Smart Grid Principal Characteristics

PROVIDES POWER QUALITY FOR THE DIGITAL ECONOMY

Developed for the U.S. Department of Energy
Office of Electricity Delivery and Energy Reliability
by the National Energy Technology Laboratory
October 2009

Office of Electricity Delivery and Energy Reliability

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference therein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed therein do not necessarily state or reflect those of the United States Government or any agency thereof.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The smart grid is defined by its seven principal characteristics. Providing power quality (PQ) for the digital economy is one of those characteristics. Our Nation's future global competitiveness demands fault-free operation of the multitude of digital devices that power our 21st century economy. We need high quality power to meet that demand.

When consumers think of 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 clean power attribute. (Issues about power reliability are addressed elsewhere in this collection of documents that cover the smart grid's principal characteristics.) This focus on PQ is deserved because of the important role digital devices have assumed in today's economy. There is hardly a commercial or industrial facility in the United States that would not suffer a loss of productivity if a serious PQ event were to impact its digital environment.

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

The smart grid will 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 such perturbations as lightning strikes, harmonic voltages, phase imbalance, and switching surges. The cost of these premium features can be included in the electrical service contract.

The smart grid will 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. The grid's advanced components will apply the latest research in superconductivity, materials, energy storage, and power electronics to improve power quality.

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

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

- PQ meters.
- System-wide PQ monitoring.
- 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 that need 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 produce PQ problems.
- New distributed generation devices (e.g., fuel cells, micro-turbines, and micro-grids) that can provide clean local power to sensitive loads.

All this technology can be applied to the problem of PQ now. However, to do so requires the coordinated efforts of government, utilities, regulators, and standards bodies such as the Institute of Electrical and Electronic Engineers (IEEE). It also requires widespread education for all the 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. Estimates of the cost of "unclean" power alone are in the order of $20 billion per year.

CURRENT AND FUTURE STATES

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

CURRENT STATE

Before delving into issues of PQ, we should first understand the things that disrupt it, including harmonics, sags, 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 1).

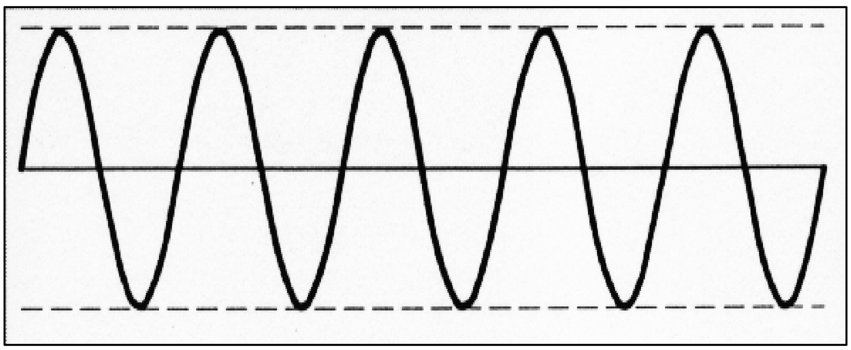

Figure 1: Normal power is supplied in smooth sinusoidal waveforms.

However, 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 (clean) sine wave envelope:

1. Sags (undervoltages)—Voltage sags are the most common power disturbance. They occur when very large loads start up, or when there is a serious momentary overload or fault in the power system. At a typical industrial site, it is not unusual to experience several sags per year at the service entrance. Many more sags occur at equipment terminals. Costs associated with sag events can range widely, from almost zero costs to several million dollars per event (see Figure 2).

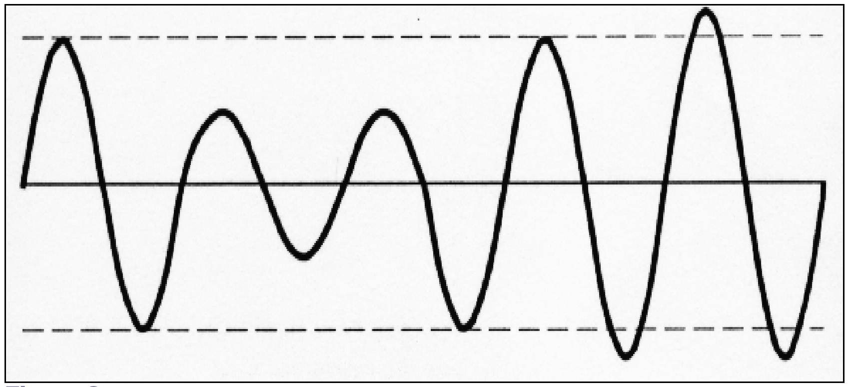

Figure 2: Voltage sags are the most common power disturbance, with associated costs ranging from zero to millions of dollars.

2. Harmonics—Harmonics are caused by "non-linear" loads, which include motor controls, computers, office equipment, compact fluorescent lamps, light dimmers, televisions, and most electronic loads. High levels of harmonics increase line losses and decrease equipment lifetime (see Figure 3).

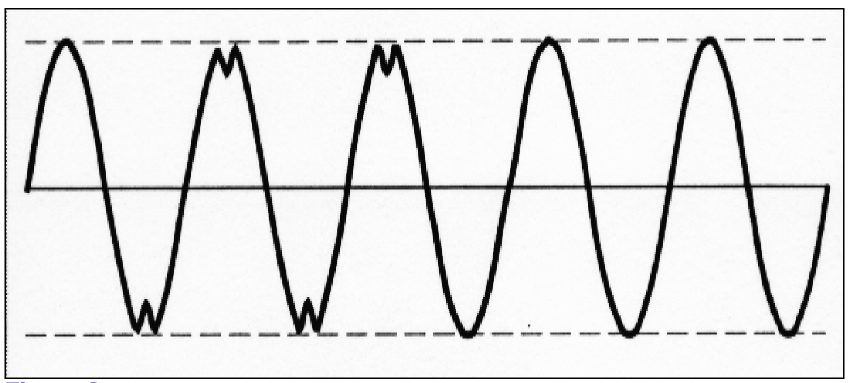

Figure 3: Non-linear loads create harmonic distortion, resulting in more line losses and reduced equipment life.

3. Spikes—Spikes are brief spurts of voltage (in the millisecond to microsecond range) that 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 can damage sensitive electronic equipment (see Figure 4).

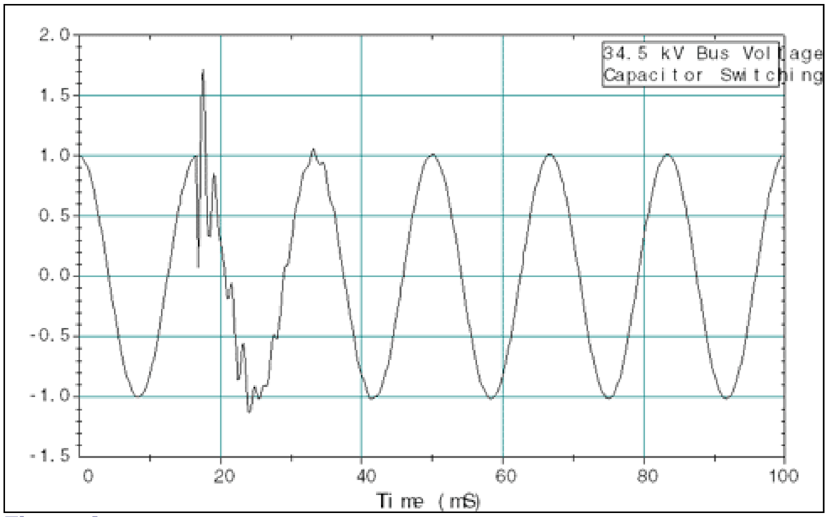

Figure 4: Spikes can damage sensitive electronic equipment.

4. Imbalances—Imbalances are steady-state problems caused by such factors 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 imbalances can gradually cause damage to equipment, especially to electric motors.

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, which may occur annually (see Figure 5).

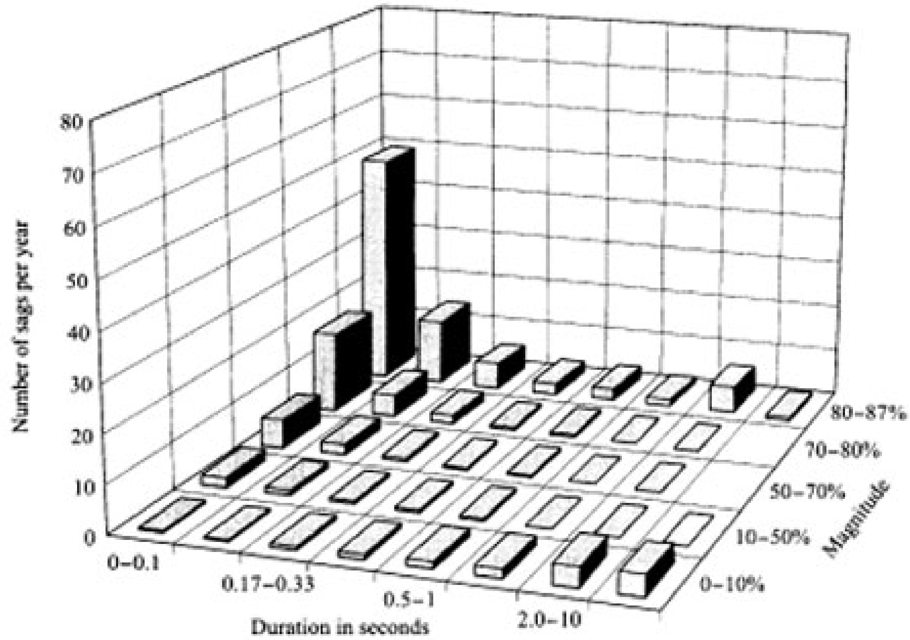

Figure 5: Results of a 5-year National Power Laboratory Survey of 130 Sites. (Source: EPRI)

The above diagram may be compared to the industry standard Semiconductor Equipment and Materials International (SEMI) F47 curve (see Figure 6—shown below in green). While there is generally reasonable matching between what the utility supplies and what the customer designs, there are also points of non-compliance. This curve more clearly shows the points of non-compliance (points below the green line). A smart grid will provide PQ that fully conforms to the customer's design criteria, as defined by industry standards.

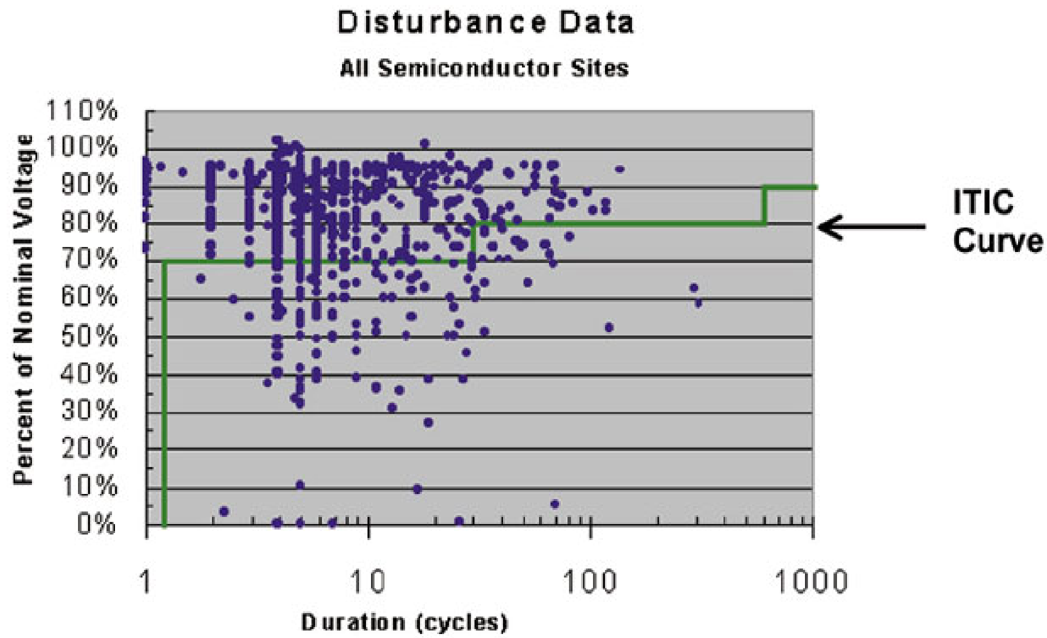

Figure 6: Sag Monitoring Data from 15 Semiconductor Sites
(Source: EPRI Solutions)
(Note: ITIC is the Information Technology Industry Council)

PQ 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. This criterion led to the selection of rural Grant County, WA, as the site for both Microsoft and Yahoo server farms.

PQ is also a large issue for industrial and manufacturing facilities. Tiny power disturbances 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 like the Semi F47 curve. This graph of voltage sag events at a manufacturing facility (see Figure 7) is a good example of voltage levels in an industrial setting. Events that caused process disruptions are circled. Note that for the circled events, the consumer's equipment does not meet the SEMI 47 standard, emphasizing that both the supplier and the user need to comply with applicable PQ standards.

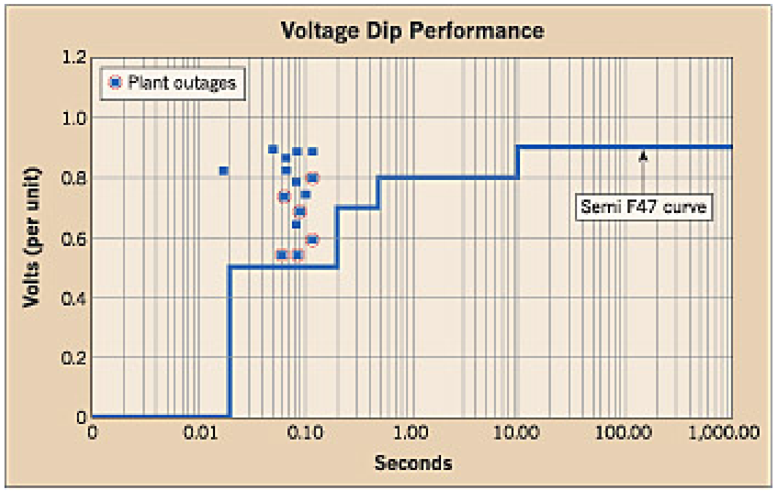

Figure 7: Voltage Sag Events at One Facility. (Source: EPRI.)

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 PQ disturbances alone cost the U.S. economy between 15 and 24 billion dollars annually. Other studies, conducted in the United States and the European Union (EU), arrive at similar conclusions. For example, a 2008 EU PQ survey concluded:

> The cost of wastage caused by poor PQ for EU-25 according to this analysis exceeds €150bn… Industry accounts for over 90% of this wastage. Dips and short interruptions account for almost 60% of the overall cost to industry and 57% for the total sample….The number of recorded voltage dips, identified by the respondents, is approximately twice the number of short interruptions.

The cost of a momentary interruption to various users, reported by McGranaghan, Stephens, and Roettger, is shown in Table 1 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

Table 1: Interruption Cost by Industry.

The most recent related study of reliability and power quality was conducted by Lawrence Berkeley National Laboratory in 2009 and reported by Sullivan, Mercurio, and Schellenberg. This study analyzes the results from 28 customer value-of-service-reliability studies conducted by 10 major U.S. electric utilities over the 16-year period from 1989 to 2005. The following summary of costs associated with various types of power disturbances—while not limited to the momentary events this paper discusses—provides additional insight into the impact of an imperfect power supply.

Estimated Average Electric Customer Interruption Costs Based on U.S. 2008 Dollars by Customer Type and Duration*					
	Interruption Duration				
	4 hours	8 hours	Momentary	30 minutes	1 hour
Medium and Large Commercial & Industrial					
Cost per Event	$59,188	$93,890	$11,756	$15,709	$20,360
Cost per Average kw	$25.0	$72.6	$115.2	$14.4	$19.3
Small Commercial & Industrial					
Cost per Event	$2,696	$4,768	$439	$610	$818
Cost per Average kw	$373.1	$1,229.2	$2,173.8	$200.1	$278.1
Residential					
Cost per Event	$7.8	$10.7	$2.7	$3.3	$3.9
Cost per Average kw	$5.1	$7.1	$1.8	$2.2	$2.6
*(Summer Weekday Afternoon)					

Table 2: Summary of Costs Associated with Various Power Disturbances.

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

FUTURE STATE

Advanced technologies deployed by the smart grid will both quickly identify and 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 and in previous years. However, 10 years ago, the amount of load from chips and automated manufacturing had increased by approximately 10 percent and is expected to increase by 50 percent in the near future. The grid must change to accommodate this changing load characteristic.

The smart grid will be rich with technologies and devices that work at every level of power generation, transmission, and distribution. Many will contribute to clean power reaching the consumer:

- PQ meters.
- System-wide PQ monitoring.
- 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 PQ 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, micro turbines, and micro-grids) that can provide local power to sensitive loads.

Applying the advanced technologies that mitigate PQ events will require support and coordination among equipment makers, power providers, regulators, 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 smart grid will supply varying grades of power and support variable pricing accordingly. The level of PQ required by consumers can vary, depending on the complexity of their equipment or criticality of their operations. As Table 1 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 have broadly described the current state of PQ 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 smart grid.

Commonly, 40 percent of power quality issues relate to the delivery of power from the utility, and 60 percent 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 smart grid must apply power quality solutions wherever they are needed—where the power begins, where it gets distributed, or where it ends. Thus, PQ solutions, like the smart grid itself, must be autonomous and distributed. The devices that mitigate PQ events must be spread among transmission and distribution components of the smart grid, but also at the sensitive load.

Distributing advanced power electronics at each level throughout the grid is key to solving many PQ problems. Many of these devices 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), Thyristor Controlled Static Capacitors (TCSC), high-speed transfer switches, etc. These FACTS devices may be connected in series and/or in shunt. While the STATCOM is connected at the load in shunt, devices like the DVR and TCSC, which are capable of eliminating voltage sags and swells as well as rapid adjustment of network impedance, are connected in series with the line. Table 3 below illustrates the application of various power electronic devices.

Power Quality Problem	Power Quality Solution				
	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 3: Power Electronic PQ Solutions
(Source: S&C Electric Company)

Transmission Level

At the transmission level, voltage sags are frequently the result of faults (short circuits), which can exist for many milliseconds. 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 due to the cost of today's power electronic components. As component costs drop, these devices will become increasingly attractive to transmission system owners.

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

Conventional techniques such as broader application of surge arresters, improved line shielding and grounding, and controlled switching angles can also be employed more aggressively to limit PQ disturbances.

Distribution Level

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

The creation of premium PQ 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 3 can be deployed in many distribution applications. Distributed generation and storage resources located close to the load, including micro-grids, can also isolate the consumer from most grid disturbances.

Expanded monitoring of the grid, as a result of Advanced Metering Infrastructure and other measurement systems, will reveal many PQ issues and allow prompt remedial actions. Correction of phase imbalance is one such action that produces the additional benefit of reducing electrical losses. With extensive real-time monitoring of PQ, problems can be identified and corrected before the customer experiences any significant impact.

Customer Level

Not all customers are equally impacted by poor quality of power. At one end of the spectrum, an integrated circuit manufacturer will 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 merely inconvenienced when a DVD player shuts down.

The PQ 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, various devices will offer solutions to PQ sensitivity.

There are a number of ways customers can limit problems with transients in their facilities. It is best to start by selecting equipment that can withstand transients, and by using proper wiring and 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 of the different categories of customers: commercial, industrial, and residential.

Commercial and industrial customers should 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 disruptions.

Commercial and industrial customers that have the most to gain by investing in PQ hardening are ranked in Table 1 above.

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 group of customers. Yet with so many small 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 many of these solutions will be enabled by the advanced technologies of the smart grid. The smart 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. Improved surge minimization on the grid can also help. The most direct way to deal with voltage sags is by providing adequate buffering at the load. For those customers who take advantage of the smart grid's distributed energy resources, local supply 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 like the Institute of Electrical and Electronics Engineers (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 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 smart 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 the methods described above, customers can also contribute to the solution. They can limit the impact of transients in their facilities by selecting equipment that can withstand them and by employing proper wiring, grounding, and surge protection.

Voltage Imbalance

In the smart grid, voltage imbalance identification will happen quickly because modern communicating meters will report any imbalance to the service provider. Voltage imbalances can cause premature failure of motors and transformers due to overheating, and can also 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 smart grid will provide solutions that mitigate PQ 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. Also, new sensing techniques will monitor the health of equipment and predict potential failures that can create PQ problems.
- **Advanced components**—These components will apply the latest research in superconductivity, materials, energy storage, and power electronics. Each of these components supports devices that improve PQ.

- **Advanced control methods**—These methods 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 database.
- **Integrated communications**—This technology will support the new protection and control systems that make the grid more reliable and reduce the occurrence of perturbations that affect PQ.

BARRIERS

We have described the smart grid requirements for providing higher PQ and we have noted solutions to meet those requirements. To deploy those solutions, we must address issues such as costs, government policies, and industry standards.

The three primary issues that must be addressed are:

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

HIGH COSTS OF DEVICES

The cost of PQ devices needs to come down to encourage wide acceptance and usage. Greater use of PQ components will reduce production costs as supply increases and as new design approaches are developed. As with any product life cycle, more economical designs will be developed when it becomes clear that a significant market exists. Advanced metering, with its ability to monitor a wide variety of PQ parameters, is an example of a device that has grown in sophistication and dropped in price due to an extensive emerging market and a resulting influx of players.

POLICY AND REGULATION

State regulatory commissions could do much to encourage PQ investment and pricing related to grades of power. Not all customers will want premium levels of PQ or wish to pay for it. Only the regulator is in a position to encourage solutions that represent the lowest overall cost and provide a fair return to investors. Regulators can also drive the development of standards for making equipment less vulnerable. For those customers who suffer significant harm due to PQ events, a premium power product could be a solution for both buyer and seller.

CODES AND STANDARDS

As influential standards bodies, IEEE and the Information Technology Industry Council (ITIC) could create standards for categories of PQ from which consumers choose according to their needs. IEEE standards have wide and deep influence on the design of consumer products, electrical system equipment, utilities, and power and communications systems.

In addition, a variety of other U.S. and international standards and guidelines influence PQ issues:

- International Electrotechnical Commission PQ standards.
- Utility PQ standards.
- Industry-specific PQ standards.
- U.S. military PQ standards.

Unfortunately, none of these standards bodies address the issue that not everyone needs premium power. When they do develop standards for various grades of power, prices can be set according to the value provided to different types of consumers.

BENEFITS

When deployment issues 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 PQ 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. The 2002 Primen report points out that 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.

The reduction of PQ 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 a 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.

RECOMMENDATIONS

Three broad actions would prepare the way for overcoming the deployment issues 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 value to society should be adopted broadly.
- When the energy delivery company is the best solution provider, the electric rates should include the incremental cost to provide superior PQ and a fair return on investment.

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

- Because PQ problems can originate in a wide variety of places along the electricity path, federal agencies and state regulators need to become more involved in determining how to allocate costs of PQ solutions among transmission, distribution, and the consumer.

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 Department of Energy and others.

SUMMARY

We conclude with a summary of the key findings relevant to providing PQ for the digital economy.

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

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 smart grid, coupled with the wider application of conventional surge mitigation techniques, enable the diagnosis and solutions of many such PQ events.

The other major source of PQ events is the load (including consumer electronics), which can cause irregularities in current that feed back into the electrical power system. The advanced components being developed for the smart grid will also help address these problems.

Consumers, whether industrial, commercial, or residential, have varying demands for PQ. With its advanced technologies, the smart grid could deliver several grades of power, from standard to premium, and provide the ability to price PQ levels accordingly. Yet even with premium power, consumers' loads need to be designed to accommodate some degree of PQ imperfection.

If the efforts of government, utilities, regulators, and standards bodies could be aligned, then smart grid principles could contribute to attaining both improved PQ and choice in level of PQ in the near future.

The benefits to productivity in the economy could mean billions of dollars in avoided costs. Equally important are 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

This document is part of a collection of documents prepared by the Modern Grid Strategy team. Documents are available for free download from the Modern Grid website.

The Modern Grid Strategy

http://www.netl.doe.gov/moderngrid/

info@TheModernGrid.org

(304) 599-4273 x101

BIBLIOGRAPHY

1. Bollen, M.H.J., “Understanding Power Quality Problems: Voltage Sags and Interruptions,” New York: IEEE Press, 2000.
2. Falcon Electric, “Power Your Customer’s Critical Equipment Reliably,” 2005.
3. McGranaghan, M., M. Stephens, and B. Roettger, “The Economics of Voltage Sag Ride-Through Capabilities,” EC&M, May 2005, http://www.ecmweb.com/mag/electric_economics_voltage_sag/index.html.
4. Power Standards Testing Lab, Product Announcement, April 2000, http://powerstandards.com/whatsnew/MakeItWorse.txt.
5. “Primen Report. Power Quality Problems and Renewable Energy Solutions,” September 2002.
6. “Primen Study: The Cost of Power Disturbances to Industrial and Digital Economy Companies,” June 2001.
7. Southern California Edison Power Quality Department. *Power Quality Handbook*. 2009, http://www.sce.com/NR/rdonlyres/66BEEBD8-C9B9-4AE3-B2AC-473BEDCE21C0/0/PQhandbook.pdf.
8. Sullivan, Michael J., Matthew Mercurio, and Josh Schellenberg, “Estimated Value of Service Reliability for Electric Utility Customers in the United States,” June 2009.
9. Targosz, Roman, and Jonathan Manson, “European Power Quality Survey Report,” 2008.
10. Whisenant, S., B. Rogers, and D. Dorr, “Creating a Business Case To Solve PQ Problems," EC&M, May 2005, http://www.ecmweb.com/mag/electric_creating_business_case/index.html.