Special Report - Session 2
POWER QUALITY AND ELECTROMAGNETIC COMPATIBILITY

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Introduction

The **scope of Session 2** (S2) has been defined as follows by the Session Advisory Group and the Technical Committee:

- **Power Quality (PQ)**: voltage quality (i.e. issues with conducted disturbances in the frequency range from 0 to 150 kHz, reaching equipment through the electricity supply); voltage profile (slow rms value fluctuations), harmonics and interharmonics, rapid fluctuations, flicker and unbalance as well as voltage dips or other transients belong to the considered phenomena. Voltage continuity issues (often referred to as supply reliability - problem of outages) complete the usual definition of Power Quality.
- **EMF, EMI and Safety:** electromagnetic fields issues, 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 (step, touch and transferred voltages...) are also considered.

The **S2 papers** will be discussed in **three events**:
- Main Session (Thursday 13 June),
- Poster Session (Tuesday 11 June),
- Research & Innovation Forum (Wednesday 12 June).

Two **Round Tables** will be organised:
- The target of quality regulation; based on CEER on 5th benchmarking report of Power Quality (RT.2a, Wednesday 12 June, am)
- Power Quality Monitoring Best Practices (CIGRE-CIRED working group) (RT.2b, Wednesday 12 June, am)

The **aim** of this **special report** is to present a synthesis of the present concerns in PQ&EMC, based on all selected papers (in S2 and other sessions: 143 papers in total).

BLOCK 1 : ELECTRIC AND MAGNETIC FIELDS, EARTHING SYSTEMS

It must be stated, that the number of presentations of measurements and field studies concerning electric and magnetic fields in CIRED was decreasing during last years. Obviously the ICNIRP limits are well established and more or less accepted in the scientific community. Especially after the recent rise of ICNIRP reference values the activity in electric engineering has declined. There are no new findings about remedial measures published, neither active shielding nor new passive shielding materials.

Electric and magnetic field measurement

This year three papers are dealing with measurement. [B1-0330(EG)] presents magnetic field (MF) measurement in an indoor LV transformer station and near a 220 kV line. In both cases field levels stay well below ICNIRP limits, in the case of the transmission line even significantly. Similar results are presented in [B1-0537(EG)]. In [B1-1089(MY)] MF measurements and simulations for a cable duct are shown. Again, no critical values have been observed. Measurements in exposed locations near overhead lines resulted in levels significantly below limits. Thus all papers confirm the introductory statement.

Electric and magnetic field simulation

The characteristics of current density induced inside the human body is presented in [B1-0075(EG)]. With a spheroid shaped phantom with constant conductivity, induced currents, when exposed to a homogeneous field of 100µT to 300µT, were measured. The achieved current density was significantly below 10mA/m² (ICNIRP). Furthermore, an algorithm for calculating the reduction factor of passive compensation loops is presented.

The calculation of the field of simple configurations (e.g. overhead lines) is quite easy. Comparison of measurement and simulation show an almost perfect match in the case of an MV underground cable [B1-1089(MY)]. Based on the results, the optimal phase arrangement with minimum MF was estimated for a cable duct with several circuits. In the case of complex structures like substations, including feeding cables, bus bars and transformers usually a high sophisticated 3D-software is used. In [B1-1060(IT)] a MF-software, developed for simulation of the field emission of MV/LV substations is presented. The model is based on the 3D computation of the Biot-Savart law, summing magnetic field vectors generated by each conductor. Simulation results are verified by measurements, showing that the software tends to give higher field levels. This could be due to shielding effects, not taken into account in the simulation. [B1-0932(IR)] utilizes a 2D finite element method (FEM), embedded in the GIS of a distribution system to address EMC and EMF issues.

The same FEM-tool is used by the authors of [B1-1298(BR)]. In contrast to the previous papers the focus is here solely on electric fields (EF) in HV substations. The results showed that for the simulated arrangement the electric field values are below ICNIRP standards. However, the mapping of the regions of maximum exposure would be an efficient measure mitigating the cumulative effects of exposure to the field on substation staff.

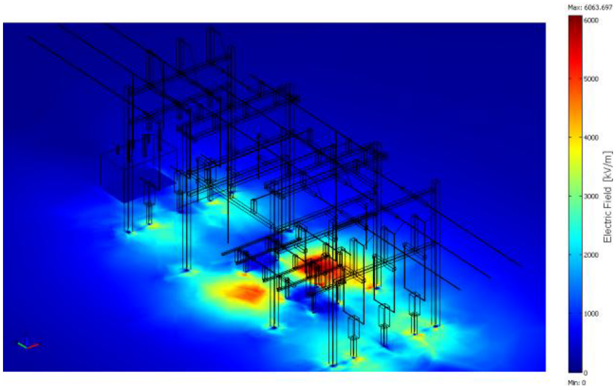

Figure 1: Distribution of the electric field on a plane situated at a height of 1.5 m in relation to substation patio, perspective view [B1-1298(BR)]

Electromagnetic interference

[B1-0499(AT)] is the only paper dedicated to EMI. A model for the calculation of unbalanced currents and mutual interference between parallel HV lines is presented. The model is based on the node potential method in combination with a chain-ladder model and the consideration of the mutual coupling between two phase-to-earth loops. Using this approach it is possible to determine the mutual interferences and interaction between two line circuits, as well as unbalance currents due to the incomplete transposition and inductive interference phenomena. In this paper, an optimization of phase arrangement regarding loop currents is shown.

Lightning

In [B1-0449(IR)], the effect of the ground reflection factor on the wave shapes of currents along lightning channel and the electromagnetic field associated with the lightning channel and causing possible interference are considered. The ground reflection factor results from the difference between the surge impedance of channel and the ground impedance. It is shown that current and M- and E-field values have a direct relationship with the values of the ground reflection factor. The authors suggest considering the ground impedance around power line and the resulting reflection factor for evaluation of electromagnetic fields and lightning induced voltages. On the other hand, the authors of [B1-0921(BR)] indicate that the impact of ground impedance on the horizontal E-field is minor compared to the stroke current propagation velocity.

Induced lightning voltages for two different MV conductor arrangements are analysed in an experimental way in a downscaled 50:1-model [B1-0556(KR)]. A comparison of a 5- wire arrangement with separated neutral and ground wire and a 4-wire arrangement with common neutral and ground showed no significant differences regarding induced voltage. However the number of grounding points along the line had an impact.

Earthing systems

Two very interesting papers pick up the topic of earthing systems. In IEEE-Std80 as well as in IEC61936 some maximum tolerable current is defined and a deterministic procedure is applied to convert that current into an allowable voltage. The implied safety of the allowable voltages derived this way relies on the value chosen for maximum permissible current being sufficiently low. 'EG-0 Power System Earthing Guide', released in Australia 2010 introduces risk management, thus replacing 'current through the body' by the risk posed by different scenarios. It has two components: the probability that the voltage hazard would cause ventricular fibrillation and the probability of an individual actually being exposed to the voltage. The authors [B1-1511(AU)] demonstrate that the choice of statistical distribution and fitting method can have a sizeable impact on the calculated fibrillation probability, particularly at lower voltages.
However, touch voltage is still the main criteria. The authors of [B1-0035(AT)] present a variety of grounding measurements, assuming that global earthing systems exist not only in densely populated regions but also in scattered settlements. Taking 80V as a limit for the advisable or tolerable touch voltage according to EN 50522, the characteristic earthing impedance of 0.01Ω leads to a limit for the earth fault current of approximately 8kA.

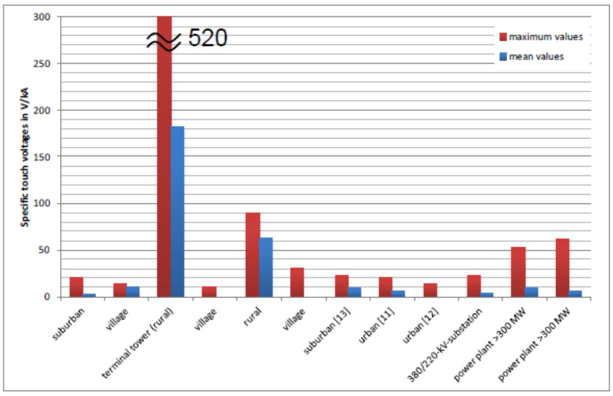

Figure 2: Typical measured specific touch voltages (V/kA) in different areas [B1-0035(AT)]

The results presented in paper [B1-0994(SI)] clearly show that in resonant grounded networks the arc intensity at the fault location depends on many ambient parameters and coil adjustments. However, it can be concluded that under normal operating conditions the arc is relatively stable and has enough energy to cause a fire on dry surface at the fault place. It can be also concluded that a touch and step voltage are not critical as long as the earthing system resistance is low enough.

Discussion and further research topics

Are problems regarding magnetic fields originating from electric power installations generally settled or is there a need for further research on mitigations methods, especially active shielding?

Papers of Block 1 (B1)

Paper No.	Title	MS a.m.	RIF	PS	Other Sess.
0035	Verification of Global Earthing Systems	X			
0075	Radiation Exposure from Electric Power Lines and Methods for Reducing the Magnetic Field Generated by Distribution Network			X	
0330	Measurements of Magnetic Fields in the Indoor Power Distribution Transformers and in the Vicinity of the HV Overhead Power Lines in Egypt			X	
0449	Ground Reflection Effect on the Lightning Electromagnetic Fields				
0499	A New Approach for the Calculation of Disturbing Currents in Inductively Coupled Transmission Lines			X	
0537	ELF Magnetic Field Measurements near Overhead Power Lines			X	
0556	Analysis on Induced Lightning of an Existing Distribution Line and a Distribution Line Including a Neutral Wire Using a Down scaled Simulation Line Model			X	
0921	Analysis of the Behaviour of the Lightning Horizontal Electric Field above a Finitely Conducting Ground			X	
0932	Finite Element Analysis of Electromagnetic Compatibility in Distribution System Based on Geographic Information System				

0994	Touch of the Conductor with Earth Surface in Resonant Earthed Medium Voltage Systems				S3
1060	Verification of Magnetic Field Prediction of a 3d Computer Model on MV/LV Substation	X			
1089	Magnetic Field Simulation & Measurement of Underground Cable System inside Duct Bank			X	
1298	Electric Field Mapping in High Voltage Substation Using the Finite Elements Method			X	
1511	Use of Finite Probabilistic Modelling to Establish Earthing Hazard Limits	X			

BLOCK 2: HARMONICS

Block 2 is entirely dedicated to harmonics. 11 papers discuss harmonics in the frequency range 2 kHz and 150 kHz. This clearly points out the importance of this topic which was just emerging in the CIRED 2011 edition. Although these papers are summarized in block 2 of session 2, they will be presented in the oral session of Block 1.

Harmonics in the 2 kHz – 150 kHz range

The major sources of emission of harmonics in the 2 kHz – 150 kHz range are related to the switching frequency of power electronics and power line communication (PLC). Emissions from power electronics are reduced by the use of EMC filters but some portion cannot be eliminated due to the filter limitations. PLC is typically found in LV grids and is used for transmitting data from energy meters or to control equipment.
Activities towards standardization in this frequency range are ongoing in several IEC working groups and within CENELEC. The work focuses on the development of standardized measurement methods and setting of emission, immunity and compatibility levels.

In [B2-1052(SE)] a proposal for a standardized measurement method is given. Proposals are done for the required voltage and current measurement, filtering characteristics and maximum quantization noise, basic measurement window and time aggregation. The paper also presents time domain indices next to frequency domain indices. This is required because the character of the distortion above 2 kHz differs with relation to distortions below 2 kHz. Also a time-frequency domain is suggested for the representation of voltage and current distortions in the 2 to 150 kHz range. According to the authors, this method allows to get a better understanding of the signal characteristics, especially if the signal is changing frequency over time. An example of such a signal in the case of a fluorescent lamp is given. A damped oscillation is noticed.

A smart meter has been investigated by means of an EMC test setup in [B2-1120(DE)]. A small frequency step width of 0.37% was chosen whereas a 2% rule is prescribed in the draft standard IEC 61000-4-19. The test result exhibits narrowband susceptibility that leads to abnormal operational states where acceptable accuracy limits are clearly exceeded. It is concluded that for narrowband susceptibility of a device (here a smart meter) the proposed 2% frequency step proposed in the draft standard is too large.

In [B2-1168(DE)] the HF emission characteristics of PV inverters are presented. It is shown that a 600 Hz or 800Hz band is suitable for the evaluation of HF voltage distortion and that the design of the EMC filter has a major influence on the resulting source behaviour of the inverter. Based on these findings the HF voltage distortion level at 25 measurement sites was evaluated. On the one hand it was shown that in grids without PV the levels are very low. On the other hand, grids with PV show elevated voltage distortion between 16 kHz and 20 kHz during daytime that can reach up to 1V. It is also noted that the highest emissions are measured close to the PV inverters. Propagation is limited. Finally a case is presented, where voltage distortion led to device malfunction and customer complaints. Levels of up to 5 V were measured at the disturbance source. Paper [B2-1036(SE)] also discusses PV installation based on experiences in northern Scandinavia. Emissions up to 25 kHz are considered. The results show that the harmonic emission is rather low (less than 5%) and constant with production.

The impact of higher frequency emission on electronic mass-market equipment is addressed in [B2-0999(DE)]. Electronic equipment installed in the vicinity of the HF source provides a better path for the harmonics compared to the grid. Especially equipment with EMC filters or rectifier with DC-link offers a low impedance path for the HF harmonics. The results in the paper are based on measurements on CFL lamps with integrated ballast. Special attention is given to the additional thermal stress of the DC-link capacitors in such equipment. Measurements were conducted with a two frequency supply voltage (fundamental 230 V + HF component VHF ranging from 1% to 7% of the fundamental). Two different behaviours (type A and B) can be recognized. For type A, a clear peak in the current ratio is noticed between 1 kHz and 5 kHz. For type B, an increased current ratio in a large frequency range is noticed. The impact of the increased current on the temperature rise of the capacitors is also measured. The paper concludes that for the discussion on immunity and emission levels also long-term effects (aging due to heating) should be taken into consideration.

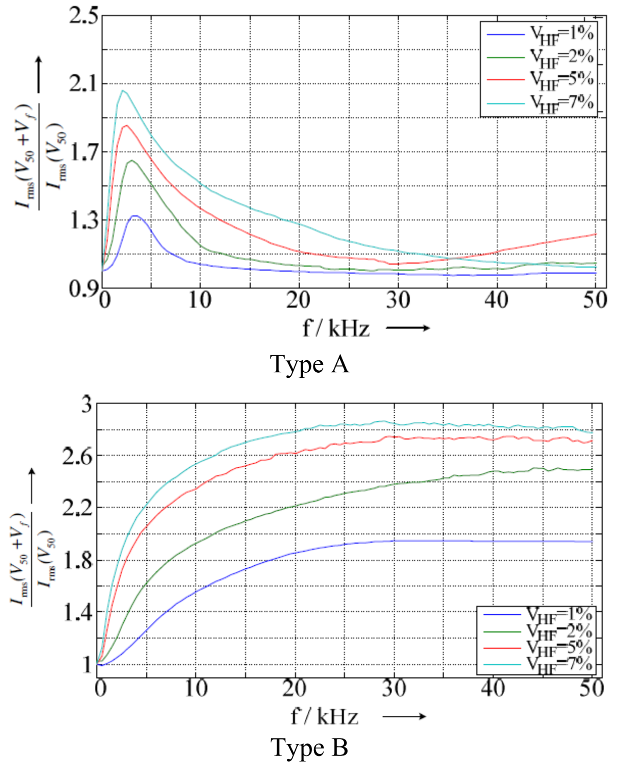

Figure 3: Type A and Type B behaviour of CFL tested with a two frequent voltage (50 Hz nominal + V_{HF}) showing the current ratio as a function of the frequency of V_{HF} [B2-0999(DE)]

The authors of [B2-0209(SE)] investigate the spread of HF current emission between devices of different sizes. Large devices can potentially cause relatively large currents flowing in nearby small devices. The paper also considers harmonic resonances due to EMC filters of devices. When a number N of identical equipment is connected to the same point, the current amplification rises proportional to the square root of N. The resonance frequency drops with the same ratio. Finally the paper discusses emission between equipment with a combination of CLC and LCL EMC filters. Also here current amplification due to harmonic resonances can occur.

In [B2-1271(AT)] is based on the analysis of reported EMI-cases. Especially automated meter reading systems using PLC (AMR-PLC) in the 3 kHz to 95 kHz range are figuring as interference source but also as an EMI victim. As a result of the reported problems, CENELEC SC 205 A set up a task force to study and document EMI cases. A second edition of the CENELEC Study report concerning this problem is in finalization.

Paper [B2-1391(FI)] also discusses AMR using PLC. In Finland, 3.6% of installed meters using PLC experienced communication problems either in commissioning or during operation. As a result, measurements were performed based on a HF current measurement method in order to facilitate the location of the disturbance source. PLC is regulated by CENELEC standard EN 50065-1 but no emission or immunity limits are specified in standards for customer equipment in the related frequency range. The interaction between PLC and variable speed drives and between PLC and switch-mode power supplies are discussed in the paper. In one case, the switching frequency of a power supply was 44.5 kHz. This voltage interfered with the PLC system, resulting in a malfunctioning of the communication.

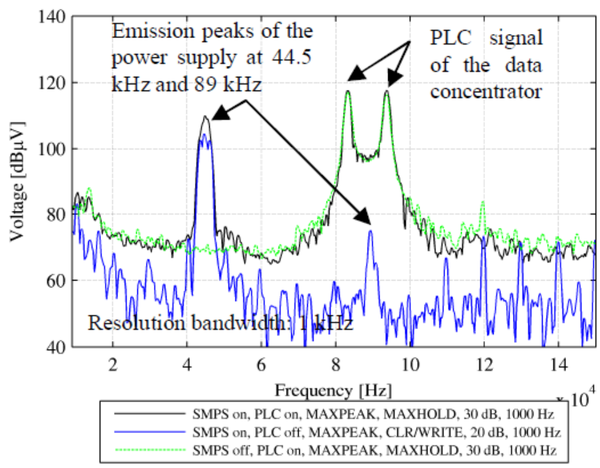

Figure 4: Conducted disturbances in PLC caused by the switching frequency of a power supply [B2-1391(FI)]

An "on-line" grid impedance meter designed for spectral impedance measurements of low voltage distribution grids over the frequency range between 2 and 150 kHz is presented in [B2-1417(CH)]. A perturbation current of 140 mArms is used and shows satisfactory results in the frequency range over 1.5 kHz. As the spectral impedance of a grid section cannot be estimated by calculation, the usage of this type of impedance meter looks promising in order to analyse problems of interaction.

In [B2-1435(BE)] a "PLC Measuring Toolbox" is used to conduct noise and impedance measurements on loads an in the distribution grid. The system comprises a 30W power amplifier to inject signals in the frequency range between 20 kHz and 120 kHz in the grid. Measurements of a large set of consumer electronics resulted in a classification of the loads in 4 categories. The combined effect of low input impedance, caused by EMC filters, and the production of high-level and periodically changing noise has the worse impact. Measurements in a LV grid showed very low impedance in the substation (1 -2 Ω).

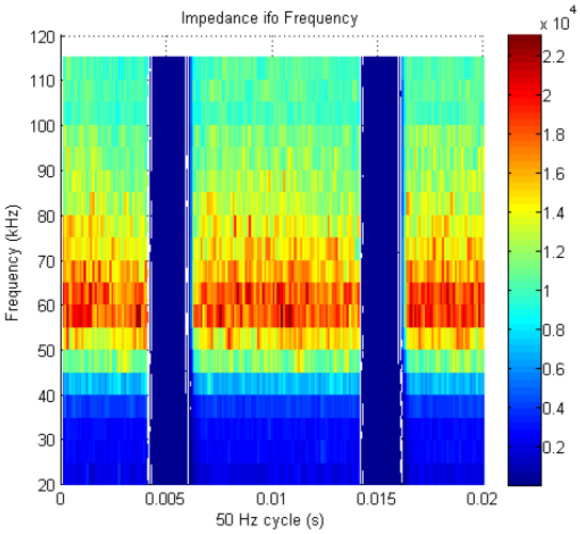

Figure 5: Periodic impedance analysis on a digital TV decoder showing very low impedance during periods of conduction of the diode rectifier [B2-1435(BE)]

Harmonics measurement techniques

Measurement and analysis of harmonics is addressed in 5 contributions. In paper [B2-0195(CH)] an RC-divider technology is proposed in order to measure harmonics with a very high accuracy over a wide frequency range even up to EHV system networks. This method should overcome the system voltage dependent behaviour of the frequency response of typical instrument transformers. Test results on a 420 kV RC- divider show high accuracy of ± 2% up to the 200th harmonic. The phase displacement error is also very low.

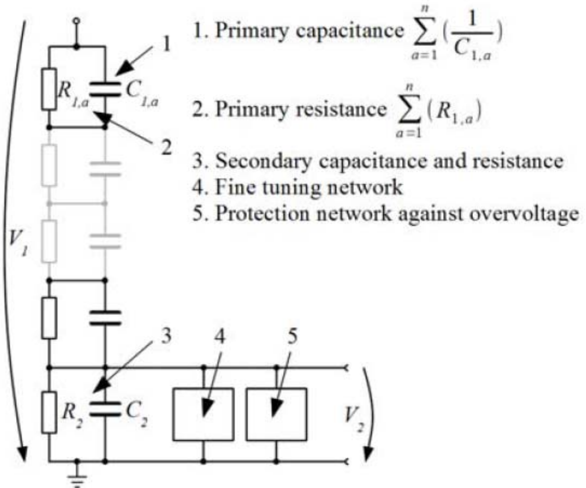

Figure 6: Electric circuit diagram of the RC-divider according to [B2-0195(CH)]

A method to identify harmonic content and their origin is presented in paper [B2-0605(PT)]. The method is used since 2005 and three case studies show its usefulness. The cases deal with odd (5th and 7th), even (6th and 8th) and triplen harmonics. For the even harmonics, it was clearly identified that the origin was a wind farm. For the triplen harmonic, the relation with the public lighting is shown.

[B2-1397(IR)] starts with the definition of the Distortion Power Quality Index (DPQI). This index is used to analyse the effects of polluting loads on a power system. DPQI provides information on how much effect each load has on the PCC. In order to characterize the loads, a reduced multivariate polynomial model is fitted by means of a one-shot training only using current waveforms.

Harmonic emission of equipment

The individual harmonic emission of street lamps and their aggregation is analysed in [B2-0291(ES)]. Measurement results for 5 HPS lamps and 2 different LED lamps are compared with the approach according to IEC 61000-3-6. The harmonic spectra of the different technologies differ. Even between the 2 LED lamps, significant differences are noticed. For the aggregation, both amplitude and phase information are measured. If the LED lamps from different manufacturers are aggregated, cancellation due to different phase angles is noticed. It is also shown that the IEC 61000-3-6 approach can lead to misleading conclusions, especially when the measurement results are taken into account, because cancellation is only partially considered in this technical report.

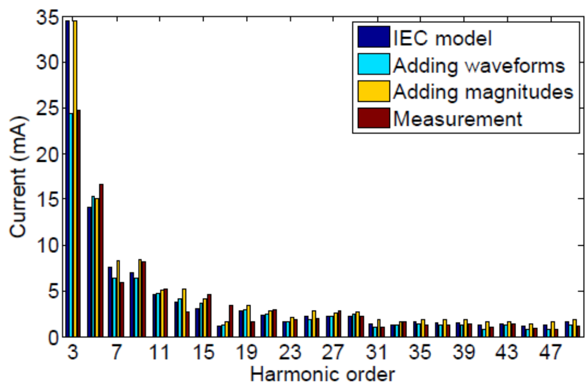

Figure 7: Different approaches for the aggregation of harmonic emission from 2 different LED street lamps [B2-0291(ES)]

Harmonic content of 18 different compact fluorescent lamps with electronic or magnetic ballast is presented in paper [B2-0615(EG)]. The radiated light is also measured to calculate the efficiency of the devices. With respect to harmonics, high THD and crest factors are reported.

[B2-1029(IR)] confirms the results on the harmonic content of compact fluorescent lamps (CFL) from the previous paper. [B2-1029(IR)] also shows results of the harmonic pollution of 10 air conditioning systems. THDi values between 26.4% and 5.2% are reported and even harmonics are present. Finally, the combined use of air conditioners and CFL is analysed. If the active power portion of the CFL with respect to the air conditioning reaches 9.7%, the current harmonics violate the Iranian standard NO.6375-2.

In [B2-0778(IT)] the harmonic pollution due to electric vehicles charging stations is examined. Amplitudes and phase values up to the 25th harmonic are reported. The charging power is changed in four steps (1.3 kW up to 3kW). At maximum charging power, the 3rd harmonic amplitude is frequently close to the limit according to IEC 61000-3-2. Decreasing the charging power has little effect on the harmonic amplitudes. The phase values seem to be rather independent of the charging power. Based on the results, the paper suggests avoiding modulation of the recharge power.

[B2-0793(BR)] presents a method based on the use of recursive least square to determine the model parameters of a transformer as a function of the frequency (up to 2580 Hz). The leakage and magnetization impedances can be determined by means of the open circuit test only. Increased frequency results in increased resistances and decrease of the inductances. The method is validated by measurements.

Paper [B2-1480(JO)] presents results measured at 191 11kV transformers in a residential area. The paper gives results of voltage (THDv) and current (THDi). One should be careful in the interpretation of both THD values. THDv is analysed with respect to loading and time of day. Most of the transformers exceed the IEEE 519 standard value for THDv (5%). It is also noticed that a lot of transformers have a low loading resulting in very high THDi.

Metering in presence of harmonics

Three papers address the performance of energy meters under non-sinusoidal conditions. In [B2-1322(CZ)], 4 types of standard energy meters were tested with linear load, phase fired control (halogen lamps) and electronic load (computers + LCD screens). In general, the cheapest meter measured with worse error than expensive ones. According to the authors, the error rises more than 6% for a highly distorted voltage supply and non-linear load (experiment 7). An experiment with electronic load shows a positive error indicating that the meter registered more energy than actually used by the application.

Table 1: Measurement errors of standard energy meters according to [B2-1322(CZ)]

METER:	1	2	3	4	5	6
Experiment 1	-0,22%	0,81%	-0,05%	0,46%	0,09%	0,00%
Experiment 2	-0,12%	0,65%	-0,21%	0,60%	0,16%	0,00%
Experiment 3	-0,83%	0,24%	-0,56%	0,51%	0,13%	0,21%
Experiment 4	-0,13%	0,98%	0,24%	0,67%	0,15%	0,27%
Experiment 5	-0,89%	0,59%	-0,71%	0,53%	0,11%	0,22%
Experiment 6	-0,53%	0,73%	-0,53%	0,60%	0,13%	0,25%
Experiment 7	6,60%	6,78%	6,23%	3,34%	0,33%	0,43%
Experiment 8	-0,12%	0,73%	0,19%	0,50%	0,12%	0,29%
Experiment 9	-0,48%	1,35%	-0,32%	0,46%	0,11%	0,26%
Experiment 10	-0,92%	0,37%	-1,24%	-0,86%	-0,04%	-0,89%
Experiment 11	-1,49%	0,45%	-2,50%	-2,48%	-0,28%	-4,01%
Experiment 12	-1,72%	0,69%	-3,24%	-3,68%	-0,62%	-4,21%
Experiment 13	-0,97%	2,24%	-3,25%	-4,29%	-1,04%	-4,55%

In paper [B2-0352(IR)] energy meters are tested based on IEEE 1459. Two energy meters are evaluated. The loads for the test are compact fluorescent lamps and an induction motor. In a first test, non-sinusoidal voltage is applied to a linear load. In the other tests, the supply voltage is sinusoidal but nonlinear loads are applied. It is concluded that some meters result is errors when the supply voltage contains high order of harmonics. Non-active power is suggested as a basis for billing purposes because it considers all disturbing terms.

In [B2-0434(CZ)] a set of analytical tools to calculate power components are discussed. Both the IEEE 1459-2010 and the Current's Physical Components Concept (CPC) are treated. The calculations are run on measured data. The IEEE method seems to be easier to interpret.

In paper [B2-1256(IR)], voltage and current measurement data from an arc furnace plant is used to analyse well known reactive power definitions. It is shown that the Sharon's definition fits best with the measurements. The Fryze definition results in the highest maximum average of reactive power.

Harmonic mitigation

To start this section, [B2-0066(EG)] gives a nice overview of the different harmonic mitigation techniques currently available, ranging from simple passive to complex hybrid active filters. The paper also gives recommendations for during the design stage of a project in order to limit the harmonics, before considering filtering. Also hybrid filters are briefly discussed. The hybrid filter is composed of a combination of passive and active filters. The passive filter portion is tuned to the dominant harmonic frequency in the system and is supplying the required reactive power for power factor correction requirements. The active filter portion is dedicated for removing all other harmonic orders and typically has a rather small power rating compared to the passive part.

The design of a harmonic filter taking into account the total investment cost is presented in [B2-0096(EG)]. The methodology is based on Simulated Annealing. In the paper, the method is restricted to single tuned passive filter structures. The algorithm is implemented in a software tool and tested on a 11 kV system with promising results.

A novel hybrid active parallel filter topology (HAPF) is presented and compared with typical hybrid active series filters (HASF) in [B2-0763(SI)]. The performance analysis is based on simulation results. The rated power of the active part in the novel topology is almost 3 times lower compared to the series filter. Simulation results also show a better filtering of the harmonics with the proposed topology.

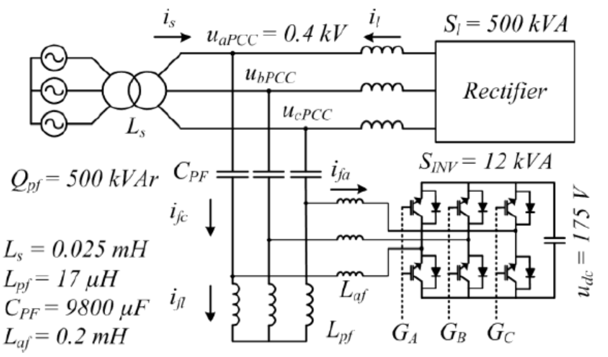

Figure 8: Hybrid active parallel filter topology for harmonic filtering and reactive power compensation (passive part 500 kVAR, active part 12 kVA, [B2-0763(SI)]

The authors of [B2-1002(IR)] suggest the use of a passive device in series to eliminate null wire, improve power quality and reduce the network losses in the LV grid. The topology is based on a YYD transformer like configuration. Simulation results show the elimination of unbalance, and better THDi values.

Paper [B2-1128(CN)] shows simulation results on harmonic characteristics before and after the integration of a shunt active power filter. The paper reveals load current amplifying risks by the equivalent circuit analysis and capacitive systems. Solutions based on component selection or modified control are proposed to overcome this risk.

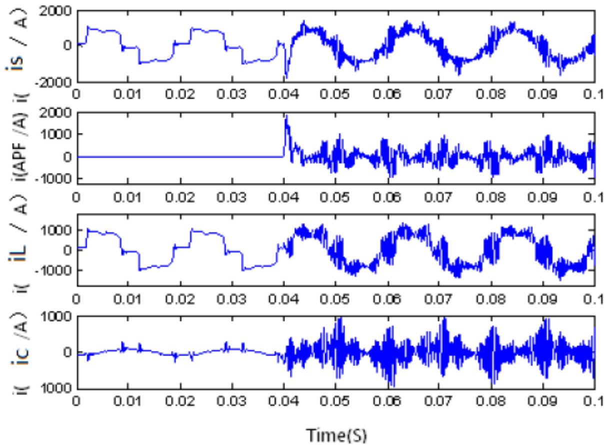

Figure 9: Simulation results according to [B2-1128(CN)] illustrating resonance problems of SAPF for compensation current-type harmonics with normal method, where, *is* grid current; *iapf* compensation current, *iL* load current, *ic* current of the shunt capacitor branch

A 10 kV series reactor failure in a cascaded capacitor bank is analysed in [B2-1037(CN)]. Field measurements revealed high harmonic content. 5th and 7th harmonic current exceed the standard and harmonic voltage and current spikes appear at specific moments. A simulation model in PSCAD/EMTDC was built. The simulation results show resonance problems of intermittent 3th and 4th harmonics in the user side. It is recommended to change the reactance rate values of the capacitor banks to solve the problem.

Paper [B2-1372(IR)] presents a case study to reduce harmonics in an automobile factory. A measurement campaign before and after the installation of an active parallel filter with the ability of load balancing is performed. A mean voltage harmonic reduction of 55% and a current harmonic reduction of 78% is registered. The energy consumption is also reduced due to the reduced harmonic content. The economic analysis resulted in a return on investment of 26 months.

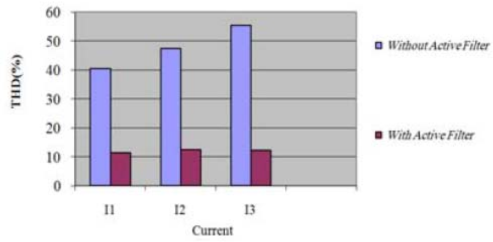

Figure 10: Harmonic current before and after the installation of the parallel active filter in an automobile company [B2-1372(IR)]

Distributed generation

Four papers discuss the impact of wind farm on the harmonics in the power system. [B2-0408(SE)] starts with measurements of harmonic spectra and interharmonics spectra of individual wind turbines (2 to 2.5 MW). Although not identical the spectra show the same tendency and all of them do emit distortion at interharmonic frequencies. The French regulations and IEEE Std. 519 are used as references. In almost all cases the emissions are below the limits. Only higher order even harmonics exceed the IEEE limits. When the emission from a wind park is considered, both primary emission, caused by sources in the park, and secondary sources, harmonic sources from outside the park, must be studied. Finally, for large wind parks amplification due to resonances should be considered as well.

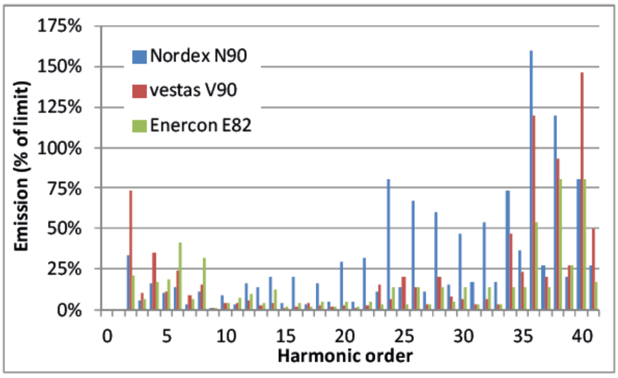

Figure 11: Emission spectra from 3 modern MW-class wind turbines as a percentage of the IEEE 519 limits [B2-0408(SE)]

The amplification due to resonances is discussed in more detail in [B2-0650(SE)]. Both models and measurements are used to get a better understanding of these phenomena. A 10 turbines wind farm model shows that harmonics at frequencies higher than 2.5 kHz are damped in the collection grid and will not reach the public grid. It is concluded that harmonic studies should be performed with the connection of any wind park to the public grid.

In [B2-0104(EG)] a doubly fed induction generator (DFIG) in a wind turbine is analysed for 3 types of converters interfacing with the rotor: a six step thyristor inverter, a six step IGBT inverter and a 3 level IGBT-PWM inverter each with a diode rectifier. Simulations are run for both super synchronous and sub synchronous operation of the DFIG. The sub synchronous operation results in a decreased harmonic content of 45% compared to the super synchronous case. The paper suggests sub synchronous operation using a 6 step thyristor inverter with passive filter for is ease of control and low cost.

The grid impact of photovoltaic installations is discussed in paper [B2-1036(SE)] based on experiences in northern Scandinavia. Emissions up to 25 kHz are considered as well as voltage variations. The results show that the harmonic emission is rather low (less than 5%) and constant with production. The spread of phase angles and magnitude for a given production seems to be small indicating only a small amount of cancellation between individual installations. In [B3-0143(UK)] it is shown that the current THD reduces when the PV production rises. Here, the fall in current THD with generation has most likely to do with the increasing dominance of the sine wave (inverter output) generation current increasingly overwhelming generally low-level load current.

[B2-1379(IR)] describes the integration of a distributed generation unit consisting of 4 gas based generator units (4100 kVA) in a MV grid in Iran. The modeling of the MV feeder and the DG is presented. For the case described in the paper, the harmonic distortion does not exceed the limitations.

Propagation of harmonics/ case studies

An overview of the techniques for the modeling and analysis of harmonics is presented in [B2-1262(DE)]. Also research needs are identified. Due to the huge number of harmonic sources with relative low rated power, the harmonic amplitudes are small and the phase angles vary in a wide range. Both statistical and probabilistic models are required to analyse group effects. Also gaining detailed knowledge of resonance conditions is seen as a major challenge.

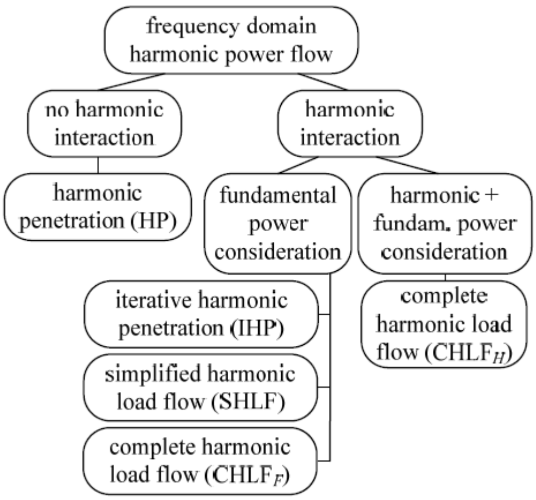

Figure 12: Classification of harmonic power flow methods [B2-1262(DE)]

In [B2-1289(PT)] measurements in the Portuguese MV and LV grids are analysed. A high 5th harmonic voltage is identified. Harmonic analysis models for simulation have been created to gain better understanding of the phenomena. It is caused by resonance created by the interaction of capacitor banks and the system. Since the detection of the problem, measures have been taken, resulting is a steady reduction of the problem. The paper also addresses even and triplen harmonics. The even harmonics are caused by wind farm. The origin of the triplen harmonics is identified as public lighting.

A method based on fuzzy-genetic algorithm for the optimal reconfiguration of capacitors is addressed in paper [B2-1316(IR)]. The method aims at the reduction of power losses and the reduction of the total harmonic distortion.

Simulations are carried out on a 33-bus radial distribution system.

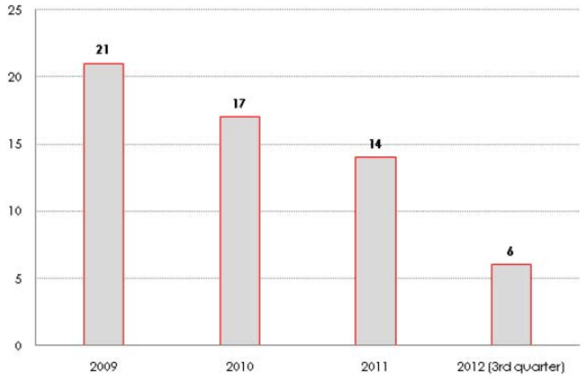

Figure 13: Reduction of the 5th harmonic voltage in the Portuguese network due to measures to reduce resonances; weeks not in accordance in 5th harmonic are shown [B2-1289(PT)]

In [B2-0256(NL)] the impact of ripple control signals on LV customers' installation is addressed. In the studied network, ripple control signals are sent at a frequency of 1024 Hz. Customer complaints are registered due to flicker and bad operation of double tariff meters although the mains signalling voltage magnitude satisfies the EN50160. The impedance spectrum is determined by means of simulations. A resonance frequency is identified close to the signalling frequency. The simulation therefore reveals an increase of the ripple signal voltage at the customers' installation.

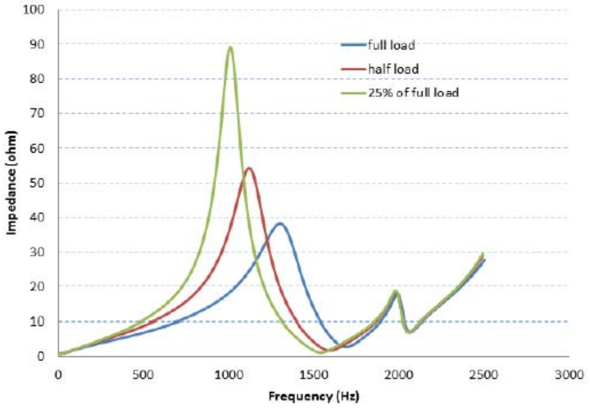

Figure 14: Simulation of the impedance spectrum for different loading situations according to [B2-0256(NL)]

Discussion and further research topics

What are the most urgent aspects to study in the context of frequency components between 2 to 150 kHz?

In which circumstances should active filter devices be preferred to passive ones, in the context of LF disturbances mitigation?

Papers of Block 2 (B2)

Paper No.	Title	MS a.m.	RIF	PS	Other Sess.
0066	Technical Considerations in Harmonic Mitigation Techniques Applied to The Industrial Electrical Power Systems			X	
0096	Reducing Harmonic Distorsion and Correcting Power Factor in Distribution Systems			X	
0104	Power Quality Generated from DFIG with Different Types of Rotor Converters			X	
0195	A Possibility to Measure Power Quality with RC-Divider	X			
0209	Spread of High Frequency Current Emission		X		
0256	Impacts of Ripple Control Signals at Low Voltage Customer's Installations			X	
0291	Street Lamps Aggregation Analysis through IEC 61000-3-6 Approach			X	
0352	Performance Evaluation of Energy Meters in Non-sinusoidal Environments Based on IEEE 1459 Standard				
0408	Harmonics - Another Aspect of the Interaction Between Wind-Power Installations and The Grid	X			
0434	CPC and IEEE Power Theory – Application for Off-Line Waveform Data Analysis			X	
0605	Harmonic Assessment on Power Networks - Application to Portuguese Distribution Grid	X			

0615	A Practical Investigation for Reassessing the Performance of Electronic Ballasts Commercially Available on the Market in Egypt			X	
0650	Propagation of Harmonic Emission from the Turbines through the Collection Grid to the Public Grid.			X	
0763	Comparison of Circuit Configuration and Filtering Performance between Parallel and Series Hybrid Active Filter	X			
0778	Preliminary Tests Results about E-Car Harmonic Emissions	X			
0793	The Use of Recursive Least Square to Determine the Model Parameters of a Transformer in Different Frequencies			X	
0999	Impact of Higher Frequency Emission above 2 kHz on Electronic Mass-Market Equipment			X	
1002	Eliminating Null Wire, Improving Power Quality and Loss Reduction by Designing Three Phase Low Voltage Distribution Network Passive Device				
1029	Laboratory Study of Power Quality of Air Condition Systems Individually and Simultaneously with Compact Fluorescent Lamps (CFL)				
1036	Grid Impact from PV-Installations in Northern Scandinavia	X			
1037	Harmonic Analysis and Simulation Research of 10kV Series Reactor Failure			X	
1052	Towards a Standardized Measurement Method for Voltage and Current Distortion in The Frequency Range 2 to 150 KHz	X*			
1120	Efficient Immunity Testing of Smart Meter Devices in the Frequency Range 2-150 KHz			X	
1128	Analysis of the Impact on the Surrounding Loads for the Application of Shunt Active Power Filter			X	
1168	Emission Levels above 2 kHz - Laboratory Results and Survey Measurements in Public Low Voltage Grids	X*			
1256	Comparison of Various Reactive Power Definitions in Non-Sinusoidal Networks with the Practical Data of Electrical Arc Furnace				
1262	Chosen Aspects for Harmonic Analysis in Distribution Networks			X	
1271	EMI of Emissions and Signals in the Frequency Range 2....150 kHz	X*			
1289	Characterization of Voltage Harmonic Distortion in the Portuguese Medium and Low Voltage Grids			X	
1316	Optimal Reconfiguration and Capacitor Allocation in Unbalanced Distribution Network Considering Power Quality Issues				
1322	Precision Check of Energy Meters under Non Sinusoidal Conditions			X	
1372	Significant Reduction of the Current and Voltage Harmonics and Balance the Unbalanced Phases with Multifunction Parallel Active Filter-AFQ in Kerman Motors Automobile Factory in Bam-Iran				
1379	Harmonic Analysis of Integrating a DG Unit to the Distribution Network – Case Study				
1391	Electromagnetic Compatibility Between Electronic Loads and Automated Meter Reading Systems Using PLC			X	
1397	Detection of Harmonic Pollution Ranking of Non-Linear Load in the HORMOZGAN Distribution Power System by Using New Power Quality Index				
1417	On-Line 2 To 150 kHz Grid Impedance Meter			X	
1435	PLC Noise and Impedance Measurements on Loads and in the Distribution Grid			X	
1480	Harmonic Penetration Assessment in Residential Areas			X	

X* = although these papers are referenced under Block 2, their oral presentation will take place in the main session *during Block 1*, i.e. between 09h00 and 10h30 (the concerned topics are actually on the borderline between Blocks 1 and 2). See final program on http://www.cired2013.org/

BLOCK 3 : VOLTAGE PROFILE, VOLTAGE FLUCTUATION, UNBALANCE AND VOLTAGE DIPS

This block gives a summary of the papers dealing with voltage magnitude related disturbances, to which belong questions of voltage level, voltage flicker, unbalance and dips. Especially the voltage level section has some overlapping, especially with session 3 (operation) but also with session 4 (integration of renewables) and session 5 (network planning)

In this year's conference this block is dominated by voltage level issues related to distributed renewable energy sources. The increasing amount connected to the public grid raises obviously some concern regarding power quality, especially maintaining voltage level within limits. However, most of the papers originate from universities and not from utilities. In [B3-0544(DE)] the large scale renewable integration in the transmission system and the distribution system is analysed. As a result the authors state that the impact on power quality - namely dip amplitude, flicker and harmonics - is rather small and controversial, leading to degradation as well as improvement. The authors of [B3-0143(UK)] report that the monitoring of power quality on a low voltage radial feeder connecting a significant amount of PV generation reveals no critical power quality degradation during periods of PV generation.

Impact of renewable on voltage profile

The most significant effect seen during power quality monitoring in a LV grid [B3-0143(UK)] was a rise in voltage associated with PV generation, being most significant in the middle of the feeder. Such mid-feeder voltage rise maybe of some concern to the networks operators when planning to add substantial PV to LV systems.

In [B3-1481(UK)] a study undertaken on a real network investigates possible problems regarding voltage rise and unbalance. Conventional (additional parallel cables) or innovative (on-load tap changer (OLTC)) mitigation solutions from a utility point of view, may offer partial improvement in reducing voltage magnitude and unbalance. Their effect was found to be rather broader than the needed local mitigation of the voltage rise.

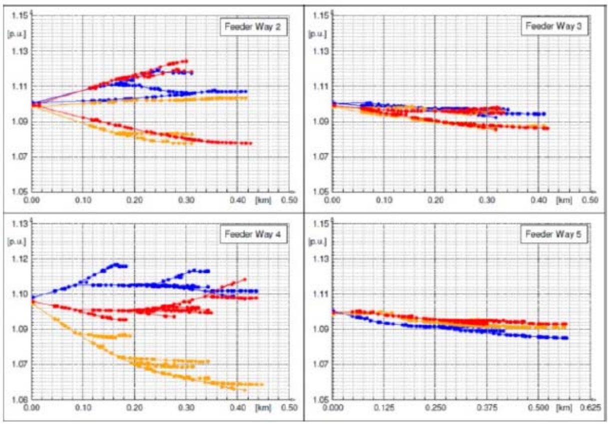

Figure 15: High Generation Voltage-Distance Plots (V_{Grid}=1.06p.u) [B3-1481(UK)]

A Monte Carlo-based assessment of impacts from residential PV generation on a real LV network for the North West of England is presented in paper [B3-1419(UK)]. The results for the studied network indicate, as expected, that PV location plays a significant role on the potential impacts on voltage. In addition, it was also observed that longer feeders present voltage issues sooner than shorter ones. Moreover, for this particular case study, there were no impacts for penetration levels up to 20% (although this becomes 10% with a higher bus bar voltage). The analysis of the effects of higher bus bar voltages also highlighted that networks with higher tap position will pose a significant constraint for the connection of PV systems. Changing fixed tap positions, however, might not necessarily be the solution as peak load (evening) will not be coincident with PV generation.

In order to increase the grid hosting capacity for PV integration, the main limitation is the voltage increase along the feeders due to higher generation power than demand. Paper [B3-0380(DE)] discusses the major research results obtained within the PV GRID project. Several technical solutions have been identified in order to increase the hosting capacity of existing distribution grids. Among these solutions, one can find on-load tap changer MV/LV transformers, advanced voltage control (HV/MV transformer), static VAR control, DSO storage, booster transformers and advanced closed-loop network operation.

A methodology to estimate the critical PV penetration level and the critical load level beyond which active measures in the LV distribution grid may be required are discussed in paper [B3-0391(BE)]. It is done by analysing the margin left to the DSOs to operate the tap changers (VOM) in a conservative way, to avoid over-voltage or under-voltage problems all over the grid with an unspecified time scope. Concerning the PV influence, if it is connected at the beginning of the feeder, for low/medium PV penetration levels, the VOM is larger than if the PVs are connected at the end of the feeder. That means deferring the need of active voltage control measures in the LV grid (the passive operation). In the contrary, the combination of factors, (1) the load increase, (2) more DG, (3) MV grid voltage

fluctuations and (4) the reverse power flow may reduce drastically the operational margin, thus accelerating the need of active measures in the distribution grid.
Paper [B3-0469(ZA)] presents an overvoltage protection scheme to prevent system overvoltage by limiting the amount of power supplied by the PV plant. The results of the simulations show that system overvoltage in grids with PV generation can be avoided by controlled switching of solar panel strings.
Paper [B3-0674(IE)] presents details of an electric vehicle impact assessment trial currently being undertaken in Dublin. The first stage of the project investigated the potential impact from electric vehicle charging on the operating conditions of existing residential network. During the trial, electric vehicles were driven and charged by typical residential electricity customers. It is shown that even though the average value recorded may still be comfortably within the limits, there may be short term occurrences where the values are recorded outside the acceptable limits.

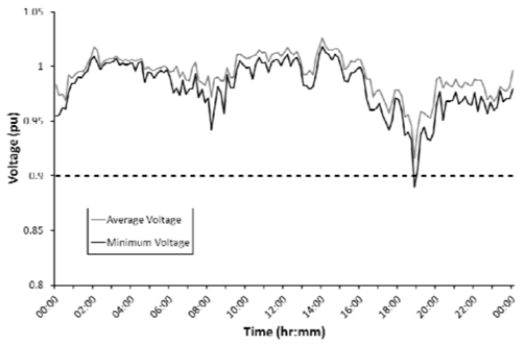

Figure 16: Voltage and current profiles for a household showing an example of the minimum voltage falling below the lower permitted limit of 0.9 pu [B3-0674(IE)]

Paper [B3-0861(BR)] presents a methodology for assessing the impact on distribution networks due to the inclusion of electric vehicles in the network. Through simulations in real networks it is possible to evaluate the impact on various components of the power grid: sub transmission lines, HV/MV SS transformers, MV primary network, MV/LV transformers and LV secondary network. Thus, issues such as diagnostics, load, voltage profile, unbalance and losses were considered.
Paper [B3-0405(BE)] proposes the use the concept of reconfiguration as a solution to meet the challenge of keeping the voltage profile within the acceptable limits in the presence of DG in LV grids. By reconfiguration, the maximum voltage at each node of the test network can be kept within limits, thus mitigating the over voltage problem due to increased DG penetration. Since the reduction in number of switching due to reconfiguration will help reduce the operation cost, this paper incorporates the objective of minimizing switching as well. It is also shown in this paper that reconfiguration can help in deferring the investment required in a transformer like adding on load tap changer.
It is confirmed in paper [B3-1273(JP)] that under the influence of the PV output fluctuation, the number of tap changing operations and the amount of voltage deviation greatly increase in distribution grids. However, some smoothing effect of PV output fluctuations must be considered and reduce these consequences to some degree. By changing the tap width, the voltage regulation is perfected and the amount of deviation of the voltage appears to be reduced. The paper concludes that when the lifetime of OLTC and the number of operations have to be assessed, it is in fact necessary to consider the smoothing effect of PV output. Based on the analysis of the power spectrum of solar radiation intensity, such a smoothing effect can be evaluated within OLTC operating range on the scale of distribution system.

Paper [B3-0609(FR)] describes a project aiming at creating value from the large amount of data from smart meters in terms of distribution network planning and power quality improvement. The prototype presented in the paper consists in automatically running a “playback”, day after day, of the system. This is made possible by projecting the individual measured load curves on the network models imported from the GIS into a grid modelling software. The tool builds dashboards and “snapshots” of each LV network element enabling network resizing or phase balancing for voltage quality enhancement purpose.

Paper [B3-0139(CN)] presents a test platform for grid-connected photovoltaic inverters (PVI). The testing methods and procedures of PVI are analysed and the development course of this detection platform is described in detail. The detection platform consists of PC machine, interface card and a data bus, AC / DC programmable power supply, power meter, RLC adjustable load, simulation of the impedance network and the measured equipment. Electric performance test, protection function test, and EMC tests, including harmonic emission, constitute the main function of the detection platform.

Voltage and reactive power management by renewables

An important topic is the voltage and reactive power management of PV inverters. In [B3-0644(DE)] the authors conclude concerning the parameterization of voltage dependent reactive power control (Q control) by solar inverters in low-voltage networks that this will probably not cause any stability issues. However, there seems to be a lack of standardization.

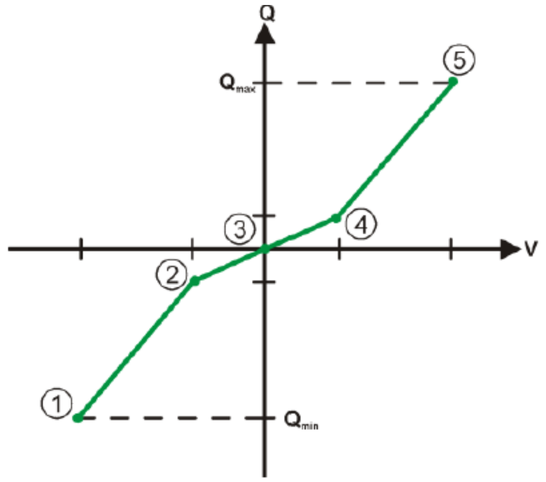

Figure 17: Example for Q-V-control curve [B3-0644(DE)]

A strategy for decentralized Q control is given in [B3-1222(DE)]. Based on simulations with a centralized controller with total observability, one can derive almost optimal Q-U curves for each single controller. In operation the decentralized controllers need no communication. Based on monitoring results of the Czech grids, paper [B3-1142(CZ)] discusses the possibility of using the Q-V regulation of some DG units to control the voltage, in combination with OLTC control. In paper [B3-1293(DE)], different control schemes of decentralized generation reactive power have been implemented in order to assess the impact of reactive power flow (injection/absorption) on the operation of the future distribution networks. The results show that controlling of the reactive power of the decentralized generation plays an important role in the future distribution networks. The simulations were conducted with data of a real life distribution network including MV and LV levels.

It is shown in paper [B3-0263(AT)] that by changing the cos(φ) of the PV inverter an enormous increase of installed PV capacity is possible. It is also shown that a rigid cos(φ) setting at the PV inverters with voltage reduction by the use of regulated distribution transformers leads to higher power losses and thermal bottlenecks. A voltage reduction of 5% is quite enough and a further reduction requires not only a controllable local power transformer with a larger control range but also network expansion (larger cross-sections, double cable …). Another effective measure to increase the installed PV power is to reduce the active power after reaching the upper voltage limit.

Paper [B3-1020(IR)] considers appropriate methods for handling DG in a power flow program (developed using MATLAB®) in order to study unbalanced distribution networks. It also investigates the impact of DG location and control mode (V- or Q-control) on the voltage profile, losses reduction and voltage unbalance factor (VUF). For the considered particular study, it is concluded that operation of DG in V-control mode not only decreases VUF and voltage deviation but also decreases the total power losses.

Energy storage systems to improve voltage profile

The unbalance of load and PV generation is usually responsible for unwanted voltage rise. That is one reason for energy storage systems emerging and their grid integration becoming more relevant. In a smart grid laboratory connected to a network model in real time digital simulator (RTDS) the authors of [B3-0504(UK)] tested the application of a battery storage system, phase individually controlled by voltage level. Significantly improvement of level, and therefore also voltage unbalance was achieved. The amount of needed energy storage devices is not specified.

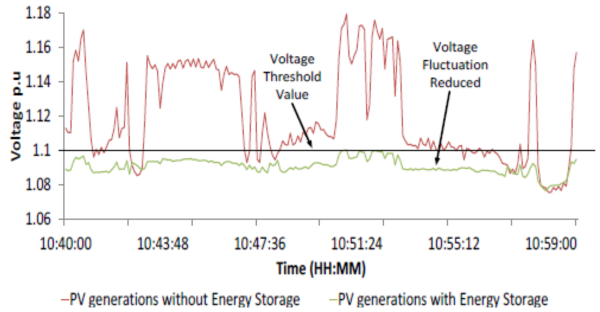

Figure 18: Voltage rise reduction by energy storage at time, summer day [B3-0504(UK)]

To ensure an additional benefit for highly PV penetrated distribution systems, different voltage control strategies for PV and PV storage systems are introduced and assessed in paper [B3-1396(DE)]. The introduced $P_{Bat}(V)$-$Q_{PV}(V)$-$P_{PV}(V)$ control strategy provides a solution to handle the trade-off between curtailing energy and violating voltage guidelines. A high self-consumption under minimum voltage violations is achievable in the given analysed scenario using this strategy. The conclusion is thus that PV storage systems capable of voltage control can provide a benefit to grid operators as well as to storage system owners.

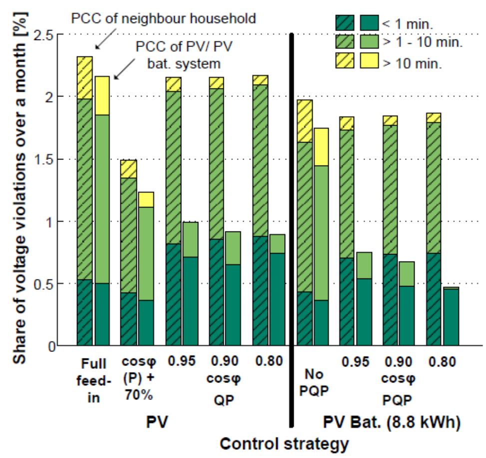

Figure 19: Voltage violations at the PCC of the neighbour household and at the PCC of the PV/ PV battery system for different control strategies [B3-1396(DE)]

In [B3-0699(UK)] electric vehicles (EV) with a battery capacity of 24kWh each are utilized as buffer. Case studies with different penetration rate of PV and EV are analysed. In each scenario, an uncontrolled charging regime from 9:30 to 16:30 was applied and the voltage profile along the 400V feeder was evaluated. An interesting research question for future work in that context is the impact of the extra charging cycles on the batteries expected lifetime.

Active devices to manage the voltage profile

In [B3-0007(IR)] alternative controllers (e.g. wavelet-based multi-resolution PI controller) are successfully implemented for better tracking control performance (PV) and more robustness and precision against the disturbances in an islanded micro grid. Further new concepts in controller design are applied by the authors of [B3-1345(IR)] to a DVR control. The 2 objectives of the control are active harmonic filtering and dip mitigation. The optimal parameterization for those tasks was found by a particle swarm optimization algorithm.
The combination of an UPFC with PV, feeding the DC circuit is presented by the authors of [B3-0346(IR)]. The device acts as an interface for PV and on the AC as active filter and dip compensator.
Paper [B3-0068(EG)] presents a novel method to enhance the voltage profile of a PV-wind hybrid system suitable for grid connection. A single stage power electronic converter is used for maximum power point tracking (MPPT), feeding AC power to the grid and reactive power compensation to enhance the voltage profile of the system.
The optimal number of compensating devices (STATCOM), their rating and number is analysed in a 33kV test system by the authors of [B3-1147(IR)]. Goal of the optimization was a flat voltage profile and alternatively minimum I^2R losses.
A new idea for the voltage regulation of radial distribution systems with DG unit at the end of the line is presented in paper [B3-0496(BE)]. It is based on the combination of two different control methods being OLTC action and reactive power compensation. The OLTC action is used in the predefined range (based on the permitted range of voltage) and a D-STATCOM manages the rest of the voltage violations. Simulation results reveal that the proposed method enables to efficiently manage the voltage control problem of a radial MV distribution system in the worst working conditions. Moreover, as the D-STATCOM is only used in the extreme voltage conditions (when OLTC cannot work anymore), it does not considerably increase network losses.
Paper [B3-0881(NO)] investigates the capability of controllable DERs and converter-interfaced loads (CILs) in a microgrid as shunt active power filters. The controller under study successfully manages any variation in active power feeding into the grid and simultaneously the inverter can be effectively utilized for power conditioning without affecting its normal operation of power generation. Inverter with the proposed approach eliminates the need for additional power conditioning equipment with operating as a shunt APF (which can be more than 100 $/kVA in low voltage level.)

The advantages of conventional SVCs in industrial installations are pointed out in [B3-0181(SE)]. Performance figures of recent installations are given, proofing the system as solid and robust solution for steady state voltage control and dynamic voltage support during dips. A hybrid SVC-STATCOM solution is presented in [B3-1045(FI)]. Reduced installation cost and especially low losses make the configuration attractive.

Voltage unbalance

Voltage unbalance in a MV network is studied in [B3-0530(UK)]. Origin for unbalance is the assumption of uneven power factor in the single phases, randomly chosen from a normal distribution during a Mont Carlo simulation. As result the level and propagation of unbalance in the network can be estimated and weak area in the network can be identified.

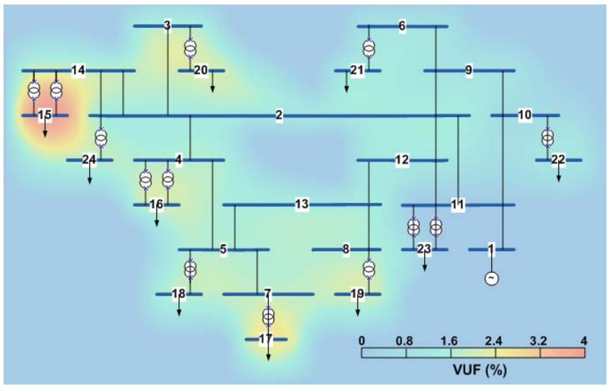

Figure 20: “Heat map” of the network indicating the areas affected by unbalance [B3-0530(UK)]

With small, single phase PV devices connected to the LV grid, uneven voltage rise in different phases leads to voltage unbalance in the system. This is illustrated by the authors of [B3-1303(BE)], addressing the overvoltage and unbalance issue, arising together (Figure 21). A new index, derived from the concept of symmetrical components, was introduced in order to quantify overvoltage and voltage unbalance in radial LV distribution feeders. It can be used for the investigation and further quantification of the hosting capacity of a given grid. Reactive power management of the DG units in order to reduce the maximum overvoltage is effective but it has a negative impact on the voltage unbalance.
Further counter measures regarding voltage unbalance are investigated in [B3-0387(BE)]. Optimization techniques with a constrained maximum number of connection-phase-swaps show that some improvement is possible but the effort for compensating weekly or even seasonal changes in unbalance is too high. Balancing the grid by phase-individually controlled three phase inverters significantly improves grid conditions. The proposed control injects the majority of the produced power in the phase with the highest power consumption, based only on local voltage information. As simple, conservative method from a utility

prospect, the installation of additional parallel cables near substations is mentioned in [B3-1481(UK)].

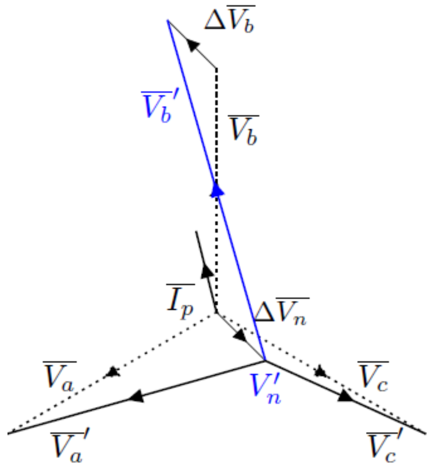

Figure 21: Phasor diagram of the three-phase voltage at the end of the feeder [B3-1303(BE)]

Paper [B3-0795(HR)] shows that the integration of a three-phase generating plant in an asymmetrically loaded low voltage line has a negative impact on losses and voltage profile. Due to the consumption asymmetry in the line, the energy does not flow in the same direction in each phase of the line. Therefore, at the end of the line the voltage is lower in the phase with the dominant consumption (as expected), while, at the same time, in phase with the dominant production voltage is higher. It is therefore concluded that measurements of voltage unbalance in low voltage networks should be obligatory as a routine analysis prior to power plant connection, and, if asymmetry is intolerable, load balancing procedures should be implemented.

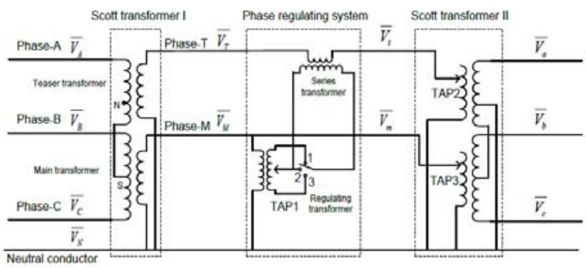

Figure 22: The diagram of the proposed voltage balancing system [B3-0246(UK)]

Paper [B3-0246(UK)] introduces an LV radial feeder voltage balancing method using Scott transformers. It converts an unbalanced three-phase voltage into a balanced three-phase voltage at either a downstream location on the feeder or at a three-phase load supply point. A "small scale" physical voltage balancing system using the proposed method has been established and tested on an LV feeder in the laboratory. Test results demonstrate that the system maintains a balanced 3 phase voltage by compensating for voltage rises and voltage drops caused by single phase load variations. Compared with the power electronics based AC-DC-AC solution, this one based on transformers and tap changers has a longer lifetime and does not inject harmonics into the LV network.

Flicker caused by large installations

Typically flicker problems arise in context with large industrial installations with fluctuating loads, in most cases electric arc furnaces (EAF). Analysis of horizontal (within the same voltage level) and vertical flicker propagation are given in two papers. A method for flicker propagation is given in [B3-0374(SI)]. The method is based on the use of interharmonics and frequency dependent transfer factors and can also be used for the summation of voltage fluctuations. The approach was verified by measurements from a case study with two EAFs as flicker source. Flicker propagation analysis based on measurements is presented in [B3-0438(RS)].

In the case of EAFs the most effective flicker mitigation method is the use of compensation devices, namely the classical static var compensator (SVC) and the more advanced VSC based STATCOM. In [B3-0438(RS)] some preliminary results of flicker reduction after installation of a STATCOM are given. According to the authors the reduction factor exceeds 2. Actually this factor is depending on the fine tuning of the controller and possible trade-offs between optimum flicker reduction and optimum Q-compensation.
A detailed EAF model based on the non-linear V/I-arc characteristics and random arc voltage variation is presented in [B3-0719(IR)]. Furthermore the authors added a SVC model with an advanced controller including a predictive algorithm. No information of achieved flicker reduction factors is provided.
A hybrid flicker compensator, consisting of a large SVC and a small STATCOM, combining the advantages of both, is analysed in [B3-1045(FI)]. Simulation results are promising, giving flicker reduction factors in the range of 4.7. A good performance combined with reduced installation cost and especially low losses makes the configuration attractive.
A special case of flicker is described in [B3-1272(NO)]. Although low flicker values (Pst and Plt) are measured, severe lighting flicker was observed by low voltage end consumers. The origin of that disturbance was a pump station with three large induction motors. A seventh harmonic current, modulated with approximately 2 Hz was detected. Obviously some cases of fluctuating harmonics, causing visible flicker, are not covered by the standard flicker meter algorithm.
The impact of a 9 MVA wind farm on the flicker level at the connection point is investigated in [B3-0491(CN)].

Measurement of the wind farm's current was used for simulating the flicker with virtual grid impedance.

Flicker and voltage fluctuations related to small appliances and EV

Customer complaints due to rapid voltage changes and flicker are reported in [B3-0238(HR)]. In order to guarantee a satisfying level of power quality according to EN 50160 the authors propose that the emission of a single customer regarding the transient voltage drop in the substation) should not rise above 4% of the limit.
[B3-1302(NO)] puts his focus on efficient room and water heating appliances and possibly arising flicker problems. Flow heaters with rated power of several kW are frequently turned on and off in time intervals from 0.5 to 2 seconds to rapidly adjust the water temperature. Heat pump compressors are sometimes installed without soft starter. The reasons are, amongst others, the price of an already expensive system and the fact that some manufacturers cannot supply a three phase inverter controlled compressor for the Norwegian 230V phase-to-phase-system

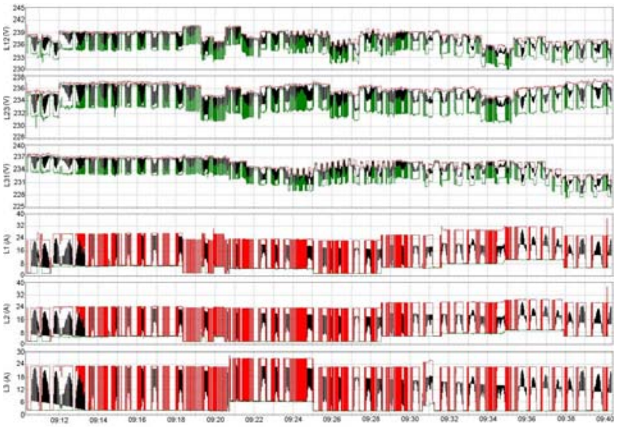

Figure 23: Very frequent load changes (red/black current), and voltage changes (green/black) due to tankless water heater in a residential home [B3-1302(NO)]

Special charging techniques of EVs can create remarkable flicker. Turning off the charging current for a short time during the charging cycle (battery status check) and pulse shaped maintenance charging led to an increase of measured flicker value from 0.4 (background level) to 1.1 pu at the wall outlet [B3-1302(NO)]. With strong grids neither normal charging nor fast charging should be a cause for local voltage quality problem. Thorough planning by the network operator is very important before installing fast charging stations. The coincidence factor of large scale charging of electric vehicles might be a reason for concern and smart charging to minimize additional load during existing peak power hours should be taken seriously [B3-1353(NO)].

With the phase out of incandescent lamps, it might be necessary to revise the existing flicker assessment method, which is based on the classical 60 W incandescent lamp. A valuable input is given by the authors of [B3-0425(US)], providing characteristics of new lighting equipment. It is found that the flicker sensitivity to fluctuating voltage in most cases is significantly lower compared to the incandescent lamp. However, in two cases non-dimmable LED lamps were found to be more sensitive. For dimmable CFL lamps, the usage of dimmers can be expected to increase their flicker susceptibility and in some cases the flicker sensitivity may be actually worse than the incandescent lamp. However, the impact of dimmer operation on the flicker sensitivity of dimmable LED lamps is comparatively less. In addition to lamps, a few non-lighting voltage sensitive household appliances were also subjected to fluctuation testing to determine their voltage fluctuation immunity levels. No malfunction was observed during flicker tests.

Voltage dips

The results of a method to estimate the voltage dip origin, is presented in [B3-0655(IT)]. The method is based on (1) the detection of events correlated to a signal coming from HV line distance protection and (2) the "detailed analysis" of MV monitored events characterized by correlated occurrence time and relevant to measuring unit belonging to a common HV grid

Table 2: HV origin voltage dips against the immunity curves (IEC 61000-4-11 and -34), [B3-0655(IT)]

Legend:	Events under class 2 curve	Events under class 3 curve	Events in class 2 immunity area
(%) of the HV origin monitored events	20,1	6,6	79,9
(%) of all the events monitored at MV level	7,1	2,3	28,3

On average in Italy about the 34% of voltage dips monitored in MV network are coming from the HV network but only the 10% of all the monitored events can be correlated to any HV lines distance protection activity.
A new strategy in determination of dip origin in DG is presented in [B3-0370(MY)]. It is based on the use of a radial basis function network (RBFN, special type of neural network). The network is trained by simulation with varying fault location and fault resistance. After the learning phase, the proposed method is computationally efficient and does not involve complex calculations. However, it would be interesting to know how the algorithm reacts on topology changes in the grid.

Usually a disturbance or a fault in a grid leads to a sequence of events with the same origin. The authors of [B3-0712(ES)] try to find typical, repeated patterns in recorded sequences. Once those patterns are known, they can be used to better describe fault situations and their evolution. They might be useful to predict future failures by recognizing the events that match the early stages of a pattern.
In [B3-0238(HR)] the authors pinpoint the fact that not only faults lead to voltage dips. Voltage and current recording, triggered by customer complaints, clearly indicated that inrush currents (motor starting) lead to corresponding voltage dips.

Dip mitigation

An inter-line dynamic voltage restorer (IDVR) is proposed in [B3-0036(EG)]. Two back-to-back Dynamic Voltage Restorers (DVRs), sharing a common DC bus are installed to independent distribution feeders. One of the involved feeders is feeding a critical load. When this critical feeder is subjected to voltage sag, its DVR will compensate this sag via voltage injection. Renewable energy sources connected to the DC bus can help to maintain a stable DC voltage. However, the methods in this paper need at least one healthy feeder.

In [B3-0040(MY)], an enhanced premium power quality (PPP) configuration is proposed to effectively mitigate power quality disturbances using a combination of conventional circuit breakers, solid state circuit breakers, active power conditioner, active voltage conditioner and a grid-connected DG set. Depending on the remaining voltage during a voltage dip, different operation modes are activated to provide a stable and reliable supply for sensitive customer.

Dip immunity

Recent developments in European grid code regulations demand the inclusion of decentralized generation (DG) into their requirements.
In [B3-1009(BE)] compliance testing of inverters according to standards for voltage dips is performed. The main objective is to determine voltage tolerance curves and trip behaviour. Inverters with and without transformer are tested, taking into account (1) pre-fault voltage level, (2) actual power output and (3) timing of switching within the cycle. The reaction of the devices was classified as seen in Figure 24. It can be concluded that some types of recent inverters are able to ride through short dips while after longer dips the inverter will take much more time to resynchronize.

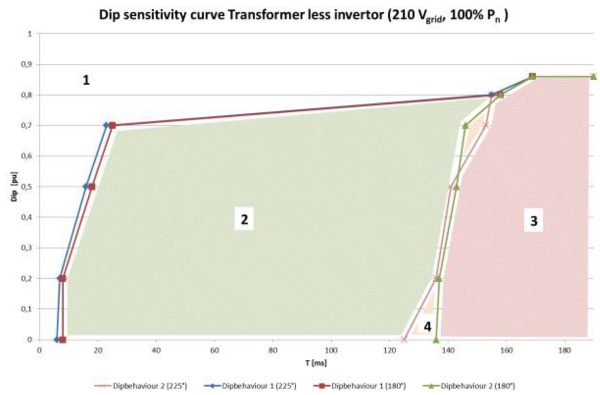

Figure 24: Example voltage tolerance curve, (1) normal operation, (2) disconnection and automatic reconnection, (3) 'hard' disconnection, (4) uncertainty range due to starting point of dip within cycle [B3-1009(BE)]

Gas-engine-driven generators, as a part of Europe's DG, need to comply with fault-ride-through (FRT) requirements; and therefore procedures to receive admission are formed. Simulation stands for the most economical way to achieve this, however the simulation models need to be validated beforehand with the help of actual low-voltage-ride-through tests. Paper [B3-0260(AT)] highlights the crucial steps of the validation procedure and questions the common practice of stability analysis and its applicability on gas-engine-driven units. Furthermore, events and operating conditions that may be critical and have not been considered so far for stability investigation are highlighted.

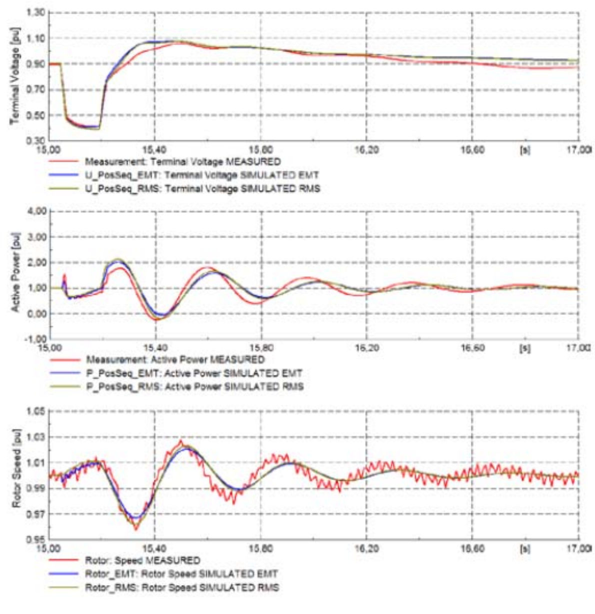

Figure 25: FRT of a 5.5 MVA / 10.5 kV gas-engine-driven generator; voltage dip lasting 150 ms [B3-0260(AT)]

Paper [B3-1429(NO)] presents computer simulations results of a simplified radial 132, 66 and 22 kV system including a 5MVA hydro power unit. The study was performed in order to assess the hydro unit's fault-ride-through capability, with special emphasis on the Critical Clearing Time (CCT) of the unit. The results show that there is a significant difference in CCT when the disturbance reflects a realistic fault in the system, i.e. a fault that reflects changes in both voltage magnitude and phase angle, compared with a disturbance for which only the change in voltage magnitude is taken into account. Since requirements regarding fault-ride-through capability found in most of today's national grid codes are defined via a specified transient voltage vs. time disturbance profile, the paper therefore suggests that these requirements should be extended to include also corresponding phase angle vs. time disturbance profiles.

Paper [B3-0859(UK)] discusses the fault ride through capability of a generic IEEE distribution system with and without renewable energy penetration. The results show improvements in the system frequency and terminal voltages during and after the fault by comparing the base case without renewables and the cases of 50% penetration of renewable energy. The system rides through the fault in the base case is slower than the cases of renewable penetration. In addition, the terminal voltages at the most severe buses from the applied fault dropped to 0.35 p.u. in the absence of renewable units' case and dropped to approximately 0.5 p.u. in the cases of including them. In conclusion, the simulation results of this paper illustrate the DG units based on renewable resources improve the system capability to ride through faults.

Power quality measurement

An automated testing tool for PQ meters is presented by the author of [B3-1362(US)]. It is possible to create test signals out of simulation or recorded disturbances as well as standardized test signals. In [B3-1077(HK)] the creation of PQ test patterns according to IEC61000-4-30 and with extended requirements on harmonics mentioned in IEC61000-4-15 is described. Different levels of test signals can be provided.

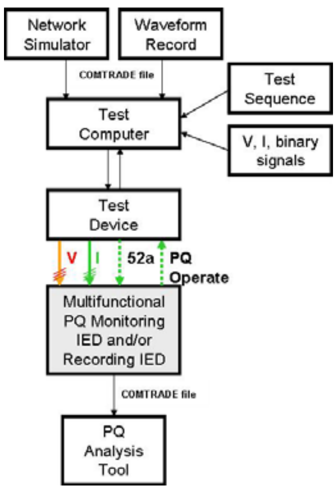

Figure 26: Test system block diagram [B3-1362(US)]

A critical review of current PQ measurement practice, focusing on measurement intervals and statistics (quantiles) was done by the authors of [B3-1174(DE)]. The analysis is based on a comprehensive database of more than 1000 measurement-weeks in 14 different public LV grids in Germany. Different aggregation intervals (1 min, 10 min, and 30 min), aggregation methods (mean, maximum) and assessment quantiles (95%, 99%) were applied on voltage magnitude, harmonics and unbalance. Generally the suitability of definitions in the existing standards is confirmed.
A zero sequence system based method used to detect transients in the power grid is proposed in [B3-0880(BR)]. The algorithm is rather simple and computationally efficient and can be easily implemented in low-cost meters.

As in recent years, several papers propose the application of wavelet transform as alternative method in power quality measurement. In [B3-0207(EG)] the detection of unacceptable flicker by means of wavelets is demonstrated. Also the detection of dips and swells is possible with WT [B3-1038(IN)], [B3-0920(EG)]. The authors of the latter claim that there is a need for changing the power quality monitoring devices' design to be based on Wavelet analysis besides Fourier analysis.
However, results are presented in those papers mainly in form of figures, allowing a qualitative evaluation. Implementation of an algorithm providing a precise figure, allowing comparison with existing methods, and arguments for the advantage over conventional methods are rare.

Discussion and further research topics

What is the future of flicker? To what extent is the modern lighting equipment less sensitive to voltage fluctuations? How should the limits (either global flicker level on the grid or individual emission limits from fluctuating loads) be revised and adapted?

Voltage control in LV distribution grids with large amount of DG: how to find the best societal compromise and management of the responsibilities? (Standardisation needs for generators and invertors and associated technical issues? Centralised voltage control techniques?)

Papers of Block 3 (B3)

Paper No.	Title	MS p.m.	RIF	PS	Other Sess.
0007	Controller Designing to Improve the Voltage and Frequency Stability of a Hybrid AC/DC Micro-Grid				
0036	Renewable Energy Fed Inter-Line DVR for Voltage Sag Mitigation in Distribution Grids		X		
0040	Power Quality Improvement Using Active Conditioning Devices in a Premium Power Park			X	
0068	The Effect of Reactive Power Compensation on Voltage Profile of Hybrid PV-Wind Grid Connected Power Generation System				S4
0139	The Design of Performance Test System for Grid-Connected Photovoltaic Inverters				S4
0143	Measurements of Power Quality and Voltage Level Effects Associated with a Photovoltaic Cluster on a Domestic Housing Estate.			X	
0181	FACTS for Voltage Stability and Power Quality Improvement in Mining			X	
0207	Suggested Flicker Monitoring System Based on Wavelet Transform		X		
0238	Customer's Impact on the Distribution Grid			X	
0246	Voltage Balancing in Low Voltage Distribution Networks Using Scott Transformers				S3
0260	Low Voltage Ride Through Capability of Gas Engine Driven Units				S4
0263	Limits of the MV/LV Grid Supplied by Renewable Energy				S3
0346	A New Approach with Modeling the Combination of Unified Power Quality Conditioner and Photovoltaic Arrays				
0370	An Alternative Voltage Sag Source Identification Method Utilizing Radial Basis Function Network		X		
0374	Calculation of Flicker Propagation in Part of the Slovenian Network with Voltage Interharmonics	X			
0380	Technical Solutions Supporting the Large Scale Integration of Photovoltaic Systems in The Future Distribution Grids				S4
0387	Phase Switching and Phase Balancing to Cope with a Massive Photovoltaic Penetration		X		
0391	Constrained PV Penetration Level in LV Distribution Networks Based on the Voltage Operational Margin				S3
0405	Reconfiguring Distribution Grids for More Integration of Distributed Generation				S4
0425	Flicker/Voltage Fluctuation Response of Modern Lamps Including those with Dimmable Capability and Other Low Voltage Sensitive Equipment	X			
0438	Flickers - Cause, Impact on the Environmental and Mitigation			X	
0469	Controlled Switching Scheme for Photovoltaic Generation for Reducing Overvoltage				S3
0491	Voltage Flicker Assessment of a Weak System Integrated Wind Farm			X	
0496	Improvement of On-Load Tap Changer Performance in Voltage Regulation of MV Distribution Systems with DG Units Using D-STATCOM				S3
0504	Using a Smart Grid Laboratory to Investigate Battery Energy Storage to Mitigate the Effects of PV in Distribution Networks	X			
0530	Probabilistic Estimation of Voltage Unbalance in Distribution Networks with Asymmetrical Loads		X		
0544	Impact of Renewable Energy Generation Technologies on the Power Quality of the Electrical Power Systems			X	
0609	First Use of Smart Grid Data in Distribution Network Planning				S5

0644	Experimental Study on Voltage Dependent Reactive Power Control Q(V) by Solar Inverters in Low-Voltage Networks			X	
0655	The Origin of Voltage Dips Monitored in MV Netwok and its Effect on the Evaluation of MV Voltage Dips Performance Indices			X	
0674	Impact of Electric Vehicle Charging on Residential Distribution Networks: an Irish Demonstration Initiative				S4
0699	Using Electric Vehicles to Mitigate Imbalance Requirements Associated with High Penetration Level of Grid-Connected Photovoltaic Systems			X	
0712	Analysis of Regularities Between Voltage Sags in a Sequence of Events Gathered in Distribution Networks			X	
0719	Voltage Flicker Severity Improvement in a Power Distribution System Including Electric Arc Furnaces				
0795	The Issue of Asymmetry in Low Voltage Network with Distributed Generation				S4
0859	Impact of Distributed Generations Based on Renewable Energy on the Fault - Ride Through Capability				S4
0861	Evaluation of the Impact of Electric Vehicles on Distribution Systems Combining Deterministic and Probabilistic Approaches				S5
0880	Transient Detection Algorithm for Low-Cost Electronic Billing Meter			X	
0881	Seamless Control of Distributed Multi-Converter System with High Power Quality				S4
0920	Footprint of Non-Typical Disturbances Using Wavelet Transform.			X	
1009	Dip Behaviour of Grid Connected Invertors	X			
1020	Impact of Distributed Generation on Unbalanced Distribution Networks				S4
1038	Power Quality Disturbance Detection Using Wavelet In Real Time			X	
1045	Power Quality Support for Industrial Load Using Hybrid SVC			X	
1077	Steady-State Signal Generation Compliant with IEC61000-4-30:2008	X			
1142	Voltage Quality and Reactive Power Flow Solution in Distribution Networks with a High Share of Renewable Energy Sources				S3
1147	Determination of the Performance of the Distribution Static Compensator (D-STATCOM) in Distribution Network				
1174	Influence of Aggregation Intervals on Power Quality Assessment According to EN 50160			X	
1222	Applied Approach for Reactive Power Control with Medium Voltage Distributed Units			X	
1272	Harmonic Voltages and Lighting Equipment Flicker Caused by Pumping Station - Measurements, Analysis and Mitigation			X	
1273	Development of Voltage Regulation Method Considering Mutual Smoothing Effect of PV in Power Distribution System				S3
1293	Reactive Power Concepts in the Future Distribution Networks				S4
1302	New Electrical Equipment and Appliances Causing Voltage Quality Challenges in the Distribution Network			X	
1303	Hosting Capacity of LV Distribution Grids for Small Dispersed Generation Units, Referring to Voltage Level and Unbalance			X	
1345	Bi-Objective Regulating of DVR Compensator to Modify Power Quality's Indices of Load				
1353	Measurements of Network Impact from Electric Vehicles During Slow and Fast Charging	X			
1362	Testing the Performance of Power Quality Monitoring Devices and Functions			X	
1396	Voltage Control Using PV Storage Systems in Distribution Systems				S4

1419	Impacts of Photovoltaics on Low Voltage Networks: A Case Study for the North West of England				S5
1429	Impact of Voltage Phase Angle Changes on Low-Voltage Ride-Through Performance of Small Scale Hydro DG Units				S4
1481	Impact of PV and Load Penetration on LV Network Voltages and Unbalance and Potential Solutions			X	

BLOCK 4 : RELIABILITY, POWER QUALITY MONITORING, REGULATION AND ECONOMIC ASPECTS

Power quality monitoring and control

[B4-0022(UY)] presents voltage level monitoring results from a DSO in Uruguay. Starting from 2009, an increasing number of measurements at customer sites needs to be performed. Currently, 1 measurement for every 15.000 customers needs to be performed. Less than 2% of the measurements resulted in an economic compensation to the customer. As the number of measurements at customer sites rises, a slight increase in the number of compensations is reported. Measurements at customer sites often result in problems (no permission by customer, theft of equipment). As a solution, energy meters with voltage recording capability are installed.

The situation in Estonia is described in [B4-0137(EE)]. Stochastic theory is used to define the optimum voltage level taking into account power losses and service time op equipment. A voltage level close to the rated voltage ± 3% seems to be optimal. An increase in the harmonic distortion is also reported. At 15% of the measurement sites, the 8% THD is exceeded.
In [B4-0141(CZ)], the relation between the short circuit impedance and voltage quality parameters is examined. A set of 450 measurement points in the Czech Republic LV grid is used. The aim is to study the dependence of voltage quality parameters on the short circuit impedance.
[B4-0324(PT)] is related to the characterization of power quality in the Portuguese transmission grid. In order to communicate the quality, a labelling system based on normalized power quality characteristics is used. It allows communicating the quality even to customers not familiar with power quality concepts.

[B4-1066(CN)] discusses the problems encountered in the Guangzhou online monitoring system. A universal data interface is constructed to be able to use data form different measurement devices from different manufacturers. The data is also used for regional power quality assessment and to study transient events and fault information correlation analysis.
[B4-0231(ID)] describes the process for setting up power quality control procedures and standards in Indonesia. The grid is characterized by an increasing number of nonlinear loads due to iron melting electric furnaces. The IEEE Std 519-1992 is used as a reference.

Distributed generation impact on PQ

The impact of photovoltaic (PV) distributed energy sources on the voltage level variation is addressed in [B4-0024(CZ)]. Grids with and without PV plants are considered. If PV plants are present, deterioration in the voltage quality was noticed in the 2011 measurement campaign. 23 LV grids with PV were measured: 22% of the grids did not fulfill the requirements in EN 50160 regarding the maximum voltage. Grids without PV all met the requirements. In order to overcome the overvoltage problems in problematic grids with PV, the tap changing on the MV/LV distribution transformer was applied. The number of grids not fulfilling EN 50160 reduced down to 4%.

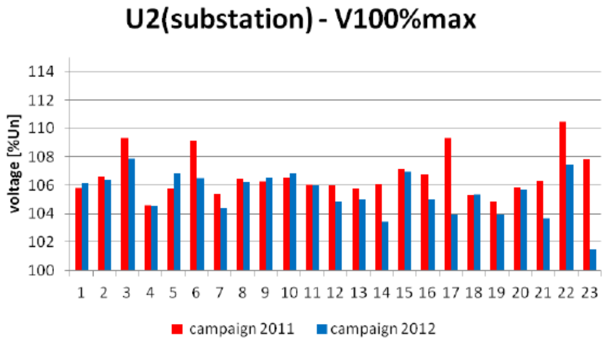

Figure 27: Evaluation of maximal 10 min RMS values of supply voltage in 23 LV grids during week measurements [B4-0024(CZ)]

Similar results are presented in [B4-0759(SK)]. Measurements performed on a distribution network before and after the installation of photovoltaic panels also show an increase of overvoltages in the system.

[B4-1314(PT)] discusses the situation in Portugal. Since 2007 a total number of 22.000 micro-generation units are in place (78 MW). A special PQ monitoring campaign to evaluate the impact of these units in the LV grid shows that the PQ indicators not significantly altered when compared to the situation before 2007. The paper presents 3 case studies to illustrate this conclusion.

In [B4-0279(AU)] the use of smart meter measurement data in the Australian LV grid is presented. The results are based on 100.000 smart meters and a 6-day measurement period. Under and overvoltages are recorded as well as 30 minute energy usage data. The tendency for the control of the grid voltage is to design for a voltage at the high end of the prescribed range. The grid contains a 4% penetration of photovoltaic panels. The results show a correlation between ambient temperature and the number of undervoltage readings (due to increased use of cooling). The increasing number of PV on the other hand results in an increased number of overvoltages.

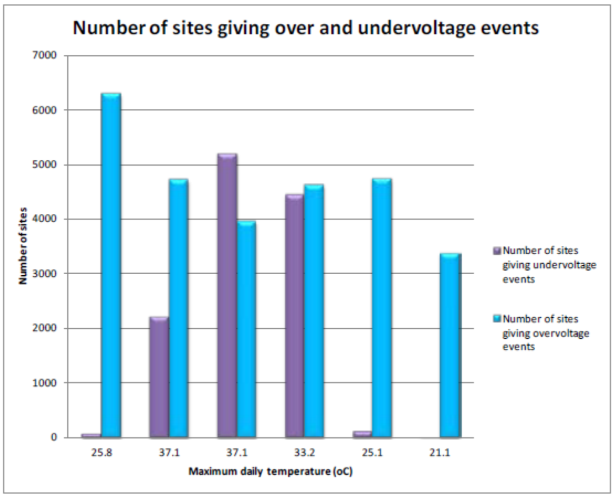

Figure 28: Number of sites experiencing over and undervoltages in the Australian grid on 6 consecutive days with different daily maximum temperature [B4-0279(AU)]

In [B4-1501(RO)] the integration of distributed generation units and the power quality monitoring system is discussed. Experiences with the integration of small hydroelectric power plants and solar power plants resulted in the suggestion to monitor the power quality in the common coupling point of the distributed generation unit. This can result in a correct evaluation of the perturbation that needs to be maintained after the connection.

The analysis of power quality by means of the so called percentile method is described in [B4-0131(MK)]. According to the authors, this method is simple to implement and results in reliable, easy to use information. The paper shows results, based on measurements at 13 single phase and 39 three-phase consumers in a Macedonian grid. The number of required measurement sites is determined by means of the Cochran formula.

In [B4-1015(BE)] a test field for LV distribution systems is presented. A realistic 230/400V feeder contains 18 residential points of connection. The supply can be modified by means of a 240 kVA programmable power supply. This allows the analysis of harmonics (up to 50 kHz) and unbalance. Also the analysis of PV systems, small wind generation and small cogeneration units is possible.

Regulation: European benchmark CEER

Three papers discuss the results of the 5th edition of the Benchmarking Report based on a survey sent out in 2011 to 29 member countries of CEER and 10 National Regulatory Authorities. Three major aspects are addressed: the continuity of supply, the voltage quality and the commercial quality. In [B4-1229(AT)] additional attention is given to analysis of disaggregated data. The correlation between Continuity of Supply (CoS) and the technical characteristics of the network is analysed. The higher the percentage of underground cables in the distribution networks the better the CoS. This paper also gives an overview of the continuity of supply regulation and compensations to individual customers when standards are not met.

Table 3: Continuity of Supply regulation according to the CEER 5th Benchmark Report [B4-1229(AT)]

CONTINUITY OF SUPPLY REGULATION AT SYSTEM-LEVEL

	Rewards	Penalties	Combination
Distribution	-	DK, HU, IT	BG, FI, FR, GB, IE, IT, LT, NL, NO, PT, SI, SE, ES
Transmission	ES	DK, HU, IT	FI, FR, GB, IE, IT, LT, NO, PT
No existing CoS scheme	AT, CY, CZ, EE, DE, GR, LV, LU, PL, RO, SK		
Intention/plans for implementation of a CoS regulation at system level has: AT, CZ, DE, GR, LU and RO.			

Paper [B4-0350(SE)] discusses the further improvements needed in EN 50160 according to the Benchmark Report. Improvements are required especially against the background of the increasing number of distributed generation units. If EN 50160 is not adjusted, it will miss its objective to harmonize voltage quality standards across Europe. This paper also discusses the use of indicative responsibility-sharing curve for voltage dips.

[B4-0349(SE)] gives guidelines for setting up and running a voltage quality monitoring programme. It should be initially well-designed to allow additional applications with minor inexpensive adjustments. The financial framework (costs assessment and financial plan) is also discussed.

Economic aspects of Power Quality

The cost of voltage dips and swells in a Swiss urban region is calculated in [B4-0255(CH)]. The results are based on a three year measurement period. A PQ cost model is presented and analysed. For the determination of the events that need to be considered in the model, the dips below the SEMI curve and swells above the ITIC curve are selected.

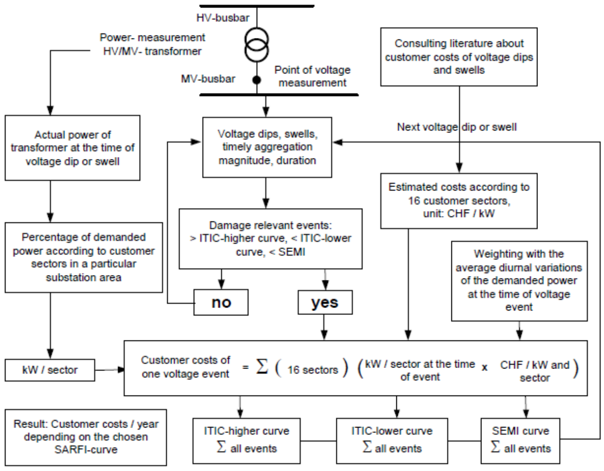

Figure 29: Elements of the Power Quality cost model to estimate the customer costs for dips and swells [B4-0255(CH)]

[B4-1123(HR)] describes the costs in a paper mill also due to voltage dips. 60% of electricity consumption is produced by cogeneration, having a positive effect with respect to dips. Equipment analysis pointed out that a remaining voltage of 75% and a duration of 80 ms is the threshold for malfunctioning. Based on this data, 19 process interruptions due per year to dips are estimated. According to measurements, 11 dips cause interruptions. The economic analysis results in a cost of 201 k€/year.

[B4-0422(IR)] starts with a check list for the gathering of information in order to perform cost analysis. Then the paper discusses 3 case studies: a commercial computer data centre, an industrial automotive manufacturer and an industrial processing plant. Both direct and indirect costs are considered.

[B4-0824(IR)] deals with Customer Dissatisfaction Index (CDI) and is based on a survey over 1400 customers in the city of Rasht, Iran. A questionnaire has revealed that interruptions between 5 and 9 in the morning are better tolerated. Programmed outages for maintenance should be considered in the morning hours. The survey also shows that the people are more sensitive about the number of interruptions than the duration.

The impact of unbalanced loads on transformer losses at distribution level and the related costs are analysed in [B4-0885(BR)] by means of a statistical method. Field measurements are used to set up a statistical load model. Subsequently, the annual losses are calculated for both balanced and unbalanced transformers. In the unbalanced case, an increase of losses between 10% and 27% is noticed. The lower the power rating of the transformer, the higher the losses seem to be.

Reliability and continuity of supply

The impact of using a shunt circuit-breaker in underground MV networks on the supply reliability is addressed in [B4-0112(CH)]. Although the probability of a fault in an underground network is less than in an overhead line, the improvement potential is more significant because of the greater customer density. This is shown by analysing the SAIFI index.

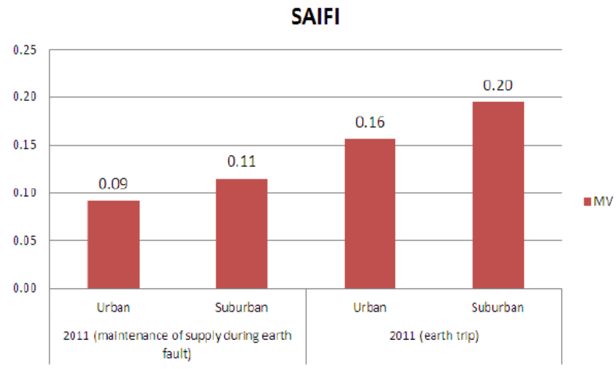

Figure 30: Improvement of SAIFI index by using a shunt circuit-breaker in underground cables (maintenance of supply during earth fault) according to [B4-0112(CH)]

Since 2010, all Swedish DSO's must report interruption data for every individual customer. In paper [B4-0317(SE)] this data is analysed to determine the reliability of the grid. SAIFI and SAIDI numbers can be interpreted in a better way. For example, some customers can suffer a higher number of interruptions than the system index SAIFI shows. The data also allows getting a more complete picture of different customer groups and even down to a specific customer regarding the continuity of supply.

In [B4-0361(EG)], the correlation between performance indicators is examined (SAIFI, SAIDI, ASAI, …) in order to draw conclusions on how to enhance the system performance. The study is based on a database containing nine years of information. To obtain relevant correlation it is found that extreme events need to be excluded from the analysis (major equipment faults for example). The paper also discusses the procedure to define such extreme events, based on IEEE 1366. Excluding extreme events might result in performance indicators that only relate to the distribution network skill and efficiency of operation.

The standard way to describe interruption costs is customer damage function (CDF) that determines relationship between interruption duration and its customer economic losses. [B4-1113(IR)] presents a practical method to estimate CDF for domestic customers. The proposed method has been applied to estimation of CDF in a distribution network. Because of relation between domestic CDF and welfare of costumers that couldn't convert to monetary equivalent, this method uses some benchmarks including "a", "b" and "g".

Through a case study it is shown in [B4-0415(PT)] that a statistical model can be made to explain and predict the Power Continuity Indicators (e.g. TIEPI, SAIDI, SAIFI) evolution, breaking them down in weather, network aging and investment drivers. The main outcome of creating such a model is that the DSO could improve its knowledge about the impact of each driver in their results and even verify in some points how a management strategic option affected them.

Discussion and further research topics

What should be the major characteristics and functionalities of a modern Power Quality monitoring system?

What are the major changes that could be brought to the EN 50160 standard, considering the actual and future characteristics of public distribution grids?

Papers of Block 4 (B4)

Paper No.	Title	MS p.m.	RIF	PS	Other Sess.
0022	Quality of Electricity Supply in Uruguay: Voltage Quality Overall Regulation and its Control Experience			X	
0024	VQ Impact of the Renewable Distributed Energy Sources			X	
0112	Improvement of SAIDI and SAIFI Reliability Indices Using a Shunt Circuit-Breaker in Ungrounded MV Networks			X	
0131	Power Quality Monitoring and Sample Size Analysis Beyond EN 50160 and IEC 61000-4-30	X			
0137	Power Quality Problems in Low Voltage Networks of Estonia			X	
0141	Voltage Quality Parameters in LV Distribution Grids in Dependence on Short Circuit Impedance			X	
0231	Development of Power Quality Control Procedures and Standards to Control The Connection of Non-Linear Loads in Electric Power Systems			X	
0255	Customer Costs Due to Major Voltage Disturbances: Estimations For an Urban Distribution Network in Switzerland	X			
0279	A "Big Data" Challenge - Turning Smart Meter Voltage Quality Data into Actionable Information	X			
0317	Interruption Data at Individual Customer Level - Experience from Sweden 2010-2011	X			
0324	Power Quality of Supply Characterization in the Portuguese Electricity Transmission Grid			X	
0349	Guidelines for Good Practice on Voltage Quality Monitoring	X			
0350	A European Benchmarking of Voltage Quality Regulation			X	
0361	Extreme Events and Reliability Performance Indicators Correlation for Distribution Utilities			X	
0415	Predictive Assessment of Power Continuity Indicators				S5
0422	Power Quality Customer Financial Impact/Risk Assessment Tool				
0759	On-Site Power Quality Measurements in Slovak Transmission and Distribution Networks			X	
0824	Calculation and Analysis of Customer Dissatifaction Index for reliability studies in Gilan Electric Distribution Network				
0885	The Unbalanced Load Cost on Transformer Losses at a Distribution System			X	
1015	Test Field For LV Distribution Systems			X	
1066	Investigation of Power Quality Online Monitoring System of Guangzhou Electricity Grid in China			X	

1113	Estimation of Customers Damage Function by Questionnaire Method				S6
1123	Economic Impact of Power Quality Disturbances	X			
1131	Research of Power Quality Comprehensive Evaluation of Regional Power Grid			X	
1229	A European Benchmarking of Continuity of Supply Regulation			X	
1314	Characterization of Decentralised Microgeneration in Portugal			X	
1501	Power Quality and Metering Monitoring Applications for Smart Network Operations			X	