



EPRI Power Quality Applications (PQA) and Advanced Distribution Automation (ADA) 2007 Joint Conference and Exhibition

End use perceptions of Power Quality – A European Perspective

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June 12, 2007

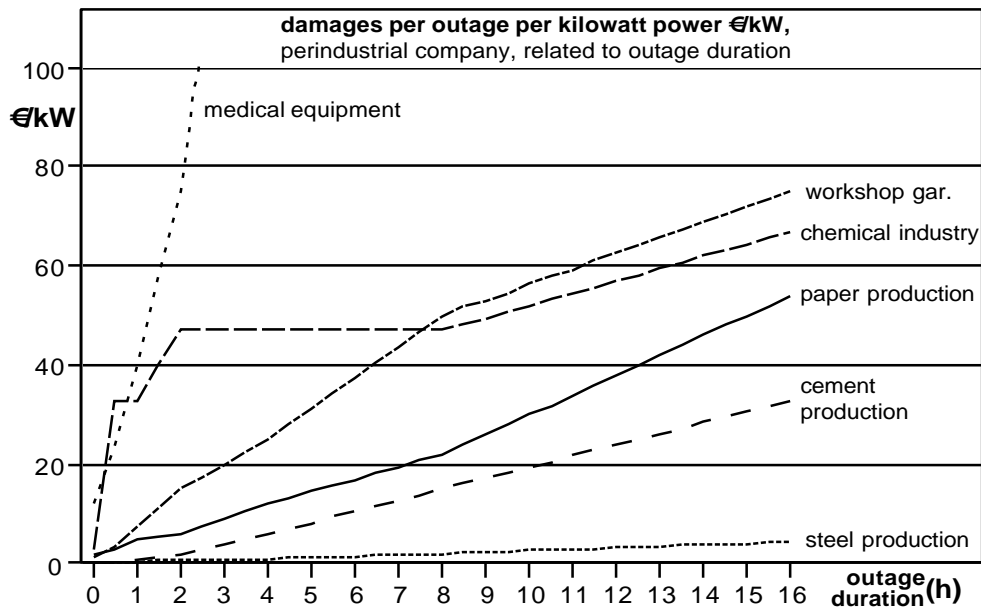
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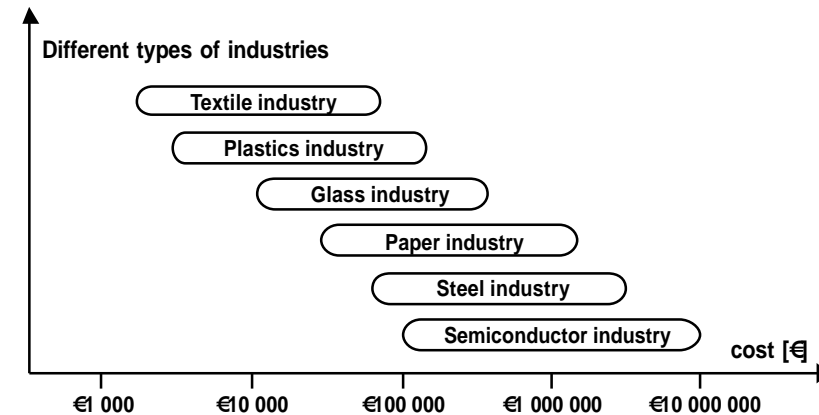
PQ cost – historical examples (1)

Dutch survey undertaken by KEMA, Arjen Jongepier et al, KEMA, EPQU magazine Vol I, No. 2, 2005.



T. Andersson and D. Nilsson, in "Test and evaluation of voltage dip immunity," STRI AB and Vatenfall AB 27 November 2002,

Sensitivity of different industries to voltage dips expressed in estimated dips cost per industry. The highest position in this ranking is occupied by semiconductor industry which, according to some other sources, experience the highest level of voltage dips cost compared to electricity bill or company turnover of any sector.



PQ cost – historical examples (2)

S. Quaia and F. Tosato, "Interruption costs caused by supply voltage dips and outages in small industrial plants: a case study and survey results," 2003

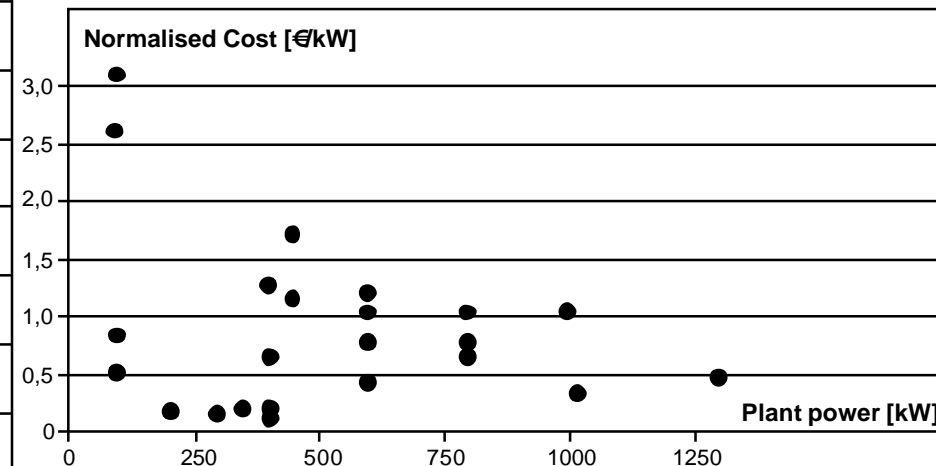
The table presents the estimated voltage sag costs for a range of industrial sectors and was sourced from S. Quaia and F. Tosato, "Interruption costs caused by supply voltage dips and outages in small industrial plants: a case study and survey results," 2003.

| Industrial process | Voltage Sag Cost (% of total yearly power cost) | | |
|--------------------|---|------------|------------|
| | Category A | Category B | Category C |
| Semiconductor | 0 to 2 | 2 to 10 | 5 to 6 |
| Pharmaceutical | 0 to 0.8 | 1 to 5 | 2 to 4 |
| Chemical | 0 to 1 | 1 to 3 | 2 to 4 |
| Petrochemical | 0 to 1 | 2 to 5 | 1.5 to 3.5 |
| Manufacturing | 0 to 0.2 | 0 to 1 | 0.8 to 1 |
| Metallurgy | 0 to 0.2 | 0 to 1.5 | 1 to 1.5 |
| Food | 0 to 0.5 | 0 to 1.5 | 0 to 2 |

R. Lamedica, A. Patrizio, A. Prudenzi, E. Tironi, and D. Zaninelli, "Power quality costs and upgrading solutions: the energy centre," 2000.

In Italy, researchers performed a survey in different areas of North-East Italy between year 1999 and 2002.

The survey focused on 200 small industrial customers of various sectors. The costs due to voltage sags are presented in normalized cost per voltage sag per kW power to enable a valid comparison between industrial sectors and sizes. The survey results are illustrated in the figure below. It was found that most sensitive plants have normalized cost per sag in the range of 0.25-1.5 Euro/kW.



PQ cost – historical examples (3)

Voltage dips cost per event based on study carried out in the University of Manchester former UMIST by J. V. Milanovic and N. Jenkins, "Power quality cost for manufacturing industries," presented on EdF workshop in Paris, 2003.

Financial losses caused by voltage sags taken from D.Chapman, "The cost of poor power quality," Copper Development Association November 2001

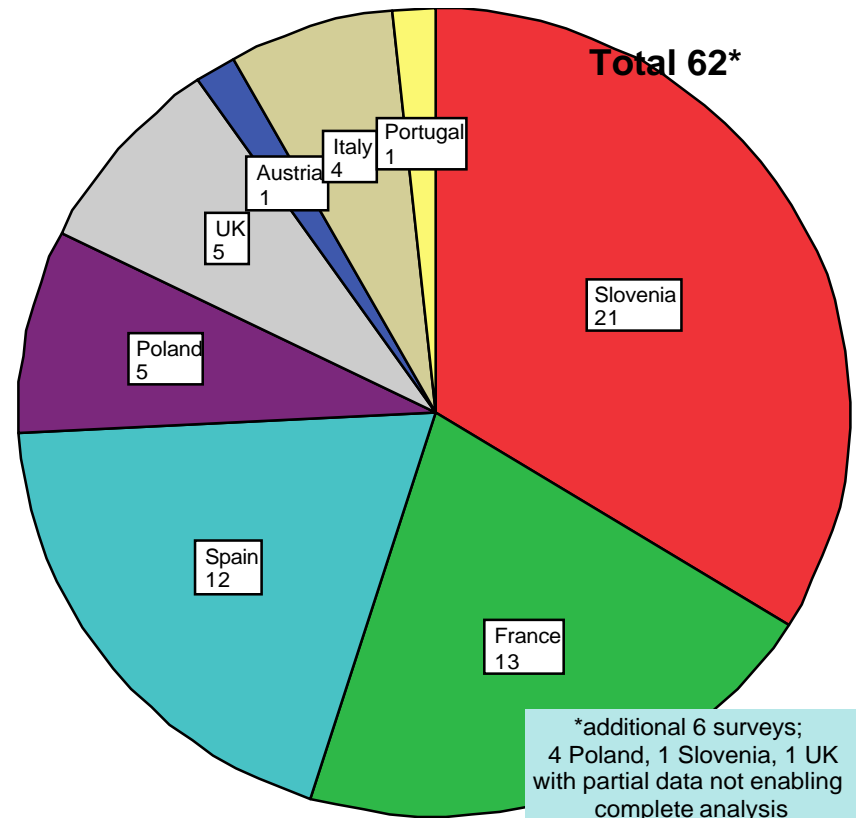
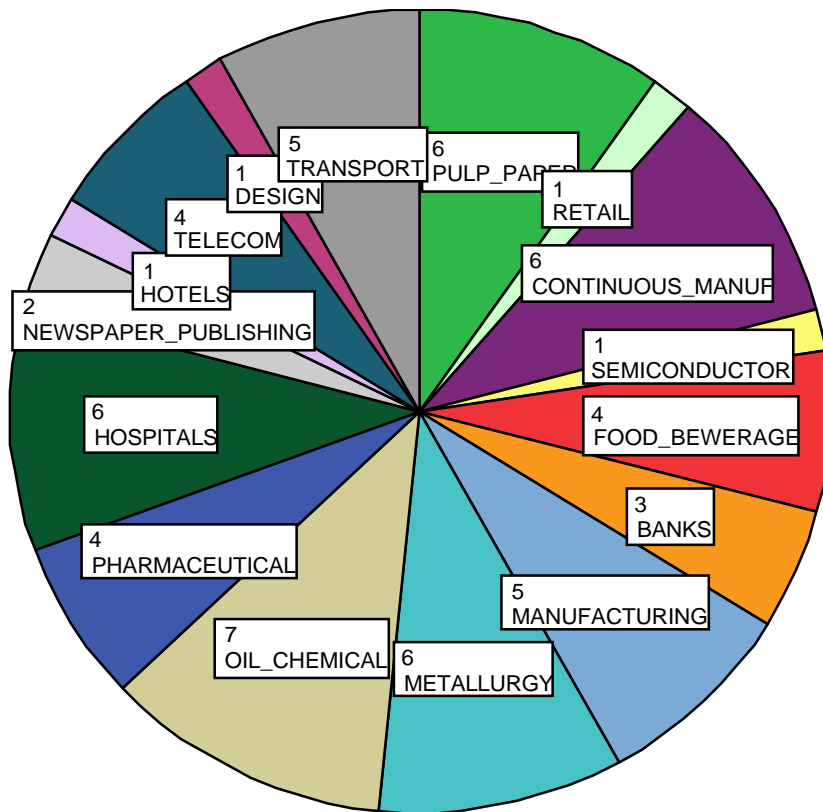
| Industry | Duration | Cost/sag |
|--------------------|--------------------|----------|
| UK steel work | 30% for 3.5 cycles | £250k |
| US glass plant | Less than 1 second | \$200k |
| US computer centre | 2 second | \$600k |
| US car plant | Annual exposure | \$10M |
| South Africa | Annual exposure | \$3B |

| Industry | Typical financial loss per event (€) | |
|--------------------------|--------------------------------------|------------|
| Semiconductor production | 3,800,000 | |
| Financial trading | 6,000,000 | per hour |
| Computer centre | 750,000 | |
| Telecommunications | 30,000 | per minute |
| Steel works | 350,000 | |
| Glass industry | 250,000 | |

LPQI PQ survey

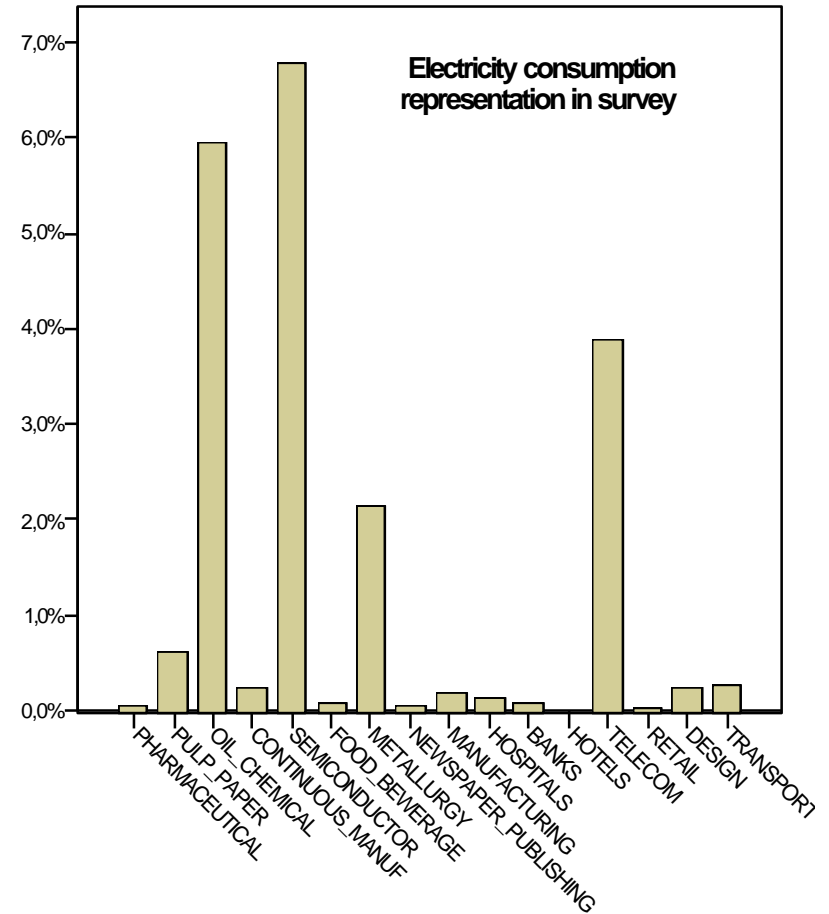
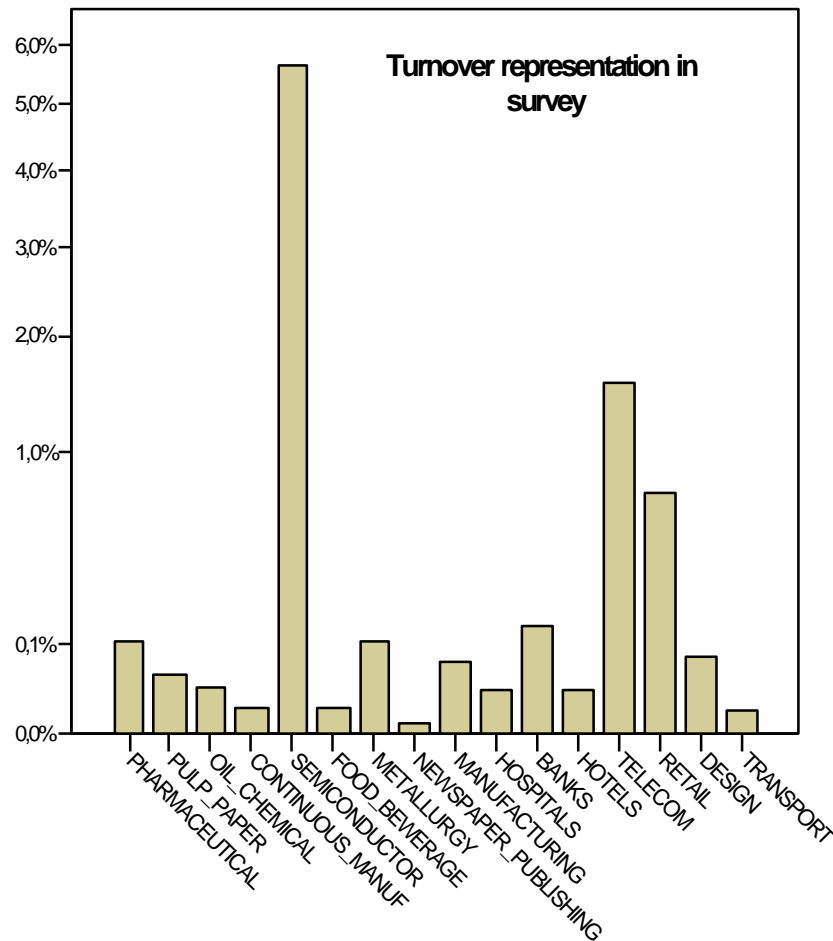
- The survey interviews and web based submission were conducted over a 2-year period in 8 European countries. In all, 62 complete and 6 partial (i.e. excluding detailed cases part) interviews were carried out. In all, 62 complete and 6 partial (i.e. excluding detailed cases part) interviews were carried out.
- These sectors represent some 38% (€6.843bn) of the EU-25 total of €17. 956bn turnover.
- 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.
- PQ costs reported in the categories of interruptions and voltage quality. All these cost were specified on an annual basis, either reported as such or pro-rated where frequency was less than once pa.
- Also hypothetical costs that would be the potential losses and risk avoided by power systems that had been immunized against the PQ disturbances under review.
- The subsequent regression analysis was performed to estimate PQ cost across those sectors with “annual turnover” as a key model indicator.

PQ survey sample

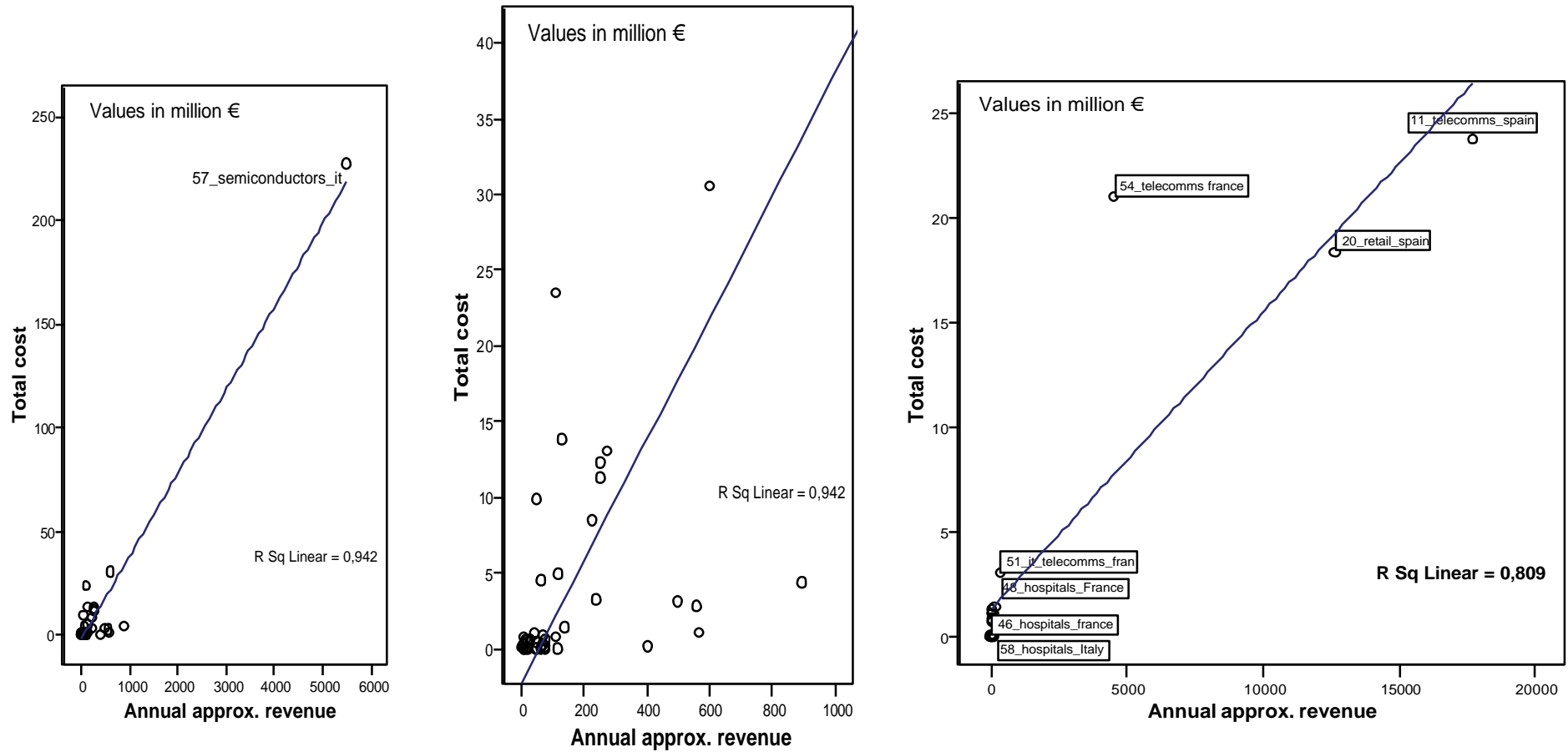


*additional 6 surveys;
4 Poland, 1 Slovenia, 1 UK
with partial data not enabling
complete analysis

Survey (sample) representation – EU25

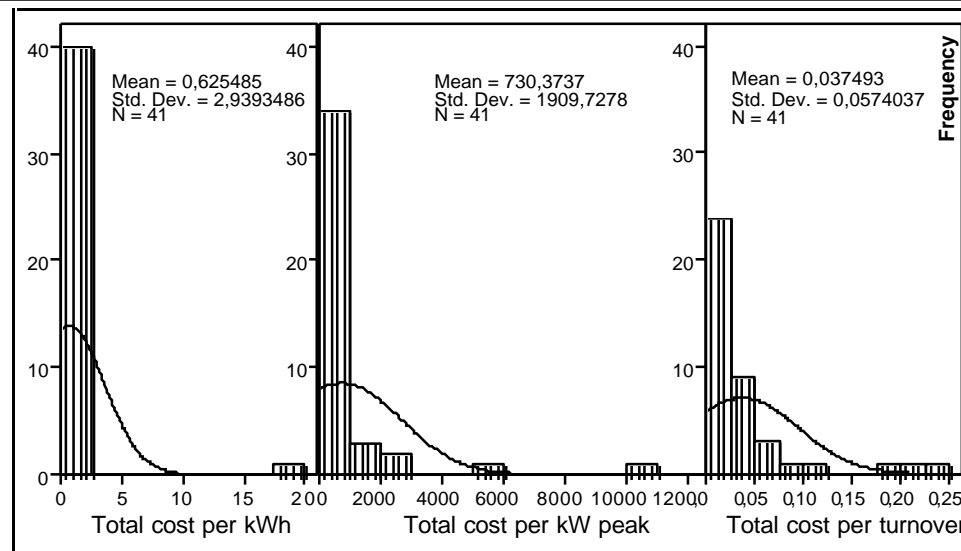


Regression model



PQ cost indices (industry)

| | Total cost per kWh €/kWh | Total cost per kW peak €/kW | Total cost per turnover (ratio) | Total cost per electricity bill (ratio) | Total cost per employment €/employee | Cost / kWh dip & short interruption €/kWh | Cost / kWh long interrupt. €/kWh | Cost / peak kW dip & short interrupt. €/kW | Cost per peak kW long interruption €/kW |
|--------------------|-----------------------------|--------------------------------|------------------------------------|--|---|--|-------------------------------------|---|--|
| Mean | 0,625 | 730,37 | 0,0374 | 7,530 | 8158 | 0,1352 | 0,0802 | 147 | 323 |
| Std. Error of Mean | 0,459 | 298,24 | 0,0089 | 5,330 | 2995 | 0,0922 | 0,0469 | 57 | 260 |
| Median | 0,031 | 95,57 | 0,0109 | 0,413 | 1218 | 0,0098 | 0,0012 | 28 | 4,18 |
| Std. Deviation | 2,939 | 1909,72 | 0,0574 | 34,163 | 19181 | 0,5903 | 0,3008 | 371 | 1670 |
| Variance | 8 | 3 647 060 | 0,0030 | 1 167,000 | 367 922 790 | 0,3490 | 0,0910 | 137 717 | 2 789 088 |
| Minimum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Maximum | 18,861 | 10 681 | 0,2375 | 218,552 | 113 638 | 3,7720 | 1,7090 | 1 771 | 10 681 |

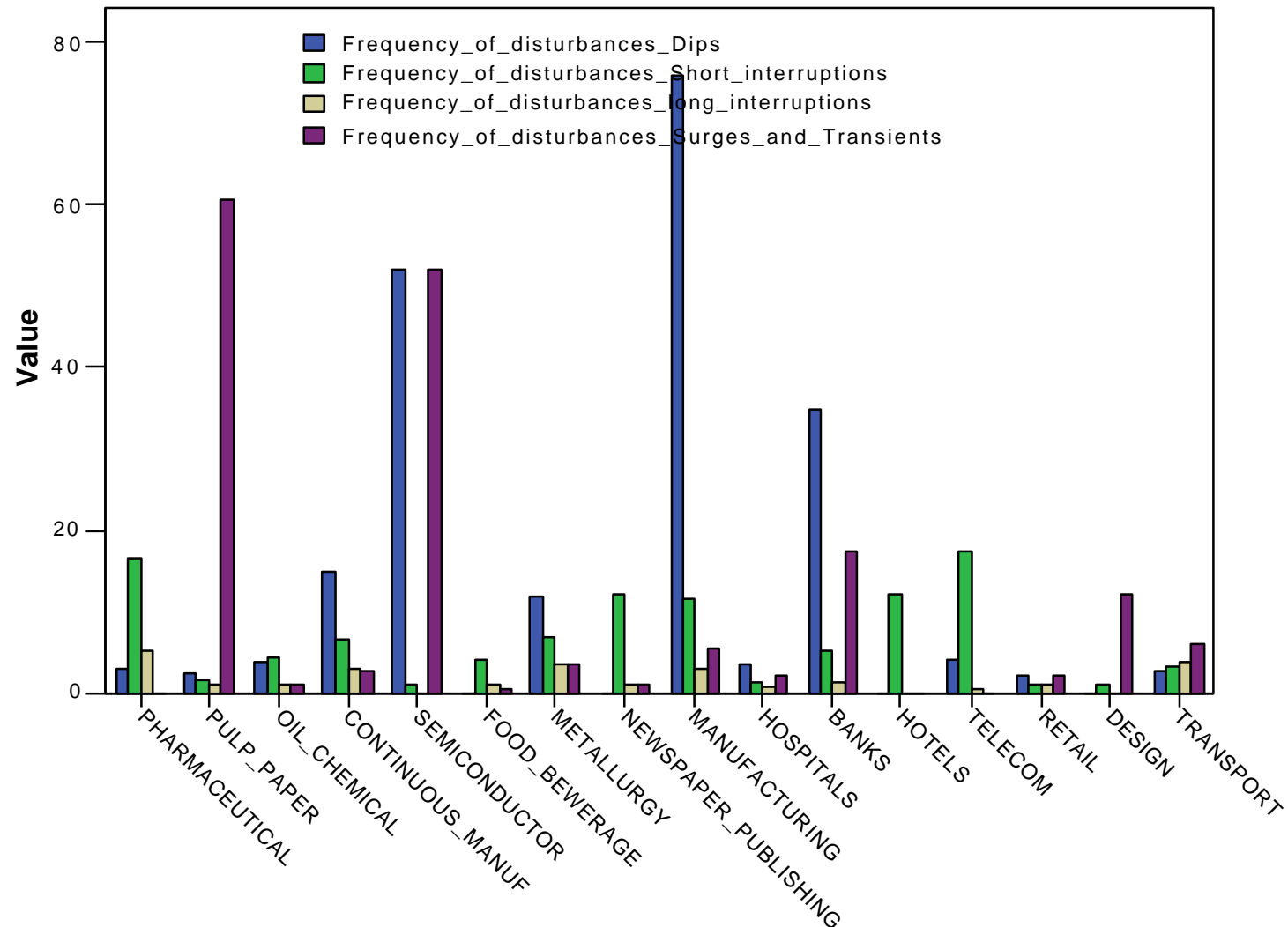


Frequency of PQ events

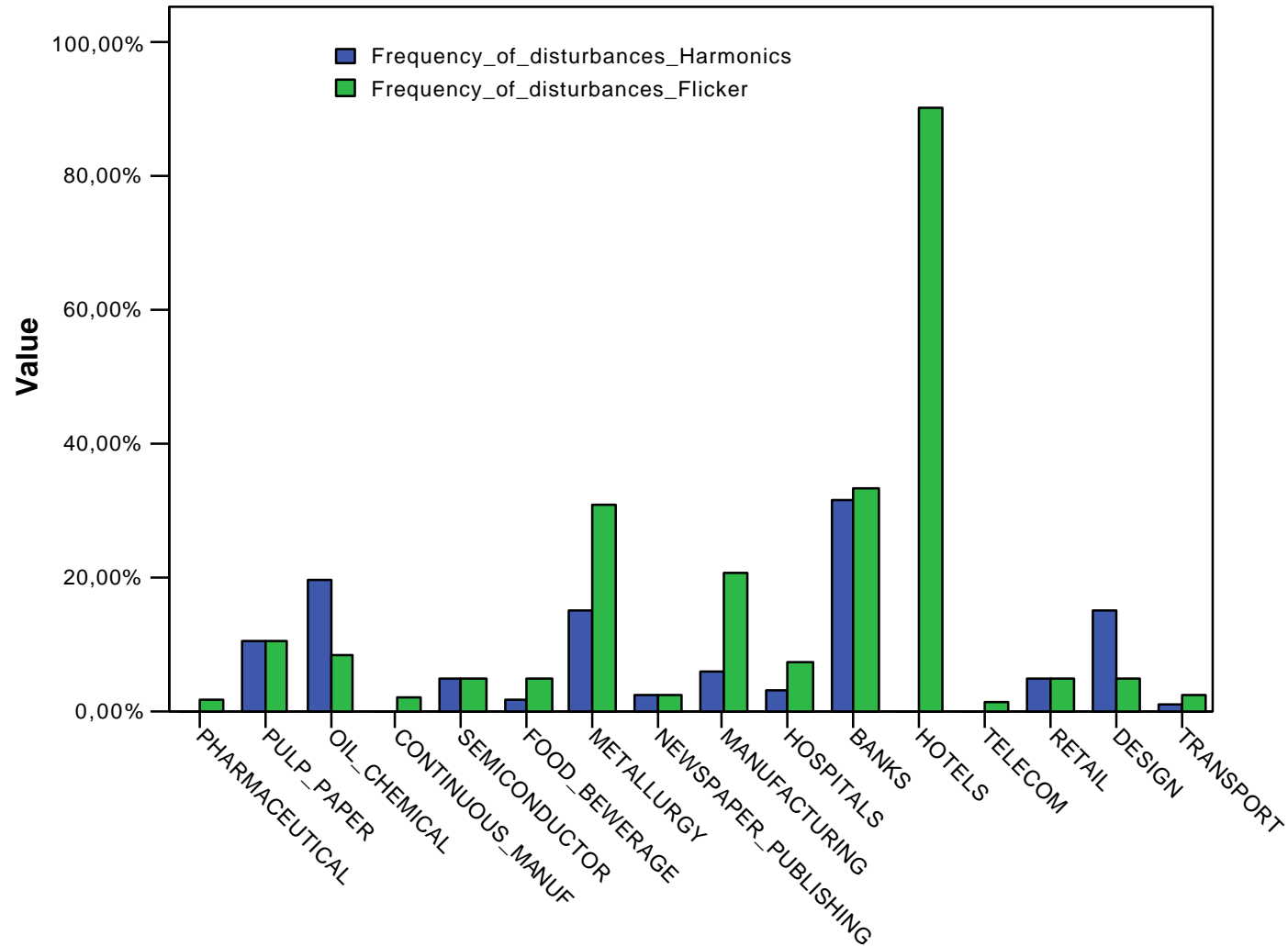
| Frequency of PQ disturbances | number of events | | | | annual % |
|------------------------------|------------------|---------------------|--------------------|-----------------------|-----------|
| | Voltage dips | Short interruptions | Long interruptions | Surges and transients | Harmonics |
| Industry | 15,7 | 6,9 | 2,2 | 13,0 | 9,0% |
| Services | 7,7 | 5,4 | 2,1 | 6,7 | 7,5% |
| Average | 13,2 | 6,4 | 2,2 | 11,3 | 8,5% |

The frequency of PQ events reported in the survey can be characterized shortly as follows. On average the MAIFI that has been measured by this Survey is approximately 6; this is 3 times bigger than SAIFI. The number of recorded voltage dips, that is identified by the respondents, is approximately twice the number of short interruptions (MAIFI). This ratio is somewhat less for the services sectors.

Frequency – events annually



Frequency – harmonics / flicker



PQ event cost

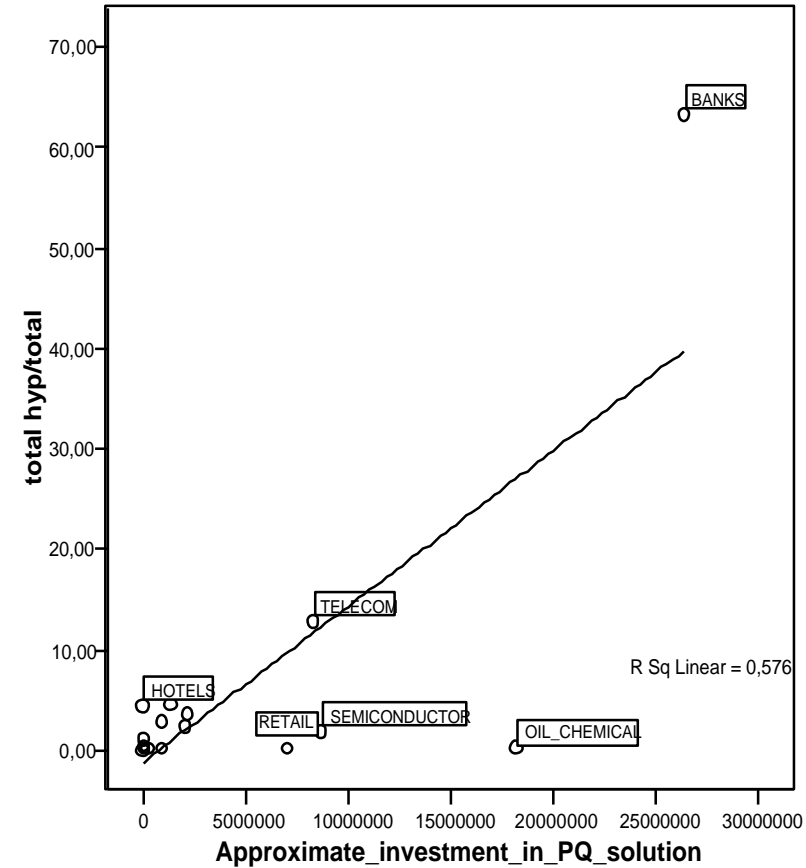
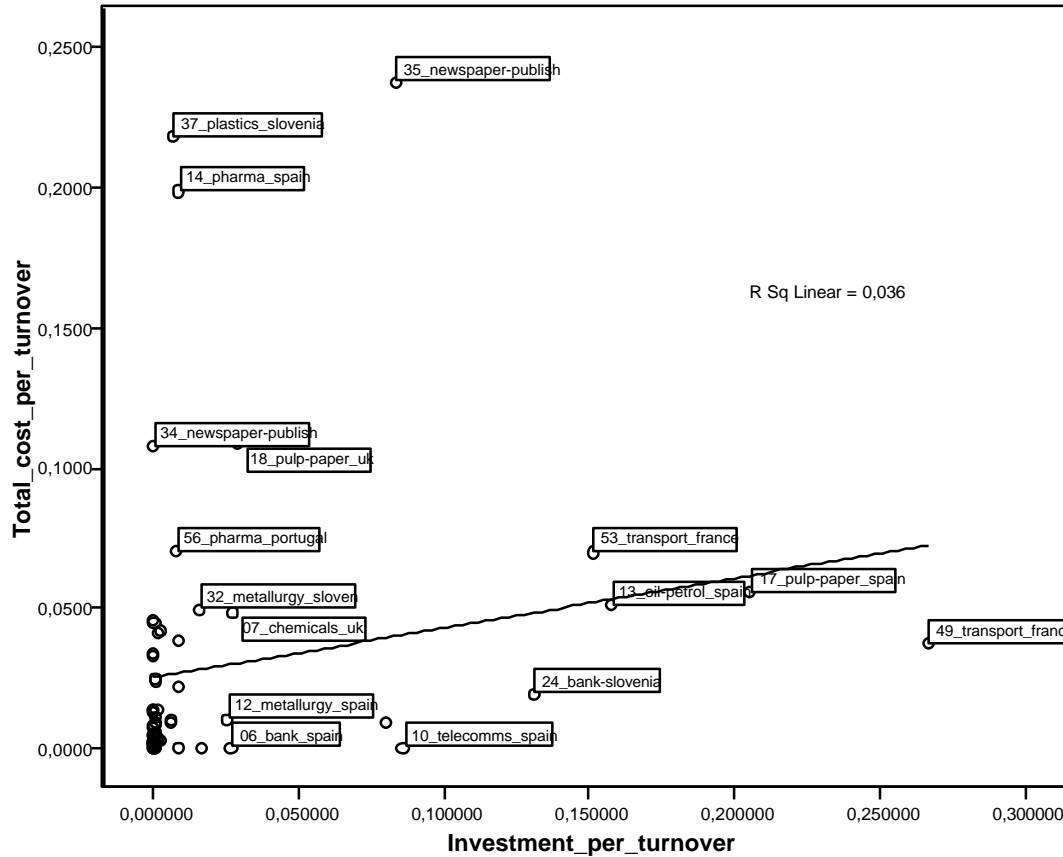
| Cost per event € | Voltage dips | Short interruptions | Long interruptions | Surges and transients |
|------------------|--------------|---------------------|--------------------|-----------------------|
| Industry | 141 635 | 205 300 | 95 478 | 186 260 |
| Services | 22 064 | 47 762 | 272 916 | 122 602 |
| Average | 119 357 | 163 153 | 148 709 | 175 871 |
| Industry* | 4 682 | 15 484 | 95 478 | 186 260 |
| Services* | 2 120 | 19 447 | 80 326 | 122 602 |
| Average* | 4 177 | 16 539 | 91 021 | 175 871 |

Remark*: 2 out of the 62 companies surveyed (semiconductors and retail) filtered out

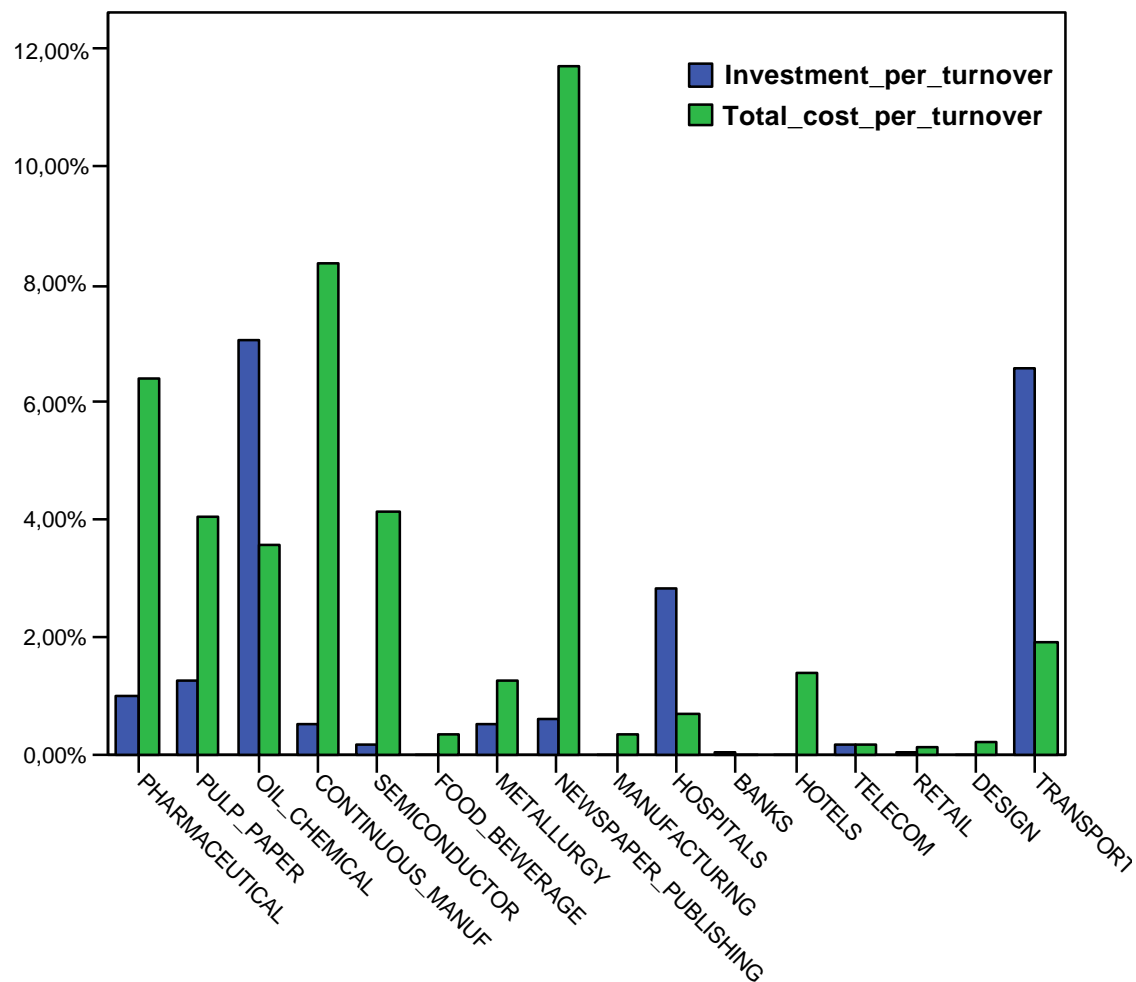
PQ consequence / solution correlation

| PQ consequence | PQ solution | Relation |
|---|---|------------------|
| Relays and contactors nuisance tripping | Harmonic filter (passive) | significant |
| Noise interference to telecommunication lines | Multiple independent feeder | significant |
| Motors or process equipment are damaged | Shielding and grounding | significant |
| Motors or other process equipment malfunctions | Back up generator | very significant |
| Loss of synchronization of processing equipment | Surge protection on key pieces of equipment | significant |
| Loss of synchronization of processing equipment | Harmonic filter (passive) | very significant |
| Circuit breakers or RCD's nuisance tripping | Line conditioner or active filter | significant |
| Circuit breakers or RCD's nuisance tripping | Back up generator | significant |
| Capacitors bank failure | Shielding and grounding | very significant |

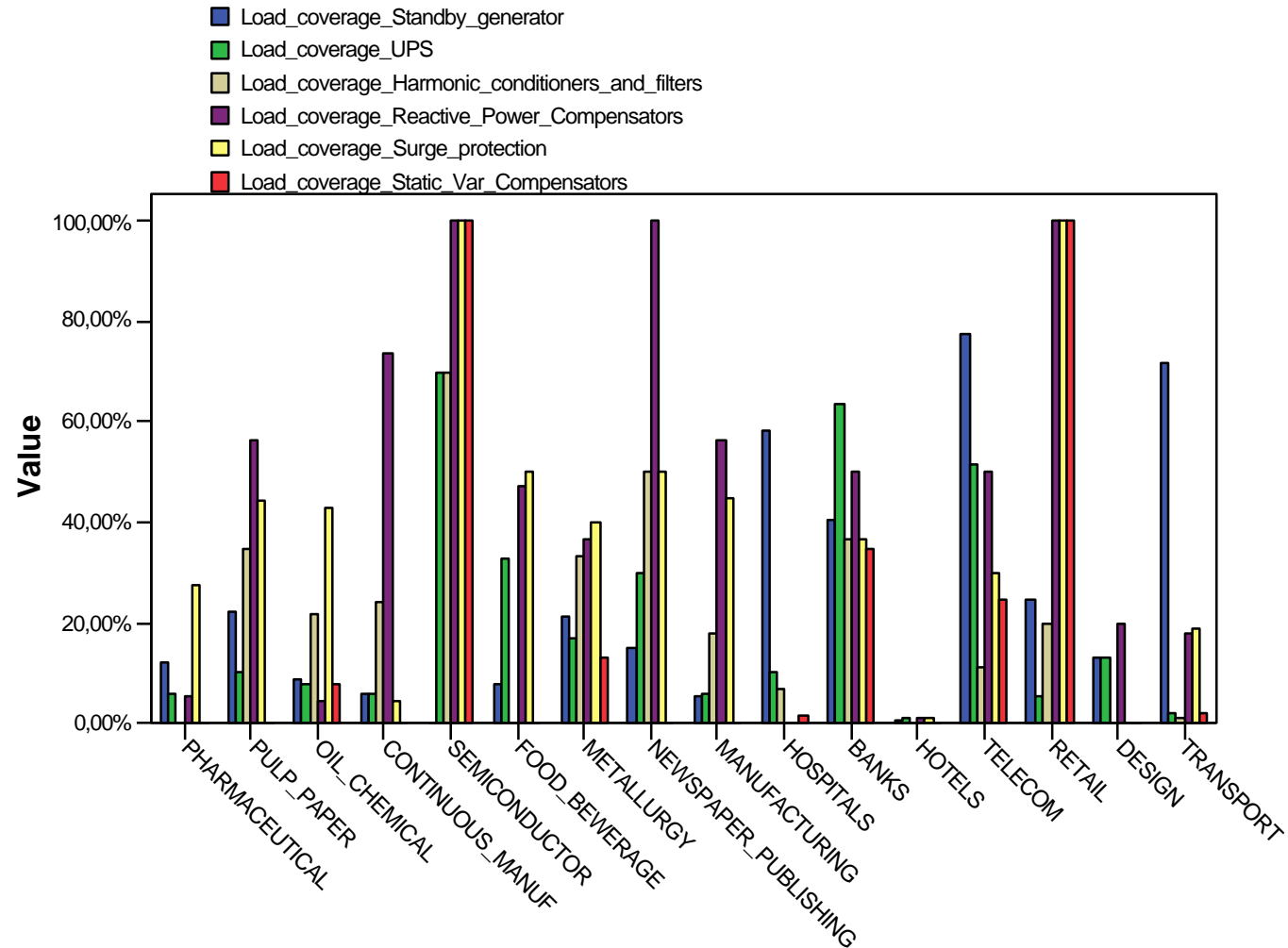
PQ investment effectiveness



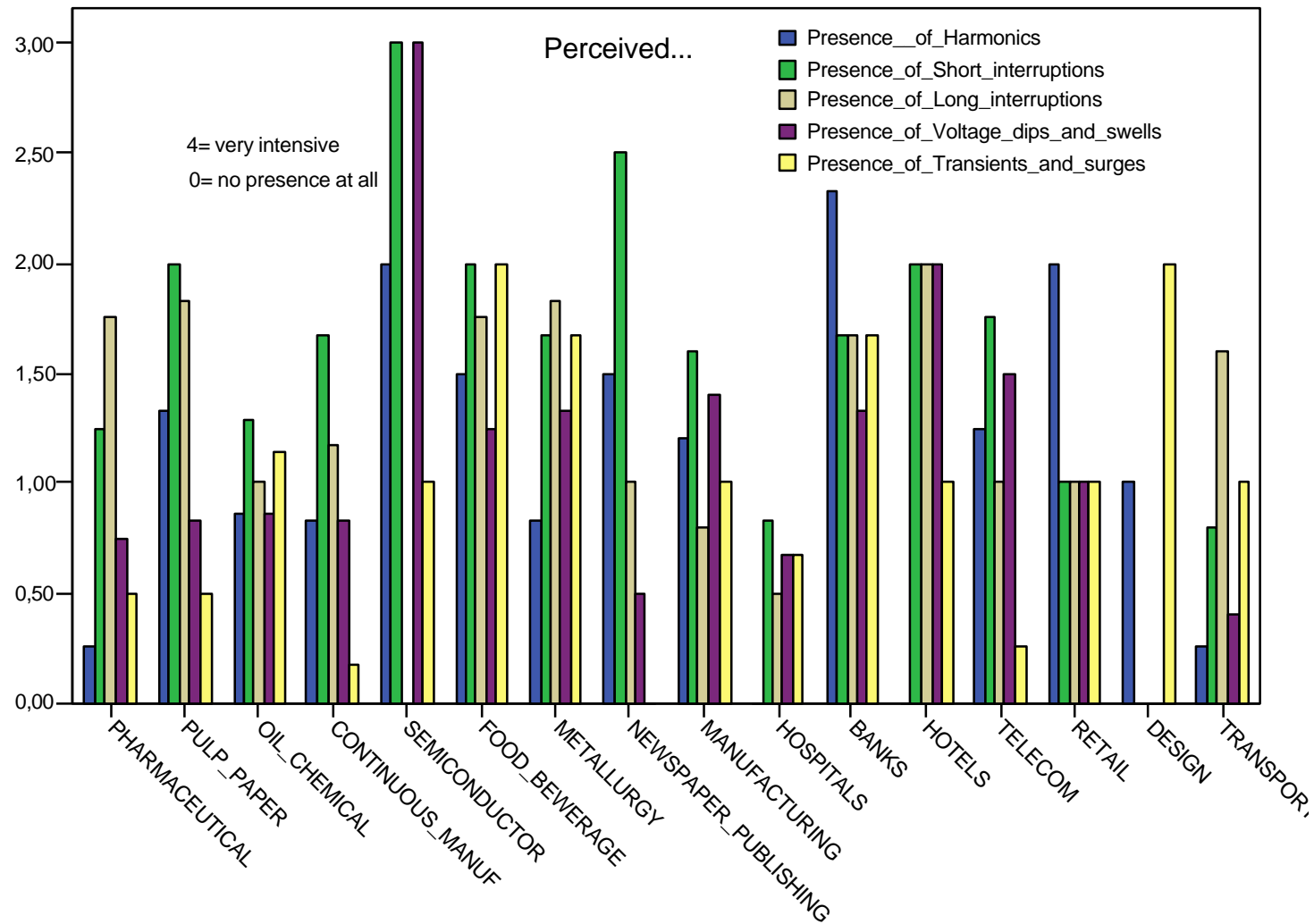
PQ investments per turnover



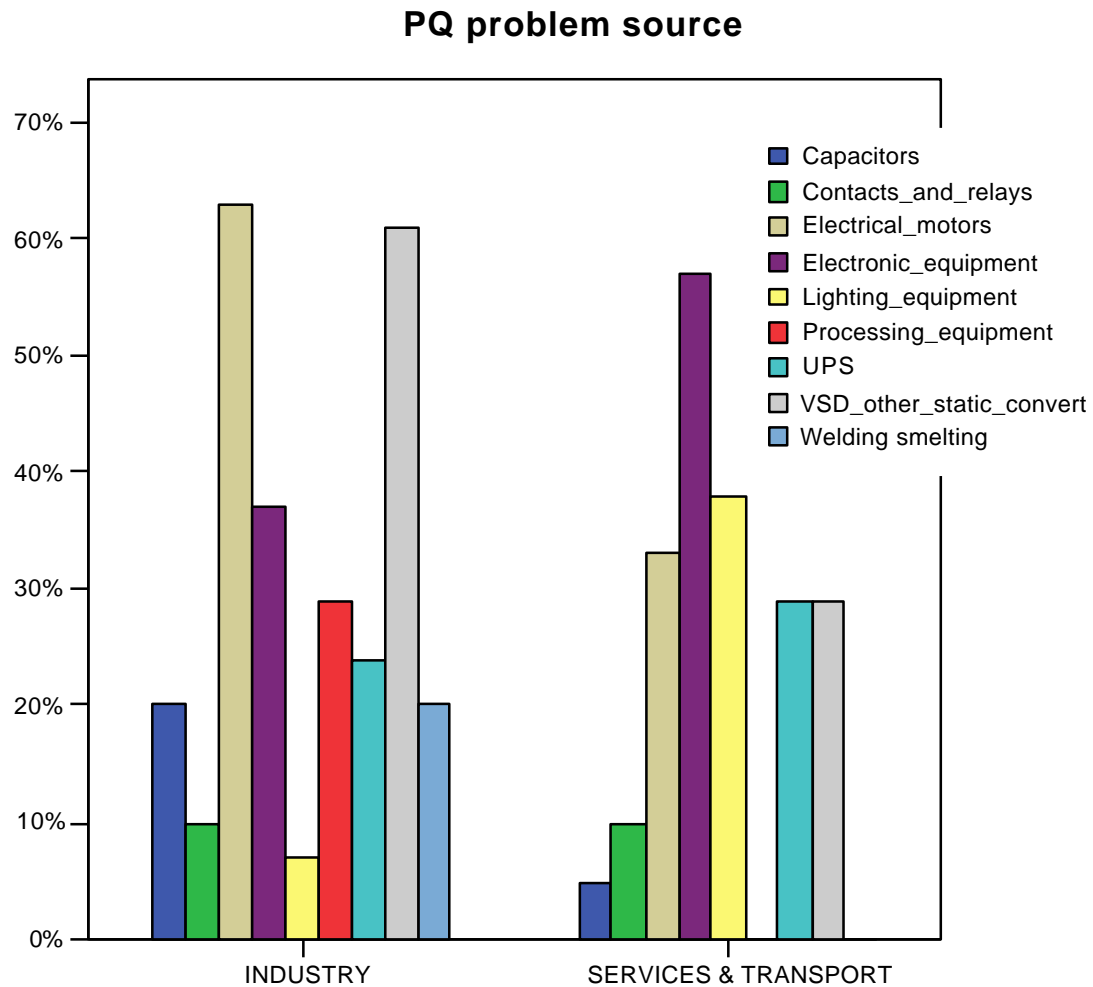
PQ solution coverage



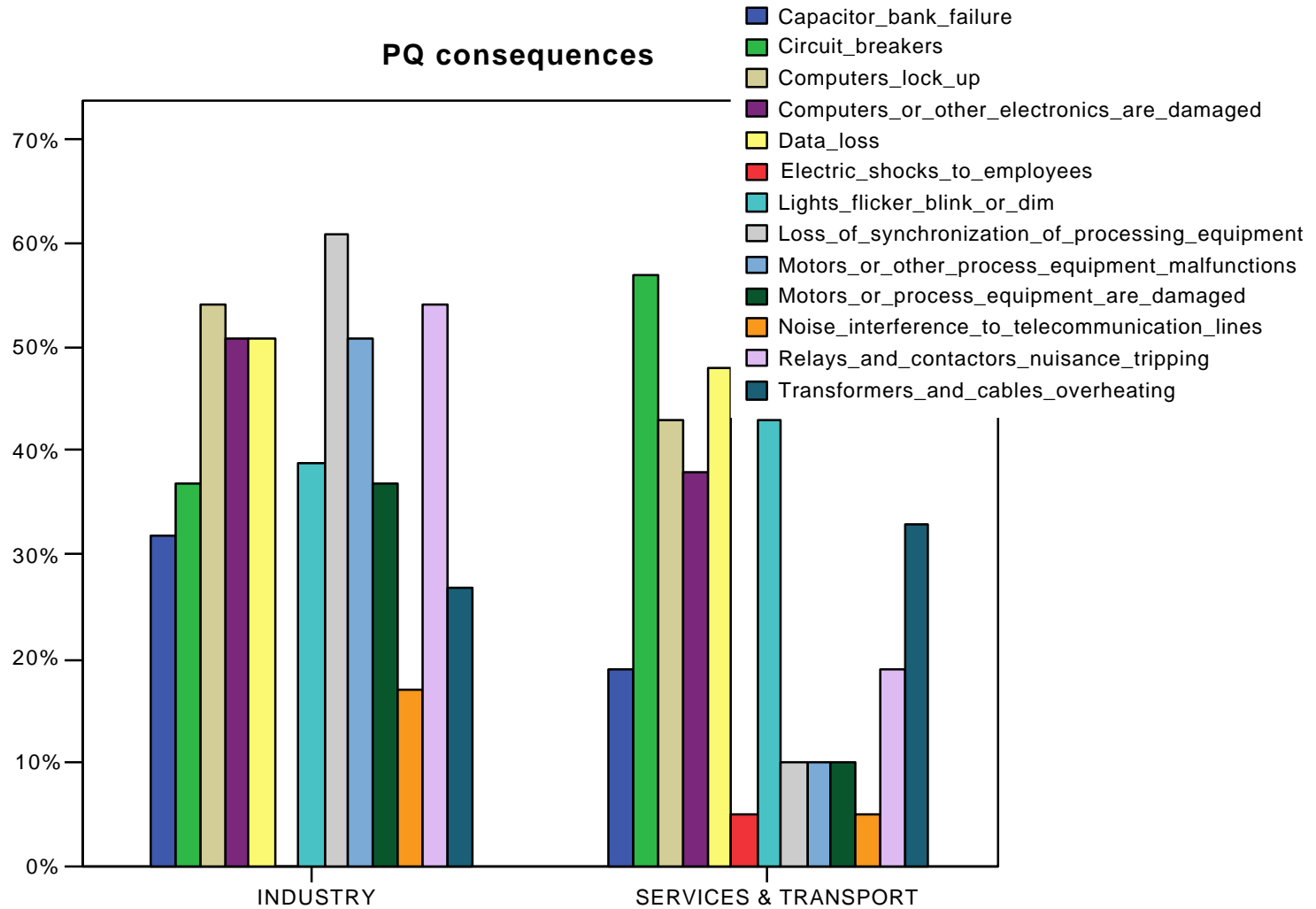
Perceived presence of disturbances



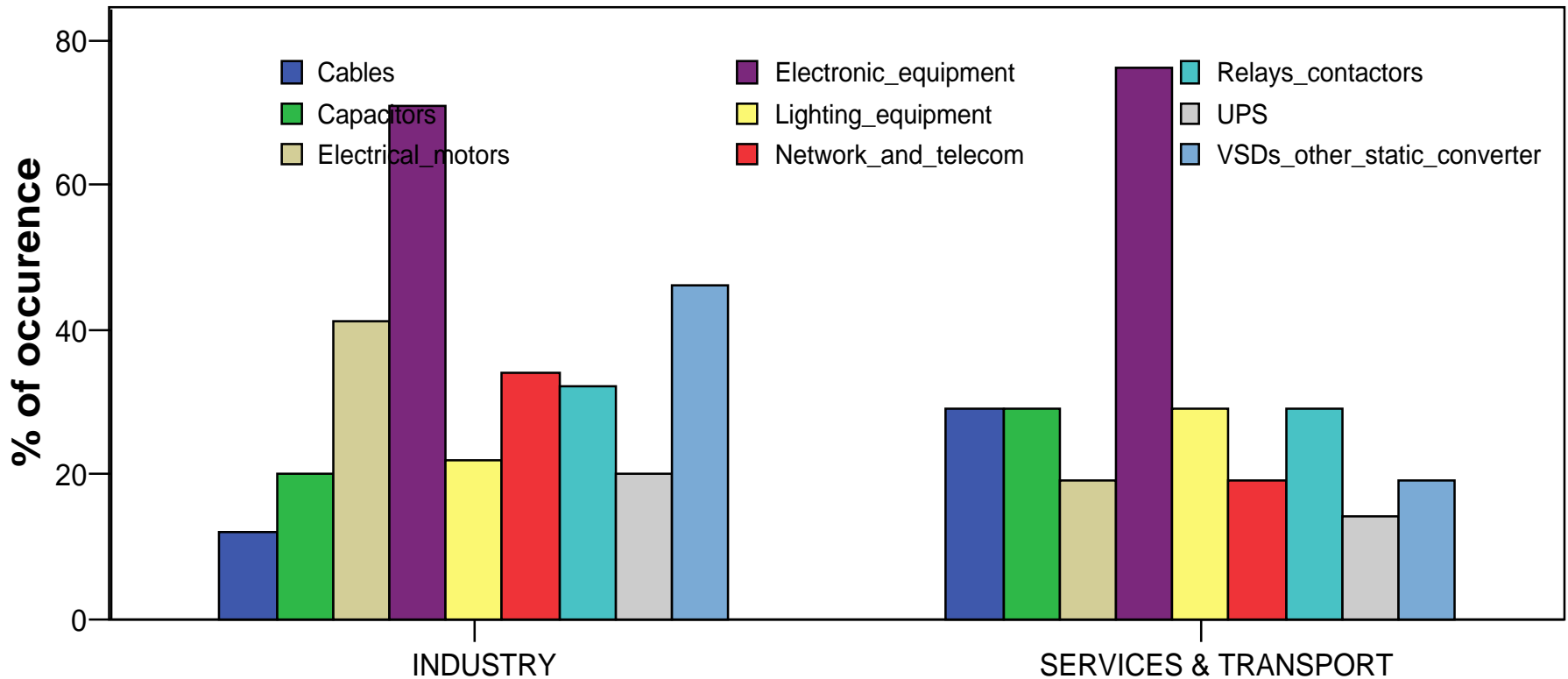
(Perceived) PQ problem source



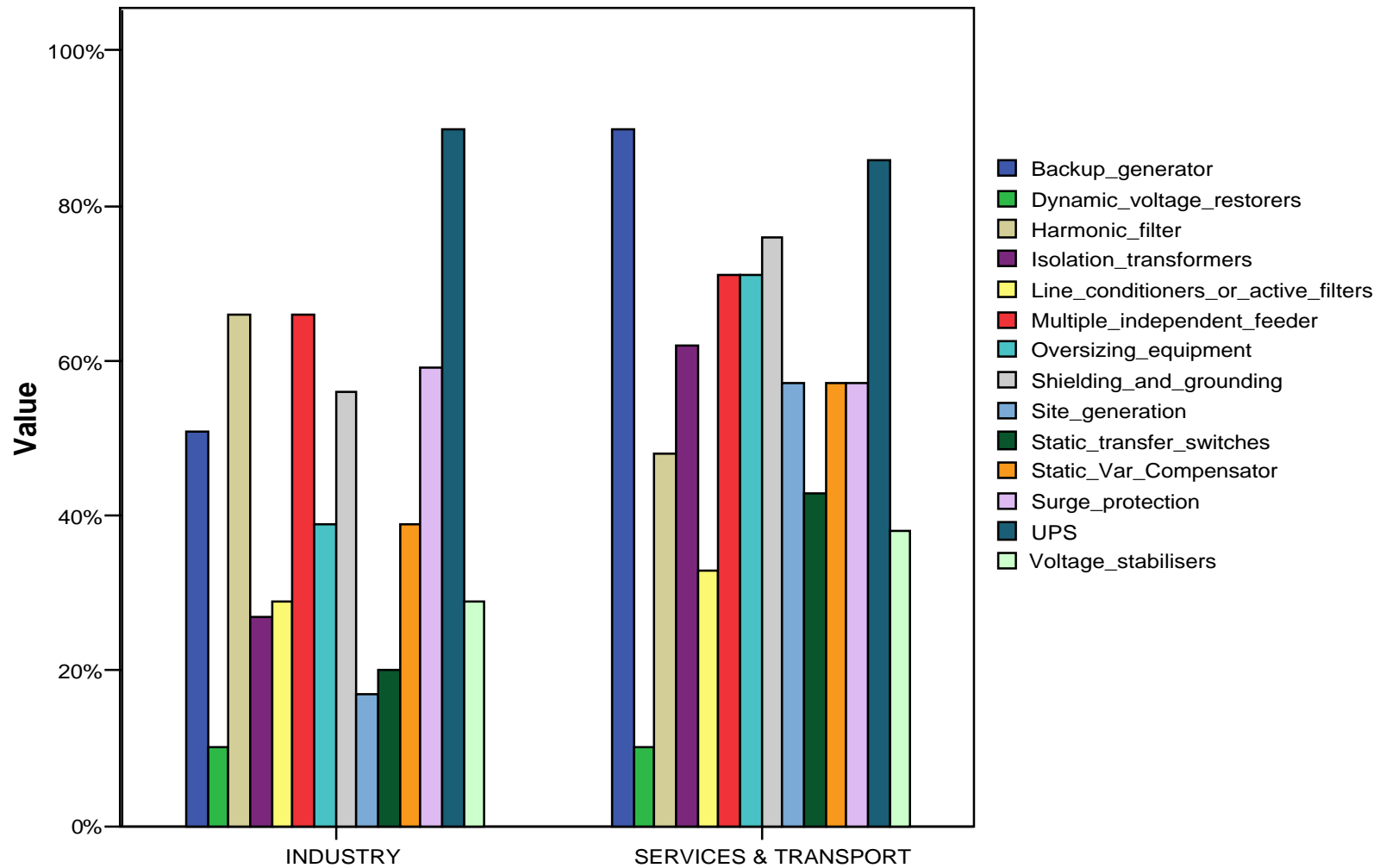
(Perceived) PQ consequences



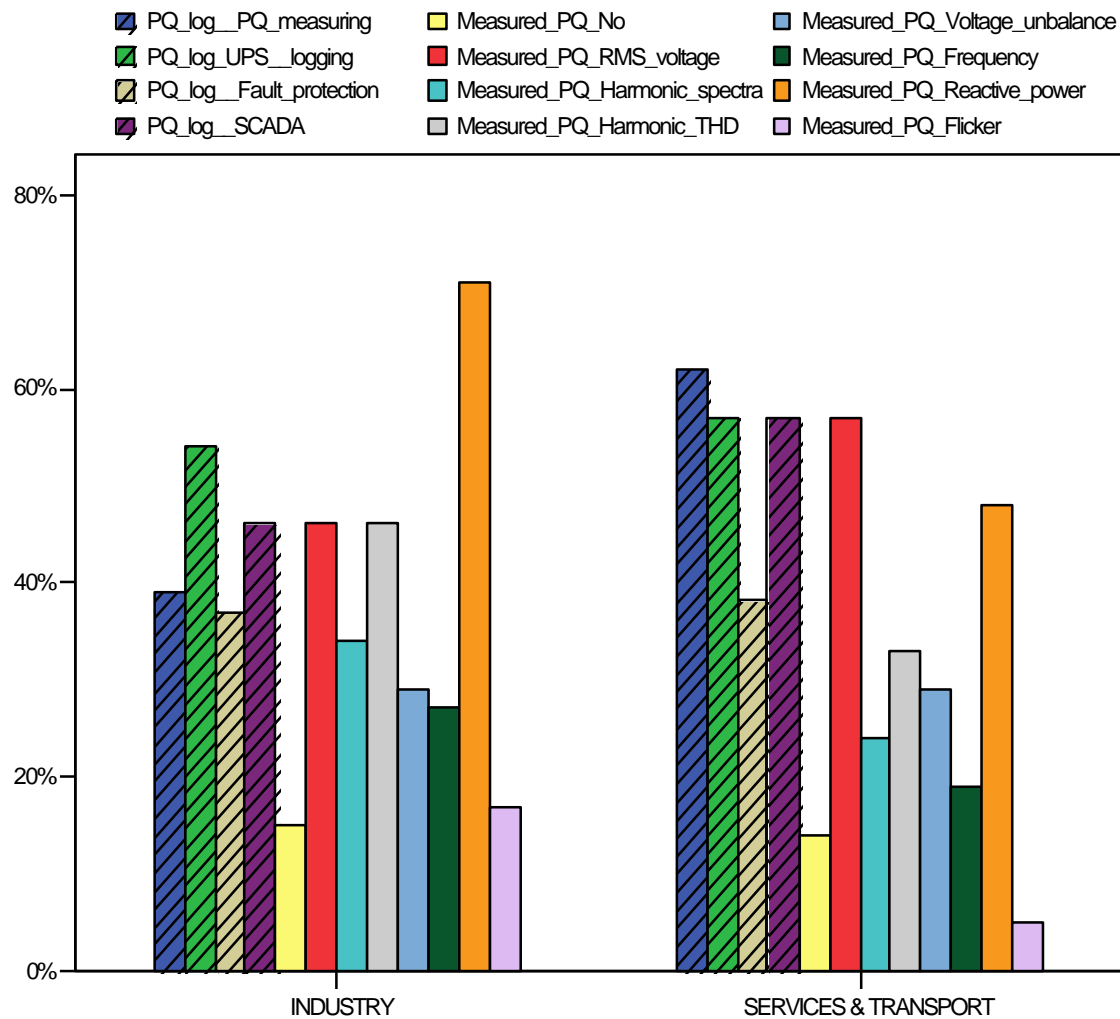
Equipment being affected



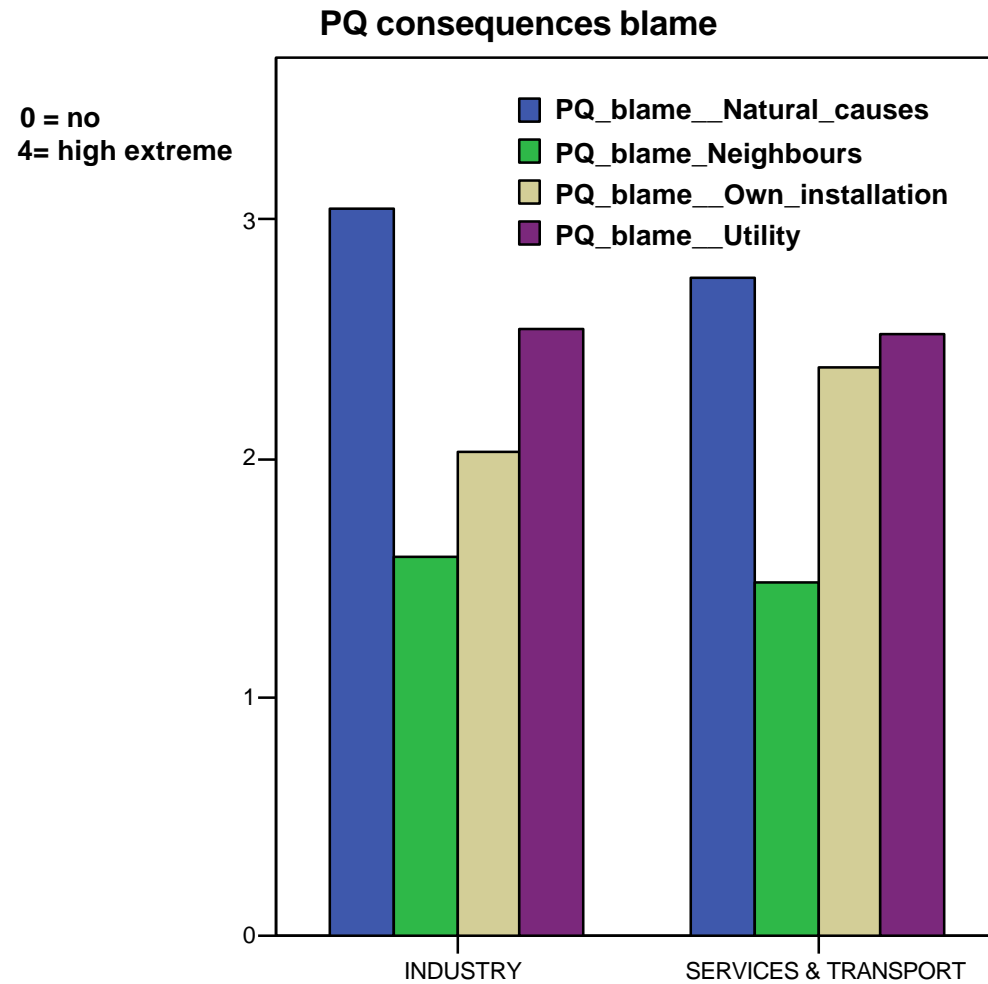
PQ solutions (perceived)



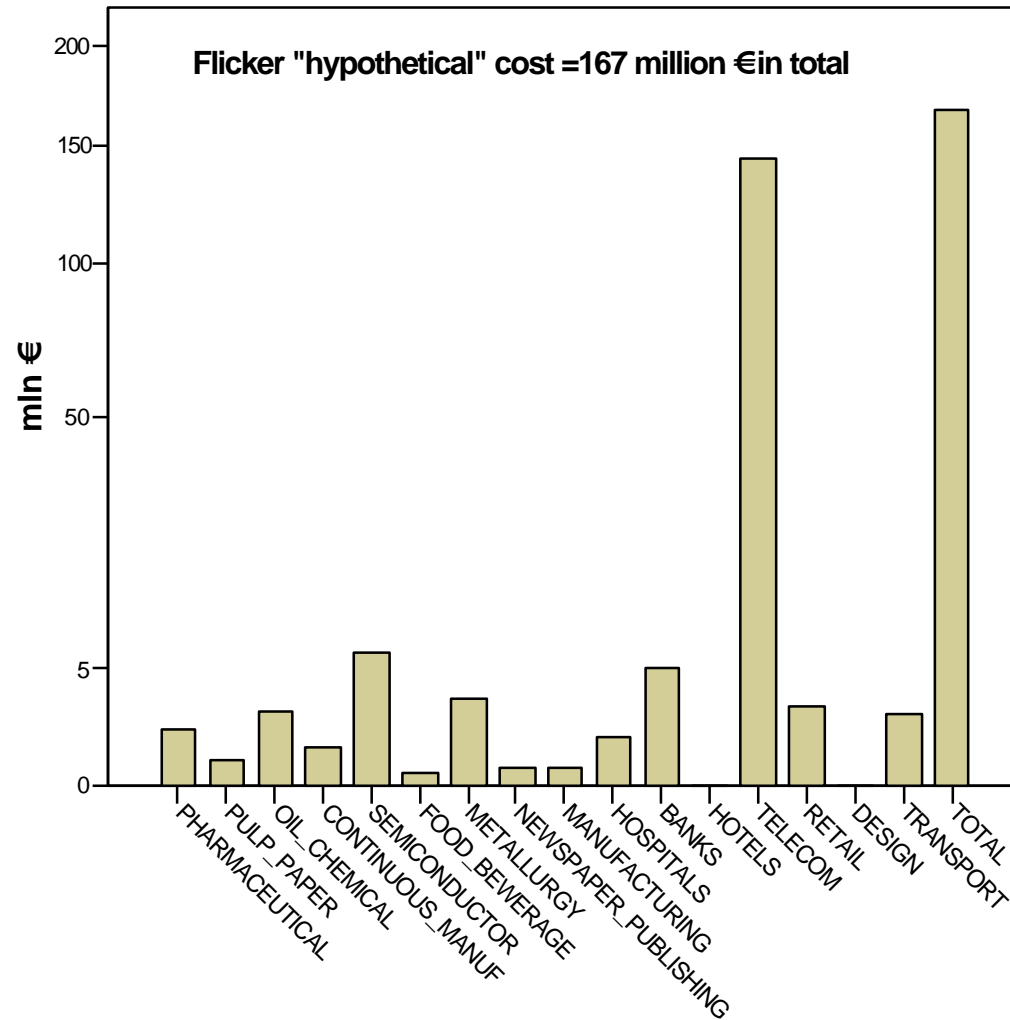
PQ measurement



PQ blame



Flicker cost (hypothetical)



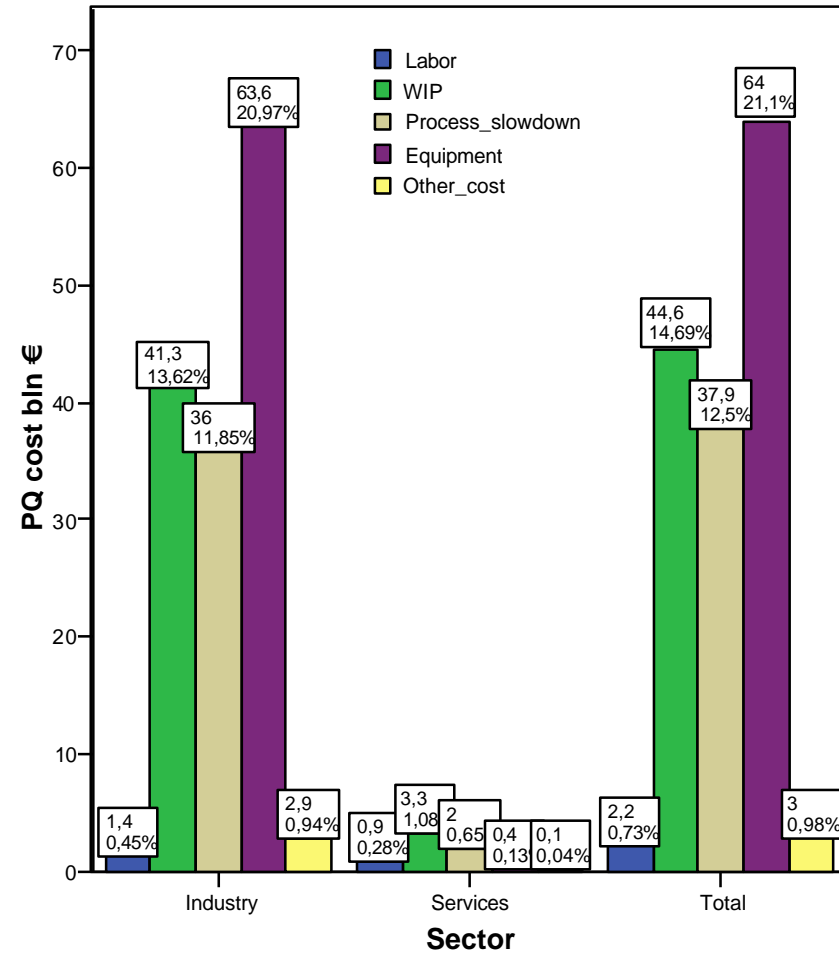
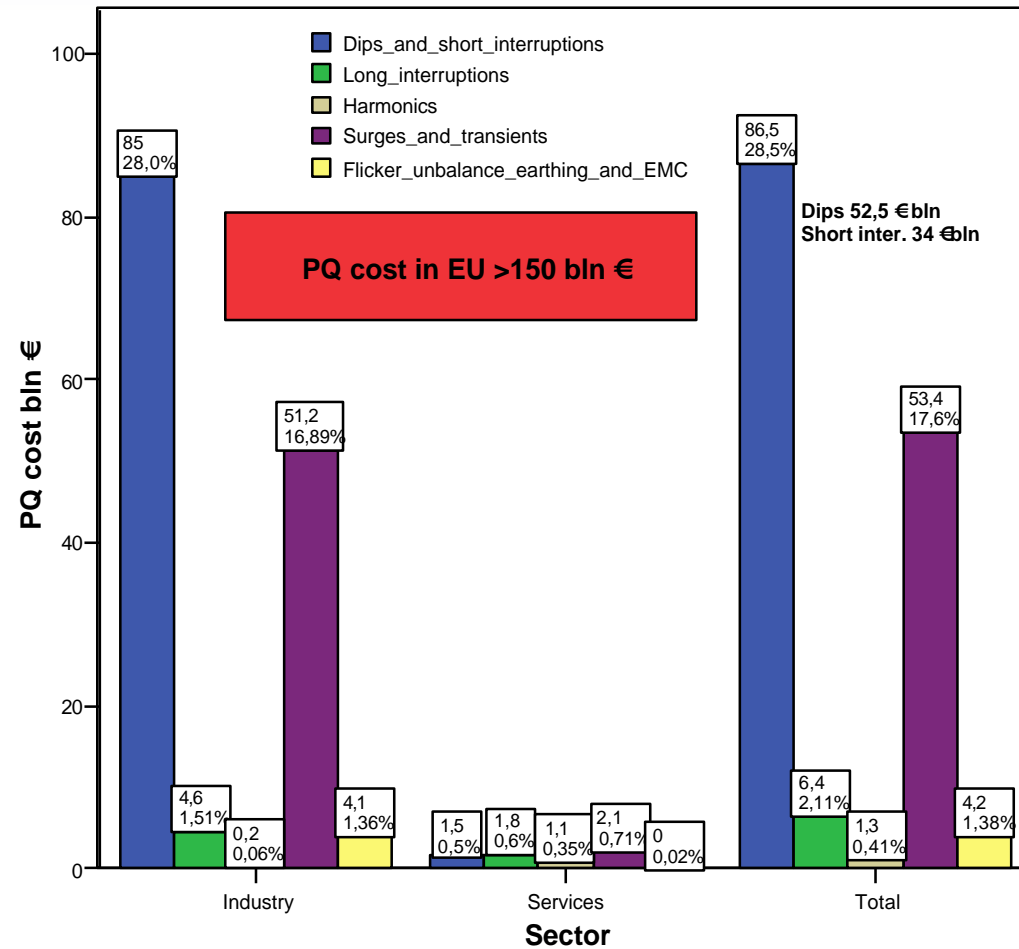
Technical conclusion (1)

- **Although there is no significant correlation between value of solutions investments and real PQ cost, a strong correlation exists between investment in PQ solutions and the hypothetical (mitigated) to real (unmitigated) PQ cost ratio.** 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. The increase in the ratio between hypothetic and real (mitigated / unmitigated) is particularly 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 rather poor correlation between perceived consequences of PQ and PQ solutions used.** In other cases relation of these is difficult to justify from technical point of view. This somehow proves **certain suboptimum in choosing PQ solution in particular case.**
- PQ solutions for all sectors covered [extrapolated from the €300 million identified by the Survey] ~ €13bn or less than 10% of PQ losses & 1% of the average estimated net profit.
- **In general “Services” apply a higher frequency of different PQ solutions than found in “Industry”. “Industry” tends to favour less costly, but also less universal - more tailored solutions whenever possible.**

Technical conclusion (2)

- There is a small but significant (positive) correlation between number of power lines and costs of short interruptions while such a correlation is insignificant in as far as dips are concerned.
- Within PQ measurement issue, a bit surprisingly 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. Examples are; reactive power is measured in 70% of industrial cases, while flicker in 15%. This is 4 times more frequently than in services sectors.
- Services sectors would less often than industry sectors put blame of insufficient PQ on natural causes and more frequently than industry blame themselves.
- Power electronics and other electronic equipment are the main source of perceived PQ problems in general. In industry electric motors are responsible for substantial part of perceived PQ problems as well. Similarly electronic equipment is the category that is perceived as most affected by PQ phenomena for both “industry” and “services”.

PQ cost summary



PQ cost conclusion (1)

- To arrive at a statistically significant and acceptable model the survey sample was divided into two sub-samples - “Industry” and “Services”.
- **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.
- Industry is hardest hit
- Dips, short interruptions, surges and transients account for 80-90% of the €150bn financial costs/ wastage
- Equipment damage and operational waste (unrecoverable work in progress & underperformance) account for similar proportions of the totals identified
- For the most sensitive industrial sectors representing €3,63 trillion (or 20% of EU25 overall turnover) PQ costs amounts about 4% of their turnover.
- The apparently insignificant contribution of “Services” to total PQ costs (0,142% of turnover) may result from certain cost underestimation as this sector often experience problems in an office environment where correctly distinguishing between a PQ cause and other root cause may be difficult.

PQ cost conclusion (2)

The unit cost (per event) of PQ disturbances are:

- The cost per voltage dip event is between 2.000 and 4.000€
- Single short interruptions on average are 3,5 times more costly for industry and 9 times more costly for services.
- The average cost of long interruptions is 90.000€ and is more homogenous across the whole survey sample.
- 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 spans between 120.000€ and 180.000€

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%

Conclusion

- Industry wastes a huge amount of resource unnecessarily.
- The nature of the main causes of poor power quality illustrates that better design and greater investment into these systems would eradicate most of these losses.
- This has always been our contention – we now have the data to support the premise.
- Measurement and diagnostics are significantly low for industrial sectors for which electrical power is so important.
- Industry [and others] would appear to be in denial about the levels of waste incurred and do not relate that to more obvious balance sheet type efficiency monitors.

PQ cost summary

| Disturbance | Occurrence | Cost | Mitigation | Critical areas – sectors |
|---------------|--|---|--|---|
| Voltage dips | <ul style="list-style-type: none"> - joint responsibility of supplier, user and neighbourhood - highly unpredictable although some indicators exist - dependency on location (neighbourhood) - usually frequency from a few to few tens a year - increasing trend | <ul style="list-style-type: none"> - usually between 2000,- € and 20.000,- €/event. Average ~2 k€ and 25% of 1 hour interruption. Cost highly dependent on dip depth and length. - in the case of continuous manufacturing dips are usually responsible for more than 50% of PQ cost. | <ul style="list-style-type: none"> - impossible to eliminate but mitigation techniques exist to reduce vulnerability level - depending on local conditions and type of equipment, different mitigation techniques and levels (equipment, user installation, network) are optimum | <ul style="list-style-type: none"> - continuous manufacturing, - electronics, control systems / equipment, automation and protection systems |
| Interruptions | <ul style="list-style-type: none"> - limited predictability, higher for long interruptions - average a few yearly, local network operator should provide information on SAIFI and MAIFI - trend stable for the amount of shorter duration interruptions | <ul style="list-style-type: none"> - from a dozen or so to tens of k€ per event. Some are of a few millions €. - average for short interruption ~10.000 €/event, 0,01 \$/ kWh, 10 \$/kW. Long interruption usually few times more costly, depending greatly on the end user type - dependency (sustained) on notification and season | <ul style="list-style-type: none"> - 99,99999% reliability systems do exist but costs can be deemed excessive - emphasis on supplier user relations, which may help to minimize consequences and selection of optimum PQ mitigation | <ul style="list-style-type: none"> - industry in general, especially high energy intensive users. Cost varies greatly and highly dependent on duration - transaction sector (credit cards, brokers, banks) food and kindred products, farming, even if interruption is relatively short |
| Harmonics | <ul style="list-style-type: none"> - impacts from both harmonic currents and voltages - directly related to harmonic currents generation sites (power electronics and small SMPS, CFLs) - most often focus on 5th, 7th and 11th | <ul style="list-style-type: none"> - energy losses, up to 50% above pure sinewave losses - life time shortening by a few to dozen or so years - reliability decrease - costs expressed as mitigation cost at the level of 20-30 bln € in countries like France or Germany, Hydro-Quebec Canada source; ~ 650 mln \$ year. | <ul style="list-style-type: none"> - possibility to mitigate consequences locally to acceptable level exist (ie THD < 5%) – costs will vary. - due to changes in power system, active, more costly mitigation may be easier but will be more expensive - the critical issue is the correct addressing of the current distortion origin | <ul style="list-style-type: none"> - neighbourhood of harmonic polluting loads - losses, lifetime & reliability reduction in transformers, motors and cables. - Consequences for ICT equipment |
| Other | <p>Consequences, especially in monetary value not well covered in technical literature. However some observation exists that short and very short disturbances like transients and surges may play higher role in PQ system immunity. Flicker, although some observations suggest that it affects equipment, is still mainly considered as restricted to causing vision problems only. However cost consequences are estimated to be up to 10% percent of an organisation's employment cost.</p> | | | |