Special Report - Session 2
POWER QUALITY & EMC

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Contents

Introduction

The **scope of Session 2** has been defined as follows by the Session Advisory Group :

- **Power Quality (PQ)** : voltage continuity (often referred to as supply reliability - problem of outages) and voltage quality (LF disturbances, ≤ 9 kHz, reaching equipment through the electricity supply) ;
- **EMI, EMF and Safety :** HF disturbances on the electricity supply and all disturbances - HF or LF - reaching equipment other than through the electricity supply ; some safety and resistibility concerns (Electromagnetic fields - overvoltages - step, touch and transferred voltages...) are also considered.

N.B. The concept of **Quality of Supply** is a little broader than Power Quality. In addition to Voltage Continuity and Voltage Quality, it includes the Commercial Quality (quality of response to telephone calls, etc., see Session 6).

The **S2 papers** will be discussed in **three events** :
- Main Session (Thursday 24 May),
- Poster Session (Tuesday 22 May),
- Research & Innovation Forum (Wednesday 23 May, 4:00-5:30 pm).

Two **Round Tables** will be organized :
- Interpretation and application of PQ measurement data (RT.2a, Wednesday 23 May, 9:00-12:30)
- European Regulators & the experience of introduced regulations (RT.2b/6c, Wednesday 23 May, 2:00-3:30 pm).

A **Tutorial** on Power Quality will take place on Monday.
Several PQ&EMC-related papers will be discussed within other sessions (S1, S3, S4, S5, S6).
So, CIRED 2007 will be a great event for all people interested in Power Quality and Electromagnetic Compatibility!

The **aim** of this **special report** is:
1) To present a synthesis of the present concerns in PQ&EMC, based on all selected papers (S2 and other sessions: 143 papers!),
2) To call for prepared contributions at the main session, on particular points which appear in the papers or which are not covered by them.

Call for prepared contributions. Prepared contributions will preferably aim at answering the questions of the Special Report. However, other kinds of contributions will be welcome:
- Fresh information on particular points which appear in the papers or which are not covered by them;
- Case studies (outstanding disturbance experiences, causes, solutions...);
- Comments on a particular paper ("I agree/disagree with that result/conclusion", "My own practical experience in the same field is...");
- Just plain questions to authors of a paper.

All prepared contributions will be published in the **Proceedings**; they will be made available to attendees at the entrance of the conference room and also on **www.cired-s2.org**. Furthermore, some of the most relevant ones will be selected for a verbal presentation (second part of each block at the main session).

General guidelines for authors of prepared contributions:
- Language: English;
- Starting with: title, name of author(s), affiliation, country, number of the relevant question in the special report or number of the commented paper;
- If you wish to use a Power Point slide show, please send the Power Point file also (only pot files received in advance will be available in the computer on the platform) ;
- **Deadline:** 4 May 2007 ;
- **E-mail to :** - emmanuel.dejaeger@laborelec.com ;
  - philippe.goossens@elia.be.

Block 1 : EMI, EMF and Safety

Four different topics are usually addressed in this first block of the session: T1) Pure EMI subjects dealing with immunity and emission, T2) questions related to (lightning or switching) transient overvoltages, T3) safety concerns due to earth potential rises (EPR)[1] and T4) EMF (Electromagnetic fields).

Session 2007 deals with 19 papers with the following repartition:
T1 : 0
T2 : 5 (B1-300,B1-370, B1-526, B1-693, B1-825)
T3 : 4 (B1-203, B1-509, B1-638, B1-805)
T4 : 10 (B1-020, B1-183, B1-242, B1-331, B1-347, B1-382, B1-432, B1-480, B1-597, B1-621)

Although the subject of some papers could be assimilated to electromagnetic disturbances under a certain point of view, the final repartition does not include any paper in topic 1.

Electromagnetic interferences (EMI)

No paper

Transient overvoltages

The overvoltages in LV networks are most of the time due to operations in the MV networks, lightning phenomena and loss of the neutral conductor. The present session addresses this topic through the experience of three network operators: Eskom, Iberdrola and Fortum.

Every year, Eskom registers a lot of claims due to a loss of neutral. In paper [B1-300(SA)], Eskom presents its investigations about this problem. The loss of neutral is mainly due to a bad installation of line taps on transformer bushings, the incorrect application of insulation piercing connectors for conductors connection and the network overloading combined with poor load balancing. Amongst the different solutions applied by Eskom to avoid the loss of neutral, a load switch selector is studied to ensure that the load is well balanced all of the time. Moreover a unit is currently developed which can monitor the current flowing in the neutral conductor and switch off the supply in case of loss of neutral in order to protect people against dangerous voltage.

Transients generated in MV networks by energizing a transformer provoke overvoltages in LV networks that strongly depend on the MV feeder, the breaker technology, the distance breaker-transformer and the LV neutral. Although, according to the standards, this type of soft overvoltage resulting from a network operation is considered as a “normal phenomenon”, paper [B1-526(SP)] reports that Iberdrola registers a growing number of claims for damage of appliances. Two questions consequently arise: either the appliances immunity is not sufficient or the facilities protection is inadequate. The authors recommend an improved overvoltage protection of the customer facilities in compliance with the regulation.

The paper and pulp industry is sensitive to voltage dips and interruptions that are mainly due to the lightning affecting the electric lines in the vicinity. Paper [B1-825(SE)] reports the implementation of solutions by Fortum and Billerud in order to improve the immunity of a paper-mill industry of Grüvon against this problem:
- Replacement of the 30 kV lines by 130 kV cables
- Rebuilding and upgrading the 130 kV line between substation A and Orrby by placing arresters on each phase (and pole-pair), bird protection on the cross-arm over each phase and double shield wires
- Modification of the protection system

After a first lightning season the results are positive.

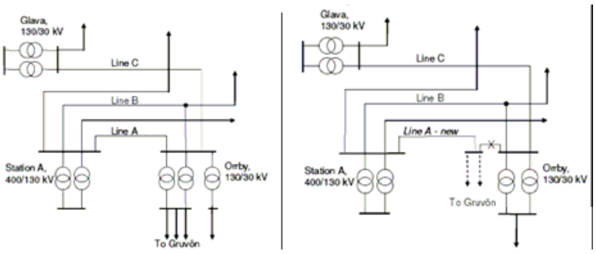

Figure 1: HV-network around Billerud-Gruvön before (left) and after (right) the modifications

On the other hand, the University of São Paulo, in collaboration with a group of electric power distribution companies, is developing a computer system to analyze claim requests related to damaged household equipment due to disturbances from the network. In particular paper [B1-693(BR)] shows how to consider surges and lightning strikes in the computer system: A critical distance which is the minimum distance from the striking point to the distribution transformer that supplies the complaining customer whose the equipment could be damaged is determined (based on ATP calculations and withstand test). The probability of lightning strikes in the region is determined by confidence ellipses.
A risk of damaged equipment arises whenever an intersection exists between the confidence ellipse and the circumference having the critical distance as radius.

Finally paper [B1-370(SE)] shows the presence of a component of a few kHz in the neutral produced by the functioning of PFC technologies. The authors discuss the case of a HF fluorescent lamp (a few kHz) equipped with PFC provoking a neutral current including noise associated with hysteresis control and peaks associated with zero-crossings. This current provokes a neutral voltage (mainly

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[1] In the following we consider the american terminology “ground” and “grounding” as equivalent to “earth” and “earthing”

inductive), which can influence the equipment by generating a current waveform that takes the phase to neutral voltage as reference.

Earth potential rise and safety concerns

It is known that in case of faults in MV grids, touch voltages occur in the LV grid when a TN system is used. In this session, papers B1-203 (NL) and B1-805 (UK) are dealing with this situation.

XLPE MV cables are more and more used in MV networks, and in particular in the Netherlands where the new meshed grids do not yet benefit from global earthing. Paper [B1-203(NL)] studies, through a validated model of new meshed grids, the influence on the touch voltage of parameters like soil resistivity, presence of extra-earthing on MV-side and screen thickness. A reduction of the “source voltage for touch” of about 40% is observed by the presence of an extra-earthing at 50 m from the MV/LV substation. This solution combined to short time settings of protection equipment lets the Dutch supplier Continuon go on with applying TN grounding in their network.

In the UK, the most common earthing arrangement on LV networks is multi-earthed TNC-S. Paper [B1-805(UK)] determines what the actual voltage rise will be on the LV neutral/earth in case of a MV fault.
The calculations, confirmed by measurements, show that the transferred potential to the first electrode A (see figure 3) is about 20% of EPR_{MV} when isolated from the others. The transferred potential to the interconnected electrodes A, B and C is 14,8% of EPR_{MV} and it decreases to 2,5% of EPR_{MV} when A, B and C are connected to low resistance electrode D.

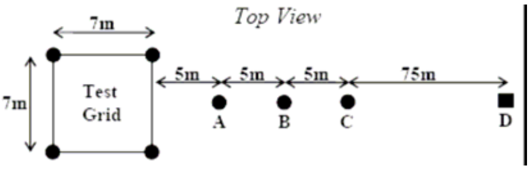

Figure 3: Test grid arrangement

Paper [B1-638(BE)] discusses the consequences of the choice of an earthing system in presence of dispersed generators (DG), the UPS and the microgrids and evokes solutions. In particular, the necessity for these units to work connected to the grid and in islanding includes a careful study.

At last Paper [B1-509(BE)] shows the results of a parametric study about the efficiency of three types of earthing systems for AC-railway in the presence of an electrical fault. The three earthing systems are 1) CdPA (earthing wire) // CdTE (buried earthing electrode) 2) CdPA only 3) CdPA + additional earthing rods. Two typical faults are tested: 1) insulator failure 2) Engine failure.

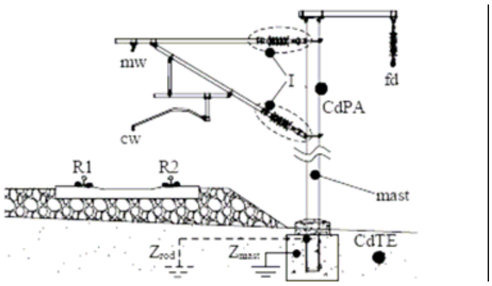

Figure 4: Reference model 2x25 kV electrification

From the study it can be concluded that amongst others:

- High leakage admittance of the tracks should be ensured. This induces other problems e.g. for the signals transmission.
- Additional rods should be connected to some or every mast in case of high soil resistivity
- CdPA and CdTE must be present

Electromagnetic fields

ICNIRP recommends to limit the exposure to the magnetic field at 100 µT (50 Hz) for the public. Most countries base their requirements on this limit but some countries require other very low limits based on epidemiologic studies (e.g. 1 µT in Switzerland).
Moreover, at least until the end of April 2008, the European Union member states have to enforce the legislative disposals needed to conform to directive 2004/40/EC fixing the minimum health and safety requirements regarding the exposure of the workers to the risks arising from the electromagnetic fields from 0 Hz to 300 GHz.
The problem at of the magnetic field is an actual and highly sensitive subject and is consequently regarded as the hot topic of this session with 10 papers dealing with the methods of measurement, measurement campaigns and mitigation techniques.

Under the question “is there a need to take action?”, paper [B1-432(AT)] proposes to non experts a simple method – based on Ampere’s law - to evaluate the compliance of their installation to the directive 2004/40/EC. In case of calculated values exceeding the limits, the authors recommend to let the exposure situation be analyzed by experts.

Paper [B1-382(BE)] points to the fact that the directive 2004/40/EC - which is based on ICNIRP - does not take into account the specificities of certain applications. In this framework the ICNIRP summation formula for evaluating the simultaneous exposition to magnetic fields of different frequencies overestimates the real cumulated magnetic field because it does not take into account the phase relation between the different occurring harmonics. Next to this the author proposes a process to make a scientifically correct workplace assessment using phantom bodies and to compare the results with the Directive's exposure limit value.

Paper [B1-621(AT)] observes, in the same way, specific problems inherent to the measurement of magnetic fields by modern field meters (spectral leakage in FFT, filter and damping effect).
Also, this paper proposes a measurement method allowing to the separation of the spatial characteristic of the magnetic field from the time characteristic. Moreover a method is proposed to identify the part of the magnetic flux density coming from a certain conductor.

Paper [B1-183(FI)] proposes another method for extrapolating the large amount of magnetic field values measured inside MV/LV substation in Helsinki in order to assess the magnetic field in the locations situated above the substations.

$$B_{obs} = KB_{meas}\frac{I_{obs}}{I_{meas}} \bullet \frac{d}{0.13} \bullet \frac{B_{obs,ref}}{B_{meas,ref}}$$

where K is the cumulative 50 Hz exposure coefficient, B_{meas} the measured magnetic field, I_{obs} the reference load current to be used in the extrapolation, I_{meas} the measured load current, d the phase distance, $B_{obs,ref}$ and $B_{meas,ref}$ respectively the reference values for the measurement point and for the observer which are defined for a known situation.
B_{obs} can be directly compared with the magnetic field 50 Hz public guideline value of 100 µT
This extrapolation method is valid since the author proves that the inaccuracy stays under 26 %.

Paper [B1-331(FI)] from the same authors proposes a way to categorize the magnetic field in indoor MV/LV substations by the layout of the LV connections (place of the LV connections, busbar/cables, shielding of the LV connections). The goal is to evaluate the risk of exceeding the public reference limits around the substations in function of the LV layout.
In addition of the numerous factors that can affect the magnetic field, the paper presents a summary of magnetic field levels measured in 50 substations from 5 companies in Finland.

Paper [B1-242(EG)] also categorizes indoor substations according to their structure and cabling system (cable, bus way[2] or busbar).
Moreover, the paper shows that LV-busbars and enclosed dry transformers give rise to low magnetic fields, the best results being obtained for LV-busways. In particular, the magnetic field measured in a flat above a substation was strongly reduced by 50% by choosing a low losses transformer and by rearranging the loads on the LV cables.

Taking into account the existence of an "installation limit value" of 1 µT in Switzerland, paper [B1-020(CH)] proposes mitigation techniques through rebuilding or shielding in order to strongly reduce de field around existing substations. Beside the presentation of good results, the authors raise some interesting questions about the problems arising from having to reach such a low limit.

Paper [B1-480(CA)] proposes a series of methods for mitigating the magnetic field produced by distribution networks. Those methods directly act on the source (shielding, conductors management etc.)

- Underground cables are preferred to aerial lines but are more expensive.
- Shielding is a very expensive solution that can be implemented only for underground networks
- The phase optimization is a very effective way to reduce the magnetic field

The authors present the split-phase solution which consist in adding two extra conductors to a three-phase circuit ABC to obtain (current ratio) A/2, A/2, B, C/2, C/2 and which consequently reduces the magnetic field (figure 5).

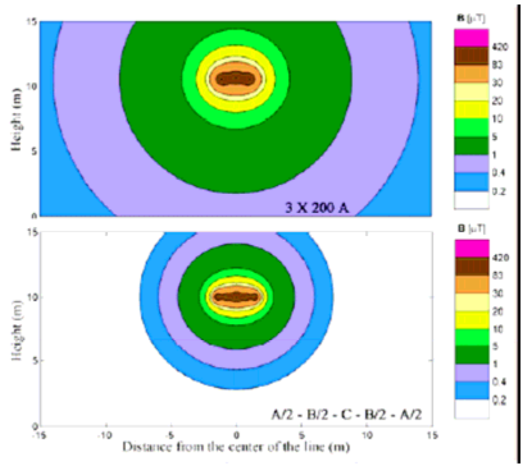

Figure 5: reduction of the magnetic field of one three-phase circuit

The impact of the phase optimization is also confirmed by paper [B1-597(AT)] which demonstrates, by calculating the magnetic field produced by different HV lines configurations (tower head geometry, phase configurations, presence of earth wire), that the choice of the type of HV-line/tower has to be carefully studied with regard to the place where the magnetic field has to be reduced (see figure 6).

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2) shielded busbar

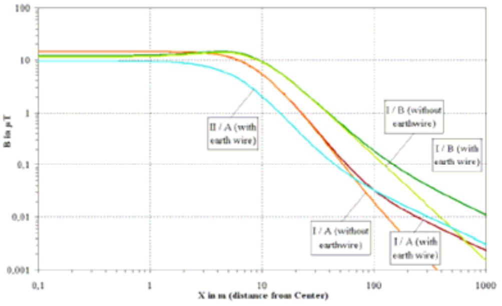


Figure 6: A=config ABC-CBA; B=config ABC-BCA; I=standardized tower head; II=compact tower head

Paper [B1-347(AR)] shows the advantages of the finite element technique for calculating the electric and magnetic fields in more complex situations (multiple conductors, asymmetric configurations, asymmetry in phases, multiple circuits, complex geometry, irregular ground, several types of ground with respective conductivity, permittivity and permeability, obstacles presence (trees, mills, etc.).

Through a developed case study the authors obtain good magnetic field mitigation by changing classic to compact configurations, by phase inversion in multi-circuits lines or by action on distortion elements (e.g. vegetation)

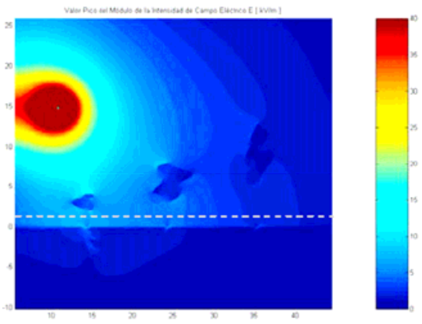


Figure 7: E field - EHV 500kV horizontal configuration with vegetation

Questions on Block 1

Transient overvoltages

B1-1: Papers 300 and 526: Which procedures do you follow to manage the claims arising from overvoltages?
As the voltage and transient measurements cannot be performed everywhere in the network, how do you determine the nature of the damages?
Do you treat the claims coming from the industrial customers and those coming from the residential customers in the same way?

B1-2: Paper 693: In Brazil, is it the responsibility of the network operators to protect the customers against the lightning overvoltages and to indemnify them in case of damage?
What is the policy in other countries?

B1-3: Paper 825: From which level of electrical disturbances do you estimate a customer can ask for a modification of the electrical network? Do you think that the network operator should contribute financially to the modification of the network in order to limit the disturbances due to lightning?

Earth potential rise and safety concerns

B1-4: Paper 805: You had planned additional measurements/calculations in the current of February and March. Do you already have some interesting results?

B1-5: Paper 509: What should the ideal track-to-ground leakage admittance be in order to assure the signaling quality and also to reduce the voltage rise of tracks in case of engine failure?

Electromagnetic fields

B1-6: Paper 382: In 2003, ICNIRP published guidance on determining compliance of exposure to pulsed fields and complex non-sinusoidal waveforms below 100 kHz. The directive 2004/40/EC refers to Cenelec standards for these situations. Doesn't Cenelec base the future TC106x on the above-mentioned ICNIRP guidance? Did you confront your method to the one exposed in the ICNIRP guidance?

B1-7: General: What is the position of regional and/or national authorities in matter of EMF limits for the public? Is there a tendency to reduce the limits to very low values such as in Switzerland? Is there a tendency to take into account the weak statistic link observed between the childhood leukaemia and a long-term middle value of 0,4 µT observed by some studies?

Block 2 : Connection of disturbing installations

Assessment of disturbing phenomena and emission levels

Modeling studies and measurements are complementary to assess voltage disturbance levels in distribution networks. New developments are reported hereafter concerning simulation tools, measurement methods and measurement results.

Modeling. The *short circuit power* Ssc at a connection point is an essential parameter to assess the emission levels of a disturbing installation. The relations are straightforward for voltage changes and voltage unbalance; they are more complex for voltage harmonics due to possible resonance phenomena (hence the need for harmonic impedance assessment).

[B2-721(CA)] reports on direct harmonic impedance measurements making use of a harmonic current generator (up to 3 A in the 120/240 V residential electrical circuit). Figure 1 shows example laboratory test results; in LV systems, however, harmonic orders higher than the 15th are frequently affected by resonance conditions.

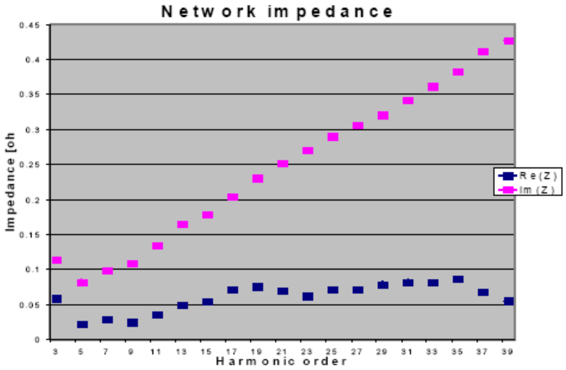


Figure 1 : Harmonic impedance measurement, laboratory test results (in ohm ; blue: real part, red: imaginary part)

[B2-161(IT)] & [B2-898(IT)] study the minimum Ssc levels needed to fulfill given limits for Rapid Voltage Changes (RVC). Starting from $\Delta u \approx \Delta S_{customer}/Ssc$ and from the assumption that $\Delta S_{customer} \approx K_t \cdot S_{rated}$ (for normal "non-disturbing customers"), it comes $Ssc_{min} \approx K_t \cdot (S_{rated}/\Delta u_{max})$. From preliminary considerations, the values of K_t may be assessed as $2/\sqrt{(S_{rated})}$ for HV and MV customers, and $1.3/\sqrt{(S_{rated})}$ for HV/MV and MV/LV substations (S_{rated} being expressed in MVA). For example, applying the assessment for MV customers, 7 % of the busses do not comply with the criterion if $\Delta u_{max} = 3$ %.

Several papers report on development of **measurement methods** concerning flicker, harmonics, power factor in presence of harmonics, high-frequency components.

Two papers propose improvements to the UIE/IEC *flickermeter*. [B2-831(PL)] claims that a flickermeter based on neural networks would give far better compliance with IEC 61000-4-15 than most presently available apparatus. [B2-663(NL)] presents a lamp model that can be adjusted within the flickermeter for different lamp types so as to get a correct flicker assessment in cases that the standard 60 W incandescent lamp is not the most widely used.

[B2-850(HR)] proposes a method to assess the contribution of a particular customer to the total *harmonic* distortion (THD) of the system voltage (measurements at different points of the network and at different moments).

[B2-745(AR)] studies the problem of assessing the *power factor* (PF) in presence of harmonics. If harmonics are taken into account in the definition of P and Q $P=\sum U_h I_h \cos\varphi_h$, $Q=\sum U_h I_h \sin\varphi_h$ then the "deformation power" D must be added in the formula giving the apparent power (see Figure 2) : $S=\sqrt{P^2+Q^2+D^2}$

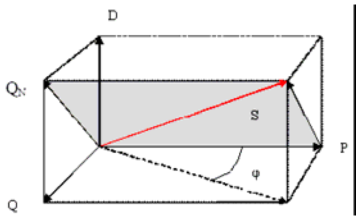


Figure 2 : Geometric representation of the links between P, Q, S and D

The proposal is then to introduce the "non active power" $Q_F=\sqrt{Q^2+D^2}$ in the assessment of the power factor $PF=\cos[\mathrm{arc\,tg}(Q_F/P)]$. This method gives a lower PF than the classic consideration of the phase angle between the fundamental components of current and voltage, i.e. a far better signal on inefficient energy demand (see also below considerations from [B2-290(MY)] on the "true power factor").

Emission limits for low-order harmonics have a.o. resulted in the use of active power factor correction (APFC) circuits which produce *high-frequency* conducted disturbances. [B2-071(SE)] shows how to measure and analyze such HF disturbances. Figure 3 gives the results for a computer with APFC : the current waveform is much closer to a pure sine wave than with a conventional rectifier power supply but its spectrum exhibits a wideband component from about 125 to 280 kHz. This component is also visible in the voltage spectrum when the computer is connected. A further spectrogram analysis shows however that what appears to be a broadband component is in fact a time-varying narrow-band signal. The signal shifts in frequency with a period of 10 ms and is therefore synchronized with the power frequency at 50 Hz.

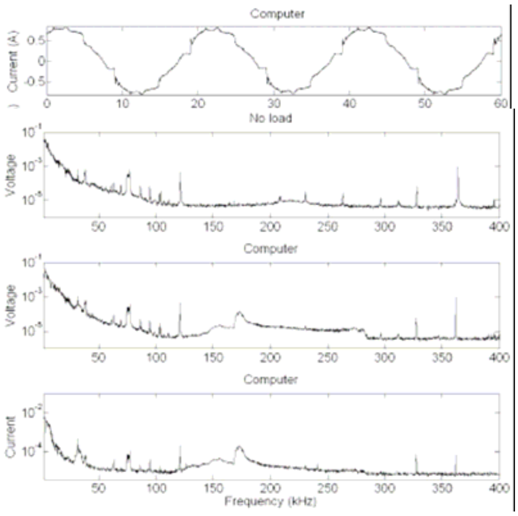


Figure 3 : Computer with switch mode power supply equipped with APFC. From the top : measured current waveform, spectrum of the voltage at no load, id with the computer, spectrum of the current

Finally, interesting **measurement results** are to be found in the following papers.

[B2-892(INT)] : an international survey of *unbalance* levels has been performed by CIGRE/CIRED JWG C4.103 as a basis for recommendations on how emission limits can be assessed for unbalanced installations connected to EHV, HV and MV systems (future IEC 61000-3-13). The survey results are summarized in Figure 4 to Figure 7 (95% weekly 10-min values).

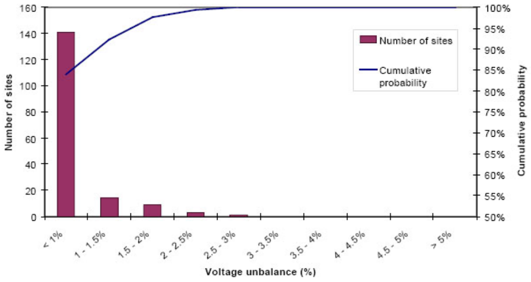


Figure 4 : Measured unbalance levels at 168 EHV sites

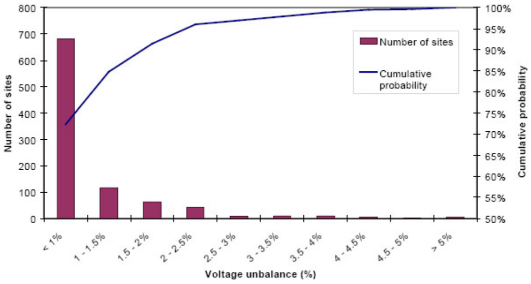


Figure 5 : Measured unbalance levels at 940 HV sites

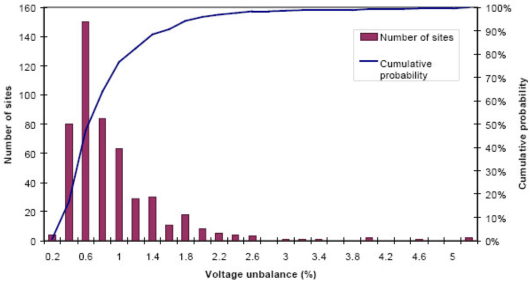


Figure 6 : Measured unbalance levels at 497 MV sites

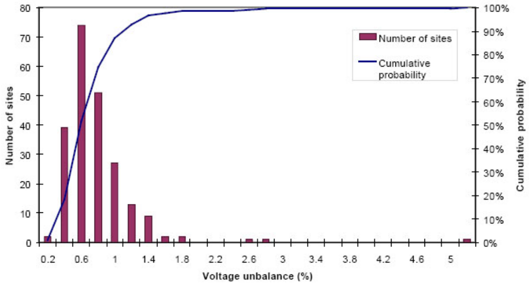


Figure 7 : Measured unbalance levels at 222 LV sites

Unbalance from untransposed lines must be taken into account (cases of heavily loaded HV lines not longer than 20 km have been shown to give rise to voltage unbalance levels of 1%). The impact of unbalance attenuation from HV to MV (typically 0.95) and from MV to LV (typically 0.9), due to motor loads, must also be considered.

[B2-610(FR)] reports on a *harmonic* survey on LV networks since 2000. As usual, the most critical harmonic order is the 5th one (but 3rd ad 9th voltage harmonics may also be very high at the end of typical LV feeders). Figure 8 shows results for 16 typical LV networks in 2006 (from 10-min averaged 200-ms RMS values).

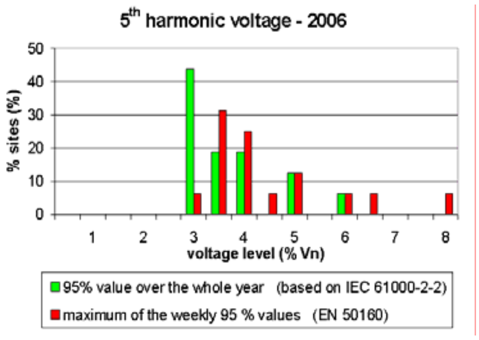


Figure 8 : 5th harmonic in French LV systems

Quite logically, worse-week statistics are more severe than yearly statistics because weekly statistics may vary a lot along the year (see Figure 9).

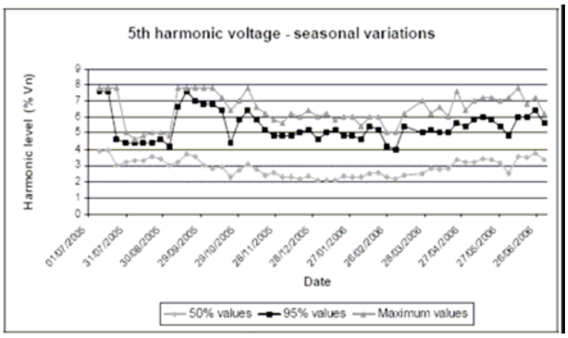


Figure 9 : Variations of the 5th harmonic voltage (weekly statistics) on a LV network

No significant evolution in harmonic voltages has been recorded between 2000 and 2006, contrarily to previous years. It is probably a positive consequence of the EN 61000-3-2 coming into force in 2001 (European standard limiting harmonic emission from household appliances).

[B2-442(GR)] gives an evaluation of the additional losses due to harmonics in the Greeks MV and LV distribution networks : 0.15-0.20% (to be added to the 6.55% power frequency losses). The authors consider such an increase as not significant (same order of magnitude as the various non-technical losses).

[B2-290(MY)] studies the same problem for Malaysian LV networks. The main cause for loss increase is the degradation of the "true power factor" :

$$\mathrm{TPF} \approx \frac{P_1}{V_1 I_1} \frac{1}{\sqrt{1+(\mathrm{THD}_I/100)^2}}$$

see Table 1. Power factor correction by a detuned harmonic filter connected at the LV bus of the MV/LV transformer results then in a reduction of about 10% in losses at fundamental frequency in the LV cables and transformer.

Table 1 : Power rating, harmonic current distortion and power factor of common LV nonlinear loads

LOAD	KVA	*THD$_I$* (%)	PF	TRUE PF
Air Conditioner	1.25	9.8	0.96	0.9
Refrigerator	0.23	4.1	0.58	0.58
Mag. Ballast FL	0.113	8.3	0.53	0.53
CFL	0.024	134	0.98	0.47
TV	0.13	115	0.96	0.59
PC	0.16	84	0.99	0.75

Disturbing loads and assessment of emission limits

[B2-893(INT)] reports on the work of JWG CIGRE/CIRED C4.103 determining PQ emission limits for installations connected to EHV, HV, MV and LV power systems. Three technical reports have been delivered to IEC concerning harmonics (updating IEC 61000-3-6), flicker (updating IEC 61000-3-7) and voltage unbalance (future IEC 61000-3-13) for EHV, HV and MV levels. A fourth report will cover emission limits for LV installations (future IEC 61000-3-14). [B2-681(BE)] gives the procedures set up in Belgium by the distribution system operators to deal with this last issue.

[B2-241(EG)] studies the harmonic currents from several types of modern lamps at nominal- and reduced voltage. Permissible standard limits are exceeded in some cases.

[B2-063(GB)] reports on-site measurements and modeling studies of harmonics on two MV distribution networks in view to the connection of new compressor motors, showing that no room was left for new emissions of 5th and 7th harmonics.

DC traction loads are known as major harmonics sources and may give rise to voltage fluctuations too. [B2-50(GB)] shows that through a careful optimization of the grid transformer impedance, it is possible to improve the performance of a metro system connected at the MV level. However, constraints on fault level may dictate the need for compensating equipment. [B2-125(IT)] looks at the possibility to connect railways substations at the MV instead of HV level where HV lines are not available. Beside the advantage of minor costs for the apparatus, this solution necessitates the careful study of possible harmonic problems.

A particular harmonic problem is reported by [B2(S3)-463(BR)] for 34.5 kV sub-transmission using the Single Wire Earth Return (SWER) system (typically for rural consumers located far from load stations). The increasing use of non-linear loads causes high third harmonic currents resulting in the disconnection of feeders.

Another issue with nonlinear loads is their modeling for power system studies. It is customary to model nonlinear loads as pure harmonic current sources, ignoring the effect of background harmonic voltages (see also below considerations from [B2-013(DE)] and [B2(S4)-641(ES)] on PV generation).

[B2-408(BE)] deals with LV harmonic simulations, introducing a new nonlinear transformer model and using two models for nonlinear loads: either fixed- or voltage-dependent current sources (simulation in the time domain). Fixed current sources gave rise to overestimation of the voltage THD by some 20 %.

[B2-764(NL)] & [B2-765(NL)] propose a new method to take account that a nonlinear load may be a voltage-dependent harmonic current source: the so-called "harmonic fingerprints". The harmonic currents of the nonlinear appliance are measured in the laboratory with an undistorted voltage and then with harmonic voltages varying from 0.5% to 5% magnitude and phase shift from 0° to 360° (Figure 10).

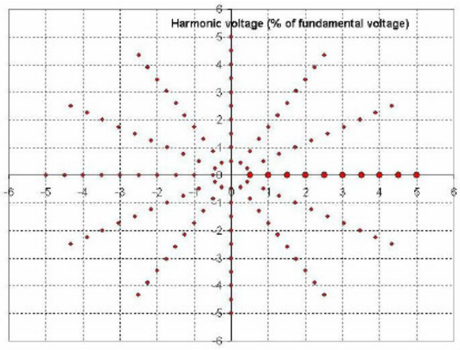


Figure 10 : different values of each harmonic voltage used to determine the harmonic fingerprint of an appliance

If the nonlinear load has a "linear behavior", including no cross-interference (a nth harmonic voltage will only give a reaction on the nth harmonic current), then a simple scheme can be used for the calculations

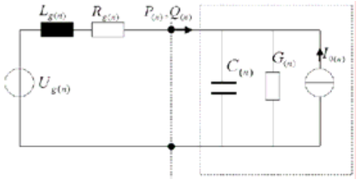


Figure 11 : Simple scheme for harmonic calculations (nonlinear load with "linear behavior") where Io, G and C are independent from harmonic order n

However, this is not the general case, see e.g. the fingerprints of a personal computer (Figure 12).

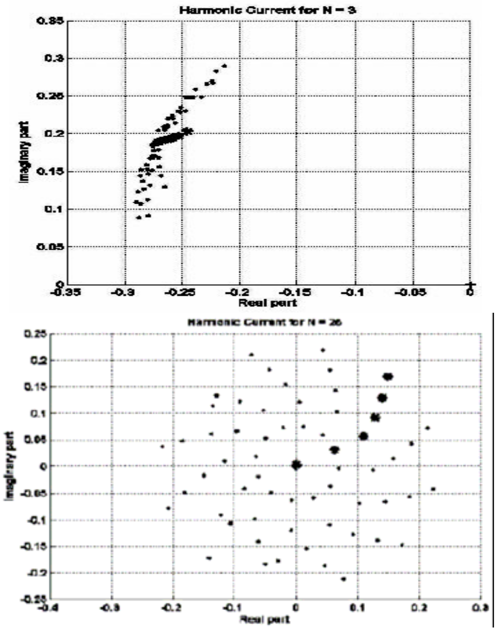


Figure 12 : Harmonic fingerprints of a personal computer for the 3rd and 25th orders

The complete fingerprint matrix must then be used for the calculations (Figure 13), and these calculations have to be repeated iteratively until convergence is reached.

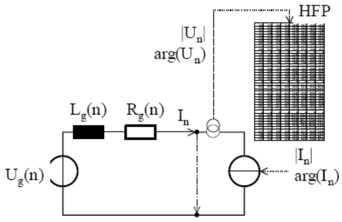


Figure 13 : Load model for nth harmonic with Harmonic Fingerprints lookup table

The responsibilities are then clear: the customer has to limit the harmonic currents injected at the connection point whereas the grid operator is responsible for the harmonic background voltages.

[B2(S5)-458(GB)] analyses two important categories of electronic nonlinear loads : an unregulated diode rectifier with or without a switching dc-dc converter (so called switch-mode power supply – SMPS). Existing general load models could be used for the representation of active power demand of these loads, but fail to accurately represent their reactive power demand (strong influence of source inductance, and internal circuit inductance and capacitance).

Dispersed generation (DG)

[B2(S4)-680(FR)] presents the French Connection Rules for decentralized generation. The procedure implies a coordination between the TSO and the DSO for the management of the waiting lists (Figure 14). The connection rules consider a.o. flicker and harmonic emission, influence on remote control signals (see also below considerations from [B2-515(BE)] on inverter impedance), voltage dip withstand capability.

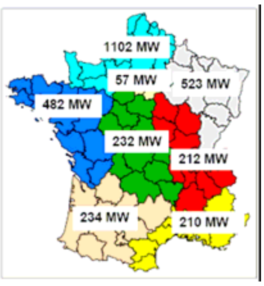


Figure 14 : Waiting lists for Decentralized Generation connections (mostly wind farms) on French distribution networks (January 2007)

[B2-225(PL)] studies the switching transients of capacitors associated with asynchronous wind generators. The Prony method proved more accurate than the Fourier transform for the assessments.

Photovoltaic (PV) generation is rapidly growing at household level due to public financial incentives. [B2-013(DE)] shows that the emitted harmonic currents depend strongly on the harmonic voltages (Figure 15), which is not considered in the present standard test conditions.

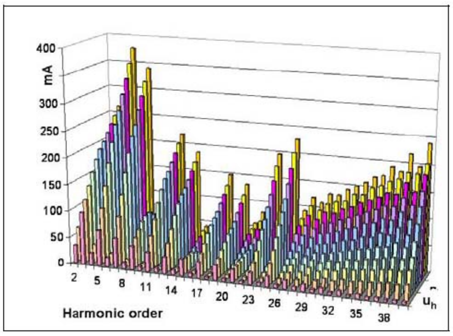


Figure 15 : Harmonic currents from 3kW-inverter (at 50% of rated power) for increasing harmonic voltages (from 0% to EN 50160 limits)

Following [B2-513(AT,SI)], PV penetration causes a very limited increase in VSV (very-short voltage variations – variations between 3 s and 10 min) but a higher increase in voltage rise. [B2(S4)-641(ES)] reports on the development of a tool for calculating the effects of PV-systems on a LV grid (voltage fluctuations, inversion of power flow, increase of fault level). Harmonic calculations are very difficult because of the effect of harmonic voltages on emitted harmonic currents.

Another possible effect of DG units is their influence on ripple control signals. [B2-515(BE)] reports on the impedance of three-phase inverter front-ends for frequencies used in ripple control. The equivalent impedance of the inverter and DC circuit (without the AC filter) is similar in shape to the AC impedance of the DC circuit, but shifted towards higher frequencies by about 50 Hz. Its magnitude depends on inverter modulation ratio, switching frequency and rated power.

Disturbance mitigation at the source

In this section we consider specific mitigation techniques (filters, compensators...) which are needed for the integration of a particular disturbing device in the power system.

The performance of the classic Static Var Compensator (SVC) is frequently insufficient to allow the connection of present very large electric arc furnaces (EAF). [B2-519(SE,CN)] reports on the use of a STATCOM of about 82 Mvar for the connection of a 140 MVA EAF in a 220 kV network in China. The flicker improvement factor (Pst 95 % values) was evaluated between 5.3 and 5.5.

[B2-505(SI)] studies HV excessive flicker levels due to two electric arc furnaces. System solutions have proven to be ineffective and difficult to realize. For one EAF, installing a series inductor should be sufficient; for the other one, a STATCOM is needed.

[B2-471(BE)] describes a global evaluation of PQ in the region of Douala (economic capital of Cameroon), leading to several recommendations such as the use of STATCOM compensation for arc furnaces and the integration of DG for fast electrification.

It is well known that transformer inrush currents may be troublesome for the network, especially when frequent switching is used (e.g. in arc furnace installations). [B2-694(IN)] presents a new mitigation technique where flux reduction is achieved by applying a voltage to the core with the help of a tertiary winding prior to primary circuit energization. The effectiveness of the method is demonstrated for single-phase transformers.

Questions on Block 2

B2-1: It has been stressed that DG will increase the fault level in distribution networks, which seems favorable for the connection of disturbing installations. However, it has also been stressed that the impedance of PWM converters is more complex than the one of conventional rotating machines. What will be the impact for disturbing load connection studies?
B2-2: PWM converters have very low emission levels for low-order harmonics but generate high-frequency conducted disturbances. Is information available concerning adverse effects of these components? What emission limits are or should be applied to them?
B2-3: Paper [B2-442(GR)] shows that harmonic losses in Greeks MV and LV networks don't exceed 0.15-0.20% (to be added to the 6.55% power frequency losses) which seems to be insignificant. However, another contribution at the CIRED conference some years ago (CIRED 2001, S2 Proceedings, p.24, contribution on Question 7.1 from R. Gretsch, available on www.cired-s2.org) concluded that harmonic losses in German networks would reach the same order of magnitude as the yearly production of a 500-MW wind farm. Are harmonic losses an economical issue or not ?
B2-4: Paper [B2-663(NL)] proposes to improve the UIE/IEC flickermeter so as to get a correct flicker assessment with several types of lamps. However, using different lamp models will yield different results for assessing the voltage quality of a given network. Besides, the present "compatibility levels", "voltage characteristics" and "planning levels" were established by making a correlation between grid exploitation records and measurement results gained with the existing flickermeter. What would then be the use of an improved measuring instrument?
B2-5: Voltage-dependent harmonic current sources [013, 408, 641, 764, 765]. Taking account of the numerous uncertainties in prediction studies, is it justified to refine the nonlinear-load models? Is it not more comfortable to have a 20% overestimation of harmonic voltages? Can the error be much more important than 20%? What should be the approach regarding the evolution of the standardization?

Block 3 : Voltage dips and other disturbances on the grid

Assessment of voltage dips and other disturbing events

[B3-671(BR)] and [B3-884(IR)] study the optimal allocation of PQ meters for **voltage dip** estimation (or, more generally, "short duration voltage variations" – SDVVs).

[B3-633(GB)] presents an automated voltage dip assessment software giving the dip performance at LV buses (i.e. at equipment terminals) from higher voltages measurements and simulations. Influence of transformers and induction motors is taken into account.

[B3-157(HR)] presents 1-week voltage dips measurements in 13 LV transformer stations. The lognormal probability distribution was found to give the best fit.

Table 2 and Table 3 from [B4-042(IT)] give the first results of the PQ monitoring campaign which started at the beginning of 2006 in Italy (600 measurement units).

Table 2 : Average yearly number of dips measured on MV busbars of Italian HV/MV substations

Residual voltage [%]	20-100 [ms]	100-500 [ms]	0.5-1 [s]	1-3 [s]	3-60 [s]	Total
90>u≥85	14.6	5.6	0.4	0.2	0.1	21
85>u≥70	17.7	17.0	0.8	0.3	0.1	35.9
70>u≥40	15.0	28.8	0.5	0.1	0.1	44.5
40>u≥10	3.2	13.8	0.3	0.1	0.0	17.4
10>u≥1	0.3	1.2	0.0	0.0	0.0	1.5
Total	50.8	66.4	2	0.7	0.3	120.

Table 3 : Yearly number of dips exceeded at 5% of the MV busbars of Italian HV/MV substations

Residual voltage [%]	20-100 [ms]	100-500 [ms]	0.5-1 [s]	1-3 [s]	3-60 [s]	Total
90>u≥85	42.9	18.7	2.4	1.0	0.6	65.6
85>u≥70	47.3	57.0	3.4	1.0	0.4	109.
70>u≥40	56.8	105.5	2.4	1.0	0.4	166.
40>u≥10	8.4	43.8	1.0	0.5	0.1	53.8
10>u≥1	1.0	7.4	0.0	0.0	0.0	8.4
Total	156.4	232.	9.2	3.5	1.5	403.

[B3-229(EG)] proposes a "sag criterion" for MV distribution networks, based on 10-years measurements, simulations and assessments of customer costs, see Table 4 where a yearly-occurrence limit is given for each dip (sag) type.

Table 4 : Proposed MV voltage dip criterion table

	0-0.05 s	0.05-1 s	1-10 s	10-60 s
70-90%	-	-	8	6
50-70%	5	2	1	0.5
10-50%	1	0.8	0.7	0.3

[B3-647(IT)] compares the voltage dip performances of three MV networks situated in the core of industrial areas. It appears that Petersen coils help to reduce not only the number of interruptions, but also the number of dips coming from the evolution of ground faults into short-circuits (this confirms the results of a previous study showing a reduction by more than 35% of the number of short-circuits).

Five papers deal with recording, analyzing and classifying **PQ events** in distribution substations. [B3-873(US)] studies the recording tools based on the types of events to be recorded, the recording capabilities of the IEDs existing in the substation and IEDs available on the market (waveform recording, high- and low-speed disturbance recording, periodic measurement logging...). Attention is also paid to the distributed PQ recording system architecture.

[B3-500(TH)] recalls the IEEE (Std.1159-1995) classification of PQ events (Figure 16). It shows that the wavelet-based method performs better than other conventional methods (RMS value, Orthogonal Component and Peak Voltage Method) for measuring magnitude and duration of PQ events.

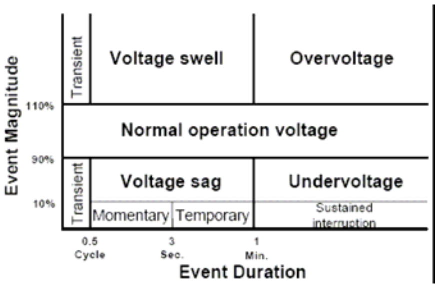


Figure 16 : Duration of voltage magnitude events as defined in IEEE Std.1159-1995

[B3-488(AE)] introduces the Windowed Wavelet transform as a new tool that can enhance wavelet-based monitoring tools (monitoring different disturbances that may reside in different frequency bands).

The two last papers in this sub-block recommend the use of the Support Vector Machine (SVM) method for automatic classification of PQ disturbances.

[B3-827(CO)] recalls the way SVM operates (Figure 17). In order to discriminate between 5 types of PQ disturbances (sag, swell, flicker, osc. transient, harmonic), a 2-step method is recommended: i) detection and identification using the Discrete Wavelet Transform, ii) classification using the SVM method (other methods like ANNs – Artificial Neural Networks – proved less efficient).

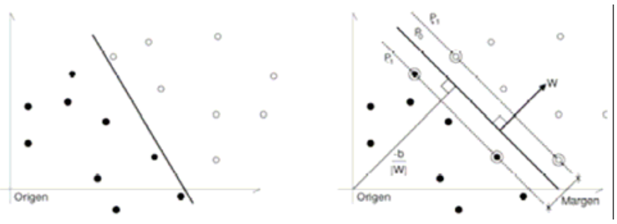


Figure 17 : Principle of the SVM method (search for the optimal separation hyper-plane between 2 categories of data)

[B3-888(SE)] deals with pure PQ events (thus not the sudden appearance of stationary phenomena like flicker or harmonics) : D1: 1-phase dip, D2: 2-phase dip, D3: 3-phase dip, D4: step-change (+), D5: step-change (-), D6: interruption, D7: transformer energizing. A 2-step method is recommended: i) detection of transition segments, ii) classification using the SVM method. Figure 18 explains what a "transition segment" (TS) is (events D1-D3 are with 2 TSs, while events D4-D7 are with 1 TS).

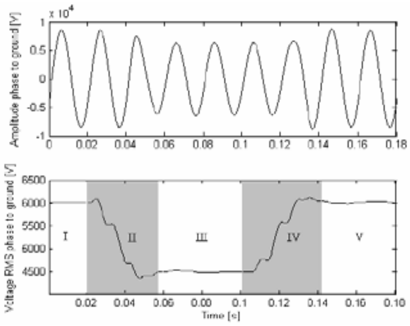


Figure 18 : Voltage event with its waveform (top) and RMS signature (bottom) ; shadowed areas indicate transition segments

Sensitivity of industrial equipment (to voltage dips and other phenomena)

[B3-173(INT)] CIGRE/CIRED/UIE JWG C4.110 has undertaken an international study on equipment voltage dip immunity which should lead to new proposals for standard immunity curves. Present equipment performance has first to be assessed. As an example, Figure 19 shows that not all contactors satisfy the ITIC curve.

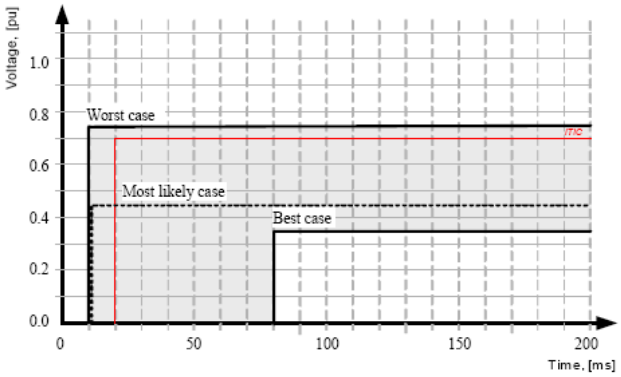


Figure 19 : Voltage tolerance curve for ac contactors with ac control coil

Voltage dips are complex phenomena which must be carefully characterized ("pre-dip", "during-dip" and "post-dip" characteristics; distinction between "simple dip events" and "composite dip events"...). The performance of a distribution system may be presented by using graphs with remaining voltage and duration, see for example Figure 20.

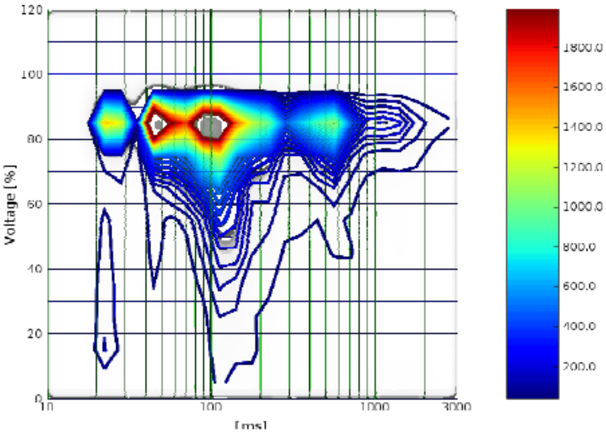


Figure 20 : Voltage-dip performance of a system (the number of dips recorded during the study is shown by the color code)

However, to obtain a complete picture of the supply performance it is essential to consider the 3-phase character of the system; different curves similar to Figure 20 should be established for different types of unbalanced dips.

Figure 21 from [B4-590(DE)] shows a typical tolerance curve for adjustable-speed drives (ASD, the most sensitive 3-phase device) : the acceptable limit depends on the need for a constant rotational speed for the driven industrial process.

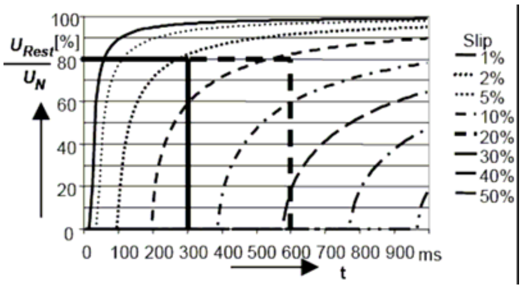


Figure 21 : Typical tolerance curve for ASDs

[B3-325(AU)] presents results of 1.5-year voltage dip measurements at seven manufacturing plants (22 kV) with systematic correlation with possible equipment stoppages. Figure 22 shows the results along with the common immunity standard curves.

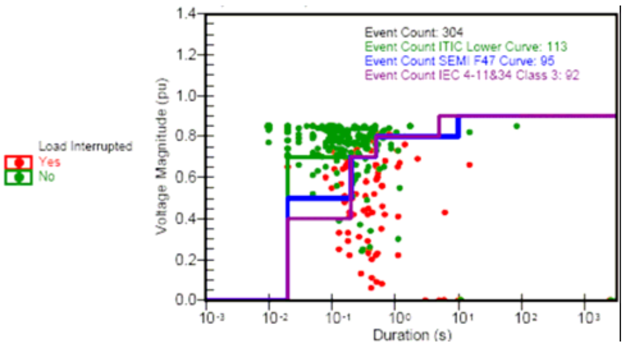


Figure 22 : 7 sites, from 15/08/2004 to 31/01/2005 voltage magnitude-duration plot with and without load interruptions

It appears that all manufacturing sites generally have ITIC immunity. Certifying equipment to IEC 61000-4-11 (<16A) or 61000-4-34 (>16A) will give no significant improvement. Most equipment stoppages will still happen. There is a need to define new immunity curves, giving differentiated immunity levels, taking account of distribution network protection design and performance (see e.g. Figure 23).

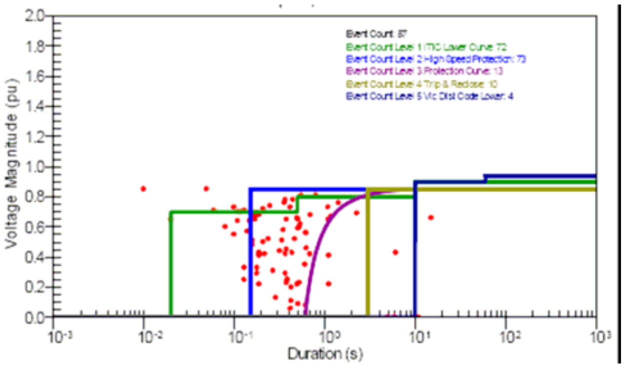


Figure 23 : Same results as on Figure 22 (but points with load interruption only), along with the proposed 5-level immunity curves

[B3-167(AR,US)] gives experimental results of voltage dip (sag) immunity for six different types of contactors, see for example Figure 24 and Figure 25.

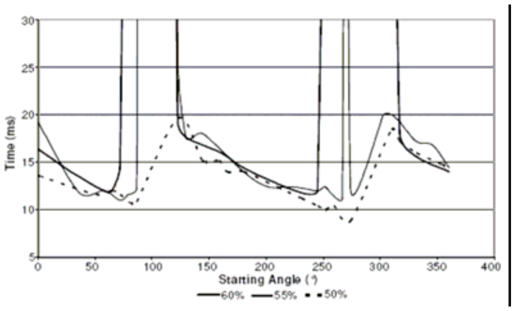


Figure 24 : Experimental contactor opening time vs. starting angle without phase-angle jump

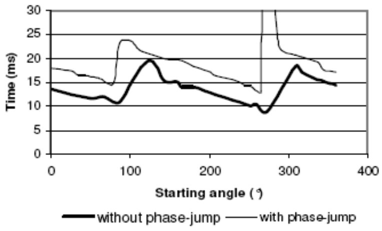


Figure 25 : Same contactor as on Figure 24, 50% curve without and with 50° phase-angle jump

The most critical moment for voltage dip initiating is around voltage zero crossing (starting angle 0°) : a voltage drop to 70-80 % (remaining voltage) is enough to cause contactor opening. For starting angle near the peak voltage, the magnitude for contactor opening drops to nearly 50 %. Figure 24 shows indeed that the opening times becomes infinite (no opening) for dips of 55 or 60 % and starting angles around 90° and 270°. Besides, Figure 25 shows that a phase-angle jump of 50° improves the contactor behavior.

Similar results were obtained with the six types of contactors, the worst conditions being zero starting angle and zero phase-angle jump.

[B3-166(AR,US)] deals with motor restart after a voltage dip or short interruption (these phenomena represent more than 85 % of industrialists' complaints to utilities, due to huge economic losses - $ 10 000 on average in case of production halt). A simplified analytical methodology is presented, that allows industrialists to determine the maximum duration that their production-line sensitive equipment may be kept in-condition for a successful restart process.

[B3-826(BE)] studies the effects of another phenomenon on induction machines: voltage unbalance. The thermal behavior of the machine is changed due to reduced torque (Figure 26) and negative-sequence currents. The motor efficiency is lowered (Figure 27), which is a problem at the time of the Kyoto protocol, knowing that induction machines represent the bulk users of energy in industry while being more and more used in micro generation units.

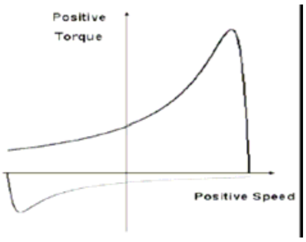


Figure 26 : Positive and negative torques of an induction motor subjected to positive- and negative-sequence voltages

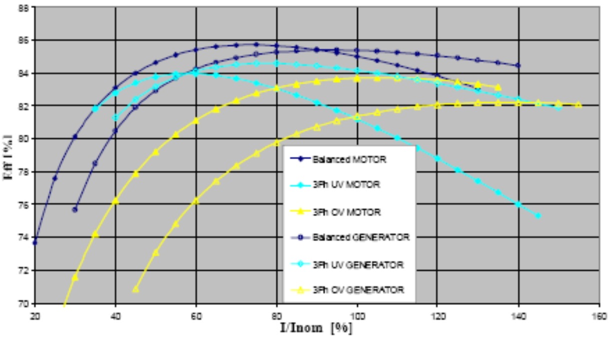


Figure 27 : Example efficiency of an induction machine (generator and motor mode) with V2/V1=4%, the three voltages being in undervoltage (UV) or overvoltage (OV)

Disturbance mitigation near sensitive equipment

In this section we consider specific mitigation techniques (filters, compensators...) aiming at protecting sensitive equipment. They may be installed in the power system or near the victim.

Voltage dips and others. [B3-054(US)] presents the Voltage Support Transformer (VST) designed to mitigate voltage dips and capacitor switching overvoltages. The VST is a single-phase transformer that mutually couples the same phases of two or more lines (HV, MV or LV). It uses a change in current from one line in which a fault condition or other power perturbation exists to create a voltage change in one or more of the other lines connected to the same bus, to maintain or support the voltage in those lines at or near pre-perturbation levels. The fault current is also reduced by the intrinsic impedance of the VST. Figure 28 shows the principle of action and Figure 29 gives the results of a high-power test.

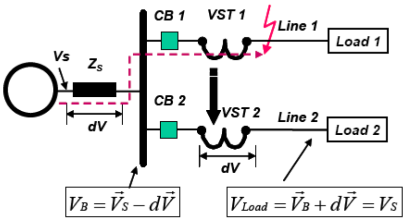


Figure 28 : Fault event with the VST

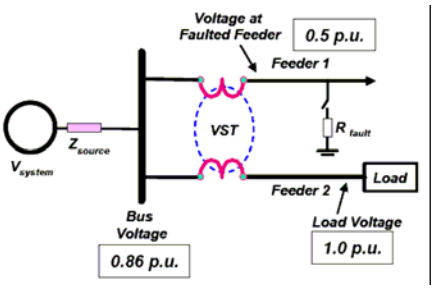


Figure 29 : Effectiveness of the VST in supporting the load voltage during faults on nearby feeders

[B3-554(ES)] presents the SET DVR which has extended capabilities as compared to the existing DVRs : additionally to compensate 30-s 50% dips, it also mitigates flicker, harmonics, unbalance and transient overvoltages – without any energy storage components. It may be connected in series (via a booster transformer) with an installation at any voltage level.

Reactive power and others. [B3(S1)-410(ES)] describes a four level power electronic converter designed for MV grid reactive power compensation. It allows optimizing power quality and operating conditions of the distribution network.

Harmonics. [B3-284(EG)] proposes to use the ANN (neural network) model to determine size and location of active power filters (APF) in a distribution system in order to fulfill harmonic limits while minimizing compensation currents.

Two papers are devoted to the problem of harmonic resonance on MV distribution systems. [B3-277(EG)] suggests a hybrid active filter for damping the resonance: an active filter is connected in parallel with a passive filter. It detects the harmonic current flowing into the passive filter and is controlled in such a way as to behave as a resistor. It prevents the passive filter from overcurrent and may totally eliminate resonances.

[B3-737(US)] considers that in many cases, it may be much more economical to control the voltage distortion experienced by all customers by changing the frequency response of the system rather than trying to solve the problem within customer facilities. This can be accomplished with a tuned capacitor bank on the MV system (see also above considerations from [B2-290(MY)] on the reduction of harmonic losses through LV filters).

Flicker. Series compensation is a classical way of reducing the flicker level downstream the capacitor. [B3(S3)-840(BR)] reports about a case of voltage oscillations in a 23 kV system due to the coupling between the series capacitor (-j35Ω) and large induction motors. It was finally decided to install the series capacitor on another feeder.

[B3-057(NL)] presents an electronic Power Quality Optimizer (PQO) designed to reduce flicker in rural LV networks. It is able to compensate single-phase phenomena. The principle of operation is similar to the STATCOM, the PQO behaving like a voltage source in parallel with the network. In the considered case study, the network reinforcement would cost more than € 100 000. A PQO with a peak rating of approx. 50 kVA could solve the problem at a fraction of the price.

Voltage unbalance. [B3-098(DZ)] describes the control of an SVC for compensating unbalanced loads on distribution systerms.

Finally, four papers study the possibility of **making use of distributed elements** (mainly PWM converters) for **PQ improvement** (mainly harmonics).

[B3-605(NL)] studies the influence of inverters for Distributed Generators (DG) on network harmonics. Figure 30 gives the model of a typical inverter with the output filter located outside the current control loop and Figure 31 shows the output impedance of this inverter. Such an inverter contributes to the harmonic voltage pollution because of its interaction with the background pollution and because its output capacitance contributes to lowering the resonance frequency of the network.

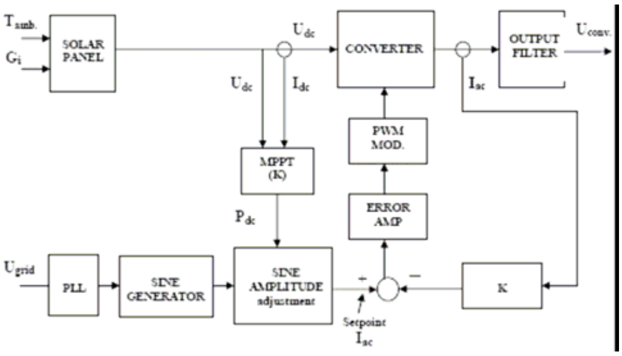


Figure 30 : Inverter model with the output filter outside the current control loop

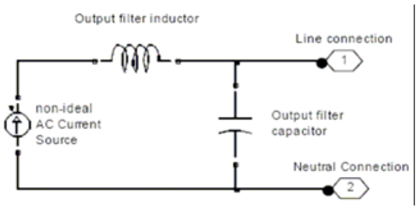


Figure 31 : The output impedance of the inverter of Figure 30 is dominated by the output filter capacitor

A first step to improvement is to build inverters with a low output capacitance, for instance by compensating the output filter with a control loop. A further step is to add a harmonic compensation loop. It becomes then possible for DG inverters to contribute to the reduction of harmonics in distribution networks as an ancillary service.

[B3-366(CN)] presents a novel control strategy for DG in view to PQ improvement (harmonics) in the distribution system. A smooth transition from interconnection- to islanding mode is also ensured.

The main objective of [B3-820(PL)] is to develop a central control system which, on the basis of a set of input signals (mainly voltages and currents measured at selected points), will generate reference signals for individually controlled, distributed devices (distributed generators, active filters, static var compensators...). Optimization of the whole is achieved by means of genetic algorithms. Simulation results are given for harmonics in the distribution system.

[B3-736(US)] concludes that integrated voltage regulation (multiple dispersed generators performing voltage regulation) can increase the voltage regulation capability and reduce the capital and operation costs. Power electronic converters have fast dynamic response, which can effectively compensate a.o. voltage dips and voltage unbalance.

Questions on Block 3

B3-1: Is automatic classification of PQ disturbances already in use? Is it done with the Support Vector Machine (SVM) method or another one ? Is such an automatic classification considered as necessary?

B3-2: Are voltage dip immunity curves like the ones of Figure 23 considered as sufficiently representative? Would it not be justified to introduce different kinds of ordinates for different kinds of sensitive loads? (e.g. the positive-sequence voltage for rotating machines, the worst-phase voltage for single-phase appliances, the best-phase voltage for capacitor-smoothed converters, ...).

B3-3: Is centralized compensation making use of dispersed converters (for DG etc.) already a reality today? What are the difficulties to be overcome? Is some local compensation (without central control) profitable as ancillary service from DG?

Block 4 : Power quality in the competitive market

Power quality indices

PQ indices are a key issue. Standards and recommendations state limits that remain useless as long as measurements do not deliver values which may be compared to the limits. Up-to-date information may be found in the report from JWG CIGRE/CIRED C4.1.04 (see the Final WG Report, "Power Quality indices and objectives", March 2004, available on www.cired-s2.org) and in the most recent draft IEC standards (IEC 61000-3-6/7/13...).

For long interruptions (>3min), allowance is foreseen for different practices such as counting the number of interrupted customers (only used at MV and LV levels) or registering the non-delivered energy. The three fundamental quality indices (site- or system indices) are always :

- AIF = average interruption frequency (=SAIFI=CI) : the yearly number of outages per customer,
- AID = average interruption duration (=CAIDI) : the average duration of an interruption,
- AIT = average interruption time (=SAIDI=CML) : the yearly average interruption time per customer (i.e. the product of the two other indices).

Simulations are often useful to predict quality indices related to possible system developments. [B4(S4)-750(KR)] shows that the reliability indices (AIT, AIF, etc.) of a distribution system including PV generations may be obtained by an analytical method, providing results almost comparable to the ones of a Monte-Carlo simulation method.

New PQ indices are considered in three papers. [B4-154(YU,BR)] shows that high levels of load unbalance induce significant real power oscillation resulting in greater losses. The "power oscillation index" (POI) is suggested as a new PQ index for MV and LV distribution networks.

Beyond general PQ indices, [B4(S3)-022(SA)] reports on criteria for selecting MAJOR incidents. Experiences gained and lessons learned from these incidents will help to enhance the supply reliability of the system.

[B4-134(SE)] starts from the observation that individual customers are satisfied as long as they have less than 3 interruptions per year, none of which lasting longer than 8 hours (Figure 32), and proposes a new reliability index: the customer dissatisfaction index (CDI), i.e. the probability that this condition is not fulfilled.

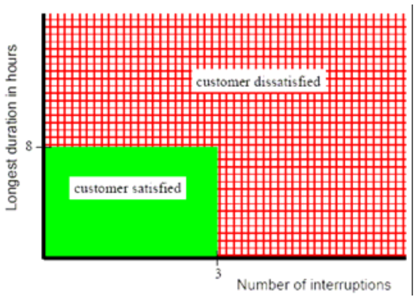


Figure 32 : Relation between number of interruptions, duration of interruptions and customer satisfaction

Then, the system average customer dissatisfaction index (SACDI) is the average value of CDI over all customers

$$\mathrm{SACDI} = \frac{1}{N}\sum_{i=1}^{N} \mathrm{CDI}_i$$

Note that CDI and SACDI may be estimated from the classic PQ indices as soon as the probability laws are known or assumed, see for example Figure 33 (Weibull distribution with shape factor 1.5 for the duration of an interruption, exponential distribution for the time between interruptions).

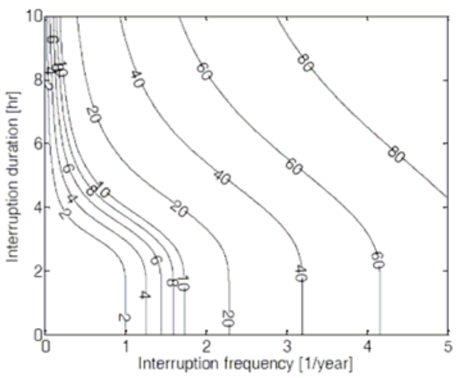


Figure 33 : Contour chart for CDI (% values) in function of the average interruption frequency AIF (or SAIFI) and the average interruption duration AID (or CAIDI)

CDI and SACDI may be used in performance reporting or in a design criterion (e.g. limiting SACDI or limiting the number of customers for whom CDI exceeds a given value).

A **global PQ assessment** is proposed in two papers. [B4(S5)-326(RU)] recommends to assess the quality of complex technical systems by the "functioning quality index" $F_x(t)$, a function that includes several quality indices.

[B4-705(PT)] recommends the use of a single PQ index when comparing different sites and different periods, for continuous disturbances on the one hand and for discrete disturbances on the other hand.

For continuous disturbances (voltage magnitude, frequency, harmonics, flicker, unbalance...), each percentile is divided by the corresponding limit. In normalized form, an index is at the limit of acceptability when its value is one. The site single PQ index is then either the greatest value (for all phenomena and all three phases) if all resulting values are lower than one, or the sum of all resulting values greater than one.

For discrete disturbances, the severity index is based on the ITIC reference curve :

$$S_e = \left| \frac{V - 100\%}{V_{REF}(t) - 100\%} \right| \cdot 100\%$$

S_e is calculated from the aggregated event list, for events outside ITIC limits, multiplied by the number of affected phases. For the selected period, the different severity indices will be summed to result in a single site index (a secondary index, the "energy loss", is also presented).

Time-dependent PQ indices (and limits). For continuous disturbances (harmonics, flicker, unbalance...), most PQ indices are week percentiles which are not sensitive to short-duration high levels. For [B4-830(ZA)], PQ compliance criteria should be questioned. The voltage level, for example, has to be U_N±10% in terms of the 95% weekly 10-min value, and 2 successive 10-min periods. However, large deviations for short periods may not be outside the specifications, even if they detrimentally affect customers' appliances. An alternative approach might be to define an acceptable envelope for the duration and magnitude of the voltage excursion, as illustrated in Figure 34. The envelope will be determined by economic considerations (network investment against customer costs and the risk of damage to equipment). A similar approach might be proposed for other PQ parameters (voltage unbalance, etc.).

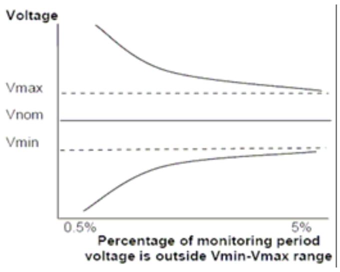


Figure 34 : Proposed definition of allowable voltage variation

Power quality monitoring in general

Hardware aspects. [B4-777(DE)] describes the hardware implementation of a PQ monitoring system. The instrument transformers were calibrated for very low errors in frequency response. Obtained results may be used in online applications.

[B4-830(ZA)] describes results from a proof-of-concept project to make a low-cost, adaptable logger to measure, store and communicate network performance data (see also the above sub-block on PQ indices).

In order to assess the supply reliability of LV distribution systems, [B4(S5)-483(CN)] proposes to select some LV monitoring points and to use the collected data to calculate PQ indices like AIT and AID.

For [B4(S3)-426(KR)], PQ monitoring can be gained from a distribution automation system (DAS) by adding new functions in the system.

Crossing databases. Following [B4-303(FR)], crossing measured data (from PQ devices) with collected ones (in the supply continuity database) allows to enrich the PQ database of a DNO in order to improve his working processes and manage more efficiently the measured customers PQ reports (about 25% of all French MV customers today).

[B4-558(ES)] describes a PQ monitoring system, matching multiple sources of information (PQ, lightning, SCADA) in order to be able to address PQ problems and their sources quickly. Many things are assessed like, for example, transformer losses due to harmonics (since only voltages are recorded, currents are approximated by using a 10% pure inductive short-circuit reactance and neglecting harmonics at the HV side of HV/MV transformers).

Customer information. [B4-558(ES)] and [B4-544(RO)] want to enlarge users audience to non-PQ specialists through web access.

[B4-705(PT)] stresses the importance of providing information from a PQ monitoring system in a very simple and fast way through the web, using compressed indices (see also the above sub-block on PQ indices).

[B4-735(BR)] presents a PQ indicator management system, based on the RIQEE (PQ index recorder), allowing to take over and warn the clients very fast at the beginning of- or before a significant disturbance.

Compliance with limits. [B4-698(AR)] presents 10-year harmonics & flicker measurements in Buenos Aires distribution systems (steady levels during the whole period). Utilities are penalized for each site in which IEC limits are exceeded (1.2 % of all sites for harmonics, 2.5 % for flicker). So far, more than 300 complaints have been dealt with, mostly due to flicker ; surprisingly, a lot of them arose for $Pst_{95} < 1$ (Figure 35).

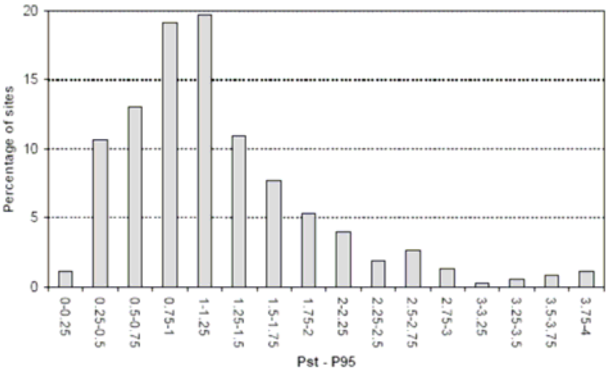


Figure 35 : Histogram of Pst values (95 percentiles) in complaint cases

[B4-544(RO)] concerns the development of a PQ monitoring system at the TS/DS interface (110 kV), with web access for final users. Preliminary 7-month data show a few values exceeding the limits for overvoltages (U>121kV), harmonics (THD>3%), and – less frequently – for flicker and voltage unbalance.

[B4-654(IT)] gives the results of 8-month PQ monitoring at MV busbars of 346 HV/MV substations and 89 MV/LV customers' substations. Voltage unbalance and THD are well within the EN 50160 limits. Plt > 1 values were recorded at 14% of the sites, but the influence of voltage dips is suspected.

[B4-093(CZ)] presents the PQ monitoring system used in the Czech Republic. 9-month results (2006) are reported for a lot of 400/110 kV and 220/110 kV substations. Limits were never exceeded for harmonics (2.5 % THD) and voltage unbalance (0.8 %). On the contrary, flicker limits were exceeded in 5 % of observed weeks for Pst_{95} and 55 % of weeks for Plt_{95}. Quite surprisingly, Plt_{95} was higher than Pst_{95} in 66 % of week measurements (*question to the authors: is it not due to special events like voltage dips, i.e. to values which might be removed before flicker analysis?*).

Correlations with system- and environmental conditions. [B4-813(DE)] presents a method based on cluster analyses that quantifies the dependencies of PQ-parameters on NCE-parameters (describing consumer and network structure, and environmental conditions). It is a first step in the development of a PQ prediction system which should allow introducing PQ aspects in planning and optimizing performance of existing networks.

For [B4-654(IT)] no correlation was found between short-circuit power on the one hand and dips, flicker, harmonics, unbalance on the other hand.

[B4(S5)-283(AU)] studies the relationship between weather variables and reliability indices. It appears that wind-gust speed is the parameter that dominates the occurrence of interruptions during storms (Figure 36). Faults begin to occur whenever wind-gust speeds exceed about 40 km/h (at such speeds, wind blown debris can begin to bridge a typical 3-4 m vegetation clearance). Future work is proposed to develop normalization techniques in order to get PQ indices (AIT, AIF, AID) which better reflect the under-lying network performance.

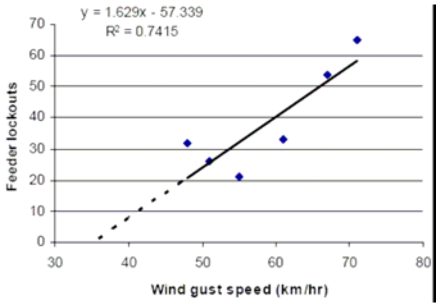


Figure 36 : Wind-gust analysis of 2005/06 exception events

Costs aspects of power quality

[B4-910(INT)] presents the new CIGRE/CIRED JWG C4.107 whose objectives are to develop a framework for analysis of the economics of PQ and to produce a guide that summarizes available information about cost-benefit analysis of PQ. It is proposed to separate PQ into two broad classes: quasi-stationary phenomena (harmonics, flicker, unbalance...) and discrete events (voltage dips...) and to consider two economic analysis methods, direct and indirect, both applicable to both types of phenomena.

[B4-244(SI)] aims at estimating the costs of **PQ-related phenomena** affecting industrial sites in Slovenia. From on-site visits and interviews, first rough estimations could be gained, contributing to a broader study carried out in 8 European countries of which the report is given by [B4-263(PL,GB)]. The study led to an extrapolation of the overall wastage caused by poor PQ in EU-25, see Figure 37. The main conclusion is that PQ costs in Europe are responsible for serious reduction in industrial performance with an economic impact exceeding € 150.10^9 per year. This is consistent with a study by EPRI CEIDS in US in 2000 (between $ $119\text{-}188.10^9$).

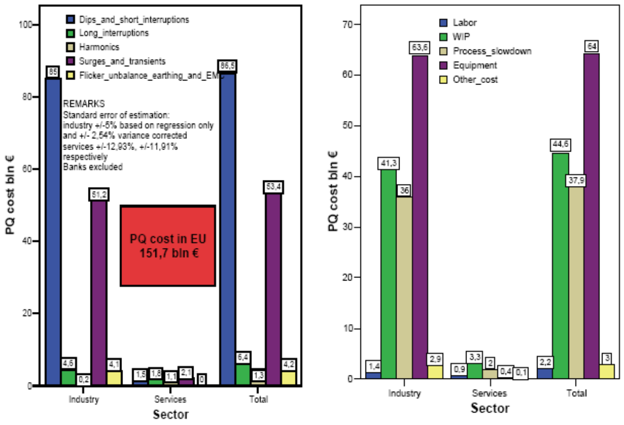


Figure 37 : Cost of PQ wastage EU-25 by PQ phenomenon and cost category

Voltage dips. Following [B3-166(AR,US)], voltage dips and short interruptions represent more than 85 % of industrialist complaints to utilities due to the huge economic losses they suffer ($ 10 000 on average in case of production halt). For the three plants considered in [B4-204(SE)], the average loss is € 150 000 (see Table 24 where 1 910 / 12.75 = 150 kEUR).

Considering a 20-year planning period for a test network (9.2 MW delivered to MV nodes at the beginning of the study period), [B4(S5)-412(IT)] starts with an optimization without voltage dip (VD) requirements (see on Table 5 the "do nothing" network), then evaluates the marginal costs for lowering the max VD frequency, see Figure 38. The conclusion is that network actions are very expensive and not fully justified for reaching quality levels probably too high for many customers.

Table 5 : Optimal network arrangements without PQ constraint ("do nothing" network)

Building cost	6109.16 k€
Cost of energy losses	1852.12 k€
CAPEX and OPEX	**7961.28 k€**
Cost of EENS	379.67 k€
Cost of voltage dips*	209.97 k€
Total cost	**8550.92 k€**
SAIDI	48 min
SAIFI	1.79
Av. VD frequency**	7.59
Max VD frequency**	12.88

*cost of single voltage dip equal to 1000€
**critical voltage threshold equal: 50%of nominal voltage

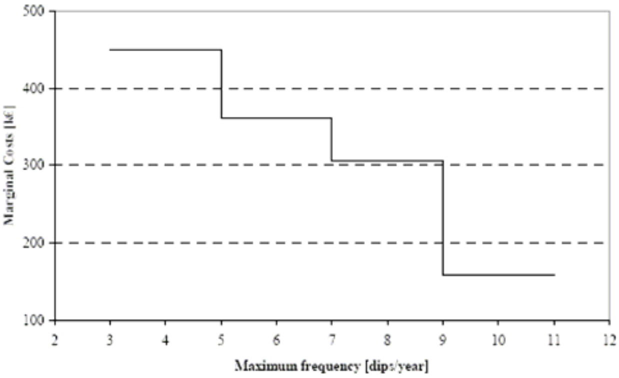


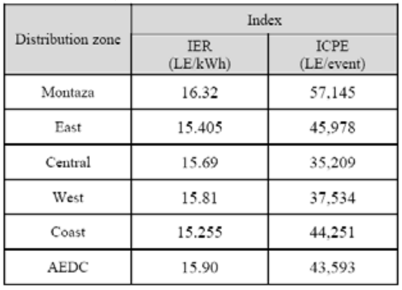
Figure 38 : Marginal cost from the "do nothing" network when lowering max VD frequency

Long interruptions. [B4(S5)-479(AR)] examines different Customer Outage Cost (COC) models, concluding that regardless the model, the decision-making process conducts to the same solutions for system development.

The aim of [B4-164(AR)] was to assess the value of ENS (energy not supplied) for residential customers. Relying on interviews, three assessment methods were used ("alternative activity", "no use of appliances" and "family income") providing consistent results. Finally, the average value for any 1-hour power cut which might occur at any time during the year is estimated at 2.82 USD/kWh.

Following [B4-226(EG)], the Alexandria Electricity Distribution Company (AEDC) assesses the reliability worth from customer outage costs. Customer surveys allow to build customer damage functions (CDF), then averaged sector CDF (i.e. SCDF) and finally a composite CDF (i.e. CCDF). The obtained CCDF and the actual interruption statistics are used to evaluate the outage cost for each distribution area and for the whole AEDC, see Table 6.

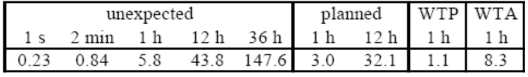
Table 6 : Outage costs for each area and for the whole AEDC
(N.B. On 19/03/2007, 1 LE = 1 EGP = 0.13 EUR = 0.18 USD)



Distribution zone	Index	
	IER (LE/kWh)	ICPE (LE/event)
Montaza	16.32	57,145
East	15.405	45,978
Central	15.69	35,209
West	15.81	37,534
Coast	15.255	44,251
AEDC	15.90	43,593

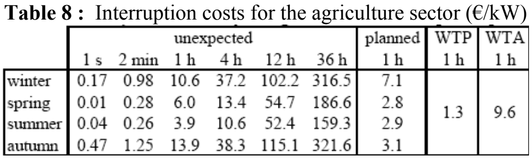
[B4(S6)-542(FI)] describes the method and gives the results of the Finnish reliability worth study, see Table 7 to Table 11 (customer surveys, direct evaluation of costs, results calculated with the aggregating method; wh refers to working hours in the tables). WTP (willingness to pay for better reliability) and WTA (willingness to accept compensation for worse reliability) questions were asked to residential and agriculture customers only. In general, reliability worth has doubled since the previous Finnish study in 1994, i.e. customers' expectations on reliability have increased.

Table 7 : Interruption costs for the residential sector (€/kW)



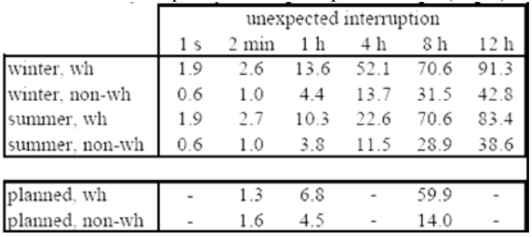
unexpected					planned		WTP	WTA
1 s	2 min	1 h	12 h	36 h	1 h	12 h	1 h	1 h
0.23	0.84	5.8	43.8	147.6	3.0	32.1	1.1	8.3

Table 8 : Interruption costs for the agriculture sector (€/kW)



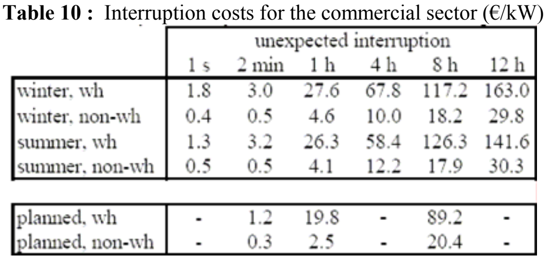
	unexpected						planned	WTP	WTA
	1 s	2 min	1 h	4 h	12 h	36 h	1 h	1 h	1 h
winter	0.17	0.98	10.6	37.2	102.2	316.5	7.1	1.3	9.6
spring	0.01	0.28	6.0	13.4	54.7	186.6	2.8		
summer	0.04	0.26	3.9	10.6	52.4	159.3	2.9		
autumn	0.47	1.25	13.9	38.3	115.1	321.6	3.1		

Table 9 : Interruption costs for the public sector (€/kW)



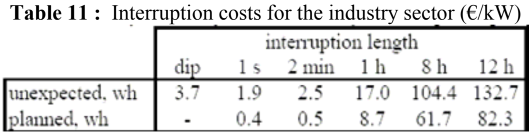
	unexpected interruption					
	1 s	2 min	1 h	4 h	8 h	12 h
winter, wh	1.9	2.6	13.6	52.1	70.6	91.3
winter, non-wh	0.6	1.0	4.4	13.7	31.5	42.8
summer, wh	1.9	2.7	10.3	22.6	70.6	83.4
summer, non-wh	0.6	1.0	3.8	11.5	28.9	38.6
planned, wh	-	1.3	6.8	-	59.9	-
planned, non-wh	-	1.6	4.5	-	14.0	-

Table 10 : Interruption costs for the commercial sector (€/kW)



	unexpected interruption					
	1 s	2 min	1 h	4 h	8 h	12 h
winter, wh	1.8	3.0	27.6	67.8	117.2	163.0
winter, non-wh	0.4	0.5	4.6	10.0	18.2	29.8
summer, wh	1.3	3.2	26.3	58.4	126.3	141.6
summer, non-wh	0.5	0.5	4.1	12.2	17.9	30.3
planned, wh	-	1.2	19.8	-	89.2	-
planned, non-wh	-	0.3	2.5	-	20.4	-

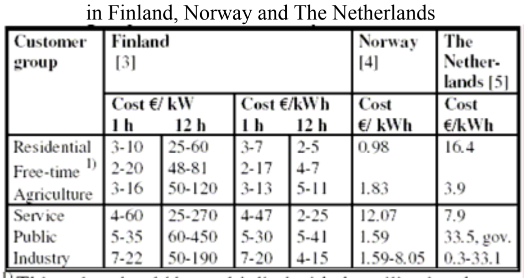
Table 11 : Interruption costs for the industry sector (€/kW)



	interruption length					
	dip	1 s	2 min	1 h	8 h	12 h
unexpected, wh	3.7	1.9	2.5	17.0	104.4	132.7
planned, wh	-	0.4	0.5	8.7	61.7	82.3

[B4(S5)-559(FI)] gives a comparison of ENS costs in several countries (Table 12). As the worth of outage costs tends to rise with time faster than other costs, it will play a more and more important role in electricity network design in the future.

Table 12 : Typical value of ENS for different customer groups
in Finland, Norway and The Netherlands



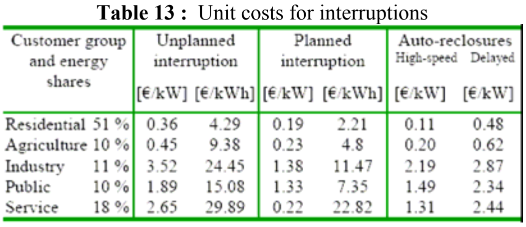
Customer group	Finland [3]				Norway [4]	The Nether-lands [5]
	Cost €/ kW		Cost €/kWh		Cost	Cost
	1 h	12 h	1 h	12 h	€/ kWh	€/kWh
Residential Free-time [1)] Agriculture	3-10 2-20 3-16	25-60 48-81 50-120	3-7 2-17 3-13	2-5 4-7 5-11	0.98 1.83	16.4 3.9
Service Public Industry	4-60 5-35 7-22	25-270 60-450 50-190	4-47 5-30 7-20	2-25 5-41 4-15	12.07 1.59 1.59-8.05	7.9 33.5, gov. 0.3-33.1

[1)] This value should be multiplied with the utilization degree of the free-time residence.

Major interruptions. [B4-534(FI)] proposes a method for evaluating the costs of extensive outage situations. Three categories of major disturbances are considered:
- class-1: 48-h outage, 45% customers, p=0.2/year
- class-2: 5-day outage, 50% customers, p=0.05/year
- class-3: 2-week outage, 100% customers, p=0.01/year.

The customer outage costs dominate the total unit costs of the major disturbances, forming about 80 % of total costs, the rest 20 % being divided almost evenly between the fault repair costs and customer compensation fees. Possible reductions of interruption durations have been studied: the achievement of the 72, 48, 24, 12 and 6 hour maximum clearance times requires severe network changes (e.g. increasing the proportion of underground cabling). Table 13 and Table 14 give some interruption cost estimations.

Table 13 : Unit costs for interruptions



Customer group and energy shares	Unplanned interruption		Planned interruption		Auto-reclosures High-speed	Auto-reclosures Delayed
	[€/kW]	[€/kWh]	[€/kW]	[€/kWh]	[€/kW]	[€/kW]
Residential 51 %	0.36	4.29	0.19	2.21	0.11	0.48
Agriculture 10 %	0.45	9.38	0.23	4.8	0.20	0.62
Industry 11 %	3.52	24.45	1.38	11.47	2.19	2.87
Public 10 %	1.89	15.08	1.33	7.35	1.49	2.34
Service 18 %	2.65	29.89	0.22	22.82	1.31	2.44

Table 14 : Unit- and expected yearly costs of major disturbances (network supplying 165 GWh/year to 14000 customers)

Network solution	Total Unit costs of disturbance [k€]			Expected yearly costs [k€/a]		
	Class-1	Class 2	Class 3	Class-1	Class-2	Class-3
Present network	1 284	2 477	30 400	257	124	304
Optimal network	693	1 995	13 428	139	100	134
6 h network	70	131	54	14	6.6	0.5
12 h network	355	365	161	71	18	1.6
24 h network	615	967	570	123	48	5.7
48 h network	1 284	1 831	1 953	257	92	20
72 h network	-	1 996	3 690	-	100	37

The impact of extensive outages can be reduced and the outage time shortened by increasing the number of maintenance personnel, while the only method for avoiding these severe disturbances is a full-scale underground cabling in both MV and LV networks. The question is what the economically reasonable boundaries are that could be set to the outage time.

Costs aspects of PQ are also discussed within [B4(S5)-074(AT)] and [B4(S5)-415(FI)], [B4(S6)-146(FR)] and [B4(S6)-319(RU)]

Regulatory aspects & market considerations

Benchmarking. [B4(S5)-712(GB)] states that the regulation has been shifting from asset-based to performance-based regulation. It proposes to reduce a real system into a limited number of representative networks, which include both fixed network parameters that a company cannot change in the short term and variable parameters that can be changed by appropriate investments. This methodology can be used to predict the reliability performance of possible investments and also to compare the performances between companies.

Following [B4(S6)-391(DK)] the Danish regulator has implemented a simple reporting scheme in order to facilitate benchmarking of the DNOs on supply continuity. Example results are given in Figure 39.

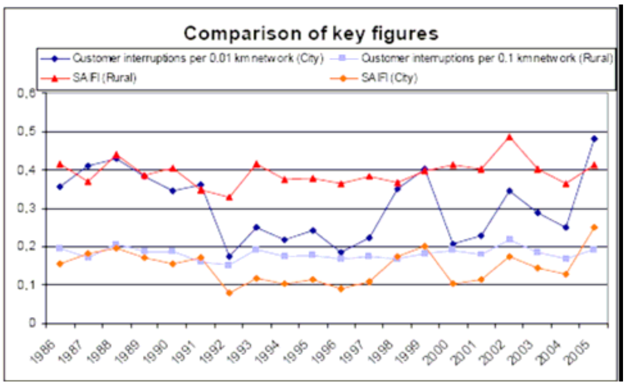


Figure 39 : Comparison of supply continuity in companies serving rural and urban areas, in terms of AIF (SAIFI) and customer interruptions per 0.01 km of 10-kV network

Compensations (penalties). [B4(S6)-677(SE)] compares the regulation policies for interruptions in Sweden and UK (see the respective "compensation levels" in Table 15 and Table 16). In a comparative case study, the use of historical interruption data for a given distribution system gives a 75% higher compensation with the Swedish model (GL) than the UK model (GS), see Table 17.

Table 15 : Compensation levels to the customers defined by the Swedish Gudrun law (GL)

Length of interruption, T	Compensation to customer	Minimum * compensation
12≤T<24 hours	12.5 % of tariff α	2 % of β
24≤T<48 hours	+ 25% of tariff α	4 % of β
48≤T<72 hours	+ 25% of tariff α	6 % of β
Following 24 hour periods	+ 25% of tariff α	+ 2% of β
α = { Individual customer's annual network tariff } β = { Yearly set base amount } = €4567 * Is always set to even 100 SEK values, rounded up		

Table 16 : Compensation levels to the customers defined by the UK Guaranteed Standard (GS)

Weather condition	Length of interruption, T	Domestic costumer	Non-domestic
Normal (GS2)	18≤T<30 hours	€75.0	€150.0
	Following 12 hour periods	+ €37.5	+ €37.5
Category 1 (GS11A)	24≤T<36 hours	+ €37.5	+ €37.5
	Following 12 hour periods	+ €37.5 , max €300	+ €37.5 , max €300
Category 2 (GS11B)	48≤T<60 hours	€37.5	€37.5
	Following 12 hour periods	+ €37.5 , max €300	+ €37.5 , Max €300
Category 3 (GS11C)	Intervals for compensation are dependent on the number of customers interrupted and the specific system in UK.		

Table 17 : Compensation to the customers with the GL and GS regulations in a particular case. The period includes the severe storm Gudrun, which stands for the majority of the total compensation.

Regulation	GL, Sweden	GS, UK Weather condition		
		Normal	Cat.1	Cat.2
Compensation (Gudrun part of the comp. in %)	€477000 (99.3%)	€273000 (99.4%)	€172000 (100%)	€76000 (100%)
Comp./customer	€506	€290	€183	€81

Societies' reactions to large disturbances are considered by [B4(S6)-599(FI)]. After the large disturbances of 2001 in Finland, new amendments to the regulation state that companies are to pay compensations to their customers for interruptions longer than 12 h (from 10% to 100% of the distribution bill, for durations up to 120 h, with a maximum of € 700. The Finnish electricity distribution industry itself has defined limits (Table 18) beyond which compensations are recommended to be paid.

Table 18 : Proposed fault limits for long interruptions

Fault location / Operating condition	Low or medium voltage network [h]	Distribution substation [h]	Primary substation and company's own regional network [h]
City	4	8	12
Urban and rural	8	8	12

Some companies take insurances for compensation fees. The consequence was a 2-10 % increase in the annual distribution bill (the cost of higher reliability level is therefore recognized by society).

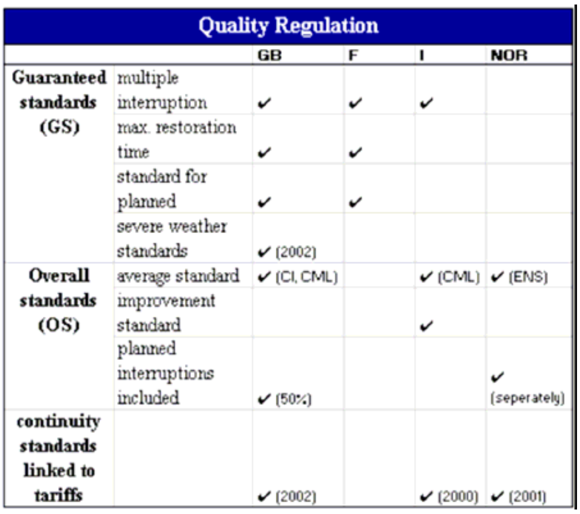
Incentives. [B4(S6)-401(FI)] stresses that efficiency benchmarking cannot be included in the economic regulation without concurrent PQ regulation. It is important to provide companies with incentives for investments that decrease total costs while improving PQ.

Following [B4(S3)-801(NO)], a Quality of Supply (QoS) regulation was introduced in Norway in 1991, including a revenue regulation taking account of the cost of energy not supplied (CENS) since 2001. The QoS regulation was extended in 2005 by inclusion of voltage- and commercial quality aspects ; it became mandatory to register and report short interruptions (≤ 3 min). Compensation for interruptions lasting > 12 h is introduced in 2007. Inclusion of short interruptions in the CENS arrangement is planned from 2009.

[B4(S5)-514(CZ)] considers that the costs of penalty payments for breaching reliability standards must be included into criterial functions when optimizing MV distribution networks, although such standards have not yet been fully implemented in the Czech Republic. The standard would set a limit on AIF and AIT on each supply point and, at the end of the year, a penalty of about € 33 would be paid to customers for whom at least one of the limits has been breached.

Following [B4-042(IT)], the Italian regulator AEEG (Autorita per l'energia elettrica e il gas) introduced in 2000 an AIT (SAIDI) regulation for long unplanned interruptions, with a financial incentive mechanism. The effect of this regulation was a reduction of AIT by 58% (1999-2005) at country level, together with a reduction of AIF (SAIFI) by 39%. In 2006, an additional regulation was introduced for the number of interruptions for the worst-served customers. AEEG is now looking at voltage quality issues and has promoted from 2005 a PQ monitoring campaign (simultaneous monitoring of 600 MV points) in order to assess the present performance of the MV distribution networks. The project is financed by the tariff. Voltage dips and variations seem to be the main causes of damages for the customers.

[B4(S6)-902(DE,CH)] gives an overview on quality regulation in four countries (Figure 40) and shows the effects of the regulation in Italy (Figure 41).



Quality Regulation		GB	F	I	NOR
Guaranteed standards (GS)	multiple interruption	✓	✓	✓	
	max. restoration time	✓	✓		
	standard for planned	✓	✓		
	severe weather standards	✓ (2002)			
Overall standards (OS)	average standard	✓ (CI, CML)		✓ (CML)	✓ (ENS)
	improvement standard			✓	
	planned interruptions included	✓ (50%)			✓ (seperately)
continuity standards linked to tariffs		✓ (2002)		✓ (2000)	✓ (2001)

Figure 40 : Overview on quality regulation in four countries

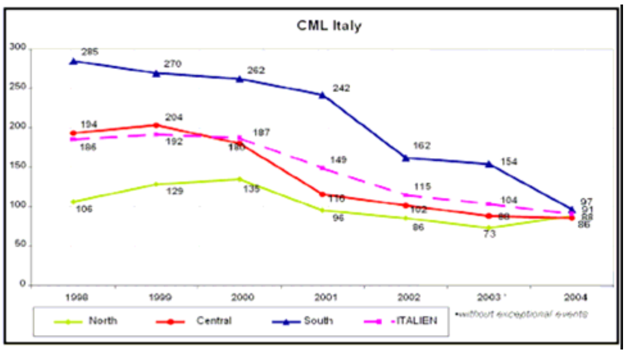


Figure 41 : Effects of quality regulation in Italy
in terms of CML (=AIT) decrease

It presents the model developed for optimization of the operational strategy and gives first results (Figure 42). It appears that a high quality of supply is possible with a small number of personal resources in "normal" years. However, in periods with exceptional events, the supply quality decreases significantly for an insufficient number of technicians.

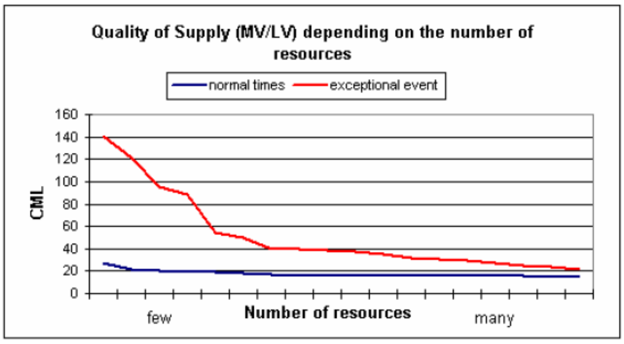


Figure 42 : CML (=AIT, min/cust./year) in a given area (urban, semi-urban, rural) in function of the number of personal resources

[B4-(S5)-425(DE)] shows that different penalties for exceeding given boundary values of reliability have different impacts depending on the characteristics of the supply area. On Figure 43, for the "alternative supply area", the required value of AIT=3min/a is only reached with very high penalties (500 k€/a per min/a exceedance).

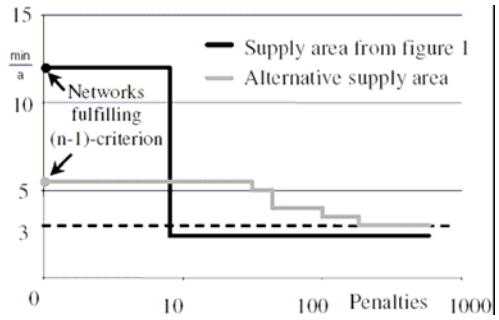


Figure 43 : Max AIT (SAIDI) of the cost-efficient network structure depending on penalties
(penalties in k€/a for exceeding the target AIT=3min/a)

[B4(S5)-321(ZA)] shows a way of classifying distribution networks in function of supply reliability in order to prioritize investments (Figure 44). Afterwards, each investment alternative is evaluated with respect to the "reliability hurdle rate" (the incentive/penalty scheme introduced by the regulator).

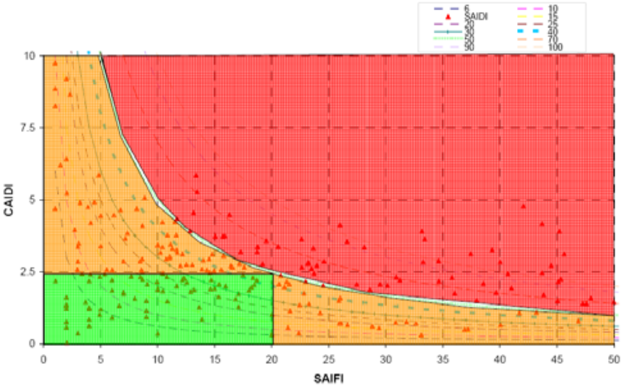


Figure 44 : Classification of networks (green: no investment required; red: immediate investigation to improve supply reliability; orange: intermediate networks)

According to [B4-103(CH)] several strategies may be chosen by regulators to determine reliability levels, e.g. 1) benchmark targets, 2) value-based targets, 3) performance-based rates, 4) reliability market-place, 5) differentiated services, 6) reliability guarantees. Figure 45 gives a comparison of AIT (SAIDI) statistics of some countries, acknowledging the fact that comparisons are difficult (definitions differ from country to country). When statistics are very good, general improvement is probably not justified. It is then more efficient to improve the reliability for customers with critical processes, by means of services with costs (e.g. redundant connections, stand-by generator, operation-contracting...).

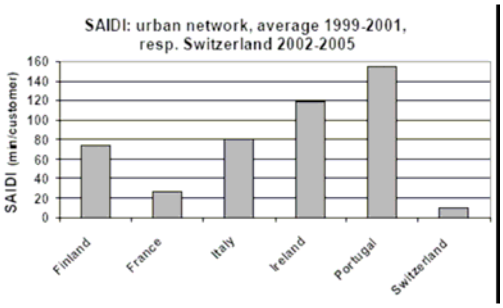


Figure 45 : Comparison of AIT (SAIDI) from unplanned interruptions in urban grids

All PQ aspects are covered by regulation in some countries. In South Africa [B4(S6)-894(ZA)], specified minimum standards for voltage dips and interruptions have been replaced by "characteristic levels" of performance (Table 19 to Table 21). Minimum standards for harmonics, flicker and unbalance are based on the recommendations made by JWG CIGRE/CIRED C4.1.04 (see the Final WG Report, "Power Quality indices and objectives", March 2004, available on www.cired-s2.org).

Table 19 : Voltage dip characterization (NRS 048-2 Ed.2)

<table>
<tr><th rowspan="2">Dip depth
ΔU
(% of U_d)</th><th colspan="3">Duration</th></tr>
<tr><th>20 < t ≤ 150 ms</th><th>150 < t ≤ 600 Ms</th><th>0,6 < t ≤ 3 s</th></tr>
<tr><td>10 < ΔU ≤ 15</td><td rowspan="3"></td><td rowspan="2">Y</td><td></td></tr>
<tr><td>15 < ΔU ≤ 20</td><td rowspan="2">Z1</td></tr>
<tr><td>20 < ΔU ≤ 30</td><td rowspan="3">S</td></tr>
<tr><td>30 < ΔU ≤ 40</td><td>X1</td><td rowspan="3">Z2</td></tr>
<tr><td>40 < ΔU ≤ 60</td><td>X2</td></tr>
<tr><td>60 < ΔU ≤ 100</td><td colspan="2">T</td></tr>
</table>

Table 20 : Characteristic voltage dip performance for 50th (and 95th) percentile of sites in South Africa

Network voltage range ($U_{nominal}$)	Number of voltage dips per year					
	Dip window category					
	X1	X2	T	S	Z1	Z2
6,6 kV to ≤ 44 kV (note)	13 (85)	12 (210)	10 (115)	13 (400)	11 (450)	10 (450)
6,6 kV to ≤ 44 kV	7 (20)	7 (30)	7 (110)	6 (30)	3 (20)	4 (45)
> 44 kV to ≤ 220 kV	13 (35)	10 (35)	5 (25)	7 (40)	4 (40)	2 (10)
220 kV to ≤ 765 kV	8 (30)	9 (30)	3 (20)	2 (20)	1 (10)	1 (5)
Note: Extensively overhead networks						

Table 21 : Characteristic interruption performance : number per MV or LV customer ; duration per interruption

Network Category (MV)	Unplanned		Planned	
	Number Per year	Duration (hours)	Number	Duration (hours)
> 80% cable	3 (6)	3,5 (18)	< 1 (3)	4 (9)
> 80% line (overhead)	18 (75)	2,5 (12)	4 (11)	3 (14)
Numbers indicate are for 50th percentile and (95th percentile).				

Improving power quality through system improvements

In this section we consider non-specific system improvements (filters, compensators, etc. are considered in Blocks 2 and 3) that aim at improving voltage quality and continuity. Only discrete events (voltage dips and interruptions) are concerned: quasi-stationary phenomena are much more a matter of emission limits and specific compensation.

Statistical studies are useful to predict the results of possible actions and to state realistic targets. [B4(S5)-145(FR)] assumes that the annual number of MV feeder cuts follows the Poisson law, see Figure 46. Investment strategy studies are based on this model. The final model will include several reliability-related parameters (equipment, environment, climatic, maintenance and ageing).

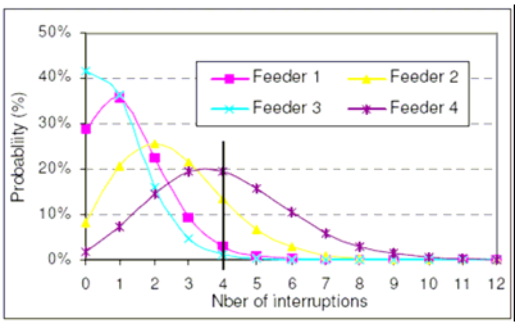


Figure 46 : Distribution probability of cuts for MV feeders

Trend analysis is applied by [B4(S5)-253(NL)] to the main reliability indices, see e.g. Figure 47. Raw data are weighted in order to reduce the influence of extreme values (outliers) and a 95% confidence interval is considered. The results help to choose realistic target values for the coming years.

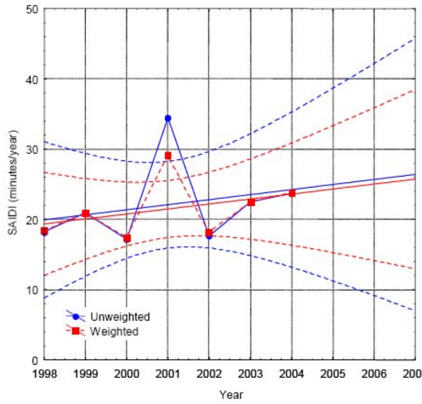


Figure 47 : Results of trend analysis for AIT (SAIDI) in a MV system

Climatic events are unavoidable but not unpredictable. [B4(S5)-135(FR) describes an action plan to reduce the impact of major climatic events likely to have a significant impact on the continuity of supply, whether relating to the overhead (storms, snow, white frost, etc.) or underground network (floods, heat waves, etc.).

Maintenance. Generally speaking, maintenance actions are possibilities to be studied along with investments for quality improvement. [B4(S5)-360(BR)] presents a methodology for maintenance or expansion planning actions in distribution systems taking supply reliability into account.

Distribution automation is an important topic for quality improvement. [B4(S3)-029(IT)] tells that the contribution of the LV network to the total AIT (SAIDI) is constantly growing, justifying to extend the remote control technology to the LV network.

[B4(S3)-017(PT)] reports on decreasing TIEPI (= AIT = SAIDI) due to increasing use of remote controlled MV lines (TCMT) in the Lisbon area (see Figure 48).

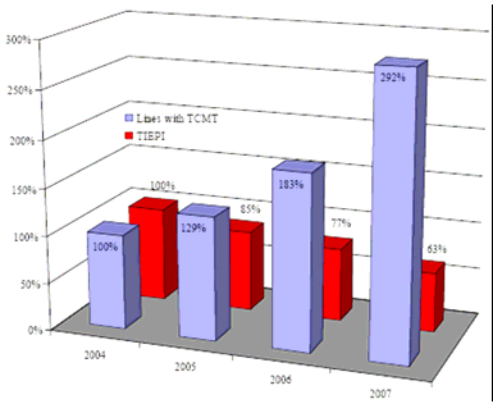
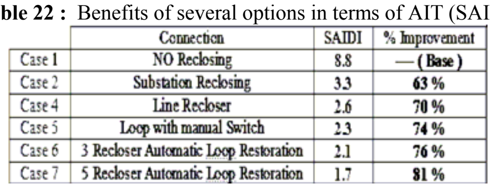


Figure 48 : AIT (TIEPI) and remote controlled MV lines (TCMT) evolution graphics

[B4(S3)-278(EG)] quantifies the benefits of distribution automation on reliability parameters, see e.g. Table 22.

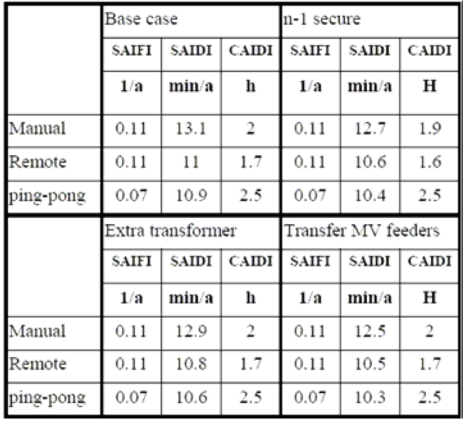
Table 22 : Benefits of several options in terms of AIT (SAIDI)



	Connection	SAIDI	% Improvement
Case 1	NO Reclosing	8.8	— (Base)
Case 2	Substation Reclosing	3.3	63 %
Case 4	Line Recloser	2.6	70 %
Case 5	Loop with manual Switch	2.3	74 %
Case 6	3 Recloser Automatic Loop Restoration	2.1	76 %
Case 7	5 Recloser Automatic Loop Restoration	1.7	81 %

[B4(S5)-249(NL)] makes advance reliability assessments in order to compare proposals to improve the supply reliability. The remote control switching provides noticeable improvements, especially in terms of AID (Table 23).

Table 23 : Reliability performance of the base case and the three options in terms of AIF (SAIFI), AIT (SAIDI) and AID (CAIDI)



	Base case			n-1 secure		
	SAIFI	SAIDI	CAIDI	SAIFI	SAIDI	CAIDI
	1/a	min/a	h	1/a	min/a	H
Manual	0.11	13.1	2	0.11	12.7	1.9
Remote	0.11	11	1.7	0.11	10.6	1.6
ping-pong	0.07	10.9	2.5	0.07	10.4	2.5

	Extra transformer			Transfer MV feeders		
	SAIFI	SAIDI	CAIDI	SAIFI	SAIDI	CAIDI
	1/a	min/a	h	1/a	min/a	H
Manual	0.11	12.9	2	0.11	12.5	2
Remote	0.11	10.8	1.7	0.11	10.5	1.7
ping-pong	0.07	10.6	2.5	0.07	10.3	2.5

[B4(S3)-739(US)] and [B4(S3)-615(CA)] describe the use of substation monitoring systems (PQ monitoring, digital fault recorders, and intelligent relays) for automatic fault location on distribution systems. PQ monitoring systems continue to get more powerful and provide a growing array of benefits to the overall power system operation and performance. The ultimate benefit of its use for automatic fault location is actual reliability improvement.

Network structure is another domain of possible improvement (including the replacement of overhead lines by underground cables). [B4(S5)-607(SE)] reports on efforts to improve the supply reliability in rural areas of Sweden, with well-defined targets in terms of AIT, AIF and AID (Figure 49). In one of the projects, the conversion from overhead line to cable network lowered AIT (SAIDI) from 1400 down to 70 min/customer/year.

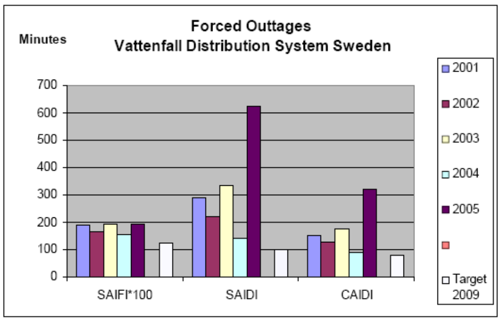


Figure 49 : Fault statistics and target 2009

For [B4(S5)-140(DE)], restructuring the existing MV cable networks using the segmentation method will improve the supply reliability, see Figure 50.

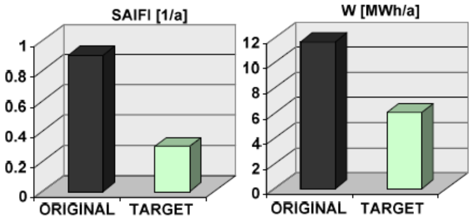


Figure 50 : AIF (SAIFI) and ENS (W) of the original and target networks

For [B4(S4)-270(CA)] planned islanding of a distribution network is an interesting tool for reliability enhancement, for example when a planned outage is needed on a transmission line.

The case of industrial distribution networks is treated by [B4-590(DE)]. One issue is the supply reliability, which depends on network structure (e.g. number of switchgear components). Specific reliability demands can be met by additional reserve networks. Another major issue is voltage dips. Changes in network structure may be favorable for reliability but unfavorable for dips (see e.g. Figure 51), so that an operational optimum has to be searched for.

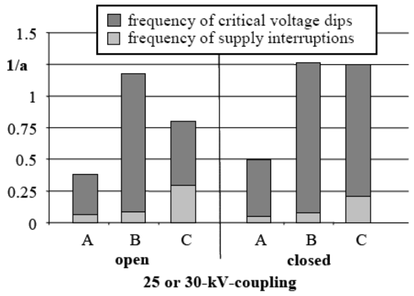


Figure 51 : Frequency of critical events for different substation coupling modes

Voltage dips. Most above actions are oriented towards shorter and less frequent interruptions. The last above study, from [B4-590(DE)], showed that improving interruptions may worsen voltage dips. The two last papers are devoted to quality improvements with respect to voltage dips.

[B4(S3)-897(IT)] shows the benefit of protecting customers by fuses instead of circuit breakers : the peak value of the short-circuit current is reduced (Figure 52) as well as the opening time, resulting in voltage dips with smaller depth and duration for all the other customers in the same MV distribution network.

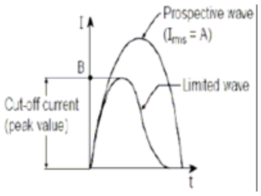


Figure 52 : Fuse limiting capability

Following [B4-204(SE)] there is a large compatibility gap between immunity of industrial equipment (mainly VSDs – variable speed drives) and actual power quality (see e.g. Figure 53). The resulting yearly loss of revenue has been estimated for three sites (see Table 24).

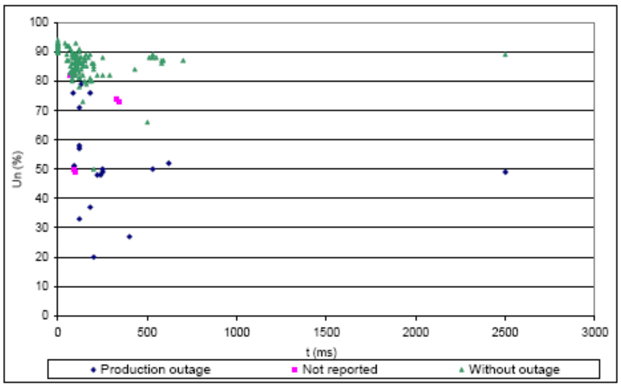
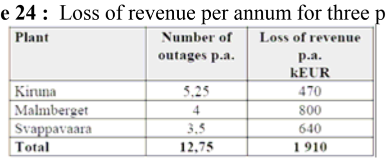


Figure 53 : Voltage dips recorded at the 130 kV feeding point of an iron ore factory – sorted by consequences

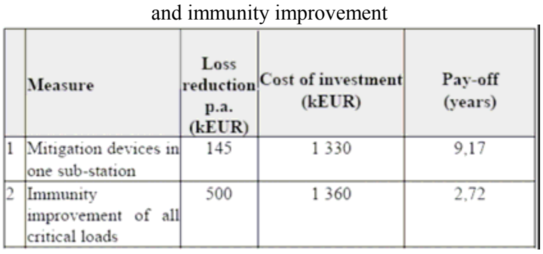
Table 24 : Loss of revenue per annum for three plants



Plant	Number of outages p.a.	Loss of revenue p.a. kEUR
Kiruna	5,25	470
Malmberget	4	800
Svappavaara	3,5	640
Total	**12,75**	**1 910**

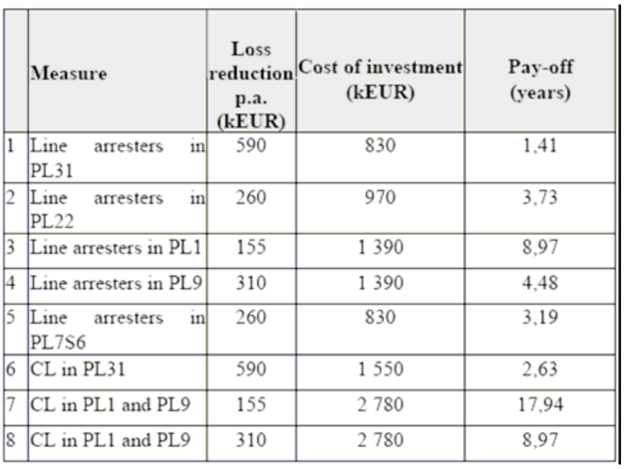
Possible improvements in the factory (Table 25) and in the power system (Table 26) have been evaluated. It appears that short pay-off times are achievable for improving the immunity of sensitive equipment (e.g. an immunity level of 0.65Un for VSDs) and for some investments in transmission lines. So, a close cooperation between the system operator and the customer will reduce the quality gap and give the optimal solution.

Table 25 : Economical evaluation of global mitigation devices and immunity improvement



	Measure	Loss reduction p.a. (kEUR)	Cost of investment (kEUR)	Pay-off (years)
1	Mitigation devices in one sub-station	145	1 330	9,17
2	Immunity improvement of all critical loads	500	1 360	2,72

Table 26 : Economical evaluation of investments in transmission lines



	Measure	Loss reduction p.a. (kEUR)	Cost of investment (kEUR)	Pay-off (years)
1	Line arresters in PL31	590	830	1,41
2	Line arresters in PL22	260	970	3,73
3	Line arresters in PL1	155	1 390	8,97
4	Line arresters in PL9	310	1 390	4,48
5	Line arresters in PL7S6	260	830	3,19
6	CL in PL31	590	1 550	2,63
7	CL in PL1 and PL9	155	2 780	17,94
8	CL in PL1 and PL9	310	2 780	8,97

Questions on Block 4

B4-1: The "ITIC approach" characterizes the quality by the number of times that a short-duration event had magnitude/duration values outside limit curves (mainly applied for voltage dips). It is suggested by [830] to extend this approach to short-duration high values of quasi-stationary disturbing phenomena. Is there support for this proposal ?

B4-2: What about the other proposals for new quality indices, like CDI and SACDI [134], or global quality indices [326, 705] ?

B4-3: What are the experiences with flicker complaints, what is generally the required Pst-level to get complaints [see also 698] ?

B4-4: Is it justified to invest in the power system in order to reduce the voltage dip quality gap as suggested in [204]?

B4-5: Power Quality Monitoring has now become a rather common practice. What can we expect as new major technological and functional evolution in this matter?

Acknowledgement

The chairman and special rapporteur of S2 wish to warmly thank Alain Robert (UCL) and Jean-Michel Meunier (Laborelec) for drawing up this eminent special report.

Table 1: Papers of Block 1 (B1) : EMI, EMF and safety

Paper No. Title Authors	MS a.m.	RIF	PS	Other sess.
020 : Electromagnetic field mitigation techniques applied to MV/LV Substations Hearn David, Luternauer Hansruedi, Schiesser Hans-Heinrich (Switzerland)			X	
183 : Validation and analysis of magnetic field measurement method to be utilized in indoor MV/LV substations Keikko T, Kettunen K, Hyvönen M, Seesvuori R, Valkealahti S (Finland)	with 331		X	
203 : LV touch and step voltages due to single-phase faults in radial MV networks van Erp F.T.J., van Deursen A.P.J., Provoost F., van Riet M.J.M., Rasing J.F.G (Netherlands)	X		X	
242 : Evaluation of Exposure to EMFs In Different Layouts of Transformer Rooms Ashour Mohamed, Youssef Kamelia, Karawia Hanaa (Egypt)			X	
300 : Impact of floating neutral in distribution systems Xivambu Mashangu (South Africa)			X	
331 : Magnetic Field Categorization in Indoor MV/LV Substations by the Structure of the LV Connection Kettunen Kati, Keikko Tommi, Hyvönen Martti, Valkealahti Seppo (Finland)	with 183		X	
347 : The Finite Elements Method applied to Electromagnetic Compatibility Study Betolaza Guillermo (Argentina)		X	X	
370 : High-frequency components in the neutral and protective-earth currents due to electronic equipment Lundmark Martin, Larsson Anders, Bollen Math (Sweden)			X	
382 : Impact of EU directive 2004/40/EC on electrical- and electrochemical plants limiting electromagnetic fields outgoing from 30th April 2008, Lange Joachim (Belgium)	X		X	
432 : EMF expos of workers in elec distrib and gener systems in regard to Direct 2004/40/EC – Is there a need to take actions? Abart A, Schmautzer E, Wallnberger G, Bitschnau E (Austria)			X	
480 : Assessment of magnetic field mitigation methods for distribution network Bourdages Michel (Canada)			X	
509 : The behaviour of different earthing systems for electrified railways using AC voltages under short circuit conditions, Sels Tom, Maes Hugo (Belgium)			X	
526 : Overvoltages in Low Voltage due to normal Medium Voltage Switching Pazos Francisco José, Amantegui Javier, Ferrandis Francisco, Barona Amaya (Spain)			X	
597 : Constructional magnetic field reducing measures of high voltage overhead transmission lines Friedl Werner, Schmautzer Ernst, Rechberger Georg, Gaun Alexander (Austria)		X	X	
621 : Measurement of magnetic flux density in the vicinity of electrical power installation Rechberger Georg, Schmautzer Ernst, Friedl Werner, Gaun Alexander (Austria)	X		X	
638 : A Comparison of Grounding Techniques for Distribution Generators Implemented in 3- or 4-Wire Distribution Grids, UPS-Systems and Microgrids, Dexters A, Loix T, Driesen J, Belmans R (Belgium)			X	
693 : Assessing the risk of damages in LV equipment due to lightning surges and their impact on customer claims Kagan N, Matsuo N, Duarte S, Rosa P, Itocazo F, Dominguez I (Brazil)	X		X	
805 : Transfer Potentials From HV to LV Installations During an Earth Fault Charlton Trevor (United Kingdom)			X	
825 : Increasing reliability of supply for the pulp and paper industry; a case study from Fortum Distribution and Billerud-Gruvön, Hasselström Jörgen, Agneholm Eskil (Sweden)			X	

Table 2: Papers of Block 2 (B2) : Connection of disturbing installations

Paper No. Title Authors	MS a.m.	RIF	PS	Other sess.
013 : Harmonic Current Emission of Photovoltaic Inverters Hearn David, Luternauer Hansruedi, Schiesser Hans-Heinrich (Germany)	X		X	
050 : Quality of Supply Issues Arising from DC Traction Loads at the Point of Common Coupling Nhavira Samuel, Polimac Vukan (United Kingdom)			X	
063 : Site Measurements and Modelling Studies of Harmonics on Distribution Network Ma Ting, Edwards Christopher (United Kingdom)			X	
071 : Measurement and analysis of high-frequency (2-150 kHz) conducted disturbances Larsson Anders, Lundmark Martin, Bollen Math (Sweden)			X	
125 : Disturbances in MV distribution lines feeding DC railway installations: characteristics, simulation and mitigation, Zaninelli D, Brenna M, Foiadelli F, Roscia M (Italy)			X	
161 : Assessment of short circuit power levels in HV and MV networks with respect to power quality Allegranza V, Ardito A, De Berardinis E, Delfanti M, Lo Schiavo L (Italy)	X		X	
225 : Assessment of transient in a power system with wind generators by application of Prony method Janik Przemyslaw, Lobos Tadusz, Rezmer Jacek (Poland)			X	
241 : Investigating the Change in Harmonics Characteristics of Different Lighting Loads Due To Voltage Drop F. Abd El Gawad Amal, E. Mandour Mohy (Egypt)			X	
290 : The Impact of Small and Medium Power Loads on Distribution Network Efficiency and Harmonic Propagation Au Mau Teng, Navamany John Steven (Malaysia)			X	
408 : Harmonic nonlinear analysis of three-phase four-wire distribution networks Degroote Lieven, Vandevelde Lieven (Belgium)			X	
442 : A practical evaluation of distribution network losses due to harmonics Papathanassiou Stavros, Kasmas Nikos, Drossos Nikos, Stavropoulos Dimitrios (Greece)	X		X	

458 : Modelling of Non-linear Electronic Loads for Power System Studies: A Qualitative Approach Cresswell Charles, Djokic Sasa, Ochije Kenneth (United Kingdom)				S5
463 : Analysis and Field Tests of the Influence of Harmonic Components for Protection Relay Currents on Single-Wire Earth Return Systems, JUNIOR E., SHIGEAKI J., C. BARIONI C., CÉSAR EDUARDO (Brazil)				S3
471 : Disturbances of the 90kV Electrical Network and the 380/220V Dist System in the Douala-Cameroon Area Nchelatebe Nkwetta D, Thong Vu Van, Driesen J, Belmans R (Belgium)			X	
505 : Evaluation of solutions for flicker mitigation in the Slovenian transmission network Blazic Bostjan, Matvoz Dejan, Papic Igor (Slovenia)			X	
513 : Impact of photovoltaic generation on Voltage Variations – How stochastic is PV? Bletterie Benoit, Pfajfar Tomaž (Austria)			X	
515 : Impedance of inverter front-ends at the frequency of ripple-control signals Vermeyen Pieter, Lauwers Piet, Driesen Johan, Belmans Ronnie (Belgium)			X	
519 : STATCOM for grid code compliance of a steel plant connection Grünbaum R, Hasler JP, Larsson T, Levrinius K, Aigner B, Park Dong C (Sweden)			X	
610 : Harmonic level measurements on French low-voltage networks BERTHET Luc, EYROLLES Philippe, GAUTHIER Jacques, SABEG Saad (France)			X	
641 : DEVELOPMENT OF A TOOL FOR CALCULATING THE EFFECTS OF PV-SYSTEMS CONNECTED TO A LV GRID, Ramirez Rodrigo, Sudrià Antoni, Rull Joan, Sumper Andreas, Perello Xavier, Villafafila Roberto (Spain)				S4
663 : Improving weighting filter of UIE/IEC flickermeter Cai Rong, Cobben J.F.G., Myrzik J.M.A., Kling W.L. (Netherlands)			X	
680 : Decentralised generation Publication of French connection rules Gonbeau Olivier, Fraisse Jean-Luc, Raimon Jean-Luc, Naslin Coralie, Baltes Frédéric, Bousseau Pierre (France)				S4
681 : Connection rules for possibly disturbing loads in low-voltage networks De Witte Michèle, Pirenne Christian, Magnus Serge, Lauwers Piet, De Jaeger Emmanuel (Belgium)			X	
694 : A NEW MITIGATION TECHNIQUE FOR TRANSFORMER INRUSH CURRENT DAVID PONNIAH BALACHANDRAN, R.SREERAMAKUMAR, SHIMNA NAIR (India)			X	
721 : Measurement of the Harmonic Impedance of LV Distribution Supply Systems (120/240V) Zavoda Francisc (Canada)			X	
745 : Discrepancy in the reactive energy measurement in single phase systems Brugnoni Mario (Argentina)			X	
764 : The making and the purpose of Harmonic Fingerprints Cobben Sjef, Myrzik Johanna, Kling Wil (Netherlands)		X	X	
765 : Harmonics: Harmonizing a shared responsibility Cobben Sjef, Hulshorst Walter, van Casteren Jasper Netherlands	X		X	
831 : APPLICATION OF NEURAL NETWORKS TO VOLT. FLUCT. MEAS. – A PROPOSAL FOR A NEW FLICKERMETER, Szlosek M, Hanzelka Z, Swiatek B (Poland)			X	
850 : Determination of specific electricity consumers which have great impact on harmonic distortion of voltage waveform, Poleto Darko, Stojkov Marinko, Trupinic Kruno (Croatia)			X	
892 : International Survey of Unbalance Levels in LV, MV, HV, and EHV Power Systems: CIGRE/CIRED JWG C4.103 Results, Koch R, Beaulieu G, Berthet L, Halpin M (Int)	with 893		X	
893 : Recommended Methods of Determining PQ Emission Limits for Installations Connected to EHV, HV, MV and LV Power Systems, Beaulieu G, Koch R, Halpin M, Berthet L (Int)	with 892		X	
898 : Relating PQ and network structure: a detailed analysis of Italian MV networks Pozzi M, Delfanti M, Lo Schiavo L, Merlo M, Pasquadibisceglie MS (Italy)			X	

Table 3: Papers of Block 3 (B3) : Voltage dips and other disturbances on the grid

Paper No. Title Authors	MS p.m.	RIF	PS	Other sess.
054 : Voltage Support Transformer a Novel Device for Improved Power Quality Kojovic Ljubomir (United States)	X		X	
057 : Mitigation of flicker in rural LV network van Overbeeke Frank, Tanovic Biljana, Meeks Theo (Netherlands)	X		X	
098 : A Micro-controller-Based voltage Balancer In a electrical distribution system Chaghi Abdelaziz, Louchene Ahmed, Bensaadi Rafik (Algeria)			X	
103 : Continuity of supply: Benchmarking five urban electric distribution utilities in Switzerland Küng Lukas, Schiesser Hans-Heinrich, Cettou Raymond (Switzerland)			X	
157 : Statistical Analysis of Voltage Sags in Distribution Network According the EN 50160 Standard - Case Study Nikolovski Srete, Klaic Zvonimir, Baus Zoran (Croatia)			X	
166 : Determination of the Maximum Time Needed for Electric Motors to Restart After a Perturbation Ends Morcos Medhat M., Gomez Juan Carlos (Argentina)			X	
167 : Contactor Immunity Related to Voltage Sag Gomez Juan Carlos, Morcos Medhat M. (Argentina)			X	
173 : CIGRE/CIRED JWG C4.110, Voltage dip immunity of equipment in installations, scope and status of the work Bollen M, Stephens M, Stockman K, Djokic S, McEachern A (Int)	X		X	
229 : Considerations For Selecting Criteria For Sag Quality Classification And Standard Eassa Nazineh, Abdel Azim Madiha, Kaseb Mona (Egypt)			X	
277 : Suggested Hybrid Active Power Filter For Damping Harmonic Resonance in Power Distribution Systems Z.El-Sadek Mohamed, M.Hamada M.A.A.Wahab, Ghallab M.R (Egypt)			X	

284 : Harmonic Intelligent Control With Active Power Filter Ibrahem Talat abu el fetoh (Egypt)			X	
325 : Distribution Network Voltage Disturbances and Voltage Dip/Sag Compatibility McMichael Ian, Barr Robert (Australia)	X		X	
366 : Design of A Novel Control Strategy for Distributed Generation to Improvement PQ in Distribution Network PEI Wei, KONG Li, SHENG Kun (China)			X	
410 : Experimental validation of MV grid reactive power compensator based on a four level power electronics converter, Amezua Aitor, Pazos Francisco José, García de Madinabeitia Pedro, Galarza Josu (Spain)				S1
488 : A New DSP Technique for Disturbance Detection, Classification and Monitoring Gaouda A.M. (United Arab Emirates)			X	
500 : Wavelet-based Voltage Calculation to Automatically Classify Power Quality Problem TRONGPANICH WATTANA, WACHIRAPAN CHAMANUCH (Thailand)			X	
554 : Industrial application experience of DVR for Power Quality improvement Azcona Eduardo, Pazos Francisco José, Olarte Javier (Spain)			X	
605 : Harmonic Reduction as Ancillary Service by Inverters for Distributed Energy Resources (DER) in Electricity Distribution Networks, Heskes Peter (Netherlands)	X		X	
633 : Automated assessment of voltage sag performance at low voltage buses Vegunta Sarat Chandra, Koay Tze Jian, Aung Myo Thu, Milanović Jovica V (United Kingdom)			X	
647 : Voltage quality analysis of MV network supplying an industrial area in Italy Valtorta Giovanni, Cerretti Alberto, Sartore Sergio, Di Marino Eugenio, Cugini Alberto (Italy)			X	
671 : Allocation of PQ meters for voltage sag estimation using evolutionary algorithms Kagan N, Ferrari E, Matsuo N, Vasconcelos G, Brasil D, Medeiros J, Correia D (Brazil)			X	
736 : Dynamic Voltage Regulation Using Distributed Energy Resources Xu Yan, Kueck John D., Rizy D. Tom, Li Fangxing (United States)		X	X	
737 : Solving Harmonic Resonance Problems on the Medium Voltage System McGranaghan Mark, Murray Dan, Peele Scott (United States)			X	
820 : DISTRIBUTED SYSTEM OF POWER QUALITY IMPROVEMENT Klempka Ryszard, Hanzelka Zbigniew (Poland)		X	X	
826 : The effect of practical operating conditions on the performance of induction machines Dexters Annick, Deprez Wim, Bastiaensen Cindy, Belmans Ronnie (Belgium)			X	
827 : Automatic PQ Disturb Detection and Classification Based on Discrete Wavelet Transf and Support Vector Machines, Vega García V, Duarte Gualdrón CA, Ordóñez Plata G (Colombia)		X	X	
840 : AES Sul's Experiences Using Series Compensation on Distribution System Jesus Nelson, Oliveira Hermes, Figueiredo Carlos (Brazil)				S3
873 : Recording of Power Quality Events in Distribution Substations Ziegler Christian, DeMicco Emil, Apostolov Alexander (United States)			X	
884 : An Efficient Determination of Voltage Sags from Optimal Monitoring Mazlumi Kazem, Askarian Abyaneh Hossein, Gerivani Yaser (Iran)			X	
888 : Automatic classification of voltage disturbances using the Support Vector Machine algorithm Axelberg Peter, Gu Irene Y.H., Bollen Math H.J. (Sweden)		X	X	

Table 4: Papers of Block 4 (B4) : Power quality in the competitive market

Paper No. Title Authors	MS p.m.	RIF	PS	Other sess.
017 : Creating value for Clients and Shareholders guaranteeing a high level Service Quality (Project LAIT) Martins Luis, Pinheiro Marcolino, Barroso Cláudio (Portugal)				S3
022 : Tracking Transmission System Performance within Saudi Electricity Company (SEC) Network Al-Bassam Laith, Al-Ghamdi Khaled, abou Elseoud Ahmed (Saudi Arabia)				S3
029 : Reduction of Supply Interruptions Duration by means of Low Voltage Network Remote Control: An Enel Distribuzione Experimentation,Cammarota Antonio (Italy)				S3
042 : The power quality monitoring campaign on medium voltage distribution networks in Italy: objectives and first results, Villa Ferruccio, Malgarotti Stefano, Porrino Adalberto (Italy)	X		X	
074 : Combined maintenance and inspection models for application in condition- and reliability-centered maintenance planning, Theil Gerhard, Demiri Besim (Austria)				S5
093 : Systems of measuring, evaluating and archiving the parameters of PQ in the dist systems in the Czech Republic Prochazka K, Kysnar F, Cvacka K, Mezera D, Hejpetr Z (Czech Republic)			X	
134 : A customer-oriented approach towards reliability indices Bollen Math, Holm Anders (Sweden)			X	
135 : How to reduce the impact of major climatic events : action plan HORVILLEUR Jacques (France)				S5
140 : Restructuring Of The Existing Medium Voltage Cable Networks Using Segmentation Method - Impact On Networks Reliability, Okraszewski Tomasz, Balzer Gerd, Schorn Christian (Germany)				S5
145 : Investment strategy studies based on a stochastic model of MV feeder quality of supply Dominique DERCLE, Laurent GAUTHIER (France)				S5
146 : Incorporating quality of service in productivity measurement: With application to French electricity distribution operators, Tim COELLI, Sergio PERELMAN, Marie-Anne PLAGNET, Elliot ROMANO, Helene CRESPO (France)				S6
154 : Investigation into Unbalance Phenomena in the Distribution Networks using Power Oscillation Index Ciric Rade Milanese Dalgerti (Yugoslavia)			X	

164 : Economic appraisal of energy non supplied STIVAL RAUL (Argentina)			X	
204 : Voltage dips at LKAB in Sweden. Analysis of dip and outage statistics, mitigation options and economical effects Gothelf Natan, Mukka Lennart (Sweden)	X		X	
226 : The Use Of Reliability Economic Analysis In Alexandria Distribution Network EASSA Nazineh, ELNAHASS Mervat, ATTIA Amani (Egypt)			X	
232 : Estimating the costs of voltage quality for industrial users: methodology and application Fumagalli Elena, Garrone Paola, Grilli Luca, Lo Schiavo Luca, Redondi Renato (Italy)			X	
244 : Consequences of Inadequate Power Quality for Industrial Consumers in Slovenia Kerin Uros, Dermelj Andrej, Papic Igor (Slovenia)			X	
249 : Advanced Reliability Assessment of a Distribution Network; Objectifying of Proposals to Improve the Quality of Supply, Berende Maarten, Slootweg Han, Casteren van Jasper, Dijk Harold (Netherlands)				S5
253 : Rationale for the Quality of Supply Policy; Determination of Quality of Supply Targets Hodemaekers John, Meeks Theo, Schulze Floris, Bloemhof Gabriel, Dijk Harold (Netherlands)				S5
263 : Pan European LPQI Power Quality Survey Targosz Roman, Manson Jonathan (Poland)	X		X	
270 : Planned islanding as a distribution system operation tool for reliability enhancement Gautier Maude, Abbey Chad, Katiraei Farid, Pépin Jean-Luc, Plamondon Marc, Simard Georges (Canada)				S4
278 : Improving Distrib System Reliability Using Distrib Automation based on Coordination between Auto-Recloser, Sectionaliser and limit Fuses, Abd el aziz awad el bayomy M, Abd El Salam G, mohamed el Haroon M. (Egypt)				S3
283 : The RElationships between WEather Variables and Reliability Indices for a Distribution System in south-east Queensland, Darveniza Mat, Arnold Chris, Rainbird Paul (Australia)				S5
303 : Improving Power Quality by databases crossing PASZKIER Bruno, SANTANDER Christophe, GAUTHIER Jacques (France)			X	
319 : ANALYSIS AND EVALUATION OF THE CONSEQUENCES OF POOR QUALITY POWER SUPPLY OF CONSUMERS, Kuznetsov Evgeny (Russia)				S6
321 : The application of Reliability Methodology to select and prioritise distribution networks within Developing Country (South Africa), Van Harte Malcolm, Carter-Brown Clinton, Gaunt Trevor (South Africa)				S5
326 : METHODOLOGICAL ISSUES CONCERNING THE QUALITY OF ENERGY SUPPLY Tadzhibaev Alexey, Kuznetsov Evgeny (Russia)				S5
360 : Integrating Maintenance and Expansion Planning for Improved Quality of Supply PELEGRINI MARCELO A., OLIVEIRA CARLOS C.C.B., GONÇALVES GLÊNIO A., HOLSBACH INGRID L. (Brazil)				S5
391 : Benchmarking Danish Network Operators on Quality of Supply Møller Jensen Morten (Denmark)				S6
401 : Incentives and obstacles of implementing efficiency benchmarking in economic regulation Honkapuro Samuli, Viljainen Satu, Partanen Jarmo (Finland)				S6
412 : Distribution network investments to improve Power Quality Pilo Fabrizio, Pisano Giuditta, Soma Gian Giuseppe (United Kingdom)				S5
415 : Reliability-based Asset Management for Investment Strategies and Decisions Haikonen Juha, Biström Marcus, Noponen Kari (Finland)				S5
425 : Quality of Supply as a Boundary Condition of Cost-Efficient Distribution Networks Paulun Tobias, Maurer Christoph, Haubrich Hans-Jürgen, Vennegeerts Hendrik (Germany)				S5
426 : Power quality monitoring of distribution networks using distribution automation system HA Boknam, SHIN Changhoon, KWON Seongcheol, Park Shinyeol (Korea, South)				S3
479 : Customer Outage Cost Models – Comparison Midence Diego, Vargas Alberto (Argentina)				S5
483 : Reliability assessment of low voltage consumers in Jinan Power Supply System Yuan Mingjun, Liu Yutian, Yu Zhanxun (China)				S5
514 : Choosing of the optimum type of the MV municipal distribution network when respecting the customer's standards of electricity supply continuity, Detrich Vaclav, Skala Petr, Gohler Milos, Spacek Zdenek (Czech Republic)				S5
534 : A Cost Analysis Method for Storm Caused Extensive Outages in Distribution Networks Kaipia Tero, Lassila Jukka, Partanen Jarmo, Lohjala Juha (Finland)			X	
542 : Research and analysis method comparison in Finnish reliability worth study Kivikko K, Järventausta P, Mäkinen A, Silvast A, Heine P, Lehtonen M (Finland)			X	
544 : POWER QUALITY MONITORING AT THE TRANSMISSION AND DISTRIBUTION INTERFACE Sorin Cristian Pispiris, Carmen Stanescu, Dorel Stanescu (Romania)			X	
558 : New trends for power quality monitoring: towards a fast response analysis ROMERO GORDON JOSE MARIA (Spain)			X	
559 : Outage cost comparison of different medium voltage networks Lågland Henry, Kauhaniemi Kimmo (Finland)				S5
590 : Serving PQ needs – operational optimization and customer orientation in industrial distribution networks Czauderna Christian, Slupinski Adam, Vennegeerts Hendrik, Wirtz Frank (Germany)	X		X	
599 : Societies' reactions to large disturbances Tahvanainen Kaisa, Viljainen Satu, Partanen Jarmo (Finland)				S6
607 : Improvement of the supply quality by introduction of a new concept for modulized distribution networks in rural areas of Sweden, Hansson Bernt, Olofsson Kristina (Sweden)				S5
615 : Accurate fault location technique based on distributed power quality measurements, Tremblay Mario, Pater Ryszard, Zavoda Francisc, Valiquette Denis, Bergeron Francois, Germain Mario, Daniel Robert, Simard Georges (Canada)				S3

654 : Results from the power quality campaign on the MV Enel network Di Marino E, Cerretti A, Valtorta G, De Berardinis E, Allegranza V (Italy)			X	
677 : Regulation Policies of Long Term Interruptions in Sweden and UK - a Comparative Study Setréus Johan, Wallnerström Carl Johan, Bertling Lina (Sweden)				S6
698 : 10 years of harmonic and flicker control by IEC normalised measurements in Buenos Aires distribution system Galinski A, Issouribehere P, Bibe D, Barbera G (Argentina)			X	
705 : QWebReport, the ultimate tool for online power quality monitoring Rocha Pedro, Pimenta Fernando, Gonçalves Conceição, Serrano Eric, Espírito Santo Bruno (Portugal			X	
712 : Reliability Evaluation of Distribution Networks and Comparison of Performance using Representative Networks Silva Alexandre, Sana MKM, Djapic Predrag, Strbac Goran, Allan Ron (United Kingdom)				S5
735 : PQ Indicator Management System – Simplified and Automatic Monitoring Prototype Implementation at CPFL Ahn S, Deckmann S, Camargo J, Zimath S, Nunes E, Frandsen R (Brazil			X	
739 : Using PQ Monitoring Infrastructure for Automatic Fault Location McGranaghan Mark, Sabin Dan (United States)				S3
750 : Analytical Reliability Evaluation of Distribution System Including Photovoltaic Generation Kim Jin-O, Bae In-Soo, Kim Dong-Min (Korea, South)				S4
777 : Implementation of the Power Quality Monitoring System for Harmonic Assesment in the Electrical Networks Dzienis Cezary, Styczynski Zbigniew (Germany)			X	
801 : Trends in quality of supply in a liberalized electricity market Kjølle Gerd, Samdal Knut, Mogstad Olve, Ryen Kjetil, Ween Hans Olav, Hestnes Birger (Norway)			X	
813 : A method for analysis of coherences between PQ and network characteristics in MV distribution networks Gasch Etienne, Meyer Jan, Schegner Peter, Schulze Lutz (Germany)		X	X	
830 : Proof-of-concept data logger for power quality monitoring Gaunt Trevor, Stowe Grant, Mostert Hennie, Geldenhuys Hendri, Dekenah Marcus (South Africa)			X	
894 : The Evolution of Regulatory Power Quality Standards in South Africa (1996 to 2006) Koch R, Dold A, Johnson P, McCurrach R, Thenga T (South Africa)				S6
897 : Voltage dips analysis by Monte Carlo approach Pasquadibisceglie Marco Savino, Bombieri Nicola, Bovo Cristian, Delfanti Maurizio, Pozzi Mauro (Italy)				S3
902 : Grid Operation in the the contrary regulation challenge of cost reduction and the supply quality Friedrich Catharina, Schweer Adolf, Küppers Stefan (Germany)				S6
910 : The economics of power quality - A systematic approach Gutiérrez Iglesias José Luis, McEachern Alex (Int)	X		X	