# Special Report - Session 2
# POWER QUALITY & EMC


**Chairman**
**Emmanuel DE JAEGER**
Belgium
emmanuel.dejaeger@laborelec.com

**Special Rapporteurs**
**Philippe GOOSSENS**
Belgium
philippe.goossens@elia.be

**Herwig RENNER**
Austria
herwig.renner@tugraz.at

**Co-author**
**Alain ROBERT**, Belgium, alain.robert@uclouvain.be


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## 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 (Tuesday 9 June),
- Poster Session (Wednesday 10 June),
- Research & Innovation Forum (Thursday 11 June).

Two **Round Tables** will be organized :
- Voltage dip immunity of equipment used in installations (RT.2a, Thursday 11 June)
- CEER/EURELECTRIC cooperation on continuity of supply and voltage quality requirements and incentives (RT.2b, Thursday 11 June).

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 to present a synthesis of the present concerns in PQ&EMC, based on all selected papers (S2 and other sessions : 166 papers !).

## Block 1 : EMI, EMF and Safety

### Electromagnetic interferences (EMI)

Four papers are devoted to specific EMI problems (that is: 4 more papers than at CIRED 2007) showing that the subject should not be forgotten.

[B1-1072(UK)] gives a short summary of the European EMC Directive 2004/108/EC (EMCD). For an apparatus, it is the responsibility of the manufacturer to carry out a conformity assessment. For a new fixed installation, the “responsible person” will be the Prime Contractor (for existing build the new EMCD is not retroactive). Some guidance is given on the question whether a large machine or installed system is apparatus or a FI.

Interaction between equipment in the frequency range 9-95 kHz is analyzed in [B1-0231(SE)]. Different household devices (compact fluorescent lamp - CFL, induction cooker, TV-set, …) and a power line communication device (PLC) were installed in a full scale electric model of a house. Most equipment form a much lower impedance path than the grid, so that conducted disturbances in this frequency range mainly flow between individual devices instead of between devices and the grid. For example, low-frequency harmonic currents of CFL sum up at the connection point but it is no longer the case for higher frequencies as shown in Figure 1.

One of the consequences is that PLC in the LV network will result in significant currents through electronic devices; future immunity requirements should be based on the permitted levels of PLC.

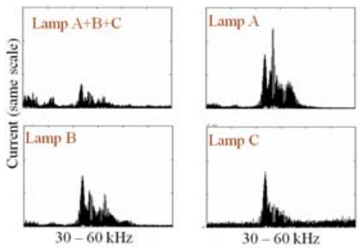


**Figure 1 :** Current spectrum (mA) for the sum of three lamps and for the three individual lamps at the connection point

[B1-0900(RO)] explains how to prepare a suitable environment for the installation and operation of IT equipment.

Switching operations in substations can cause significant transient electromagnetic fields with possible electromagnetic interference to sensitive electronic substation equipment. [B1-0296(CN/UK)] presents a wireless sensor network management protocol for transient EMF measurement. The main features are a robust tree topology and simultaneous triggered measurement (measured time synchronization error between different nodes < 1μs).

### Transient overvoltages

Transient overvoltages, caused by switching operations (3 papers) or lightning strokes (5 papers) remain a major concern in distribution networks. No problems linked with loss of LV neutral conductor are reported at this session. Specific switching problems linked with dispersed generation (DG) and wind parks (WPs) are addressed in the first two papers.

**Switching transients** caused by switching (reconnection) of DGs in LV grids are analyzed in [B1-0975(UK)]. Simulation results showed no problematic overvoltages in a vast majority of the cases but worst case scenarios were identified for further detailed study: overvoltage levels reached 1.4 pu within customer electrical supply (single generator at max production while customer's load is at minimum), 1.5 pu in urban networks and 1.6 pu in rural networks (high penetration scenarios).

[B1-0364(SE)] studies switching problems caused by wind parks: off-shore collection grids consist of vast amount of cables, which have low surge impedance compared with overhead lines. Laboratory experiments have verified the occurrence of repetitive pre-strikes and re-ignitions. A high number of repetitive voltage transients below the arrester protection level can occur at the incoming terminals of the transformer, with higher time derivatives than the standard lightning impulse test.

[B-0253(IT)] investigates the influence of the electrical parameters with special emphasis on stray capacitances and inductances of MV cables and MV/LV transformers. Simulations of different configurations (with different cable lengths) are carried out and possible resonance conditions on primary and secondary side of the transformer in the frequency range of 150-300 kHz are pointed out, giving rise to overvoltages during energization.

An analysis of special line sections of a HV line with regard to **lightning** strike sensitivity is given in [B1-0214(CN)]. Large spans (≥ 600m), great height differences (≥ 100m) and big corner angles (≥ 45°) are identified as critical. Countermeasures are discussed.

A new method to refine the results of lightning information systems is presented in [B1-0726(SI)]. A flash density map with improved resolution of 100 x 100 m is calculated using statistical methods applied to the error ellipse of the lightning location system. The result is used to identify lightning "hotspots" for the distribution grids, thus gathering information for specific residual measures.

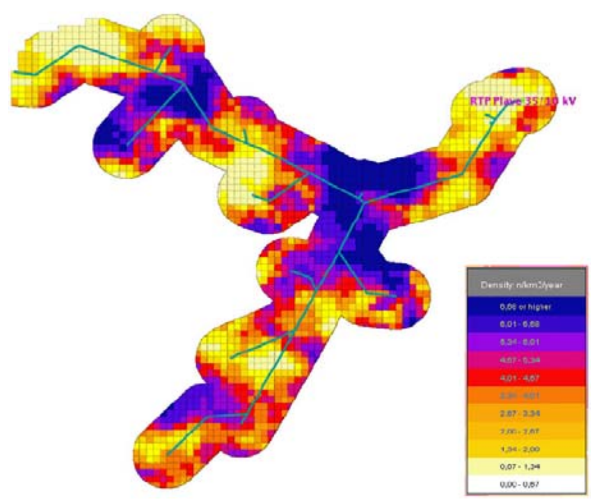

**Figure 2 :** High resolution flash density map for a MV-feeder (density expressed as n/km$^2$/year)

The risk of lightning strikes for a wood pole line in open terrain, and areas one-sided shielded or double-sided shielded by trees was evaluated in [B1-0947(UK)], using electrogeometric modeling. Arresters connected to earthed crossarms allow better protection. Adequate protection is provided with arresters installed on the two outer phases in the case of a line in open ground or with a single arrester in the case of a line in naturally shielded ground. In our opinion, the results for shield ground 1 (Fig.3 in the paper) are questionable. The authors were asked to give an explanation during the presentation of the paper.

Transient overvoltages due to lightning on covered MV lines are simulated in [B1-0652(FI)].The influence of the surge currents rise time on the transient voltage was analyzed in detail. There is no significant effect on the peak voltage, but the voltage distortion increases in case of short rise times while the arrester energy dissipation decreases. Induced voltages are lower on covered conductors than on bare conductors.

Lightning overvoltages are studied by [B1-0634(CZ)] for distribution underground cables inserted in overhead lines. Simulation results show that the principal weak points are the junction poles (poles where the cable is connected to the overhead line). The problem comes from a risk of overloading of the surge arresters, partially attributed to a relatively high value of the pole earthing resistance (30Ω) used in the model, in comparison to a low resistance of the surge arrester (1Ω).

**Earthing, earth potential rise and safety concerns**

Earth potential rise (EPR) problems are studied for three particular cases: a wind turbine, an urban network with a global earthing system (GES) and an industrial plant (3 papers). Continuity of supply considerations make the Petersen coil attractive for MV neutral point earthing, but its use may be delicate according to the type of network and its evolution (4 papers). Finally, the new concept of active earthing is introduced, giving more flexibility than the Petersen coil (1 paper).

[B1-0937(UK) shows, that there is a considerable influence of the impedance of the tower on the wind turbine earthing system. Especially for fast (1/5µs) pulses, the peak value of the transient **EPR** reaches significantly higher values when taking the tower into account. To reduce those overvoltages a new earthing arrangement is proposed, using a horizontal insulated conductor parallel with a buried bare conductor.

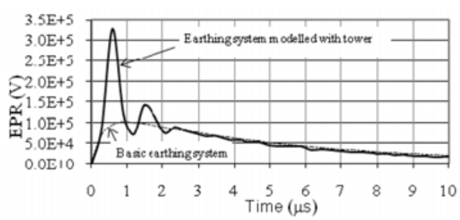


**Figure 3 :** Turbine base transient earth potential: effect of including tower structure in model

Double earth faults (involving two substations belonging to the same MV line) are analyzed in [B1-0696(IT)] in the context of a global earthing system (GES: in urban areas the earth electrodes of the secondary substations are interconnected). Simulations show, that EPR resulting from double earth faults are relatively high. Due to the complex structure of the earthing systems it is not possible to identify a general trend in the EPR for different fault locations as it was done for the case of single-line-to-earth fault.

The dimensioning of the earthing system in industrial plants is described with case studies by the authors of [B1-0022(SA)], following the rules of standard IEEE 80. Since the earth potential rise turned out to be quite high, a detailed calculation of touch and step voltages was necessary.

[B1-0620(HR)] gives an overview of the procedure to be followed before putting a **Petersen coil** in operation. Field measurements have shown that about 10% of earthing systems of MV/LV substations will need some kind of improvement.

Criteria for choosing the optimal MV earthing system are studied by [B1-0646(HR)] through computer simulations, field tests, etc. The first recommendations may be summarized as follows: i) resonant earthing with ferro-magnetic-core Petersen coils in semi-urban radial networks, ii) low-ohmic earthing with fixed tapped coils in parallel as an option in urban networks, iii) ungrounded neutral points or low-ohmic earthing with fixed tapped coils in parallel as an option in rural networks.

More and more cables are used in the Chinese 10kV distribution networks, which results in growing capacitive currents [B1-0132(CN)]. A criterion, based on the cable length rate and the capacitive current, has been established in order to assess when the neutral point earthing mode should be adjusted from earthing through arc suppression coil to earthing through low resistance.

Another solution is proposed by [B1-0307(AT)] for the same problem: the concept of self healing resonant grounded grids should be kept for supply continuity reasons. In case of raising earth fault currents, the concept should evolve to transient middle ohmic earth fault compensated network: when an earth fault is detected, if the normal arc extinction time (0.05-1.0s) is exceeded, the suppression coil is shunted by a current limiting resistor and the fault is switched off by the protection device. During this process, the touch voltages will not exceed the limit values (Figure 4).

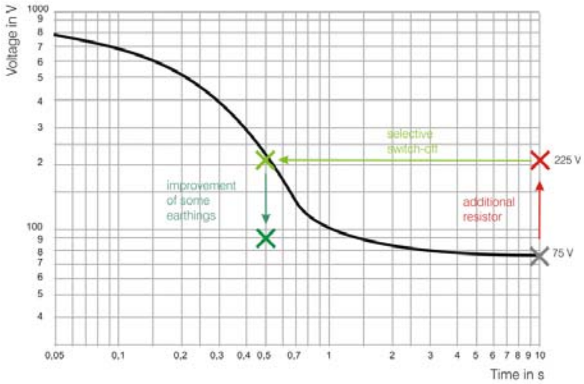


**Figure 4 :** Permissible touch voltages depending on the duration of current flow

[B1-0158(ES)] presents an **active earthing system** for MV networks, based on a multi-frequency power converter. "Active earthing" means that any phase-to-ground voltage can be created by injecting the appropriate current (Figure 5). This system allows network enhanced operation and maintenance (transient earth-fault extinction, fault detection, fault location, network condition oriented maintenance, operation with weak insulation points), giving rise to improved supply continuity.

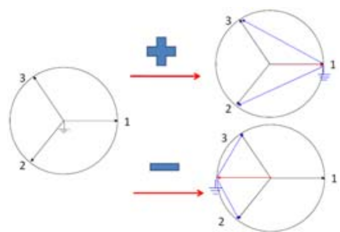


**Figure 5 :** Any phase-to-ground voltage can be created by adding the appropriate zero-sequence voltage

## Electromagnetic fields

As usual, the most numerous papers are devoted to EMF (mainly MF) problems. Knowing the limits (1 paper), exposure levels have to be assessed with appropriate calculation and measurement methods (4 papers). Assessing the health risk may require to evaluate the induced cell currents (3 papers). The effectiveness of existing or improved mitigation methods has to be assessed also (3 papers).

[B1-1072(UK)] gives a short summary of the **European EMF Directive** 2004/40/EC (EMFD) which is actually based on the **ICNIRP guidelines** and of which the application has been postponed until 2012. The EMFD requires that employers ensure their workers are protected from EMF exposures exceeding the reference levels (Figure 6). Contrarily to the EMCD which is not retroactive (see above), the EMFD apply to all workplaces, both new and existing. The need is pointed out for power station, substation, etc, sites to be characterized and managed from an EMC/EMF viewpoint.

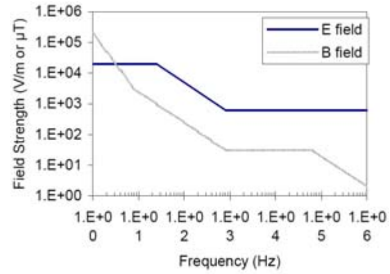


**Figure 6 :** Occupational reference levels up to 1 MHz

A simplified approach for **calculating the magnetic field** produced far from power lines is presented in [B1-0059(EG)] using power series expansion. Comparison with real measurements with MV distribution lines gives good correlation.

To assess the exposure of utility workers to the magnetic fields generated by overhead and underground distribution networks, 3D calculations are described in [B1-1008(CA)]. For currents up to 400A, the volumes where the magnetic field exceeds 420 µT (ICNIRP limits for the head and the torso) are small. The only exception to this finding is the rising pole structure (Figure 7).

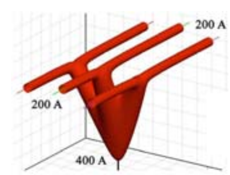


**Figure 7 :** Volume, where the field exceeds 420 µT around a typical rising pole configuration

Magnetic field measurement near underground distribution systems are presented in [B1-0405(CA)]. Fields resulting from a transformer stray flux can be neglected compared with the field of the primary side and secondary side connections, especially in the presence of neutral currents (the transformer housing, made of steel, provides significant reduction of the field). Results are far below the ICNIRP limits. For public exposure, a maximum of 12 µT was measured on top of a transformer. For utility workers, a maximum of 80 µT was recorded in a cable vault.

A quick and efficient method for EMF evaluation considering multiple sources and frequencies is presented in [B1-0627(AT)]. Instead of using electric or magnetic field strength, exposition ratios, which allow an easy summation to a total exposition ratio according to ICNIRP guidelines are used. The great advantage of this method is that precalculated results of exposition ratios of power lines, railways, cables, etc, can be considered and easily summed up.

In the case that the ICNIRP reference values are exceeded, a detailed analysis of the **induced cell currents** has to be done. Three different methods to calculate the induced currents in human body due to low frequency EMF are compared in [B1-0060(EG)]. It is shown, that the simplest method, using a cylindrical homogeneous body model and simple RMS values (neglecting field direction) delivers quite good indicative results with reasonable calculation effort.

[B1-0182(FI)] presents a risk assessment procedure (based on BS 8800) for workers in indoor MV/LV distribution substations. General health risks are assessed, including magnetic field risk evaluation. Dosimetric current density calculations are based on measured magnetic fields. Exposure action values were exceeded for several working tasks but no limit values in any of them.

The additional influence of magnetic field harmonics on the human cell model according to ICNIRP is covered in [B1-0616(AT)]. It is shown, that the classical weighting functions neglecting the phase angle usually lead to an overvalued weighting of exposure. Applying the new proposed method, it is sufficient to take harmonics up to 19th order into account.

[B1-0163(IT)] presents the high magnetic coupling passive loop (HMCPL) for magnetic field **mitigation** of power cable. Shielding conductors are coupled with phase conductors via magnetic cores (Figure 8), thus providing high mutual impedances even for short sections. The method is validated by laboratory setups (e.g. $I_{shield}/I_{source} = 0.95...0.97$). A typical application is the shielding of cable junctions.

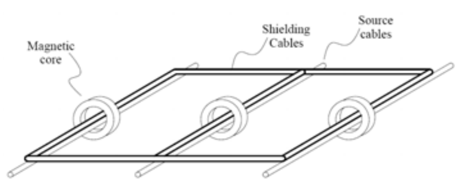


**Figure 8 :** HMCPL – geometrical layout

The impact of phase positions of overhead lines on the magnetic field is analyzed in [B1-0628(AT)] for three common European tower designs (double circuit 400kV overhead lines). The results (show great differences due to different allocation of the phases (Figure 9). It appears also that optimization for a distant point may result in stronger fields under the power lines.

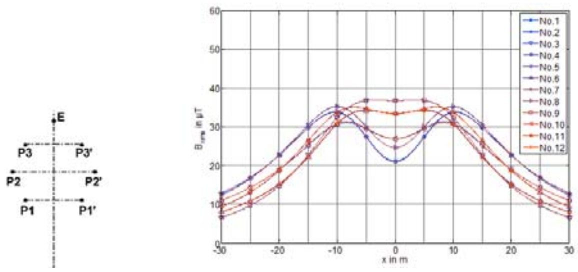


**Figure 9 :** Magnetic flux density for 3-level tower with different phase arrangements

[B1-0306(CN)] is the only paper entirely devoted to the electric field. Simulations for the case of buildings below HV lines are carried through. Field deformation and local increase are presented: the electric field is high near the building but very small inside. Mitigation methods are compared (Table 1).

**Table 1 :** Comparison of three mitigation methods

| methods | Improving region | effect | cost | power-off | evaluate |
|---|---|---|---|---|---|
| 1 | all region | poor | expensive | yes | not recommended |
| 2 | all region | general | cheap | no | considerable |
| 3 | a local region | effective | cheap | no | recommended |

1: raising the tower
2: installing the shield lines to the tower
3: setting ground lines to the building

### Further research topics

Is the active earthing principle promising for future applications? Is it to be largely applied or only for specific cases?

Taking harmonics into account for field evaluation according to ICNIRP might change the resulting exposition significantly. Is this approach really practical?

What kind of current should be used for magnetic field evaluation: rated current of device, maximum expected operating current, protection system setting, short circuit current? What should be the measurement averaging interval?

## Block 2 : Steady-state disturbances

### Emission and propagation of steady-state disturbances

Main steady-state disturbances are (inter)harmonics, voltage fluctuations (flicker) and voltage unbalance. Four papers deal with disturbance emission from some disturbing installations, while three papers are concerned with the propagation of disturbances in the network. The particular case of dispersed generation (DG) and microgrids is treated in a further section.

**Emission.** [B2-0164(SE)] shows trends in harmonic emission by large groups of modern computers over a 7-year period. The measurements clearly show that the harmonic distortion is decreasing significantly while the power consumption per computer did not change significantly.

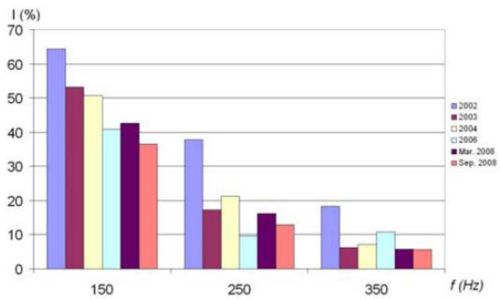


**Figure 10 :** Evolution of harmonic content of computers

[B2-0456(BE)] gives an overview of all possible mechanisms that can generate harmonics when using a PWM (pulse width modulation) converter. Simulations with a single-phase converter give the results of the combination of the grid voltage that is not sinusoidal (but that contains a certain harmonic at a certain level) with the generated current that – inherently – will contain harmonics too (that will depend on the superposed voltage harmonic). The most important harmonic produced by the converter is the third one, but it is not strongly influenced by the other harmonics present on the network; the amplitude of the other produced harmonics is more influenced by the other ones present on the network. However, they remain rather lower than the third one.

[B2-0019(SA)] investigates harmonics in a steel factory with three arc furnaces and two ladle furnaces. THD (total harmonic distortion) reached 6.5% at the 230 kV utility bus making the use of filters necessary.

[B2-0767(BR)] presents the simulation tools developed for the analysis of disturbing loads in distribution networks (voltage variations from induction motors, x-ray devices, welding machines, arc furnaces).

**Propagation.** [B2-0377(PT)] deals with harmonic analysis (simulations, measurements) in HV and MV distribution networks and presents the tools developed by EDP.

Flicker related problems have increased in the Dutch networks in the last decade (many complaints) [B3-0102(NL)]. Induction motor start simulations were used to analyze the flicker propagation behavior in a typical Dutch MV and LV grid. The results indicate that the flicker level strongly depends on the voltage variation and switching frequency of the loads, but hardly on the switching intervals between different loads. Flicker transfer coefficients are 0.15 from LV to MV but 1.00 from MV to LV.

[B2-0497(AU/ZA)] and [B2-0500(AU/ZA)] report on a method for estimating voltage unbalance influence coefficients. In the propagation from HV to MV power systems, the transfer coefficient can even exceed 1 for commonly prevailing passive constant-power loads, whereas it can be lower than unity for induction motor loads. In the propagation from a busbar to other neighboring busbars of a network, the influence coefficients can be approximated to unity for passive loads, but considerably lower than unity when the network supplies a large proportion of induction motor loads.

**Sensitivity to disturbances, acceptable levels**

For steady-state disturbances, emission limits of disturbing installations are defined in such a way that resulting levels should normally not give rise to complaints. And in fact, complaints are far less frequent than with disturbing events like voltage dips or interruptions. With harmonics and voltage unbalance, an intermediate case is often reported: derating factors are recommended in certain situations (3 papers). On the other hand, flicker complaints may be received, and it is interesting to note cases were limits were exceeded without complaints or conversely (5 papers in Block 3).

**Harmonics and unbalance.** [B2-0227(US/FR)] lists the effects of disturbances on induction motors and standard requirements. For example, the harmonic voltage factor (HVF) should be limited to 0.02 pu (IEC). The negative-sequence component should be limited to 1% of the positive-sequence component over a long period, or to 1.5% for a short period (a few minutes). NEMA derating curves are available in case of higher values. The authors recommend a power monitoring device to guarantee compliance with the relevant standards and avoid abnormal operation and loss of lifetime.

$$HVF = \sqrt{\sum \frac{u_h^2}{h}}$$

Beside [B2-0227(US,FR)], no contributions are reported regarding immunity problems with respect to unbalance, probably because unbalance levels are quite small and below limits in public grids as reported in [B2-0167(DK)], [B3-0363(IT)] and [B4-0514(CZ)].

Harmonics have significant effect on the losses of transformers, leading to additional thermal stress and necessary derating when supplying large amounts of nonlinear loads. [B2-0432(RO)] compares calculated and measured losses for five different transformers, showing surprisingly high discrepancies.

[B2-1047(IR)] studies additional losses due to harmonics in a transformer supplying a communication centre (with $THD_I = 63\%$), calculating loss of life, derating factor, etc.

**Flicker.** Many flicker problems in distribution networks are due to switching events. They are therefore considered in Block 3.

### Customer emission levels and emission limits

Once the acceptable levels ("compatibility levels") are known, the quality targets (e.g. the "voltage characteristics" of the European standard EN 50160) may be defined. In order to satisfy them, the system operators have to assess their internal quality objectives ("planning levels") and to distribute parts of them ("emission limits") to their customers. IEC published in early 2008 the Technical Reports 61000-3-6/7/13 giving guidelines for the assessment of emission limits, respectively for harmonics, voltage fluctuations (flicker), and unbalance. Network operators must be in state of verifying if these emission limits are well respected or not, thus assessing the emission levels. Three papers are concerned with this subject.

[B2-0470(BE)] reports on the work accomplished by CIGRE-CIRED JWG C4-109 in the context of the assessment of disturbances emission levels. Existing assessment methods are reviewed and practical guidelines will be given in the final guide to be issued in 2009.
Simultaneous measurement of harmonic voltages brings interesting complementary information. For example, Figure 11 shows a plot area of 5th harmonic voltage vs. 5th harmonic current. The straight lines indicate respectively the network impedance (below) and the customer impedance (above) at the 5th harmonic frequency. In the considered case, the harmonic voltages result from the background level and the distorting load, without any prevalence of the one or the other. When the grid is the dominant source, they are grouped along the line of the customer impedance. When the load is the dominant emitter, the points are mostly grouped along the lower line (network impedance) thus representing harmonic emission $E_h = Z_h I_h$.

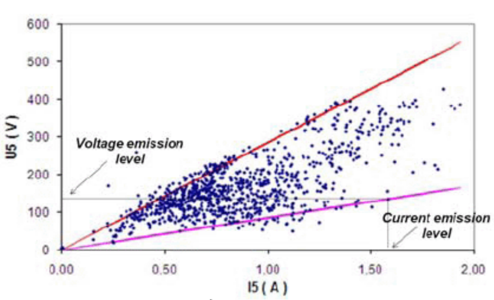


**Figure 11 :** Example of 5th harmonic voltage vs. current

[B2-0240(FR)] presents a method to assess flicker emission with fast monitoring of RMS values (voltage, active and reactive powers) and IEC flickermeter emulation. High sampling rate in RMS value recordings is preferable (1-cycle or even 1/2-cycle values). The method makes it possible for utilities to perform flicker assessment with their available monitoring data with very low computing burden.

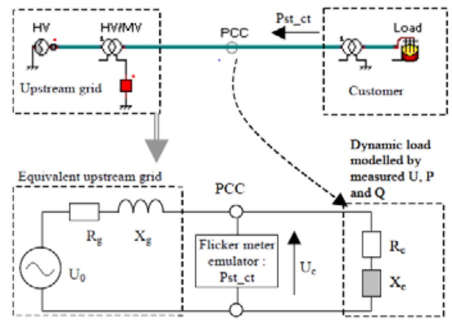


**Figure 12 :** Principle of flicker assessment with measured customer powers and equivalent grid model

[B2-0248(INT)] gives an overview of the guidelines which are used in DE, CH, AT and CZ for the assessment of emission levels for disturbing installations in LV and MV networks ("Technical Rules for Assessment of Network Disturbances" (TR), 2nd edition, 2007). Two-stage procedures are recommended (Figure 13), using easy-to-obtain input values and available software, to be applied for voltage changes, flicker, unbalance, harmonics, commutation notches,...

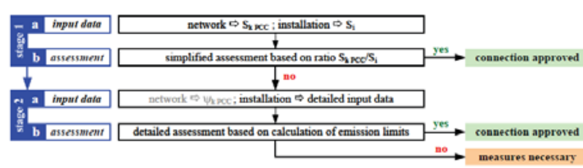


**Figure 13 :** General procedure for assessment of a network disturbance.

### Compensation of disturbances

Several compensation methods may be used to mitigate excessive emission or resulting levels: conception of disturbing installations (e.g. use of special transformers) or coordination between them, optimal use of capacitors, passive or active filters, dynamic var compensators... (11 papers).

[B2-0160(BE)] analyses the impact of plug-in hybrid electric vehicles on the distribution grid. The uncoordinated power consumption by charging of the batteries can lead to problems. Coordinated charging is proposed, making use of a smart metering system, to reduce power losses and improve PQ.

[B2-0297(EG)], [B2-0441(UA/EG)] and [B2-0531(IT)] present algorithms to determine the optimal sizing and placement of capacitors in distribution systems considering different aspects like power losses, load unbalance and harmonics (DG is also considered in [B2-0297(EG)]).

[B2-0516 (IE)] details the on-site measurements and computer modeling carried out as part of the harmonic analysis of a large mine in Ireland undergoing expansion. Two synchronous motors are replaced by asynchronous motors fed through 12-pulse Variable Speed Drives (VSD) and new capacitor banks are tuned at the 5th harmonic to reduce harmonic emission to acceptable levels.

[B2-0653 (SE)] addresses the installation of an SVC (static var compensator) on the hoisting system of an iron ore mine, resulting in strong reduction of voltage variations and THD, while increasing the hoisting capacity by 30%. A similar device installed in an oil field is used for reduction of voltage variations and negative sequence system (voltage unbalance) [B3-0052 (SE/CO)].

[B2-0662 (FR)] demonstrates the application of a Hybrid var Compensator (HVC) designed to mitigate flicker produced by a car shredder of 2.35 MW (S = 2.70 MVA nominal, with overloads up to 4.46 MVA). The HVC consists of a fixed de-tuned capacitor bank rated 1.57 Mvar associated with an Active Harmonic Filter (AHF, often called STATCOM) rated +/- 1.25 Mvar. HVC is an appropriate solution for industrial medium-size loads.

Another application of hybrid compensation is described by [B2-0092(EG)], but for a big installation: an aluminum plant fed by 460 MVA 12-pulse uncontrolled rectifiers. Harmonic problems caused frequent service interruptions and huge economic losses in the last four decades of the factory existence. The problem was solved by the combination of three passive filters (56 Mvar) and an active filter (45 MVA) which was added in order to eliminate the resonances.

The three last papers concentrate on unbalance mitigation. [B2-0095(CN)] evaluates the reduction of negative-sequence current injected into the grid by single-phase railways substations, achievable with different kinds of traction transformers (V/V, Scott, impedance balancing...) (note a printing mistake, last column of Table 1 in the paper: values should continuously decrease from 1.0 to 0.0).

[B2-0611(AU)] describes the refurbishment of ten SVCs providing the Negative Phase Sequence (NPS) balance support to the railway electrification network in Central Queensland. The SVCs were built between 1984 and 1987 and they operated reliably for 15 years. Between 1999 and 2005 a high number of SVC failures were experienced, mainly due to aged electronic components. The paper documents the best engineering practices developed for the refurbishment process.

Besides the classical SVC, another application of the Steinmetz theory for current unbalance compensation is possible with AC/AC converters. [B2-0310(IT)] proposes a method for the stability analysis of the compensation control.

**Distributed Generation (DG) & Power Quality**

DG may be related to PQ problems (impact on voltage profile and fluctuations, harmonics...; voltage dip ride-through capability) which have to be addressed (8 papers). However, a more recent concept – "microgrid" – is gaining attention (this concept appeared only once in the CIRED 2007 special report and it was in Block 1 about earthing problems). Islanded microgrid operation is a chance for improved continuity of supply (see Block 4), but specific problems must be identified and controlled (6 papers).

A number of papers [B2-0172(IE), B2-0271(NL), B2-0400(IT), B2-0301(JP)] investigate the impact of DG units on the **voltage profile**. Voltage constraints imply limits for the penetration of DG in distribution systems. The allowable penetration level may be increased by generation curtailment or by reactive power control (Figure 14). Similarly, [B2-0679(UK)] shows that voltage step constraints may be quite restrictive to DG penetration if generators are operated at lagging power factor (real and reactive flows are then in the same direction and both contribute to voltage rise at the generators).

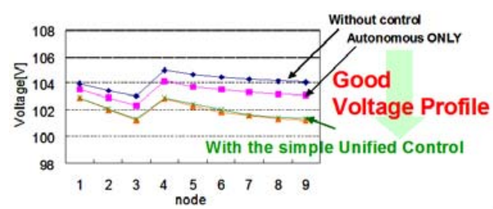


**Figure 14 :** Example of voltage profile improvement by autonomous/unified reactive power control (penetration of PV systems was 40%)

[B2-0518(ES)] applies genetic algorithms for the optimal placement of wind farms and SVC units for best voltage profile and maximum **ride-through capability** of wind turbines in case of voltage dip (this last problem is also considered by [B3-0689(GR)], see Block 3).

[B2-0245(IT/DE)] deals with the summation of **(inter)harmonics** due to grid-connected photovoltaic (PV) inverters. The PV system assessment is based on experimental results. It appears that (Figure 15) low-order ($h<10$) harmonic currents tend to sum up arithmetically, whereas higher-order($h>17$) harmonics and interharmonics tend to sum up in an almost Euclidean (quadratic) way.

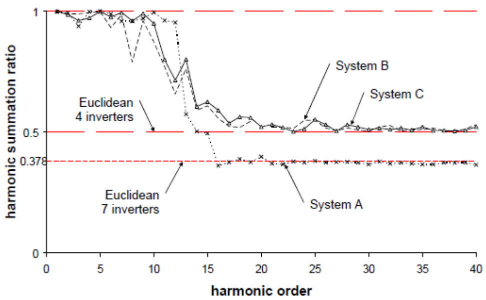


**Figure 15 :** Harmonic summation ratio for the three PV systems at different harmonic orders.

Consequently, if a significant amount of photovoltaic generation is installed in a LV-system, all odd-order harmonics are high (Figure 21) [B2-0243(DE)].

In [B2-0008(FI)] simulations are made to analyze the voltage and current THD in a **microgrid** before and after islanding. The grid impedances will change and the microgrid will be much more sensitive to the harmonic currents produced by converters and possible distorting loads. Recommendations are given to ensure high PQ in islanded microgrid (Figure 16).

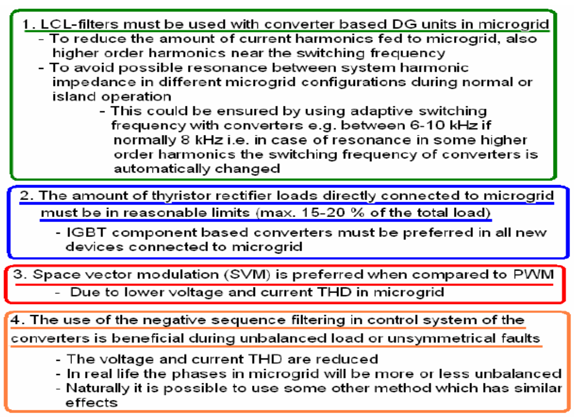


**Figure 16 :** Recommendations for high PQ in islanded microgrids

[B2-0607(SE/HK)] proposes performance indices of frequency variations, voltage variations, voltage dips and reliability for islanding microgrid (resp. temporary and permanent island operation), providing guidance for researchers and developers of microgrids.

[B2-0873(IT)] studies the integration of a micro wind generator (20 kW) in a microgrid (connected to the LV side of a MV/LV substation transformer). The generator is a synchronous permanent magnet generator, with an IGBT (insulated gate bipolar transistor) inverter with PWM modulation at 10 kHz, under control of a measurement, communication and monitoring (MSM) system. The voltage THD varies between 0.9% and 1.3% (reaching its maximum value at maximum generated power), while the harmonic current injection remains below 5% of the nominal current.

[B2-0159(ES)] reports on overvoltages that have been detected in solar plants when an upstream switch is opened and one or several inverters are isolated from the rest of the grid (isolated inverters feed and over-excite transformers). These overvoltages can give rise to damages to some pieces of low voltage electronic equipment like revenue meters.

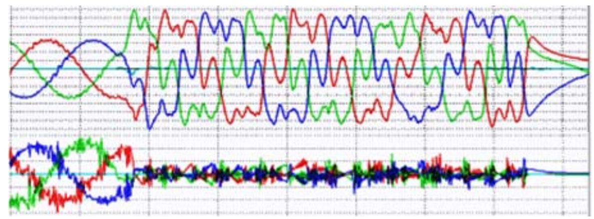

**Figure 17 :** Voltages and currents during LV inverter switching-off

Another potential voltage problem in microgrids might arise from loads with negative differential impedance (NDI) [B2-0549(NL)]. More and more loads with a controlled AC to DC power supply behave as constant-power loads and have an NDI (Figure 18, Figure 19). The study shows that the NDI of constant-power loads has voltage stability effects only at frequencies below the fundamental, so that the possible impact is not very likely (but needs attention).

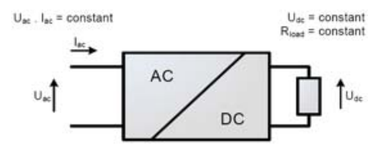


**Figure 18 :** Constant-power load

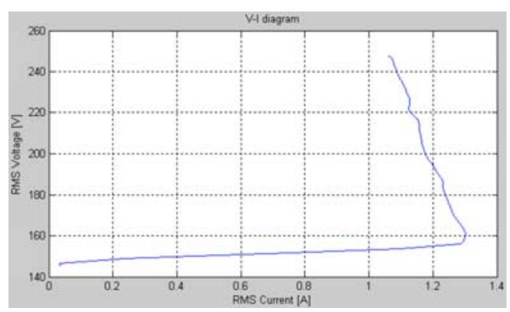


**Figure 19 :** $V_{RMS}/I_{RMS}$ curve of a PC + LCD screen (NDI around the normal operating point of $230V_{RMS}$)

### Measurement methods and results

Some questions are still debated about the correct measurement of harmonics and flicker (2 papers), the state of the art being the conformity with IEC 61000-4-30 (2 papers). Harmonic level measurements give an indication about the effectiveness of emission limits; the safety margin appears to be high in Japan, but not so high in Germany in presence of significant PV generation (2 papers). Finally, four papers report on PQ evaluation with respect to the European standard EN 50160, and an innovative PQ classification is proposed.

The discrete Fourier transform (DFT) is generally used for **harmonic measurements**. One of the main problems with this method is spectral leakage (due to errors in synchronizing fundamental and harmonics). [B2-0430(IT)] proposes a two-step procedure that requires the successive application of ESPRIT (estimation of signal parameters by rotational invariance technique) and DFT methods. The effectiveness of the method (fast computation and accuracy of the results, also for interharmonics) is demonstrated with case-studies (Figure 20).

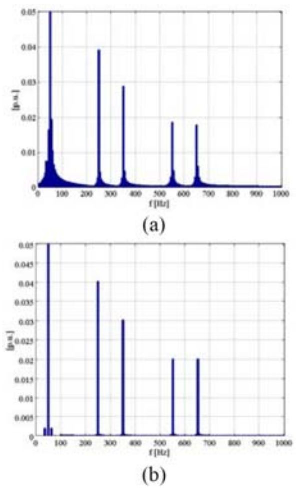


**Figure 20 :** Spectrum of a signal with harmonics (h = 5, 7, 11, 13) and interharmonics (37 and 63 Hz), applying DFT (a) and ESPRIT-DFT (b) methods

[B3-0789(NO)] claims that the **flickermeter** response to RVCs can differ from instrument to instrument. That means that existing flickermeters are not reliable for the left-hand part of the $P_{st}$=1 curve (say, for less than 200 voltage changes/min, see e.g. Figure 40).

Following [B3-1020(BR/CO)] a signal processing method including wavelet transformation could be used not only for disturbing events but also for steady-state disturbances (see Block 3).

[B4-0677(DE/AT)] describes a test system for accuracy verification of PQ measurement instruments according to IEC 61000-4-30 (see Block 4).

IEC 61000-4-30 ensures that all compliant PQ instruments will produce the same results when connected to the same signal [B2-1070(US)]. A new set of technologies (coming from several fields like digital cameras, power-over-ethernet, mobile phones, submarine sonar systems...) make it possible to manufacture 3-phase PQ instruments that are fully compliant with the Class A requirements of the standard at ultra-low-cost.

[B2-0243(DE)] presents the results of **harmonic voltage** measurements in German MV- and LV-systems with different load mixture (industrial, residential, commercial, rural). High levels of low- and odd-order harmonics were measured in all kinds of systems. Even- and high-order harmonics are also present in industrial systems. If a significant amount of photovoltaic generation is installed in the LV-system, all odd-order harmonics are high (Figure 21).

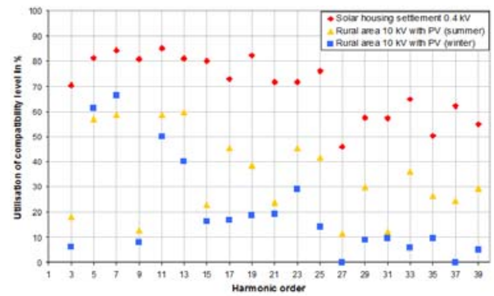


**Figure 21 :** Utilization level (% compatibility level) of harmonic voltages (odd order) – systems with solar generation

Limits for harmonic currents were prescribed in Japan in 1994. [B2-0332(JP)] analyses the distribution and the annual trend of harmonic voltage between 1994 and 2007 in Japan. It appears that: i) the harmonic voltage levels have recently been decreasing (Figure 22), ii) the distribution of voltage distortion is similar to the logarithmic normal distribution (Figure 23) and there are very few areas where the harmonic voltage distortion is larger than the compatibility levels. The author concludes that the existing limits of harmonic currents are effective and sufficient.

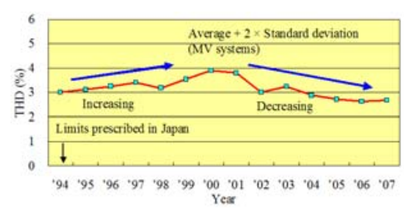


**Figure 22 :** Annual trend of THD levels in Japan

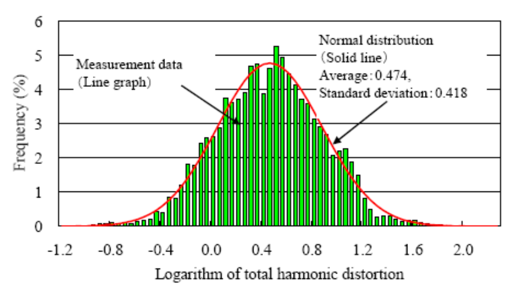


**Figure 23 :** Distribution of logarithm of THD in Japan

[B3-0737(IT)] and [B3-0363(IT)] report on results from 3 years experience of **PQ monitoring** (monitored busbars covered 11 % of the Italian MV networks). No significant correlation was found between MV short circuit power and flicker, THD (Figure 24) or voltage unbalance.

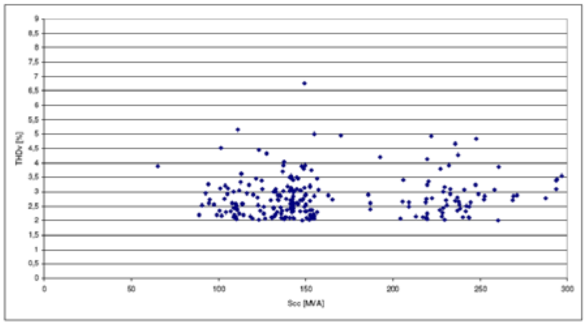

**Figure 24 :** Correlation between THD and short circuit capacity in MV bus bars

[B2-0167(DK)] gives the results of a pilot project for PQ measurements in Denmark, limited in a first stadium to the 10-30 kV grid in Copenhagen. Results are well below the EN 50160 limits (contrarily to the situation in the Czech LV networks [B3-0086(CZ)]). However, data were not recorded for a few (less than 0.1%) 10-min periods. It would be a problem if a full set of measurements was required in order to prove a "100% of the time" compliance which has been suggested by regulators as a possible improvement of EN 50160.

[B2-0450(NL)] describes a pilot project of cheap PQ monitoring in 10 HV/MV substations. In the coming years, the whole MV network will be covered and LV monitoring will be extended too. A classification has been defined for every PQ aspect, in a range from A (very good) to F (very poor). On one week, there are 1008 10-min intervals and then 1008 values for every PQ phenomenon, which can be described by an average value ($X_{avg}$) and a standard deviation ($\sigma$). Assuming a normal distribution, the following equation gives the value $X_{limit}$ which is not exceeded for Y% of the measured values:

$$X_{limit} = X_{avg} + k(Y)\cdot\sigma$$

It means that for a given limit ($X_{limit}$) and a given non-exceeding probability (Y), the couples of possible values for $X_{avg}$ and $\sigma$ are situated on a straight line. Y is generally chosen as 95%, which gives k(Y) = 1.65. In case of flicker, the limit value is $X_{limit} = 1$. Then, for $X_{avg} = 0$ we get $\sigma \approx 0.6$ and for $\sigma = 0$ we get $X_{avg} = 1$, see Figure 25. This line can be seen as the EN 50160 limit. In order to obtain a better differentiation, five extra parallel lines can be drawn, resulting in 6 areas from A to F.

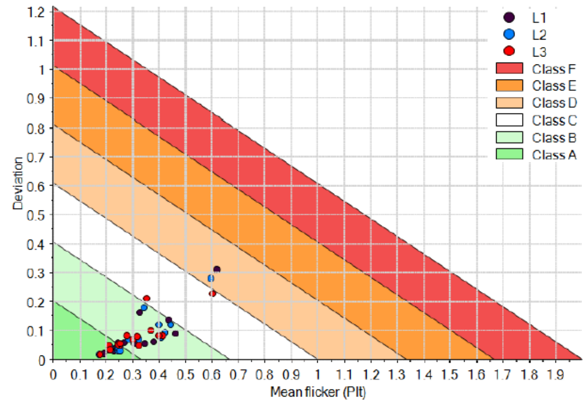


**Figure 25 :** Classification of a PQ aspect

**Further research topics**

Convergence between immunity levels and recommended PQ levels (e.g. EN50160) is sometimes questioned. Should some of the recommended levels ("compatibility levels", "voltage characteristics", "planning levels"...) be revised ?

Assessment of emission levels: are the methods recommended by JWG CIGRE/CIRED C4-109 suitable to be included in contractual requirements ?

The classification of PQ aspects in 6 classes is a new idea [B2-0450(NL)]. What could be the use of it (reporting to the regulator, to the customers...) ? Is it better than just publishing the quality indices ?

Are wavelet based algorithms able to measure all PQ parameters (events, continuous, different acquisition times) with high accuracy ? Will they replace standard methods (FFT, flickermeter) ?

## Block 3 : Disturbing events

**Power quality indices**

PQ indices are well defined for steady-state disturbances (IEC 61000-3-6/7/13, EN 50160, etc.) but are still much more debated for events like voltage dips and interruptions.

For **long interruptions** (>3min), the three fundamental quality indices (site- or system indices) are always:

- AIF = average interruption frequency (=SAIFI: system average interruption frequency index, =CI: customer interruptions) : the yearly number of outages per customer (n/customer/year),
- AID = average interruption duration (=CAIDI: customer average interruption duration index) : the average duration of an interruption (min/outage),
- AIT = average interruption time (=SAIDI: system average interruption duration index, =CML: customer

minutes lost) : the yearly average interruption time per customer (i.e. the product of the two other indices) (min/customer/year).
There are however different ways of obtaining them, e.g. counting the number of interrupted customers (only used at MV and LV levels) or registering the non-delivered energy. There is a need for harmonization of definitions [B4-0911(INT)].

For **voltage dips** (sags), two-dimensions tables (e.g. depth/duration) have been used for a long time, as well as global indices like SARFIx (System Average RMS Variation Frequency Index) giving the yearly number of dips with remaining voltage lower than x (for a whole system or just a busbar). The trend is now to rely the quality index to the immunity curves of some sensitive equipment, the aim being for a customer to assess the yearly number of troubles to be expected.

For example [B3-0058(EG)] uses the lost energy in a dip event
$W = (1-V_{pu})^{3.14}\cdot t$ (expressed in seconds)
where $V_{pu}$ is the remaining voltage and t the dip duration (defined in IEEE P1564 – the lost energy for 1-phase events on the CBEMA curve, Figure 30, is constant). The Average Voltage Sag Energy Index (AVSEI) for a site is given by the average value of W for the site.

For comparing dip performances in different regions, [B3-0737(IT)] proposes global indices closely related to the immunity characteristics of apparatus : the average number of voltage dips per measuring point that lie respectively below the two immunity curves defined for classes 2 and 3 in IEC 61000-4-11/34 (Figure 26).

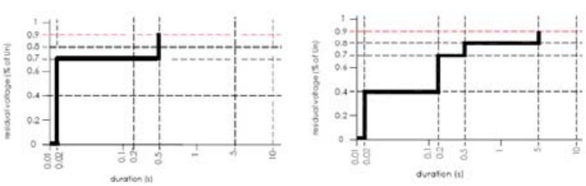

**Figure 26 :** Voltage dip immunity curves 2 and 3 (IEC 61000-4-11 and IEC 61000-4-34)

More refined characterization may be obtained by using immunity classes as proposed in [B3-0149(INT)], see Figure 27 and Figure 28.

### Sensitivity of equipment to voltage dips and swells

Most problems regarding sensitivity of equipment are linked to voltage dips, which is confirmed by the number of corresponding contributions (6 papers). Immunity of domestic appliances against swells is considered in one paper.

[B3-0149(INT)] announces the final report of the JWG CIGRE/CIRED/UIE C4.110 on voltage dip immunity of equipment in installations. A structured approach is proposed for selecting adequate equipment or mitigation methods. Voltage dips are classified in three categories: Type I (a major drop in magnitude of 1 phase-to-neutral or 2 phase-to-phase voltages), Type II (a major drop in magnitude of 2 phase-to-neutral or 1 phase-to-phase voltage), and Type III (a major and approximately equal drop in magnitude of all 3 phase-to-phase or phase-to-neutral voltages). The WG also proposes to label electrical equipment for use in industrial installations, based on its immunity to voltage dips. The classification consists of two parts: a voltage-dip immunity requirement (Figure 27 and Figure 28) and a pass/fail criterion (1.- Full operation, 2.- Self-recovery, 3.- Assisted-recovery).

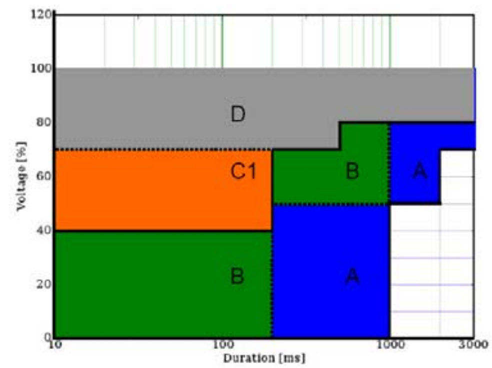


**Figure 27 :** Proposed immunity classes against voltage dips of Type I and Type II (unbalanced dips)

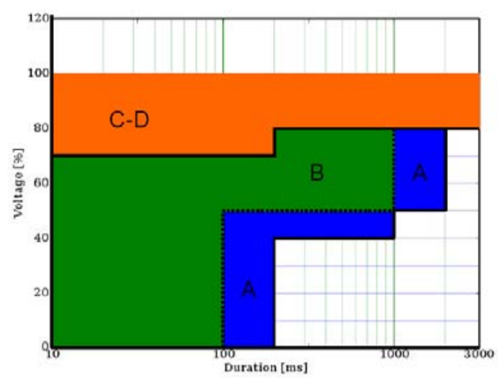


**Figure 28 :** Proposed immunity classes against voltage dips of Type III (balanced dips) (preliminary proposal)

The effect of voltage dips on induction motors is analyzed by the authors of [B3-0327(EG)] with a simplified steady state model. Based on the torque-slip characteristics the critical time beyond which the machine stalls is calculated. Comparison with an exact 6th order model shows good compliance. Results can be a used for relay coordination in industry.

Fault ride-through (FRT) requirements for distributed generation are part of most grid codes. In [B3-0689(GR)] typical depth-time characteristics for dips in a weak MV grid are calculated (all types of faults and fault resistances). The results are compared with an international selection of FRT requirements (see e.g. Figure 29 for symmetrical faults). It can be seen that WTs fulfilling the requirements are also suitable for islands or other weak grids.

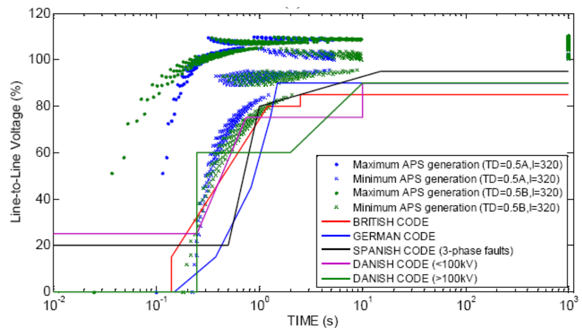


**Figure 29 :** Voltage dips due to 3-phase faults in a medium sized island grid and wind turbine FRT requirements of selected grid codes

Poor PQ is frequent in Nigeria: "If power equipment and loads could talk or express feelings, I am sure they would have made a big protest against the great injustice imposed on them" [B3-0018(NG)].

The following papers report immunity test series for LV single-phase equipment. In [B3-0965(MY)] test points were chosen according to ITIC (Figure 30) for IT equipment, IEC 61000-4-11 (Figure 26) for domestic loads and SEMI F47 (Figure 31) for motor loads.

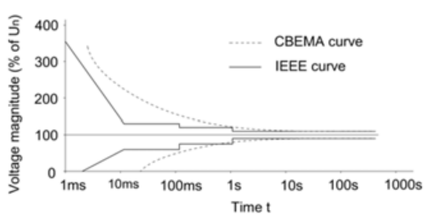


**Figure 30 :** Immunity curves for IT devices : the classic CBEMA curve evolved into ITIC and finally IEEE 446 curves

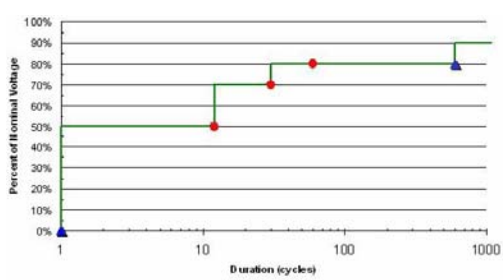


**Figure 31 :** SEMI F47 required semiconductor equipment voltage dip ride through capability curve

The authors of [B3-0556(CZ)] tested a variety of light sources (incandescent, fluorescent, high pressure...). The standard EN 61547 is considered as not satisfactory (tests are not fully representative of real conditions and immunity levels are not determined). Immunity curves were established according to several function criteria (see Figure 32 for instantaneous value of luminous flux falling down to zero).

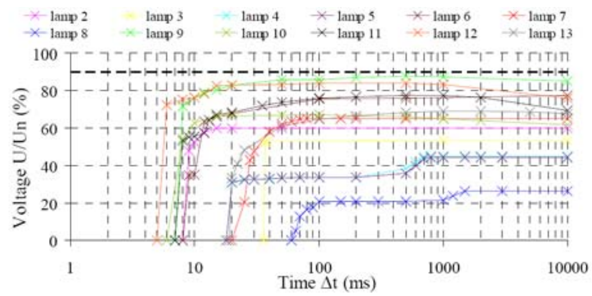


**Figure 32 :** Immunity curves of all tested light sources (230 V, rectangular shape of voltage dip)

62 domestic appliances (TVs, PCs, lighting equipment etc.) were tested against swells (rms overvoltages) [B3-0781(NO)]. They showed in general good immunity in the test range (from $U_N$+12% to $U_N$+40% lasting from 100 ms up to 100 s). Only 7 appliances malfunctioned, 3 of them being damaged.

### Assessment of voltage dips and other disturbing events

For **interruptions**, the question is not the measurement but the data collection. [B3-0716(NO)] describes the FASIT standard for reliability data collection, and reliability indices calculation and reporting. For example, in the interruption reports the calculation of ENS is based on the expected load curve (not the interrupted power) in the interruption time period.

**Measurement techniques.** Specific techniques are still being developed in order to capture and correctly characterize events (4 papers).

Especially in the field of measurement of events (dips, swells, transients, rapid voltage changes) the application of wavelets might become important, as a number of papers during the last years illustrate. The authors of [B3-0063(MY)] analyzed different common types of mother wavelets with regard to their ability to detect voltage sags. A set of features, based on standard mathematical indices, was used for detection. The Gaussian mother wavelet proved to be best for this task.

For automatic classification of power quality disturbances, [B3-1020(BR/CO)] presents a signal processing method including wavelet transformation (WT) and classification with artificial neural network (ANN) or alternatively a support vector machine (SVM). Applied on different test signals, SVM proved to be superior to ANN regarding success rate in classification and computation time.

[B3-0062(MY)] uses a signal processing technique (S-Transform) for detection of events and then a classification technique using SVM. Countermeasures against PQ deterioration may then be initiated, preventing equipment maloperation.

Due to power electronic applications, voltage dips frequently come along with strong distortion or even frequency deviation. DFT based methods may introduce significant errors in identifying the magnitude of the fundamental harmonic amplitude. The authors of [B3-0840(UK/ES)] present a Newton type algorithm (NTA) to overcome those problems. The algorithm was applied to a measurement system monitoring the voltage ride through capability of a wind farm (double fed induction generators).

**Statistics** are important to characterize PQ with respect to voltage dips and interruptions, trying to isolate the influence of exceptional events.

A dip measurement campaign in Canada [B3-0346(CA/SE)] confirms the need of adequate long observation time to meet the requirements of meaningful statistics. Extreme weather conditions have a significant impact on the result, in the presented case 62% of the events were recorded within 24 days (6 % of observation time). In an analyzed semi urban feeder dip type II according to the classification of [B3-0149(INT)] was dominant, whereas in a rural feeder it was dip type I.

[B3-0737(IT)] and [B3-0363(IT)] report on results from 3 years experience (the monitored busbars covering 11 % of the Italian MV networks. It was experienced, that saturation of PT during earth faults in grids with isolated or compensated neutral produce apparent dips, thus falsifying the statistics. Cable networks seem to have a higher dip rate per km, possibly due to more unsuccessful reclosure operation and further propagation according to lower impedance. A rather high variation of the dip performance in different regions was observed, though the structural parameters of the grids are quite similar.

[B3-0909(HR)] studies the correlation between daily load curve and reliability indices. It appears (Figure 33) that the probability of interruptions is higher during heavily loaded power system. On the other hand (Figure 34), interruptions that happened out of working hours are of longer duration (availability of emergency staff within the company).

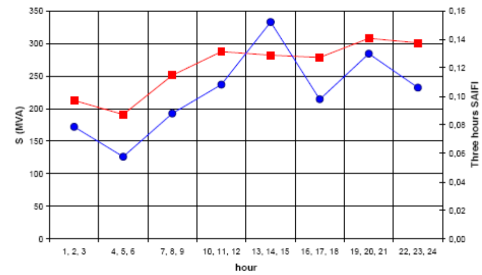


**Figure 33 :** Three-hour values of daily load curve S (■) and SAIFI (●) for unplanned interruptions

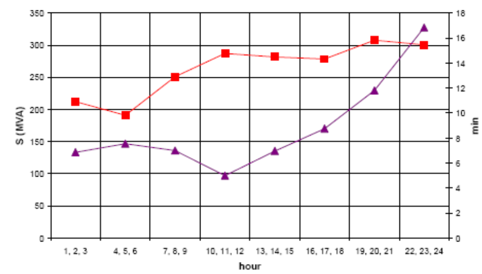


**Figure 34 :** Three-hour values of daily load curve S (■) and CAIDI (▲) for unplanned interruptions

The reliability performance of a distribution system exhibit a stochastic behavior, see e.g. the results of a Monte Carlo simulation on Figure 35 [B3-0910(UK/PT)]. There is a need for reliability models of the system to be used as opposed to relying only on variable historical network performance as is currently being done by regulators.

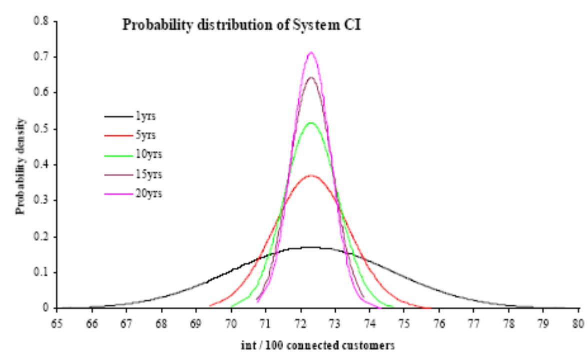


**Figure 35 :** Variability of system CI (= AIF = SAIFI) for different sampling number of years

[B3-0113(CH)] suggests to use smoothed numbers for continuity indices like SAIDI or SAIFI to lower the yearly variation and allow a better check of compliance with guidelines (Figure 36, Table 2).

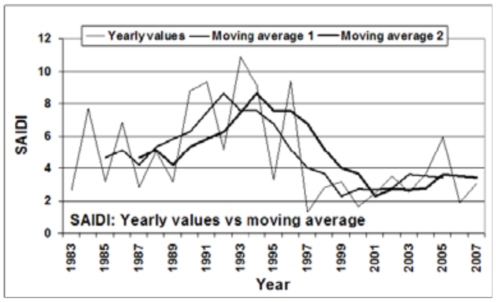


**Figure 36 :** Time-series of yearly values of SAIDI from ewz. Two moving average curves are drawn, moving average 1 is placed in the middle, resp. 2 at the end of the 5-year period.

**Table 2 :** Reliability recommendations for Swiss electrical networks according to the "Distribution Code" of the VSE (Association of Swiss Electrical Enterprises).

| Guidelines for Swiss utilities | | | | |
|---|---|---|---|---|
| Network | Criterions | SAIFI | SAIDI | Max. outage duration per event (h) |
| urban | community with at least 10000 inhabitants, at least 60 per hectar (0.01 km2) build up area | 1 | 30 | 4 |
| semi-urban | 35-60 inhabitants per hectar build up area | 3 | 100 | 6 |
| rural | < 35 inhabitants per hectar build up area | 4 | 200 | 12 |
| mountainous | single customers | 5 | 300 | 18 |

[B3-0233(PT/SE)] examines the concepts of "exceptional events" and "force majeure events" as used within quality of supply regulations among 20 European countries. It is concluded that "exceptional events" are more appropriate for regulation but that they should cover events that are both sufficiently rare and with an effective cause beyond control of the network operator.

In case of outage, the process of restoring the electricity supply to customers is not simple [B3-0351(CZ)]. Different ways of gathering the data will then lead to different values of system reliability indices and of costs of penalty payments.

In order to estimate the financial risk induced by the future German regulation, [B3-0373(DE)] presents a method to assess the probability distribution of reliability indices. Exemplary results are given in Figure 37 for system related reliability indices.

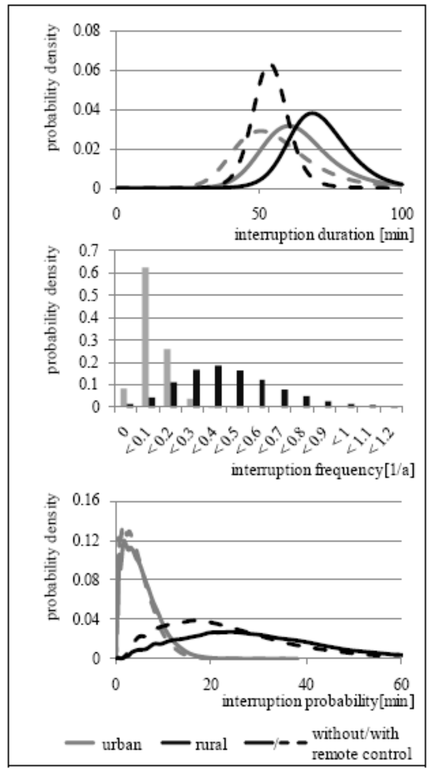


**Figure 37 :** System related reliability indices (AID min/interrupt, AIF interrupt/customer/year, AIT min/customer/year)

In the UK, performance benchmarks have been adopted by the regulator to facilitate the comparison of CI (or AIF or SAIFI) and CML (or AIT or SAIDI) performances between DSOs [B3-0958(PT/UK)]. However, a conceptual flaw has been identified in the calculation formulas: the calculation of average network length should be weighted by the number of connected customers to each feeder. The impact of the present errors is that incorrect incentive messages are being sent to DSOs.

**Simulation.** To estimate the number of dips, a customer may suffer from, long time measurement and different kinds of simulation methods, usually based on reliability statistics are used.

Unbalanced dips, originating from the transmission system, usually change their appearance (type) in the underlying grids according to the vector group of the transformers. [B3-0185(AR)] demonstrates the efficient use of symmetrical components in modeling the dip propagation and concludes that dips of Types I and II are the most probable for industrial installations.

Voltage dip prediction requires some knowledge about the distribution of faults along the lines. The authors of [B3-0013(CN)] present a new algorithm based on the maximum entropy principles. The application of this algorithm on the IEEE 30 bus test system with Monte Carlo simulation of fault positions yielded more accurate results than the approach with uniform, normal or exponential distributions.

A simulation tool for the calculation of dip distributions is presented by [B3-0268(FR)]. Comparisons between measured and calculated results are given in Figure 38 and Figure 39. Reasons for discrepancies are analyzed in view to future improvements. It should be possible to assess the probability not to exceed a given performance level for voltage dips in terms of number, depth and duration.

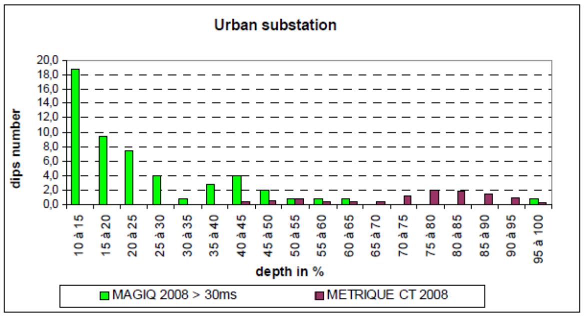


**Figure 38 :** Comparison between measured (MAGIQ2008) and calculated (METRIQUE) results in urban substation

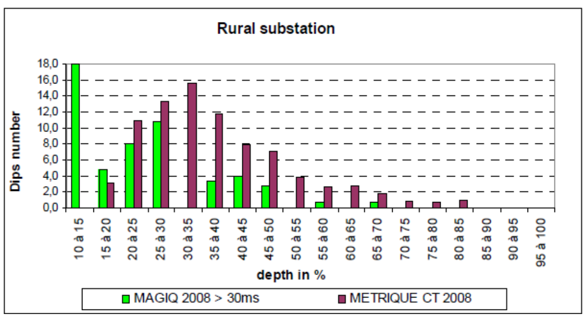


**Figure 39 :** Comparison between measured (MAGIQ2008) and calculated (METRIQUE) results in rural substation

**Switching events.** Voltage dips may be due to switching of loads or equipment. Mitigation is then possible at the source of the problem (controlled switching).

The authors of [B3-0604(AU/US)] use dip transfer coefficients, derived from load flow calculations, to estimate the origin of a dip due to load switching. The complexity increases with the number of unmonitored bus voltages. A possible further development is a system wide optimum monitoring location scheme.

[B3-0988(UK)] presents a simplified method for estimating voltage dips through transformer inrush. The simple inrush model has a number of limitations; however it is viewed as appropriate for the assessment of typical wind farm connection studies. A simple rule of thumb was derived: if the ratio of the network short-circuit MVA to the transformer "inrush" MVA is equal to or greater than 8.5, the transformer energization is unlikely to create a voltage step-change of greater than 3%.

[B3-0123(CN)] analyzes the voltage variations caused by the switching of capacitors. They remain totally located within the allowance of the ITIC (former CBEMA) voltage tolerance curve (Figure 30).

Controlled switching is discussed in two papers. [B3-0128(CN)] discusses the development of a MV "synchronous" circuit breaker, minimizing inrush currents during energization and restrike probabilities during denergization of capacitor banks. [B3-0194(CH)] proposes a new algorithm to reduce the stresses that occur during power transformer energization.

**Flicker.** Unlike dips, swells, harmonics and unbalance, flicker usually will not affect the functionality of devices but directly disturb human beings. CIRED/CIGRE working group C4.108 elaborated a report about the sometimes poor correlation between measured flicker levels in HV and customer complaints [B3-0755(INT)]. Two main reasons are investigated: i) significant load-dependent attenuation of flicker from EHV/HV to LV is possible and indeed likely, ii) modern lighting technologies can be 4-6 times less susceptible than 230V, 60W incandescent lamps (Figure 40).

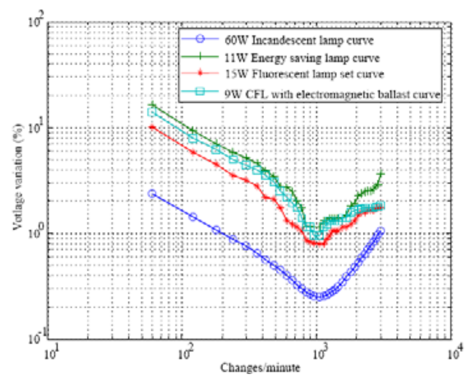


**Figure 40 :** Instantaneous flicker sensation curves for sinusoidal input voltage modulation

[B3-0086(CZ)] presents 3-year PQ measurements in 80 LV distribution networks of the Czech Republic. About10% of monitored networks do not fulfill the present EN 50160 limits for voltage level, about 40% for flicker (and it will worsen with the proposed changes of EN 50160). However, less than 0.1% of customers are complaining about poor voltage quality.

Nevertheless, flicker limits should not be changed without care, while flicker-related complaints remain a frequent problem [B3-0102(NL)].

A phenomenon, closely related to flicker, is "rapid voltage changes" (RVCs). Although mentioned in several standards (Figure 41), there is still a lack of definition (Figure 42), indices and relevance. CIGRE/CIRED working group

C4.108 has prepared a contribution to that topic [B3-0758(US/BE)]. The paper summarizes existing concepts, definitions and measurement methods. Furthermore proposals for indices, covering measuring intervals from half cycle to 10 min are given. However, much work remains to be done to insure that they do indeed address an area of need in an accurate, repeatable and technically defensible manner.

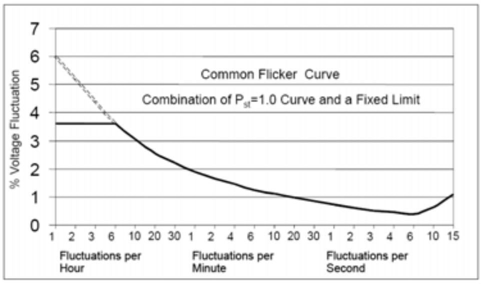


**Figure 41 :** Practical limit curve commonly used in North America : combination of limits for flicker (right-hand part of the curve) and for rapid voltage changes (horizontal left-hand part of the curve)

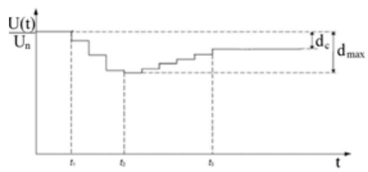


**Figure 42 :** $d_c$ and $d_{max}$ are two possible conceptual definitions of rapid voltage changes

Tests made by SINTEF [B3-0789(NO)] show that the flickermeter response to RVCs can differ from instrument to instrument. The authors claim that there is therefore a need for separate requirements, as it is already included in the Norwegian regulation. An RVC is defined as an RMS voltage change within ±10% of agreed voltage level, which occurs more rapid than 0.5% per second. RVCs are expressed as $\Delta U_{steadystate}$ and $\Delta U_{max}$ (corresponding to respectively $d_c$ and $d_{max}$ in Figure 42). Limits for RVCs at the point of connection of any customer are given in Table 3.

**Table 3 :** RVC limits depending on the nominal voltage value $U_N$ (kV)

| RVCs | Maximum frequency pr 24 hours period | |
|---|---|---|
| | $0{,}23 \leq U_N \leq 35$ | $35 < U_N$ |
| $\Delta U_{steadystate} \geq 3$ % | 24 | 12 |
| $\Delta U_{max} \geq 5$ % | 24 | 12 |

**Disturbance mitigation near sensitive equipment**

Several technical solutions exist to mitigate voltage dips or interruptions, respectively at equipment-, plant- or system level. The choice is always the result of a cost/benefit analysis (4 papers).

In an oil production facility, supplied by a weak 230 kV grid, voltage dips caused production failures due to trips of AC drives [B3-0052(SE/CO)]. After installing an SVC on the MV bus bar the voltage was stabilized, the power import increased by 30 MW and 95% of device tripping was avoided.

Different solutions will provide different degree of protection requiring different amount of investment. For choosing the optimal mitigation technique, the customer cost regarding production failure due to poor power quality must be known. An assessment procedure is given in [B4-0842(UK)].

For choosing between voltage dip mitigation options, independent yet coordinated technical and financial assessments are presented in [B3-0546(UK)]. Improvements are possible at equipment level (improving equipment resilience), plant level (installation of DVR – dynamic voltage restorer) or network level (PQ contract). The chosen tool for voltage dip financial analysis is the Stochastic Net Present Value (SNPV) – the best mitigation option being the one with highest SNPV.

[B3-1044(IE)] proposes the development of an economic framework for the societal cost/benefit analysis of PQ issues. In many cases, it is the cost of the consequences of poor PQ which are set against the cost of improving the network, whereas the correct approach is to compare the costs of options to mitigate the consequences (installation of a UPS by the user, network reinforcement...) against the cost of accepting the consequence.

**Further research topics**

The need may be recognized to limit the magnitude of the voltage changes due to a single customer, in order to limit the risk for the voltage to vary outside the allowable range. This is an emission limit problem. But are rapid voltage changes (RVCs) a real EMC problem ? Their possible visible effects on lighting are taken into account by the flicker limits. Is there another reason to limit them in the voltage ?

When the international flickermeter was developed, one of the requirements was a correct evaluation of RVCs. The discrepancies between instruments from different manufacturers [B3-0789(NO)] are then not normal. What should be changed in the relevant standard to ascertain a correct behavior of the flickermeter in the low-frequency range ?

The incandescent lamps will soon be forbidden in many countries. Will flicker remain a problem ? Will it be necessary to change the flickermeter or the limits ?

What is the experience on validation of simulated dip performance by monitoring ?

When reporting about PQ, which quality indices should be taken for voltage dips ?

What is the impact of voltage swells on equipment ? (particularly in the context of increased levels of DG).

## Block 4 : Power quality in the competitive market

**Power quality monitoring in general**

Wide-area PQ monitoring systems are implemented in more and more countries (6 papers; see also [B2-0167(DK)], [B3-0363(IT)], [B3-0737(IT)], [B2-1070(US)]). A new trend is to take benefit from progress in smart meters or more generally IEDs (intelligent electronic devices), and communication systems, to develop integrated PQ monitoring systems (5 papers; see also [B2-0450(NL)].

[B4-0584(CA)] describes a wide-area **PQ monitoring system** (WAPQ) which may be used to address one or more of three main needs: standards compliance, system reliability improvements, and customer satisfaction. Potential problems are also analyzed: data integrity, biased results and double-counting.

[B4-0677(DE/AT)] describes a test system for accuracy verification of PQ measurement instruments according to IEC 61000-4-30. The tests run automatically and are designed to be carried out "in the field" without dismounting the measurement instrument. It would be important for efficient instrument testing to have a standardized interface (suggestion for further standardization activities).

In Romania, a permanent PQ monitoring system has been installed at the interface between transmission and distribution systems, at 110 kV voltage level [B4-0949(RO)].

In the Czech Republic, PQ is monitored at the 62 points of delivery between transmission and distribution systems on the 110 kV side [B4-0514(CZ)]. [B4-0291(CZ)] presents a project of voltage quality evaluation at the points where electricity is being measured for invoicing purposes (adding a PQ monitor). The system was installed at 400 points without supply interruptions. [B4-0987(CZ)] gives a thorough study of PQ data compression (benchmarking of various lossless algorithms).

Low-cost **smart meters** make it possible to get statistical information about voltage levels at customer's sites [B4-0198(AT)]. Increase of voltage observed in many cases is caused by unbalanced loads.

Automatic Meter Reading (AMR) systems, which are widely used today, allow gathering interesting information about PQ parameters in a cheap and easy way, although it is not compliant with IEC 61000-4-30 [B4-0564(RO)].

[B4-1014(BR)] presents a Power Quality Monitoring System (PQMS) which centralizes and structures the information collected from intelligent electronic devices **(IEDs)** throughout the power system.

The new IEC 61850 international standard for **substation communications** has significant impact on all aspects of substation monitoring and control, including PQ related functions [B4-1063(US)]. Different PQ monitoring and recording systems may be developed, making use of several IEDs available in the substation.

[B4-0961(US)] describes the development of a Next Generation Power Information System that will provide an open platform for implementing advanced monitoring system applications that involve integration with many different data sources. It will provide web-based access and management to a wide variety of power system information, making access to information available to a wide range of users, both internal and external to the company.

**Value of poor PQ**

An assessment of the incurred costs is important for the choice of a mitigation method against voltage dips or interruptions (see above), and also for the choice of a system improvement (see below). The customer value of poor PQ is furthermore the basis of many regulatory frameworks. Four more papers address the issue.

[B4-0103(NL)] reviews in general terms the techno-economic impacts of poor PQ for both the customer and the DSO, especially for harmonics, flicker and dips.

Consumers-perceived economical evaluation of PQ has been investigated in Brazil for home consumers with the highest dissatisfaction levels (AIF > 8 outages/ customer/ year and AIT > 15 h/customer/year) [B4-1017(BR)]. The home interview survey showed that only 25% were willing to pay for the execution of proposed investments.

[B4-0806(UK)] presents a detailed opinion-based PQ survey of Indian Pharmaceutical Industry. The annual cost of downtime due to all PQ events can be as much as 10.33% of the total company's annual turn-over. Voltage dips alone account for about 50% of this cost. [B4-0842(UK)] describes a methodology to estimate the Cost Of Downtime (COD) of industrial processes due to voltage dips (see e.g. Figure 43 for a typical pharmaceutical manufacturing process).

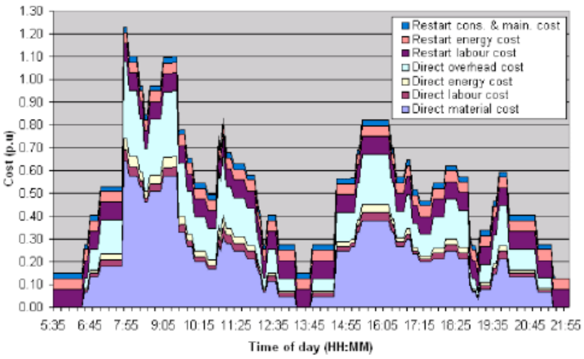


**Figure 43 :** COD profile for the example manufacturing process with time of day

## Regulatory aspects

The Council of European Energy Regulators (CEER) has published its 4th Benchmarking Report on Quality of Electricity Supply (www.energy-regulators.eu) [B4-0911(INT)]. It is dealing with: i) continuity of supply: need for harmonization of definitions of quality indices like SAIDI, SAIFI, etc - call to IEC, CENELEC, IEEE, ii) voltage quality: thanks to the cooperation between CEER and CENELEC, the EN 50160 standard is being revised in order to be acceptable from a regulatory point of view, iii) commercial quality: trend to use Guaranteed Standards (GSs) instead of / in addition to Overall Standards (OSs) ; trend also to tie the GSs to direct automatic compensations in case of non-compliance.

Most financial incentives/penalties are concerned with supply continuity. Information in this respect is to be found on OSs (6 papers), GSs (2 papers) or a combination of OS & GS (2 papers). A last paper describes a GS with voltage quality related penalties.

**Overall Standards.** For [B4-0713(DE)], the quality regulation alone is not enough to avoid underinvestment, particularly if there is a growing need for replacement investments. There is a necessity of additional investment incentives.

[B4-0057(EG)] announces a regulatory framework including connection rules for disturbing loads and assessment of PQ economics (optimum cost-benefit analysis). [B3-0058(EG)] presents an incentive/penalty mechanism based on 3-years average continuity indices (SAIFI and SAIDI).

In Denmark, DSOs and RTSOs with an unacceptable continuity of supply for the average (worst-served) customer in 2007 had to reduce their income cap by 1% (0.5%) the following year [B4-0704(DK)]. The Danish Energy Regulator Authority made in October 2008 the first benchmarking of DSOs and RTSOs continuity of supply, including all voltage levels from LV to 150 kV. The Danish Energy Association finds however the benchmark models defective and too complex.

In Portugal, EDPD operates distribution networks for over 6.6 million customers [B4-0548(PT)]. The Performance Based Regulation (PBR) includes a sliding-scale incentive mechanism with collar and cap to determine the reward or penalty. The maximum reward or penalty incurred is 5M€ annually (Figure 44) with reference to the performance observed 2 years before. There is an underlying target for TIEPI (a quality index which may be seen as an approximation of AIT) with no costs for the customer. The mechanism has been set to value the non-distributed kWh at 1.5€.

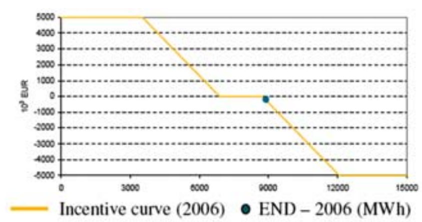


**Figure 44 :** Quality of supply incentive scheme for 2006

[B4-0494(NO)] describes the extended incentive based regulation on continuity of supply adopted in Norway : the new interruption cost assessment incorporates short interruptions and time dependency of interruption costs, see Figure 45, Table 4, Figure 46, Figure 47.

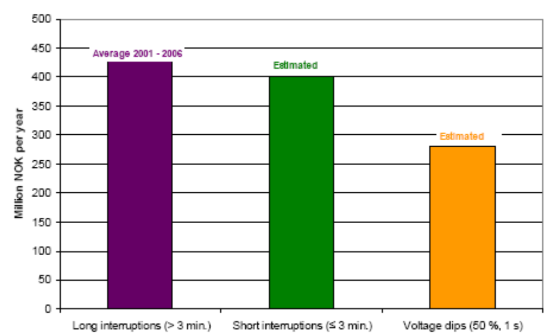


**Figure 45 :** Total costs of interruptions and dips in Norway (1 NOK is about 0.11 EUR)

**Table 4 :** Interruption cost functions in NOK/kW (r = interruption duration in h)

| Customer group | Cost function | |
|---|---|---|
| | All durations (r) | |
| Agriculture | 10.6 · r + 4 | |
| Residential | 8.8 · r + 1 | |
| | r = 0 – 4 hours | r > 4 hours |
| Industry | 55.6 · r + 17 | 18.4 · r + 166 |
| Commercial | 97.5 · r + 20 | 33.1 · r + 280 |
| Public | 14.6 · r + 1 | 4.1 · r + 44 |
| Large Industry | 7.7 · r + 6 | 3.1 · r + 23 |

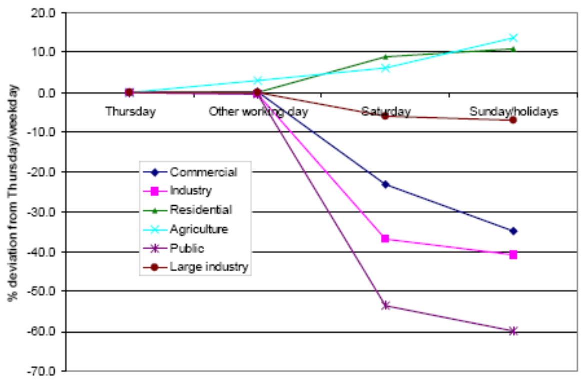


**Figure 46 :** Deviation (%) in cost from working day

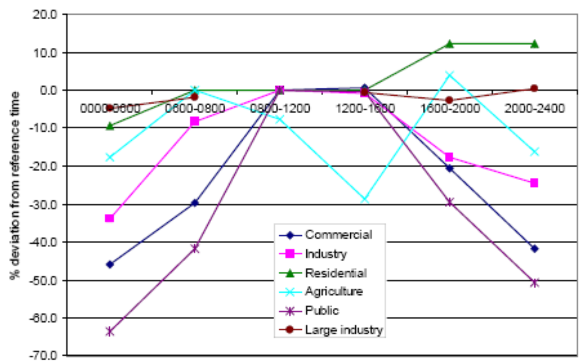


**Figure 47 :** Deviation (%) in cost from reference time

**Guaranteed Standards.** For [B4-0383(HU)] the concept of worst-served customer should include commercial quality and voltage quality in addition to continuity of supply. He also proposes that GS include automatic payment instead of payment on request.

[B3-0113(CH)] evaluates the total cost of penalties for interruption durations exceeding given limits, for the ewz company (Table 5). In relation to other costs, it seems to be a minor problem.

**Table 5 :** The costs of downtime limit of 4 or 6 hours per event, assuming a fine of CHF 200 (about € 131) - if the limit is exceeded. Data are from ewz, averaged over the period 1983-2007.

| Downtime per event (min) | Average number of affected customers per year | Affected to total number of customers with outages | Total fine (example CHF 200.- per customer and event) to be paid by the company |
|---|---|---|---|
| 240 | 633 | 1.93 | 126000 |
| 360 | 208 | 0.63 | 41600 |

**Overall and Guaranteed Standards.** In the UK, DSOs are subject to an interruptions incentive scheme (IIS) which rewards or penalizes them with regards to the quality of supply in terms of CI (or AIF or SAIFI) and CML (or AIT or SAIDI) [B4-0638(UK/PT)]. They are also subject to Guaranteed Standards (GS) of performance for worst-served customers: i) GS2: payment is due to customers experiencing an interruption >18h (£50 for the first 18h plus £25 for each additional 12h, N.B. £1 is about €1.08), ii) GS2A: payment is due to customers who experience 4 or more interruptions each lasting ≥3h (but <18h) in any single year (£50). A Sequential Monte Carlo Simulation (SMCS) method makes it possible to assess the number of worst-served customers (e.g. 0.9% of the DSO's total number of customers for GS2 and 0.03% for GS2A) and also the variations of this number with changing thresholds for GS2 or GS2A.

The Finnish distribution network regulation aims at minimizing the total costs of network operations (TOTEX), which has three components: capital costs (CAPEX), operational costs (OPEX) and outage costs (OUTAGE) [B4-0693(FI)]. CAPEX, OPEX and OUTAGE are the objects of different incentive schemes. For OUTAGES, if the yearly outage costs (see unit prices in Table 6) are above (below) the reference level based on historical data, the regulation model decreases (increases) the allowed profit of the DSO. Worst-served customers are not forgotten: for interruption durations ≥12h, standard compensations have to be paid to the customers (in the regulation model, these payments are included in the OPEX).

**Table 6 :** Prices for different types of outages used in the Finnish regulation model

| Unexpected interruption | | Planned interruption | | Short auto reclosing | Long auto reclosing |
|---|---|---|---|---|---|
| €/kW | €/kWh | €/kW | €/kWh | €/kW | €/kW |
| 1,1 | 11,0 | 0,5 | 6,8 | 0,55 | 1,1 |

**Guaranteed Standard about VQ.** In Argentina, penalties are to be paid by DSO's to customers when flicker or harmonics exceed the limits [B4-0762(AR)]. The limits are the usual values of the compatibility levels for MV and LV networks (1 for $P_{st}$, 8% for THD, 6% for $U_5$, 5% for $U_3$ and $U_7$, etc.). Measurements are mostly made at the LV side of MV/LV transformer, for all 10-min periods during at least 7 days. Penalties are due when limits are exceeded for more than 5% of the total measurement time. The formulas (given in the paper) indicate a maximum of 2ARS/kWh (ARS = Argentine pesos, 1ARS is about 0,29USD) for 10-min intervals above the limits.

## Improving power quality through system improvements

For steady-state disturbances, the main point is to limit emission from disturbing installations. For disturbing events, there is an economic optimum between mitigation near sensitive equipment (see Block 3) and system improvement. More than thirty papers deal with system improvements resulting in improved PQ. Several technical means are described: system planning taking account of PQ costs and other data (e.g. the customer dissatisfaction index – CDI – or equipment reliability data); improved maintenance; insulation coordination; distribution automation (DA); microgrids (see also Block 2), possibly with electricity storage and DG; MV neutral point earthing (see also Block 1); arc killers; fault current limiters (FCL); LVDC...

**System planning.** [B4-0847(BR)] proposes a hybrid method for short-circuit simulations (random and deterministic approaches). For planning purposes, costs related to long duration interruptions and disruptions due to voltage dips are considered in addition to costs of investment and power losses. The consideration of PQ costs can definitely alter the optimal network configurations along the stages of a planning horizon (Figure 48 shows the importance of PQ costs vs. investment/loss costs).

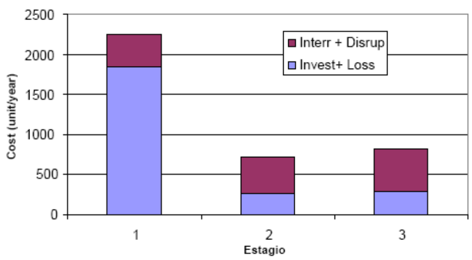


**Figure 48 :** Total costs in each planning stage

[B4-0811(CZ/FI)] presents an application of genetic algorithms to the distribution network reconfiguration for minimization of interruption costs. The results show that different penalization models lead to various optimal outputs.

In order to evaluate the benefits of alternative investment strategies in terms of reliability indices, [B4-0990(UK/PT)] proposes a Representative Networks (RN) model.

[B4-0982(ZA)] studies the relationship between distribution network performance improvement and infrastructure investment cost. For example, Figure 49 shows that, for a particular feeder class, equipment at cost factor = 1 results in an approximately 20% improvement in reliability measured in terms of SAIDI; the addition of new substations would imply nearly 11 times the cost for only approximately 3.5 times improvement in performances.

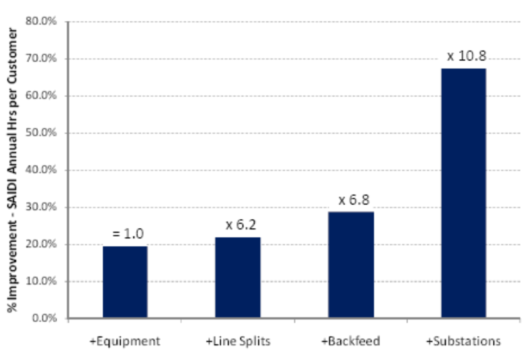


**Figure 49 :** Example improvement vs. cost factor

[B4-0633(FI)] presents an integrated network-planning tool with modern reliability- and asset management functionalities. Improvements are described with the classic SAIDI and SAIFI indices (complemented by CAIDI and MAIFI) but also with the new SACDI (system average customer dissatisfaction index).

[B4-0367(SE/FI)] shows the use of the Customer Dissatisfaction Index (CDI) in a pilot network planning case. Two different levels of satisfaction criteria have been used, one for domestic customers (max 8 h or 3 interruptions) and one for important customers (max 1 h or 2 interruptions). CDI = 1 means non-compliance every year (CDI = 0.5 - every second year, CDI = 0.1 - once in ten years, etc.). Five different cases (original network = base case) with various investment and reliability levels were studied. According to Figure 50 the fully cabled network (Case 4) is the most economic solution. The analysis shows that it is almost always profitable to invest in higher reliability.

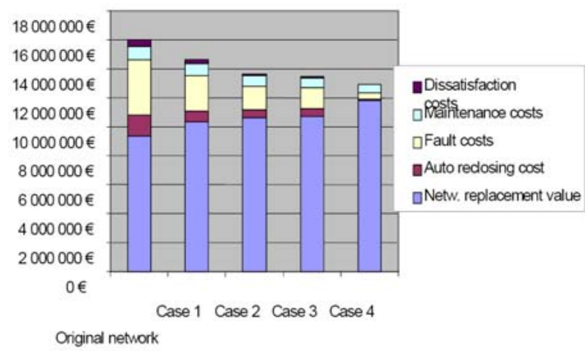


**Figure 50 :** Summary of present value of costs and acquiring value of assets

[B4-0851(SE)] presents distribution equipment reliability data and their impact on system reliability studies (Figure 51, Figure 52). The quality of the reliability data is of fundamental importance to the reliability analyses.

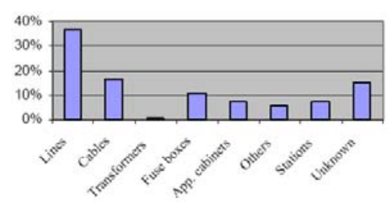


**Figure 51 :** Sustained outages by equipment categories on distribution systems in Sweden during 2004-2005

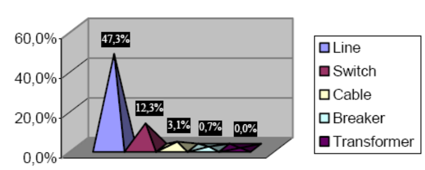


**Figure 52 :** Rank of impact on system total energy not supplied

**Maintenance.** [B4-0590(BR)] presents an application of Fuzzy Logic to assess contractor's maintenance and emergency services. The results of implementation have shown that the reliability indices have improved after the detection and correction of the wrong procedures of the crew in the field.

Maintenance strategy has an important impact on component condition and system supply reliability [B4-0839(DE)]. Simulations allow to compare different strategies in view to optimize cost performance (Figure 53).

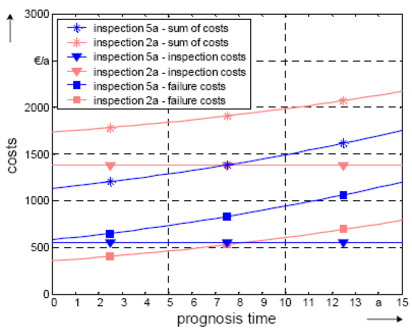


**Figure 53 :** Comparison of cost factors related to load interrupters depending on maintenance intervals (2 years vs. 5 years)

The Norwegian quality of supply regulation differs from many other countries in penalizing also interruptions due to maintenance [B4-0349(NO)]. It has resulted in a dramatic reduction in planned (notified) interruptions (Figure 54) and it has triggered the development of a novel method for performing maintenance on air insulated load switches without interruption of supply to the customers. This method is consisting of insulating plates with integrated bypass shunt cables. It brings in itself cost savings as shown in Table 7.

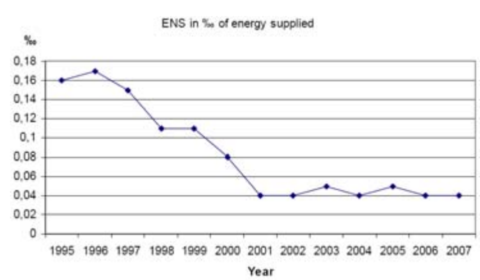


**Figure 54 :** Trend curve. Energy Not Supplied (ENS) for notified interruptions in ‰ of energy supplied.

**Table 7 :** Utility value per job for non-interruptive maintenance (M3) compared to interruptive maintenance (M2); all figures in kNOK (1 NOK is about 0.11 EUR).

| | Labour costs | Notific. costs | Interr. costs | SUM |
|---|---|---|---|---|
| M2 daytime | 5 | 3 | 13 | 21 |
| M2 night-time | 11 | 3 | 6 | 20 |
| M2 average* | 8 | 3 | 9,5 | 20,5 |
| M3 | 4 | 0 | 0 | 4 |
| Gross cost savings (M2 average vs M3) | 4 | 3 | 9,5 | 16,5 |

**Insulation coordination.** One major contribution to the reduction of AIT (TIEPI) in Portugal (Figure 55, Figure 56) is given by revised Insulation Coordination Guidelines to be applied throughout the HV (60 kV) and MV (30, 15 and 10 kV) networks [B4-0777(PT/NL)].

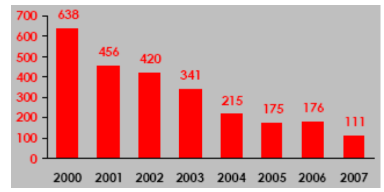


**Figure 55 :** MV outage time reduction (min) in Portugal (TIEPI) 2000-2007

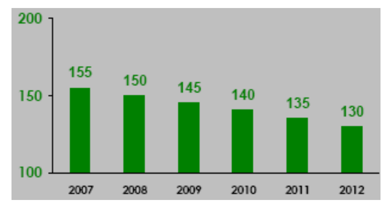


**Figure 56 :** MV outage time reduction goals (min) in Portugal (TIEPI) 2007-2012

**Distribution automation (DA).** Starting from unit costs of ENS corresponding to those of the second Finnish regulatory period (1.19 €/kW and 11.9 €/kWh), [B4-0141(FI)] assesses the potential locations for cost-effective MV line reclosers.

[B4-0459(PT/NL)] describes a Distribution Automation (DA) project, based on fault breaking devices, with auto-reclosing function, the benefits being evaluated from the monetary value of ENS. Figure 57 shows that the optimum is not sensitive to small changes in the number of switches.

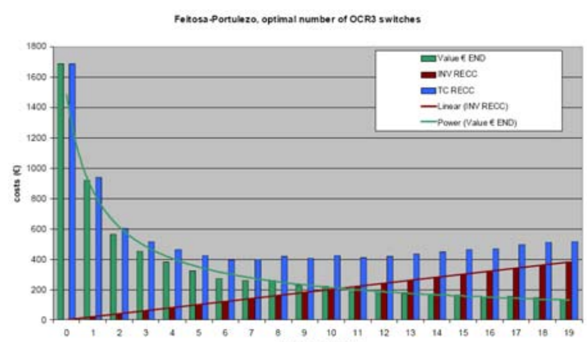


**Figure 57 :** Example results for 1 feeder : TC = total costs (= sum of END value + investments in DA-devices)

[B4-0548(PT)] gives a benefit/cost analysis for investment in automation devices (e.g. Figure 58). The benefits are accounted for in euros, based on the economic signal provided by the incentive scheme (see above "cost aspects of PQ").

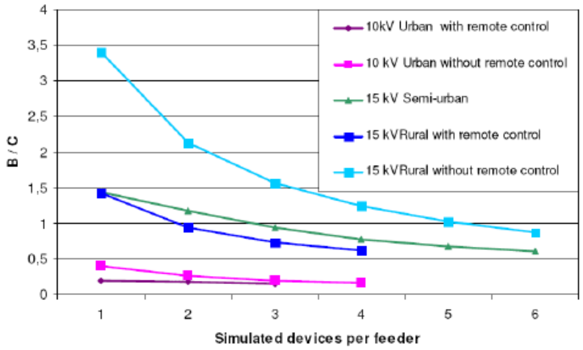


**Figure 58 :** Benefit/Cost (B/C) vs. investment in automation devices

In Bosnia and Herzegovina, the reliability of supply indices (Figure 59) show significant difference with other European countries [B4-0844(BA)]. Improvements are foreseen by adapting the network structure and introducing distribution automation.

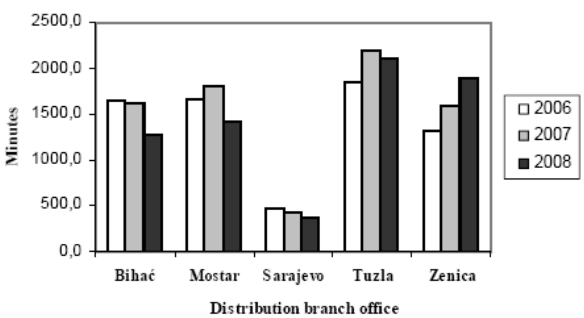


**Figure 59 :** SAIDI on MV distribution networks, period 2006-2008

Since 1999, Enel Distribuzione has improved the continuity of supply (Figure 60) with two principal solutions: i) remote control of MV/LV substations, ii) Petersen coil in HV/MV substations [B4-0561(IT)]. A further step is to install a MV circuit breaker along the lines, with focus on 2 indicators: i) cumulative duration of long (t > 3min) interruption per LV customer, ii) number of long and short (1s < t < 3min) interruptions per LV customer. A method has been developed to find the optimal location for the circuit breaker, in view to reduce penalties or increase awards linked to the regulation. It appears that the effect of a circuit breaker installed along the line is similar to the one obtained by building a new primary substation.

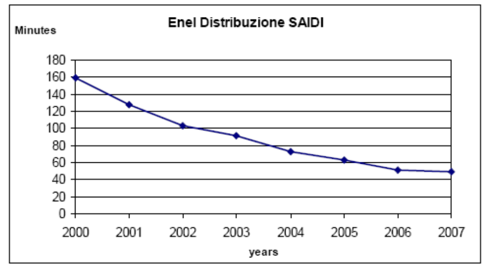


**Figure 60 :** Enel Distribuzione SAIDI in the last 8 years

**Microgrids.** Some consumers require constant availability of electrical energy and need UPS systems; [B4-0879(CH)] introduces an alternative in form of connections to a separate network (secondary network), which can be a "smart grid" (integrating embedded generation and storage devices).

[B4-0776(NL)] describes a smart MV/LV substation with energy storage that improves voltage quality, continuity of supply and load profile. To reduce THD for example, Resistive Harmonic Damping (RHD) is implemented as ancillary service in the electricity storage system. Immunity can also be increased against voltage dips and flicker. Microgrid working is possible when needed.

Energy storage technology can be cost effective for the power system construction, operation and maintenance; it can also reduce the ENS for important users. In [B4-0471(CN)], pilot projects are described with BESS (battery energy storage system) like 100kWx8h NAS, 100kWx2h LiFePO4 or 100kWx1.5h NiMH. [B4-0493(FR)] reviews the more general use, location and benefits of DESS (distributed energy storage systems), see Table 8 and Table 9.

**Table 8 :** Nine selected energy storage technologies and some of their characteristics (f.=a few)

| Technology | Feasible power range (system) | Nominal discharge time | DC round-trip efficiency |
|---|---|---|---|
| Pb-acid | f.kW-f.10MW | 2-8h | 70-85% |
| NiMH | f.kW-f.MW | f.10min-hours | 65-75% |
| Li-ion | f.kW-1MW | f.10min-hours | 85-90% |
| NAS (high T°) | 50kW-f.10MW | 7-9h | 85-90% |
| ZEBRA (high T°) | 5kW-500kW | 2-10h | 85-90% |
| VRB (redox flow) | f.kW-10MW | f.hours (flexible) | 80-85% |
| ZnBr (redox flow) | 25kW-f.MW | 2h30 | 75-80% |
| Flywheel | f.kW-f.10MW | 10s-f.minutes | 85-95% |
| Ultracapacitor | f.kW-f.MW | 1s-f.10s | 85-98% |

**Table 9 :** Typical locations for DESS

| | Storage location |
|---|---|
| A | At HV/MV substation |
| B | At DG unit connected to a dedicated feeder |
| C | At any point of an existing MV feeder |
| D | At DG unit connected to an existing feeder |
| E | At customer facility connected to MV grid |
| F | At MV/LV substation |
| G | At any point of an existing LV feeder |
| H | At "prosumer" facility connected to LV grid |
| I | At customer facility connected to LV grid |

Following [B4-0887(DE)], a large scale integration of electric vehicles as battery storage devices could constitute mobile storage systems providing fast-response assistance. The overall result could be an increased stability and reliability of the electric grid.

**MV earthing** (see also [B4-0561(IT)] and Block 1). [B4-0521(UK)] studies the potential for arc suppression coils (ASC's) and residual current compensation (RCC) devices to improve network performance. A threshold of 5 years is considered for the CI and CML savings to payback the initial cost of installing the complete ASC system. Assuming that 50% of all permanent overhead line faults are single-phase and an ASC can be expected to save some 50% of CI's and CML's, the number of viable substations may be assessed. Results are e.g. 14 substations on a total of 77 (33kV) or 74 substations on a total of 623 (11kV).

**Arc killer.** An "Arc Killer" device can detect and suppress an internal arc fault on a secondary distribution switchgear in less than 125 ms [B4-0177(FR)]. The consequences and the damages due to an internal arc fault are then reduced to the minimum, improving the service continuity (the maintenance work time is low and the other cubicles can be re-energized).

**Fault current limiter (FCL).** Increased penetration of DG and increased interconnection of networks lead to higher fault currents and the necessity to limit them. [B4-0533(US)] describes a solid state current limiter (SSFCL) where the limiting inductor is normally shunted by an SGTO switch. [B4-0140(UK/DE)], [B4-0225(UK)], [B4-0898(IT)] and [B4-1068(UK)] present superconducting fault current limiters (SFCLs) where the increased current density caused by the passage of fault current causes the temperature of the superconducting material to rise with the result that the material reverts to a normal resistive state.
The fault current limiter reduces the depth of voltage dips and the risk of interruptions. This could allow existing radial circuits to be operated interconnected, with associated improvements to customer supply continuity and voltage quality (flicker and harmonics). A first SFCL has been installed in a UK distribution network in January 2009 (Figure 61).

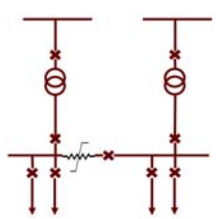

**Figure 61 :** Installation of a SFCL in a bus-section configuration

**LVDC.** The LVDC-technology improves supply reliability (lowering of SAIFI and SAIDI) and voltage quality (filtering of voltage disturbances) [B4-0682(FI)]. There are also further economic incentives in replacing 20 $kV_{AC}$ and 400 $V_{AC}$ distribution by 750 or 1500 $V_{DC}$ (smaller cross-sections, lower number of distribution transformers, see e.g. Figure 62). The cost-effectiveness depends on the price of AC/DC and DC/AC converters. For example, Figure 63 shows that the replacement of MV branch lines by LVDC is economic for lengths > 600 m for OH lines. Connecting energy storages and distributed generation into the DC section improves the situation even further [B4-0795(FI)].

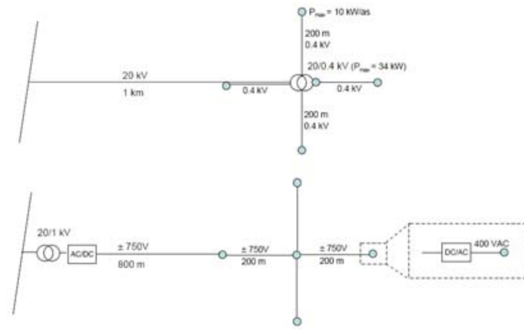


**Figure 62 :** Comparison of network structures (LVAC vs. LVDC)

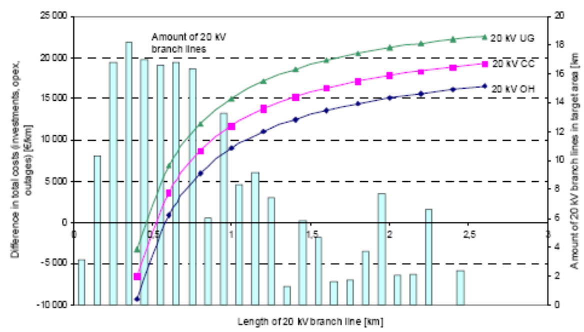


**Figure 63 :** Cost-effectiveness of replacement MVAC ==> LVDC

**Several means.** [B4-0442(SE)] describes an approach to improve reliability in rural and semi-rural MV network. Available methods are listed in Table 10. The ranking of the proposed projects is made taking account of SAIDI benefit and cost (Figure 64).

**Table 10 :** Main solutions used to mitigate weather related outages and their respective benefit and cost

| Method | Effectiveness | Cost |
|---|---|---|
| Cablification | High | High |
| Aerial cable | High | High |
| Covered overhead conductor | Medium | Medium |
| 1 kV, LV systems | Medium | Low |
| Feeder automation | High | Low |
| Pole mounted reclosing switches | High | Medium |
| Widening of line corridors | Medium | Low |

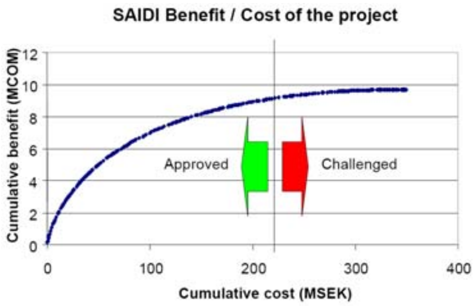


**Figure 64 :** Ranking and estimated SAIDI benefit of proposed projects based on benefit-to-cost ratios (COM = ratio cost per reduced customer outage minute; MCOM = COM·$10^6$; 1 SEK is about 0.09 EUR)

**Further research topics**

What kind of PQ parameters could it be interesting to monitor with smart meters (potentially at each house) ? How will the DSO handle the amount of PQ data.

May PQ improvement (increased voltage continuity) be an incentive for microgrids or is it just a by-product ?

Is there a need to include voltage quality in addition to voltage continuity in the regulations ?

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

| Paper No. Title<br>Authors | MS a.m. | RIF | PS | Other sess. |
|---|---|---|---|---|
| **0022 : Toward Safe Grounding to Industrial Plants Saudi Arabia Case Study**<br>Shwehdi M.H, Johar U.M, Sheltami T.R (Saudi Arabia) | | | X | |
| **0059 : Applying a Simple Approach for Evaluating the Magnetic Fields Produced by Power Lines**<br>Eassa N, Karawia H (Egypt) | | | X | |
| **0060 : Study and Evaluation of Induced Currents in Human Body from Exposure to Electromagnetic Fields at Low Frequencies,** Hossam-Eldin A, Youssef K, Karawia H (Egypt) | X | | X | |
| **0132 : Neutral Point Grounding Modes for 10 kV Grids in Shanghai Shinnan Area**<br>Zhou X, Wang W, Zhang J (China) | | | | S3 |
| **0158 : Active Earthing System for MV Networks by Means of Power Electronic**<br>Pazos F.J, Amezua A, Gutiérrez I, Santamaria G, Garcia J.M, Valverde V (Spain) | | | | S1 |
| **0163 : Magnetic Field Mitigation of Power Cable by High Magnetic Coupling Passive Loop**<br>Canova A, Giaccone L (Italy) | | X | X | |
| **0182 : Magnetic Field Risk Evaluation of Workers in Indoor Distribution Substations**<br>Keikko T, Pääkkönen R, Kännälä S, Seesvuori R, Valkealahti S (Finland) | | | X | |
| **0214 : Analyses of Transmission Lines in Special Regions with High Lightning Strike Rates and its Countermeasures**<br>Wu Z (China) | | | X | |
| **0231 : Measurements of Interaction between Equipment in the Frequency Range 9 to 95 kHz.**<br>Rönnberg S, Wahlberg M, Bollen M, Larsson A, Lundmark M (Sweden) | X | | X | |
| **0253 : Influence of Leakage Parameters on Resonance Phenomena in Radial Distribution Networks**<br>Brenna M, Foiadelli F, Zaninelli D (Italy) | | | X | |
| **0296 : Wireless Network Management Optimized for EMI Measurement in Power Substations**<br>Siew W.H, Liu K.Y, Stewart R.W (UK), Li Q (China) | | | X | |
| **0306 : Analysis of Power Frequency Electric Field for the Buildings under the High Voltage Overhead Lines**<br>Zhujinglin, Mengyu (China) | | | X | |
| **0307 : Resonant Grounded Grids - Quo Vadis !?**<br>Fickert L, Achleitner G, Schmautzer E, Obkircher C, Raunig C (Austria) | | | | S5 |
| **0364 : An Experimental Investigation of Switching Transients in a Wind-Collection Grid Scale Model in a Cable System Laboratory,** Reza M, Breder H, Liljestrand L, Sannino A, Abdulahovic T, Thiringer T (Sweden) | | | | S1 |
| **0405 : Magnetic Field Generated by Underground Distribution Network**<br>Turgeon A, Bourdages M, Richard L, Giroux J, Houde L (Canada) | | | X | |
| **0616 : Influence of Harmonics in the Magnetic Field under Consideration of Current Cell Models**<br>Aigner M, Gaun A, Schmautzer E (Austria) | | | X | |
| **0620 : Earthing System Evaluation and Influence on Protection Performance in Resonantly Earthed MV Networks**<br>Hutter S (Croatia) | | | | S3 |
| **0627 : Quick and Efficient Method for Low-Frequency EMF Evaluation of Electric Power Systems Considering Multiple Sources with Different Frequencies and Harmonics,** Schmautzer E, Friedl K, Aigner M (Austria) | X | | X | |
| **0628 : Impact of Phase Positions on the Low Frequency Electric and Magnetic Field of High-Voltage Overhead Lines**<br>Friedl K, Schmautzer E (Austria) | | | X | |
| **0634 : Transient Overvoltages on Distribution Underground Cable Inserted in Overhead Line**<br>Orságová J, Toman P (Czech Republic) | | | | S1 |
| **0646 : The Criteria for Neutral Point Treatment Selection in 20(10) kV Radial Networks in "Elektra" Zagreb**<br>Kulis I.G, Boras M, Njavro B, Vidovic F, Sagovac G, Duric I (Croatia) | | | | S5 |
| **0652 : EMTP Simulation of Lightning Overvoltage Discharge to Medium Voltage Overhead Lines with Covered Conductors,** Omidiora M.A, Lehtonen M, Millar R.J (Finland) | | | X | |
| **0696 : Double Earth Fault effects in Presence of Interconnected Earth Electrodes**<br>Campoccia A, Rivan Sanseverino E, Zizzo G (Italy) | | | X | |

| | | | | |
|---|---|---|---|---|
| **0726 : Evaluation of Lightning Threat in Distribution Networks**<br>Kosmac J, Lalota Jericek G, Djurica V, Toros Z (Slovenia) | X | | X | |
| **0900 : Control and Monitorising the Supply of IT Equipment**<br>Iliuta M, Gulinschi V, Popescu S (Romania) | | | X | |
| **0937 : Potential Rise and Safety Voltages of Wind Turbine Earthing Systems under Transient Conditions**<br>Elmghairbi A, Haddad A, Griffiths H (UK) | | | X | |
| **0947 : Application of Surge Arresters for Lightning Protection of 33kv Wood Pole Distribution Lines**<br>Bhattarai R, Harid N, Griffiths H, Haddad A (UK) | X | | X | |
| **0975 : Switching Transient Analysis of Small Distributed Generators in Low Voltage Networks**<br>Clark D, Haddad A, Griffiths H (UK) | | | X | |
| **1008 : Calculations in 3D of the Magnetic Fields Generated by Distribution Networks**<br>Bourdages M, Gravel S (Canada) | | | X | |
| **1072 : EMC and EMF Regulatory Issues for the Power Industry**<br>Marshman C, Tyndall M (UK) | X | | X | |

***Table 2: Papers of Block 2 (B2) : Steady-state disturbances***

| Paper No. Title<br>Authors | MS<br>a.m. | RIF | PS | Other<br>sess. |
|---|---|---|---|---|
| **0008 : Voltage and Current THD in Microgrid with Different DG Unit and Load Configurations**<br>Laaksonen H, Kauhaniemi K (Finland) | | X | X | |
| **0019 : Harmonics Investigation in a Steel Factory**<br>Shwehdi M.H (Saudi Arabia) | | | X | |
| **0092 : Harmonic Resonance Detection and Prevention in the Aluminum Company of Egypt at Nag-Hammady**<br>El-Sadek M.Z, Wahab M.A.A, Hamada M, Ghallab M.R (Egypt) | | | X | |
| **0095 : Evaluation of Negative Sequence Current Injecting into the Public Grid from Different Traction Substations in Electrified Railways,** Wang H, Tian Y, Gui Q (China) | | | X | |
| **0159 : Power Frequency Overvoltages Generated by Solar Plants**<br>Pazos F.J (Spain) | | | | S4 |
| **0160 : Stochastic Analysis of the Impact of Plug-In Hybrid Electric Vehicles on the Distribution Grid**<br>Clement K, Haesen E, Driesen J (Belgium) | | | | S4 |
| **0164 : Evolution of the Harmonic Distortion from State-of-the-Art Computers – 2002 to 2008**<br>Larsson A, Lundmark M, Bollen M, Wahlberg M, Rönnberg S (Sweden) | X | | X | |
| **0167 : Power Quality Measurents in the 10-30 kV Grid in Copenhagen**<br>Jensen M.M, Christensen J.S (Denmark) | | | X | |
| **0172 : Impact of High Penetrations of Micro-generation on Low Voltage Distribution Networks**<br>Richardson P, Keane A (Ireland) | | | | S4 |
| **0227 : Increasing the reliability of induction motors with power monitoring systems**<br>Bickel J (USA), Gruffaz F (France) | | | X | |
| **0240 : Customer Flicker Emission Assessment: A New Method Based on RMS Value Measurements**<br>Yang X, Klein F, Kratz M, Gauthier J (France) | | | X | |
| **0243 : Catalogue of Harmonic Measurements in Power Systems**<br>Schlabbach J (Germany) | | | X | |
| **0245 : Operation of Multiple Inverters in Grid-Connected Large-Size Photovoltaic Installations**<br>Chicco G, Spertino F (Italy), Schlabbach J (Germany) | X | | X | |
| **0248 : Methods for the Assessment of Emission Levels for Disturbing Installations connected to Low and Medium Voltage Networks,** Ammeter U (Switzerland), Hanzlik J (Czech Republic), Meyer J (Germany), Zierlinger J (Austria) | X | | X | |
| **0271 : Maximum Penetration Level of Distributed Generation Without Violating Voltage Limits**<br>Morren J, de Haan S.W.H (The Netherlands) | | | | S4 |
| **0297 : Optimal Sizing and Location of Capacitor Bank and Distributed Generator in Distorted Distribution Networks by Genetic Algorithms,** Mady I.T.A (Egypt) | | | | S5 |
| **0301 : Voltage Rise Suppression by Reactive Power Control with Cooperating Photovoltaic Generation Systems**<br>Hojo M, Hatano H, Fuwa Y (Japan) | | | | S4 |
| **0310 : Analysis of a Closed Loop Control for Current Unbalance Compensation Based on AC/AC Converters**<br>Marino P, Raimondo G, Torre G (Italy) | | | X | |
| **0332 : Statistical Analyses of the Distribution and the Annual Trend of Harmonic Voltage in Japan**<br>Yukihira K (Japan) | X | | X | |
| **0377 : Voltage Distortion in Large-Scale MV and HV Distribution Networks: Harmonic Analysis and Simulation**<br>Santos C, Jorge L, Blanco A, Bastião F, Ferreira L, Carvalho P, Carvalho F (Portugal) | | | X | |
| **0400 : Limits to Dispersed Generation on Italian MV Networks.**<br>Delfanti M, Pasquadibisceglie M.S, Pozzi M, Gallanti M, Vailati R (Italy) | | | | S4 |
| **0430 : An ESPRIT and DFT-based New Method for the Waveform Distortion Assessment in Power Systems**<br>Bracale A, Carpinelli G (Italy) | | X | X | |
| **0432 : Experimental Correction of Transformer Losses, which Operates in Harmonic Regime**<br>Felea I, Rancov N, Has V (Romania) | | | X | |
| **0441 : Optimal Capacitor Placement in Distribution System Considering Mutual Coupling, Load Unbalancing and Harmonics,** Zhezhelenko I.V, Gorpinich A.V (Ukraine), Khalil T.M (Egypt) | | | | S5 |
| **0450 : Extensive Measurements and Classification of PQ Aspects in MV Networks**<br>Provoost F, Cobben S, van Buijtenen W (The Netherlands) | X | | X | |

| | | | | |
|---|---|---|---|---|
| **0456 : Study of the Harmonic Behaviour of PWM Converters under Distorted Voltages**<br>De Witte M, Pankow Y, De Jaeger E (Belgium) | | | X | |
| **0470 : Disturbance Emission Level Assessment Techniques – Cigre / Cired Joint Working Group C4.109**<br>De Jaeger E (Belgium) | X | | X | |
| **0497 : Propagation of Voltage Unbalance from HV to MV Power Systems**<br>Paranavithana P, Perera S (Australia), Koch R (South Africa) | | X | X | |
| **0500 : A Generalised Methodology for Evaluating Voltage Unbalance Influence Coefficients**<br>Paranavithana P, Perera S (Australia), Koch R (South Africa) | | X | X | |
| **0516 : Field Measurements, Modelling and Simulation for Harmonic Analysis of a Large Industrial Power System**<br>Doyle P, Burke O, Phang W (Ireland) | | | X | |
| **0518 : Optimal Placement of Facts Units for Minimizing the Impact of Voltage SAGS in Power Networks with High Wind Energy Penetration,** Alonso M, Amaris H (Spain) | | | | S5 |
| **0531 : Multiobjective Optimal Allocation of Capacitors in Distribution Systems: A New Heuristic Technique based on Reduced Search Space Regions and Genetic Algorithms,** Carpinelli G, Noce C, Proto D, Russo A, Varilone P (Italy) | | | | S5 |
| **0549 : Power Electronic Loads with Negative Differential Impedance in a Low Voltage Distribution System**<br>Heskes P.J.M, Myrzik J.M.A, Kling W.L (The Netherlands) | | X | X | |
| **0607 : Performance Indices and Objective for Microgrids**<br>Bollen M (Sweden), Zhong J, Lin Y (Hong Kong) | | X | X | |
| **0611 : SVC Refurbishment Experience for Critical Coal Train Haulage Network**<br>Vu T, Johnson A (Australia) | | | | S3 |
| **0653 : Dynamic Var Compensation of mine hoists for Improvement of Power Quality and Increase of Productivity at LKAB,** Sweden, Gothelf N, Mukka L, Payerl C (Sweden) | | | X | |
| **0662 : Flicker Control with Hybrid Var Compensator**<br>Lupin J.M, Bolduc R, Chenevard L (France) | | | X | |
| **0679 : Impact of Voltage Step Change Constraints on Distribution Network Capacity for Distributed Generation**<br>Dent C.J, Ochoa L.F, Harrison G.P (UK) | | | | S5 |
| **0767 : Impact Evaluation of Disturbing Loads on Secondary and Primary Distribution Networks**<br>Ledesma T.P, Schmidt H.P, Meffe A, El Hage F, Donadel C.B (Brazil) | | | X | |
| **0873 : Grid Impact and Integration of Micro Wind Generation**<br>Calderaro V, Galdi V, Piccolo A, Siano P (Italy) | | | | S4 |
| **1047 : The Review and Analysis the Destructive Effects of Harmonics on a Sample MV/LV Transformer**<br>Mousavi S, Tavan B, Bakhtiari H (Iran) | | | X | |
| **1070 : A New, Ultra-low-cost Power Quality and Energy Measurement Technology - The Future of Power Quality Measurement,** McEachern A, Eberhard A (USA) | | | X | |

***Table 3: Papers of Block 3 (B3) : Disturbing events***

| Paper No. Title<br>Authors | MS p.m. | RIF | PS | Other sess. |
|---|---|---|---|---|
| **0013 : Voltage Sag Assessment Based on Maximum Entropy Principle**<br>Xiao X, Ma C, Yang H (China) | | | X | |
| **0018 : Effects of Voltage Sags, Swell, and Other Disturbances on Electrical Equipment and Their Economic Implications**<br>Edomah N (Nigeria) | | | X | |
| **0052 : Static Var compensator to Increase Availability of Colombian Oil Field**<br>Grünbaum R, Rasmussen J, Silva A (Sweden), Canal M, Bonilla F (Colombia) | | | X | |
| **0058 : Procedure for Quality Model Regulation of Distribution Systems in Egypt**<br>Mady I, Eassa N, Abdel Azim M (Egypt) | | | X | |
| **0062 : A New Technique for Power Quality Based Condition Monitoring**<br>Faisal M.F, Mohamed A (Malaysia) | | | | |
| **0063 : Comparison of the Effectiveness of Various Mother Wavelet Functions in the Detection of Actual 3-Phase Voltage Sags,** Faisal M.F, Mohamed A (Malaysia) | | | | |
| **0086 : New Limits for Voltage Quality in LV Networks and the Costs and Time Necessary for Meeting Them**<br>Procházka K, Mezera D, Hejpetr Z, Kloud J (Czech Republic) | | | X | |
| **0102 : Flicker Propagation Study in a Typical Dutch Grid**<br>Bhattacharyya S, Cai R, Cobben S, Myrzik J, Kling W (The Netherlands) | | | X | |
| **0113 : Reliability Indices: The Determination of Reference Values for Swiss Electric Distribution Networks**<br>Schiesser H.H, Bader J, Küng L (Switzerland) | | | | S5 |
| **0123 : Effects of Capacitor Switching on Dynamic Power Quality in Urban Distribution Networks**<br>Pan G, Pan Y, Zhang X (China) | | | X | |
| **0128 : Development of MV Synchronous Circuit Breaker**<br>Mu J.W, You Y.M, Lei Y (China) | | | | S1 |
| **0149 : CIGRE/CIRED/UIE Joint Working Group C4.110, Voltage Dip Immunity of Equipment in Installations - Main contributions and conclusions,** Bollen M.H.J (Sweden), Stephens M, McEachern A, Brumsickle B (USA), Djokic S.Z, Neumann R, Milanovic J.V (UK), Romero J (Spain), Ethier G, Zavoda F (Canada), Stockman K (Belgium) | | | X | |
| **0185 : Calculation of Voltage SAGS Originated in Transmission Systems using Symmetric Components**<br>Casarotto C, Gomez J.C (Argentina) | | | X | |
| **0194 : Reduction of Voltage Stress and Inrush Current of Power Transformers using Controlled Switching**<br>Ebner A (Switzerland) | | | | S1 |

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| **0233 : Exceptional Events and Force Majeure Events and their Use in the Electricity Sector**<br>Falcão A (Portugal), Bollen M (Sweden) | | | X | |
| **0268 : A New Simulation Tool to Predict Voltage Dips**<br>Berthet L, Paszkier B, Santander C, Dercle D (France) | X | | X | |
| **0327 : Quasi-Steady State Characterization of Induction Machine Behavior Under Voltage Sag and Momentary Interruption Conditions,** Anass L, Abdelrahman M, Badr M.A.L (Egypt) | | | X | |
| **0346 : The Behavior of Power Distribution Feeder Dips**<br>Zavoda F, Tremblay M (Canada), Bollen M (Sweden) | | | X | |
| **0351 : Evaluation of the Successive Restoration of Electricity Supply to Customers in Distribution Networks in Connection with the Regulation of Electricity Supply Continuity,** Skala P, Detrich V, Grülling S (Czech Republic) | | | | S6 |
| **0363 : Power Quality Survey in Progress on the MV Enel Network: Analysis of Gathered Data**<br>Valtorta G, D'Orazio L, Sartore S, De Berardinis E (Italy) | | | X | |
| **0373 : Probability Distributions of Reliability Indices of Electrical Distribution Networks**<br>Krahl S, Ohrem S, Haubrich H.J (Germany) | | X | X | |
| **0546 : Risk based Evaluation of Investment in Voltage Sag Mitigation**<br>Chan J.Y, Milanovic J.V, Delahunty A (UK) | X | | X | |
| **0556 : Light Sources Immunity to Short Voltage Dips and Interruptions**<br>Drápela J, Bok J, Slezingr J, Pithart J (Czech Republic) | | | X | |
| **0604 : Voltage Sag Source Location Identification**<br>Latheef A, Negnevitsky M (Australia), Faybisovich V (USA) | | | X | |
| **0689 : Evaluation of Voltage Dip Characteristics in Autonomous Island Networks and Correlation with Wind Turbine F Curves,** Papaefthimiou S, Papathanassiou S, Papadopoulos M (Greece) | X | | X | |
| **0716 : FASIT - A Tool for Collection, Calculation and Reporting of Reliability Data**<br>Heggset J, Kjolle G, Sagen K (Norway) | | | | S5 |
| **0737 : The Italian Power Quality Monitoring System of the MV Network: Results of the Measurements after 3 Years Campaign,** Chiumeo R, Porrino A, Garbero L, Tenti L, de Nigris M (Italy) | | | X | |
| **0755 : A Review of Flicker Objectives related to Complaints, Measurements, and Analysis Techniques**<br>Halpin M (USA), Cai R. (The Netherlands), De Jaeger E (Belgium), Papic I (Slovenia), Perera S (Australia), Yang X (France) | X | | X | |
| **0758 : Suggestions for Overall EMC Co-ordination with regard to Rapid Voltage Changes**<br>Halpin M (USA), De Jaeger E (Belgium) | | | X | |
| **0781 : Laboratory Tests of Electrical Appliances Immunity to Voltage Swells**<br>Seljeseth H, Sand K, Fossen K.E (Norway) | X | | X | |
| **0789 : Rapid Voltage Changes - Definition and Minimum Requirements**<br>Brekke K, Seljeseth H, Mogstad O (Norway) | X | | X | |
| **0840 : Estimation of Voltage Dips at the Terminals of Double Fed Induction Generators**<br>Terzija V, Stanojevic V, Strbac G (UK), Molina A, Gómez E (Spain) | | | X | |
| **0909 : The Relationship between Reliability Indices and Daily Load Curve**<br>Jadrijev Z, Majstrovic M, Majstrovic G (Croatia) | | | | S5 |
| **0910 : Variability Evalution of Distribution Networks Quality of Supply Performance Indices**<br>Marantes C (UK), Pais A (Portugal) | | | | S5 |
| **0958 : Quality of Supply performance benchmarking: imporvements to methodology**<br>Pais A (Portugal), Marantes C, d'Albertanson B, Strbac G (UK) | | | | S6 |
| **0965 : Voltage sag sensitivity of home appliances and office equipment**<br>Chilukuri M.V, Lee M.Y, Phang Y.Y (Malaysia) | | | X | |
| **0988 : A Simplified Method for Estimating Voltage Dips due to Transformer Inrush**<br>Bathurst G (UK) | | | X | |
| **1020 : Automatic Power Quality Disturbance Classification using Wavelet, Support Vector Machine and Artificial Neural Network,** Vega V, Kagan N (Brazil), Ordoñez G, Duarte C (Colombia) | | X | X | |
| **1044 : Assessing the Economics of Power Quality**<br>Walsh A (Ireland) | | | X | |

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

| Paper No. Title<br>Authors | MS p.m. | RIF | PS | Other sess. |
|---|---|---|---|---|
| **0057 : An Approach Towards a Systematic Framework for the Assessment of Power Quality Issues**<br>Eassa N, Elnahass M, Kaseb M, Attia A (Egypt) | | | X | |
| **0103 : Consequences of Poor Power Quality for Grid Operators**<br>Bhattacharyya S, van Lumig M, Cobben S, Myrzik J, Kling W (The Netherlands) | X | | X | |
| **0140 : Fault Limiting Technology Trials in Distribution Networks**<br>Klaus D, Wilson A, Jones D, McWilliam J, Creighton A (UK), Dommerque R, Bock J (Germany) | | | | S1 |
| **0141 : Impacts of Quality Improvement Incentives on Automation Investments in the Finnish New Regulation Model**<br>Lagland H, Kauhaniemi K, Hakola T, Rintamäki J (Finland) | | | | S5 |
| **0177 : The "arc killer": the internal fault suppressor**<br>Piccoz D, Preve C, Buffa F, Grosjean P (France) | | | | S1 |
| **0198 : Smart Metering Features for Managing Low Voltage Distribution Grids**<br>Abart A, Lugmair A, Schenk A (Austria) | | | | S5 |
| **0225 : A Practical Superconducting Fault Current Limiter**<br>Hopewell P, Husband M, Smith A (UK) | | | | S1 |

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| **0291 : Evaluation of Voltage Quality at the Points of Electricity Measurements for Invoicing Purposes** Pospíchal L, Hoder K, Pernica D (Czech Republic) | | | X | |
| **0349 : Regulation of Quality of Supply - An Innovation Driving Force? Novel Equipment for Reducing Customers' Interruption Costs by Bypassing Switches During Maintenance,** Samdal K, Solum G, Ramslie L.W (Norway) | | | X | |
| **0367 : CDI Service Level Index: Pilot use in Network Planning** Holm A, Owe P, Bollen M.H.J (Sweden), Pylvänäinen J, Paananen H (Finland) | X | | X | |
| **0383 : Methods for Determining Worst-Served Customers** Tersztyanszky T (Hungary) | | | X | |
| **0442 : Reliability-based Planning in Rural Areas; Goals, Methods, Prioritization, and Follow-up at Fortum Distribution** Bengtsson P, Persson L.A, Oberger K, Hasselström J (Sweden) | | | | S5 |
| **0459 : Increasing Quality of Supply of EDP Through Optimal and Strategic Distribution Automation Design** Oliveira R, Blanquet A (Portugal) , Bloemhof G (The Netherlands) | | | | S5 |
| **0471 : Improving the Power Quality and Power Reliability by Energy Storage Technology－The Practice of SMEPC** Zhang X, Zhang Y (China) | | | | S4 |
| **0493 : Energy Storage Systems in Distribution Grids: New Assets to Upgrade Distribution Networks Abilities** Delille G, François B, Malarange G, Fraisse J.L (France) | | | | S4 |
| **0494 : Incorporating Short Interruptions and Time Dependency of Interruption Costs in Continuity of Supply Regulation,** Kjolle G, Samdal K, Brekke K (Norway) | | | | S6 |
| **0514 : Power Quality Level in 110 KV Networks in the Czech Republic** Kysnar F, Prochazka K, Herman A (Czech Republic) | | | X | |
| **0521 : Assessing the Potential for ARC Suppression Coil Technology to Reduce Customer Interruptions (CI's) and Customer Minutes Lost (CML's),** Sinclair J, Gray I (UK) | X | | X | |
| **0533 : Development of a Test Protocol for a 15 kV Class Solid-State Current Limiter** Sundaram A, Gandhi M (USA) | | | | S1 |
| **0548 : Quality of Supply Driven Investment Planning and Regulatory Support Using Representative Networks** Pais A, Ribeiro J, Clemente N, Afonso L, Alberto C (Portugal) | | | | S5 |
| **0561 : Continuity of Supply Improvement by Means of Circuit Breakers along MV Lines** Valtorta G, Calone R, D'Orazio L, Salusest V.G (Italy) | | | | S5 |
| **0564 : PQ Indices Evaluation in Distribution Networks using AMR Database** Stanescu D, Rosca I, Blagu I (Romania) | | | X | |
| **0584 : Considerations for a Wide-area Power Quality Monitoring System** Kingham B (Canada) | X | | X | |
| **0590 : Maintenance Service Management System to Implement Strategies to Improve Service Quality** Henriques H.O, Andrade W.S, Tavares E.P, Motta C.E, Caparroz S.L (Brazil) | | | | S6 |
| **0633 : Reliability-based Network Analysis in Optimal Asset Management** Pylvänäinen J, Lehtinen H, Kohtala J, Verho P (Finland) | | | | S5 |
| **0638 : Evaluation of Worst Served Customers on Real Size Distribution Networks using Sequential Monte Carlo Simulation Techniques,** Marantes C, d'Albertanson B (UK), Pais A (Portugal) | | | | S5 |
| **0677 : Automated Test System for Accuracy Verification of Power Quality Measurement Instruments** Meyer J, Schegner P, Domagk M, Hillenbrand F (Germany), Kuntner R (Austria) | X | | X | |
| **0682 : Potential and Strategic Role of Power Electronics in Electricity Distribution Systems** Lassila J, Keipia T, Haakana J, Partanen J, Koivuranta K (Finland) | | | | S5 |
| **0693 : Incentive Based Regulation of the Finnish DSOS – Experiences of the Finnish Regulator** Kinnunen M, Paananen A, Saajo V.P (Finland) | | | | S6 |
| **0704 : Benchmarking of Continuity of Supply** Hansen P (Denmark) | | | | S6 |
| **0713 : Investment Incentives in the context of Revenue Cap Regulation** Maeding S (Germany) | | | | S6 |
| **0762 : Disturbances (Harmonics and Flicker) in Distribution Networks** Ruiz L (Argentina) | | | X | |
| **0776 : A Smart MV/LV-Station that Improves Power Quality, Reliability and Substation Load Profile** Kester J.C.P, Heskes P.J.M, Kaandorp J.J, Cobben J.F.G, Schoonenberg G, Malyna D, De Jong E.C.W, Wargers B.J, Dalmeijer A.J.F (The Netherlands) | | | | S1 |
| **0777 : Insulation Coordination Best Pratices leading to Improving Continuity of Supply Improve** Herculano A, Nunes P, Correia de Barros M.T (Portugal), Engelbrecht C.S, Hesen P.L.J (The Netherlands) | | | | S5 |
| **0795 : Impact of Low Voltage DC System on Reliability of Electricity Distribution** Kaipia T, Peltoniemi P, Lassila J, Salonen P, Partanen J (Finland) | | | | S5 |
| **0806 : Financial Impact of Power Quality on Indian Pharmaceutical Industry – Survey Results** Vegunta S.C, Milaniovic J.V (UK) | | | X | |
| **0811 : An Application of Genetic Algorithms to the Distribution Network Reconfiguration for Minimalization of Interruption Costs,** Paar M, Toman P (Czech Republic), Verho P (Finland) | | | | S5 |
| **0839 : Impact of Maintenance on Component Condition and System Supply Reliability in Distribution Networks** Zickler U, Schnettler A, Schwan M (Germany) | | | | S5 |
| **0842 : Estimation of Cost of Downtime of Industrial Process due to Voltage SAGs** Vegunta S.C, Milaniovic J.V (UK) | | | X | |
| **0844 : Quality of Electricity Supply Indices – JP Elektroprivreda BIH** Becirovic E, Dzizic M, Tepavcevic S (Bosnia and Herzegovina) | | | X | |
| **0847 : Electric Power Distribution Planning considering Power Quality Costs** Cebrian J.C, Kagan N (Brazil) | | | X | |

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| **0851 : Reliability of Distribution Network Components**<br>He Y (Sweden) | | | | S1 |
| **0879 : Towards a Smart Network in a Business District: Combining Dispersed UPS with Distributed Generation**<br>Bader J, Luternauer H, Kueng L (Switzerland) | | | | S5 |
| **0887 : Technical Assessment Of Dispersed Electric Vehicles In Medium Voltage Distribution Networks**<br>Pollok T, Dederichs T, Smolka T, Theisen T, Schowe von der Brelie B, Schnettler A (Germany) | | | | S4 |
| **0898 : Development, Installation and Operational Experience of a Superconducting Fault Current Limiter in a Distributed Generation Test Facility,** Dalessandro R, Ascade M, Bartalesi D, Bocchi M, Rossi V, Martini L (Italy) | | | | S1 |
| **0911 : Monitoring of and Regulations on Quality of Electricity Supply in European Countries**<br>Brekke K, Esteves J, Falcão A (Portugal), Bollen M, Westergaard T, Kolessar R (Sweden), Lo Schiavo L, Villa F (Italy), Reti G (Hungary), Haber A (Austria) | | | X | |
| **0949 : The Conduction of Power Quality Disturbances between Distribution and Transmission Grids**<br>Stanescu C, Gal S, Pipiris S (Romania) | | | X | |
| **0961 : Next-Generation Power Information System**<br>Elmendorf F, McGranaghan M, Dai Z (USA) | X | | X | |
| **0982 : Determining a Relationship between ESKOM Distribution Network Performance Improvement and Infrastructure Investment Cost,** Nunes N, Carter-Brown C, Cameron M (South Africa) | | | | S5 |
| **0987 : Looseless Encodings and Compression Algorithms Applied on Power Quality Datasets**<br>Kraus J, Tobiska T, Bubla V (Czech Republic) | | | X | |
| **0990 : Alternative Investment Strategies for Improving Distribution System Reliability by using Representative Networks,** Sana M, Keirudeen M, Rebic J, Djapic P, Strbac G (UK), Silva A (Portugal) | | | | S5 |
| **1014 : PQMS – Power Quality Monitoring System**<br>Bernardes R, Ayello F (Brazil) | | | X | |
| **1017 : Consumers' Perceived Economical Evaluation of Power Quality**<br>Cyrillo I.O, Pelegrini M.A, Borger F.G, Anuatti F, Belluzzo J.R, Longue C.A, Tahan C.M.V (Brazil) | | | X | |
| **1063 : Impact of IEC 61850 on Power Quality Monitoring and Recording**<br>Apostolov A (USA) | | | X | |
| **1068 : Managing Urban Network Fault Levels- A Role for Resistive Superconducting Fault Current Limiter?**<br>Singh N.K, Burt G.M, Brozio C, Robertes D, Bright C.G, Husband M (UK) | | | | S5 |