European Power Quality Survey Report

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1. Foreword and Executive Summary

Since the end of the 1990s the European Copper Institute [ECI] has been concerned about the impact experienced by commerce and industry of the changing nature of the energy demands organisations face as a result of equipment technological advances, the increasing need to build in resilience into their electrical power installations and the presumed mounting costs of not taking either adequate preventative or reactive action to accommodate the changes.

After some preliminary small scale studies into the impact of poor power quality on such organisations and as the empirical but anecdotal evidence mounted being discussed at length among the growing membership of the Leonardo Power Quality Initiative [LPQI*], so ECI decided to mount an extensive research project into what the impacts were on key energy using industrial sectors of their not coping with poor power quality.

The project itself took over two years to complete and its results have been exposed in 2007 to a broad technical academic community with a view to securing their support and agreement for this work, the findings of which, whilst not surprising to us, make very negative reading in terms of the avoidable wastage and economic losses incurred by these industrial sectors at a time when energy and resource efficiency are the demands of today. Apply this to more commercial interpretation and it is clear that the EU’s competitive position is also unnecessarily undermined as a result of this wastage.

This report presents the European PQ Survey – it is clear that the industrial sectors interviewed annually lose upwards of €150 billion as a direct result of their electrical power installations not being sufficiently reliable and resilient for today’s and future operating demands.

The causes of these losses are not new nor are the Power Quality [PQ] phenomena involved. What was both surprising as well as concerning was and we suspect is still the relative lack of analysis and measurement that take place among these power critical industries to be able to know what is causing these damaging interruptions to their operations.

2. Introduction

In 2005 to 2006 the Leonardo Power Quality Initiative team conducted a European PQ Survey. The study comprised 62 face-to-face surveys carried out in 8 European countries. This allowed for an extrapolation of the overall wastage caused by poor PQ in EU-25 and for the analysis of many associated issues such as user perceptions of PQ problems, the causes of PQ problems, the equipment mainly affected and any PQ solutions that were available and adopted. Additionally PQ metering and where the sources of poor PQ lie were also investigated.

A small scale respondent self-completion web based survey was also carried out.

The aim was to investigate industrial sectors that accounted for the lion’s share of non-residential energy use and a significant share of EU 25 turnover. This resulted in respondents from 16 industrial sectors being interviewed, who were technically oriented with the added definition of being senior and experienced enough to be able to answer detailed and sometimes commercially sensitive questions.

* LPQI was an EC supported 3-year programme that set up a unique virtual Application Guide of papers addressing Power Quality phenomena www.lpqi.org
The questionnaire comprised two unequal halves. The first 5 Parts were straightforward data gathering relating to PQ problems experienced, mitigation solutions respondents were aware of and they had installed, perceived sources of PQ issues, measurement undertaken and relations with the supplying electrical utility. The 6th Part investigated real or hypothetical PQ Phenomena Cases to understand what consequences each would have on that particular organisation.

Initially interviewing was carried out by the project team. A network of academic centres and PQ specialists was then recruited to expand the interviewing capacity and carry out the remainder of the field work. Each group was individually briefed to ensure coherence of technique and responses. The questionnaire was translated into 7 languages. The survey form is available on:

http://www.leonardo-energy.org/drupal/node/3758

All raw data generated was scrutinised centrally and any additional information needed were secured by follow up questioning.

Based on the evidence received the project management then analysed the data in two ways – statistically cross referencing the Parts 1-5 information and then calculating what the real or hypothetical economic impact was in each of the cases studied. These calculations investigated *prima facie* losses as well as other wastage that occurred but was surprisingly absent from any existing productivity or corporate financial analysis.

The project has been managed in equal parts from Poland and from London.

3. Survey sample

The survey interviews and web based submission were conducted over a 2-year period in 8 European countries. In all, 62 complete and 6 partial (i.e. excluding Part 6) interviews were carried out. The Table 1 presents the numbers of surveys across 16 specified sectors.

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<thead>
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<td>3</td>
</tr>
<tr>
<td>Continuous manufacturing excluding pulp and paper, publishing separately</td>
<td>6</td>
</tr>
<tr>
<td>Food and beverage</td>
<td>4</td>
</tr>
<tr>
<td>Hospitals</td>
<td>6</td>
</tr>
<tr>
<td>Hotels</td>
<td>1</td>
</tr>
<tr>
<td>Manufacturing (general; machinery, automotive parts, etc.)</td>
<td>5</td>
</tr>
<tr>
<td>Metallurgy</td>
<td>6</td>
</tr>
<tr>
<td>Newspaper publishing</td>
<td>2</td>
</tr>
<tr>
<td>Oil / Chemical</td>
<td>7</td>
</tr>
<tr>
<td>Pulp and paper</td>
<td>6</td>
</tr>
<tr>
<td>Pharmaceutical</td>
<td>4</td>
</tr>
<tr>
<td>R&amp;D, designing services</td>
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</tr>
<tr>
<td>Retail</td>
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</tr>
<tr>
<td>Semiconductor</td>
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</tr>
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<td>Telecommunication</td>
<td>4</td>
</tr>
<tr>
<td>Transport</td>
<td>5</td>
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</table>
These sectors represent some 38% (€6.843bn) of the EU-25 total of €17.956bn turnover and 1.862 TWh or 70% of the Region’s 2.650 TWh of final electricity consumption.

The Table 2 presents numbers of surveys per country. The partial data responses were received from Poland [4] and 1 each from UK and Slovenia

**Table 2: LPQI study – number of surveys per country**

<table>
<thead>
<tr>
<th>Country</th>
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<tr>
<td>France</td>
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</tr>
<tr>
<td>Italy</td>
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<tr>
<td>Poland</td>
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<td>Portugal</td>
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<td>Slovenia</td>
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<td>Spain</td>
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<td>United Kingdom</td>
<td>5</td>
</tr>
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</table>

**4. Exploring Power Quality cost – methodology of data collection**

The main purpose of this project was to estimate costs of wastage generated by inadequate power quality for those sectors within the EU-25 for which electrical power is critical. Previously, well-known international studies have only addressed some aspects of this issue. For example, the CIGRE report covers costs caused by interruptions in 5 of the now EU27 countries.

PQ costs in this survey have been reported in the following categories:
- Voltage dips and swells
- Short interruptions
- Long interruptions
- Harmonics
- Surges and transients
- Flicker, unbalance, earthing and EMC problems

The harmonics category was further subdivided to focus on particular impacts that were treated as separate cases, defined as follows:
- Overstressing insulation, effects on electrical equipment including transformers, capacitors, motors; the consequences of not measuring TRMS (True Root Mean Square); additional losses.
- Overheating of the neutral conductor (e.g. burn off and subsequent disruption or damage of electrical equipment).
- Nuisance tripping of protective devices
- Malfunction of equipment control systems due to additional zero crossing

To calculate the total cost of each PQ disturbance the following PQ cost categories were analysed for each disturbance category.
**Staff cost**

Personnel rendered unproductive through disrupted work-flow / process. This cost was calculated either by:
- multiplying total number of the man-hours of staff who were unable to work and average man-hour rate of staff who were unable to work
or
- or by estimating the percentage of the plant activity (in terms of added value) which was stopped and multiplied by the idle time of such stoppage. This value was then compared to the total production time of the plant.

**Work in progress**

This category includes:
- Costs of raw materials involved in the production or services which was irrevocably lost
- Labour involved the production or services which was irrevocably lost
- Labour needed to make up for lost production, sales, or services (such as overtime pay, extra shifts, etc.)

**Equipment malfunctioning**

The consequence of the equipment being affected was defined as slowing down of company activity or as production running out of specification. In this case both the percentage of such slow down was calculated, taking into account additional “idle” time, the value of products running out of specification and / or the value of insufficient quality of products.

**Equipment damage.**

The consequence of the operating equipment being affected was defined as experiencing damage to it, the shortening of its lifetime, premature components wear out and the need for additional maintenance or repair. The cost components included:

- Cost of equipment being damaged (completely and scrapped) or cost of its repair. This category typically included transformers, capacitors, motors, cables, contactors, relays, protective equipment, electronic equipment and lighting bulbs.
- Cost to run and/or rent backup equipment if necessary.
- Additional maintenance costs because of excessive equipment component wear out. Usually these included bearings, if a machine was unbalanced due to distorted power, insulating, disconnecting any protective / signalling components and resets or reinstallation.

**Other costs**

This category usually included:

- Penalties due to contract non-delivery or late delivery
- Environmental fines / penalties
- Cost of evacuation of personnel and equipment (this also could include ensuring the safety of external communities)
- Costs of personnel injury (including the on-costs incurred through inability to work)
- Increased insurance rates (equipment, personnel, corporate liability)
- Compensation paid out
Specific costs

For some disturbances some specific cost categories were distinguished:

- Harmonics - electricity bill. By operating electrical equipment in a non-linear environment, additional eddy currents, heat dissipation and consequent energy losses may be experienced. It was however not easy to measure them as a full harmonic spectrum would have been needed. As an indication, a typical, large office environment generates ~50% extra losses in transformers. Other possible problems which may arise from harmonic pollution refer to the correct measurement of electrical energy consumption and problems related to the utility imposing penalties for harmonic pollution of the surrounding distribution network.

- Flicker can cause migraine and can be responsible for so called “sick building syndrome” which reduces personnel productivity. The impact of Flicker was defined for example as a comparison of staff error rates between flicker-free and flicker environments.

Savings

To make the total calculation fair and complete, “savings” resulting from PQ disturbances were calculated. These usually included:

- Savings from unused materials or inventory
- Savings from wages that were not paid
- Savings on your energy bill

These savings were deducted from the gross PQ cost. The final result represents the total cost of PQ for the plant in question.

5. Methodology of analysis

All these cost were specified on an annual basis, either reported as such or pro-rated where frequency was less than once pa.

Apart from specifying real PQ cost of wastage, respondents also defined those hypothetical costs that would be the potential losses and risk avoided by power systems that had been immunized against the PQ disturbances under review.

Based on 11 individual cases per complete interview the subsequent regression analysis was performed to estimate PQ cost across those sectors that offered a convergence of 4 specific indices. These indices initially were: employment, energy consumption, contractual power, annual turnover.

After refining them, the study concludes that “annual turnover” was a key indicator for a regression model (see tables 3 and 4).

To arrive at a statistically significant and acceptable model the survey sample was divided into two sub-samples - “Industry” and “Services”. The Banking sector was excluded because of its anomalous size and structure.

The industry model

Analysis shows that for the “Industry” sector the estimation of how much wastage is
caused by poor PQ is 4% of annual turnover.

The services model

The model estimation of wastage caused by poor PQ is 0.1419% of annual turnover.

Statistical bias is real danger in research like this, especially in terms of how representative the study is of the target universe. This was however resolved once the random and statistically based samples were checked. The regression analysis applied to this PQ Survey project proved that the samples and models are large and good enough to conclude that the variation explained by the model is not due to chance and that the relationship between the model and the dependent variable - annual PQ costs - is very strong.

The charts in Figure 1 present the cost extrapolations of wastage caused by the range of PQ phenomena throughout the sectors investigated in EU-25: PQ cost is characterized by disturbance type (absolute value in € bln and % value of total cost) and cost components.

Figure 1: Extrapolation of PQ cost to EU economy in LPQI surveyed sectors

- Dips and short interruptions
- Long interruptions
- Harmonics
- Surges and transients
- Flicker unbalance earthing and EMC

REMARKS
Standard error of estimation:
industry +/-5% based on regression only and +/- 2.54% variance corrected services +/-12.93%, +/-11.91% respectively
Banks excluded

PQ cost in EU >150 bln €
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. That the proportion of these total PQ costs/ losses accounted for by “Services” is so relatively small is possibly explained by cost underestimations by service sector organisations that often experience PQ problems in, say, an office environment, where distinguishing between the cause of a given PQ issue and other root causes may be difficult.

Furthermore some services sectors like data centers, which probably experience high PQ costs, have no representation in the survey. Hospitals fit well into the “Services” model and demonstrate slightly higher PQ costs than other service sectors.

Dips and short interruptions account for almost 60% of the overall cost to industry and 57% for the total sample.

This extrapolation corresponds well with those levels indicated by EPRI CEIDS [3] PQ survey (2000) in the US which reports between $119-188bn as the cost of poor PQ generated wastage in the US with 4% of companies reporting annual costs of 10% or more of annual revenue and 9% reporting costs between 1 and 9,99%.

6. PQ cost in detail

As has already been mentioned, the study shows that the economic impact of inadequate PQ costs industry some 4% of turnover and “services” some 0,15%. Whilst these values are extrapolations based on the sample interviewed, even given the survey sample of 42 industrial companies and 21 services companies, it can be said with confidence that significant differences exist between the two.

Among industrial companies the highest values occur in typical continuous manufacturing industries and lower values in the metallurgical, food and beverages and general manufacturing sectors.

Within services sectors hospitals are significantly higher than other groups.

Industry v Services

The Tables 3 and 4 below present the statistics relating to different PQ cost frequencies, grouped by “industry” and “services”.

Explanation of why the most accurate model would be based on PQ cost per company turnover is found on Page 12 immediately after Table 4.
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<th></th>
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<td>Total cost per kWh long</td>
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<td>Total cost per kWh turnover</td>
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<td></td>
<td>Total cost per kWh</td>
<td>Total cost per kW peak</td>
<td>Total cost per turnover</td>
<td>Total cost per electricity bill</td>
<td>Total cost per employment</td>
<td>Cost per kWh dip and short interruption</td>
<td>Cost per kWh long interruption</td>
<td>Cost per peak kW dip or short interruption</td>
<td>Cost per peak kW long interruption</td>
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<td>167 328</td>
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<td>268</td>
<td>83 603</td>
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<td>5 872,29</td>
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The three “industry” histograms presented in Figure 2 show the distribution of frequencies for different type of PQ cost indices. They show that in case of PQ cost per turnover indicator, the frequency is closer to the normal distribution curve whilst the ratio of Mean to Standard Deviation is far lower than in case of other indices.

When comparing other statistics, especially variance, it is clear that the most accurate model would be based on PQ cost per company turnover.

When analysing other indices, it also is apparent that the more appropriate representation are values that are closer to Median rather than Mean.

Figure 2: LPQI survey. Frequency distribution of different PQ cost indices

Profiles of economic impacts by sector

The general structure of PQ cost for each sector is presented below:

Figure 3: LPQI survey, PQ cost components
It is noticeable that in typical continuous manufacturing sectors the losses incurred by lost work-in-progress (WIP) is quite significant and responsible for about one third of the PQ costs recorded.

The slowing down of processes, which sometimes integrates WIP, and labour cost where these are not visible as independent components, is understandably even more significant.

In other sectors the situation is less clear with either labour cost or equipment related costs being the most important source of economic losses.

Finally, in relation to public services like hotels and retail sector, PQ impact is measured as slowing down their business activities, in terms of revenues that are irrevocably lost.

The Figures from 4 to 8 present PQ cost structure for 5 major groups of PQ disturbances - dips, short and long interruptions, harmonics and surges and transients. The specific observations are:

- **Voltage dips** - WIP accounts for almost 50% of PQ cost and the largest single source of PQ caused economic losses, with process slow down accounting for a further 30%.

Figure 4: LPQI survey, PQ cost components per disturbance type
- **short interruptions** - the cost structure is similar but costs relating to equipment failure / premature ageing are more significant. This is in part explained by the influence of the semi-conductor sector. This sector claims to be fully immunised against dips; however evidence suggests a lack of immunity to short interruptions, in which the category of equipment related cost dominates.

*Figure 5: LPQI survey, PQ cost components per disturbance type*
- **Long interruptions** - the importance of labour costs increases, reaching some 20% on average. This is twice as great as the equivalent figure for “voltage dips” and some 40% higher than with “short interruptions”. In addition there are instances where some of the other cost categories take on greater importance and these tend to be related to the long term economic consequences created by penalties (commercial or statutory), loss of brand equity or the need for unanticipated business investment to regain lost sales / market share.

Figures 6: LPQI survey, PQ cost components per disturbance type

- **Harmonics** - process slow down generates almost two thirds of all harmonics related costs. Equipment related costs represent about 25% these harmonics costs. However, only 8 out of 62 companies specified PQ cost of harmonics that related to additional energy losses. This cost in total is 186,000 € and represents about 1% of the total cost of harmonics to the sample.

Figure 7: LPQI survey, PQ cost components per disturbance type
- **transients and surges** - production outage is again a major source of economic losses and is responsible for two thirds of total PQ costs and consequential losses. One interesting observation from one of continuous manufacturing companies – see the figure 8 was that 90% of transient/surge cost was reimbursed successfully to them, presumably by their electricity supplier.

**Figure 8: LPQI survey, PQ cost components per disturbance type**
The breakdown of costs by different PQ disturbances is presented in Figure 9.

**Figure 9: LPQI survey, PQ disturbances cost structure in the survey sample**

On average the absolute share of impacts of the 6 categories of disturbances taken from the total survey sample is as follows:

- Voltage dips 23,6%
- Short interruptions 18,8%
- Long interruptions 12,5%
- Harmonics 5,4%
- Transients and surges 29%
- Other 10,7%

Further commentary about each of these can be made:

- Voltage dips are the most important source of impacts in the continuous re most significant for food, metallurgy and newspaper publishing.
- Long interruptions are most costly for hotels and other "public services" sectors.
- Transients and surges are the most damaging for the telecommunications sector and for the pharmaceutical sector.

**Frequency of disturbances**

This section now summarises the PQ Survey results relating to the frequency of different PQ disturbances by individual industrial sector as illustrated by the bar chart in Figure 10:
These are annualised data giving the frequency of disturbances per sector. In this figure one metals company claiming short interruptions every day has been filtered to avoid distorting the overall picture.
The Survey also analysed the frequency of harmonics and flicker expressed in time percentage per year as illustrated by the chart in Figure 11 as well as the average (yearly) values of disturbance frequencies broken down by the two categories “Industry” and “Services”. See Table 5.

Table 5: LPQI survey Frequency of PQ disturbances

<table>
<thead>
<tr>
<th>Frequency of PQ disturbances</th>
<th>number of events</th>
<th>annual %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Voltage dips</td>
<td>Short interruptions</td>
</tr>
<tr>
<td>Industry</td>
<td>15.7</td>
<td>6.9</td>
</tr>
<tr>
<td>Services</td>
<td>7.7</td>
<td>5.4</td>
</tr>
<tr>
<td>Average</td>
<td>13.2</td>
<td>6.4</td>
</tr>
</tbody>
</table>

On average the MAIFI [Momentary Average Interruption Frequency Index] that has been measured by this Survey is approximately 6; this is 3 times bigger than SAIFI [System Average Interruption Frequency Index]. The number of recorded voltage dips, that is identified by the respondents, is approximately twice the number of short interruptions.

This ratio is somewhat less for the services sectors.
Cost per event of PQ disturbances

The cost per event identified by the Survey are shown in the chart in Figure 12:

Figure 12: LPQI survey, PQ cost per event for different disturbances

To avoid potential distortion, 2 out of the 62 companies surveyed (semiconductors and retail) have been filtered out.

The average values of cost per event, that is the real losses incurred by the respondents as a result of PQ disturbances, are presented in the Table 6:

Table 6: LPQI survey, PQ cost per event

<table>
<thead>
<tr>
<th>Cost per event €</th>
<th>Voltage dips</th>
<th>Short interruptions</th>
<th>Long interruptions</th>
<th>Surges and transients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>141 635</td>
<td>205 300</td>
<td>95 478</td>
<td>186 260</td>
</tr>
<tr>
<td>Services</td>
<td>22 064</td>
<td>47 762</td>
<td>272 916</td>
<td>122 602</td>
</tr>
<tr>
<td>Average</td>
<td>119 357</td>
<td>163 153</td>
<td>148 709</td>
<td>175 871</td>
</tr>
<tr>
<td>Industry*</td>
<td>4 682</td>
<td>15 484</td>
<td>95 478</td>
<td>186 260</td>
</tr>
<tr>
<td>Services*</td>
<td>2 120</td>
<td>19 447</td>
<td>80 326</td>
<td>122 602</td>
</tr>
<tr>
<td>Average*</td>
<td>4 177</td>
<td>16 539</td>
<td>91 021</td>
<td>175 871</td>
</tr>
</tbody>
</table>
Remark*: 2 out of the 62 companies surveyed (semiconductors and retail) filtered out. These results can be summarised as follows:

- The cost per voltage dip event is between 2.120 and 4.682€.
- Single short interruptions on average are 3.3 times more costly for industry and just over 9 times more costly for services.
- The average cost of long interruptions is 91.021€ and is more homogenous across the whole survey sample.

All these results are quite comparable to different studies described at the beginning of this chapter.

Assessing the generic cost per event for surges and transients is more problematic because of the lack of other research into these PQ phenomena. For this Survey it ranges from 120.000€ to 180.000€.

7. Power Quality solutions

The companies covered by the study invest yearly €297.5 million into different power quality solutions. The Figure 13 charts the proportion of load per sector covered by different types of redundant or mitigatory solutions.

The analysis of these solutions produced some interesting conclusions:

Many of the correlations between solutions (both investment and load coverage) and PQ cost, frequency of events or sensitivity to PQ problems, which were thought to have been significant, have not been proven. The Table 7 presents all significant relations, where 0.05 is used as reference threshold (the lower the value, the higher
the probability of dependence), between PQ consequences and PQ solutions, as confirmed by our survey. One further interpretation of these data is that they suggest that, be it for reasons of incorrect or lack of measurement, much of the solutions adopted have in fact been wrongly specified thus generating even further wastage. Being outside the immediate scope of this survey this whole area could be another area of investigative interest.

Table 7: LPQI survey, PQ consequence / PQ solution correlations

<table>
<thead>
<tr>
<th>PQ consequence</th>
<th>PQ solution</th>
<th>Sig value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relays and contactors nuisance tripping</td>
<td>Harmonic filter (passive)</td>
<td>0.040</td>
</tr>
<tr>
<td>Noise interference to telecommunication lines</td>
<td>Multiple independent feeder</td>
<td>0.035</td>
</tr>
<tr>
<td>Motors or process equipment are damaged</td>
<td>Shielding and grounding</td>
<td>0.046</td>
</tr>
<tr>
<td>Motors or other process equipment malfunctions</td>
<td>Back up generator</td>
<td>0.009</td>
</tr>
<tr>
<td>Loss of synchronization of processing equipment</td>
<td>Surge protection on key pieces of equipment</td>
<td>0.023</td>
</tr>
<tr>
<td>Loss of synchronization of processing equipment</td>
<td>Harmonic filter (passive)</td>
<td>0.010</td>
</tr>
<tr>
<td>Circuit breakers or RCD’s nuisance tripping</td>
<td>Line conditioner or active filter</td>
<td>0.037</td>
</tr>
<tr>
<td>Circuit breakers or RCD’s nuisance tripping</td>
<td>Back up generator</td>
<td>0.048</td>
</tr>
<tr>
<td>Capacitors bank failure</td>
<td>Shielding and grounding</td>
<td>0.007</td>
</tr>
</tbody>
</table>

* Relationship between PQ consequence and solution tested by Chi-Square test (1 sided): the lower the significance value [Sig], the less likely it is that the two variables are independent (unrelated). Usually 0.05 is used as reference threshold.

The Figure 14 shows a certain relationship (although not proven by the linear regression model; RSq Linear = 0.036) between PQ investment and the PQ Costs experienced. The slope angle suggests a positive relationship between PQ investment and PQ unmitigated costs.

Figure 14: LPQI Survey, PQ cost / PQ solution investment relation
Although there is no significant correlation between solutions and real cost, a strong correlation exists between investment in PQ solutions and the hypothetical to real cost ratio*.

This results in an indirect but clear link between solutions and (real) consequences. See Figure 15.

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**Figure 15:** LPQI Survey, Mitigated and unmitigated PQ cost per unmitigated (real) PQ cost ratio as a function of PQ solution investment

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*That is, the ratio between actual costs experienced and the costs an organisation would have experienced if they had suffered losses due to a PQ event.
The following broad conclusions can be made:

- The increase in the ratio between hypothetic and real (mitigated / unmitigated) is very visible in case of UPS.
- One side effect of UPS’ use is the increased cost of harmonics. This can be explained by suboptimal use of UPS systems that are based on diffused small units without active power wave modulation, which in turn generates significant input current distortion.
- There is a small but significant (positive) correlation between number of power lines and costs of short interruptions while such a correlation is insignificant as far as dips are concerned.

8. Perceived levels of Power Quality

The study provided a number of additional conclusions regarding the perceived levels of PQ such as the occurrence of PQ problems, their sources and the equipment affected by them.

The occurrence of different equipment being affected by PQ, is presented in Figure 16. Electronic equipment is most affected in the “industry” and “services” categories. Static converters and electric motors are the next most affected. All other equipment types are more evenly affected in the “services” category.

Figure 16: LPQI Survey, Occurrence of equipment being PQ affected in annual %

Below are some additional findings from the survey.

- The perceived level of presence of different PQ disturbances for all sectors is presented in Figure 17 and varies quite noticeably.
- The semiconductor respondents did not specify experiencing long interruptions, whilst they did record very intensive occurrence of voltage dips and short interruptions.
- For all sectors, on average, the presence of short interruptions is perceived as being the most intensive and disruptive.
The same differences in perception between the “Industry” and “Services” categories also apply to the consequences of poor PQ - see Figure 18 - and amount to:
- Loss of synchronization of processing equipment, which is very common for continuous manufacturing, caused “Industry” considerable problems for their activity.
- Lock ups of computers and switching equipment tripping were the second most problematic.
- As far as “Services” were concerned, circuit breakers tripping and data loss cause the greatest problems.
- According to this Survey, respondents said that electric shocks are not relevant to the PQ issues investigated.
The main sources or causes of PQ problems, see Figure 19, are defined as follows.

- Motor driven systems and, in general, static converters are the main sources of PQ problems for “Industry”.
- Electronic equipment and components are the equivalent main source for the “Services” category.
Regarding PQ solutions, the Figure 20 presents the preferences of the two categories, “Industry” and “Services”.

- Both specify UPS most frequently.
- Back up generators, which prove to be most effective in case of long interruptions, are dominant in Services.
- Harmonic mitigation through harmonic filters is reported at 45% to 65% frequency
- For “Industry” passive filters are almost three times more popular than active filters
- For “Services”, active filters are slightly more prevalent.
- In general “Services” apply a higher frequency of different PQ solutions than found in “Industry”.
- “Industry” tends to favour less costly, more ad hoc solutions whenever possible.

Figure 20: LPQI Survey, PQ solutions applied as % of cases
9. her observations from the survey

Looking at where the fault for poor PQ resides, in general the blame usually is placed squarely with external causes [Figure 21]. Within that general statement, “Services” more frequently admit that their installation could be the source.

Figure 21: LPQI Survey, poor PQ responsibility, 0 – no, 4 - high extreme,
PQ measurement was of great concern because this Survey identified a worryingly low level of measurement of PQ parameters across the board. The implication of this was that there is a patchy level of understanding and acceptance of the fact that ensuring adequate PQ for these power critical industrial sectors has to start with continuous and correct measurement logging of their power systems.

Figure 22 presents the feedback to two questions – the ability to identify the sources of PQ events (the first 4 bars per category of the chart) and their frequency (the remaining 8 bars per category) and the continuous monitoring of the key PQ parameters that further diagnose these issues:

- For the identification data set, the average response across all information sources was a 50% - a level to repeat which is significantly low for industrial sectors that depend on good PQ. Within that, the “Services” direct PQ measurement is much more frequent than that occurring in “Industry”, where PQ data gathering is more reliant on the different PQ data acquisition components installed in their power systems.

- Concerning continuous monitoring of key PQ parameters, this is more prevalent with “Industry” than with “Services”. “Industry” continuously measured both reactive power and Flicker several times more frequently than “Services”. In 70% of the “Industry” cases, reactive power is subject to continuous measurement and this could be for financial reasons when reactive power is likely to be subject to separate accounting procedures.

**Figure 22: LPQI Survey, PQ monitoring, 4 left bars - source of PQ event information, remaining bars – measured PQ parameter**
A high proportion of the companies interviewed (46 out of 62) agreed that Flicker generates PQ costs in terms of losses generated in employee efficiency, losses which can amount to 10% of annual employment cost. These costs are related to vision problems with symptoms like fatigue causing increased error rate. These consequences relate to reduced productivity / inefficiency in work and in extreme cases employee compensation. These costs would amount 167 mln € which is equivalent of approximately 1.5% of all hypothetical (mitigated) and real (unmitigated) cost. As this is an area of current and as yet inconclusive debate and although respondents affirmed that their employees’ efficiency was reduced by the levels of Flicker experienced, the Flicker Cases at this stage have all been treated as „hypothetical“.

Finally, in addition to the summary of these technical findings and as was stated earlier but merits repeating, it is astounding that industrial sectors, for which electrical power is critical, are not fully aware of these issues.

The main conclusion however remains that PQ costs in Europe are responsible for a serious reduction in industrial performance with an economic impact exceeding €150bn.