Appendix A4:
A Systems View of the Modern Grid

PROVIDES POWER QUALITY FOR 21ST CENTURY NEEDS

Conducted by the National Energy Technology Laboratory
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EXECUTIVE SUMMARY

Providing power quality for 21st century needs is one of the seven principal characteristics in a systems view of the modern grid. (See Figure 1.) Our future global competitiveness demands fault-free operation of the digital devices that power the productivity of our 21st century economy. And we need clean power to meet that demand.

Figure 1: The Modern Grid Systems View provides an "ecosystem" perspective that considers all aspects and all stakeholders.

When consumers think of power quality (PQ), they think of reliable power that is free of interruption, and clean power that is free of disturbances.

The focus of this paper is on the attribute of *clean* power. Issues about power *reliability* are treated by other papers in this collection of documents about principle characteristics of the modern grid. This paper provides a look at how the modern grid will help to provide power quality for 21st century needs. Although it can be read on its own, it supports and supplements "A Systems View of the Modern Grid," an overview prepared by the Modern Grid Initiative (MGI) team.

Power quality, or clean power, deserves such focus because of the importance of digital devices that have become the engines of so many industries in today's economy. There is hardly a commercial or industrial facility in the country that would not suffer lost productivity if a serious PQ event impacted its digital environment.

The level of delivered power quality can range from "standard" to "premium", depending on consumers' requirements. Not all commercial enterprises, and certainly not all residential customers, need the same quality of power.

The modern grid would supply varying grades of power and support variable pricing accordingly. The grade of delivered power is largely determined by the design of the electrical distribution facilities serving a given customer. Special attention can be devoted to minimizing the effect of perturbations. The cost of these premium features can be included in the electrical service contract.

The modern grid would support the mitigation of PQ events that originate in the transmission and distribution elements of the electrical power system. Its advanced control methods will monitor essential components, enabling rapid diagnosis and precise solutions to any PQ event. In addition, the grid's design will include a focus on the reduction of PQ disturbances arising from lightning, switching surges, line faults and harmonic sources. Its advanced components will apply the latest research in superconductivity, materials, energy storage, and power electronics to improve power quality.

Finally, the modern grid would help buffer the electrical system from irregularities caused by consumer electronic loads. Part of this will be achieved by monitoring and enforcing standards that limit the level of electrical current harmonics a consumer load is allowed to produce. Beyond this, the modern grid will employ appropriate filters to prevent harmonic pollution from feeding back into the grid.

Specific technologies and approaches the modern grid will bring to bear include:

- Power quality meters.
- System wide power quality monitoring.
- Grid-friendly appliances that control their high-load components, such as compressors and heating elements.
- Premium power programs that include dedicating office parks and neighborhoods to premium power usage.
- Various storage devices, such as Superconducting Magnetic Energy Storage (SMES) and advanced batteries, to improve power quality and stability, or to supply facilities needing ultra-clean power.
- A variety of power electronic devices that instantly correct waveform deformities.
- Monitoring of electric system health to identify and correct impending failures that could produce PQ problems.
- New distributed generation devices (e.g. fuel cells and micro-turbines) that can provide clean power to sensitive loads.

All this technology can be applied to the problem of power quality in the near future. However, to do so requires the coordinated efforts of government, utilities, regulators, and standards bodies such as IEEE. It also requires widespread education for all the modern grid's stakeholders.

The benefits of improved PQ could be tremendous in both cost avoidance and the resulting productivity gains. Clean, reliable power could also produce opportunities for economic growth to areas of the country previously denied the benefits of high-technology industry.

A PRIMER ON POWER QUALITY

Before we delve into the issues of power quality, we should understand the things that disrupt it, including sags, harmonics, spikes, and imbalances.

The power supplied by electric utilities starts out as a smooth sinusoidal waveform. This is the waveform produced at the power plant by electrical generators. (See Figure 2.)

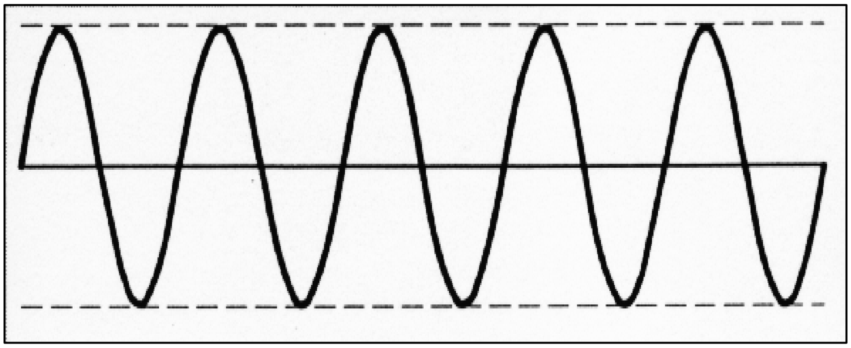


Figure 2: Normal power is supplied in smooth sinusoidal waveforms.

But as this power moves from the generator through the transmission and distribution systems and on to the customer's equipment, it can be affected by four kinds of perturbations that can distort its pure sine wave envelope:

1. Sags (undervoltages) — Voltage sags are the most common power disturbance. (See Figure 3.) They occur when very large loads start up, or as a result of a serious momentary overload or fault in the system. At a typical industrial site, several sags per year are not unusual at the service entrance. Many more occur at equipment terminals. Costs associated with sag events can range widely, from almost nothing to several million dollars per event (Primen Report. Power Quality Problems and Renewable Energy Solutions. September 2002.)

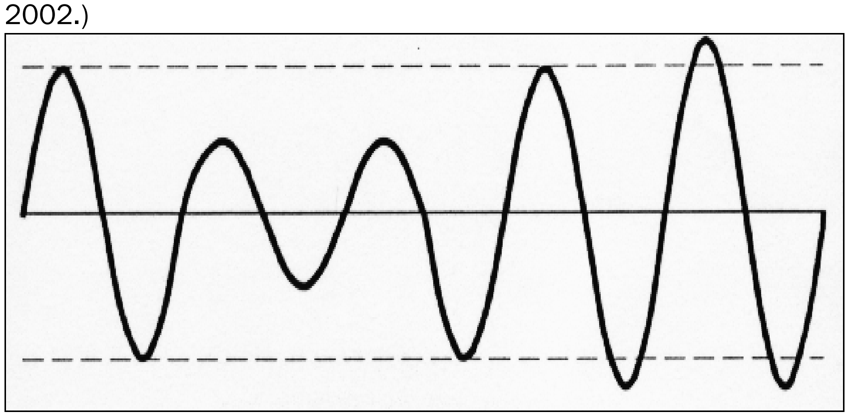


Figure 3: Voltage sags are the most common power disturbance, with associated costs ranging from zero to millions of dollars.

2. Harmonics — Harmonics are caused by "non-linear" loads, which include motor controls, computers, office equipment, compact fluorescent lamps, light dimmers, televisions and, in general, most electronic loads. High levels of harmonics increase line losses and decrease equipment lifetime. (See Figure 4.)

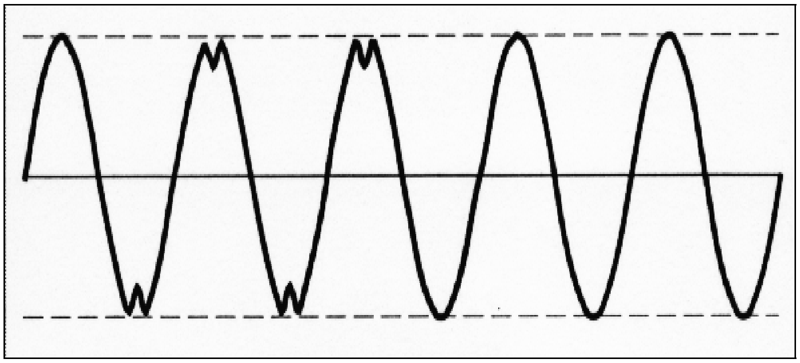


Figure 4: Non-linear loads create harmonic distortion, resulting in more line losses and reduced equipment life.

3. Spikes — Spikes are brief spurts of voltage (in the millisecond to microsecond range) when voltage can shoot up many times higher than normal. Spikes are caused by lightning and switching of large loads or sections of the power system network. They can disrupt the operation of data processing equipment and damage sensitive electronic equipment. (See Figure 5.)

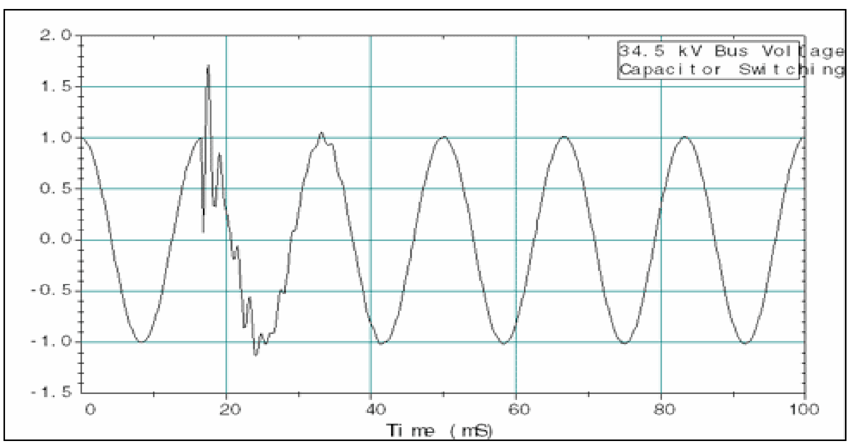


Figure 5: Spikes can damage sensitive electronic equipment.

4. Imbalances — Imbalances are steady-state problems caused by such things as defective transformers or uneven loading of grid phase wires. They are not as easy to identify as the other problems, which show up clearly in the waveforms, but they can gradually cause damage to equipment, especially to electric motors.

Note that in none of the above PQ events is power totally interrupted.

CURRENT AND FUTURE STATES

This section describes the current state of PQ and why problems persist. It then describes how power quality in the future would be enhanced by the modern grid.

CURRENT STATE

Voltage sags represent by far the largest PQ issue. Because voltage sags are mostly due to unforeseen and uncontrollable events, the number of voltage sags experienced in the power system varies from year to year. Several industry studies conducted in the last decade provide insight on the number of voltage sags at particular magnitudes and durations that may occur annually. (See Figure 6.)

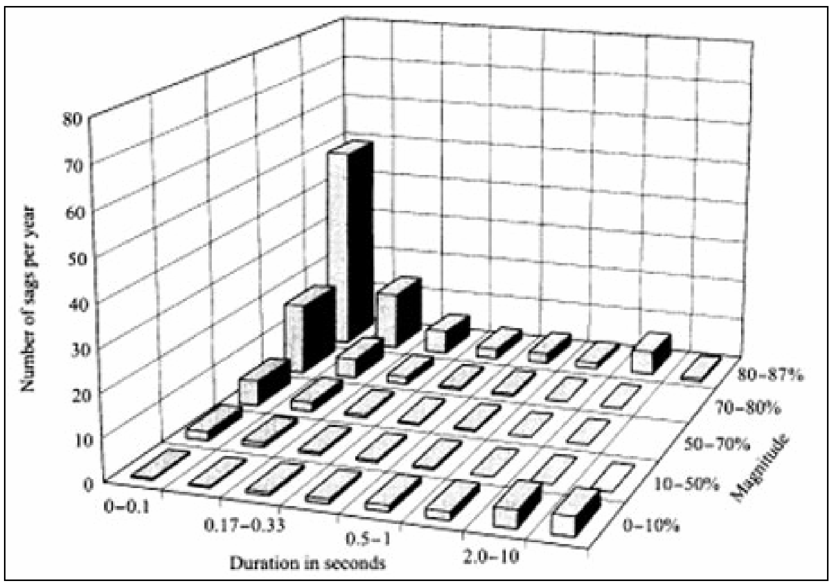


Figure 6: Results of a 5-year National Power Laboratory survey of sag density (duration, magnitude and frequency of occurrence) at 130 sites. Image courtesy of EPRI.

A modern grid should provide PQ that fully conforms to the customer's design criteria, as defined by industry standards.

The above diagram may be compared to the industry standard Semiconductor Equipment and Materials International (SEMI) F47 curve (green line in Figure 7.) While there is generally reasonable matching between what the utility supplies and what the customer designs to, there are also many points of non-compliance. This curve more clearly shows the points of non-compliance (points below the green line). Of particular note is the concentration of 30% to 60% magnitude voltages having between two and twenty cycle durations. None of these events conform to the Information Technology Industry Council (ITIC) curve criteria.

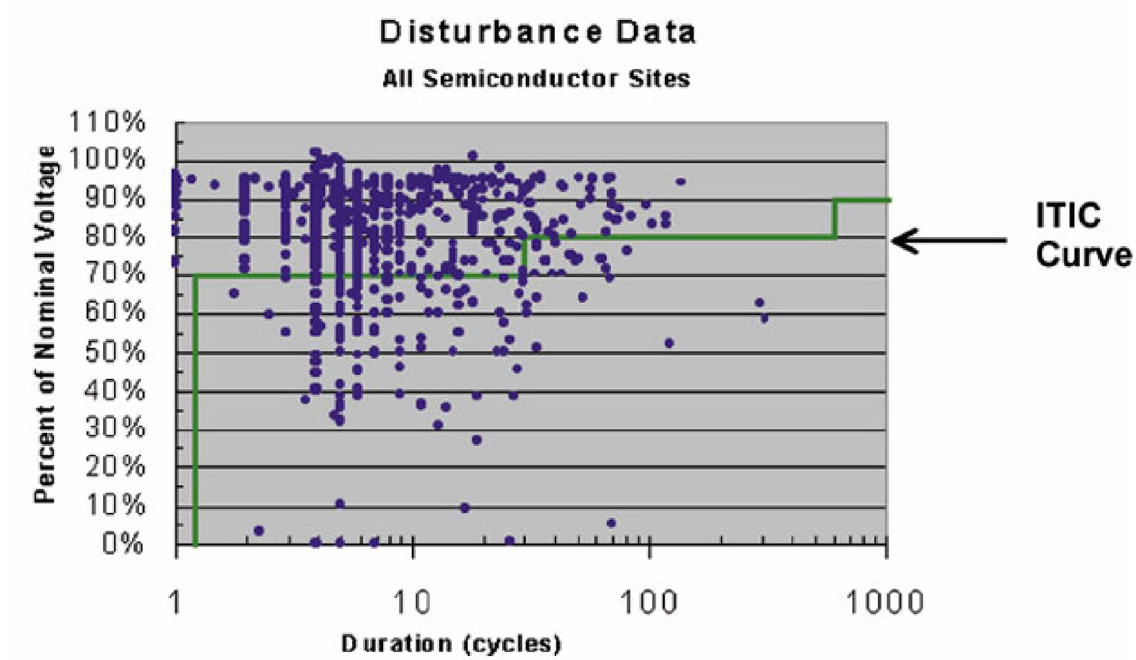


Figure 7: Sag Monitoring Data from 15 Semiconductor Sites show that power quality is not meeting customers' design criteria. Image courtesy of EPRI.

Power quality is an important issue for the information industry. For example, deciding where to locate power-sensitive server farms depends largely on the availability of clean, reliable power. Those criteria led to the selection of rural Grant County, Washington as the site for both Microsoft and Yahoo server farms.

Power quality is also a large issue for industrial and manufacturing facilities. Tiny power disturbances can wreak havoc with the increasingly complicated, computerized machinery found along assembly lines today. At the same time, customers must design their processes to conform to criteria such as the SEMI F47 curve. This graph of voltage sag events at a manufacturing facility is a good example of interruption levels in an industrial setting. (See Figure 8.) Events that caused process disruptions are circled. (Note that for the six circled events, the consumer's equipment did not meet the SEMI 47 standard.)

Based on both Figure 7 and Figure 8, it can be concluded that neither the power delivery supplier nor the industrial user has consistently conformed to the ITIC industry standard.

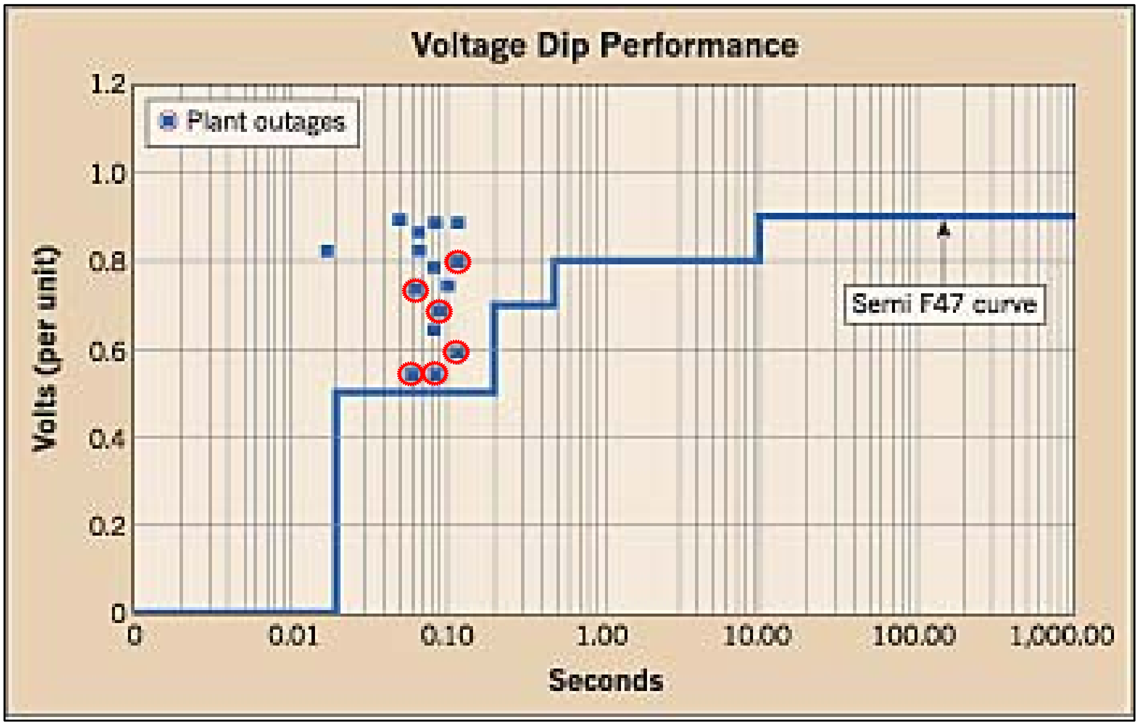


Figure 8: Voltage Sag Events at one facility show that both customer equipment and power supplies contribute to PQ problems. Image courtesy of EPRI.

The stakes are high: Work stoppages can cost a company up to $500,000 an hour, and power-related problems may cost U.S companies more than $100 billion a year. A 2001 Primen study concluded that power quality disturbances alone cost the US economy between $15-24 billion annually. The cost of a momentary disruption to various users in dollars per kilowatt is shown in Figure 9 below.

	Cost of Momentary Interruption ($/kW demand)	
Category	**Minimum**	**Maximum**
INDUSTRIAL		
Automobile manufacturing	$5.0	$7.5
Rubber and plastics	$3.0	$4.5
Textile	$2.0	$4.0
Paper	$1.5	$2.5
Printing (newspapers)	$1.0	$2.0
Petrochemical	$3.0	$5.0
Metal fabrication	$2.0	$4.0
Glass	$4.0	$6.0
Mining	$2.0	$4.0
Food processing	$3.0	$5.0
Pharmaceutical	$5.0	$50.0
Electronics	$8.0	$12.0
Semiconductor manufacturing	$20.0	$60.0
COMMERCIAL		
Communications, information processing	$1.0	$10.0
Hospitals, banks, civil services	$2.0	$3.0
Restaurants, bars, hotels	$0.5	$1.0
Commercial shops	$0.1	$0.5

Figure 9: Disruption Cost by Industry shows that some industries suffer more than others from power quality problems. Image courtesy of EPRI.

Problems persist with power quality. The number of sensitive loads continues to grow, while the costs to minimize PQ events remain relatively high. Clearly, the number of sensitive loads will only continue to grow with advances in communications and information technology.

There exists a large debate as to who should bear the costs of PQ improvement; the utility or the consumer. The development of new rate structures that offer premium quality has not been broadly adopted. Regulatory commissions have not placed a priority on resolving this dispute.

FUTURE STATE

Advanced technologies deployed by the modern grid will both mitigate power quality events in the power delivery system and protect end users' sensitive electronic equipment.

Because sensitive electronic loads represent an increasing portion of the total power system load, power quality will be of growing importance in the 21st century. Twenty years ago, the amount of electrical load associated with chips (computer systems, appliances, and equipment) and automated manufacturing was miniscule. The power system design was well suited to the type of loads that existed then. But ten years ago, the amount of load from chips and automated manufacturing had grown to about 10%. And in the future it can be expected to grow to more than half. The grid must change to accommodate this changing load characteristic.

The modern grid will be rich with technologies and devices that work at every level of power generation and delivery. All will contribute to clean and reliable power reaching the consumer. Included among these are:

- Power quality meters.
- System wide power quality monitoring.
- Grid-friendly appliances that control their high-load components, such as compressors and heating elements.
- Premium power programs that include dedicating office parks and neighborhoods to premium power usage.
- Various storage devices, such as Superconducting Magnetic Energy Storage (SMES) and advanced batteries, to improve power quality and stability or to supply facilities needing ultra-clean power.
- A variety of power electronic devices that instantly correct waveform deformities.
- Monitoring of electric system health to identify and correct impending failures that could produce PQ problems.
- New distributed generation devices (e.g. fuel cells and micro-turbines) that can provide clean local power to sensitive loads.

These applications are discussed further in the Requirements section.

Applying the advanced technologies that mitigate PQ events will require support and coordination among equipment makers, power providers, power users and standards bodies. The resulting design criteria and industry standards must be employed at every level of the electric system, including at the customer's load. This will ensure that the delivered power quality is consistent with the provider's capabilities and the needs of the consumer.

In the future, the modern grid will price power in accordance with the grade of power required by the user. The level of power quality required by consumers can vary, depending on the complexity of their equipment or criticality of their operations. As the data in Figure 9 clearly shows, a premium power offering holds greater appeal to a semiconductor manufacturer than to a newspaper printer, although both would benefit. Hence, customized premium power packages should be developed to meet these differing industry needs. Not all commercial enterprises, and certainly not all residential customers, need premium power.

Requirements

We've broadly described the current state of power quality and discussed its future state. This section introduces the design requirements and solutions needed to make improved PQ an integral characteristic of the 21st century modern grid.

Commonly, 40% of power quality issues relate to the delivery of power from the utility, and 60% relate to the use of power within an industrial facility. (*Specification Guidelines to Improve Our Power Quality Immunity and Reduce Plant Opportunity Costs, RGLSolutions, IEEE PCIC 2002*)

The modern grid must apply power quality solutions wherever they're needed — where the power begins, where it gets distributed, or where it ends. Thus, power quality solutions, like the modern grid itself, must be autonomous and distributed. The devices that mitigate PQ events must be spread among transmission and distribution components of the modern grid, but also right at the sensitive load.

Distributing advanced power electronics at each level throughout the grid is key to solving many PQ problems. Many solutions fall under the broad heading of Flexible AC Transmission Systems (FACTS), even though some are actually deployed on distribution systems.

FACTS and related technologies, including Uninterruptible Power Supplies (UPS), are implemented and realized through the application of power semiconductor switches applied to high-speed controlled compensation devices. Examples include Static Compensators (STATCOM), Dynamic Voltage Restorers (DVR), and Thyristor Controlled Series Capacitors (TCSC). These FACTS devices may be connected in series and/or in shunt. While the STATCOM is connected at the load end in shunt, devices like the DVR and TCSC, having the capability of eliminating voltage sags and swells as well as rapid adjustment of network impedance, are connected in series with the line. Table 1 below illustrates the application of various power electronic devices.

Power Quality Problem:	PQ Solutions: Source-Transfer System	Uninterruptible Power Supply System	Dynamic Voltage Restorer	Distributed Static Compensator	Adaptive VAR Compensator
Voltage Sags < 50%	✓	✓	✓		
Voltage Sags > 50%	✓	✓			
Power Interruptions < 30 Seconds	✓	✓			
Power Interruptions > 30 Seconds	✓	✓			
Voltage Flicker				✓	✓

Table 1: Examples of Power Electronic Solutions that are key to providing power quality.

Transmission Level

At the transmission level, voltage sags are frequently the result of faults (short circuits), which can exist for many milliseconds. In the past, little could be done to reduce this effect. Today, high voltage static VAR compensators (SVCs) are fast enough to mitigate many of these events. However, these devices tend to be quite expensive, partly due to the small numbers deployed and also due to the cost of today's power electronic components. As component costs drop (discussed in MGI Advanced Components paper), these devices will become increasingly attractive to transmission system owners.

Looking toward the future, affordable current-limiting devices will be able to reduce the severity of voltage sags associated with faults. And eventually, lossless superconducting transmission lines will further reduce voltage sag concerns.

Distribution Level

At the distribution level, a variety of techniques are available to improve the quality of power delivered to the end customer. Since lightning is a major source of PQ problems, greater use of underground facilities can minimize this contribution.

Creating premium power quality business parks, where sensitive load customers can locate, can also be valuable. These parks can be directly connected by underground feeders from distribution substations. They can be fed by redundant feeders via high-speed source transfer switches, so that when one feeder is perturbed, the other can immediately take over.

The various power electronic devices shown in Table 1 can be deployed in many distribution applications. And distributed generation and storage resources located close to the load, including micro-grids and green power devices, can isolate the consumer from most grid disturbances.

Customer Level

Not all customers are equally impacted by poor quality of power. At one end of the spectrum, an integrated circuit manufacturer will likely incur very large losses if a PQ event shuts down or perturbs the process. At the other end of the spectrum, a homeowner may be only inconvenienced when a DVD player shuts down.

The power quality solution not only includes technologies that improve and maintain power quality, but also those that make customer loads more tolerant. Within the customer's facility, advanced devices will offer solutions to PQ sensitivity.

There are a number of ways customers can limit problems with transients in their facilities. It's best to start by selecting equipment that can withstand transients, and by using proper wiring/grounding practices. In addition, there are many spike suppression devices that can protect customer equipment.

Different sets of requirements must be specified to meet the needs for the different categories of customers: commercial/industrial and residential.

Commercial and industrial customers must be able to select the grade of power they need and then design their systems accordingly. Grid PQ mitigation techniques must then be coordinated with the customer's *load sensitivity characteristic* to prevent PQ events that can lead to plant outages.

Residential customers will also have varying power quality needs, depending on the sophistication of their home electronics. Here, much rests with the vendors of consumer products, which need to be designed to better tolerate common PQ events. In general, PQ events are more of an inconvenience than an economic burden to this class of customer. But with so many companies now based at home, the impact to the small business economy is not one to be ignored.

Specific Solutions for Specific PQ Problems

Each of the four PQ problem areas has its own technical solution, and all these solutions will be enabled by the advanced technologies of the modern grid. The modern grid will provide PQ that fully conforms to the customer's design criteria, as defined by industry standards. Standards such as SEMI 47 provide a basis for consumer load behavior and a realistic design target for service providers. Both consumers and service providers need a mutually acceptable standard in order to develop their respective designs.

Voltage Sag

Current-limiting and FACTS devices will help reduce the severity of voltage sags associated with power system faults. The most direct way to deal with voltage sags is by providing adequate buffering at the load. And for those customers who take advantage of the modern grid's distributed energy resources (DER), local generation could be provided in a variety of forms such as storage devices, micro-turbines and micro-grids.

Harmonics

Advanced filters will be very effective in the elimination of harmonic distortion. A series active filter, for example, presents a high impedance path to harmonic currents, thereby preventing them from flowing from the load to the source and vice versa.

In most cases, customer-owned equipment is the source of harmonics. Harmonics originating in customer equipment can also cause power quality problems for other utility customers, as well as to the power delivery system itself. Responsibility for controlling harmonics is twofold:

- **The customer is responsible for limiting harmonic currents that interfere with the power system.**
- **The utility is responsible for maintaining the quality of the voltage waveform.**

Since these responsibilities are highly interrelated, guidelines must establish harmonic limits for each party. Technical groups such as IEEE develop these guidelines and they must be enforced by utilities and state commissions.

Transients (Spikes)

Service providers will employ a number of system design strategies to minimize transients.

- Proper grounding and shielding, combined with the liberal application of lightning arresters, will minimize lightning-related spikes.
- Modern controlled switching techniques will minimize power system switching transients (e.g. capacitor bank switching).
- The use of the modern grid's advanced maintenance techniques — that prevent faults from occurring in the first place — will minimize transients related to power system faults.

While spikes on the grid can be reduced by methods described above, customers can also contribute to the solution. They can limit voltage spike problems in their facilities by selecting equipment that can withstand them and by employing proper wiring, grounding, and surge protection.

Voltage Imbalance

In the modern grid, voltage imbalance identification will happen quickly because modern communicating meters will report it to the service provider. Voltage imbalances can cause premature failure of motors and transformers due to overheating, and can cause electronic equipment to malfunction. The service provider will normally correct a severe voltage imbalance problem once it is identified.

KEY TECHNOLOGIES THAT OFFER SOLUTIONS

Carefully chosen and deployed, the key technologies of the modern grid will provide solutions that mitigate these power quality disturbances throughout the system:

- **Sensing and measurement technologies** — The broad deployment of modern meters will provide extensive information regarding the quality of power throughout the grid. This information will be valuable in both resolving problems as they are quickly identified, as well as in the design of grid enhancements and expansions. Also, new sensing techniques will monitor the health of equipment and predict potential failures that can create PQ problems.
- **Advanced components** — These will apply the latest research in superconductivity, fault tolerance, storage, and power electronics. Each of these components supports devices that improve power quality. Some examples include:
    - FACTS and related devices using power electronics.
    - Current Limiting Devices using superconductivity.
    - Superconducting devices such as synchronous condensers and SMES that improve voltage quality.
    - Intelligent switching devices that determine the integrity of a circuit before re-energizing it.
    - New clean power distributed resources employed at the local level that isolate loads from grid problems
- **Advanced control methods** — These will monitor essential components, enabling rapid diagnosis and precise solutions appropriate to any event. Advanced control methods are designed to maintain the grid in a stable state at all times and to provide extensive condition information. Proactive prevention of PQ events will be a result of this vast new data base.
- **Integrated communication** — This will support the new protection and control systems that make the grid more reliable and reduce the occurrence of perturbations that affect PQ. Near real time availability of data allows proactive actions that can prevent equipment deterioration, another source of PQ problems.

BARRIERS

We've described the modern grid requirements for providing higher power quality and we have noted potential solutions to meet those requirements. But there remain some barriers to the deployment of those solutions. We must address issues such as costs, government/regulatory policies, and industry standards.

The three primary issues that must be addressed are:

- Reducing the high costs of modern PQ-enhancing devices.
- Implementing policies and regulations to encourage investment in PQ programs, including those that provide pricing related to grades of power.
- Updating codes & standards.

HIGH COSTS OF DEVICES

The cost of PQ improvement devices needs to come down in order to encourage wide acceptance and usage. Greater use of these devices will reduce their costs as their supply increases and as new approaches to their design are developed. As with any product life cycle, more economical designs will be developed when it becomes clear that a significant market actually exists.

Power electronics has a key role in PQ, as described throughout this report. Power electronics also makes a significant contribution to a number of other modern grid characteristics, making it a key technology for grid modernization. Hence there is a huge potential market for advanced power electronic components. The reduction in cost of this important component will eliminate one barrier to achieving PQ that meets 21st century needs.

Advanced metering, with its ability to monitor a wide variety of PQ parameters, is an example of a PQ-related technology that has grown in sophistication and dropped in price due to an extensive emerging market (and resulting influx of players).

Technology advances that can be expected in the future (such as lower cost storage, distributed generation that delivers harmonic-free power; advanced monitoring that detects impending PQ events, and faster protective schemes) all contribute to reducing barriers to improved PQ.

POLICY AND REGULATION

The absence of a differentiated policy, regarding PQ delivery to customers with differing needs, is a large barrier. For those customers who suffer significant harm due to PQ events, a premium power product can be a solution for both buyer and seller. State regulatory commissions could do much to encourage PQ investment and pricing related to grades of power.

Only the regulator is in a position to encourage PQ solutions that represent the lowest overall cost to society, while providing a fair return to investors. Until increased investment in better PQ by regulated power delivery companies is encouraged by regulators, this missing incentive will remain another PQ barrier. In the meantime, debate will continue over who is responsible for making PQ better.

CODES AND STANDARDS

IEEE and other standards organizations have wide and deep influence on the design of consumer products, electrical system equipment, utilities, and power and communications systems.

Standards organizations have not created standards for categories of power quality that consumers choose from according to their needs. Standards for various grades of delivered power could serve as the basis for differentiated PQ pricing. Such standards will also help educate the many players involved in PQ issues, since this is a topic that is not well understood. This lack of understanding is itself a barrier.

BENEFITS

When barriers are overcome, the benefits will include both cost avoidance and new opportunities for economic growth.

Merely avoiding the productivity losses of poor quality power to commercial and industrial customers can shed billions of dollars of waste from the economy. The costs associated with power quality events at commercial facilities such as banks, data centers, and customer service centers can be tremendous, ranging from thousands to millions of dollars for a single event. The costs to manufacturing facilities can be even higher. Voltage dips that last less than 100 milliseconds can have the same effect on an industrial process as an outage that lasts several minutes or more (September 2002 Primen report).

The reduction of power quality problems will produce a proportional reduction in several categories of loss:

- **Scrapped materials** — This cost can be significant in industries where both the manufacturing process and product quality are extremely dependent on power reliability and quality.
- **Customer dissatisfaction**— Although difficult to quantify, this factor can create a negative perception that loses clients, revenue, and goodwill.
- **Lost productivity**— Even if the business shuts down, overhead costs continue and compound the resulting loss of revenue.
- **Consumer safety**— In some manufacturing processes, such as crane operation in steel production, power perturbations can create safety dangers.
- **Contractual violations**— Liquidated damage losses and litigation exposures can result from failing to meet specific deadlines.

Intelligently improving PQ in the nation's power system will offer opportunities to broaden and enrich the commercial bases of struggling communities and regions. Rural communities will be able to support clean, high-tech industries that demand high quality and reliable power. New jobs and higher tax bases will transform regions and communities that once depended solely on agriculture or single industries.

Since poor power quality leads to both shorter electrical equipment life and higher electrical (KWH) losses, economic and environmental benefits also accrue to the utility when PQ is improved.

RECOMMENDATIONS

Three broad actions would prepare the way for overcoming the barriers for PQ improvement and realizing its benefits.

1. PQ solutions must be tailored to the differing requirements of customers.

- Cost/benefit analyses should be conducted, taking into account the full range of benefits that improved PQ delivers. State utility commissioners, service providers and consumer representatives should work together to develop these studies. Those solutions with a favorable net present value to society should be adopted broadly. And such broad adoption will reduce the cost of solutions (such as those associated with power electronics devices) further advancing the spread of PQ enhancement programs.
- When the energy delivery company is the solution provider, the electric rates should include this associated cost and a fair return on the investment.

2. Government leadership is needed to hasten an answer to the question of who owns the PQ problem.

- PQ problems can originate in a wide variety of places along the electricity path. Therefore, federal agencies and state regulators need to become more involved in how to allocate costs of PQ solutions among transmission, distribution and consumer participants.
- Since customers have differing needs and priorities, a differentiated regulated approach makes the most sense.

3. Programs to provide PQ education should be developed and broadly publicized.

- Customers need to be better educated about the PQ issue so their facilities can be designed to accommodate today's PQ imperfections.
- For future planning by consumers, the emerging solutions should be widely publicized by the Modern Grid Initiative.

SUMMARY

We conclude with a summary of the key findings relevant to providing power quality for 21st century needs.

Clean electrical power is a necessity to commercial and industrial facilities that depend on sensitive digital control and communications systems to keep computing centers and manufacturing operations running productively.

Consumers, whether commercial or residential, have varying demands for power quality. With its advanced sensing and measuring technologies, the modern grid could deliver grades of power from standard to premium, and provide the ability to price the varying levels of PQ accordingly.

The consumer needs to recognize that *perfect power* is not a realistic goal. Therefore, consumer loads need to be designed to accommodate some power quality imperfections.

Almost half of PQ disturbances originate in the transmission and distribution elements of the electrical power system. The advanced monitoring and control functions of a modern grid, coupled with the wider application of conventional surge mitigation techniques, enable the diagnosis and solution~~s~~ of many such PQ events.

The other major source of PQ events is the load from consumer electronics, which cause irregularities in voltage that feed back to the electrical power system. The advanced components being developed for the modern grid will also help address these problems.

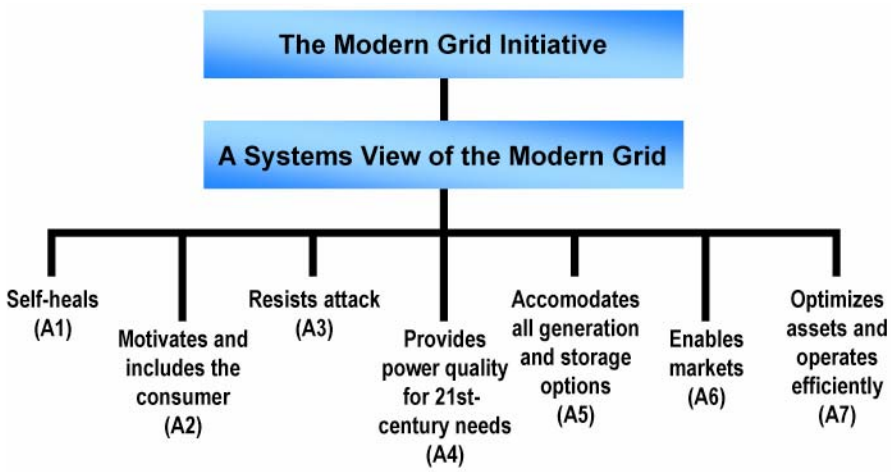
By aligning the efforts of government, utilities, regulators, consumers and standards bodies, we can attain both improved PQ and choice in level of PQ in the near future.

The benefits to productivity in the economy could mean many billions of dollars in costs avoided. Harder to measure, but just as important, are the new opportunities for economic growth that emerge when new 21st century industries answer the call from regions that offer clean, reliable power.

For more information

Other principal characteristics of the modern grid, besides power quality, will be designed to provide reliable power to the consumer. These other characteristics (e.g. Self-heals, Resists Attack, Accommodates all Generation Options), are described in companion papers published by the Modern Grid Initiative.

This document is part of a collection of documents prepared by The Modern Grid Initiative (MGI) team. For a high-level overview of the modern grid, see "A Systems View of the Modern Grid." For additional background on the motivating factors for the modern grid, see "The Modern Grid Initiative." MGI has also prepared seven appendices that support and supplement these overviews by detailing more specifics on each of the principal characteristics of the modern grid. This paper describes the second principal characteristic: "Provides Power Quality for 21st Century Needs."



Documents are available for free download from the Modern Grid Web site.

The Modern Grid Initiative

Website: www.netl.doe.gov/moderngrid

Email: moderngrid@netl.doe.gov

(304) 599-4273 x101

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