THE ECONOMICS OF POWER QUALITY – A SYSTEMATIC FRAMEWORK FOR THE ASSESSMENT

José Luis Gutiérrez Iglesias
UNESA – Spain
gutierreziglesias@unesa.es

The Members of JWG C4.107[1]

Alex McEachern
Power Standards Lab – USA
Alex@PowerStandards.com

ABSTRACT

Although power quality is widely recognized as an important issue, there is still no consensus on its total economic impact. Indeed, there is not even consensus on how to measure this impact.

A Joint Working Group, JWG C4.107, has been formed between CIGRE (electric power transmission emphasis) and CIRED (electric power distribution emphasis) to develop a systematic approach to this issue.

The Joint Working Group plans to develop a framework for analysis of the economics of power quality, and plans to create a bibliography of existing references. However, gathering specific values and data to assess the economics of power quality is beyond the Scope of the Joint Working Group; the work will be limited to developing a framework.

INTRODUCTION

In the area of power quality, it is sometimes easy to reach a technically correct solution, and convert it into a standard, only to find out later on that the standard has unexpected and unfortunate economic effects for society as a whole.

At present, there is increasing activity world-wide from industrial associations, e.g. SEMI[1], and from electric regulatory bodies and their advisors, e.g. a new PQ regulatory paper[2] being submitted by the European Regulators' Group for Electricity and Gas for public comments, as well as from standards setting organizations such as IEC and IEEE regarding power quality regulation and solutions. These activities include setting standards on equipment immunity to power quality events[3][4], revising technical standards such as EN 50160[5], and standardizing power quality measurements[6].

All of these activities have both intentional and inadvertent economic consequences. Each activity may increase or decrease the costs associated with power quality (or may increase some costs and decrease other costs), or the activity may shift costs from one party to another, either intentionally or inadvertently.

Academic researchers are beginning to assess economic costs and benefits related to the new technical requirements, but there is not a single repository for their results.

In order to arrange a bibliography, and to assess and realign multiple approaches at the worldwide level, a new CIGRE-CIRED **JWG C4.107: ECONOMIC FRAMEWORK FOR POWER QUALITY** began work in 2006.

JWG C4.107 aims to produce a guide that summarizes available information about cost-benefit analysis of power quality, and to propose a framework how to assess costs, how to assess the economic impact of mitigation, and how to assess the economic impact of immunity.

SCOPE

The scope of the JWG is:

- Review and document methods of assessing these costs that have been used to date, including such aspects as:
  - Direct and indirect costs to customers (e.g. production losses and plant damage)
  - Energy losses associated with poor power quality
  - Cost of energy not supplied
  - Methods of collecting customer costs

---

[1] When this paper was prepared, the membership of JWG was: Convenor : *Jose-Luis GUTIERREZ IGLESIAS.* Members : *Detmar ARLT, Gerhard BARTAK, David CHAPMAN, Alice DELAHUNTY, Philippe EYROLLES, Zbigniew HANZELKA, Bill HOWE, Alex McEACHERN, Rafaël JAHN, José Júlio LEITAO, Jovica V. MILANOVIC, Matt O'KANE, Angela RUSSO, Roman TARGOSZ, Mario TREMBLAY, Jasper VAN CASTEREN, Mathieu VAN DEN BERGH, Raghavan VENKATESH, Paola VERDE.* By correspondence : *Math BOLLEN, Mats HAGER, Robert KOCH, Patxi PAZOS, Gregorio VARGAS*

  - Actual customer costs collected to date for various industry sectors
- Propose a standardized method of collecting the above information, based on the experience of various international studies.
- Recommend a methodology of using this data to cost and motivate power quality interventions on the power system or within the customer plant.
- Provide indicative costs for specific industry sectors, where possible.

We hope that this paper will provoke vigorous discussion during Session 2 of CIRED, and we look forward to constructive guidance and comments.

BASIC CONSIDERATIONS

Assessing the financial trade-offs associated with power quality disturbances is difficult.

The following example illustrates some of the complexities.

Consider the financial aspects of the most common power quality event, a voltage dip. First, of course, there is the cost associated with the consequences of the dip. For many years, researchers have proposed methods to obtain network-level losses due to dips; other researchers have focussed on customer plant-level losses; and still others have focussed on equipment failures and recovery costs. Second, there is the cost associated with various possible mitigation approaches, which can range from rearranging distribution networks, to increased tree trimming, to installing voltage regulating transformers. Third, there is the cost associated with increasing equipment immunity to voltage dips, which includes everything from engineering costs to testing costs to manufacturing costs. All three of these costs interact. It is quite possible to trade off an increase in one of these costs for a decrease in another: for example, increasing equipment immunity may reduce the necessary cost for mitigation; or if it is determined that the original cost of a voltage dip is small, it may not be necessary to invest in the cost of mitigation.

Before analysis of the tradeoffs between various costs and solutions can be considered, all of the costs must be accurately known.

There are different types of PQ problems, each with different causes and effects and solutions and, thus, different cost implications to be considered.

To initiate a study of this nature, we need knowledge of the type of PQ problem, its origin, what losses might result from it, and the costs associated with various types of mitigation and immunity activities. In some ways, this can be re-stated as a question: how much money should be invested to prevent the PQ problem, or to make it have no effect?

This question leads to a different, difficult, and, in fact, unavoidable question: which involved party should be responsible for paying which costs?

A disturbance may be created on the public power network, or transmitted from one user to another on the public power network, or it may be created inside customer premises. Each of these different cases may lead to different conclusions about appropriate cost sharing.

The cost of disturbances must not be confused with the cost of the subset of disturbances created or transmitted on the public power network. In general, the costs of an individual disturbance are only incurred when the disturbance actually arrives at the equipment terminal. In other words, if a disturbance does not affect a piece of equipment, it has no cost.

The cost of mitigation should be thought about carefully – it may not be the best, or most effective, approach. For example, according to practical experience of the semiconductor manufacturing industry, the most expensive solution is to insert disturbance mitigation devices (filter, UPS, etc.) in front of equipment. In contrast, the least expensive solutions is to adjust the design of the equipment, so that it can tolerate disturbances. Typically these adjustments consist of very small component changes, plus some engineering and testing. In other words, voltage quality is a compatibility problem - we can either make the voltage quality better, or we can make the loads tough enough to tolerate "normal" events. The latter is much cheaper, and is the approach encouraged by IEC series 61000-4-X standards.

LOOKING AT AN OPTIMUM COST-BENEFIT ANALYSIS

The process of evaluating PQ costs requires the establishment of a methodology based on the fundamental premise of implementing a suitable **cost-benefit analysis**.

It is generally found that accurate PQ cost assessment involves careful consideration of three major factors: disturbance profile at the busbars involved, customer load susceptibility, and calculation of the losses induced by damage or malfunction of equipment, or process interruption.

The aggregation of the costs of voltage quality disturbances is a complicated issue as well. A disturbance event may affect one piece of equipment, but the consequences may be much wider, because other equipment may turn off. Should the costs caused by the other equipment be included in the cost of the event? The same problem applies to complete factories: if one factory shuts down due to a voltage dip, and its lack of output causes another factory to delay its production, should the cost in the second factory be considered? Another way to ask the same question: do we want to measure only the direct cost of a voltage dip, or do we want to measure the total cost to society? This is an important question, because it determines how much society should spend on making equipment tougher.

From the electric utilities' point of view, reducing the number of voltage dips and short interruptions would improve customer satisfaction. In today's competitive electrical market, the standard of power quality has to be constantly upgraded to ensure business survival. The question is: how do we justify for the investments to improve power quality?

Obviously, precise information regarding the financial losses incurred by disturbance events is essential to both customer and the utility. This information provides the basis for cost-benefit analysis for all potential investments. Actual financial losses are customer specific and depend on many factors including customer category (industrial, commercial etc.), type and nature of activities interrupted and customer size. Moreover, financial losses are also event specific, where different severity of voltage dips could incur very different losses to customers.

PQ COST EVALUATION METHODOLOGY

For the purposes of cost evaluation, JWG C4.107 proposes to separate power quality[2] into two broad classes: quasi-continuous variations, and discrete events.

Quasi-continuous variations are slowly changing power quality situations, such as supply voltage variations, flicker, voltage unbalance, and harmonic and interharmonic voltages.

Discrete events are sudden, abrupt power quality events, such as supply voltage dips, swells, interruptions, and transient overvoltages.

To extract data about power quality costs, JWG C4.107 will consider two economic analysis methods.

The **Direct economic analysis method**. considers the probability of event occurring, characteristics of events, probability of equipment response to those characteristics, cost of equipment response, cost of immunity or mitigation, indirect costs subsequent to event, economic analysis of heat losses, reduced lifetime of equipment, incorrect protection operation, etc. This data leads to a very precise answer about the costs of a power quality event, but correct input values (or even correct ranges of input values) are difficult or impossible to obtain. So we also consider the second economic analysis method.

The **Indirect economic analysis method** considers such economic measures as: How much is a customer willing to pay to avoid this event? How much did historical events cost? What is the total market size for existing solutions for this problem? Etc. This data provides less precise measurements of costs, but it is generally easier to obtain correct values, or correct ranges of values.

Both methods can be applied to both types of events.

The JWG intends to consider frameworks both for evaluating PQ economic costs incurred by the electricity supplier (with the assumption that the end-user characteristics are fixed), and the PQ economic costs incurred by the end-users (assuming that the electricity supplier characteristics are fixed). We recognize that changes by either group can affect the other group's costs.

INITIAL IDEAS ABOUT THE PROPOSED GUIDE

The principal purpose of JWG C4.107 is to produce a guide that provides a general overview of established and new methodologies used to assess the financial losses incurred by consumers (including industry) by power quality disturbances, in particular voltage dips, short interruptions and harmonics.

The first part of the guide focuses on quantifying the economic damage suffered by industrial customers due to nuisance process trips induced by voltage dips and short interruptions. For this purpose, guidelines provided by IEEE Standard are discussed and critically assessed to reveal their major strengths and weaknesses. Also, representative studies conducted in Europe, US and Asia[7] are investigated, with their findings and reported losses presented, to demonstrate the scale of the losses. Finally, methodologies recently proposed by researchers for financial loss assessment of voltage dips and short interruptions are gathered and discussed[8].

The second part of the guide focuses on quantifying the economic effects of the harmonics on all equipment and components. The effects of voltage and current distortion on any equipment or component fall in three classes: additional energy losses, premature aging, and misoperation.

Different methods may be used for the assessment of financial consequences of harmonics[9].

Deterministic methods are adequate when all the items of the analysis, from the operating conditions of the system to

---

[2] Long interruptions will not be considered as part of the scope of this JWG, as this has been extensively addressed by the previous CIGRÉ study committee 38 – (published as TB191) in 2001.

the discount rate value, are known without uncertainty.

Probabilistic methods are instead needed when some of the problem variables are affected by uncertainties. This clearly happens for proposed or theoretical systems, or also for existing systems where some expansions have to be planned. However, engineers are often involved in estimating costs of future operation of existing systems when both cash flows and operating conditions of the system vary over a given range, and thus introduce a degree of uncertainty.

OTHER WORK IN JWG C4.107

The work on creating a comprehensive bibliography on topics of power quality economics has begun. The first draft of the section of essential concepts and terminology has been written, and is currently under review.

A web-based bibliography on the topic of power quality economics is being created for the use of the JWG. This on-line bibliography can be searched by the members of the JWG using a variety of methods, including keywords, the type of PQ disturbances, etc.

The term "power quality" instead “voltage quality” was accepted, because it conveys the concept that voltage disturbances are, in fact, a result of interactions between customer-caused and nature-caused disturbances in current.

CONCLUSIONS

The aim of JWG C4.107 is to establish an appropriate framework of methodologies that will assist engineers and economists of all parties involved in PQ problems in finding the best trade-offs and solutions.

The Joint Working Group has concluded that the economic impact of power quality events, such as dips and transients, must be considered in a different way from the economic impact of quasi-continuous power quality situations, such as harmonics, flicker, and unbalance.

Two distinct methods of measuring the economic impact of power quality have been identified. First, there are analytic methods, which consider the probabilities and impacts of events and situations. Second, there are indirect methods, which rely on the marketplace to indicate and aggregate the economic impacts.

The Group recognizes the difficulty of the task set before us.

Precise data are unavailable in many cases; the existing analysis methods are either not uniform or lack clarity; and there is a controversy about how to share the costs.

However, we also recognize that practical decisions are being made, world-wide, every day, regarding investments and costs of power quality, and development of regulations and standards is continuous. So, we are optimistic that the Group can contribute to improved decision making in this area, by providing a concise summary of existing knowledge in a single guide and proposing a common framework and methodology for dealing with this important issue.

REFERENCES

[1] SEMI F47-0706, “Specification for Semiconductor Processing Equipment - Voltage Sag Immunity”. Semiconductor Equipment and Materials International, 3081 Zanker Road, San Jose, California 95134 United States. July 2006.

[2] European Regulators Group for Electricity and Gas, “Towards Voltage Quality Regulation in Europe”, Document E06-EQS-09-03. December 2006.

[3] IEC 61000-4-34, Ed 1, “Testing and measurement techniques – Voltage dips, short interruptions, and voltage variation immunity tests for equipment with input current more than 16 A per phase”, International Electrotechnical Commission. October 2005.

[4] IEC 61000-4-11, Ed 2, “Testing and measurement techniques – Voltage dips, short interruptions, and voltage variation immunity tests”, International Electrotechnical Commission. March 2004.

[5] EN50160:2000, “Voltage Characteristics of Electricity Supplied by Public Distribution Systems”, European Norms available from various European national Standards Bodies.

[6] IEC 61000-4-30, Ed 1, “Testing and measurement techniques – Power Quality Measurement Methods”. International Electrotechnical Commission. February 2003.

[7] IEEE Recommended Practice for Evaluating Electric Power System Compatibility With Electronic Process Equipment, IEEE Standard 1346, 1998.

[8] J. V. Milanovic and C. P. Gupta, "Probabilistic assessment of financial losses due to interruptions and voltage sags – “IEEE Transactions on Power Delivery, vol. 21, 2006” - Part I: The methodology," pp. 918-924. "Probabilistic assessment of financial losses due to interruptions and voltage sags - Part II: Practical implementation, pp. 925-932.

[9] Verde Paola, Carpinelli Guido, F. Gagliardi, Probabilistic Modelings for Harmonic Penetration Studies in Power Systems., 5th IEEE International Conference on "Harmonics in Power Systems, Atlanta (USA), Settembre 1992, pp. 35-40.