Power Quality

Customer Financial Impact/Risk Assessment Tool

Introduction

Electric power quality problems associated with interactions between distribution and end-user systems can be prevented. While power quality is a well used (almost over-used) term, surveys of large users that buy power at transmission and distribution voltages turn up relatively few complaints about the quality of their incoming power, while surveys of small users connected at secondary voltages turn up numerous complaints about the quality of their incoming power. Three major changes in the characteristics of customer loads and power distribution systems have altered the nature of the power quality equation: (1) greater sensitivity of devices and equipment to power quality variations, (2) the interconnection of sensitive loads in extensive networks and automated processes, and (3) an increase in loads that use power electronics in some type of power conversion process.

This brochure was created to provide commercial/industrial facility managers with concepts, parameters and a checklist that spell out how to compile PQ cost data into simple formulas and calculate the total cost of power quality operating problems for a wide range of different types of businesses. Selected commercial/industrial case studies are presented to illustrate a basic spreadsheet format to assist in analyzing the total cost of a power disturbance.

PQ areas of financial losses

What is a ***power quality problem***? It is any deviation of electricity applied to the equipment that results in damage or misoperation of electronic equipment or other electrical devices. Some common symptoms of power quality problems in facilities are:

- unexplained equipment trips or shutdowns
- occasional equipment damage or component failure
- erratic control of process performance
- random lockups and data errors
- power system component overheating

Power quality problems can be complicated, involving the facility wiring, natural phenomena such as lightning, interacting facility equipment, and equipment connections to the electric power system. Most commercial and industrial production machinery is typically designed to operate with flawless electricity from the electric utility; however, many things interfere with electricity as it travels from the utility to a customer's equipment that produces revenue-creating products and/or services.

A review of some of the work targeted to quantify the financial losses and risks of power quality problems indicates that a significant number of dollars are spent annually (see reference 3). Investigated data confirms that PQ costs deviate widely among users. How much it costs depends on a variety of factors. For example, research on the effects of interruptions in the agricultural sector showed that different types of farms, including large and small operations, had significant variations in costs due to interruptions in service.

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In the industrial sector, the interruption costs of production processes can range widely, due to the potentially large number of product categories involved and the relative complexity of the production process for each category type. Capturing the annual costs of power quality is a complicated procedure and in reality they can only be estimated. The costs of power quality problems and solutions can vary dramatically, depending on the nature of the problem, the existing electric service system, and the type, ratings and electromechanical performance characteristics of the commercial/ industrial equipment.

As an example, an automobile industry study (see reference 4) brought out several important issues related to cost. The following three points exemplify the consequences of power quality problems to auto manufacturers: (1) a large machinery plant may consume electricity at a rate of $2,000 per hour, but a voltage sag for less than one-tenth of a second may cause production losses as high as $200,000, (2) subsequent to a voltage sag, the restarting of assembly lines may require starting air compressors and boilers, reprogramming or resequencing of controls, and clearing the line of damaged work in process (the labour cost may be $25 per hour for each of 2,000 production workers, therefore $50,000 an hour total), and (3) one auto company estimated a typical loss during a momentary interruption to be about $40,000 per incident, for a total of $10,000,000 per year for all of its plants.

Different estimates have been made for the total cost to the customer resulting from power quality problems in the United States. In the United States, as early as 1987, costs of power quality impacts for the manufacturing sector were estimated at between $12.8 and 25.6 billion dollars per year (see reference 5). In 1990 the cost of field service organizations and other macro-economics figures projected the cost of power quality problems at $34 billion or more per year (see reference 6). Similar estimates abound since that time. Recent market research shows that the industry related to the manufacture, sale and service of power quality improvement or protection equipment is about a $2 billion per year industry.

Why does industry suffer $12 to 34 billion dollars in losses while spending only $2 billion per year toward solving the problem? Maybe it's because the costs of power quality problems are elusive. It may be possible to actually account for the costs related to an incident in a particular case, but it is very difficult to truly account for lost time, or the value of a telephone call that didn't get through or a sale that might have been made. What is clear is that the total impact to the national economy is enormous and growing and, perhaps more important, unknown.

A number of factors having the greatest impact on how large PQ losses may be are detailed in the next sections. Once the complete cost of disruption related to PQ is understood, the cost of reducing or eliminating disruptions of the actual types of PQ variations being experienced, versus paybacks, can be analyzed.

Parameters affecting cost of impacts

Today most engineering economic assessment studies must take into account existing conditions and the losses associated with no change, the benefit derived from system modifications and the cost to implement the modifications with financial criteria such as internal rate of return, life cycle costs, depreciation, taxes, etc. In many cases, businesses do not perform detailed economic analyses and will address a power quality problem only when it is obvious or critical. As a result, the quickest solution is often chosen, without regard for rate of return.

An important part of assessing PQ-related costs is determining what, specifically, is being affected, and where, or in what aspects of business operations, do these costs show up. Some efforts have been made to identify and classify disturbances and other PQ costs. In the IEEE Orange Book (reference 7), the point is made that any production losses due to power interruptions in industrial plants, operating at 100% efficiency, will result in the direct loss of the profit of the item or service being derived from the facility. The more obscure types of disturbances, undetected transients, voltage sags and/or swells, and harmonic distortion, are most often associated with ***hidden costs***.

Hidden costs usually result from damage, or losses, not immediately or readily observed. In a case study of commercial buildings, it was noted that the majority of the power quality costs were hidden and could be traced to wiring/grounding problems and harmonic generation by the business machine power supplies within the facility. A similar case study of process industries (reference 8) showed that the significant costs were both identifiable and hidden, and that the identifiable costs were usually the result of voltage sags and impulsive transients. In this latter case, the hidden costs frequently could be traced to harmonic distortion created by electronic adjustable speed drives and a resultant harmonic magnification effect caused by resonance with capacitor banks.

Power quality costs can show up in many aspects of industrial and commercial operations. Costs include field service warranty work, manufacturing interruptions, loss of productivity, loss of revenue, decreased competitiveness, lost opportunities, product damage, wasted energy and decreased equipment life. Because many of these power quality cost elements can be key factors in determining of the costs for action as well as inaction, following are brief examples that define these parameters:

- *Field service costs* – undetected disturbance events that result in component or circuit-board failures with no verifiable cause and where either the equipment manufacturer absorbs the repair costs or the customer must bear the field service costs for parts, labour, consultants, electrical contractors, etc. Field service costs should be included as an element of the cost of restarting after a power disturbance.
- *Manufacturing costs* – because some portion of certain manufacturing systems is affected by PQ disturbances, the whole system may not meet the performance requirements, product quality, production rates or production volume. In these cases, the manufacturers have found it necessary to invest in backup systems of some sort to avoid disturbances, whether the disturbances are observable or not. Since many manufacturing systems are composed of inter-linked and/or dependent subsystems, the cost of these backup systems must be considered as part of the total PQ costs to manufacturing. The proactive manufacturer that has investigated these PQ linkages and invested in adequate backup/protection systems will have lower cost per unit service or product loss/repair figures than the manufacturer that is uneducated inexperienced, or completely ignores the need for proper backup/protection systems.
- *Productivity costs* – usually impacted by both hidden and direct, or identifiable, costs, e.g., idle manpower due to an interruption, clean-up operations, or corrective maintenance and the diverting of resources, which effectively decreases productivity and increases costs. Specific examples include the added costs to redo lost payroll records, unique customer data or illegible CAT scan images due to a PQ disruption. Productivity costs are a significant element of the cost of labour for employees affected by a power disturbance and those involved in restart efforts.
- *Loss of revenue* – any direct interruption to a manufacturing process can interrupt sales or severely impact revenue flow, resulting in delayed production schedules. The loss of revenue from any kind of process interruption is generally an observable or direct cost. The following two sections give a step-by-step checklist to compile basic information with detailed formulas to calculate PQ costs and loss of revenue due to a power disturbance.
- *Decreased competitiveness* – PQ problems in the manufacturing environment can often result in customer dissatisfaction and a poor-quality product, as well as delayed production schedules. These shortcomings almost certainly decrease competitiveness and can be very costly.
- *Lost opportunity* – any PQ problems that impact any type of product and/or service processes can also mean a lost opportunity for

sales, for the marketing of a new product at just the right time, or for the marketing of seasonal products at the peak of the season.

- *Product damage* – sometimes PQ problems in manufacturing processes can result in product damage. Occasionally, the damage can be directly observed and the damaged product discarded or recycled. Product damage can be costly if the damage is subtle and the effects take some time to surface. Service or product losses due to a power disturbance need to be known in quantifying PQ costs. As will be seen in the following sections, the number of units of service or product losses and the cost per unit of service or product loss/repair are key elements in determining the total cost of a power disturbance.
- *Wasted energy* – any interruption to a manufacturing process will result in a waste of energy in the restart process. In the case where product damage occurs because of a process stoppage or mis-operation due to some type of disturbance, the energy up to that point is wasted. The amount of energy wasted and the cost per unit energy are factors in the total cost of a power disturbance and are frequently included in the company's overhead costs.
- *Decreased equipment life* – many systems that experience disturbances, both detected and undetected, have resulted in decreased equipment life. High-energy, fast-rise-time transients can cause outright circuit board failure, even for systems protected by transient suppressors, or can cause degradation over time such that burnout is only delayed. Harmonic distortion and phase unbalance can combine to overstress motors and transformers, shortening their useful lifetimes, and consequently increasing production costs. Hence, equipment lifetime affected by PQ disturbances can show up as direct and hidden costs. An example of how hidden PQ costs can be added to identifiable PQ costs is contained in the section on calculating PQ costs.

The next section addresses how to compile the basic costs for financial impact data calculations.

Checklist for compiling basic PQ cost data

High-speed electronic systems and equipment may be more sensitive to disturbances in the AC power system than are conventional loads. The effects of power disturbances on sensitive electronic equipment can take a wide variety of forms, including data errors, system halts, memory or program loss, and equipment damage. In many cases, it is difficult to determine whether the system hardware and software malfunctions are actually caused by disturbances in the power system supplying the equipment. These PQ realities compound the complexity of collecting basic costs for data calculations.

To successfully compile basic costs, a thorough analysis of the power system and loads should be conducted to define the areas of concern as accurately as possible before attempting to solve the problem. Coordinate with involved parties, the equipment user/owner, electronic equipment manufacturer/supplier, and discuss the objectives of compiling basic costs. This approach can enable cost-effective solutions to be implemented that not only correct the existing conditions but also minimize future problems.

The key is to understand and define the problems, and to estimate cost impacts before attempting to solve them. Effective communications are essential to determine proposed solutions and their basic costs. Following is a checklist to walk through the process of gathering information.

(✓) **Identifying what sensitive electronic equipment is experiencing problems (e.g., type, location).** While the users of the electronic equipment are primarily concerned with the productivity of the equipment, they need to be made aware to report that the equipment is not performing as intended, and it is costing the company money.

(✓) **Document the types of equipment malfunctions or failures (e.g., data loss, lockups, component damage).** Arrange to meet with equipment users to establish objectives of compiling basic costs associated with loss of production and increased operating expenses. While technical details on power disturbances are normally of little interest to the end-users, it is important that they provide their best feedback on equipment upsets.

(✓) **Determine when the problems occur (e.g., time of day, day of week, particular system operation).** Valuable information to assist in solving facility power problems and compiling basic costs is obtained by keeping an accurate log of equipment errors and malfunctions. An effective method to document this kind of information can include meetings between the building manager and BC Hydro personnel. In this way, site-specific information on disturbances that occur on the utility distribution system can be related to the site's internal power anomalies. As these issues are discussed between both parties, this is an excellent opportunity to develop insights on such items as the value of lost production, and/or the end-user's methodology to establish the company's basic costs of power quality impacts.

(✓) **Establish those coincident problems occurring at the same time (e.g., lights flicker, motors slow down).** Single observations such as these provide valuable clues to identify possible problem sources and PQ impact basic costs at the site. For example, perhaps a large horsepower induction motor being started "across the line" seems to be creating a current surge, resulting in a perceptible lighting system flicker. Armed with documented symptoms like this, you can direct intelligent and probing questions at the electrical equipment suppliers to determine what the most cost-effective solutions might be.

(✓) **Investigate possible problem sources at site (e.g., arc welders, air conditioning, copy machines, and any equipment with rectifier input power supplies).** This approach involves gathering equipment power quality immunity and emissions guidelines from equipment manufacturers or testing labs, where equipment is characterized to determine immunity and emissions to voltage sags, impulse transients, system fault responses, and harmonics environment. Equipment power quality "performance envelopes" are essential to accomplishing evaluations on basic costs for production and/or service impacts.

(✓) **Make inquiries regarding existing protection for equipment (e.g., transient voltage surge suppressors, isolation transformers, internal electrical filtering circuit devices, etc.).** The job of compiling basic costs and selecting power enhancement vary for many reasons. One frequently ignored factor is that the equipment's own internal PQ protection or filtering may be dysfunctioning, or interacting with other electronics-based loads. Combining these facts with the range of available technologies and the different power quality options offered by equipment suppliers can make compiling basic costs intimidating.

Fomulas to calculate PQ costs

Neither power quality, nor the lack of it, is without cost. As mentioned already, an important part of assessing PQ-related costs is determining what specifically is being affected and where, or in what aspects of business operations, these costs show up. Some long-term studies reveal the effects of hidden, as well as identifiable, costs for both the utilities and their customers. Most of the literature deals with the cost of interruptions, identifiable disturbances, and naturally, identifiable costs (reference 9).

Identifiable and hidden PQ costs

Identifiable costs are generally associated with voltage sags and momentary, or longer, electric service anomalies. Identifiable costs are sometimes referred to as "direct costs," notably including labour hours, costs of scrap, damaged products or services, costs of rework, costs to reprogram or replace lost data, costs to re-run an in-process test that was interrupted, and costs of damaged manufacturing or service equipment.

Hidden costs are sometimes referred to as "indirect costs," or "soft costs." These reflect costs of lost sales, costs of premature equipment failure, costs of out-of-specification products or services, costs of impacts on just-in-time delivery systems, and costs associated with poor reputation for non-delivery.

Some equations have been developed (reference 3) to identify rough estimates of costs due to power disturbances on processes, from a cash flow perspective. Upfront identifiable and hidden costs that need to be quantified should include the following:

Total Cost of a Power Disturbance (TCPD)

= (Ⓐ + Ⓑ + Ⓒ + Ⓓ) in dollars

where:

Ⓐ = Cost of labour for employees affected (in dollars)

Ⓑ = Service or product loss due to power disturbance (in dollars)

Ⓒ = Cost of restart (in dollars)

Ⓓ = Hidden costs (in dollars)

The values of Ⓐ , Ⓑ , Ⓒ and Ⓓ can be calculated as follows:

Ⓐ = Ⓔ x Ⓕ x (Ⓖ + Ⓗ)

Ⓑ = Ⓘ x Ⓙ

Ⓒ = Ⓚ x Ⓛ x (Ⓖ + Ⓗ) + Ⓜ x Ⓙ

Ⓓ = Ⓝ x Ⓞ

where:

E = number of productive employees affected

F = duration of power disturbance/interruption (in hours)

G = base hourly rate of employees affected (in dollars)

H = overhead hourly cost per employee affected (in dollars)

I = units of services or products lost due to power disruption

J = cost per unit of service or product lost/repaired due to power disruption

K = restart time (in hours)

L = number of employees involved in restarting

M = units of equipment damaged due to restart

N = element(s) of hidden costs

O = $/hidden cost element

Following are three illustrative examples of the proposed framework to calculate PQ costs:

Case 1 – Commercial computer data centre

Problem description – The data centre provides computer support to 10 remote locations for all business computing. Applications include payroll and time-keeping, production and cost control, inventory and general accounting. During the last year, 20 downtime episodes occurred as a result of electric voltage sags or momentary interruptions lasting from 30 cycles to a few seconds, which disrupted work production for an average of 0.6 hours. Typically, transactions in progress were lost as well as recent remote transactions. Recovery included rebuilding of payroll files and discovering what needed to be reprocessed, then retransmitting the right data from all of the remote sites. Normally, 10 new sales are recorded each business hour and are valued at approximately $250 income.

$TCPD_{\text{Case 1}}$ = Ⓐ + Ⓑ + Ⓒ + Ⓓ

Ⓐ = (100 employees) x (0.6 hours) x [($15/hour) + ($7.5/hour)] = $1,350/episode

Ⓑ = (200 lost transactions) x ($22.5/transaction) = $4,500/episode

Ⓒ = (0.5 hours/restart) x (100 employees) x ($22.5/hour) + (2 bad disks/power supplies) x ($1500/repair) = $4,125/episode

Ⓓ = (6 lost sales) x ($250/lost sale) = $1,500/episode

$TCPD_{\text{Case 1}}$ = $1,350 + $4,500 + $4,125 + $1,500 = $11,475/episode

If there were 20 power quality disturbance episodes per year as characterized above, the yearly power quality cost impact on this customer would be 20 x $11,475/episode = $229,500/year.

Case 2 – Industrial automotive manufacturer

Problem description – This automobile manufacturer experiences tripping of adjustable speed drives (ASDs) and robotics for no apparent reason. Some electronic damage occurs, but the real problem is downtime. The downtime associated with each of these problems averages 30 minutes, and that has a growing financial value in lost time, production and raw materials. A special problem is the paint shop, where robots painting cars are interrupted. While 50 unpainted cars result due to each disruption, there are significant hidden costs associated with resanding an additional 50 cars ($35 per car), lost paint ($25 per car), and the need to repaint cars ($75 per car) that have out-of-specification paint coats. In addition, since this auto plant runs at full capacity, 50 lost car sales ($500 per car) increases the total hidden costs per car to $635. The problem seems random, and the cause is the transient associated with utility capacitor switching. The utility has turned off automatic control and is now coordinating the manual operation of the capacitors with the manufacturer. This is unacceptable as a permanent solution, as the capacitors are not available to control utility voltage as needed.

$TCPD_{Case\ 2}$ = Ⓐ + Ⓑ + Ⓒ + Ⓓ

Ⓐ = (1,000 employees) x (0.5 hours) x [($17/hour) + ($9/hour)] = $13,000/episode

Ⓑ = (50 unpainted cars) x ($75/car) = $3,750/episode

Ⓒ = (0.5 hours/restart) x (50 employees) x ($26/hour) + (4 damaged ASDs/controllers) x ($500/repair) = $2,650/episode

Ⓓ = (50 resanded & repainted cars) x ($135/repaint) + (50 lost car sales) x ($500/lost sale) = $6,750 + $25,000 = $31,750/episode

$TCPD_{Case\ 2}$ = $13,000 + $3,750 + $2,650 + $31,750 = $51,150/episode

Case 3 – Industrial processing plant

Problem description – This industrial plant (plastics, chemicals, textiles, etc.) experiences tripping of motor-contactors because of utility distribution system faults over a wide area. They are exposed to about 10 to 20 events per year ranging from a few cycles to 10 seconds. Each event costs about one hour of lost production by idling 350 employees, creating scrap materials, and the subsequent restarting costs. There are 175 motor-contactors ranging from 1 horsepower to 250 horsepower. Up to 30 of the contactors malfunction anytime their electric service voltage drops to 88% of normal. All the motor-driven systems need to operate together to produce products from this plant. Process equipment "drop-outs" affect many plastic material temperature controller systems during each disruption. This situation results in 20 reels of out-of-specification plastic product and the need for extensive clean-up with chemical agents. Hidden costs of each disruption are estimated at $725 per reel.

$TCPD_{Case\ 3}$ = Ⓐ + Ⓑ + Ⓒ + Ⓓ

Ⓐ = (350 employees) x (1 hour) x [($12/hour) + ($4/hour)] = $5,600/episode

Ⓑ = (125 reels plastic sheet) x ($175/reel) = $21,875/episode

Ⓒ = (1 hour/restart) x (10 employees) x ($16/hour) + (2 damaged contactors & 1 damaged motor) x ($750/repair) = $3,850/episode

Ⓓ = (20 out-of-spec reels) x ($725/reel) = $14,500/episode

$TCPD_{Case\ 3}$ = $5,600 + $21,875 + $3,850 + $14,500 = $45,825/episode

At times a simple PQ cost analysis might only include TCPD elements A, B, and C, but a more complete PQ cost analysis should include D, hidden costs. Hidden PQ costs may not be associated with interruption of service or observable disturbances, but can result in increased costs by one or more of the following:

- increased equipment losses
- reduced product quality
- increased maintenance costs

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