitry that limits the initial power demand when a UPS has been operating in emergency mode and commercial power is restored. Also, it controls the rate at which UPS output increases to normal.

Substation – Location where high voltage transmission lines connect to switchgear and step-down transformers to produce lower voltages at lower power levels for local distribution networks.

Suppressor – See Arrester

Surge – A short duration high voltage condition. A surge lasts for several cycles where a transient lasts less than one half cycle. Often confused with "transient".

Switch Gear – A group of switches, relays, circuit breakers, etc. Used to control distribution of power to other distribution equipment and large loads.

Synchronization – Maintaining a constant phase relationship between AC signals.

Synchronous – Events that have the same period or which occur at the same time. For instance, a synchronous transfer mechanism for a standby power generator transfers power to or from the utility in phase. In other words, the voltage waveform of the generator and of the utility are in phase and the waveforms occur at the same time and interval during the transfer.

Synchronous Motor – An AC motor whose speed is exactly proportional to the power input frequency.

Tap – A connection point brought out of a transformer winding to permit changing the turns ratio.

Tap Switcher – A voltage regulator which uses power semiconductors, rated at line voltage and current, to switch taps of a transformer thereby changing the turns ratio and adjusting output voltage.

Telemetry – (From telemetering) Measurement with the aid of intermediate means that permit the measurement to be interpreted at a distance from the primary detector. A site telemetry system supplies the intermediate means of communication for all major environmental units at the site. Data from these units can then be interpreted by a computer. Site telemetry differs from central monitoring in that it uses the distributed processing power of monitored equipment from a variety of manufacturers.

Three Phase Power – Three separate outputs from a single source with a phase differential of 120 electrical degrees between any two adjacent voltages or currents. Mathematical calculations with three-phase power must allow for the additional power delivered by the third phase. Remember, both single phase and three phase have the same phase to phase voltages, therefore you must utilize the square root of 3 in your calculations. For example, kVA equals volts times amps for DC and for single phase. For three phase the formula is volts times the square root of three times amps.

Total Harmonic Distortion (THD) – The square root of the sum of the squares of the RMS harmonic voltages or currents divided by the RMS fundamental voltage or current. Can also be calculated in the same way for only even harmonics or odd harmonics.

Transducer – A device that senses one form of energy and converts it to another, i.e., temperature to voltage (for monitoring).

Transfer Switch – A switch used to transfer a load between a UPS and its bypass source.

Transformer – A static electrical device which, by electromagnetic induction, regenerates A.C. power from one circuit into another. Transformers are also used to change voltage from one level to another. This is accomplished by the ratio of turns on the primary to turns on the secondary (turns ratio). If the primary windings have twice the number of windings as the secondary, the secondary voltage will be half of the primary voltage.

Transient – A high amplitude, short duration pulse superimposed on the normal voltage wave form or ground line.

Transient Response – The ability of a power conditioner to respond to a change. Transient step load response is the ability of a power conditioner to maintain a constant output voltage when sudden load (current) changes are made.

Triac – An electronic device that provides switching action for either polarity of an applied voltage and can be controlled from a single gate. Usually composed of two SCR's connected back to back.

Undervoltage – A voltage condition that is less than normal (nominal) voltage levels for more than one minute.

UPS – Uninterruptible Power Source (or supply).

Voltage – The electrical "pressure" that creates the flow of current. Voltage is analogous to water pressure. It is the different in pressure that creates flow. Small businesses typically receive electricity at 120 volts.

Voltage Regulation – The ability of a power conditioner to maintain a stable output voltage when input voltage fluctuates.

Watt (W) – The unit of power. Equal to one joule per second.

Wye – A wye connection refers to a polyphase electrical supply where the source transformer has the conductors connected to the terminals in a physical arrangement resembling a Y. Each point of the Y represents the connection of a hot conductor. The angular displacement between each point of the Y is 120 degrees. The center point is the common return point for the neutral conductor.