# A GUIDE FOR THE MANAGEMENT OF THE ECONOMICS OF POWER QUALITY

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## *ABSTRACT*

*Utilities are generally regulated monopolies, funded by customers and charged with producing a product to a standard set by the regulator.*
*In this paper, an approach for the analysis of the economics of power quality is developed. The approach has focused on three issues:*

- *To produce a guide for how to assess costs, how to assess the economic impact of mitigation and the economic impact of immunity.*
- *To set a standardized definition of worst served customers. Indicators that give information on a certain group of worst served customers are introduced*
- *To build up a quality function to assess the company's way of running its operation. The quality function is evaluated on the basis of interruption statistics and outage cost. It takes into account both redundancy adjustment and the valued quality.*

## INTRODUCTION

Power quality is now considered as a characteristic of electrical supply which should be more closely defined and regulated. However there is a trade off between the benefits from improved power quality and the costs for achieving it, with the cost benefit analysis required quite difficult to formulate.
In many cases it is the cost of consequences of poor power quality which are set against the cost of improving the network, whereas the correct approach is to compare the costs of options to mitigate the consequences against the cost of accepting the consequence.
Power quality covers a range of characteristics of the electrical energy supplied to customers through the utility network. Certain aspects of power quality may have a deleterious impact on equipment or processes resulting in economic loss to the customer.
These power quality features can be mitigated either by the utility or by the customer. If mitigated by the utility the extra costs are "socialised" in that the extra network costs will be collected from all utility customers through increased tariffs. Conversely, if mitigated by the customer a different set of costs will be incurred but these will be borne solely by the customer concerned.
From the societies point of view the optimum decision is one where the mitigation measures required produce the most economically advantageous solution for society as a whole.
In some situations economics of scale by the utility would indicate that the utility can meet the customers power quality requirements most effectively. In other situations the power quality aspect causing problems might be particular to one part of a particular customers process, and would best be mitigated by local measures by the customer.
At present, there is increasing activity world-wide from industrial associations, and from electric regulatory bodies and their advisors, as well as from standards setting organizations. These activities include setting standards on equipment immunity to power quality events, revising technical standards, and standardizing power quality measurements.
All of these activities have both intentional and inadvertent economic consequences. Each activity may increase or decrease the costs associated with power quality, or the activity may shift costs from one party to another, either intentionally or inadvertently.

## POWER QUALITY COST EVALUATION

In order to arrange a bibliography, and to assess and realign multiple approaches, a guide was produced that summarizes available information about cost-benefit analysis of power quality, and to propose a framework for how to assess costs, how to assess the economic impact of mitigation, and how to assess the economic impact of immunity.

### Scope and Analysis

The scope of the work is:

- Review and document methods of assessing these costs including: direct and indirect costs to customers, energy losses associated with poor power quality, methods of collecting customer costs and energy not supplied.
- Propose a standardized method of collecting the above information.
- Recommend a methodology of using this data to cost and motivate power quality interventions on power system or within the customer plant.

Before analysis of trade offs between various costs and solution can be considered, all of the costs must be accurately known.
There are different types of power quality problems, each with different cause and effects and solutions, thus, different cost implications are to be considered.
Knowledge of type of power quality problem, its origin, what losses might result from it, and the costs associated with various types of mitigation and immunity activities are needed.

## Evaluation methodology

For the purpose of cost evaluation, we propose to separate power quality into two broad classes:

- Quasi-continuous events, which are slowly changing power quality situations, such as supply voltage variations, flicker, unbalance and harmonic
- Discrete events, which are sudden, abrupt power quality events, such as voltage dips, swells, interruptions and transient over voltages.

To extract data about PQ costs we considered two economic analysis methods:

- The direct method, which considers the probability of event occurring, characteristic of events, probability of equipment response to those characteristics, cost of immunity or mitigation.
- The indirect method, which considers some economic measures such 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 solution for this problem.

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, representative studies conducted in US, Europe and Asia are investigated, methodologies recently proposed by researchers for financial loss assessment of voltage dips and short interruptions are gathered and discussed.
The second part of the guide focuses on quantifying the economic effects of the harmonics on all equipment and components. Different methods may be used for the assessment of financial consequences of harmonics.
Deterministic methods are adequate when all the items of the analysis are known. Probabilistic methods are instead needed when some of the problem variables are affected by uncertainties.

# DEFINITION OF WORST SERVED CUSTOMERS

There are several but different methods for determining worst served customers. The majority of customers are well served; i.e. they have no or little problems with supply. Indices of service quality are invaluable in measuring system performance of supply quality. The average number and duration of interruptions per customer do not tell us anything about the customers who suffered the most outages, the bad quality of voltage, etc. Greater emphasis needs to be placed on the issues faced by worst served consumers.

## Quality of service

There have been many different approaches to classifying the quantitative aspects of electricity supply.
Quality of service can be divided in: commercial quality and power quality.
Power quality can be divided into: continuity of supply and voltage quality.

### Commercial quality

Commercial quality deals with quality of the relationship from the non- technical point of view before the beginning or during the supply.
Commercial quality covers many aspects of the relationship, although not all of services can be measured and regulated through standards or other instruments.
The most frequently used areas of commercial quality are: connection of the customers, customer care, technical service (e.g. solving problems related with voltage or meter) and meter reading and billing.

### Continuity of supply

The majority of indices in use provide a measure for the average number and duration of interruptions that took place or for the average time during which the supply was not available.
From the customer point of view, the disadvantage of system indices is that they only provide information for the average customer, not for any individual customer.
An individual customer is in principle only interested in the interruptions that impact its point of connection. Customer experiences don't necessarily correlate to system indices, and averages can hide a multitude of sins.

### Voltage quality

Voltage quality can simply be described by deviations from normal values for the voltage frequency, voltage magnitude and by the distortion of the voltage wave shape. From the customer's point of view, the main characteristics of the voltage have been becoming an important issue due to the increase in the sensitivity of end user equipment over the past thirty years.

## Approaches to define the worst served customer

### Standardized definition

The IEEE standard contains two indicators which can give information on worst served customers:

- Customers Experiencing Multiple Interruptions (CEMIn).
  This index indicates the ratio of individual customers experiencing more than a certain number (n) of interruptions to the total number of consumers served during a given period.
- Customers Experiencing Multiple Sustained Interruption and Momentary Interruption Events (CEMSMIn)
  This index is the ratio of individual customers

experiencing more than a certain number (n) of both sustained and momentary interruptions events to the total number of consumers served during a given period.

**Individual Customer Standards**

Single customer continuity standards are generally expressed as the maximum yearly number of interruptions and/or a maximum yearly duration of interruptions, but can also concern other continuity indicators. Single customer continuity standards are thresholds applied to continuity indicators that have to be respected for every single customer connected to the network.
In Alexandria the percentage of consumers without electricity is monitored and illustrated in Fig.1

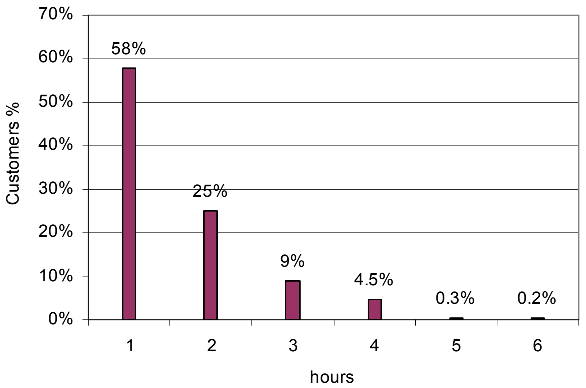


Fig.1. Percentage of consumers without electricity in Alexandria in 2010

**Definition related to voltage quality**

In some countries penalties are foreseen in case the voltage limit standards are not met. In others still, the distribution company must take appropriate steps to rectify the causes of inadequate voltage quality within a given time.

## QUALITY FUNCTION

A quality addition is made to the network performance, which relates to an assessment of the company's way of running its operations. In the introductory stage, only power cuts will be handled in the quality function. In the longer term, other parts of delivery quality may be added to the assessment. The quality addition is calculated on the basis of the interruption statistics and outage cost.
A ratio- the debiting ratio-defined as the company's revenue divided by the sum of network performance and quality addition is calculated.
Debiting ratio= Revenue/(Network performance + Quality addition)
The quality function is used for valuing how the network company pursues its operations.
The quality function consists of:

- A positive contribution (addition) from the Redundancy Adjustment.
- A negative contribution (deduction) in the form of the valued quality.

Valued Quality= Quality achieved- Expected quality.

### Redundancy adjustment

System design and component reliability are two critical factors to consider in determining the right level of redundancy for a system.
Premium power system design can be categorized into three general levels of redundancy:

- System-plus-system redundancy.
- Component level redundancy
- Single point of failure.

System-plus-system redundancy means that the power system is designed with two identical, completely redundant systems. Component level redundancy means that each critical component of the system is designed with an additional, like-kind, component to carry the load if one of the components fails. Single point of failure means that some portions of the system may be hardened against failure, however, when taken as a whole, the system is susceptible to failure if only one component fails.
The redundancy adjustments specify the magnitude of additions in percent to the system components, e.g. the conductor lengths or transformers that are made at each network level. In simple terms, they describe the percentage addition to the new procurement value for each network level.
The sum of interruption costs for every node in the network is calculated. This interruption cost is compared with the cost of providing a reserve conductor or a reserve transformer for each node. If the cost of the reserve component is lower than the total interruption cost of the node, the reserve is established in the network, it is then assumed that the total interruption cost at this particular node will cease.

### Quality achieved

The reported interruption values measured in SAIFI and SAIDI, which are the System Average Interruption Frequency Index and the System Average Interruption Duration Index, serve as the basis for the calculation of the quality achieved. The calculation is carried out separately for scheduled and unscheduled interruptions in accordance with the following formula:

Quality achieved (LE)=F * P(kW) * (A+time/60*B)

Where:
F : is the interruption frequency
P(kW) : is the mean power= Energy(kWh)/number of customers/8760

Time : is the mean interruption time in minutes
A : is the interruption valuation for the interruptions occurring in LE/kW
B : is the interruption valuation for switched-out energy in LE/kWh

A report of delivery quality measured in SAIFI and SAIDI in Alexandria Electricity Distribution Company (AEDC) over a period of five years (2006-2010) is shown in Fig.2, Fig.3.

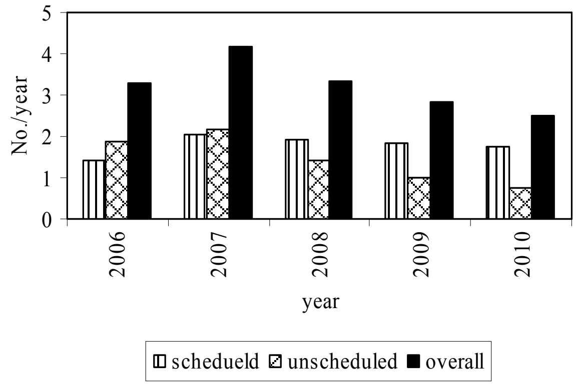


Fig.2. System Average Interruption Frequency Index (SAIFI)

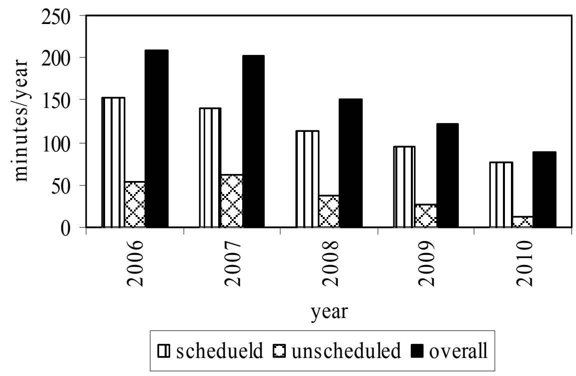


Fig.3. System Average Interruption Duration Index (SAIDI)

## Expected Quality

For a redundancy – adjusted network, the number of interruptions and their durations an average customer will experience, measured in LE/ kWh average costs are evaluated. The result is known as the expected quality.

## CONCLUSIONS

The aim of this research is to establish an appropriate guide that will assist engineers and economists of all parties involved in power quality problems in finding the best trade offs and solutions.

The process of evaluating power quality 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 power quality cost assessment involves careful consideration of three major factors: disturbance profile, customer load susceptibility, and calculation of losses induced by damage or malfunction of equipment, or process interruption.

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

There is no standardized definition of worst served customers. Worst served customers could suffer from not only continuity, but commercial and voltage quality, too. Therefore the definition of worst served customers should cover: commercial quality target for the most important services and voltage minimal requirements. The number of customers receiving services below the worst served level thresholds ought to be published in the performance reports.

The Guide also described how the quality function is built up. The quality function is the method that is used for valuing how the network company pursues its operation. The quality function is added to the sum of all the costs of network performance, and is evaluated on the basis of the interruption statistics and outage cost. It takes into account both the redundancy adjustment and the valued quality.

However, we recognize that practical decisions are being made, world-wide, every day, regarding investments and costs of power quality. So we hope the guide can contribute to improved decision making in this area.

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