CONTENTS
Introduction – Call for Contributions.............................................. 1
I EMI, EMF and Safety ............................................................. 2
Electromagnetic Interferences (EMI) ........................................... 2
Transient overvoltages ................................................................. 2
Earth Potential Rise and safety concerns ................................... 2
Electromagnetic fields ................................................................. 4
II Connection of Disturbing Installations ................................... 5
Disturbing loads ........................................................................ 5
Dispersed generation (DG) ......................................................... 7
Assessment of disturbing phenomena and emission levels ............... 9
III Voltage dips and other Disturbances on the Grid ................. 11
Voltage dip assessment ............................................................... 11
Power Quality monitoring in general ......................................... 13
Voltage dip sensitivity of industrial equipment ......................... 15
Voltage dip mitigation techniques .............................................. 16
IV Power Quality in the Competitive Market .......................... 17
Power Quality indices ................................................................ 17
Costs associated with Power Quality ........................................ 20
Improving Power Quality ......................................................... 23
Regulatory aspects & market considerations ................................ 23
List of Papers ............................................................................ 25

INTRODUCTION – CALL FOR CONTRIBUTIONS

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, \( \leq 9 \text{ kHz} \), 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.).

The S2 papers will be discussed in **three events**:
- Plenary Session (Wednesday 8 June), also called "Alpha",
- Poster Session (Thursday 9 June),
- Research & Innovation Forum (Tuesday 7 June, 4:00-5:30 pm).

Three Round Tables ("Beta") will be organized:
- Voltage dip indices & benchmarking (Tuesday, 9:00-12:30)
- Lightning protection of MV and LV lines (Tuesday, 2:00-3:30)
- European Regulators & Quality of Supply (Tuesday: 2:00-5:30).

A Tutorial on Power Quality will take place on Thursday.

Several PQ&EMC-related papers will be discussed within other sessions (S3, S4, S5, S6).

So, CIRED 2005 will be a great event for all people interested in Power Quality and Electromagnetic Compatibility!

The aim of this special report is:

1) to present a synthesis of the present concerns in PQ&EMC, based on all selected papers (S2 and other sessions: 130 papers!),
2) to call for prepared contributions at the plenary session, on particular points which appear in the papers or which are not covered by them,
3) to stimulate the free discussion at the plenary session.

The 2005 plenary session will be divided in four blocks of 90 minutes:

1) EMI, EMF, Safety,
2) Connection of disturbing installations (emission limits for harmonics, flicker or unbalance ; filters or compensators, etc.) and monitoring methods,
3) Voltage dips and disturbances in customers installations (immunity levels, remedial measures, etc),
4) Power quality as seen by the different players in the competitive market (system operator, regulator, customers, etc).

Each block will be divided in two main parts:

1) a few presentations by key note speakers or authors,
2) discussion (prepared contributions and free discussion).

Call for prepared contributions. Prepared contributions will preferably aim at answering the questions of the Special Report. However, other kinds of contributions will be welcome:

- fresh information on particular points which appear in the papers or which are not covered by them;
- case studies (outstanding disturbance experiences, causes, solutions...);
- comments on a particular paper ("I agree/disagree with that result/conclusion", "My own practical experience in the same field is...");
- just plain questions to authors of a paper of the plenary session.

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

General guidelines for authors of prepared contributions:

- language: English;
- starting with: title, name of author(s), affiliation, country, number of the relevant question in the special report or number of the commented paper;
- if you wish to use a Power Point slide show, please send the Power Point file also (only ppt files received in advance will be available in the computer on the platform);
- deadline: 25 May 2005 (possibly 31 May at the very latest);
- e-mail to: alain.robert@elia.be;
- jean.hoeffelman@bel-engineering.com;
- emmanuel.dejaeger@laborelec.be;
- cewings@ieee.org.uk.
I EMI, EMF AND SAFETY

As usually four different topics will be addressed in this first part of the session: 1) Pure EMI subjects dealing with immunity and emission, 2) questions related to (lightning or switching) transient overvoltages, 3) safety concerns due to earth potential rises (EPR)\(^1\) and 4) EMF (Electromagnetic fields).

Electromagnetic Interferences (EMI)

Only three papers deal with pure EMI problems (i.e. interferences between equipment or systems). The first one, paper P2I-627 (IR), addresses by two different means, shielding and cryptography, the protection of data signals in the environment of HV substations. The second one, paper R2I-12 (CR) concerns RF noise measured in the Power Line Carriers (PLC) frequency band; it shows, in particular, that most interferences are non-stochastic and mainly correlated with the local electrical load. The third one, paper S2I-657 (EG), discusses some results from an EMTP based program designed for calculating the influence of overhead lines on metallic pipelines. This well-known problem is, of course, more a safety concern than an EMI problem but we leave it in this section because it is mainly based on inductive coupling.

Question 1

1.1 Methodologies for assessing the influence of HV overhead lines on pipelines and on telecommunication lines have been many times described in papers and guidelines (cf Cigré guide 95, ITU-T Directives). However little information is available about regulations and responsibilities. What are, in this respect, the current practices in the different countries? Is it of common use that the last installed supports the cost of the interference studies?

1.2 It has been recalled that RF noise could interfere with broadband Power Line Carriers (PLC), but it is well known also that PLC are considered as one possible new source of EMI. Are there new developments concerning this topic that are worth mentioning?

Transient overvoltages

Lightning overvoltages (OV) and lightning protection remain one of the most important concerns operators have to face mainly when dealing with MV/LV overhead networks.

Paper S2I-128 (YU) discusses the way ZnO surge arresters can be selected for protecting the MV network taking into account their energy absorption capability and the MTBF to achieve. Surge OV in the LV network are partly due to direct induction and partly to transfer across the MV/LV transformer. An analysis of the behaviour of some distribution transformers is presented by the authors of paper P2I-648 (AR). Not only the distribution networks need to be protected: railways systems are also concerned. In that case the rails play a particular role in that they need simultaneously to offer a return path for the currents, like a neutral conductor does, but also, at least for DC systems, to be insulated in order to minimize stray currents flowing into the earth. This particular situation has led the authors of paper S2I-226 (CH) to develop a special LV protection device ensuring the surge currents to be correctly diverted to earth without leading to unacceptable touch voltages. Although lightning OV represent the main stress for MV/LV networks, other sources of transient OV, like switching operations, should not be ignored. In that respect, the authors of paper S2I-530 (PT) make use of EMTP for analysing the behaviour of MV networks when feeders are energised. At the other end of the network, even the energising of small LV loads like PC’s can lead to severe transients as highlighted by the authors of paper P2I-613 (SE).

Question 2

2.1 A clear positive correlation is made in paper S2I-128 between tower footing resistance and energy absorption capability of surge arresters. Is this feature due to the fact that, with low footing resistances, most of the lightning energy is diverted to earth before reaching the surge arrester? Could the same correlation be made if the lightning stroke was supposed to occur in the direct vicinity of the surge arrester?

2.2 The lightning protection of MV overhead lines has been very often addressed in Cired. Are there now general guidelines available for helping the utilities in correctly dimensioning and locating the surge protective devices?

2.3 Surge arresters in MV networks are mainly used for the protection of MV equipment like transformers or cables. In LV networks the equipments to be protected are mainly located within the customers installations. Where is, in that respect, the limit of responsibility between the network operator and the customer? Has the “deregulated marked” changed something in the way to address this quality criterion?

Earth Potential Rise and safety concerns

Lightning and switching are at the origin of transient overvoltages; fault currents lead to temporary overvoltages (TOV) and Earth potential rises (EPR) of longer duration that can have severe consequences on safety if they exceed the insulation coordination (IC) of the LV material or lead to a higher risk of indirect contacts (step or touch voltages).

\(^1\) In the following we consider the American terminology “ground” and “grounding” as equivalent to “earth” and “earthing”
A special case of TOR that can also affect the IC in LV network is the interruption of the neutral conductor, as recalled by some authors (S2I-472 IT, RO - withdrawn). One of the main parameters affecting these issues is the way the networks are earthed (or not) and the way the “earths” are distributed or shared within the network or between MV and LV networks. In particular, the role of the so-called “global earth” has proved its particular efficiency during the last decade. This important topic is again discussed in several papers. In particular, it was generally admitted that the growing use of XLPE cables in MV networks could affect the quality of the global earth due to the fact that they are much better insulated to ground than the classical paper insulated cables. This feature, however, is not supported by the author of paper S2I-055 (YU) who shows that, at least in urban area, thanks to its natural extension, the efficiency of the global earth network could be at least as high as that of an equivalent paper insulated conventional network. The opposite point of view is defended in paper S2I-458 (IT) where recourse is made to bare buried conductors for mitigating the absence of earthing properties of the XLPE cables (Figure 1).

The possible transfer of EPR to LV networks is analysed in paper S2I-166 (CA) for the typical North American rural overhead network using a multigrounded neutral in the MV network and practically no LV network (Figure 2). Taking into account that the earth impedance of long lines increases only as the square root of the soil resistivity, whereas that of a substation grid increases linearly with the soil resistivity, the author draws some conclusions that are not so far from those found in paper S2I-055.

Two papers presented in Session 3 address further EPR issues. Paper S3-044 (CH) proposes the single pole operated earthing breaker (Figure 3), in order to cope with some drawbacks of MV systems with isolated neutral or with Petersen coil.

According to paper S3-414 (DK), the relatively high harmonic components tolerated at the MV level by the EN 50160 European standard may result in single line to ground (SLG) fault currents dominated by the harmonic contribution that will not be damped by a resonant earthing. All these contributions show that there is no unanimity about the best way to let the networks evolve. For some authors the impedant earthing combined with a good global earthing system, involving sometimes the LV network, is the solution of the future, whereas for others, the resonant earthing (Petersen coils) remains the best choice. These different approaches have, of course, also a strong influence on the improvement of the Power Quality and more particularly on the reduction of the AID and the AIF (see "Improving Power Quality" in Block IV).
Question 3

3.1 The paradoxal - but good - earthing properties of XLPE cables presented in paper S2I-55 are partly due to the assumption that the neutral conductor of the LV network is connected to the earth of the MV/LV substation; i.e. that the global earthing includes the LV network. What would be the conclusions in the more general case of separated MV and LV earths? Is this a new argument in favour of their interconnexion? What about rural networks?

3.2 There is a general statement saying that a low soil resistivity leads to a higher safety. However, the highest the soil resistivity, the more earth electrodes are involved in the global earthing, the slowest the gradient of the EPR is and the higher the additional resistances are in the body to soil current path. Hence, is it possible to moderate the general statement?

3.3 Paper P2I-420 shows the possible evolution of a MV network from a resonant earthing scheme to a mixed resonant-impedant scheme. Is this a general trend? Are there other similar – or opposite - experiences in other networks?

Electromagnetic fields

The recent publication of the new European Directive 40/2004/EC concerning the exposure of workers to EMF has reinforced the need to have means and standards at disposal for assessing the field levels in different locations or from specific sources. These means can also be used for assessing the exposure of the general public that remains the main concern. A summary of the EMF problematic can be found in paper P2I-637 (AR). Assessment methods for HV substations are described in papers P2I-716 (EG), P2I-083 (CN), and S2I-431 (SI). Paper P2I-716 involves a survey in the vicinity of urban MV/LV transformers showing that at 1 m distance the CP95 is already at about 60 µT. Paper P2I-083 analyses the field produced by some specific sources and their possible local or global influence at the boundaries of the substation, whereas paper S2I-431 recommends to use an hybrid approach, which takes into account the important differences that can appear between values derived from theoretical models under rated load conditions and actual values measured under operational conditions. Mitigations techniques for cables are presented in papers P2I-083 (CN) and R2I-205 (BR, ES, GB, PE, SE). The latter introduces a very interesting optimisation method validated by a reduced scale model.

Two other papers present special methods for assessing fields. The first one (R2I-082 - CN), prepared by the authors of paper P2I-083, describes an evaluation method suitable for reactive coils. The second one (R2I-522 – IT) proposes a way to identify an equivalent source system for complex 2D type (power lines...) or 3D type (transformers...) sources. Coming back to mitigations methods, the authors of paper S2I-091 (IT) present a case study where aluminium screens are used for reducing the field produced by a double trefoil 132 kV XLPE line in the vicinity of the junctions that are in flat configuration (Figure 4).

Figure 4: Aluminium shields surrounding a double power link at a junction level

A completely different problem is addressed in paper S2I-466 (FI) where the authors worry about the risk that the presence of harmonics in distribution networks reduces the actual power frequency limit well beneath the reference level (100 µT at 50 Hz) in the vicinity of LV switchgears.

Question 4

4.1 In comparison with the previous sessions where the main concern was the exposure of the public, the new European Directive draws now the attention on the exposure of the workers. In that respect, and except for live line works and air core reactors, are there other specific sources that have been identified in MV substations? What are the proposed solutions? What is the possible financial impact of this directive for distribution operators?

4.2 Mitigation techniques such as shielding by metallic materials, use of passive loops or optimal conductors management are now largely described in the literature. How far are those techniques actually used in HV and MV substations? Are there cases where distribution cables had to be shielded when crossing sensitive areas? What is the experience in countries like Switzerland and Italy where the regulation sets limits that are more severe than the international recommendations?

4.3 Paper S2I-466 (FI) stresses upon the risk that the presence of harmonics in LV networks could lead to transgress the ICNIRP limits. Are there similar experiences in other countries? Does the earthing scheme (TT, TN...) strongly influence the resulting magnetic field levels due to the presence of stray currents? Are there already broadband field meters available, using a filter allowing to correctly take the harmonics into account according to the ICNIRP guidelines?
II CONNECTION OF DISTURBING INSTALLATIONS

Disturbing loads

Paper S2II-175 (GB, MY) presents a methodology to derive the linear and non-linear load composition of an aggregated load model, based on harmonic measurements at the service entrance feeder. Based on harmonic current spectra of typical non-linear loads and measurement results, a weighted coefficient, representative of the percentage of each type of non-linear load, is determined.

Paper P2II-298 (CZ) gives an overview of particular low-frequency interferences generated by three-phase bridge rectifier. The first issue is non-characteristic harmonics, arising due to unbalanced conditions in the power grid and converter asymmetries (e.g. non-symmetrical firing angles). The second part is focused on interharmonics, usually occurring as a consequence of dynamic changes of circuit parameters (voltage dips, load variations...).

Harmonic voltage distortion levels have to be controlled through product emission limits for LV equipment and assessment procedures for the connection of larger equipment (e.g. IEC 61000-3-6). Besides the growing number of distorting loads, another reason for the increase of harmonic voltage distortion is an environmental one: it is now far more likely for new circuits to be underground rather than overhead.

Paper S2II-053 (GB) examines the impact of MV & HV underground network extensions on harmonic voltage distortion, using real-life case studies in the UK. The major conclusion is that there is a need, in some circumstances, to exercise control over harmonic impedance as well as harmonic current injection. A minimum factor of 2 should be used up to the 8th harmonic for MV & HV rural underground networks at voltages of 33kV and above, if the “Worst Case Impedance Curve” (IEC 61000-3-6) approach is used (Figure 5).

As a matter of fact, due to the increasing part of underground lines, rural HV & MV networks may progressively have a significantly reduced capacity to accept 5th or 7th harmonic current injections.

Harmonic voltage distortion levels have to be controlled through product emission limits for LV equipment and assessment procedures for the connection of larger equipment (e.g. IEC 61000-3-6). Besides the growing number of distorting loads, another reason for the increase of harmonic voltage distortion is an environmental one: it is now far more likely for new circuits to be underground rather than overhead.

Paper P2II-062 (CH) reports about harmonics that have been experienced in distribution networks, due to some topological changes. The distortion levels are sometimes above the indicative values of planning levels as given in IEC 61000-3-6 and sometimes even above the limit values of EN 50160.

Measurement results illustrate the situation, while a complete model of the system confirms the presence of acute resonances and the influence of the network configuration. Typical mitigation measures are also investigated (changing the network topology, passive shunt filters, blocking series filters and active filters.)

The long-term thermal effects of harmonics are discussed in paper P2II-700 (US). This paper describes harmonic de-rating factors, based on the harmonic spectrum of the load, which can be used to size line and neutral conductors of three-phase electrical distribution systems. It shows a.o. that MV/LV transformers may become significant harmonic current sources when operated above nominal voltage, see Figure 6.

Figure 6: harmonic components of transformer exciting current (In = rated current ; Im = magnetizing current ; I1, I3, I5, I7 = fundamental and harmonic components of Im)

Paper P2II-668 (BR) presents an unusual application of shunt harmonic filters, pole mounted at the low-voltage side of a 13.8/0.22 kV transformer, which feeds several ordinary residential consumers. The results show that this approach could relieve the transformer and also improve the voltage and power factor levels. As far as Brazil is concerned, the presented proposal pay-off is expected to be reached within 2 years.

Paper S2II-703 (EG) proposes a new method for designing the parameters of harmonic filters used with distorting loads in industrial premises. It proposes to replace the usual high pass filter with a simple shunt capacitor, which can operate with fewer losses.

Paper S3-414 (DK) draws the attention to the fact that harmonics may have significant effects on single line to ground (SLG) fault currents, see in Block I the section on "Earth Potential Rise and safety concerns".

Disturbances due to frequency components at several kilohertz (1...15 kHz) became more and more important in recent years. Paper S2II-052 (DE) explores causes for this development, such as increased use of PWM converters or reduction in system damping, together with ordinary
converter loads leading to an excitation of the natural system frequency. Contrarily to line-commutated converters, which are generally considered as harmonic current sources, self-commutated (PWM) converters need to be considered as voltage sources. The voltage distortion at the feeding bus-bar is determined by the voltage divider formed by the converter transformer and the supply network (see e.g. Figure 7).

The effects of these phenomena may be the malfunction of electronic office equipment, blowing of power supply units, malfunction of electronic controls or unacceptable noise.

Figure 7: LV-busbar voltage with a self-commutated converter connected; pulse frequency = 3kHz

The method proposed in paper P2II-395 (FR) uses the periodicity of the converter variables, in steady state operation, in order to put them in a matrix form in the frequency domain and reproduce typical current spectra (see Figure 8).

The method needs no long calculation time and gives a theoretical solution of the considered system. One of the main advantages is the analytical expression of current and voltage harmonics, allowing to determine the influence of system parameters (control strategy, passive elements, etc.).

Figure 8: Typical current spectrum of a PWM converter for small embedded generation unit

Papers S2II-144 (DE, FR) and P2II-512 (IT, SE) deal with disturbances caused by electrical arc furnaces (EAF).

In paper S2II-144 (DE, FR), the authors show typical current and voltage waveforms measured during tap-to-tap time on an EAF. A method of data acquisition and analysis is described in view to evaluate electrical performances and network disturbances. Harmonics and flicker are the highest during scrap melting. In this period, a significant unbalance is also observed. This unbalance affects several harmonics differently and induces, in each phase, large active and reactive power variations. These variations increase the flicker effect and decrease the active power transferred to the electrical arc. In the future, new power electronic supplies will be used to overcome these problems.

Paper P2II-512 (IT, SE) describes an SVC installation at an EAF melt shop of 85 MVA. The flicker severity factor at the 220 kV point of common coupling has been limited to $P_{f,95} = 1.3$ (although the network is relatively weak, the short-circuit level being slightly less than 3 GVA). The SVC installation has also led to better furnace performance in respect to increased available power and less electrode consumption.

Measurements on air conditioner systems are presented in paper S2II-291 (AU). Three types of split-phase air conditioners are studied including direct on line starting (DOL), soft starter and inverter fed units. Results of testing and subsequent calculations illustrate that the direct on-line and soft starter units do not meet requirements of the relevant PQ standard for LV distribution systems (voltage drop >6%).

Paper S2II-322 (ES) is dedicated to capacitor bank switching, one of the most demanding operations in MV networks, due to its frequency and the associated transients. It is both an important maintenance concern, since strong currents affect breakers and capacitors, and a frequent PQ issue, as voltage transients can affect customers (for example, Figure 9 shows the de-energization transient of a capacitor bank, with restrikes).

The development of new digital protection algorithms will enable permanent monitoring of MV and HV capacitor banks to be carried out, allowing a more effective preventive maintenance. The consequent breaker improvements will also lead to significant PQ benefits.

Figure 9: Capacitor bank de-energization, with restrikes

Figure 10: rms voltage and current signature of a soft starter air conditioner unit (the test impedance being approximately a quarter of the reference impedance, specified in IEC 61000-3-3)
Soft starters need further development but can easily be designed to provide more suitable performance. There are also significant harmonic emissions from asymmetrical soft starter currents for short periods, and also due to saturation of compressor motors during normal operation. Inverter fed air conditioner units utilising three-phase motors provide the most suitable solution to PQ issues.

Paper P2II-369 (PL) describes a case study of disturbances created by welders in MV and LV networks.

Paper R2II-407 (ES) investigates situations where DSTATCOMs increase reliability of the voltage regulation in distribution networks, for instance in the presence of dispersed generation. This kind of solution might be considered when the classical voltage regulators (on load tap changers, capacitors banks, etc.) cannot fulfil the requirements. In many occasions the connection of several DSTATCOMs could be necessary in order to reduce costs and increase flexibility. Unfortunately, the electrical distances could originate interactions in the regulators, generating oscillations and dynamic instability. The sensibility indices defined in the paper permit to characterize the interaction level and to distinguish between favourable or unfavourable interaction.

**Question 5**

5.1 How do DNOs (distribution network operators) practically deal with the problem of connecting disturbing loads in LV networks?

5.2 Are there any recent industrial experiences with modern compensating devices such as STATCOM, active filters etc.?

5.3 What to do with the reported decrease in resonance frequencies? Does it mean reduced emission limits for customers or some control over harmonic impedance from the system operator?

**Dispersed generation (DG)**

The impact of Dispersed Generation on PQ has become a major issue in distribution networks (S4-281 CZ). Main addressed phenomena are: voltage profile, attenuation of ripple control signals, harmonics, flicker, voltage dips. Frequency components due to PWM converter interfaces are also an issue (see the section on “Disturbing loads”).

In the frame of the EU funded “DGFACS” project, a study was performed in Spain with the objective of characterizing DG sites and to provide valuable information for simulation purposes. The major results are given in paper P2II-051 (ES).

A long-time measurement campaign on a wind farm (15 × 2 MW doubly-fed induction generators - DFIGs) is presented in paper P2II-202 (PL). No significant impact was found on the HV (110 kV) network. According to paper S4-095 (NO), measurements in two MV networks with a limited amount of distributed generation, also concluded that no significant influence on disturbance levels could be noticed.

The same conclusion is given in paper S2II-416 (FR), presenting PQ studies for wind farm grid connection (regulatory aspects, connection procedure and studies, performance comparative study, experimental results, some technical solutions, conclusions and forecasts). It might however change in the future: the above favourable results are explained by:

- a strong short circuit power at the point of common coupling, which had been a technical constraint for first sites selection,
- low unit power of wind turbines at the first sites.

Figure 11 shows the ability of DFIGs to be operated with minimized constraints for the MV network. It also illustrates the possible control of the reactive power, leading to minimised impact (or even potentially positive influence) on the voltage profile (short- and long-term).

**Figure 11:** «Clean coupling» of a doubly fed induction generator

![Figure 11](image)

Figure 12 illustrates the possible attenuation of ripple control signals, which can be limited by the use of an active filter.

**Figure 12:** Ripple control signal attenuation and effect of filter

In paper P2II-032 (GR) a harmonic penetration study is presented for a wind farm consisting of variable speed turbines, with extended submarine cable connections. The low switching frequency of the wind turbine output converters falls near a parallel resonance of the system, resulting in a marginally acceptable situation.
Paper P2II-354 (GB) demonstrates that LV distortion levels are not rising proportionally to the penetration of small inverter-connected sources of renewable energy. However, above a certain penetration level, a rapid deterioration can be expected (Figure 13). It is therefore essential that power utilities are equipped with appropriate simulation tools, in order to anticipate the permissible levels of small embedded generation penetration. These may vary according to the network parameters as well as inverter types. Moreover, the method can be used for studying harmonic cancellation switching strategies, aiming at PQ improvement.

Paper S4-560 (IT) shows that a suitable design of the DC/AC interface is essential, enabling a positive impact - rather than negative - of a PV plant on PQ.

Flicker. The connection of wind turbine generators (WTGs) in weak distribution systems may result in voltage fluctuations, or flicker. Doubly-fed induction generators (DFIGs) provide a means to rapidly control reactive power, as well as to smooth variations in real power. Figure 14 and Figure 15 (S4-672 US) show a comparison between DFIG and an ordinary pitch-regulated induction generator (IG).

DG has several voltage dips implications: as a source, as a victim (see block III, "Voltage dip sensitivity of industrial equipment"), or as an influencing factor for dips due to faults in HV or MV networks.

DG as a source of voltage dips. Typical wind farms consist of several wind turbines, each operating at less than 1 kV and connected to the MV grid system via a transformer. The energisation of turbine transformers causes a transient phenomenon ("inrush current") with voltage dips/fluctuations on the local grid as a result. Voltage dips depend on transformer inrush magnitude, number of transformers energized simultaneously, point-on-wave switching angle, initially energised transformers and three-phase non-simultaneous energisation.

System studies for three proposed MV wind farms (33 kV) have been done using PSCAD software (P2II-135 GB). The model has been verified with site measurements. Voltage dips due to simultaneous energisation of all turbine transformers exceed the permitted limits at two sites. It is therefore recommended to either install a pre-insertion resistance (PIR) at the wind farm main circuit breaker, or install additional 33kV switches and care for adequate switching sequences. Since switchgear incorporating PIR is not generally available at 33 kV, its application needs to be addressed by equipment manufacturers.

DG as an influencing factor for dips resulting from faults in HV networks. An increasing shift from "centralized generation" to "dispersed generation" will lead to a reduction of the fault level in the transmission system (S4-104 SE). This will lead to an increased number of dips at the HV interface (primary side of the HV/MV transformer) between transmission and distribution. An example is given in Figure 17 for three values of the end-user immunity:
70%, 75% and 80% residual voltage (SARFI-70, SARFI-75 and SARFI-80).
The influence on the MV interface is more complex, depending on the type of DG. The presence of generator units at distribution level may mitigate voltage dips, giving a reduced dip frequency as compared to the HV bus. However, most power-electronic interfaces will trip rather quickly.
Most doubly-fed machines will disconnect within a few cycles, but during those few cycles the voltage is pulled down by the heavy reactive-power consumption (the rotor is short-circuited almost immediately to protect the power electronics).
Synchronous generators on the other hand have indeed a beneficial influence (they are common for combined-heat and power installations). There is a voltage dividing effect due to their impedance and the impedance of the HV/MV transformer. Figure 18 gives an example with a transformer impedance of 0.20 pu and a generator impedance of 0.25 pu.

Assessment of disturbing phenomena and emission levels

Papers S2II-534 (BE) and P2II-121 (CN) deal with some practical aspects and technical choices for the implementation of IEC standard 61000-4-30. They describe computer-based measurement platforms and discuss some concepts, such as the synchronization of the time intervals. Both papers show how statistical output as well as clear and explicit graphics can be obtained, according to IEC standards.

Paper R2II-140 (BE) proposes different methods based on amplitude-phase-frequency (APF) estimators to define the magnitude and frequency of voltage fluctuation components and, more generally, to detect any other PQ phenomenon leading to signal envelope modification. Experimental measurements show that the use of linear and non-linear operators to track flicker is accurate, easy to implement and imposes less computational burden, proving their efficiency in real-time measurements.

Alternatively, paper P2II-617 (CN) introduces DCT (Discrete Cosine Transform) for short time disturbances detection. It is shown that short time PQ disturbances (such as voltage dip, voltage swell and voltage interruption) can be detected and extracted through DCT transform, even in the presence of serious noise.

The study presented in paper P2II-663 (AR) aims at optimising the number of measurements to be performed in order to characterize any distribution network regarding harmonic levels. The following aspects are considered:
- classifying feeders according to consumption rates,
- assessing short-circuit levels,
- defining a reference point.

Question 6

6.1 What could be the consequences of a large penetration of converter-connected embedded generation units in LV distribution networks? Paper P2II-354 foresees a more than proportional rising of THD levels; is it not in contradiction with the classical saturation effect with a large amount of similar distorting installations?

6.2 Which are the practical difficulties, regarding Power Quality, related to the connection of windmills to distribution networks?

6.3 On the other hand, which benefit can be drawn from the presence of such generators in distribution networks?

6.4 Will improved ride-through capabilities of converter-coupled generators dramatically change the influence of DG on voltage dips?
It also includes results from a measurement campaign, with the purpose of finding statistical relationships between harmonic indices and network parameters.

Many simulation tools are available today, in order to analyse PQ problems. Several papers deal with such applications, for the prediction of harmonics propagation or PQ state-estimation. The efficiency of the Alternative Transient Program (well known as ATP) to this purpose can be appreciated, through the examples proposed in paper P2II-693 (AR).

Paper R2II-065 (FR) discusses three-phase PQ analysis using full matrix modelling methods, which give particularly truthful results for power transformers, power lines and induction machines. Using single-phase models is inadequate for harmonic unbalanced components. Even for voltage dip investigation, the symmetric model is insufficient to assess the attenuation through a 3-legged power transformer. For industrial network harmonic diagnosis, it is recommended to use 3-phase impedance calculation in order to reveal, among other things, unbalanced harmonic resonances.

The following curves (Figure 19) show the impedances calculated at the secondary of 5-legged and 3-legged transformers (1 MVA, 50Hz) by use of a true 3-phase model. For a 3-legged power transformer, the error from single-phase impedance calculation is very important.

Paper R2II-715 (EG) proposes fault and disturbance prediction, based on state-estimation techniques. It shows how to adapt a power system simulation tool for the prediction of disturbance levels in various locations, based on data from specific locations where PQ meters are installed (Figure 20).

Paper P2II-377 (BR) proposes a method in order to predict the voltage profile on a probabilistic base. Three voltage supply levels have been set by ANEEL (the Brazilian Electrical Energy Regulation Entity) for the customers: adequate, inadequate and critical, as well as two violation indicators: Relative Duration of Inadequate Voltage Violation - RDI and Relative Duration of Critical Voltage Violation – RDC. These indicators should not exceed a given maximum time percentage.

From typical daily load curves, distribution curves are calculated for voltage probability, so that the risk of excessive RDI and RDC indicators can be calculated for each point in the network, allowing the utility to correct possible voltage problems.

The question of assigning responsibilities for disturbance emission is dealt with in three papers (S2II-190, S2II-635 and R2II-344).

Paper S2II-190 (IT) presents an analysis of classes of harmonic distortion responsibility and proposes an identification procedure, relying on two methods based on 1) the definition of conforming and nonconforming current and 2) the evaluation of the sign of harmonic active power. In paper S2II-635 (AR) simpler procedures are proposed, assigning the responsibility for the voltage to the utility, and the responsibility for the current to the customer.

Paper R2II-344 (SE) describes a new measurement method to determine how flicker propagates throughout the network and to trace the dominant flicker source. It is basically a development of the flickermeter standard IEC 61000-4-15, which is applied to the current in addition to the voltage waveform. The low frequency variations in voltage and current are first filtered and then multiplied and averaged to get a new quantity called “flicker power”. This new quantity is shown to have the same attributes as active power. The sign and magnitude of flicker power give the direction of the flicker propagation as well as tracing the dominating flicker source, as verified by simulations and field tests.

The measurement method described in paper P2II-180 (NL) gives a useful characterization for DG inverters and, more generally, all kinds of loads in relation with their
harmonic behaviour. The parameters $I_h/I_n$, $G$ and $C$ (see the equivalent circuit in Figure 21) could be used in the relevant standards.

Rough calculations show that a negative conductance (possible for several types of inverters) can lead to a significant increase in harmonic distortion and should be avoided for this reason. Furthermore, the capacitance of the equipment should also be limited.

Paper S2II-218 (CA, DE) proposes an artificial network (AN) for repeatable measurements and correct assessment of current emissions in the range 2-9 kHz from LV apparatus (Figure 22). Test results gained with a first prototype are reported. The AN is to be connected between the common LV supply system and the equipment under test (EUT). The circuitry both isolates the EUT from the distortion of the supply system and preserves this system from injected disturbing signals. It provides a power source with appropriate and stable standardised impedance characteristics. This new artificial network is expected to be adopted by IEC.

Paper S2II-143 (GB) focuses on low voltage faults which are responsible for a large proportion of PQ issues within distribution networks. The evolution stages confirm the reoccurring nature of cable faults as they progress naturally from their dormant stage to their permanent stage. During this evolution the incipient fault causes many disruptions resulting in transients, voltage dips, strong even harmonics and short-circuit current bursts (Figure 23). Such voltage dips and short-circuit current bursts can cause small-scale distributed generators to trip and disconnect from the network; these effects can be minimised by optimising the protection of the generator and, if appropriate, by introducing fault current limiters. On the other hand, higher voltages introduced by distributed generators may have the effect of triggering incipient LV faults into sustained failures.

Targeting cable faults using online detection and location equipment is a promising method of managing repeated fuse operations. However this would need significant investment and is currently not yet economically viable. By targeting faults after a first fuse operation with portable online equipment, it should be possible to detect and locate the failure before a second fuse operation.

**Voltage dip assessment**

Papers P2III-219 (CZ), P2III-286 (TH) and S2III-388 (NL) report on investigations to determine the magnitude and duration of voltage dips by faults simulation methods. Faults are simulated in order to obtain voltage dip magnitudes at a given point. The dip duration can be determined from the operating time of relays and clearing time of circuit breakers in each part of the network. Statistical distributions of several kinds of voltage dips may then be assessed without waiting for years of site monitoring.

Papers presented in other sessions also report on voltage dip prediction by network simulations (S4-104 SE, S4-562 BR, S5-572 BR). Simulations may combine dips and interruptions (S5-078 IT) or deal with interruptions only (S5-185 NL, S6-634 AR).

**Question 7**

**7.1** The network harmonic impedance is an important parameter for connection studies. How is this parameter estimated in practice?

**7.2** Are the existing modelling and simulation tools sufficient for PQ analysis? What are the actual needs? What are the recent research topics and the future trends?

**7.3** How are responsibilities for disturbance emission dealt with from a contractual point of view?

**III VOLTAGE DIPS AND OTHER DISTURBANCES ON THE GRID**

PQ events characterized by deviations of rms voltages are the most common causes for tripping of sensitive industrial processes. Voltage dips are perhaps the most important power supply disturbance, because they are more common than interruptions and may affect many equipment.

**Voltage dip assessment**

Papers P2III-219 (CZ), P2III-286 (TH) and S2III-388 (NL) report on investigations to determine the magnitude and duration of voltage dips by faults simulation methods. Faults are simulated in order to obtain voltage dip magnitudes at a given point. The dip duration can be determined from the operating time of relays and clearing time of circuit breakers in each part of the network. Statistical distributions of several kinds of voltage dips may then be assessed without waiting for years of site monitoring.

Papers presented in other sessions also report on voltage dip prediction by network simulations (S4-104 SE, S4-562 BR, S5-572 BR). Simulations may combine dips and interruptions (S5-078 IT) or deal with interruptions only (S5-185 NL, S6-634 AR).

Paper S2II-143 (GB) focuses on low voltage faults which are responsible for a large proportion of PQ issues within distribution networks.

The evolution stages confirm the reoccurring nature of cable faults as they progress naturally from their dormant stage to their permanent stage. During this evolution the incipient fault causes many disruptions resulting in transients, voltage dips, strong even harmonics and short-circuit current bursts (Figure 23).

Such voltage dips and short-circuit current bursts can cause small-scale distributed generators to trip and disconnect from the network; these effects can be minimised by optimising the protection of the generator and, if appropriate, by introducing fault current limiters. On the other hand, higher voltages introduced by distributed generators may have the effect of triggering incipient LV faults into sustained failures.

Targeting cable faults using online detection and location equipment is a promising method of managing repeated fuse operations. However this would need significant investment and is currently not yet economically viable. By targeting faults after a first fuse operation with portable online equipment, it should be possible to detect and locate the failure before a second fuse operation.

**Figure 23**: Voltage wave shape during an intermittent arc event measured at the LV fault location.
Paper P2III-005 (ES) discusses the preliminary results of a PQ audit conducted at a high-tech campus, where voltage and current were measured in various R&D buildings. The paper examines the causes and effects of power disturbances that affect computer or other microprocessor based equipment. “Enhanced power supply” or “low-cost customer-side” protection solutions are discussed. The massive penetration of electronically controlled devices (the "digital society") could be responsible for an increase in PQ problems; in particular, most computerized diagnostic instruments, found in biochemical R&D laboratories, are becoming very sensitive to even minor power perturbations.

Paper P2III-725 (EG) gives an overview of harmonics and voltage dips affecting industrial zones in Egypt. Mitigation methods are discussed.

Paper P2III-333 (PT) reports on analysis of PQ problems for HV and MV customers, through correlations between recorded events and possible problems in factories.

A new framework for voltage dip quality standards is proposed in paper S2III-388 (NL). Voltage dips are classified in nine categories belonging to three main regions (Figure 25).

The upper region (K0, M0, L0) depicts the area where it is impossible to reduce or alleviate the dips much further; the responsibility for preventing damages belongs to the equipment manufacturers. The bottom region (K2, M2, L2) depicts the area where the equipment cannot be expected to ride-through and where mitigation equipment is generally not economical; it is the responsibility of the network company to minimize the number of such dips. The mid region (K1, M1, L1) depicts the area where the responsibility is mainly with the consumer. The "dip criterion" is the maximum allowed value for each average occurrence per dip-type per year (DK0, DK1, ...); it defines the "dip quality standard" (Figure 26 gives an example).

Although voltage dips are defined as a short duration decrease in rms voltage, there is no full agreement on their characterization and severity evaluation. Dips have been mainly characterized by magnitude and duration (worst phase values only in case of unbalanced dips). However, additional parameters are needed for accurate event characterization, and prediction of sensitive equipment behaviour during unbalanced dips. Hence the well-known ABCDEFG classification has been introduced, together with the consideration for phase angle jumps in addition to voltage magnitudes.

Paper S2III-105 (SE) addresses voltage dip characterization making use of a Phasor Measurement Unit (PMU), which provides the positive sequence voltage, estimated once on each cycle, and the phase angle estimated with GPS as time reference. If the PMU functionality is extended to record three-phase voltages with higher frequency and intelligent threshold recording, it can be considered as an excellent device for voltage dip measurements.
Question 8
8.1 Are simulation tools frequently used in order to predict the statistical occurrence of voltage dips? Are some of them commercially available?
8.2 Voltage dips are rather complex phenomena: which level of sophistication is needed, for their detection, measurement and characterization?

Power Quality monitoring in general

PQ monitoring is nowadays a basic practice, required for many technical reasons (troubleshooting, technical management of the system, investment and planning purposes), marketing reasons (care policy towards the customer) and liability reasons (reporting towards Regulation Authorities).

Any monitoring system aims at assessing well-defined PQ indices in order to characterize the quality in a meaningful way (see "PQ indices" in block IV).

Paper P2III-728 (YU) reports on interruption statistics, in particular on the use of reliability indices like AIF (=SAIFI=CI), AID (=CAIDI) and AIT (=SAIDI=CML) since the year 2002 for benchmarking purposes.

The new German statistics on outages and supply interruptions, making reference to the DISQUAL indices, are presented in paper P2III-199 (DE). The authors point out that supply availability is a complex matter that cannot be expressed comprehensively in a single index (of which an example is nevertheless given in Figure 28). Detailed information on the quality performance of networks is needed, including the reliability of network components. The results are of high importance for network planning, operation and other decisions.

---

2 Availability of supply indices, Unipede, Distribution Study Committee 50.05DISQUAL, Ref.: 0500Ren9733, July 1997.
It is stressed that the availability of voltage transformer supervision functions is essential in order to avoid incorrect detection of voltage dips and interruptions due to failure in the voltage circuits.

Paper S2III-123 (FI) presents a system consisting of protection relays with disturbance recording and TCP/IP communication gateway, distribution transformer condition monitoring units with SMS communication, and advanced remotely readable energy meters with PQ monitoring functions (Figure 29). PQ data provided by various apparatus are stored in a relational database called PQDB. A web-based application with analysing and reporting functions is developed to present PQ data via Internet. The use of measurement data for network planning and operation purposes are also discussed, as well as possibilities for network business regulation.

Paper P2III-130 (BE) describes the development of an intelligent quality management system (the “Q-master” project) for the transmission system, from EHV down to the MV interface with distribution. A database is developed to gather all PQ data coming from different types of devices: quality monitoring devices, fault recorders and digital revenue meters. Applications are developed to produce indices that characterize system and customer’s level of PQ. The development of new applications which combine PQ data with information from other sources should help to quickly identify problem conditions, finding the cause and determining the best solutions for the system and the customers.

PQ monitoring is also practiced, for more than six years now, in the Belgian distribution networks. Paper P2III-473 (BE) describes this experience in details; it gives an actualised survey of the progress, the regulatory framework, the final goals and the technical system configuration (actually, more than 400 fixed monitoring devices are operated in MV distribution networks, from a central control room). Data acquisition, processing and reporting solutions are discussed.

Paper P2III-206 (MY) describes the PQ Monitoring System that has been put in place by TNB in Malaysia. TNB can now focus on utilising the data to improve the PQ performance of the system and working with customers to minimize their exposure to PQ issues. The collected information is available (almost on-line) within the company and for customers.

The disturbance recording and PQ monitoring system described in paper P2III-240 (DE) is running for approximately one year in Germany and has brought an immediate benefit to the system operators. An SMTP server automatically distributes disturbance records and PQ reports according to EN50160. The collected data will be used for long-term statistics in order to support the power system-planning department and asset managers.

In addition, the system has been helpful to react upon events very quickly, e.g. to compare calculated and measured values, after voltage drops on important nodes due to faults on adjacent lines. Archiving PQ data and reports will help meeting the power system regulation authority requirements.

Paper P2III-385 (DE) describes a method of PQ characterization in distribution networks, aiming at going beyond EN 50160 reporting, by using several performance indices. Their values are directly proportional to the actual reserve with respect to the allowed limits at the measurement sites. The various indices ($r_k$) are combined to give site indices ($r_V$), which in turn can be consolidated to produce network indices ($r_N$), as depicted in Figure 30. Considering statistical aspects already during site selection results in performance indices giving a good estimation of average PQ levels in the analysed distribution networks.

A fuzzy logic approach is proposed for quantifying voltage quality in paper R2III-002 (TR). The proposed approach can be divided into three steps (Figure 31): 1) voltage quality problems are detected and separated (e.g. voltage dips, swells and harmonics); 2) each fuzzy section gives individual quality values; 3) these quality values are multiplied by weighting factors, ranging from 0 to 1 and defined by the consumer. Finally, a general voltage quality index is obtained.
Question 9

9.1 Which are the main advantages and drawbacks of permanent PQ monitoring? Are there possible alternatives?

9.2 What are the future trends in PQ monitoring (methodology, instrumentation, site selection, type of reporting etc.)?

Voltage dip sensitivity of industrial equipment

Paper S2III-568 (SE, US) describes testing procedures for evaluating equipment sensitivity to voltage dips. Industry standards for testing voltage dip immunity provide a starting point. However, real world voltage dips can have characteristics significantly different from test conditions and additional testing may be required.

Two types of studies are required. At first statistics are needed on the frequency of occurrence of the different dip types. But the impact of dip types and characteristics should also be considered in the decision. Dip types that have a severe impact on equipment should be included, even if they are not very common.

The example ASD (adjustable speed drive) testing described in the paper illustrates the importance of including multi-phase dips when considering the behaviour of some types of three-phase equipment. One noticeable result (see Figure 32) is a large difference in the minimum DC-bus voltage as a result of dip characteristics (this voltage is mainly determined by the highest phase-to-phase voltage).
been investigated within the framework of the European research project DISPOWER, which addresses the technical challenges resulting from the increasing penetration of distributed generation into power networks.

Paper S2III-359 (AT) describes tests conducted on a set of domestic PV products. Large differences have been observed between PV inverters but they are in general very sensitive to voltage dips. They should have a better ride-through capability, within the limits required for the anti-islanding protection. Designing improved PV inverters seems to be possible with modest effort. For example, Figure 35 shows the behaviour of a PV module with fast MPP (Maximum Power Point) tracker.

![Figure 35: Example of behaviour of an inverter with fast MPPT recovery (dip: 60 % - 40 ms) (Upper: AC waveforms / Lower: DC waveforms)](image)

On Figure 36, the pre-event operation point (next to the MPP) and the post-event operation point are shown on the PV generator characteristic (I-V and P-V curves). The operation point is severely affected by the voltage dip (power reduction of about 50%), but since the MPP tracker is fast, the inverter recovers rapidly the pre-sag power.

![Figure 36: Fast MPPT recovery (dip: 60 % - 40 ms) Pre- and post event operation points on the I-V characteristic](image)

Simulations reported in paper S4-498 (SI) also show stable operation for voltage dips to around 0.6 pu.

**Question 10**

Are the actual immunity testing standards well understood and applied? Are the suggested testing methods, disturbances levels and performance criteria well defined and realistic enough for industrial purpose?

**Voltage dip mitigation techniques**

Paper S2III-099 (MY) shows the results of a study aiming at using a STATCOM (static synchronous compensator) for voltage dip mitigation. Results from simulation and laboratory tests are shown for almost balanced voltage dip conditions, due to motor starting (5 kW motor): the voltage dip was reduced from 28% to 18%, which means a reduction of the voltage drop by about 10%. It is deduced that the STATCOM may significantly reduce the number of trippings for sensitive equipment.

**Electrical energy storage** is likely to have more and more applications in distribution systems. Battery Energy Storage Systems (BESS) are mostly used for e.g. transmission and distribution facility investment deferment, voltage regulation, load levelling and integration within renewable energy generation plants.

Paper S2III-210 (JP, MY) describes the use of Advanced Sodium Sulphur (NaS) Batteries, which enable load levelling and PQ improvement. Various applications are described together with case studies of potential benefits to utility and customers. Typical specifications for a Hi-Tech Industry are given in Table 1. Standby mode is preferable to UPS mode, to avoid energy losses. High-speed event detection and high-speed transfer switch are then required to ensure that the load will not be affected by voltage dips.

<table>
<thead>
<tr>
<th>Load Levelling</th>
<th>Rated Output</th>
<th>10% of peak demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of Rated Output</td>
<td>3.6 hours (200% 50%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Power Quality</th>
<th>Pulse Power Output</th>
<th>5 times rated output (half of demand secured)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of Pulse Power</td>
<td>30 seconds in one hour</td>
<td></td>
</tr>
</tbody>
</table>

Using compensating equipment within a factory or in the distribution system itself is sometimes debated. Paper S5-593 (IR) reports on studies for optimal size and placement of DVRs (dynamic voltage restorers) in distribution systems.

One of the possible actions at the distribution network level is the Improvement of the protections. Paper S3-649 (AR) stresses that it is difficult to influence voltage sag depths but that overcurrent protection settings may be optimised in order to increase the number of dips situated above the well-known CBEMA or ITIC curves (Figure 37).

Paper R2III-050 (IT) presents the Fault Decoupling Device (FDD) as a new possible means to mitigate voltage dips. The FDD general architecture is shown in Figure 38.
The principle of operation of the device is based on the parallel resonance. A three-phase capacitor bank is installed at the secondary of the MV/LV transformer, while a three-phase inductor is placed at the beginning of each LV feeder. The series connected inductors and the capacitors are designed in order to realize parallel resonance at power frequency. Under normal conditions, the FDD does not affect the load operation (inductors are short-circuited while the capacitor is off). If a short-circuit occurs on a feeder, the control will insert the inductors (of the relevant feeder) and the capacitors, so that the faulted phases are seen from the busbar as infinite impedances (Figure 39 shows simulation results in case of a single-phase fault).

The FDD also reduces fault currents (interesting to mitigate the increase in fault levels due to a growing concentration of distributed generators in distribution networks).

**Question 11**
11.1 Are mitigation systems available for very high power levels? Are they economically justified? What are the future trends in this matter?
11.2 Are there any recent industrial experiences with modern compensating devices such as DVR (Dynamic Voltage Restorer) or Fast Static Switches?

### IV POWER QUALITY IN THE COMPETITIVE MARKET

It is necessary to find the optimal balance between cost effectiveness and quality of supply for network planning and operation in liberalised markets. On the other hand, costs associated with “non-quality” (incorporating possible mitigation techniques) are an issue for electricity consumers. The role of regulating authorities is important in the search for economic equilibrium and equity - regarding Power Quality - between the various players.

**Power Quality indices**

System operators are requested to report on power system performance towards external parties, such as users and regulators. Some PQ indices have already been defined in standards, others are still missing. The joint working group (JWG) CIGRE-CIRED C4.07 has collected available measurement data and existing indices for MV, HV and EHV systems, and recommends a set of internationally relevant PQ indices and objectives, as presented in paper S2IV-131 (BE, CA). The paper also sends a message to equipment manufacturers to provide monitoring equipment able to measure the recommended indices and to implement the flagging concept, as introduced in IEC 61000-4-30. A common set of PQ indices should allow different system operators to measure and report quality in a consistent and harmonised manner.

For steady state disturbances, such as harmonics, flicker and unbalance, two categories of indices can be distinguished according to their use:

- Indices for **planning levels**: internal quality objectives (the "cake" to be shared between disturbing installations);
- Indices for **voltage characteristics**: external reporting on system performance.

In reporting voltage characteristics, two levels of indices can also be distinguished: Site indices and System indices (performance of a whole system or subsystem).

For voltage dips, the recommended parameters are the remaining voltage and the duration. Time aggregation is recommended to prevent double counting of close successive events. However, the JWG does not recommend real quality indices (like SARFI or other ones). The lack of international agreement on such indices for one of the most important PQ phenomena is the reason why the Round Table on "Voltage Dips Indices & Benchmarking" is organized (Tuesday 7 June, 09:00-12:30).

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

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

Paper S2IV-362 (AR) emphasises that the AIF (=SAIFI) and AIT (=SAIDI=CML) indices are widely employed, but that, at MV and LV levels, they often rely on the number of interrupted customers. The time of occurrence and the energy not supplied (ENS) are ignored. All the customers have the same weight in the calculation, regardless of the tariff, billed energy, and voltage supply level. Would it not be better to rely on ENS (as is generally done at HV level) and establish links with the commercial system?

In Finland, the Energy Market Authority asks for eight continuity indices: number and duration of unexpected and planned interruptions (weighted with the annual energy of affected secondary substations), number of high-speed and delayed auto-reclosures (weighted in the same way) and annual number of unexpected interruptions in low voltage and medium voltage networks. The new guidelines, commented in paper S2IV-049 (FI), classify interruptions according to Figure 40.

Figure 40: Interruption classification proposal, according to the Finnish Energy Market Authority (AR = auto-reclosure)

Figure 41 shows the detailed classification of the new interruption statistics. Compared to the old ones, some new items due to network design development have been introduced (e.g. covered overhead line, air cable, etc. in column "location"). The biggest changes have been made to the handling of interruption sectors and the row-based data collection:

\[
\begin{align*}
\text{AIT} &= \frac{\sum \text{ENS}}{\text{YAP} \cdot 8760 \cdot 60} \quad \text{(h/cust./year)} = \frac{\sum \text{ENS}}{\text{YEC} \cdot 10^6} \quad \text{(min/cust./year)} \\
\text{AID} &= \frac{\sum \text{PNS}}{\sum \text{PNS}} \quad \text{min/interruption} \quad \text{(AID = CAIDI)}
\end{align*}
\]

where
- ENS = Energy Not Supplied for each interruption (interrupted power x duration) (MWh)
- \(\sum\text{ENS}\) = sum of all ENS for the last 12 months (MWh)
- YAP = Yearly Average Power consumption in the system (MW)
- YEC = Yearly Energy Consumption in the system (TWh).
- \(\sum\text{T} \cdot \text{PNS}\) = \(\sum\text{ENS}\) = \(\sum\text{ENS}\)
- AID = \(\frac{\sum\text{PNS}}{\sum\text{PNS}}\) = \(\sum\text{ENS}\) = \(\sum\text{ENS}\) (AID = CAIDI)

\[
\begin{align*}
\text{AIT} &= \frac{\text{short interruption}}{\text{long interruption}} \\
\text{AIF} &= \frac{\text{planned interruption}}{\text{planned interruption}} \quad \text{(AIF = SAIFI)}
\end{align*}
\]

CIRED 2005

Session 2 - Power Quality & EMC
due to different repairing times, different durations within one interruption form the interruption sectors; each one is represented as one row in the database. One of the advantages is the possibility to filter certain events out from the statistics (e.g. an exceptional storm that hits a small area).

Paper S2IV-040 (IT) gives the results of a detailed study carried out for assessing the probabilistic representation of time to failure and restoration times for a large urban MV distribution system. Various goodness-of-fit statistical tests have been carried out by using data related to the faults occurred during three years. The most suitable probability distributions identified are used to calculate local and global reliability indices.

A new Power Quality Directive was put into force on January 1st 2005, in Norway, paper S2IV-335 (NO). The proposal includes new requirements for PQ documentation, PQ information and PQ service as well as new limits for certain voltage quality phenomena. The phenomena dealt with are mainly the same as defined in EN 50160. However, the proposal intends to go further than EN 50160 on some phenomena. The major differences are:

- 100% values instead of 95% values,
- 1 minute averages for rms voltage variations instead of 10-minute,
- Plt limits in addition to Plt limits (see Figure 42: \( P_{lt} \) values may remain smaller than 1.0 while \( P_{st} \) ones largely exceed 1.0, leading to complaints),
- a stricter limit for voltage steps occurring very often,
- 5% limit for THD as a week average,
- limits for higher order harmonics,
- introducing some limits for HV and EHV.

Paper S2III-388 proposes the "CARCI" index for voltage dips (see "Voltage dip assessment" in Block III).

The likely increase of voltage variations with an increasing penetration of distributed energy resources may be a reason for introducing additional voltage-variation indices covering the range in time scales between the "very short" (3 s) and the "short" (10 min) standard time intervals. Paper S2IV-287 (DE, SE) introduces the very-short-variation index to quantify the difference between the 3-s and the 10-min rms values of the voltage:

- after every "very-short" (3-s) interval, the difference \( \Delta U_{vs} \) is calculated between the 3-s rms and the 10-min rms voltages (the 10-min rms being updated each time),
- after every "short" (10-min) interval, the "very-short-variation index" \( \Delta U_{vb} \) is obtained as the rms value of all \( \Delta U_{vs} \) values in the interval (see e.g. Figure 43).

As a consequence, a voltage measurement would result in three indices over each 10-min interval:

- the short-time (10-min) flicker severity \( P_{st} \),
- the 10-min VSV index \( \Delta U_{vb} \),
- the short-time (10-min) rms voltage \( U_{vb} \).

Paper S2IV-335 (NO) gives the results of a detailed study carried out for assessing the probabilistic representation of time to failure and restoration times for a large urban MV distribution system. Various goodness-of-fit statistical tests have been carried out by using data related to the faults occurred during three years. The most suitable probability distributions identified are used to calculate local and global reliability indices.
It is further proposed to use a 1-min rms voltage, which would give a better insight in the performance of the voltage control than the 10-min values (see Figure 44).

Figure 44: 3-s (top), 1-min (centre) and 10-min rms voltage values (LV)

**Question 12**

12.1 Are the compatibility levels (as actually defined by IEC standards) adequate or do they need to be revised?

12.2 Are the voltage characteristics as defined in the European standard EN 50160 satisfying or is there a need to go further?

12.3 What are the actual practices in order to collect reliability data and compute reliability indices?

12.4 Is there a need to define more sophisticated indices (compared with the classical AIT, AIF, AID etc.) for assessing reliability? What should be those indices?

12.5 What about quality indices related to voltage dips and short interruptions?

12.6 Is the "very-short variation index" proposed in paper S2IV-287 necessary? In other words, is the flicker severity index not sufficient to qualify the quality regarding small rapid voltage changes?

**Costs associated with Power Quality**

**Interruptions** remain the first phenomenon for which cost evaluations are being performed. Some general evaluations may be found, see for example Table 2 (S5-250 GB, ZA) and Table 3 (S5-014 CH).

According to a Dutch utility (S5-185 NL), the average cost = total costs paid to recover from failures, divided by the total number of failures (from statistics and verbal information). In 2002: (€ 2.2 Million) / (201 failures) = € 11.000 per failure. This € 2.2 Million comprised € 1.4 Million of time depending costs and € 0.8 Million of fixed costs (e.g. component costs).

More specifically, outage costs are often related to the energy not supplied (ENS), as presented for example in Figure 45 for different countries (S6-489 SE) or in Table 4 for different customer groups (S6-336 FI, NO, SE).

**Table 3**: estimated interruption costs per customer and branches and total costs per supply area (1 EUR = 1.5 CHF)

<table>
<thead>
<tr>
<th>Customer category</th>
<th>Residential</th>
<th>Industrial</th>
<th>Commercial</th>
<th>Other</th>
<th>Total costs per year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Subsidy</td>
<td>Non-subsidy</td>
<td>Subsidy</td>
<td>Non-subsidy</td>
<td>Subsidy</td>
</tr>
<tr>
<td></td>
<td>EUR/kWh</td>
<td>EUR/kWh</td>
<td>EUR/kWh</td>
<td>EUR/kWh</td>
<td>EUR/kWh</td>
</tr>
<tr>
<td>Residential</td>
<td>0.068</td>
<td>0.06</td>
<td>0.014</td>
<td>0.03</td>
<td>0.014</td>
</tr>
<tr>
<td>Agricultural</td>
<td>0.54</td>
<td>0.5</td>
<td>0.18</td>
<td>0.26</td>
<td>0.18</td>
</tr>
<tr>
<td>Industrial</td>
<td>2.6</td>
<td>2.7</td>
<td>0.89</td>
<td>1.1</td>
<td>0.89</td>
</tr>
<tr>
<td>Public</td>
<td>0.65</td>
<td>0.4</td>
<td>0.23</td>
<td>1.5</td>
<td>0.23</td>
</tr>
<tr>
<td>Service</td>
<td>1.9</td>
<td>1.1</td>
<td>0.94</td>
<td>2.9</td>
<td>0.94</td>
</tr>
</tbody>
</table>

According to a Dutch utility (S5-185 NL), the average cost = total costs paid to recover from failures, divided by the total number of failures (from statistics and verbal information). In 2002: (€ 2.2 Million) / (201 failures) = € 11.000 per failure. This € 2.2 Million comprised € 1.4 Million of time depending costs and € 0.8 Million of fixed costs (e.g. component costs).

More specifically, outage costs are often related to the energy not supplied (ENS), as presented for example in Figure 45 for different countries (S6-489 SE) or in Table 4 for different customer groups (S6-336 FI, NO, SE).

**Table 4**: interruptions costs per customer groups (NO)

<table>
<thead>
<tr>
<th>Customer group</th>
<th>Notified customers (kWh)</th>
<th>Not. notified customers (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial</td>
<td>7.61</td>
<td>8.05</td>
</tr>
<tr>
<td>Trade and service</td>
<td>8.20</td>
<td>12.87</td>
</tr>
<tr>
<td>Agricultural</td>
<td>1.22</td>
<td>1.83</td>
</tr>
<tr>
<td>Residential</td>
<td>0.98</td>
<td>1.59</td>
</tr>
<tr>
<td>Public sector</td>
<td>1.22</td>
<td>1.59</td>
</tr>
<tr>
<td>Wood processing and energy intensive industries</td>
<td>1.34</td>
<td>1.59</td>
</tr>
</tbody>
</table>

According to a Dutch utility (S5-185 NL), the average cost = total costs paid to recover from failures, divided by the total number of failures (from statistics and verbal information). In 2002: (€ 2.2 Million) / (201 failures) = € 11.000 per failure. This € 2.2 Million comprised € 1.4 Million of time depending costs and € 0.8 Million of fixed costs (e.g. component costs).

More specifically, outage costs are often related to the energy not supplied (ENS), as presented for example in Figure 45 for different countries (S6-489 SE) or in Table 4 for different customer groups (S6-336 FI, NO, SE).

Unit costs have been defined in Finland by the Regulator (S2IV-304 FI) according to outage types and customer groups, as shown in Table 5.

**Table 5**: unit outage costs for customer groups in Finland (AR = auto-reclosing = short interruptions)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>0.068</td>
<td>0.014</td>
<td>0.03</td>
<td>0.014</td>
</tr>
<tr>
<td>Agricultural</td>
<td>0.54</td>
<td>0.23</td>
<td>1.5</td>
<td>0.73</td>
</tr>
<tr>
<td>Industry</td>
<td>2.6</td>
<td>1.1</td>
<td>1.9</td>
<td>2.1</td>
</tr>
<tr>
<td>Public</td>
<td>0.65</td>
<td>1.5</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Service</td>
<td>1.9</td>
<td>0.95</td>
<td>1.1</td>
<td>2.1</td>
</tr>
</tbody>
</table>
Outage costs may be further differentiated according to the duration of the interruptions. Paper S5-250 (GB, ZA) reports on sector customer damage functions (SCDFs): annuitised costs of standby plants as well as costs of loss of business, normalised by annual energy consumption, are plotted against corresponding average interruption duration for business customers (Figure 46) and for large users (Figure 47).

Paper S6-300 (IT) presents the results of a large survey where three estimates were considered to assess the cost of an interruption: 1) direct costs, 2) WTP = willingness to pay = the price which the consumer would be willing to pay to another company ready to take over with a reserve service, 3) WTA = willingness to accept = the discount that would be considered satisfactory after an interruption. Figure 48 shows direct costs vs interruption duration for several types of customers.

Direct costs, WTA and WTP were then normalized on ENS, giving Table 6, Table 7 and Table 8.

Table 6 : direct costs, €/kWh (3 min: €/kW)

<table>
<thead>
<tr>
<th></th>
<th>Households</th>
<th>Business</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 minutes</td>
<td>8.02</td>
<td>55.16</td>
</tr>
<tr>
<td>1 hour</td>
<td>25.34</td>
<td>117.98</td>
</tr>
<tr>
<td>2 hours</td>
<td>20.41</td>
<td>87.79</td>
</tr>
<tr>
<td>4 hours</td>
<td>15.73</td>
<td>67.18</td>
</tr>
<tr>
<td>8 hours</td>
<td>9.08</td>
<td>40.01</td>
</tr>
</tbody>
</table>

Table 7 : WTA & WTP, €/kWh (3 min: €/kW) - Households

<table>
<thead>
<tr>
<th></th>
<th>WTA</th>
<th>WTP</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 minutes</td>
<td>5.55</td>
<td>1.38</td>
</tr>
<tr>
<td>1 hour</td>
<td>12.03</td>
<td>5.75</td>
</tr>
<tr>
<td>2 hours</td>
<td>13.92</td>
<td>2.68</td>
</tr>
<tr>
<td>4 hours</td>
<td>11.24</td>
<td>2.25</td>
</tr>
<tr>
<td>8 hours</td>
<td>6.89</td>
<td>1.36</td>
</tr>
</tbody>
</table>

Table 8 : WTA & WTP, €/kWh (3 min: €/kW) - Business

<table>
<thead>
<tr>
<th></th>
<th>WTA</th>
<th>WTP</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 minutes</td>
<td>34.16</td>
<td>4.80</td>
</tr>
<tr>
<td>1 hour</td>
<td>79.75</td>
<td>10.70</td>
</tr>
<tr>
<td>2 hours</td>
<td>57.89</td>
<td>7.75</td>
</tr>
<tr>
<td>4 hours</td>
<td>48.12</td>
<td>6.63</td>
</tr>
<tr>
<td>8 hours</td>
<td>28.99</td>
<td>3.98</td>
</tr>
</tbody>
</table>

The choice of incentive rates by the Italian Regulator has been based on this study. Compared with the Norwegian values, the Italian ones seem very high (Table 9). It is explained by the fact that electricity consumption is much lower in Italy.

Table 9 : Incentive rates set by regulators in Norway and Italy

<table>
<thead>
<tr>
<th>Customer</th>
<th>Sector</th>
<th>NORWAY (NVE, survey 2001-02, Postal interviews)</th>
<th>ITALY (AEEG, survey 2003, face to face interviews)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household</td>
<td>Residential</td>
<td>1.0</td>
<td>10.8</td>
</tr>
<tr>
<td>Business</td>
<td>Industrial</td>
<td>8.5</td>
<td>21.6</td>
</tr>
<tr>
<td>Other</td>
<td>Trade &amp; services</td>
<td>12.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Agricultural</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Public services</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Large industry</td>
<td>1.7</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

However, outage costs are not the only important data. Figure 49 - which comes from the CIRED 1997 S2 Special Report - shows that the ultimate goal is the socio-economic optimum.

Figure 49 : Assessment of the network quality target by minimising the combined national costs

Figure 50 (S5-602 DE) shows the influence of the load density on the interruption frequency AIF (=SAIFI=CI). Figure 51 further shows that:
- correlations costs/reliability are highly non-linear,
- using automation technology is much more cost effective for lowering AIT than changing the network structure,
- the related benefit is higher in less densely loaded areas.

Figure 50: influence of load density on AIF

Figure 51: comparison of the impact of network structure and automation technology on AIT (=SAIDI=CML), depending on load density (sc)

Paper S6-216 (IT) defines an index giving an average cost per customer and per minute reduction of AIT (=SAIDI) : \[ \text{Index} = \frac{1}{\Delta Q \cdot N_c} \ (\text{€/min/customer}) \]
where
- \( I \) = amount of 4-year investment for better PQ in the area,
- \( \Delta Q \) = reduction of AIT from 1999 to 2003,
- \( N_c \) = number of customers in the area.

Figure 52, Figure 53 and Figure 54 give the results for respectively high- (urban area), medium- (semi-urban area) and low load concentration (rural area).

Figure 52: 4-year cost improv. AIT - high load concentration

Figure 53: 4-year cost improv. AIT - med. load concentration

In addition to interruptions, voltage dips are more and more perceived as an economic problem requiring cost evaluations. Paper S2IV-356 (IT) presents the results of a 2004 survey with industrial consumers. In order to get comparable results, PQ costs have been normalized using the user’s contractual power, giving the so called global specific annual cost (GSC). Outages cause a GSC of almost 14 €/kW, while dips cause a little more than 6 €/kW.

It is not obvious from the paper whether "short interruptions" (duration < 3 min) are classified in the "outage" or the "dip" category. It is nevertheless interesting to compare these findings with the Norwegian total annual costs of Table 10 (S2IV-335 NO), where it appears that long interruptions contribute to approx. 50 % of total costs related to interruptions and dips.

In addition to interruptions, voltage dips are more and more perceived as an economic problem requiring cost evaluations. Paper S2IV-356 (IT) presents the results of a 2004 survey with industrial consumers. In order to get comparable results, PQ costs have been normalized using the user’s contractual power, giving the so called global specific annual cost (GSC). Outages cause a GSC of almost 14 €/kW, while dips cause a little more than 6 €/kW.

It is not obvious from the paper whether "short interruptions" (duration < 3 min) are classified in the "outage" or the "dip" category. It is nevertheless interesting to compare these findings with the Norwegian total annual costs of Table 10 (S2IV-335 NO), where it appears that long interruptions contribute to approx. 50 % of total costs related to interruptions and dips.

Table 10: total annual customers' costs in Norway (1 EUR = approx. 8 NOK)

| Long interruptions (< 3 min) | ~50 MNOK/year |
| Short interruptions (≥ 3 min) | ~600 MNOK/year |
| Voltage dips | ~170-330 MNOK/year |
| Total | ~1 600-1 800 MNOK/year |

Paper S2IV-289 (BE) focuses on a specific techno-economic question: it shows how to take into account both energy efficiency and PQ aspects when considering to install an adjustable speed drive (ASD). Considering a typical annual number of trips due to voltage dips (in the range 0-10), it can be concluded that dips have to be considered if process outage costs exceed 5% of the annual savings due to energy efficiency. Process outages due to 3ph dips on the one hand or due to 1- and 2ph dips on the other hand have to be considered separately, as demonstrated above (Block III, "Voltage dip immunity").

Harmonics. Paper S2IV-717 (EG) presents Benefit/Cost (B/C) ratio analysis for harmonic problems. Results are given for ten case studies, see Table 1.

Table 11

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Active filter</th>
<th>K-rated</th>
<th>D-filt.</th>
<th>Tuned filter</th>
<th>Power capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.186</td>
<td>-</td>
<td>0.99</td>
<td>0.21</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>0.122</td>
<td>-</td>
<td>0.95</td>
<td>0.29</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>-</td>
<td>0.76</td>
<td>0.58</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>-</td>
<td>0.57</td>
<td>0.32</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>0.132</td>
<td>-</td>
<td>0.65</td>
<td>0.249</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>0.312</td>
<td>0.042</td>
<td>1.5</td>
<td>0.103</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>-</td>
<td>-</td>
<td>0.21</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.54</td>
</tr>
<tr>
<td>9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.571</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.364</td>
</tr>
</tbody>
</table>
**Question 13**

13.1 Do we have significant figures to quantify the costs associated with “non-quality” in industrial cases?

13.2 Is there a consensus on the way to define and assess these costs? (In particular, is it pertinent to normalize them with respect to the contractual power of the users?)

13.3 How is it possible to include these economic parameters in quality indices and, further, in quality contracts?

**Improving Power Quality**

PQ improvements have two mains aspects:

- Considering steady-state phenomena, PQ is generally much more related to emission limits for disturbing installations than to network quality (except some particular cases, like resonance phenomena);
- Considering events, PQ is generally much more related to network quality than to disturbing installations (except some particular cases, like capacitor, transformer or motor switchings).

Several papers (P2IV-077 RO, S5-185 NL, S5-602 DE, S6-216 IT, S6-532 FR, S6-634 AR, S6-636 AR, S6-720 EG) describe recent network improvements as implemented by system operators, sometimes as a result of regulation incentives.

Paper P2IV-077 (RO) focuses on strategies and policies for medium and long term (including education and training of company employees).

Cost-benefit analyses are reported in several papers (S5-185 NL, S6-216 IT, S6-634 AR, S6-636 AR, S6-720 EG). As a result, for example, the authors of S5-185 (NL) prioritized the following actions:

- for AID (=CAIDI) reduction:
  - install GPS in each repair crew vehicle,
  - review protection philosophy and procedures,
  - readjust protection relay settings,
  - earth the isolated neutral system;
- for AIF (=SAIFI=CI) reduction:
  - pro-active cable joint replacement strategy,
  - procedures for cables & joints handling at excavation sites.

Other actions are pointed out in paper S6-216 (IT):

- for AID (=CAIDI) reduction:
  - remote control of switchgears in MV/LV substations;
- for AIF (=SAIFI=CI) reduction:
  - new planning criteria for maintenance interventions, based on actual AIF values,
  - new HV/MV substations to reduce the average length of MV lines,
  - replacement of MV insulators,
  - replacement of MV bare conductors by insulated ones,
  - wide installation of Petersen coils.

Paper S5-602 (DE) shows that, in view to reduce the AIT (=SAIDI=CML), the use of automation technology with influence on the restoration time AID (=CAIDI) is much more efficient than a more complex network structure affecting the interruption frequency AIF (=SAIFI=CI).

Examples are given of possible improvement results:

- in Italy (S6-216 IT), from 1999 to 2003:
  - AIT (=SAIDI=CML) : from 153.8 to 72.1 min/cust./year,
  - AIF (=SAIFI=CI) : from 3.49 to 2.26 int./cust./year,
  - AID (=CAIDI) : from 43.2 to 32.1 min/int. ;
- in France (S6-532 FR), from 1996 to 2002:
  - AIT : from 65 to 45.6 min/cust./year,
  - AIF : from 1.55 to 1.15 int./cust./year (values are also given for short interruptions 1s<t<3min : from 3.90 to 2.00, and for very short interruptions <1s : from 6.00 to 3.73).

**Regulatory aspects & market considerations**

Regulators play an increasing role in ensuring that society gets the optimum quality of supply level. Like in 2001 and 2003, representatives of the CEER (Council of European Energy Regulators) will take part in a Round Table at CIRED 2005 (on Tuesday afternoon).

There are still big differences between different countries. The concepts of guaranteed standards of performance (which relate to individual service delivery and carry a penalty payment) and overall standards (which govern overall target performance for a service item, frequently including quality incentives) are of growing use.

In France, work undertaken in 2000 to define the minimum criteria for HV quality of electricity was interrupted at the regulatory consultation stage due to strong opposition arising in 2001 (S6-532 FR). Since then, several major players demonstrated their desire to see regulatory bases concerning the quality, but a preliminary in-depth technical evaluation is considered desirable.

Following paper P2IV-015 (KE) there is a need to investigate whether utilities measurements are in agreement with customers’ needs and perspective. The findings reveal a significant gap between the conventional measurements and the “Customers perception of service quality”.
In the Czech Republic (S5-086 CZ), the annual amount of payment of a distribution company was studied in case of guaranteed standard involving the payment of 33 € per supply point if a limit is exceeded. The limit may be expressed as the maximum number of interruptions per year Ln (=AIF) or their maximum cumulated duration Lt (=AIT=SAID=CML). Figure 55 shows that:
- if the limit on AIT is strict (15-90 min/cust./year), the limit on AIF has practically no influence,
- if the limit on AIT is not strict, the limit on AIF becomes dominant,
- strict limits on AIT and AIF represent a risk of great financial losses for the distribution company (several hundreds of thousands or even millions €).

Papers S2IV-304 and P2IV-443 (FI) describe the Finnish example. During the first 3-year regulation period (2005-2007), PQ has no impact on tariffs but reference data are being collected in view to their use for the second 3-year period. Different regulation models are still under consideration. Making use of unit outage costs as given in Table 5, it is possible to assess one annual outage cost for every company, see e.g. Table 12. Power quality is then measured as outage costs, which may be added to operational costs, as showed in Figure 56.

In Sweden, it is intended to introduce a "quality function" in the regulation of network tariffs (S6-489 SE). Initially, only power cuts will be handled but, in the longer term, other aspects of delivery quality may be added. The design of the model presently focuses on the charge level, whereas marginal significance is assigned to the quality issue. Such a model would be reasonable if Sweden had high network charges and good quality compared to other countries. Various comparisons have shown that the opposite is true: Figure 57 shows that the quality is lower in the Nordic countries than in Central Europe and the UK. Figure 45, on the other hand, shows that interruption costs are higher in the Nordic countries. It has also been found that network charges are relatively low in those countries. It is therefore fundamentally wrong to have a regulatory model in Sweden that gives priority to low network charges in relation to improved quality.

Direct compensation may become effective in Norway, on 1st January 2007, for all customers affected by sustained fault interruptions in HV and MV networks (S6-464 FI). But several alternatives are still under consideration (e.g. including momentary interruptions and/or LV networks).

In South Africa, interruption limits are specified in a national standard (S5-250 GB, ZA), see e.g. Table 13. Comparing the resulting quality with statistics from OECD countries (Figure 58), the present limits are considered "not unreasonable", but tighter limits may be appropriate in the future, particularly for the provinces with highest load densities.

In Hungary, a supply quality regulation was introduced in 2003 (S6-497 HU). The penalties/incentives system is based on system indices. Besides two classical "continuity
of supply" indices - AIT (=SAIDI=CML) and AIF (=SAIFI =CI) - there is a "network security" index called "outage rate" (OR) which is defined as the ratio of non-supplied power to the available power. The three indices are specific to each distribution company, based on past 3-year averages. The penalty/incentive mechanism is as follows:

- the regulated tariff will be decreased
- by 1% if the performance is worse by 10% than the standard for one of the 3 indices (i.e. 3% lowering of the tariff if the performance is bad for the 3 indices),
- by 0.5% if the performance is worse by >5% & <10% ;
- on the contrary, the profit limit will be increased by 10% if any of the performances is better by 10% and none is worse.

Paper S2IV-152 (IT) analyses the regulation scheme applied in Italy during the period 2000-2003 and the modified scheme proposed for the next regulatory period (2004-2007).

AIT (=CML=SAIDI) regulation is generally perceived as fair as it recognizes the differences in historical and operating conditions through differentiation of improvement targets. Furthermore, applying a symmetric incentive scheme – i.e. not only penalties for under-performance but also rewards for over-performance - strengthens the acceptance of the system.

The AIT regulatory scheme is confirmed for the second regulatory period, with the addition of guaranteed continuity standards (referring to the maximum yearly number of long unplanned interruptions for HV and MV consumers), together with related penalties (see Table 14 and Table 15).

Paper S2IV-658 (CN) explains how a Power Quality Market (PQM) could assure a global socio-economic optimum. The PQM system consists of four components: ER charging and trading market (electromagnetic pollution emission rights), PQ-service market, PQ technology & information market, PQSD (PQ Supervision Department, i.e. the Regulatory Authority).

According to paper S6-695 (CN), quality insurance based electricity pricing is more effective than conventional regulation to improve both investment efficiency and risk allocation. At a given location, the basic (existing) quality may be described by steady- and transient-state indices, see for example Table 16, where:

- MUR = Maximal Unqualified Rate (% of time that a specified level is exceeded each day for a steady-state phenomenon),
- MVT = Maximal Violation Times (number of times per day that an event exceeds a specified level).

With the quality insurance system, the customer will pay a higher tariff according to his needs for better MUR and MVT (if he still receives the basic quality, the compensations paid by the utility will exactly compensate for the higher tariff).

Regarding PQ contracts, the Italian Regulatory Authority only established a few general rules:

- the parties must define the agreed standard of quality, the premium price to be paid by the customer and the penalty to be paid by the DNO in the event of non-compliance, specifying cases of exclusion;
- the quality standard shall be expressed as a threshold applied to one or more indicators of voltage continuity or quality. With reference to the indicators for which there is no measurement obligation, the parties shall arrange for measurement during a period of at least one year prior to the stipulation of the PQ contract.

Table 14 : Guaranteed continuity standards for maximum number of long interruption per year

<table>
<thead>
<tr>
<th>Customers</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>HV customers, meshed connection</td>
<td>1 long inter/year</td>
</tr>
<tr>
<td>HV customers, new radial connection</td>
<td>2 long inter/year</td>
</tr>
<tr>
<td>MV customers, high density districts</td>
<td>3 long inter/year</td>
</tr>
<tr>
<td>MV customers, medium density districts</td>
<td>4 long inter/year</td>
</tr>
<tr>
<td>MV customers, low density districts</td>
<td>5 long inter/year</td>
</tr>
</tbody>
</table>

Table 15 : Unitary penalty in case of mismatching guaranteed continuity standards for max. number of long interruption per year

<table>
<thead>
<tr>
<th>Customers</th>
<th>$V_a [\text{kW}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HV customers</td>
<td>1</td>
</tr>
<tr>
<td>MV customers, interrupted power up to 500 kW</td>
<td>2.5</td>
</tr>
<tr>
<td>MV customers, interrupted power beyond 500 kW</td>
<td>2</td>
</tr>
</tbody>
</table>

Question 14

14.1 Are there possibilities to include the “customer perceived quality” in a regulatory scheme? Are there any experiences in that field?

14.2 Referring to Paper S6-695, are there examples of quality contracts between utilities and industrial customers? Is it to be considered as an alternative or complement to regulatory incentives?

LIST OF PAPERS

N.B. Papers keep the reference numbers which were attributed to them when abstracts were received before the selection process. They are grouped in several categories:

- S2 = Plenary Session S2
- P2 = Poster Session S2
- R2 = Research & Innovation Forum S2.

Within each category, they are further grouped in four blocks:

- I = EMI, EMF and Safety
- II = Connection of disturbing installations
- III = Voltage dips and other disturbances on the grid
- IV = Power Quality in the competitive market.

Finally, PQ&EMC related papers presented in other sessions (S3, S4, S5, S6) are listed also.
Plenary Session 2

S2I-055 Comparative Analysis of Grounding Systems Formed by Feeders in One Case with Uninsulated and in the Other Case with Insulated Metallic Sheaths
Ljubivoje M. POPOVIC, JP Elektrodistribucija – Beograd (Serbia and Montenegro)

S2I-091 Magnetic Field Mitigation Above a Double Trefoil HV Underground Power Line
Mauro ZUCCA, Istituto Elettrotecnico Nazionale Galileo Ferraris di Torino (IEN), Paolo RIBALDONE, AEM Trasporto Energia, Torino (Italy)

S2I-128 Estimation of the surge arrester outage rate caused by lightning overvoltages
SAVIC Milan, Faculty of Electrical Engineering, Belgrade (Serbia&Montenegro)

S2I-166 Earth Potential Rise Influence near HV Substations in Rural Areas
Yves Rajotte, Hydro-Québec IREQ, Jean De Sève, Jacques Fortin, Hydro-Québec TransEnergie, Richard Lehoux, Hydro-Québec Équipement, Georges Simard, Hydro-Québec Distribution (Canada)

S2I-198 Modelling and live measurements of step and touch voltages at LV customers in urban areas caused by MV faults.
F.T.J. VAN ERP, Nuon Techno, F. PROVOOOST, A.P.J. VAN DEURSEN, P.L.J. HESEN, Eindhoven University of Technology (The Netherlands)

S2I-226 New Concept For The Protection Against Lightning Overvoltages And Touch Voltages
Marco BRIZZI, Bernhard RICHTER, ABB Switzerland (Switzerland)

S2I-334 Performance of Common Grounding System during ground faults
Fabio Massimo GATTA, Stefano LAURIA, Giuseppe PARISE, Donato DEL GROSSO, Università degli Studi di Roma “La Sapienza” (Italy)

S2I-431 Guidelines To Determine And Evaluate Low Frequency Electromagnetic Fields In Working Areas Inside Distributive Power Stations
Rudi VONCINA, Breda CESTNIK, Elektroinstitut Milan Vidmar - Slovenian Power Research Institute (Slovenia)

S2I-458 A study on the use of bare buried conductors in an extended interconnection of earthing systems inside a MV network
Angelo CAMPOCCIA, Gaetano ZIZZO, Università di Palermo (Italy)

S2I-466 Occupational Magnetic Field Exposure In Working Nearby Low Voltage Switchgears
Tommi KEIKKO, Tampere University of Technology, Reino SEESVUORI, Pentti KALLIOMÄKI, Tampere Power Utility, Jouko PIHLAJAMAA, ELKAMO (Finland)

S2I-472 Low Voltage Networks Operational Neutral Interruption Impact Assessment (withdrawn)
Gianfranco CHICCO, Politecnico di Torino (Italy), Petru POSTOLACHE, Cornel TOADER, Universitatea Politehnica din Bucuresti, Mircea SCUTARIU, Electrica Muntenia Sud Distribution and Supply Company (Romania)

S2I-530 Electrical Disturbances in Low Voltage Networks due to Reenergization of Medium Voltage Networks
P. Nunes, A. Morched, G.D. Marques, LABELEC, F. Frazao, A. Sarmento, EDP Distribuição (Portugal)

S2I-657 Novel Technique to Calculate The Effect of Electromagnetic Field of H.V.T.L. on Metallic Pipeline by Using EMTP Program
Ghada M. Amer, Benha Higher Institute of Technology (Egypt)

S2I-052 Disturbances due to Voltage Distortion in the kHz Range ; Experiences and Mitigation Measures
Christian UNGER, Kurt KRUEGER, Martin SONNENSCHEIN, Rainer ZUROWSKI, Siemens (Germany)

S2I-053 The Impact of Rural MV & HV Underground Network Extensions on Harmonic Voltage Distortion
Douglas ELLIS, EDF Energy (UK)

S2I-062 Harmonic Voltage Amplification in a Distribution Network due to Resonance of Transfer Impedance to the EHV Transmission
Dr. Adel HAMMAD, Serge LAEDERACH, Nordostschweizerische Kraftwerke (NOK), Georg KOEPPPL, Koepl Power Experts (Switzerland)

S2I-144 Measurements and evaluations of electrical disturbances on a steel plant using two AC Arc Furnaces
Gianluca POSTIGLIONE, Philippe LADOUX, INPT-ENSEEIHT/CNRS (France), Dirk RIEDINGER, Badische Stahl - Engineering (Germany)

S2I-175 Establishment of Load Composition in Aggregate Harmonic Load Model at LV Buses Based on Field Measurements
M.T. Au, Universiti Tenaga Nasional (Malaysia), J.V. Milanovic, The University of Manchester (UK)

S2I-190 A contribution to solve the problem of attributing harmonic distortion responsibility
Mariano G. IPPOLITO, Giuseppe MORANA, Francesco RUSSO, Università di Palermo (Italy)

S2I-218 An artificial network for emission tests in the frequency range 2-9kHz
R. BERGERON, Hydro-Québec (Canada), W. GAWLIK, Siemens, R. GRETSCH, University of Erlangen-Nuremberg (Germany)

S2I-291 Assessing The Impact Of Increased Air Conditioner Load On Power Quality in Australia
Lianne MOLLER, Duane ROBINSON, Sarah PERERA, Vic GOSBELL, University of Wollongong, Frank BUCCA, Integral Energy, Huntingwood (Australia)

S2I-322 Capacitor Bank Monitoring for Switching Transient Reduction
F.J. PAZOS, J.J. AMANTEGUI, F. FERRANDIS, H. GAGO, E. AZCONA, A. BARONA, Iberdrola (Spain)

S2I-416 Wind farm integration- Power quality management for French distribution network
Coraille NASLIN, Olivier GONBEAU, Jean Luc FRAISSE, EDF Réseau Distribution, Than Chau THAI, EDF R&D (France)

S2I-534 Assessing Complicated Power Quality Issues Offline with IEC 61000-4-30 Compliant Toolbox.
Bernard Dethy, Emmanuel De Jaeger, Michel Dascotte, Laborelec, Philippe Goossens, Elia (Belgium)

S2I-635 Criteria For The Assignment Of Responsibilities For Disturbances Between Utility And Load In Distribution Networks
Pedro E. ISSOURIBEHERE, Gustavo A. BARBERA, IITREE-UNLP (Argentina)

S2I-703 New Concept for Harmonic Filtration in Distribution Networks of Industrial Firms
M.Z. El-Sadek, Assiut University, G. Shabib, High Institute of Energy, M.R. Ghalbah, Upper Egypt Electrical Distribution Company (Egypt)

S2II-099 Application Of Inverter Based Shunt Device For Voltage Sag Mitigation Due To Starting An Induction Motor
A.F. Huweg, S.M. Bashi, N. Mariun, N.F. Mailah, University Putra Malaysia (Malaysia)
S2I1I-105 Phasor Based Voltage Sag Monitoring and Characterization

Roberto C. LEBORGNE, Chalmers University of Technology, Daniel KARLSSON, ABB Automation Technologies (Sweden)

S2I1I-123 Comprehensive solution for using distribution automation equipment in voltage quality monitoring

Sauli ANTILA, Pertti JARVENTAUSTA, Antti MAKINEN, Kimmo KIVIKKO, Tampere University of Technology (Finland)

S2I1I-143 The impacts of underground transients and incipient faults on the quality and reliability of supply in low voltage networks

N.G. VAN LUIJK, EDF Energy (UK)

S2I1I-177 On the Detection and Recording of Voltage Dips and Interruptions

Alexander APOSTOLOV, AREVA T&D Automation (USA)

S2II-210 Application of Battery Energy Storage System with Power Quality Support in Malaysia

Mohd Fadzil MOHD SIAM, Asnawi BUSRAH, TNB Research (Malaysia), Hyogo TAKAMI, Jun HAGIHARA, TEPCO (Japan)

S2II-359 Sensitivity of Photovoltaic Inverters to Voltage Sags - Test Results for a Set of Commercial Products

B. Bletterie, R. Bründlinger, H. Fechner, arsenal research (Austria)

S2II-388 A Customer Oriented Approach To The Classification Of Voltage Dips


S2II-568 Evaluating Voltage Dip Immunity of Industrial Equipment

M. Stephens, M. McGranaghan, EPRI Solutions (USA), M. Bollen, STRI (Sweden)

S2II-647 A Novel Methodology To Locate Originating Points Of Voltage Sags In Electric Power Systems

Juan GOMEZ, Daniel TOURN, Marcos FELICI, National University of Rio Cuarto (Argentina), Medhat MORCOS, Kansas State University (USA)

S2IV-040 Probabilistic representation of the distribution system restoration times

Enrico CARPANETO, Gianfranco CHICCO, Rada PORUMB, Politecnico di Torino, Emiliano ROGGERO, AEM - Azienda Energetica Metropolitana, Torino (Italy)

S2IV-049 Developing of Compilation of Interruption Statistics in Finland to Meet Various New Requirements

Kimmo KIVIKKO, Pertti JARVENTAUSTA, Antti MAKINEN, Tampere University of Technology, Tony EKLUND, Finnish Energy Industries Federation (Finery), Elina LEHTOMAKI, Finnish Electricity Association (Sener), Osmo ALASALMI, Graninge Kainuu, Tero ISOVIITA, Port Energia, Kimmo VAINIOLA, EON Finland (Finland)

S2IV-131 Power quality indices and objectives

Germain BEAULIEU, Hydro-Québec (Canada), Geert BORLOO, Elia (Belgium)

S2IV-152 Continuity Of Electricity Supply Regulation Driven By Economic Incentives: Does It Work? The Italian Experience

Luca LO SCHIAVO, Roberto MALAMAN, Ferruccio VILLA, Autorita per l'energia elettrica e il gas (Italy)

S2IV-287 Quantifying voltage variations on a time scale between 3 seconds and 10 minutes

Math H.J. Bollen, Mats Häger, STRI (Sweden), Christine Schwagerl, Siemens (Germany)

S2IV-289 Installing Variable Speed Drives: Energy Efficiency Profits versus Power Quality Losses

Marcel DIDDEN, Jean-Marie DE HOE, Jean CALLEBAUT, Emmanuel DE JAEGER, Laborelec (Belgium)

S2IV-304 Power Quality Factors in Efficiency Benchmarking

Lassila J., Honkapuro S., Viljainen S., Tahvanainen K., Partanen J., Lappeenranta University of Technology, Kivilkko K., Antila S., Mäkinen A., Järventausta P., Tampere University of Technology (Finland)

S2IV-335 Quality Of Supply Regulation In Norway ; Going Beyond EN 50160

Helge Seljeseth, Kjell Sand, Knut Samdal, SINTEF Energy Research (Norway)

S2IV-356 Surveying supply reliability and voltage quality at Italian customers

Riccardo CHIUME, Stefano MALGAROTTI, Giuseppe SIMIOLI, CESI, Giuseppe ESPOSITO, Dario ZANINELLI, Politecnico of Milano, Alberto PRUDENZI, University of L'Aquila, Stefano QUALA, University of Trieste (Italy)

S2IV-362 A Complementary Approach To The Standard Distribution Continuity Indices (IEEE Std 1366)

Lujun RUIZ DIAZ, Edenor (Argentina)

S2IV-658 Research on Power Quality Market System

Guanghou JIN, Gengyin LI, Ming ZHOU, School of Electrical Engineering, North China Electric Power University (P.R. China)

S2IV-717 The Cost of Harmonic Losses and Mitigations in Distribution Systems

Mohamed Ashour, Kamelia Youssef, Alexandria Electricity Distribution Company, Salah El Sobki, Cairo University (Egypt)

Poster Session 2

P21I-083 A Simplified Method for Magnetic Field Prediction of 110/10kV Indoor Substations at the Design Stage

Chunyan SONG, Guoqi CHEN, Chunjie ZHU, Design Institute of Hangzhou Municipal Electric Power Bureau, Zhengcui FU, Shanghai Jiaotong University (P.R. China)

P21I-620 Earth Fault Trails And Measurements In Rural 20 kV Networks As Basis For Improving The Performance Of These Networks

Stefan Höne, Siemens, Dr. Alexander Montebaur, Hans Joachim Nehkor, Avacon (Germany)

P21I-613 Transients due to Load Energizing in a Low Voltage System

Anna TJADER, Jaap DAALDER, Chalmers University of Technology (Sweden)

P21I-627 EMC Consideration for Control Signal in High Voltage Substations

FARAMARZ FAGHIHI, RONAK PAKZAD, Iran University of Science and Technology, MORVARID SEHATKAR, University of Tehran, FERESHTEH FAGHIHI, Hormozgan University (Iran)

P21I-637 ELF electromagnetic fields and human health

Raul STIVAL, Epe (Argentina)

P21I-648 Experimental Study Of The Transfer Of Overvoltage Surges Through Distribution Transformers

German ZAMANILLO, Juan GOMEZ, Daniel TOURN, Edgardo FLORENA, National University of Rio Cuarto (Argentina)

P21I-716 EM Field Environmental Surveys of DT Stations

Kamelia Youssef, Hanaa Karawia, Alexandria Electricity Distribution Company (Egypt)

P2II-032 A Study Case on Harmonic Distortion Created by Variable Speed Wind Turbines

Stavros PAPATHANASSIOU, Michael PAPADOPOULOS, National Technical University of Athens (Greece)
P2II-051 Measurement campaign and assessment of the Quality Of Supply in RES And DG facilities in Spain
Eugenio PEREA, Eduardo ZABALA, J. Emilio RODRIGUEZ, Asier GIL MURU, Fundacion LAIBEN, Hugo GAGO, Iberdrola Distribucion Electrica (Spain)

P2II-121 Data processing technology in power quality monitoring system in distribution system
XIAO XIAN-YONG, YANG HONG-GENG, HE JIN-DING, Sichuan University School of Electrical Engineering & Information, Chengdu (P.R. China)

P2II-135 System Studies Of Voltage Dips Resulting From Energisation Of MV Wind Turbine Transformers
Ting MA, Power Technology, E.ON UK, Andrew CADMORE, Renewable Energy Systems Group (UK)

P2II-180 Predict the level of harmonic distortion due to dispersed generation
Sjef Cobben, Wil Kling, Eindhoven University of Technology, Sjef Cobben, Continuum, Peter Heskes, ECN, Henk Oldenkamp, OKE-Services (The Netherlands)

P2II-202 The Influence of Wind Turbines on Power Quality in the HV network in Poland
Maciej Mroz, ENION Distribution Company in Cracow (Poland)

P2II-298 Non-characteristic Harmonics and Interharmonics of Power Electronic Converters
Vaclav KUS, Zdenek PEROUTKA, Pavel DRABEK, University of West Bohemia (Czech Republic)

P2II-354 Assessment of Harmonic Distortion Levels in LV Networks with Increasing Penetration Levels of Inverter Connected Embedded Generation
Adam DYSKO, Graeme M. BURT, James R. MCDONALD, University of Strathclyde, Ian B.B. HUNTER, SP PowerSystems (UK)

P2II-369 Influence zones and disturbance levels in LV and MV distribution network in result of supply of industrial welder lines equipped with power conditioner
Jerzy ANDRUSZKIEWICZ, Enea, Jozef LORENC, Krzysztof MARSZALKIEWICZ, Poznan University of Tech. (Poland)

P2II-377 Risk assessment and minimization of voltage levels violations in distribution systems
Carlos OLIVEIRA, Andre MEFFE, Enery - Polytechnic School of the University of Sao Paulo, Renato GUIMARAES, ENERSUL - Empresa Energética de Mato Grosso do Sul S/A (Brazil)

P2II-395 An analytical method for power quality assessment applied to grid-connected power electronics converters
Vanya IGNATOVA, Seddik BACHA, Laboratory of Electric Engineering of Grenoble, Pierre GRANJON, Laboratory of Images and Signals (France)

P2II-512 SVC for maintaining of power quality in the feeding grid in conjunction with an electric arc furnace in a steel plant
Rolf GRUNBAUM, ABB Power Technologies (Sweden), Danilo DOSI, ABB Power Technologies (Italy), Leonardo RIZZANI, Ferriere Nord (Italy)

P2II-617 Short-time disturbance detection using DCT analysis in distribution system
Xiao Xianyong, Yang Hong-geng, Liu An-ding, Sichuan University School of Electrical Engineering & Information, Chengdu (P.R. China)

P2II-663 Harmonic Content Diagnosis in an Electric Power Distribution System
Pedro Vidal, Hector Perez, Energia San Juan (Argentina)

P2II-668 Single-tuned filter on low-voltage side of distribution systems: performance evaluation
J.R. Macedo, ESCELISA, J.W. Resende, M.I. Samesima, UFU (Brazil)

P2II-693 ATP modelling of distribution networks for the study of how harmonics propagate
Norberto A. Lemozy, Alejandro Jurado, University of Buenos Aires (Argentina)

Ajit K. Hirianandani, DTE Energy (USA)

P2II-005 Power quality in high-tech campus: an exemplary case study
Antonio MORENO-MUNOZ, Victor PALLARES, Matias LINAN, Universidad de Cordoba, Juan J. GONZALEZ, Universidad de Cadiz (Spain)

P2II-130 From Stand-alone Monitoring Device to Intelligent Quality Management System.
Philippe GOOSSSENS, Geert BORLOO, Alain ROBERT, Elia (Belgium)

P2II-199 Implementation Of The New German Statistic On Distortions And Supply Availability
M. SCHWAN, K. von SENGBUSCH, FGH, J. SCHANZLE, U. BECKER, EnBW Regional, J. BRAND, Süwag Energie (Germany)

P2II-206 System-Wide Power Quality Monitoring Project
Fariz ABDUL RAHMAN, Tenaga Nasional Berhad (Malaysia)

P2II-219 Frequency of Occurrence of Voltages of Specific Size to Occur at the Nodes of Distribution and Transmission Power Systems in Case of a Three-phase Short Circuit, as Identified by Definition
Vladimir BLAZEK, Petr SKALA, Brno University of Technology (Czech Republic)

P2II-240 Power Quality Monitoring and Analysis System T. SEZI, SIEMENS, K. ZIMMER, J. LANG, PFALZWERKE (Germany)

P2II-247 New results of investigating the characteristics of voltage quality in distribution systems and the problems of their evaluation
Vaclav VYSKOCIL, MEGA Brno, Karel PROCHAZKA, EGC-EnerGoConsult, Pavel SANTARIUS, Technical University of Ostrava (Czech Republic)

P2II-286 Investigation of Voltage Sags Due to Faults in MEA’S Distribution System
Tosak THASANANUTARIYA, Metropolitan Electricity Authority (MEA), Somchai CHATRATANA, National Science and Technology Development Agency (NSTDA) (Thailand)

P2II-323 IQS, a new format for the Power Quality data
Bruno PASZKIER, Christoph SANTANDER, EDF R&D (France)

P2II-333 Power Quality Analysis of HV/MV Customers Through Monitoring Of Distribution Network Substations
Antonio AMORIM, Antonio CARDOSO, Nuno MELO, EDP (Portugal)

P2II-385 Efficient Methods For Power Quality Surveying In Distribution Networks
Jan MEYER, Peter SCHENGER, Gert WINKLER, TU Dresden, Michael MUHLWITZ, DREWAG Stadtwerke Dresden, Lutz SCHULZE, Avacon (Germany)

P2II-424 Common guidelines for reliability data collection in Scandinavia
Jorn HEGGSET, SINTEF Energy Research, Annie HEIEREN, EBL Kompetanse, Rune K. MORK, Statnett (Norway), Jorgen S. CHRISTENSEN, DEFU (Denmark), Sven JANSSON, Elforsk (Sweden), Kimmo KIVIKKO, Tampere University of Technology (Finland)
P2I1-473 PQ Monitoring in Belgian Distribution Networks
Piet LAUWERS, Christian PIRENNE, Philippe SOMMEREYNS, Netmanagement, Wouter VANCOETSEM, Emmanuel DE JAEGHER, Michèle DE WITTE, Laborelec (Belgium)

P2I1-725 Survey of Power Quality Problems in Industrial Zones in Egypt
Dr. G.A. Abdel Salam, Sameh Medhat Nasri, Cairo Electricity District Company (Egypt)

P2IV-015 Power Quality In The Competitive Market: The customer Perspective On Monitoring, Reporting And Benchmarking Of Service Quality
Joseph NJOROGE, Kenya Power and Lighting Company (KPLC) (Kenya)

P2IV-077 Power quality, energy efficiency and the performance in the electricity distribution and supply companies
Stefan GHEORGHE, ELECTRICA, Cristina TANASA, ELECTRICA Moldova, SDFEE lasi (Romania)

P2IV-443 Power Quality In Regulation Of Distribution Companies - A Finnish Case
Markku KINNUNEN, Ritva HIRVONEN, Energy Market Authority (Finland)

P2II-728 Reliability indicators analysis for distribution network in Elektrovojvodina
Milanko RADIC, EPS JP Elektrovojvodina, Dusan RADIC, EM inzengerij, Novi Sad (Serbia and Montenegro)

Research & Innovation Forum Session 2

R2I-012 Indoor Network Noise In The Broadband PLC Frequency Range
Dubravko SABOLIC, Vanja VARDA, HEP, Alen BAZANT, Faculty of Electrical Engineering and Computing, Zagreb (Croatia)

R2I-082 A Practical Magnetic Field Evaluation Method for 10kV Air-core Reactors
Chunyan SONG, Chunjie ZHU, Guoqi CHEN, Design Institute of Hangzhou Municipal Electric Power Bureau, Shuwen DU, Zhengcai SONG, Shanghai Jiaotong University (P.R. China)

R2I-205 Design and validation of power frequency magnetic field conductive shielding for underground power cables
E. Salinas, London South Bank University (UK), Y.Q. Liu, J. Atalaya, J. Daalder, Chalmers University of Technology (Sweden), P. Souza, Iajuba Federal University (Brazil), J. Atalaya, Universidade Nacional de Ingenieria (Peru), P. Cruz, University of Seville (Spain)

R2I-522 Identification of Equivalent Source System for electromagnetic field pollution evaluation
A. Canova, F. Freschi, M. Repetto, M. Tartaglia, Politecnico di Torino (Italy)

R2I-065 Advanced Methodologies and New Tool for Multiphase Power Quality Analysis & Mitigation
Xavier YANG, EDF R&D (France)

R2I-140 Voltage Flicker Tracking based on Amplitude-Phase-Frequency (APF) Estimators
Cristina GHERASIM, Johan DRIESEN, Ronnie BELMANS, K.U. Leuven - ESAT-ELTEC (Belgium)

R2I-344 A measurement method for determining the propagation of flicker throughout a network
Peter G.V. AXELBERG, UNIPOWER, Math H.J. BOLLEN, Lulea University of Technology, Irene Y.H. GU, Chalmers University of Technology (Sweden)

P2II-407 Identification And Quantification Of The Regulation Interaction Between 2 DSTATCOM In A Distribution Grid
Sergio AURTENECHEA, Josu GALARZA, Jose Ramon TORREALDAY, Mondragon Unibertsitatea, Estanis OYARBIDE, Universidad de Zaragoza (Spain)

P2II-715 Prediction of Electrical Power Quality Disturbances Using State Estimation Techniques
Nazineh EASSA, Ahmed ABOUELSOUUD, Alexandria Electricity Distribution Company (Egypt)

R2II-002 A Fuzzy Expert System for Quantifying Voltage Quality in Electrical Distribution Systems
Fuat KUCUK, Omer GUL, Istanbul Technical University (Turkey)

R2II-050 Performances of the Fault Decoupling Device when Unbalanced and Multiple Faults Occur on Distribution Systems
Giacomo COCCIA, Mariano G. IPPOLITO, Giuseppe MORANA, Università di Palermo (Italy)

Session 3 PQ&EMC related Papers

S3-044 Concept and Practical Testing of Single Pole Operated Earthing Breakers in an Urban MV Cable Network
Piet ABAECHERLI, Adrian SCHMID, Regionalwerke AG Baden, Georg KOEPPPL, KOEPPPL POWER EXPERTS, Gerd VOSS, ABB Sichéron (Switzerland)

S3-414 Influence Of Harmonic Voltages On Single Line To Ground Faults In Distribution Networks With Isolated Neutral Or Resonant Earthing
Stefan SORENSEN, Hans NIELSEN, Aalborg University, Hans Jorgen JORGENSEN, DEFU (Denmark)

S3-649 Effect Of The Overcurrent Protection Settings On Distribution Systems On The Resultant Power Quality
Juan GOMEZ, Gabriel CAMPETELLI, Marcos FELICI, National University of Rio Cuarto (Argentina)

Session 4 PQ&EMC related Papers

S4-095 Power Quality Measurements in Two Norwegian MV networks with Distributed Generation
Annigerd PLEYM, Helge SELJESETH, SINTEF Energy Research (Norway)

S4-104 Impact of increasing penetration of distributed generation on the dip frequency experienced by end-customers
Math H.J. Bollen, Mats HAGER, STRI (Sweden)

S4-281 Management of Voltage Quality in Distribution System within Dispersed Generation Sources
Josef TLUSTY, Czech Technical University in Prague, Frantisek VYBIRALIK, Stredoceska energeticka, Group CEZ (Czech Republic)

S4-498 Simulating the Dynamic Response of a Photovoltaic Generation System to Voltage Sags
Bostjan BLAZIC, Arsen JURASIC, Igor PAPIC, University of Ljubljana (Slovenia)

S4-560 A solar converter for distributed generation able to improve the power quality supply
Francesco CASTELLI DEZZA, Michele DIFORTE, Roberto FARANDA, Politecnico di Milano (Italy)
Session 5 PQ&EMC related Papers

S5-014 Continuity of Supply in a Swiss Urban Electrical Network - A Spatial Analysis
Hans-Heinrich SCHIESER, Jürg BADER, Elektrizitätswerk der Stadt Zürich (EWZ) (Switzerland)

S5-078 Combining Modelling of Long, Short Interruptions and Voltage Dips : a Markovian solution
Massimiliano GIORGIO, Roberto LANGElla, Teresa MANCO, Alfredo TESTA, Second University of Naples (Italy)

S5-086 Analysis of the assumed cost of penalties payments in a municipal MV distribution network
Vaclav DETRICH, Karel MATONOHA, Zdenek SPACEK, Jana HURKOVA, EGU Brno, Petr SKALA, Brno University of Technology (Czech Republic)

S5-185 Quantitative Risk Assessment; a key to cost-effective SAIFI and SAIDI reduction
Marko KRUITHOF, John HOPEMAEKERS, Eneco Netbeheer, Rob VAN DIJK, KEMA (The Netherlands)

Session 6 PQ&EMC related Papers

S6-216 Continuity Of Supply in Italy: The Experience Of Enel Distribuzione During The Regulatory Period 2000-2003
Francesco AMADEI, Enel Distribuzione (Italy)

S6-300 The Use of Customer Outage Cost Surveys In Policy Decision-Making: The Italian Experience In Regulating Quality Of Electricity Supply
Antonella BERTAZZI, Luca LO SCHIAVO, Autorita per l’energia elettrica e il gas, Elena FUMAGALLI, Politecnico di Milano (Italy)

S6-336 Comparision Of Interruption Statistics And Their Use In Network Business Regulation In Nordic Countries
Kimmo KIVIKKO, Sauli ANTILA, Pertti JARVENTAUSTA, Antti MAKINEN, Tampere University of Technology, Jukka LASSILA, Satu VILJAINEN, Kaisa TAIVAHANAINEN, Jamo PARTANEN, Lappeenranta University of Technology (Finland), Olve MOGSTAD, Sintef Energy Research (Norway), Matz TAPPER, Svensk Energi - Sweden Energy (Sweden)

S6-464 Increasing regulation and customer expectations of quality of supply and their impact on distribution network management system development
Jukka KURI, Marcus BISTROM, Timo LAINE, Tekla Corporation (Finland)

S6-489 Quality control in the Swedish regulation and balance between network charges and quality
Per-Olof Nilsson, Vattenfall Eldistribution (Sweden)

S6-497 First Results of Performance Based Regulation of Supply Quality in Hungary
Tibor TERSZTYANZKÝ, Hungarian Energy Office (Hungary)

S6-532 Power quality regulation and standardisation - The French example
Philippe CRUCHON, Ministère de l’Economie, des Finances et de l’Industrie, Saâd SABEG, EDF Distribution, Yvon COATANEA, CEI TC8, Nathalie BAUMIER-DUPHIL, EDF R&D (France)

S6-634 Quality Of Service Approach For Risk Management And Cost Optimisation For Electricity Networks
Claudio GUIDI, Jorge ESPAIN, Jorge GARCIA, Guilleremo LAYERENZA, PA Consulting Group (Argentina)

S6-636 Continuous Improvements applied to the Quality of Technical Services in EJESA
Alejandro Enrique Soza (Argentine)

S6-695 Quality Insurance Based Electric Energy Pricing With Different Power Quality
Gengyin LI, Guanghou JIN, Ming ZHOU, School of Electrical Engineering, North China Electric Power University (P.R. China)

S6-720 Evaluation of Organisational and Technological Aspects That Affect Service Quality
Nazineh EASSA, Alexandria Electricity Distribution Company (Egypt)