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), with the more general concept of electromagnetic compatibility (EMC) and with some related safety problems in electricity distribution systems.

Special focus is put on voltage continuity (supply reliability, problem of outages) and voltage quality (voltage level, flicker, unbalance, harmonics). This session will also look at electromagnetic compatibility (mains frequency to 150 kHz), electromagnetic interferences and electric and magnetic fields issues. Also addressed in this session are electrical safety and immunity concerns (lightning issues, step, touch and transferred voltages).

The aim of this special report is to present a synthesis of the present concerns in PQ&EMC, based on all selected papers of session 2 and related papers from other sessions, (152 papers in total). The report is divided in the following 4 blocks:

Block 1: Electric and Magnetic Fields, EMC, Earthing systems
Block 2: Harmonics
Block 3: Voltage Variation
Block 4: Power Quality Monitoring

Two **Round Tables** will be organised:

- Power quality and EMC in the Future Grid (CIGRE/CIRED WG C4.24, RT 13)
- Reliability Benchmarking - why we should do it? What should be done in future? (RT 15)

BLOCK 1: ELECTRIC AND MAGNETIC FIELDS, EMC, EARTHING SYSTEMS

Electric and magnetic field measurement and simulation

According to the contributions, the electric field at mains frequency is only a topical issue for medical devices. An upcoming theme is the EMC in the smart grid with focus on high frequency electric and magnetic fields

The problem of measurement and simulation of electric and magnetic fields – respectively the consistency of their results for mains frequency – seems to be a solved problem. Discrepancies between measurement and calculation can arise from unbalanced loading of the phases in LV systems [B1-1069(IT)].

[B1-0362(MY)] presents the magnetic field of an underground cable. Measurement and simulation results fit well. Field reduction by optimal phase configuration of parallel arranged feeders is taken into consideration. In the case of overhead lines, the layout of the towers and the line sag influence the results. Therefore the authors of [B1-1540(RS)] are using actual measurements and simulations for field evaluation. Results obtained by measurements reflect the real situation, and provide the field distribution that existed in the conditions at the time of measurements. Calculations with worst case assumptions complement the analysis.

Measurement and simulation in the case of overhead lines and cables are usually reduced to a two-dimensional problem in the section plane orthogonal to the conductors. A more complex problem is the evaluation of fields originating from substations. The authors of [B1-0205(AR)] show by comparison with measurements that their simulation tool is accurate enough to evaluate the impact of new substations or modification of existing substations on the magnetic field. In a case study the LV board is identified as primary source for the field stress. The same is stated in paper [B1-1541(RS)] and [B1-0651(IT)]. Rearrangement of the LV board and connections often results in significant reduction of magnetic field levels.

Public and Occupational EMF exposure

Electric and magnetic field measurement in close vicinity of a rooftop PV system are presented in paper [B1-0426(EG)]. The resulting field levels are far below the relevant limits.

An interesting approach, combining SCADA data, GIS data and EMF simulation, is given in paper [B1-1561(IR)]. The idea is to identify EMI sources relevant for public exposure by spatio-temporal data mining of the distribution system.

EU-directive 2013/35/EU of the European Parliament regarding the exposure of workers to the risks arising from EMF includes minimum requirements for the protection of workers. However, persons with an active implantable medical device make up a growing group, also for people still being in working life, leaving a remaining risk for interference. The authors of [B1-1478(FI)] designed a test setup with a human-shaped phantom and analysed the immunity of different pace makers against electric and magnetic fields. Tests were performed near a 400 kV overhead line and in vicinity of a 400 kV shunt reactor. All tested devices withstood an exposure of several 100 µT. One device switched into safety mode during the test near the overhead line. Since the magnetic field in that case was below 3 µT, the reason for the mentioned malfunction could have been the electric field (6.7-7.5 kV/m).

Shielding techniques

The primary approach to reduce the EMF stress in vicinity of a substation is the optimal design and layout of the LV board and connectors as mentioned in [B1-0205(AR)], [B1-1541(RS)] and [B1-0651(IT)]. If this should not be sufficient, the next step is the (passive) shielding of components or parts of the substation. Different materials have been tested by the authors of [B1-0651(IT)]. The results are given in Figure 1.

Measurements of magnetic induction field (µT)					
Measuring point (height)	LV cables in the initial set-up	LV cables in the optimized set-up	Aluminium Shield on LV TR bushings	Aluminium Shield on (LV+MV) TR bushings	Ferromagnetic Shield on LV TR bushings
A - 1,5 m	43	43	22	25,4	23,9
A_{bis} - 2,8 m	87	5,65	2,06	2,49	3,68
B - 1,1 m	3,94	3,34	1,69	1,5	1,32
C - 1,1 m	3,4	2,8	2,28	2,03	1,66
D - 1,1 m	4,3	5,7	4,2	4,02	4,2
E - 1,1 m	0,45	0,5	0,46	0,38	0,5
NB: Transformer MV/LV: 630 kVA; 8,4/0,23 kV; I_{LV}(average value): 400 A					

Figure 1: Results of LV cable setup optimization and different shielding materials [B1-0651(IT)]

Shielding of components or parts of the substation is preferred against shielding of the substation's wall and ceiling. The authors of [B1-1069(IT)] derive basically the same conclusions. The shielding system described allows a sufficient field reduction with a total cost of material between half to one third of the cost of a traditional shielding system. Also the installation effort is significantly reduced.

A prototype of an active shield is presented in [B1-1060(IT)]. The device is able to process several filed measurement inputs and to drive multiple shielding loops. A minimum-field-tracking-algorithm allows the correction of the parameter setting during operation, thus providing the possibility to react on changes of the environment. Practical tests proved the basic hardware concept. The functionality of the minimum-field-tracking-algorithm was verified by simulation of a MV/LV substation

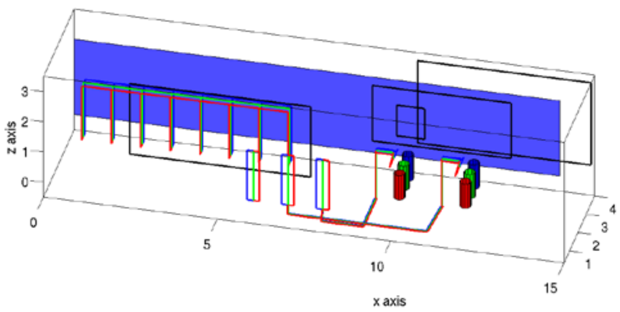

Figure 2: Geometry of the substation (red, blue and green conductors represents the phase conductors L1, L2 and L3), the optimum active shield (black conductors) and the inspection plane (blue) [B1-1060(IT)]

EMC in the smart grid

With the upcoming smart grid technology, many questions have been raised regarding the compliance of the electromagnetic emissions of the smart meters installed on the grid. In [B1-1054(PT)] measurements performed under real field conditions for installed equipment using different communication technologies (GMS/GPRS, Radio Frequency, PLC) are presented. The results prove that the values of the signals generated by the analysed devices are several times lower than the maximum levels defined by ICNIRP and EU directive 2009/EC/72. Similar tests were done by the authors of [B1-1484(FI)] and [B1-0922(FR)]. The focus was put on PLC technology and possible health risk due to the high frequency electromagnetic field (30-100 kHz). Results indicate that the magnetic fields during smart meter activity (read out) are far below ICNIRP reference values. Laboratory measurements show that in a distance larger than 20 cm the measured values are equivalent to ambient noise level. Field measurements at existing installations confirm laboratory results.

Earthing systems and earth faults

The concept of the global earthing system is mentioned in several standards and allows a cost effective earthing design. The authors of [B1-1118(DE)] give an example how to proof the existence of such a global earthing system. Based on the requirements defined in EN 50522, measurements of potential rise, maximum touch voltages and earthing impedance in an industry park were performed. Besides the reduction of step and touch voltages, a global earthing system will also decrease the induced voltage in pipelines. This explains the fact that simulated induced voltages often exceed measured values, as it is stated in [B1-1058(AT)]. However, data describing the earthing system are hardly accessible. The difficulty of estimating the current distribution in a global earthing system is mentioned in [B1-1467(AT)].

The Dutch national regulators have recently announced their visions to various regional network operators in the Netherlands about the minimum safety requirements of public networks. In the Netherlands, the electricity distribution network is mainly fed by underground cables. In the last years, an increasing trend of stealing of copper conductors from the network cables and earth conductors has made the network operators concerned about the vulnerability of their electricity networks to safety issues. The safety regulation for the Dutch LV network specifies to limit the fault voltage within 66 V or to restrict the fault clearance time within 5 s, as shown in Figure 3. Various types of earthing systems are discussed in [B1-0385(NL)]. A study by Endinet (DSO) shows, that only approximately 5% of analysed nodes violate the above conditions because of rather long cables or other reasons such as missing or improper earth conductor connections or broken PEN conductor.

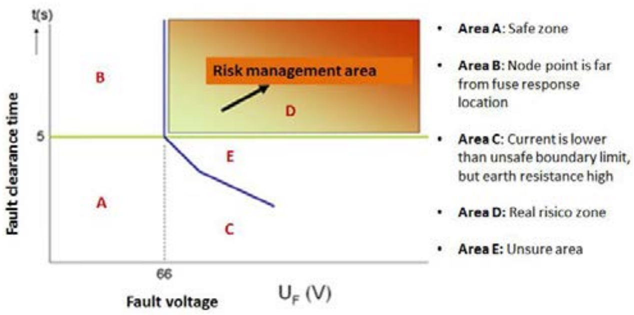

Figure 3: Risk management criteria for Endinet's network [B1-0385(NL)]

[B1-0787(PT)] emphasizes an integrated methodology for earthing system design. An important part is the ground resistivity measurement and modelling. Correct modelling of the HV system including grounding wire and tower earthing systems not only allows the estimation of short circuit currents but also the current distribution between substation earthing system and the grounding wire. The application of the methodology is demonstrated in a case study, where a basic grounding design could be refined and thus safety improved. A design tool for MV substation earthing systems is presented in [B1-0394(UK)]. Based on the characteristic data of the grid – including protection data – soil data and standard earthing arrangements, touch and step voltages are calculated. The most significant output from the tool is the 'target resistance' that must be achieved at the new substation. Additionally the tool provides an indication of how a given resistance will be achieved in a given soil type (e.g.

single rod, multiple rods, or horizontal electrode).

In resonant grounded grids, the residual earth fault current is often dominated by harmonics. The authors of [B1-1516(AT/DE)] present a simulation method for the estimation of those harmonic components. Besides the pre-fault harmonic voltages, the frequency dependant impedance of the system determines the harmonic currents. The authors had the possibility to apply their method to a real 20 kV-grid and compare the simulation results with measurements. It turned out, that the simulation assumption of equivalent harmonic sources in the feeding 110 kV-grid gives the best match. Resonance condition can lead to excessive harmonics in the fault current (Figure 4).

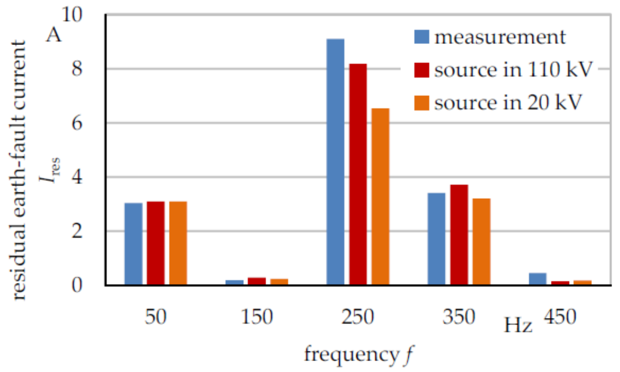

Figure 4: Comparison of the measured and calculated harmonic earth-fault current (two different locations of the harmonic current sources) [B1-1516(AT/DE)]

Lightning protection

In general, power lines are operated at the highest possible economical voltage levels to minimize losses and maximize energy transfer. The 22 kV/230 kV transformer of a remote communication tower in rough terrain, supplied by a 22 kV overhead line, failed 4 times in 2 years due to lightning as in [B1-1176(ZA)] reported. As solution, the transformer was relocated to a reachable location and the last km of the MV line was operated with 230 V. The basic insulation level (BIL) of this section was lowered to 275 V by installing LV surge arresters. The lightning performance was significantly improved; none of the recorded indirect lightning strokes and just one of 14 direct strokes resulted in a line fault. The authors of [B1-0998(ZA)] analysed the possibility to lower the BIL of an MV line. Based on measurements of induced voltages on a 22 kV feeder of 156 km length, the BIL could possibly be lowered from 300 kV to 150 kV by elimination of the gap in the pole bonding. This will eliminate wood damage and will lower the surge energy and voltage amplitudes, equipment on pole mount installations will benefit significantly.

Transients

The transient interaction between the transformers affects the magnitude and duration of the sympathetic inrush current. This has become a significant issue for medium or large transformers. System study of the inrush caused by energisation transformers connected in parallel to distribution networks are discussed in [B1-1189(AU)]. The results of simulation and a small scale experiment show that sympathetic inrush will occur if the other transformers are connected in parallel. Increasing the number of already energised transformers will increase the sympathetic inrush current transients.

The transfer function of Rogowski coils and the according electronic integrator is analysed in [B1-0747(CN)]. Several design recommendations are derived from the study.

Potential scope of discussion

It seems that most of the magnetic field problems concerning substations can be solved by passive shielding. The future of active shielding could be not near the source of the field but close to sensitive devices.

The presented magnetic field studies so far do not take into account harmonic currents.

Risk based design of earthing systems as discussed in the joint CIGRE/CIRED WG B5.35 could decrease installation costs. Is society willing to bear the risk?

Table 1: Papers of Block 1 assigned to the Session

Paper No.	Title	MS a.m.	RIF	PS	other session
0205	Use of Magnetic Field calculation tools to design MV / LV substations			X	
0362	Magnetic Field Simulation & Measurement of Underground Cable System inside duct bank			X	
0385	Risk management in a low voltage network on safety issues from asset management perspective			X	
0394	A New Design Tool for Distribution Substation Earthing Safety	X		X	
0426	ELF Electric and Magnetic Fields Emission due to Rooftop Photovoltaic System			X	
0651	How to contain Electromagnetic Fields in Medium Voltage Substations: experience in design and operations			X	
0747	Research on Response of Rogowski Coil Electronic Current Transformer to Transient Signal			X	
0787	An integrated methodology for design of grounding systems			X	
0922	Exposure to electromagnetic fields emitted by smart meters using power line communication technology	X		X	
0998	Choice of MV feeder BIL to maximize QOS and minimize equipment failure	X		X	
1054	EMC analysis of the EDP Distribuição Smart Grid			X	
1058	Impact of Global Earthing Systems on the Inductive Influence of Buried Isolated Metallic Pipelines			X	
1060	Low-cost active shield for MV/LV substations	X		X	
1069	Local Distributor Zero Emission Substation			X	
1118	Proof of a Global Earthing System	X		X	
1176	QOS challenges of operating MV overhead line at LV in a high lightning density area			X	
1189	Energising Inrush Current Transients in Parallel-Connected Transformers			X	
1467	High Current Earth Faults in Resonant Grounded Networks under Aspects of a Global Earthing System				S3
1478	New Directive 2013/35/EU on Occupational Exposure to Magnetic Fields and Electrical Workers Use of Active Implanted Medical Devices (AIMDs)			X	
1484	Emission of smart meter electromagnetic field (50-100 kHz) in Finland			X	
1516	Comparison between simulations and measurements of harmonics in residual earth fault currents of a 20 kV-network	X		X	
1540	Measurement and Calculation of Non-Ionizing Radiation Levels in the Vicinity of 35 kV Overhead Power Lines			X	
1541	Practical Application of Technique for Reducing Levels of Magnetic Field Emitted by 10/0.4 kV Substation			X	
1561	Spatio-Temporal Mining for EMI forecasting in GIS-FME Model				

BLOCK 2: HARMONICS

Block 2 is entirely dedicated to harmonics including interharmonics, subharmonics and supraharmonics. With respect to the last two CIRED Conferences, there is a reduction of papers with respect to the harmonics in the frequency range 2 kHz and 150 kHz instead of an emerging, who rather was expected since in our opinion this domain is still of major importance. Next to that, the distinction between the major topics is still consistent within the harmonic subtopics.

Harmonics in the 2 kHz – 150 kHz Range

The emission and immunity in the 2 kHz to 150 kHz range is a fast evolving area, especially since the impact of switch power supplies and grid connected inverters used for renewable energy sources are massively introduced in nowadays LV network. Standards are still under consideration. For measurements, test engineers are nowadays designated to measurement methods used in adjacent frequency ranges, meaning 0 to 2 kHz (harmonics) and 150 kHz – 30 MHz (conducted emission). Activities towards standardization in this frequency range are ongoing in several IEC working groups and within CENELEC. The work focuses on the development of standardised measurement methods and setting of emission, immunity and compatibility levels. The only partially related standard is the EN 50065 on low voltage network signalling (power line communication). In the latter, specific artificial mains networks (AMN) are described.

The search for an appropriate measurement method under laboratory conditions is still under discussion. The paper [B2-1653(BE)] describes next to the laboratory measurements, which are giving accurate and reproducible measurements, also measuring tools for troubleshooting purposes including the constraints for an appropriate in situ test probe. Not only the normally used devices for in situ EMI measurements are analysed, but also which of these are preferred for in situ HFPQ measurements. (Figure 5 and Figure 6)

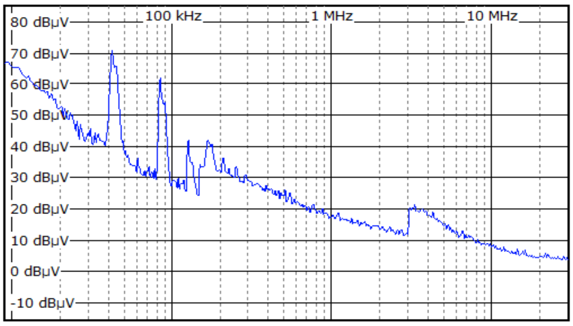

Figure 5: Measurement on CFL with current probe EZ [B2-1653(BE)]

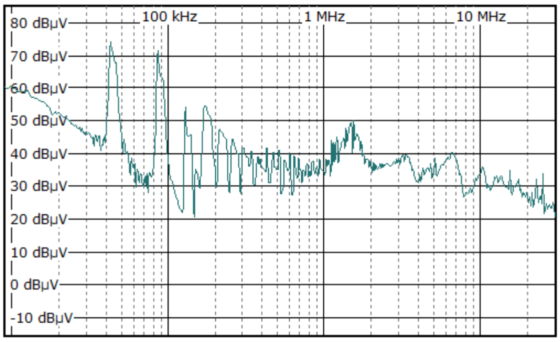

Figure 6: Measurement on CFL with voltage probe [B2-1653(BE)]

The primary and secondary emissions into the installation in the frequency range between 2 and 150 kHz, (including the frequency range where power line communication is used) is discussed in [B2-1621(SE)]. The spread of emissions in the frequency range 2 kHz to 150 kHz differs from the harmonic emissions. There is a distinction between primary emission and secondary emission. Primary emission is defined as the emission originating from the equipment under test and mainly affected by the topology of the EUT, its impedance at the connection point and possible resonances with the network. Secondary emission however is defined as the emission that is generated elsewhere and propagates to the EUT due to the low impedance level at the terminal of the equipment. The secondary emission is not always present and is mainly affected by emission from the neighbouring equipment and the impedance at the terminal of the EUT in relation to impedance of the grid and of the installation.

To be able to study electromagnetic interference due to conducted disturbances in the frequency range 2-150 kHz by simulations, some models have been developed in [B2-1348(BE)]. The developed models are based on the Matlab/Simulink software and its Power Systems Toolbox, including PV inverters. This model for the LV distribution grid is needed for the research of conducted disturbances in the 2 up to 150 kHz domain. The development of that model presented in this contribution is of major importance since such a model is not trivial because most of the models found in literature are only available for low frequencies. Moreover, the Power Systems Toolbox does not allow changing the parameter values of the standard models. The presented model can be divided into two main components and is discussed in the paper. Models have been established in order to study these disturbances by simulation and let the authors conclude that amplification as well as attenuation are both possible along a LV feeder, due to its natural characteristics. It also has been confirmed that power supplied by PV has no influence on the magnitude of HF disturbances and the presence of the rectifier does not have a negative effect on HF disturbances. However, loads connected to the grid will have an influence on HF but they are hard to model.

Communication of smart meters is mainly based on PLC. This can be disturbed by HF emission of a variety of loads like LED lamps. The authors of [B2-1066(IT)] investigated the possible interference of PLC and HF noise of different loads in an experimental study. They suggest, in order to guarantee undisturbed operation of smart meters, to apply strictly the emission and immunity limits indicated in EN 50065-1. The paper [B2-0523(ES)] studies the interaction between LED lamps connected to different industrial environments, and how they behave in an identical environment. Harmonic emission up to 150 kHz (defined as supraharmonic) has been considered in the study. The outcome of this contribution is the impact on the secondary emission of LED lamps when they are exposed to different EMC environments. Same background distortion leads to different behaviour for different lamps. Since there is not that many research in this domain at industrial environment, conclusions are drawn based on real measurements. The same lamp at different locations presents different emission both in the harmonic as well as in the supraharmonic range. Since there are no immunity limits regarding luminaries in the harmonic range or in the range above 2 kHz for conducted disturbances, the contribution [B2-1068(SE)] deals with the conducted disturbances of them. Although, the duration of the emission from power line communication is short, the overall impact and risk of interference of luminaries can occur. It is shown that waveform distortion can interfere with, among others, the control functions of a lamp. The waveform measured in the tests shows that interference was reproducible under lab conditions. If the supply voltage contains both harmonics and higher frequency components, disturbance of the lamp control functions can occur (Figure 7). Still it has not yet been proved, but from the applied spectra it is most likely that harmonic components above 2 kHz cause problems.

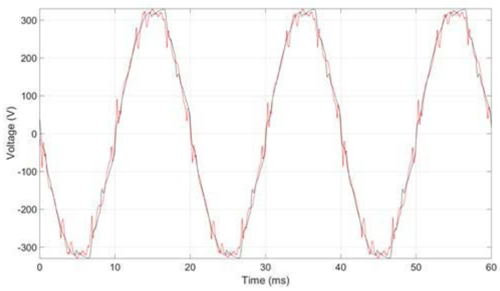

Figure 7: Voltage waveform from measurement in the laboratory (red) and original waveform (black) as a reference [B2-1068(SE)]

Paper [B2-0285(SE)] summarizes the state of art of the discussions in CIGRE/CIRED joined working group C4.24, concerning supraharmonics. There is an increasing interest from the international standard-setting community in knowledge about distortion in the frequency range 2 to 150 kHz. Due to the limitations given by the 61000-3-2 standard, there is a major reduction of emission in the lower-frequency ranges. On the other hand, due to the switching frequency of nowadays inverters there is an increase of higher frequency emission (supraharmonics) by equipment. Power electronics has emerged as a ubiquitous technology, which plays a critical role in almost all areas where SPS and PWM are applied. Power electronics converter is an important source of waveform distortion, but, as shown in this paper, power electronics can also be the key to mitigate distortion, when the proper technology is employed.

Harmonic emission of equipment

The contribution [B2-1483(IR)] deals with LED for street lighting systems, since this type offers the advantages of increased energy efficiency and provides energy savings as well as colour quality. This paper investigates the harmonic distortion in recent street lighting according to the IEC61000-3-2 standard. The results of 5 samples of high brightness LED lamps with different power ratings from various manufacturers are presented. It can be concluded that all LED luminaires are compliant with IEC61000-3-2 standard. In [B2-0481(IR) the impact of mass utilization of CFLs on the power quality of distribution system is analysed. During the cold season the total current harmonic distortion (THDi) is significantly higher than in the warm season. This is due to the higher fundamental current, caused by air condition.

Frequency converters in wind power plants are sources of harmonic currents that can result in an increase of harmonic levels in the electrical power system. In this paper [B2-0816(SE)] the authors discussed the issue of connecting these sources to the grid, especially with respect to harmonic aggregation and amplification or attenuation. It is shown that the harmonic emission from a wind turbine, which differs from that generated by a conventional generator, will create more likely interharmonics which are time-varying in a different way. Besides that it is proven that the total harmonic emission of a wind park is determined by aggregation between turbines and amplification due to resonances in the collection grid. It will depend on the characteristics of individual wind turbines, harmonic current, transfer functions of the collection grid, and on the emission from the individual turbines.

The authors of [B2-0377(IR)] analyse the impact of the massive implementation of distributed generation, especially the used power electronics, on the resonance phenomena in the LV grid. Since power electronics based

DGs are connected to the grid via L, LC or LCL filters, these filters will create low frequency harmonic resonances. The results of the study of inverter topology, control method and output filters are presented in this paper. It is shown that resonant frequencies can be determined by frequency analysis and will appear in both modes, islanding and grid-connected mode. The study of frequency resonance sensibility of a single inverter microgrid is based on three factors, network impedance, up-stream short circuit power and switching frequency with respect to filter cut-off frequency.

Modelling of Harmonics

The paper [B2-0062(EG)] presents the thermal modelling of a transformer feeding linear loads according to IEEE guide, in order to analyse the hotspots and maximum oil temperature in mineral oil transformers. It is shown that in the dynamic thermal model, the hotspot temperature doesn't follow the maximum oil temperature instantaneously and consequently there is no linearity. This is also verified in MATLAB by linear load variations according to the dynamic thermal model and applied to a 2.5 MVA, liquid filled transformer. The transformer is equipped with thermocouples and tested at varying loads. The measured temperatures are compared with the predicted temperatures of the dynamic thermal model. Also non-linear loads were applied in order to determinate the additional losses and heating. Finally, an algorithm is presented to determine the loading capability of transformer in the presence of non-linear load currents. The ageing model is verified again using simulation in MATLAB.

A new method for optimal placement of capacitor banks for the reduction of the cost of energy losses and improvement of voltage profile, using a gravitational search algorithm, was presented by the authors of paper [B2-0142(IR)]. The presented method includes both linear and non-linear loads in the radial and meshed networks. Also the harmonic limits of the voltage are considered. Next to that, an objective function is considered in order to minimize the costs due to energy losses, capacitor installations, network total harmonic distortion and the deviation of the voltage fundamental component. The authors used a fuzzy logic approach with a membership degree assigned to each parameter. The simulation results were tested on the IEEE 123-Bus distribution network.

In paper [B2-0207(EG)] the authors present several optimization techniques on test systems to solve the problem of optimal harmonic meter placement for estimation of harmonic sources. Several algorithms are applied to the problem such as complete enumeration, sequential method, genetic algorithm, particle swarm optimization and linearised biogeography optimization technique. Those algorithms are applied on two test systems to investigate their effectiveness in solving the harmonic meter placement problem. They have shown that the last mentioned simulation technique clearly provides the optimal number and locations of harmonic meter placement with full observability depth on both objective functions.

The subject addressed in paper [B2-0267(FR)] is to use equivalent multi-frequency voltage source method, instead of conventional current source method, in assessing harmonic analysis of non-linear loads. The authors state that this approach can bring about some interaction between disturbance source, grid parameters such as impedance and background harmonics. Since new disturbance loads are mainly built with transistor-based converters (most of them IGBTs) they can be considered as voltage source converters. An advantage of this method is that multi-frequency voltage source can be used to study the PQ behaviour when switched in to voltage/frequency control mode. It is even possible to simulate certain harmonic interaction between non-linear loads and the upstream grid. Two case studies have been carried out compared to on-site measurements in order to validate the model.

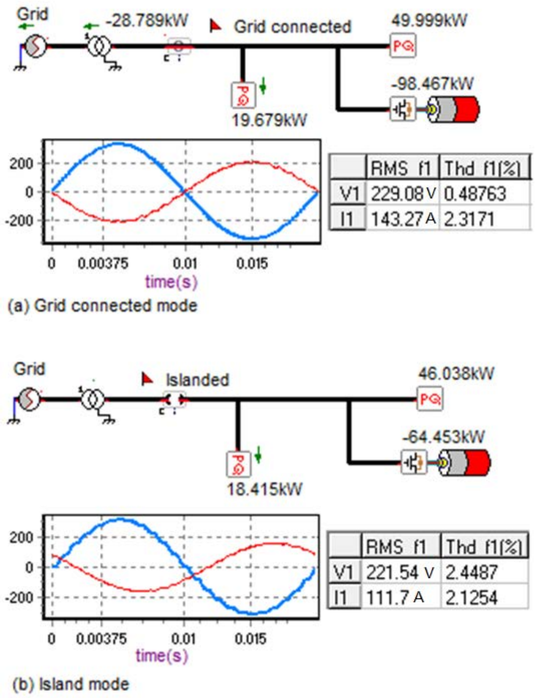

Figure 8: Voltage and current at the input of an energy storage unit of the micro grid [B2-0267(FR)]

In this paper [B2-0381(DE)] the authors want to focus on a method for modelling of small non-linear loads by means of frequency coupling admittance matrices. Based on measurements they can conclude that the used technique delivers equivalent Norton admittance matrices of the actual non-linear device. In order to validate the model, various non-linear loads (LED lamps) were used as test objects. It is shown how the absorbed currents vary in dependency of amplitude and phase of voltage harmonic distortion. The results show that modelling small loads with high non-linearity by means of frequency coupling matrices cannot be done easily with reasonable effort and performance.

In the last decade, harmonic analysis of Japanese MV and LV network has been done. Consequently a classification of both MV customers single phase load and LV customers three phase and single phase is performed. The authors of [B2-0919(JP)] used this knowledge for estimating the harmonic distribution with many harmonic sources in the distribution networks. They demonstrated a harmonic state estimation method with limited measurement condition by using the fifth harmonic current phase angle classification model for transient simulation.

[B2-0946(CO)] presents the sequential-time simulation mode for harmonics recently included on EPRI's OpenDSS program. This simulation mode is used for evaluating the behaviour of harmonics at a certain point when the load changes with time. The model of the load is modified by adding a parallel R-L at different percentages. For evaluating the performance of the load, configured as a series R-L, parallel R-L or a weighted combination of both; the power quality park proposed by EPRI for creating a micro-grid is used. The results suggest that a 50% combination of parallel and serial R-L is an adequate solution for almost all simulations.

The development of an electric power theory under non-sinusoidal conditions is a wide and complex topic. Therefore the authors of paper [B2-1386(BR)] present an analysis with respect to the interpretation of reactive power, based on different theoretical approaches. The first researches in the area date back from the 30^{ths}. Since there is not a full consensus, interpretations of these definitions may help for further design. Consequently this paper aims to contribute to studies in non-sinusoidal systems with focus on power definitions with a special attention to reactive power and its implications. It was observed in reactive compensation study that, even taking the value of Q to zero, there was neither a reduction of apparent power nor improvements in power factor.

Harmonic Mitigation

The paper [B2-0325(EG)] has shown theoretically and by simulation, that active harmonic filtering by applying the pulse multiplication technique with a simple modification on the existing configuration is possible. The approach is to use 12-pulse converter configuration using a phase shift power transformer to achieve low harmonics at the ac line current and low ripple at the dc output voltage. It is proved that this system reduces THD in the ac source current from 9% to 3% and lower ripple in the dc output voltage with the advantage of simple, lower source voltage THD, size, and cost.

In this paper [B2-0056(ID)] the authors present the results of the filter design of a customer with an arc furnace connected to 20 kV with an installed power of 3465 kVA, supplied by a 31.5 MVA power transformer (150 kV / 20 kV). The steps are given in Figure 10. The alternative circuit design to calculate current harmonic of filter is based on IEEE Std 1531-2003. If the results obtained from theoretical approach in comparison with the standard IEEE 519-1992 are within the limits, then the calculation can proceed to the next step. By applying the filter, the PF of 0.86 increased to 0.95, while the harmonic current of order 5 was reduced by 34.5%.

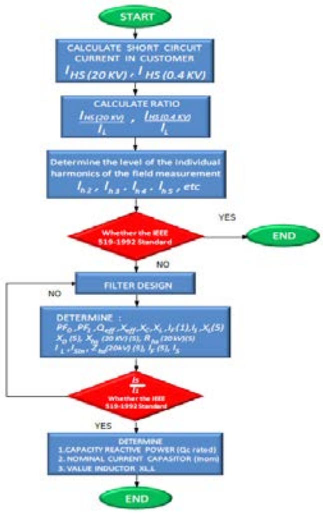

Figure 9: Steps to determine the capacity of harmonic filters with single-tuned filters for 20 kV & bus 0,4 kV [B2-0056(ID)]

It is well known that harmonic currents lead to an increase of transformer losses. The intent of this contribution [B2-0625(IN)] is to present existing technologies that can be adopted to suppress/control the voltage harmonic distortion. The authors state that the key challenges to increased efficiency in systems driven by electrical machines lie in three areas: reduction of number of power electronic devices, operate the drive at maximum system efficiency and increase the efficiency of the transformer with non-sinusoidal loads. The mitigation of harmonics by the use of phase shifting transformers, zigzag transformers, K-factor is analysed and results gathered from a few case studies are presented. A detailed analysis is also performed using ETAP and PS-CAD software in confronting non-sinusoidal loads. Conspicuous technologies which are not only for reducing the harmonic distortion but also to improve the efficiency of power systems also were presented.

The authors of the paper [B2-0944(TH)] are presenting the harmonic filter design for 115 kV and illustrate a procedure to design harmonic filters for a 32 MW induction furnace. This is essential for eliminating and reducing the effects of harmonics in a power system to comply with the regulation of the grid operator. Consequently, both total harmonic distortion in voltage and harmonic current at any individual order has to comply with the given limits. Using DIgSILENT PowerFactory simulation software the variation of the harmonics, the impact of impedance variation versus frequency, and the evaluation of the effect of harmonic filter in the system were studies using actual recorded data. The analysed load is an induction furnace, 32.24 MW with an averaged PF of 0.82 and connected at 22 kV. The point of common coupling (PCC) to assess the harmonic level is at 115 kV. The harmonic filter design was very adequate. After the integration in the network, the voltage distortion and harmonic current are dramatically reduced to comply with the regulation.

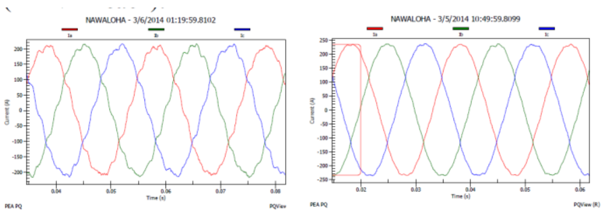
(a) Without harmonic filter. (b) With harmonic filter.

Figure 10: Harmonic current waveform at the PCC [B2-0944 (TH)].

This paper [B2-0950(DK)] deals with stabilizing method of the interaction problems among the interconnected power electronics based power devices in a power distribution system. The impedance based stability criterion is used to study the effect of the active damping on the system stability. There are mainly two types of damping approaches, one is the passive damping method and the other one is the active damping. The passive damping can be implemented in a simple and inexpensive way, but it reduces the overall system efficiency. Instead of dissipating it, the energy can be collected by additional control effort. However, it requires additional sensors for feedback signal or state estimators, which complicates their control loops and sometimes they are also sensitive to the filter parameter variation. The results show that not all inverters need to have active damping for stabilizing the network but some of inverters can effectively change the impedance of the network, thus the overall network becomes stable.

Distributed generation & EVs

Since EVs are supposed to become a serious contender for a noticeable share of the car market in the near future, the authors of paper [B2-0873(CA)] want to present the effects of the integration of EVs on the PQ parameters of the distribution grid. Since EVs draw power through power electric circuits from the utility grid when being charged, potential power quality impact of mass penetration of EVs must be taken into consideration. This study was conducted to address this concern, i.e. to determine the collective impact of EVs on the power quality of both primary and secondary distribution systems. In summary, there is no significant harmonic emission in the power distribution systems in comparison with other home appliances with non-linear load characteristics. However, EVs can create problems as transformer overloading, increase in conductor electrical losses, the neutral voltage/current rise, etc. These impacts are mainly noticeable in the secondary distribution networks and can be mitigated by using smart charging strategies.

In paper [B2-0935(IR)], the effect of EVs injecting current harmonics in a standard IEEE 30-buses distribution network is studied, where the substation voltage was considered as a non-sinusoidal voltage source and modified for EV (Figure 2.8). In order to generalize this study, the authors used different hours of a day by using a daily load curve, and optimum time for charging of EV batteries. The findings showed that injecting the current harmonics of chargers causes a drop in the voltage profile and increases the power loss. Moreover, current harmonics have a great influence on increasing the total harmonic distortion of the current. Finally, the results of optimum working times of parking lots showed that covering all time intervals of a day increases the daily cost.

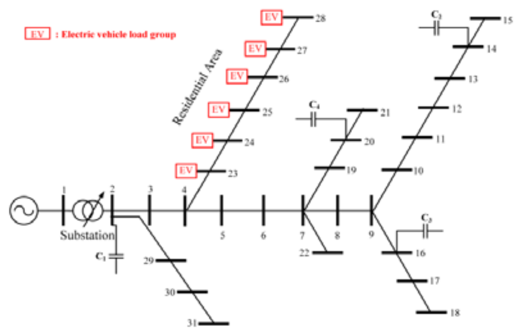

Figure 11: Modified IEEE 30-bus 23 kV distribution systems with residential feeders [B2-0935(IR)]

The authors of this contribution [B2-1214(FR)] made an evaluation of every electrical connection request for charging infrastructures on the distribution network. Within that context, an investigation of both LF current harmonics (0 – 2 kHz) and HF disturbances (2 - 150 kHz) induced by electric vehicles in the LV network was performed. Regarding LF currents (harmonics), the vehicles tested individually do not emit high current harmonics (Figure 14). However, in cases where cancellation effects were not found, high voltage harmonics are observed. With respect to PLC, despite the lack of a global EMC standard defining compatibility levels in the range 2 – 150 kHz, the vehicles tested did not lead to unacceptable performance losses in the conditions of the tests.

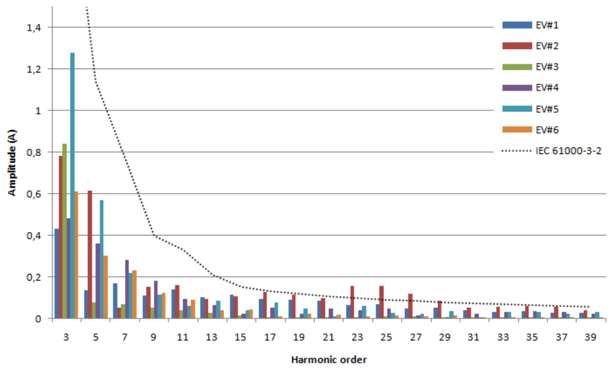

Figure 12: Current spectra during the stabilised charging phase of the vehicles tested [B2-1214(FR)]

The authors of paper [B2-0954(UK)] explore whether multi MW solar parks can be represented by simplified models when carrying out harmonic analysis. Solar park inverters are typically represented by an equivalent choke impedance, which does not reflect the internal design of the inverter (typically an LCL filter). In this paper, solar inverter models are compared for varying capacities of solar park, from 1.6 MW up to 28.8 MW. The analysis also considers whether an equivalent model of the background network can be used. The results show that for large solar parks, the fault equivalent choke model of the inverter will produce inadequate results if the strength of the background network at PoC is low. However, when the solar park is connected to a strong background network, the impact of the inverter LV side impedance at the PoC is negligible, while the level of detail to which the surrounding background network impedance is represented can influence the harmonic impedance scans at the PoC.

Propagation of Harmonics, Case Studies

This paper [B2-0427(EG)] describes a case study of a 32 kWp PV installation connected to the distribution network via three phase inverter. For the analysis, the authors focused on measuring the electrical parameters before and after installing PV at different solar irradiance levels. The most important conclusion on this study is that all PQ parameters remained within the ±5% variations and haven't been affected by installing this PV installation

A current harmonics analysis of a charging station of an electrical vehicle (EV) and a photovoltaic system (PV) connected to the grid at the same connection point is performed in this contribution [B2-0657(AT)]. At this connection point, energy of the PV system is fed to the grid using a photovoltaic inverter while at the same time, energy for the EV charging station is taken from the grid. The results show that the harmonic load of EV charger and PV system never compensates. The adding up of the harmonic currents of the PV system and the EV charger are strongly depending on the phase angle of the according harmonics. It is shown that most harmonic currents are decreasing if the PV system is connected to the grid.

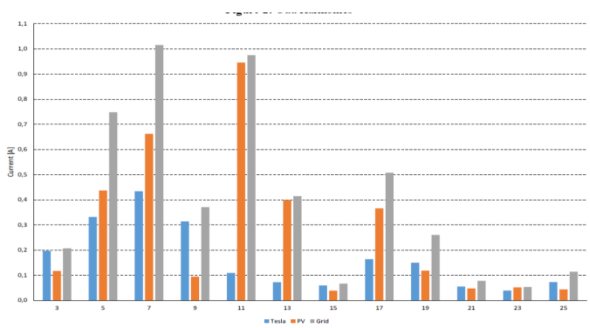

Figure 13: Current harmonic spectrum of grid, EV and PV [B2-0657(AT)]

The authors of paper [B2-1404(DE)] discuss the impact of a high penetration of EVs on the PQ parameters, including the high frequency components in an urban residential low voltage grid. The results are based on field study, where ten EVs were provided to ten households which are connected to one feeder of an urban public distribution grid. Starting the measurement without EVs serves as reference, a coordinated charging of the EVs (connecting and disconnecting) according to a defined schedule was performed. Single phase connected EVs can have a significant impact on unbalance, especially in case of not being equally distributed to the phases. The impact on harmonic currents considerably depends on magnitude and phase angle of the charging current harmonic content. Measurements of high frequency harmonics show that most of the switching frequencies of EVs are in the range between about 10 and 100 kHz. The emission level of the current supraharmonics can become 1 A and even more.

In this contribution [B2-0153(IR)] a 15 kVA 3-phase dry transformer has been modelled under both linear and non-linear loads and also under balanced and unbalanced supply voltage. Distribution transformers are generally built and designed at balanced supply voltage and linear loads with sinusoidal currents. However, nowadays with widespread use of non-linear loads, such as extensive application of power electronics, battery chargers and other high frequency producing devices, there is an increase of harmonic currents. It is shown that unbalanced supply voltage on a transformer with non-sinusoidal load currents intensifies transformer losses and decreases the expected lifetime.

A survey with respect to the PQ parameters of the Czech distribution grid is described by the authors of paper [B2-0403(CZ)]. One of the detected problems was with harmonic voltage in approximately 7% of the LV distribution grids. The survey is based on the evaluation of approximately 600 PQ measurements which were made in dedicated points of the LV grid with known system impedance according to the IEC 60725 standard. The purpose of this paper is to determine the average value of each harmonic voltage, to compare this value with the limit value according to the EN 50160 standard. It is shown that the value of reference impedance can be used for a decision about the responsibility for poor voltage quality in distribution grids.

Excessive harmonic voltage levels can result in additional losses, overheating and malfunctioning of power system equipment and connected loads. In this paper [B2-0920(AU)] harmonic allocation for a reduced HV/EHV transmission system in Australia are undertaken utilising IEC/TR 61000-3-6 strategies. It is shown that the application of the IEC/TR 61000-3-6 allocation methodology using the purely inductive network model approach will omit key issues associated with transmission networks. It is shown that the use of more realistic network modelling will provide much improvement, however results also suggest that harmonic voltages cannot be guaranteed to be below the planning levels for some network scenarios. The allocation methodology of the IEC technical reports does not accommodate future network augmentation and large complex loads injecting harmonics at undefined phase angles.

The authors of this contribution [B2-0091(EG)] present a detailed PQ study due to harmonics that had been made on an industrial zone in Egypt. It consists a of three phase source feeding a 400 HP DC motor and a 6- pulse drive fed connected to the LV side of a 500 kVA (11/0.5 kV) three phase transformer. A resonance case between plain capacitors and supply transformers feeding the load occurred, hence there was a big risk of the capacitor damage and over voltage occurrence. Since the steady state design approach was not solely adequate, also a transient analysis study was performed. Five cases were analysed to study the impact of switching on the harmonic filters. The simulation had been done using a MATLAB program model. Simulation results showed that at the switching-on moment, an overvoltage at a range of 650 V to 580 V occurred and lasted for 0.3 seconds. The current total harmonic distortion reached up to 115%. In conclusion, the authors stated that the overvoltage and overcurrent transients must be taken into consideration when choosing the required rated voltage and rated current of the installed capacitor banks and harmonic filters.

This contribution [B2-0135(EE)] deals with parallel resonances in LV networks particularly in case of powerful non-linear loads and where the capacitors are not equipped with detuned (filtering) reactors. By measuring harmonic currents in both the transformer and capacitor they could conclude that resonance was found, most likely due to the 5th harmonic. However measurements show that the resonance often takes place at much higher frequencies, particularly at the 11th, 13th or 17th harmonic order. It was found that the resonance intensity is not very sharp (Figure 15), therefore the step power rating of LV capacitors in the battery is not critical. The type and total power of converters installed (6-pulse or 12-pulse) are affecting the presence of resonance the most.

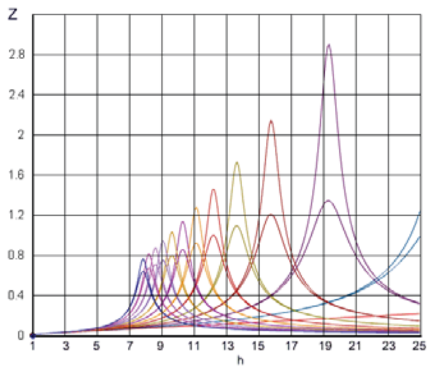

Figure 14: Impedance curves Z(Ω) = f(h) of a LV network including a 12-stage capacitor battery [B2-0135(EE)]

The paper [B2-0344(EG)] discusses the causes of the magnification of the currents in the neutral conductor in four wire supplied systems caused by non-linear loads. These neutral conductor currents are known as triple–N harmonics. In their conclusions, the authors noticed that third order harmonic components of the line currents are all in phase, so they sum arithmetically rather than cancelling by vector addition (zero sequence effect). The neutral current amplitude may exceed the phase current in amplitude at the supply frequency due to these third order harmonics and will stress the neutral conductor of a cable and even decrease torque of direct on line induction motors. A derating of the used transformers or the use of K- factor transformers is suggested.

The authors of the paper [B2-1017(SE)] present measurements of harmonic voltages and currents for low-voltage customers supplied by a Swedish network operator in order to map the harmonic levels in LV grids. To perform adequate analysis, measurements were carried out at 61 different locations during a one-week period with respect to the EN50160 standard. Voltage and current distortion were compared with a number of objective values in Swedish and international documents. The survey shows that the planning levels are exceeded at several locations, especially for harmonics 5, 15 and 21. The cause of this exceeding is not mentioned.

This contribution [B2-1352(UK)] deals with the low carbon emission applications in LV grids, using heat pumps, EVs and PV installations. The heat pumps and EV charger that were examined exported a large amount of 3rd, 5th and 7th harmonic current. The heat pumps that were recorded showed a wide range of harmonic content. However, PV inverters tested within the laboratory emitted a much lower harmonic current than the heat pumps and EVs. Low order harmonic are typically phase aligned and consequently will sum within the feeder. On the other hand, the higher the harmonic order the more the phase of these harmonics tends to be randomly distributed and thus will cancel within the feeder. The low-order harmonics tend to be drawn at similar phase angles because the distortion is synchronised to the mains cycle. There is a danger that, even if each item is compliant with a product standard the accumulated low-order harmonic currents in the network would give harmonic voltages exceeding the planning standard.

Potential scope of discussion

Emission in the frequency range of 2-150 kHz becomes more and more a problem. For a consolidated standardisation that determines limits it is necessary to have a confirmed knowledge about current and future emission and immunity characteristics of devices.

Table 2: Papers of Block 2 assigned to the Session

Paper No.	Title	MS a.m.	RIF	PS	other session
0056	Single Tuned Harmonic Filter Design As Total Harmonic Distortion (THD) Compensator			X	
0062	Thermal modelling and ageing of transformer under harmonic currents			X	
0091	Switching on Harmonic Filter Transient Analysis			X	
0135	Resonances in LV Industrial Networks When Using Shunt Capacitors for Power Factor Correction			X	
0142	Fuzzy Optimal Placement of Capacitors in the Presence of Non-linear Loads in Unbalanced Distribution Networks using GSA Algorithm				
0153	Evaluation of 3 Phase Dry Transformer under Non-Sinusoidal Load Currents and Un-balanced Voltage Supply				
0207	Optimal Harmonic Meter Placement For Estimation Of Harmonic Sources Using Artificial Intelligence Techniques		X	X	
0267	Disturbance load modelling with equivalent voltage source method in grid harmonic assessment			X	
0285	Ongoing work in CIGRE working groups on supraharmonics from power-electronic converters	X		X	
0325	Active Filters Application for Metro A.C. Substations			X	
0344	The Analysis of Magnification of Neutral Current in the Presence of Power Quality Problems			X	
0377	The effects of widespread use of power-electronic based DG on grid power quality				
0381	Performance Analysis for Non-Linear Load Modelling with Frequency Coupling Admittance Matrices			X	
0403	Problems of harmonic voltage in the LV distribution grid			X	
0427	The Effect of Photovoltaic Rooftop systems on Grid Power Quality			X	
0481	Measurement and assessment of the mass utilization of CFLs on power quality of Ahwaz's distribution system in the warm and cold periods				
0523	LED lamps under different EMC environnments	X		X	
0625	Impact of Voltage Distortion on Energy Efficiency			X	
0657	Results of harmonic interactions of EV chargers and PV systems			X	
0816	Harmonic Aggregation and Amplification in A Wind-Park	X		X	
0873	Power Quality Impact of Electric and Plug-In Hybrid Vehicles			X	

0919	Validation of a Harmonic State Estimation Method Based on Fifth Harmonic Current Characteristic of Utility Customer using Transient Simulation		X	X	
0920	Practical Issues with Transmission System Harmonic Allocation using IEC 61000.3.6 Ed. 2 2008	X		X	
0935	The Effect of Plug-in EV's Charger on Harmonic Analysis of Distribution System And Determination Optimum Charging Time				
0944	Power System Harmonic Mitigation Solution for 115 kV Customer of PEA			X	
0946	Harmonics analysis using sequential-time simulation for addressing smart grid challenges				S5
0950	Stabilization of Harmonic Instability in AC Distribution Power System with Active Damping			X	
0954	Modelling Solar Parks for Harmonic Studies			X	
1017	Mapping of harmonic levels in the low-voltage network			X	
1066	Impact of non-intentional disturbances on Distribution Line Communication			X	
1068	Field and laboratory measurements of interference with light equipment due to waveform distortion originating from a large rectifier			X	
1214	ERDF Endorses Power Quality for E-Mobility			X	
1348	Conducted Disturbances in the Frequency Range 2-150 kHz: Influence of the LV Distribution Grids			X	
1352	Impact of LV connected low carbon technologies on harmonic power quality			X	
1386	CONSIDERATIONS ABOUT REACTIVE POWER UNDER NONSINUSOIDAL CONDITIONS			X	
1404	Impact of Electric Vehicle Charging on Unbalance and Harmonic Distortion - Field Study in a Urban Residential Area	X		X	
1483	Harmonic analysis of LED street lighting according to IEC61000-3-2; a case study				
1621	Measurements of primary and secondary emission in the supraharmonic frequency range, 2-150 kHz			X	
1653	In-situ measurements on HFPQ	X		X	

BLOCK 3: VOLTAGE VARIATIONS

This block gives a summary of the papers dealing with voltage magnitude related disturbances, covering the questions of voltage level, voltage flicker, unbalance and dips.

Voltage Level Affected by Distributed Generation

Due to the growing penetration of new types of loads and generation the voltage level can vary significantly with time due to infeed of dispersed generation or charging of electric vehicles. Therefore specific measures have to be taken in order to minimize expensive grid reinforcement measures. 11 papers dealing with this issue have been submitted and propose smart solutions and analyse their capability to increase hosting capacity including voltage regulation and storage. Broadening of the permissible voltage range in LV grids and adaption the Grid Code and EN 50 160 is another way to bring more flexibility to the distribution system operator.

[B3-1636(BE)] discusses the question if a broader voltage range could be acceptable in distribution grids. A survey of the different stakeholders including manufacturers, regulators, network operators and independent PQ experts has been conducted in the Netherlands and Belgium. The conclusion was that the most promising change of the voltage limits would be to allow the lower limit of Un-15% with a new time limitation (e.g. for 10% in a week or 5% in a longer periods as compared to currently 5% in a week). This could prevent PV production in areas with high penetration being switched off during peak production. Additional flexibility of the voltage band would be beneficial for the distribution network operator under the condition that household appliances work properly within this range. In [B3-0578(BE)] the question is addressed from a different point of view. Measurements to investigate the influence of a range of the supply voltage between 230 V ± 15% were performed to a wide variety of household appliances. The major conclusion is that both at low and high voltages the performance is affected leading possibly to an undesired loss of comfort for the customer.

A new non-parametric methodology to assess the capability of a distribution system to meet predefined voltage levels is proposed in [B3-0572(IR)]. Voltage level may no longer follow normal distribution and even be bimodal in the presence of distributed generation. Normality of the voltage at five industrial power consumers was tested using Kolmogorov-Smirnov method. Voltage at all five nodes did not follow normal distribution, Johnson transformation and fitting to non-normal distributions like Weibull and Gamma distributions also failed. Calculating capability indices assuming that the data fits these distributions yields misleading results. Therefore a non-parametric technique was applied which allowed the calculation of capability indices. [B3-0393(ZA)] has shown that appropriate statistical load data for both over- and undervoltag are crucial for calculating voltage drops and rises with or without embedded generation. A probabilistic method was developed based on the statistical moments of the Beta distributed load currents which is well suited for calculating voltage variation. [B3-0641(BE)] presents a probabilistic framework which analyses in a fast optimised way the voltage profile along LV feeders, considering the uncertainty of their loading parameters node by node, based on real smart meter data. The presented framework can simulate either perfectly balanced systems or unbalanced systems

A hybrid methodology to forecast electrical quantities to proactively control voltage and reactive power is presented in [B3-1308(BR)]. The simulations discussed in the paper focus on short term forecast (10 minutes) of voltage and reactive power at certain monitoring points and take into account information from power flow calculations and state estimation.

In [B3-0332(DE)] a systematic comparison of different control algorithms for voltage regulated distribution transformers (VRDT) is undertaken. Five different urban and suburban grids have been analysed by probabilistic load flow analysis and field measurements with the aim to maximize PV hosting capacity. Results show that bus bar voltage control is sufficient in most grids, while remote sensors can offer more flexibility for PV generation positioning.

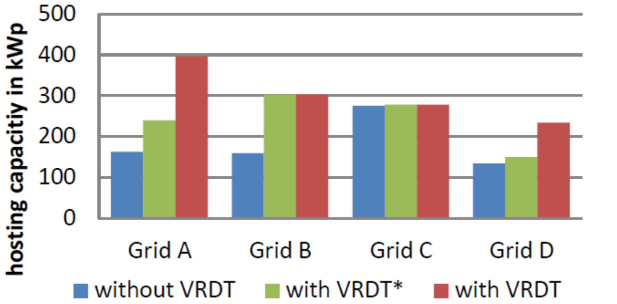

Figure 15: Hosting capacity grid A – D (with VRDT*: Hosting capacity limit to 30 kWp per house by definition Parameter: BVC, U0 = UN, UB = +/- 2.5 %) [B3-0332(DE)]

In [B3-0588(DE)] two dynamic RMS simulation models of the voltage control system Q(V) are presented The models have been validated against a significant number of measurements and yield a very high consistence. Subsequently, they can be incorporated into transient simulation models to determine the stability of distribution grids with a high degree of decentralised energy resources using reactive power control.

In [B3-0817(BR)] the application of series compensation in a medium voltage radial system is evaluated and tested in a 23.1 kV voltage feeder to reduce the voltage drop and improve voltage stability. Thorough analysis and simulation is necessary as sub-synchronous oscillations can occur. The application of series capacitor banks in MV systems is limited by the power factor and the less favourable R/X ratio as compared to HV systems.

[B3-1512(US)] describes the field trial of a power electronic device which regulates the voltage on the LV network. The device uses a unified power flow controller (UPFC) architecture with a capability for shunt reactive current injection and series voltage control.

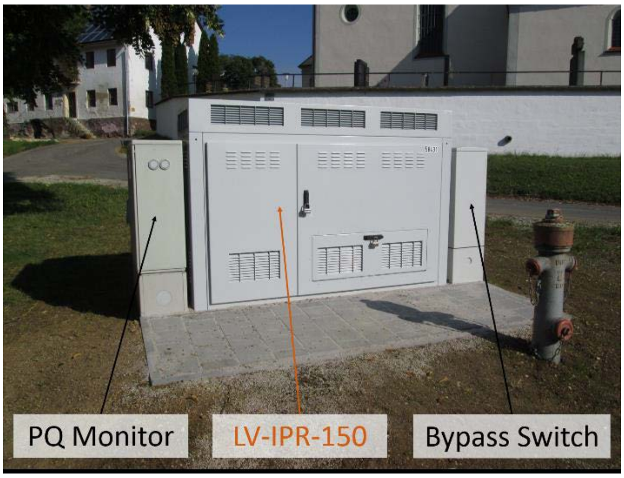

Figure 16: The power regulator, LV-IPR-150, as deployed in the field trial. The configuration includes a third-party power quality (PQ) monitor and a third-party bypass switch [B3-1512(US)]

During the trial period the voltage at the downstream side of the device was held steady. This worked even though the input voltage (upstream side) varied considerably. The direction of power flow changed many times due to a 20 kW PV downstream.

The role of distributed generation in emerging electrical power systems is discussed by [B3-1009(IR)]. Allocation of hybrid renewable energy systems with storage is optimised using HBMO (honey bee mating optimization) with the aim to minimize real power losses and improve the voltage profile in radial distribution systems. The proposed methodology has been tested on the IEEE 33 bus system.

Voltage Level affected by Electric Vehicle Charging

In [B3-0266(IR)] the consequences of connection and disconnection of electric vehicles with V2R functionality are discussed with respect to limits for the permissible voltage band in LV and MV distributions grids. Improvement or deterioration of PQ indices depends on performance of the EV after connection to the grid. In this paper the term ‘hosting capacity’ of a feeder is extended to account for the number of EV that can be connected to a feeder without violating the PQ indices. Simulations show that it is necessary to consider optimal charging of the EVs to increase the hosting capacity. Power system data of the smart grid pilot project in Pattaya city have been used for simulations of the impact fast charging stations have on a MV grid in [B3-1354(TH)]. Monte Carlo simulation is applied by randomly assigning input values consisting of daily distance travelled for determining the state of charge of battery, arrival time an charging duration. The simulation shows that the voltage characteristics and drop in the distribution system are affected by the fast charging stations. The fast charging stations lead to abrupt voltage changes, which affect sensitive loads.

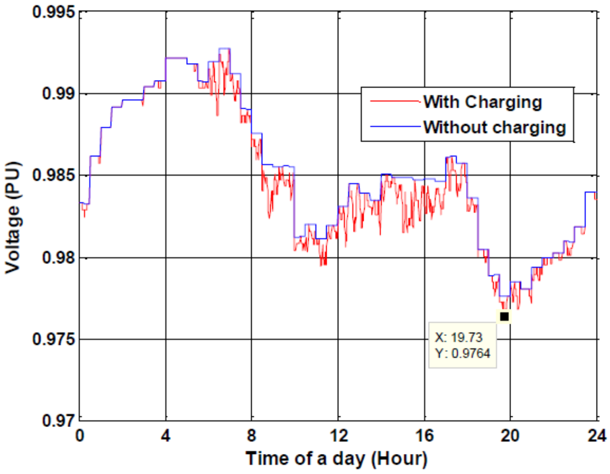

Figure 17: Voltage profile in case of 2,500 EVs in area [B3-1354(TH)]

The benefits of active front-end Electric Vehicle Supply Equipment (EVSE) was analysed in [B3-1092(DE)]. Offering the feature of independent regulated reactive power, an EVSE with a self-commutated active front-end helps to stabilize the voltage in remote locations.

Flicker and Fast Voltage Variation

The phenomenon flicker gets increased attention, as on the one hand the reference for flicker the incandescent lamp is phased out and the phenomenon has to be investigated and standardised for new types of lamps. On the other hand new types of generators and loads connected via inverters produce rapid voltage changes in the system, which may lead to volatile luminance of lamps and thus a disturbance of the visual perception. 12 papers have been submitted, which address the question how to adequately deal with flicker under the new circumstances. Long-term flicker is an essential parameter of voltage quality and the effect of distributed generation on flicker is a question under investigation as it could limit the installable peak power in distribution grids.

The phenomena leading to flicker of compact fluorescent lamps (CFLs) and light emitting diodes (LEDs) are discussed and analysed in [B3-1100(FI)]. Recently high levels of third order harmonics, especially 15 and 21, and flicker by CFLs have been observed which might be related. The authors point out potential gaps in the current EMC standards. There are clear indications both theoretically and from measurements that certain interharmonics cause flicker with energy-saving lamps, which is not captured by the flicker-meter algorithm as the flicker of energy saving lamps seems to be related to the fluctuations of the voltage peak value. Therefore the flicker standard IEC 61000-4-15 which is based on the standard 60 W incandescent lamp needs to be completely revised. Furthermore the authors point out that the standard method for measuring interharmonics gives insufficient frequency resolution to detect interharmonics that might potentially cause light flicker.

[B3-0409(ES)] presents the immunity test protocol developed by working group MT 1 of IEC-TC34 to test the sensitivity of modern lamps to voltage fluctuations. The main objective is to establish a common and objective reference for evaluating the immunity of lamps in terms of illuminance flicker. The idea is to limit light fluctuations during the design process, so that existing compatibility levels and measurement procedures could still be used. The design of the light flicker-meter is based on the IEC flicker-meter with two main modifications: the input is the light output of the lamp instead of the voltage signal and the parts related to the response of the incandescent lamp need to be adjusted.

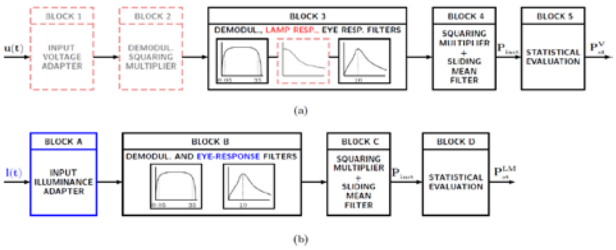

Figure 18: Block diagram of the IEC flicker-meter; (b) Block diagram of the light flicker-meter [B3-0409(ES)]

A solution for flicker-meter implementation on the platform of power quality analysers is presented in [B3-1077(CZ)] according to the current standard IEC 61000-4-15 2.0. The main challenge is the choice of the right sampling rate and the resampling rate, which is needed for the correct operation of the power quality analyser, which needs further analysis. The tests which have been conducted indicate that the requirements according to IEC 61000-4-15 2.0 can be met for the highest class F1 with a high-end hardware platform and for F3 with several low-end platforms.

[B3-1441(RO)] focuses on the data of PV power plants provided by the nationwide PQ monitoring system. The Romanian TSO has revised the technical norms for the connection of wind and PV power plants and requires conformity certificates for distributed generation. The data analysis for several sites connected at MV level shows that long-term flicker was the only PQ indicator that was outside of the limit. A detailed analysis performed in 2014 indicates that high flicker values are accompanied by other PQ events such as voltage dips and interruptions. Simultaneous measurements show little propagation effect. This suggests that there may be no actual flicker phenomenon, but individual high values of short-term flicker during voltage events. The probability of severe events was found to be greater in case of PV power plants put into operation when there is not enough daylight available to ensure a steady power flow. The authors point out that regulation should account for the relationship TSO/DSO energy producers from renewable sources regarding PQ compliance and development.

Based on the current maximum PV penetration in [B3-0060(DE)] a model with variable PV gradients and grid parameters is presented which takes long-term flicker as limiting power quality criterion for the installable PV power in the low voltage grid. The simulations of the PV-occasioned long-term flicker show, that this PQ criterion is not exceeded if thermal current limits of cables and transformers and normative voltage rise are respected.

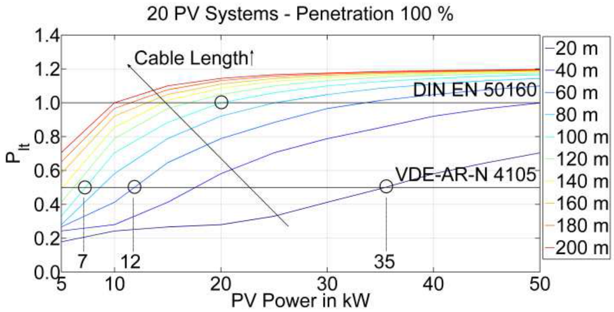

Figure 19: Simulated long term flickers for various cable lengths and PV system sizes [B3-0060(DE)]

In [B3-0231(EE)] the effects of distributed generation on different PQ indices are analysed using measurements from producers. The paper focusses on small producers with a production capacity between 200 kW to 5 MW and gives an overview of the connection process. The results of the measurements are presented using the Power quality Index method. The overall average PQI value is 44%; EN 50 160 limits were only exceeded for flicker. However, no correlation between the active power infeed at the measuring points and flicker was found.

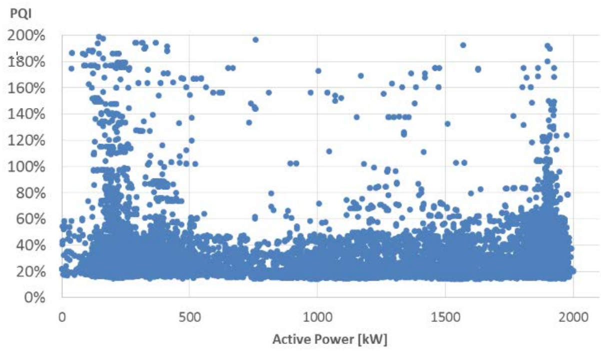

Figure 20: PQI and active power scatter plot for measurement point MP5 [B3-0231(EE)]

[B3-0375(SE)] addresses the topic of very short voltage variations (VSV). This study shows that wind and solar power under some circumstances may lead to an increase in the VSV-levels in the grid. The main concern is not flicker but how such an increase will affect equipment.

The effects of the mass deployment of high-inrush devices like heat pumps are investigated in [B3-1229(US/CA)]. A computer model for the distribution system with a detailed model of a typical compressor used in modern heat pumps and air conditioners was developed and validated. The model was used to analyse the impact of different mitigation measures.

In [B3-0446(CN)] a fast algorithm for flicker reduction with a Static VAR Compensator (SVC) is introduced, which employs a phase-lock method based on synchronization frequency decomposition and transformation. Performance test results for a 110 kV steel plant with two 18 MVA steel furnaces and two 7 MVA refining furnaces are presented for a 28 MVA SVC showing a flicker improvement above 50 % and keep the long term flicker below 1.0 pu.

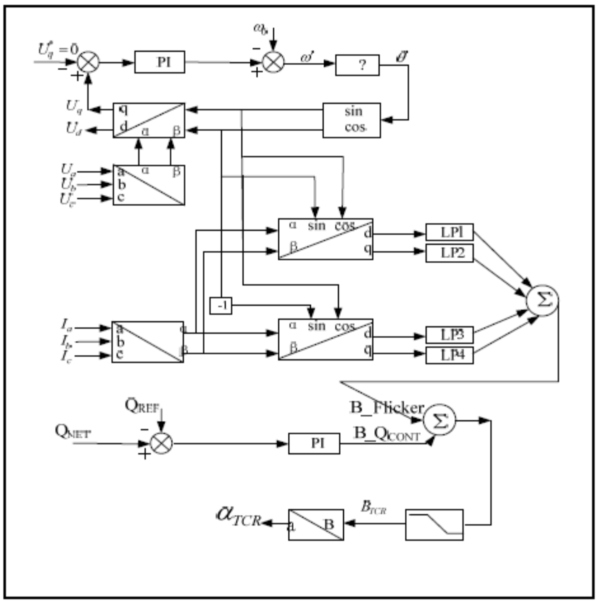

Figure 21: Function block of voltage flicker reduction algorithm [B3-0446(CN)]

The application of a low speed flywheel energy storage system (FESS) for fluctuation suppression is discussed in [B3-0591(IR)]. The design process for a low speed FESS is described with the aim to find an inexpensive solution with simplified maintenance. A simulation has been carried out in order to evaluate the applicability of the system for wind generators.

In [B3-0683(NL)] the application of static UPS is proposed as an economic alternative to conventional grid reinforcement in areas with low population density and therefore long LV underground cables with high circuit impedance and radial topology. In a specific case, load changes cause fast voltage variations of more than 15%. Three scenarios have been compared for that case showing that the total cost for solving the PQ problem is less for the UPS - both in conventional and higher efficient technology - than for grid reinforcement.

In paper [B2-1444(US)] an analysis of the voltage quality behaviour due to the use of induction motors, including large starting current surges and sudden increases due to mechanical load variation are discussed. In addition, the power delivery from PV systems can also change the grid voltage rapidly. The resulting voltage variations can cause problems ranging from nuisance flicker to equipment failure. To minimize the impact of these voltage variations, utilities tend to resort to grid reinforcements, lowering grid impedance by replacing conductors and transformers. Since grid reinforcement is time consuming and expensive alternative approaches are presented. Dynamic simulation and functional modelling calibrated with power quality measurements from the field can provide insight with respect to the effectiveness and limitations of a possible solution. This should be carried out before field deployment begins.

Unbalance

A Universal Compensator (UC) for Power quality improvement is presented in the paper [B2-0452(IT)]. The authors state and prove by measurements that it compensates both harmonic currents, reactive power and unbalances of disturbing loads and is able to supply sensitive loads in island mode. A 50 kVA UC model has been designed. The simplified circuit scheme is represented in Figure 3.2 and a digital simulation model is used to assess its performance. The control of the device automatically switches between the grid connected operating mode to island mode when a grid disturbance occurs. The main goal of UC during island mode is to restore the grid voltage at the load connection point with an adequate quality level. A fixed frequency hysteresis band modulation, with predictive calculation of threshold values, is adopted for the generation of switching commands.

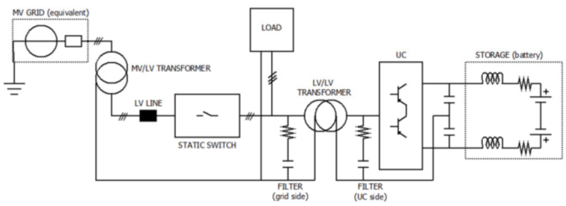

Figure 22: UPQC schematic [B2-0452(IT)]

Unbalanced loads and single phase PV limit the hosting capacity of LV feeders due to a faster exceeding of the overvoltage limit. The authors of [B3-1082(AT)] analysed the effect of balanced Q-control and individual phase control of PV inverters. The asymmetrical control using the individual phase voltages provides the best results regarding overvoltages but could lead to an increase of the negative sequence component. In theory, the controller could also influence the negative sequence component and limit the reactive power control to avoid exceeding the limit.

The paper [B2-0595(IR)] describes the current balancing based on an automated phase tracking in case of distributed single-phase loads in a three-phase system. Therefore they use the feeder phase and load profile of each single-phase load to reconfigure the network by an optimization process called ‘phase tracer'. As a result, the balancing of the current of three phases decreased the neutral conductor current in substation's transformer by more than 80%. The classic method for zeroing the neutral current in substations is only focused on the neutral node in the transformer of substation. The proposed method not only reduces the current of neutral node in substation but also decreases the current of other neutral conductors in the other parts of LV network. Also the power loss in conductors has been decreased by about 8%.

A low voltage network load balancer was designed and homologated for use on the French public grid in 2009. This contribution [B2-1004 (FR)] analyses 5 years of operation of 60 devices installed between 2010 and 2014. In 95% of the cases phase voltage deviations were reduced from an average 16% to the standard limits of ± 10%. The balancer consists of 3 zig-zag coupled 1:1 transformers that are connected to the 3 phase wires (**Figure 24**) and create a neutral point connected directly to the relatively high impedance neutral wire. As the impedance of the transformers is lower than the line impedance, it creates a low-impedance zero-sequence path that unloads the neutral wire and improves phase current balancing. The installation cost of the balancers represented a mere 6.4% of the planned reinforcement budget.

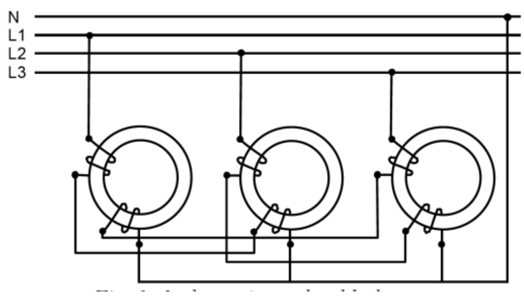

Figure 23: Zig-zag 3 phase load balancer [B2-1004(FR)]

The paper [B2-1201 (TH)] discusses the impact of EVs on voltage unbalance in the distribution system. A model of distribution network has been developed with the DIgSILENT PowerFactory, where the assignment of EVsto each node is performed by a Monte Carlo method. Charging scenarios focus on overlaps of charging periods in each phase while charging is considered over 6 hours and simulations are carried out for 5 cases. The value of the unbalance factor increases gradually along the length of feeder and reaches a maximum value at the end of the feeder as shown in Figure 25

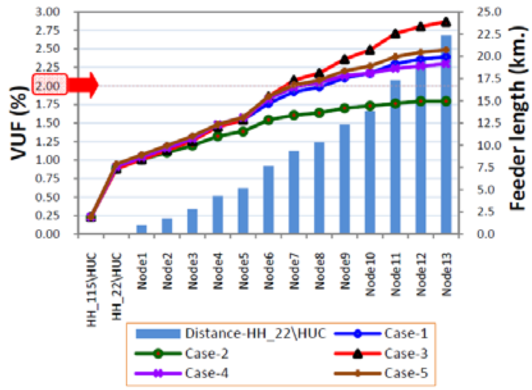

Figure 24: Phase unbalance versus feeder length [B2-1201(TH)]

Similar to the previous contribution also paper [B2-1437(TH)] discusses the impact of EVs on distribution system. Since EVs are movable and their charging periods are quite uncertain and depend solely on drivers' behaviour, the impact on the voltage profile is hard to predict, especially in case of slow charging single-phase system. This may cause voltage unbalance in the MV distribution system. This study simulates a 22 kV system. The EV's charging behaviour is modelled based on stochastic variables. From the simulation results, it can be found that the coordinated charging can be used to improve the performance of distribution system regarding high penetration of EV charging. The presented paper also suggests guidelines for primary prevention.

The paper [B2-0108(UK)] addresses power quality issues with respect to the negative sequence requirement, at the point of common coupling between Transmission System Operator and Railway Infrastructure Company. The railway traction power demand is a single-phase demand that presents an unbalanced voltage at PoC to the transmission system and general limits of unbalance in UK are given in the Energy Networks Association (ENA). The usual way to mitigate the unbalance in traction systems is applying a load balancer to ensure that the unbalance at 400 kV due to the single phase traction power demand is within the given constraints. Since regenerative breaking is subsequently introduced, a redesign for the scenario when traction is exporting power to the TSO network is needed and discussed. The paper suggests mitigation measures in order to enable the trains to run in regenerative breaking mode without operational constrains.

Voltage Dips

This paper [B2-0183(SE)] summarizes the state of discussions in CIGRE/CIRED joined working group C4.24, concerning expected impacts on the power quality of future methods for volt-var-control in the distribution grid. The positive impacts include the reduction of the number of overvoltage and undervoltage events and also a reduction of voltage unbalance, when different control schemes are applied. Potential negative impacts include an increased number of short-duration undervoltage events, rapid voltage changes, flicker, and voltage transients, a higher risk of harmonic resonances and increased emission of supraharmonics. All these potential impacts are discussed in the paper. The main question that should be asked, and that is still waiting for an answer, is whether there are cases where the negative impacts of VVC exceed the positive impacts. It is important that these cases are identified and be the base for recommendations to network operators that want to introduce new ways of volt-var control.

The authors of paper [B2-0253(US)] give an overview, including a five-step approach with respect to the new IEEE Standard 1564-2014 that identifies appropriate voltage sag indices and characteristics of electrical power and supply systems as well as the methods for their calculation. Next to an overview, it also summarizes the IEEE 1564 methods for quantifying the severity of individual voltage sag events. The methods are appropriate for use in transmission and distribution systems. To give a value to the performance of a power system in terms of voltage sags, the guide presents a five-step procedure: 1) Obtain sampled voltages with a specified sampling rate and resolution, 2) Calculate event characteristics as a function of time from the sampled voltages, 3) Calculate single-event characteristics from the event characteristics, 4) Calculate site indices from the single-event indices of all events measured during a certain period of time and finally 5) Calculate system indices from the site indices for all monitored sites within a certain power system.

The paper [B2-0496(IT)] addresses in particular the evaluation and characterization of sequence of voltage dips (Figure 26) on the new generation telecommunication network, which provides the main Italian towns with ultra-broadband services. Since ultra-broadband requires more energy, there is the need to supply from the local electrical distribution network and consequently the analysis of dip behaviour which could reboot ultra-broadband devices installed in the street cabinets. A compensation strategy for short term storage devices, including super-capacitors to compensate the most frequent voltage disturbances is discussed. As shown in the paper, the engineering solution adopted by Telecom Italia is based on supercap technology.

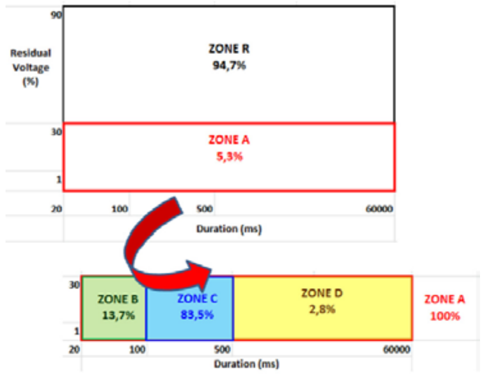

Figure 25: Reboot zone (A) for UBB devices [B2-0496(IT)]

The authors of paper [B2-0836 (ES/SE)] perform detailed analysis of disturbance recordings, using accurate segmentation methods. They state that a joint causal and anti-causal (CaC) segmentation method can give good results, where the presented methods have only been tested with synthetic signals. However, in this contribution the performance of the so called CaC segmentation has been experimentally analysed with a set of real measurement signals. Experimental results show that CaC segmentation is useful to detect both slow and fast transitions on dips. Furthermore, a classification of dip types can be made based on the proposed method: dips with fast transition in two phases or fast transition in one phase and no detection in other one, these dips are due to two-phase or single-phase to ground faults and have a fast recovery; dips with slow transition on two or three phases, are due to three-phase or two-phase to ground faults and have a slow recovery. An event identification method based on the evaluation of transient behaviour is proposed in [B3-1656(CN)]. Morphological Max-Lifting and Nonlinear Principal Component Analysis is used. The method was successfully applied to test signals.

Paper [B2-1059(UK)] presents the concept of provision of differentiated levels of voltage sag performance and proposes a mitigation strategy to fulfil this concept using FACTS devices. A system index of voltage sag performance is proposed to represent the satisfactory degree of the actual sag performance in accordance with the customer requirements. Using the latter as objective function, Greedy algorithm is adopted to search the optimal mitigation solutions among initial device placements which are selected based on voltage sag performance. In the paper, a 295-bus generic distribution network is used as test system. In the zonal selection, the procedure is the same as the global selection, except that the ranking procedure is performed within the zones rather than within the whole network. With these initially pre-selected locations, Greedy algorithm is used (Figure 27) to search the potential solutions (i.e., optimal placement of FACTS devices and their optimal rating settings) to minimize the gap between the threshold and bus performance index achieved after the application of mitigation solutions. It is demonstrated that choosing optimal placement of devices for the purpose of provision of differentiated sag performance in the network is more effective (75% reduction in mitigation effort, and therefore cost) if the sag gap index is used compared to the use of the general system sag index.

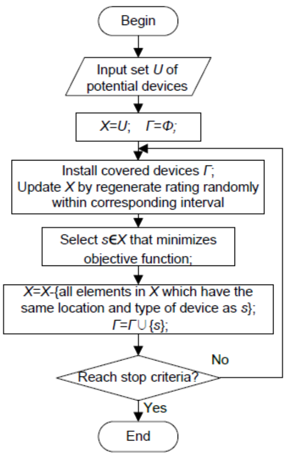

Figure 26: Flowchart of greedy algorithm. [B2-1059(UK)]

The paper [B2-1064(UK)] investigates the characteristics and differences among six single-event characteristics, including the widely used indices which are recommended in IEEE Standard 1564. Through comprehensive comparison analysis, this paper aims to provide guidelines for selecting appropriate sag index for particular study cases provided. The area covered by the voltage tolerance curve (Figure 28) represents sag susceptibility.

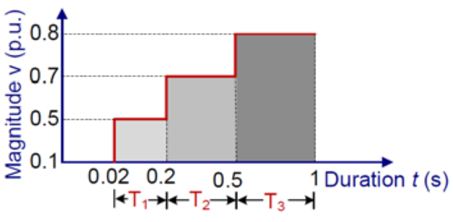

Figure 27: Used voltage tolerance curve [B2-1064(UK)]

Main conclusions of this study can be given as follows: Both voltage sag energy and lost energy indices calculate the energy that is not delivered during voltage events while missing voltage - time area index can be selected if IT equipment is the main concern. From the perspective of distinguishing the sag severity of different events, the sag severity index as defined in the paper provides information about sag magnitude and duration.

With the increased importance of quality of supply around the world in the recent years, the paper [B2-1067(UK)] investigates effective, network-based mitigation schemes to ensure the effective management of PQ. Isolating transformers, phase shifting transformers, undergrounding techniques and series reactors are investigated to solve PQ problems. The mitigation effect of these techniques is presented statistically at system level and at zonal level. The results have shown that the variation of system level and zonal PQ performance is pronounced when different mitigation techniques are applied. Differentiated PQ performance can be provided by selecting appropriate mitigation techniques and proper zones to implement these mitigation techniques. For sag phenomena, the use of undergrounding overhead lines, and placement of series reactors are investigated. The results show that using series reactors can result in better sag performance than using undergrounding techniques.

In paper [B2-1121(DE)] the massive change in generation of electrical energy is discussed. Since conventional power plants are more and more substituted by distributed renewable energies a significant reduction of rotating inertia is found. Consequently a large amount of permanent grid connected rotating inertia will then be lost and system services like voltage support, short-circuit current and short-circuit capacity will decrease (Figure 29). In order to get impressions of the effect of reduced rotating inertia on expansion of voltage dips, different scenarios regarding changes of the residual load and the number of active power plants are investigated in the German distribution network and presented is this contribution.

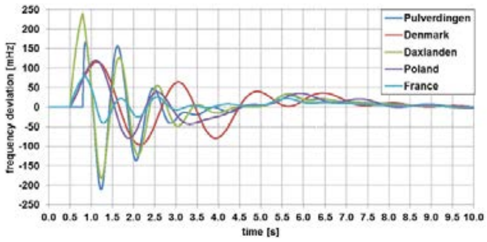

Figure 28: Frequency deviations after a 300 ms three-phase short-circuit at the substation Pulverdingen [B2-1121(DE)]

Comparing the development of affected load in all scenarios leads to basic statements about the effects of reduced rotating inertia on expansion of voltage dips by three-phase faults. The behaviour of the dynamic model after a three-phase short-circuit is shown based on voltage and frequency deviation plots. To analyse the effect, six different scenarios are set up. The results are presented in a comparative way.

The authors of paper [B2-1172(CN)] emphasise the impact of voltage dips in power electronic convertors. During voltage sags, the inverter can trip due to a lacking low voltage protection and cause inverter to stop working. This will result in non-planned outages in the continuous production enterprises, leading to huge economic losses and even personal safety accidents. Two kinds of voltage sag protection (VSP) systems are researched and developed based on DC support technology, which take network residual voltage and batteries as energy source, respectively. It is shown that through a boost DC/DC converter, the VSP system delivers a constant DC voltage, supporting the inverter's DC bus. The system with batteries also can be used to protect the inverter from short interruptions. In accordance with the duration of voltage sag and load requirements, the design of protection system and the configuration of batteries is introduced. Experimental data and field applications show that the two kinds of VSP systems can ensure the normal operation of the inverter during voltage sags which significantly improves the reliability.

Paper [B2-1229(US/CA)] presents a guide to a successful accommodation of the mass penetration of high inrush current devices such as air conditioners, heat pumps, various types of commercial compressors, power tools and on-demand water heaters on the low voltage distribution network. Residential and small commercial devices that commonly demand high inrush power during starting are analysed. (Figure 30). The inrush during start-up of these devices can cause voltage sags on the utility system, which may be severe enough to damage equipment components. For future research, it is recommended to continue the study by utilizing the highly-detailed model of the Hydro Ottawa distribution system The determination at which penetration levels mitigation measures are warranted are also discussed, including possible mitigation measures. These measures include restoring the system in sections, installing additional transformers, and connecting to other sources.

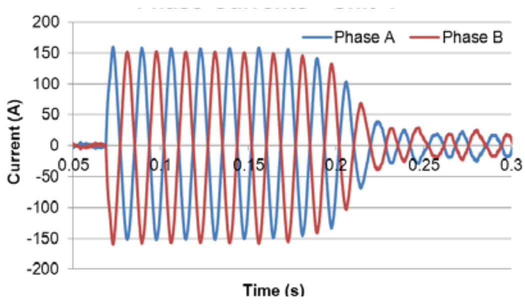

Figure 29: Measured inrush current during start-up of a residential heat-pump [B2-1229(CA)]

The authors of paper [B2-1485(IT)] present a novel method for the monitoring of voltage dips on MV networks. The monitoring architecture is included in a smart grid project and makes extensive use of the IEC 61850 communication between the protection relays in primary substation. A suitable sensitivity of protection relays is presented in order to accomplish the correct classification of voltage dips It is shown that this aspect could be critical especially for phase-to-phase overcurrent protections, which could not detect a fault if overcurrents do not exceed the fixed threshold (e.g., in the presence of high resistance faults): in these cases, the monitoring system would attribute a HV origin to dips caused by the DSO. The innovative monitoring system proposed in this contribution makes extensive use of ICT resources.

In paper [B2-1508(EG)] voltage sags have been recorded (Figure 31) for the purpose of discrimination and assessment. The system under study has been simulated in MATLAB/SIMULINK environment in order to study the causes of voltage sag (faults, transformer energizing, load switching and induction motor starting). The simulation has been done to find out the actual causes of the phenomena considering system construction and operating scenarios. A two-dimensional chart has been used to identify the origin of voltage sags via the single-event characteristics (sag magnitude, sag duration). Simulation results and recorded voltage sags have been allocated on one chart. The allocation showed that there is an overlap between voltage sags due to single line to ground faults (SLGF) and voltage sags due to transformer energizing in distribution networks. Voltage sag duration is mainly affected by the fault clearing time. In case of transmission faults, voltage sag magnitude is affected by fault resistance magnitude, fault type and fault location. From comparison of simulation results and recorded measurements it is found that voltage sag characterization using sag magnitude and sag duration is not enough to distinguish between voltage sags originating from distribution system faults and those from transformer energising.

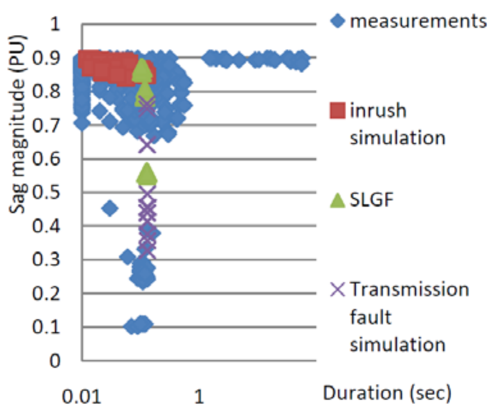

Figure 30: Recorded voltage sags and simulation results [B2-1508(EG)]

The paper [B2-0302(EG)] compares the effectiveness of installing two types of FACTS devices, the Static synchronous compensator known as STATCOM, and the Unified Power Quality Controller UPQC (Figure 32) to enhance the low voltage ride through capability of a grid-connected wind energy conversion systems. These devices allow fast recovery after a ground fault and prevent the system from rotor over-current and dc-link overvoltage. Results of the study revealed the better performance from the non-zero stator current during fault and the slight increase in rotor speed of the wind energy conversion systems with UPQC. Faster recovery and smoother profiles are proven in this contribution when employing the UPQC. An overview on power conditioning systems and technologies for renewables, storage and microgrids is given in [B3-0898(IR)].

Potential scope of discussion

Regarding flicker the phase out of incandescent lamps, which have been the reference for flicker and the penetration of distribution grids with new equipment leads to a completely new situation and the necessity to revise the existing standards themselves as well as their coordination. This includes product standards, power quality regulations and subsequently compatibility levels and emission and immunity levels. As the phenomena leading to flicker for new types of lamps (CFLs, LEDs) are not yet fully understood, studies will have to be conducted regarding the immunity of new types of lamps, the effect of the complex interaction of non-linear equipment in the LV grid on flicker and the relation between flicker and interharmonics.

Table 3: Papers of Block 3 assigned to the Session

Paper No.	Title	MS p.m.	RIF	PS	other session
0060	How much photovoltaic capacity can handle distribution grids with regard to the long term flicker?	X		X	
0108	HV Connection options when introducing regenerative braking on HS trains			X	
0183	Volt-var control and power quality (CIGRE/CIRED C4.24)			X	
0231	Impact of small producers on power quality in distribution grids based on Elektrilevi OÜ grid			X	
0253	Overview of IEEE Std 1564-2014 Guide for Voltage Sag Indices			X	
0266	Power Quality Assessment in Distribution Systems Embedded with Electric Vehicles and its Enhancement by Optimal Charging				
0302	Comparing the LVRT Capability of Grid Connected Wind Energy Conversion System with Different FACT Devices			X	
0332	Control Algorithms for Voltage Regulated Distribution Transformers Maximum Grid-Integration of PV and Minimal Wear	X		X	
0375	Very short variations in voltage (timescale less than 10 minutes) due to variations in wind and solar power				S4
0393	Voltage profiles on LV residential feeders with PVEG using a practical, probabilistic approach				S4
0409	A protocol to test the sensitivity of lighting equipment to voltage fluctuations	X		X	
0446	voltage flicker reduction with SVC in steel plant			X	
0452	A Universal Compensator for Power Quality Improvement in LV Distribution Grids			X	
0496	Characterization of sequence of events potentially responsible for the reboot of ultra-broadband telecommunication devices			X	
0572	Assessing voltage conformity by capability analysis				
0578	Influence of the supply voltage on the performance of household appliances	X		X	
0588	A dynamic RMS-model of the local voltage control system Q(V) applied in photovoltaic inverters				S4
0591	Fluctuation suppression of a WECS by using a SRM equipped flywheel energy storage system				
0595	Current Balancing for Distributed Single Phase Loads Based on Automated Phase Tracing				
0641	Probabilistic Analysis Tool of the Voltage Profile in Low Voltage Grids				S5
0683	Power Quality improvement in rural areas with static UPS technology			X	
0817	Series Compensation on Medium Voltage Radial Systems			X	

0836	Tests and Analysis of a novel Segmentation method using Measurement Data		X	X	
0898	Power Conditioning Systems for Renewables, Storage, and Microgrids				
1004	3-Phase Low Voltage Network Load Balancer: A Cost Effective Solution to Line Voltage Variations	X		X	
1009	Optimal placement of hybrid renewable energy system for minimum real power and voltage profile improvement in radial distribution system using HBMO				
1059	Provision of Differentiated Voltage Sag Performance Using FACTS Devices		X	X	
1064	Comparative Analysis of Different Voltage Sag Characterisation Indices			X	
1067	Provision of Differentiated Power Quality Using Network Based Mitigating Solutions			X	
1077	Detailed analysis of class F1 / F3 flicker meter implementation according to the recent IEC standards			X	
1082	On the effectiveness of voltage control with photovoltaic inverters in unbalanced low voltage networks				S4
1092	Reactive Power Support for Optimal Grid Integration of Fast-Charging Infrastructure in German Low-Voltage Networks				S5
1100	Interharmonics and light flicker	X		X	
1121	Effect of reduced rotating inertia on expansion of voltage dips caused by three-phase faults in the German Power Transmission Network			X	
1172	Research on Voltage Sag Protection system based on DC Support Technology			X	
1201	IMPACT ANALYSIS ON VOLTAGE UNBALANCE OF PLUG-IN ELECTRIC VEHICLE HOME CHARGING IN THAILAND DISTRIBUTION SYSTEM			X	
1229	A Guide to Successful Accommodation of Mass Penetration of High Inrush Current Devices on Distribution Networks			X	
1308	Hybrid Forecasting Techniques Applied to Distribution Systems for Proactive Voltage Control			X	
1354	Impact Analysis of Fast Charging to Voltage Profile in PEA Distribution System by Monte Carlo Simulation.			X	
1437	Analysis of Unbalance Electric Vehicle Home Charging in PEA Distribution System by Stochastic Load Model			X	
1441	CONSIDERATIONS ON PHOTOVOLTAIC POWER PLANT POWER QUALITY REQUIREMENTS			X	
1444	Modeling the effectiveness of power electronics based voltage regulators on distribution voltage disturbances			X	
1485	A novel Smart Grid architecture for the monitoring of voltage dips according to Italian Resolution ARG/elt 198/11			X	
1508	Discrimination and Assessment of Voltage Sag in Distribution Networks			X	
1512	A comparison of field results with modelled behaviour for a power electronics regulator used to manage dynamic voltage variation on a feeder with high PV content				S1
1636	Network housekeeping with stretched Low Voltage limits			X	
1656	Power Disturbance Identification based on Transient Behaviours Using Morphological Max-lifting Scheme and Non-linear Principal Component Analysis			X	

BLOCK 4: POWER QUALITY MONITORING

Power quality performance is a critical issue in network operation and planning today and is gaining more importance for future intelligent networks. Increased penetration of distributed generation as well as a rising number of sensitive loads and industrial processes together with regulatory framework direct attention of DSOs, customers and regulators towards monitoring and eventually control of the level of PQ provided in distribution networks.

Power Quality Monitoring and Control

Historically advanced DMS function including monitoring and control has been reserved to the transmission system. Monitoring functionalities have already been installed in several countries in distribution networks for a number of years. This subsection comprises 10 papers analysing results of monitoring campaigns and future prospects. With the increased demand for reliable power supply and PQ regulation there will be a rise of advanced DMS systems in MV grids.

In [B4-0046(CZ)] long-term monitoring of voltage dips in the Czech Republic is presented and discussed. To set limits for voltage dips the detailed assessment of long-term monitoring has to be carried out. Results of initial assessment of long-term voltage dip monitoring are published in this paper. A largely random occurrence of voltage dips was recorded on all voltage levels. The annual number of dips in MV networks varies between 10 and 120 dips, which is two times more than in HV networks. More than 75% of dips recorded in HV and MV levels have duration less than 0.1 second, whereas this is true only for 50% in LV. The annual number of dips at LV level of the substations varies between 26 and 265 dips, which is two times more than in MV networks. During several temporary VQ surveys in the LV network, more than ten thousand shallow dips with a residual voltage just below the start threshold for voltage dip recording have been registered. This raises the question if shallow dips in range (85%-90% Un) have serious effects on customers' equipment operation and if they should be included into VQ assessment and compliance with binding VQ values.

[B4-1657(ME/RS)] presents the results of power quality measurements that have been performed in a typical coastal distribution network from 2004 to 2012. The network in coastal regions is often relatively weak and faces challenges due to rapid integration of new loads as well as renewable generation. The long-term measurements have shown that PQ today is at an acceptable level. The authors of the paper propose that permanent monitoring should be performed and used to generate a simulation model for a coastal distribution network.

[B4-1407(DE/CH)] discusses an approach for web-based voltage quality monitoring in Switzerland. In order to meet the demand of the Swiss regulatory authority for transparent and countrywide PQ statistics a web-based application for reporting voltage quality according to EN 50 160 has been initiated by a working group of the Association of Swiss network operators (VSE). The application is independent of the manufacturer of measurement equipment and accessible via internet. Each DSO can benchmark its own data with those from other DSOs. The data can be used for annual statistics and for reporting to the regular authority. Over the last seven year analysis has shown, that in most cases the limits according to EN 50160 are not exceeded. In the last three years a significant increase in the 9th and 15th harmonic voltage has been observed in urban areas and requires further attention in the future.

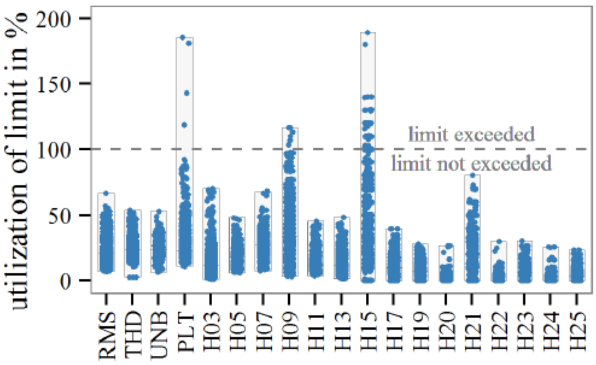

Figure 31: Overall performance of sites in urban areas [B4-1407(DE/CH)]

[B4-0317(CZ)] presents results of long-term monitoring for selected voltage harmonics, flicker and unbalance in the Czech Grid on all voltage levels. The trends of changes of the selected parameters from 1997 to 2012 are considered to be relatively stable.

Smart meters will be rolled out in Norway in 2019. [B4-1161(NO)] and [B4-1178(NO)] highlight the unique opportunity to achieve a new dimension of observability of the LV grids with smart meters, which has the potential to save costs and make the DSOs network operation and planning more efficient. Including voltage monitoring functionalities in the smart meters would generate small additional cost as compared to the cost for the smart meter roll-out with huge benefits as quick detection of dangerous faults, deep overview over the available voltage margins in the grid, identification of the parts of the grids that need reinforcement and handling of customer complaints.

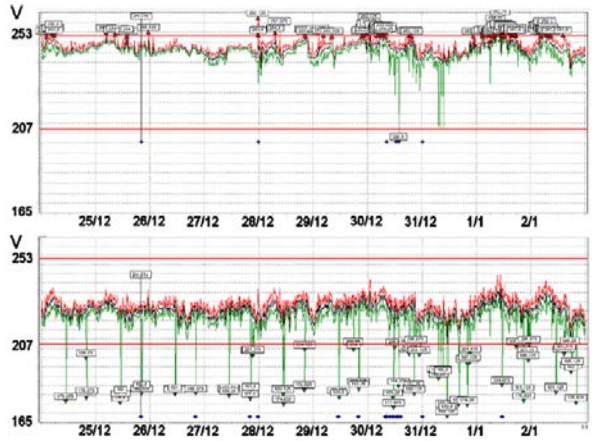

Figure 32: Voltage measurement in LV feeder with no voltage margins left and limit values were exceeded [B4-1161(NO)]

[B4-1582(BR)] presents results of the Brasilian project Smart City Búzios. The installation of distributed generation requires the identification and measurement of its power quality characteristics aiming to guarantee the quality supplied. The impacts in voltage, current and power factor with the respective harmonic analysis after the installation of photovoltaic systems and wind generators are shown.

[B4-1654(ZA/BE)] highlights the benefits of synchronous, coherent voltage and current data by means of two case studies. It is shown that synchrophasors could provide additional network performance information on renewable sources of energy integrated at distribution level. Phase angle changes could be made observable by the system operator and lead to a better understanding how sudden changes in production can affect voltage stability in the distribution network. On-line modelling is another smart opportunity if PQ instrumentation is designed according to the latest draft of the IEC 61000-4-30 Class requirements.

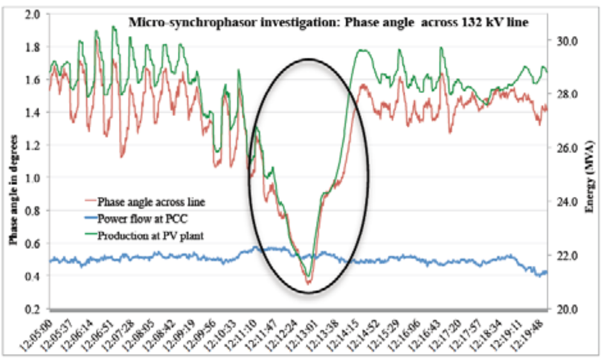

Figure 33: The phase angle across a 132 kV distribution line connecting a PV plant to the PCC [B4-1654(ZA/BE)]

There is an increased need to the network owner to integrate DER in system operation. [B4-0391(SE)] describes a study which will be undertaken within the project 'Smart Grid Gotland'. The aim is to extend the use of a DMS system with a zone concept dedicated to limit fault impact to optimize production of DER in the network through switching of network configuration. With power quality measurement functions distributed in the network the PQ parameters will be studied at normal operation and at restoration after disturbances. The study shall give valuable information if generation can be redistributed rather than load and if optimisation of DER is possible during isolation and restoration after disturbances.

[B4-0398(SE)] describes the approach to combine existing and modern equipment towards a self-healing network. Within the same project 'Smart Grid Gotland' the self-healing capacities of the existing rural MV grid with new reclosers with sufficient breaking capacity and Intelligent Electronic Devices (IED) at crucial points will be analysed. The novelty of the concept is that the economic benefits and the localization of the reclosers are optimised taking into account payback time in terms of customers affected and changes in reliability indices and the physical environment respectively. The system will be monitored and controlled as an entity by a DMS with advanced fault localization and restoration function based on short circuit calculations and load flow analysis. The challenge lies in the information interchange between IEDs and DMS.

Analysis of Origin and Propagation of PQ Phenomena Using Monitoring

Studies show, that voltage sags, harmonics and transients are the power quality disturbances with the highest economic impact. Therefore the propagation of PQ phenomena has to be thoroughly understood in order to assign and resolve problems at their origin. The impact of dips to the customers greatly depends upon the design and robustness of process equipment. Power quality complaints often involve the question of the origin of the PQ phenomena. 6 papers deal with the task to resolve these issues systematically by data available through monitoring.

Paper [B4-0382(NL)] describes the process that has been defined on demand of the Dutch Regulatory Authority to become more transparent on supply voltage quality and to define the source of various PQ problems in the network. All Dutch network operators participate in a voltage quality workgroup. As a result customer information about PQ has been spread via Internet, the complaint registering method has been improved and measures have been taken to conduct PQ more efficiently. In case of serious PQ problems at a customer site a weeklong measurement is done at the POC. The measured data are analysed and if the source is located at the operator's site, measures are taken immediately. If the problem is located at the customer's site, the utility gives advice to the client how to solve his PQ problem.

[B4-0236(DE)] describes the concept and result of PQ recording and assessment for a large industrial plant. The goal was a continuous registration and documentation of the power supply quality as an evidence for all connected customers inside an industry park area that the provided power complies with the quality specified in the energy purchase contracts. The existing SCADA system has been enhanced by twelve PQ recorders with complete recording of voltage characteristics. All fault records and power quality data are analysed in one single system. The grid power quality is evaluated on basis of the assigned Grid Codes and visualised in the control centre. The system provides the electricity provider of the industrial park with many sensitive as well as disturbing loads with the necessary evidence for power quality. It allows the identification of root causes in case of equipment damage or process disruptions.

[B4-0148(IT)] discusses the voltage dip monitoring and analysis, which has been set up with respect to regulation in Italy. As a first step toward the economic regulation of voltage quality in the Italian distribution networks measuring and recording all voltage dips occurring at all MV busbars of all HV/MV substations is mandatory. The time of start, the duration, the involved phases and the value of the retained voltage are some of the features to be recorded for each voltage dip. In 2014 Enel Distribuzione (ED) has completed the installation of 3500 power quality analysers at the MV voltage busbars of the HV/MV substations. In this paper the preliminary results obtained analysing the first more than 50000 voltage dips registered are presented, with particular attention to different rules adopted for establishing the voltage dip origins. The assessment of the concurrence of two voltage dips was conducted with different aggregation ranges (0 ms, 60 ms, 100 ms). The assumption was made that if the time delay between the occurrence of the first voltage dip of the group and the last voltage dip of the same group is not greater than 100 ms the origin is in the HV network, otherwise the origin is in the MV network. The analysis showed that further analyses with a larger number of stations and more data have to be done in order to establish rules for voltage dip origins.

In [B4-0152(NL)] the transfer of voltage dips from the HV to the MV network and then to the LV network is studied with respect to the role of the transformers. For phase voltage measurements improved ways of reporting dips are discussed. The most appropriate measurement approaches are then proposed for monitoring dips in the HV and MV networks, which bring a number of benefits for the DSOs. Statistics of voltage dips can lead to misleading conclusions if the specific dips are not monitored and reported properly. The transfer of dips from a HV to a LV network depends upon the transformers (star/delta, star star). Phase and line dips in the HV network are transferred in the corresponding phase and line dips in the MV network through a YNyn transformer. Then, line dips in the MV network are transferred to phase dips in the LV network through a Dyn transformer. One-phase faults are dominant in the HV- and MV-networks, but they are not perceived as dips in the LV networks. A four-year field measurement data set from a monitor that is installed in the main substation of a 10 kV network in the Netherlands has been used. It includes a four-year measurement of phase voltage dips originating from the HV and MV networks. With the PQ monitor settings, where monitors in the HV- and MV networks are meant to measure phase voltage dips, better information of voltage dips in MV substations can be gathered by including the source of the dips (1ph, 2ph or 3h faults) while reporting focusing on two-phase and three-phase dips, which significantly affect the customers. By recalculating the line voltage dips in the MV network, in which one-phase dips from the HV and MV networks are not seen by the end users, it is also possible to focus on the dips that ultimately affect the end-users. Regarding the four-year field measurement only 20% of the total phase dips in the MV network affect end users. With more reliable information, line dips of the MV networks can then be reported using the standard dip table in EN 50160. By relating the transfer of dips to the characteristics of voltages that affect the end-users, it is recommended that line voltage dips should be monitored and reported in the MV networks. To distinguish the contributions of the HV and MV networks to the total number of dips monitored in the MV networks, the monitors of the HV networks are recommended to measure phase and/or line voltage dips depending on the type of transformers connecting the HV to the MV level (star/delta , star/star).

[B4-663(NL)] proposes a method for analysing the propagation of PQ phenomena through the distribution network based on wide-area field measurements. As existing PQ analysers are simultaneously but not synchronously recording measurements, the data is not appropriate for the calculation of transfer impedances in the network, but it can be used for the calculation of equivalents at each individual busbar. These equivalents can then be used to create load equivalents for each type of PQ phenomenon and to analyse the influence of loading levels on the propagation of PQ levels. The results of the analysis are meant to be used as guidance for network design and input for the relevant standards.

[B4-0894(CN)] introduces the Shanghai power quality monitoring system, which was put into operation in 2008 and since then has continually expanded. The PQMS actually consists of 400 monitoring terminals and integrates data of more than 7000 points. The main power quality issues are harmonics and voltage dips. Since 2008 the harmonic levels have significantly improved.

Harmonics sensitive equipment is increasing on the one hand and on the other hand traditional pollution sources as railways as well as new dispersed pollution sources are growing, which makes localization and control of harmonics more difficult. A new method of harmonic tracing called impedance changing method has been developed. In the paper an enlarged coverage rate of PQ monitoring and the comprehensive utilization of harmonic tracing methods are proposed in order to effectively supervise and trace the dominant sources of harmonic distortion.

Management and Analysis of Big Data

With expanding PQ monitoring including more monitoring devices and increased sampling rates the number of PQ data, that have to be stored, transmitted and analysed is rapidly increasing. Verification of product quality compliance for a large number of customers becomes more and more important with the advent of future smart grids. A close link between PQ measurements and network control is an essential requirement for an improved operation of future grids. The efficient implementation of PQ monitoring for the operation and management in all voltage levels requires strategies like a multilevel PQ monitoring approach, the effective integration of PQ functionalities to smart meters and other intelligent electronic devices which are part of other applications as well as a simplified procedure to set up PQ modules and the technique of distributed data storage. 7 papers propose and discuss solutions to dealing with big data.

In [B4-0458(CN)] Principal Component Analysis (PCA) and its derivative algorithms Probabilistic PCA and Kernel PCA are applied to PQ event data compression. As nodes and phases in a power grid usually have high correlations, more data may not necessarily include more information. PCA transforms data to a space of lower dimension and lowers redundancy. The performance of the methods is compared as to compression ratio and recovery error it is found that PPCA and KPCA have smaller errors than PCA.

Number of principal components	1	2
PCA	8.15%	2.87%
PPCA	5.61%	1.06%
KPCA	5.82%	1.22%

Figure 34: Recovery errors of PCA, PPCA and KPCA with 1 or 2 principal components [B4-0458(CN)]

As the existing large-scale PQ monitoring system of Shanghai is facing the problem of data storage and running speed, [B4-0697(CN)] introduces the private cloud as key technology to solve this bottleneck for the further development of PQMS. The current PQMS in Shanghai is upgraded to a cloud platform with multi-service functions. The private cloud is built behind the firewall of the PQMS and based on Virtualization Technology. The Hyper V platform uses high-performance blade servers with optimised storage systems and high-speed transmission networks as hardware. By utilizing private cloud technique, the new system is able to transition data from the existing system smoothly.

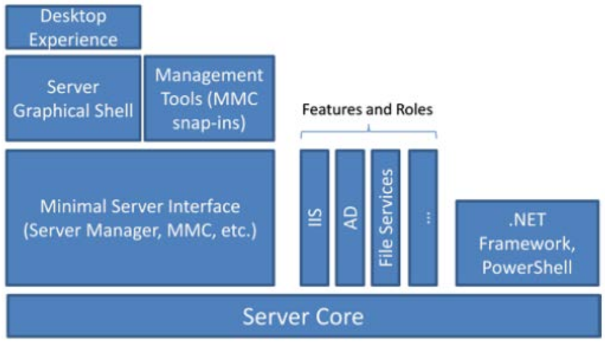

Figure 35: The architecture of virtual platform [B4-0697(CN)]

Smart meters generate an enormous amount of data. The subject addressed in [B4-1298(DE)] is a clustering method that can be used for data compression and additionally speeds up steady-state power flow computations. At first a standard power flow computation of the uncompressed smart meter data is conducted which yields a complete dataset reflecting the grid situation. Agglomerative hierarchical cluster analysis of the voltage data permits to assign model cases to similar voltage profiles. A following Monte Carlo simulation uses this data base of voltage profiles whenever a similar load situation appears significantly reducing the runtime. The algorithm has been tested with one-phase systems, the strongest clusters were identified for two-hour-periods, were the amount of data to be stored can be reduced by about 20% while speeding up power flow computations by about 40% on average.

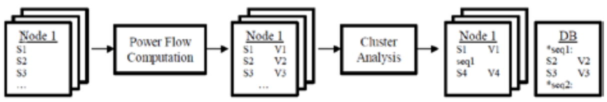

Figure 36: Overview of smart meter data compression on a server [B4-1298(DE)]

[B4-1401(DE)] addresses methods for a comprehensive graphical visualization of large PQ measurement data, which is based on a PQ index. According to EN 50160 82 PQ parameters are analysed for every measurement site and every 10-minute interval. To ensure comparability between the different PQ parameters, the 95th percentiles of the 10-minute values of one week were normalised relating them to their limits. The resulting PQ index represents the percentage reserve of the considered PQ parameter to the respective limit. The graphical representation is based on maps with flexible or fixed PQ zoom level, which provide a quick and comprehensive overview about the PQ status of the whole supply area and allow easy identification of problematic regions. [B4-1422(CZ)] describes a method for storing a large amount of data from power quality meters. The data of all PQ analysers are first transmitted to a data concentrator and stored in the best resolution available. The concentrator then periodically runs an algorithm, which marks data according to power quality with an index. The most important data are stored in the highest available resolution; less important data are stored in lower resolution. Several data compression methods are presented.

[B4-0115(IN)] refers to requirements for PQ monitoring systems for future smart grids. It is expected that dedicated PQ monitors are stepwise replaced by new IEDs with PQ functions. A powerful and cost-effective PQ system requires effective communication links. IP networks based especially those based on the IPv6 standard guarantee, that PQ monitoring systems can be easily improved and expanded in the future. A modular PQ functionality should be integrated into an as small as possible module that is simply plugged into the smart meter. These interfaces should be standardised to allow easy interchangeability and should not need an individual set-up. Only highly aggregated information should be continuously transferred to a central site. The data transfer should be initialised by the smart meter (push-principal) following an approach that randomizes the sent time of individual smart meter to avoid a simultaneous request of a huge amount of meters. To guarantee a reliable and cost-efficient treatment of PQ data international standards are necessary. This could be either standards for file formats or even better directly for the communication interface. [B4-0234(IN)] highlights the need to upgrade smart meter specifications and changes needed in regulatory norms for more effective PQ monitoring and enhanced consumer satisfaction.

Standardization of PQ and EMC

The development of the distribution grid involves on the one hand new phenomena and on the other hand new challenges as to interoperability of PQ monitoring systems. Standardization for the future grids is very important in order to be prepared and effectively solve these issues. 9 papers have been submitted which reflect ongoing work in standardization and working groups regarding PQ and EMC. The new phenomena include harmonics in the range of 2 kHz to 150 kHz, which are not yet covered by PQ standards.

[B4-0258(US)] deals with the revision of IEEE STD 1159.3 PQDIF. IEEE Standard 1159.3-2003 specifies the Power quality Data Interchange Format PQDIF. The PQDIF file format standard allows the processing and analysis of power quality measurements using multi-vendor and multi-device data. The paper presents the changes planned for the revision in 2016 which will reflect the evolvement in the field of power quality monitoring since 2008 and include recommendations how to store rapid voltage events and transient events.

[B4-0181(SE)] gives a status report on the joint working group C4.24 of CIGRE and CIRED ‘Power quality and EMC Issues Associated with Future Electricity Networks’. C4.24 obtained its mandate in 2012 with the objective to address the emissions (harmonics and unbalances) by new types of devices connected to the distribution network as production or load especially with active power electronic interface in order to clarify if new ways of considering PQ in design will be required. The impact of the PQ issues at the distribution level on the transmission system will be analysed. In this paper more details are given on four activities: voltage dips, feeder reconfiguration, demand side management, power quality and economics. Starting of drive-controlled motors is expected to lead to less severe dips than starting of induction motors. However the harmonic emission might be high during the starting of the motor resulting in a new type of phenomenon preliminarily named as a ‘short-duration distortion due to device starting’. There is an increasing emission in the frequency range between 2 kHz and 150 kHz also known as ‘supraharmonics’. There is serious need for more standardization; study of the propagation of supraharmonics will also require the development of new models for power-system components. There is a general trend of replacement of non-electronic loads by electronic loads. This takes away a source of damping at resonance frequencies. The replacement of overhead lines by underground cables will shift resonances to lower frequencies. Voltage support services in the transmission grid have been considered as one of the ancillary services. This is an example for the distribution network to have economic evaluations for voltage variations caused by newly installed DGs and equipment. The work in the group is on-going with two more years to go toward the final report. Also [B4-0273(CA)] provides a status report of the CIGRE/CIRED Working Group C4.24 The working group will be addressing the need for new measurement techniques, more complex and more accurate, capable to provide the information required in future networks, which will be undergoing dynamic architecture reconfiguration and will be witnessing old and new phenomena affecting the quality of supply. Therefore PQ monitoring with traditional analysers together with the use of new approaches using intelligent electronic devices as smart meters will be needed. The shift towards emissions in the supraharmonic range from 2-150 kHz will require new types of transducers, namely sensors, which will replace the traditional instrument transformers. New indices are needed for harmonic phase angles with respect to the fundamental voltage and also for supraharmonics.

Mismatch between electromagnetic compatibility standards and regulations is also discussed in [B3-1166(NO)] and suggestions are made for revising product standards, power quality regulations and the CE-marking process. In Norway SINTEF Energy Research has been involved in a number of cases with problems in EMC, which should have been prevented by regulation. The authors conclude that the coordination between compatibility levels in power quality regulations, immunity limits in product standards is missing and appliance testing is inadequate. In a detailed manner the authors recommend changes in the product standards, power quality regulations and CE approval process, which could resolve these issues. The authors call for the relevant standardization groups and regulators to revise relevant standards and regulations and to coordinate compatibility levels and immunity- and emission limits.

[B4-0372(DE)] summarizes the ongoing development in international standards which are triggered by the challenges of Energiewende, i.e. fluctuating power infeed from all voltage levels, decreasing short circuit power and industries with modern processes which are sensitive to rapid voltage changes. This development according to the authors requires a gapless monitoring. The new requirements for measurement are taken into account in the revision of IEC 62586-1, the compliance of products is dealt with by IEC 62586-2. Limits and thresholds specified in IEC/DTS 62749 exceed the power quality limits defined in EN 50 160. IEC 6100-4-30 includes new measurement methods for rapid voltage changes, current characteristics and for conductive emissions in the frequency range between 2 - 150 kHz.

Although many PQ phenomena are well defined in international standards, there is no standard way to evaluate PQ as a whole for a site or a network. [B4-0860(UK)] presents a methodology to comprehensively evaluate the PQ for a network or a bus considering both the suggested planned levels set by the utility and the expected different customers' requirements. The suggested index is calculated based on the concept of PQ reserves using numerical consolidation of several separate indices for harmonics, flicker and unbalance.

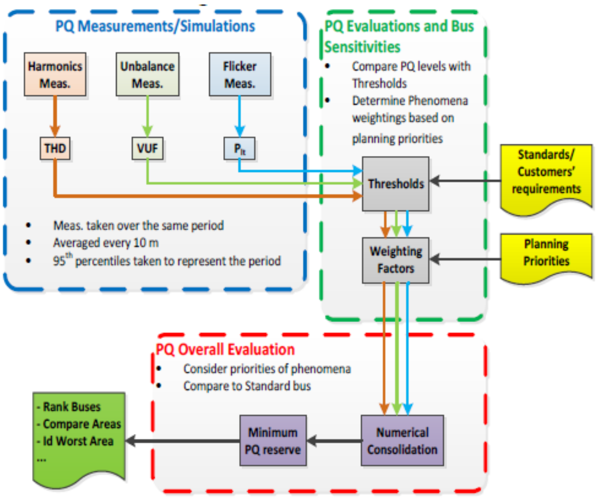

Figure 37: Framework for PQ combined evaluation [B4-0860(UK)]

[B4-0384(PT)] presents new challenges in the development of EDP's PQ monitoring platform. EDP Distribuição has been constantly monitoring PQ since 2001, internal and external changes, particularly the new edition of the Quality of Service code in 2014 have led to a dynamic development of the monitoring platform. Of vital importance for the future is the standardization of PQ measurement methods, regulatory reports and PQ data interchange format.

[B4-1625(DK)] addresses the question how power quality related requirements in grid codes could be enforced and how a tool can support the assessment of power quality as part of the grid connection process related to generation units.

[B4-0726(FR)] proposes to extend ISO50001 standard on Energy Management created in 2011 to the management of Power quality in order to provide an internationally recognised methodology to implement, manage and continuously improve power quality in an electrical network. The aim is to enable each organization to set and pursue its own goal to improve power quality, to reduce unexpected downtime and optimize equipment lifetime. The three fundamental steps for power quality management (measurement and monitoring, results interpretation and analysis, corrective and preventive actions) are presented and recommendations for are provided for each of them.

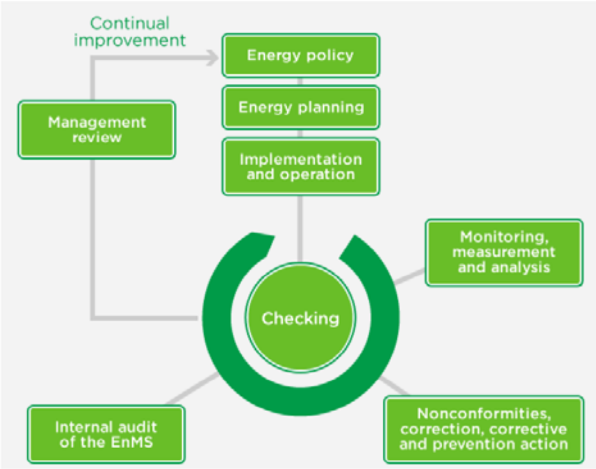

Figure 38: Energy Management System based on the 'Plan – Do – Check – Act' Methodology of ISO 50001 [B4-0726(FR)]

Reliability Assessment and Benchmarking

In [B4-1008(AT), a universal comparative method based on Monte Carlo simulation is presented. The method takes into account various smart grid technologies and their impact on the grid, such as the automatic restoration scheme. Additionally, the definition of system component availability scenarios is possible. As output, the system reliability as a function of component availability is provided. The impact of substation configurations and remote controlled switches on the reliability of distribution grids is evaluated in [B4-1158(NL)]. It can concluded that the substation configuration only has a little impact on the reliability indices. The application of remote controlled switches has a positive impact on the overall SAIDI figures. It can be concluded largest reduction in SAIDI is obtained by automating the normally open separation points. [B4-0731(FI)] investigates the reliability of a 10-kV feeder in a realistic network using the Three-Layer Reliability Technique. In this, the three critical zones, i.e. layers, were identified to obtain the partial reliability indices to comprehensively assess reliability. The selected feeder was tested in three cases under six weather scenarios that describe load and generation patterns typical in the Nordic countries. Like in the previous paper it is concluded that introducing network automation significantly improves reliability and decreased the outage costs. The connection of CHP did not add, from the reliability point of view, significant benefits to the tested network over the 40-year project lifespan. In [B4-1620(FI)] the modelling of simultaneous faults – for instance during major storm events - by using the Monte-Carlo simulation in a distribution system is presented. The method enables the evaluation of the effect of the repair time in different situations, and also to model various solutions to enhance the reliability of the network.

[B4-0182(US/AT)] presents results of the reliability benchmarking for North America (Canada and United States) by the IEEE Working Group on Distribution and for Europe by the Council of European Electricity Regulators (CEER) in collaboration with the Energy Council Regulatory Board (ECRB). The paper reviews the basis for the North American and European benchmark studies and discusses steps to advance this work further. The annually voluntarily conducted benchmarking study in North America is based upon summarised daily interruption data, which is categorised by SAIDI, CAIDI and SAIDI. Utilities are given an anonymous identifier and are segmented by size and continental region. The 2014 survey results are presented, quartile performance levels are calculated and trends or those values provided. The IEEE Distribution Reliability Working Group has produced IEEE Standard 1782 'Guide for the Collection, Categorization and Utilization of Reliability Data' in order to ensure proper interpretation and application of the reliability data and indices. In its most recent activities it has begun collaborating with European regulators. Reliability indices for almost all European countries are published in the fifth Benchmarking Report and its follow-up report BR 5.2. Data for the benchmarking is provided by the national regulatory authorities and reported at a national level. Besides reliability data, namely SAIDI and SAIFI, also data on continuity of supply are gathered. Data on short interruptions is available for 8 countries and planned interruptions for most countries. The correlation between reliability (SAIDI) and the amount of underground cables has been investigated. The monitoring of the continuity of supply shall be expanded. The opportunity for cross-continental assessments are rich and include direct comparison as well as impact of weather and underground percentages and may serve to provide key findings for both communities. In [B4-1012(ES) a methodology to calculate reliability indices based on the modelling of the different fault clearing technology algorithms is presented. Time intervals needed by each step of restoring the electric service after a fault are taken into account.

[B4-1173(BR)] presents a study aimed at evaluating the technical service quality provided by the electric power distributors in Brazil based on a Multi Criteria Decision Making Method (MCDM). The methodology is applied to the power distribution performance indicators, which are currently available, by Brazilian regulation with the aim to determine the most relevant dimensions of service quality.

Economic aspects of Power quality

In [B4-0392(IR)] the effects of harmonics generated by non-linear customer loads on losses and lifetime of MV transformers and LV feeders are analysed. A complex formula to calculate the harmonic penalty for customers is proposed and the need to set a standard to determine the effect of non-linear loads on PQ and equipment is discussed.

[B4-0714(NO)] describes examples from the Nordic countries of quality of supply regulation models using customer interruption cost. The interruption cost models are usually based on cost data collected through customer surveys. Since the quality of supply regulation directly affects the network companies' income, it is essential to analyse the impact of changing the regulation scheme itself or the input data. A consistent methodology for cost estimation and data analysis would be of high value, enabling comparison of different quality of supply regulation schemes and providing predictability for the network companies.

[B4-0876(AR)] discusses the value of Energy Non Supplied for various groups of customers in Argentina. A stochastic sample of clients was considered for five main categories of customers and a market research study was conducted in order to determine the cost of a power supply failure.

Potential scope of discussion

IPv6 is the most recent version of the Internet Protocol and is intended to replace the current IPv4, as this is limited to approximately 4.3 billion addresses. Using a 128-bit instead of a 32-bit address, IPv6 will provide 7.9x1028 more addresses than IPv4. With the transition to Internet Protocol version 6 (IPv6) that is expected to materialize within the next five to ten years we are at the dawn of an Internet of Things that will deeply impact all technological development including electricity distribution. An exponential rise of data is expected that need to be securely and efficiently handled. Therefore in the next years thorough and conjoint efforts should be made from the stakeholders in the electricity sector including distribution grid operators, equipment manufacturers and regulators to be prepared in time. Multilevel solutions for data management, compression, analysis and system immunity are needed with the aim to sustain a reliable and efficient operation of the distribution grids.

Table 4: Papers of Block 4 assigned to the Session

Paper No.	Title	MS p.m.	RIF	PS	other session
0046	Evaluation of long-term voltage dip monitoring in HV, MV and LV networks			X	
0115	Power Quality Monitoring Systems for future Smart Grids			X	
0148	Voltage dip monitoring and analysis in Enel Distribuzione network			X	
0152	Measurement Approach for Monitoring Voltage Dips in HV and MV Networks	X		X	
0181	CIGRE/CIRED working group C4.24 – power quality and EMC issues associated with future electricity networks – status report			X	
0182	Benchmarking of reliability: North American and European experience	X		X	
0234	Power Quality Monitoring with Smart Meters			X	
0236	Power-Quality recording and evaluation in an industrial area (chemical park)			X	
0258	Revision of IEEE Std 1159.3 PQDIF			X	
0273	CIGRE/CIRED/IEEE working group C4.24 - New measurement techniques in the future grid	X		X	
0317	Evaluation of Power Quality in Regional Distribution Networks			X	
0372	Power Quality: New Tendencies in Standardization and Challenges of Energiewende			X	
0382	Implementing a systematic approach towards solving power quality complaints - from a network operator's perspective			X	
0384	New Challenges in the development of EDP DISTRIBUIÇÃO'S PQ monitoring platform			X	
0391	Benefits of using DMS-system for distribution network to optimize DER			X	
0392	Penalty calculation of non-linear loads in electric power distribution network				

0398	Combining existing and modern equipment to a new generation of Self Healing Network			X	
0458	Power quality data compression using principal component analysis			X	
0663	Analysis of the propagation of Power Quality phenomena using wide-area measurements	X		X	
0697	The private cloud based smart data management system for power quality monitoring			X	
0714	Customer interruption costs in quality of supply regulation: methods for cost estimation and data challenges	X		X	
0726	Power Quality Management Methodology			X	
0731	Layered reliability assessment of a typical Finnish medium voltage network under multiple weather and load scenarios				S5
0860	Characterisation of Power Quality Performance at Network Buses Using Unified Power Quality Index		X	X	
0876	Economic Valuation of the Power Outages in Argentina			X	
0894	Power Quality Analysis and Harmonic Tracing in City Grid based on Big M onitoring Data			X	
1008	The impact of restructuring urban and suburban distribution grids with Smart Grid approaches on system reliability				S5
1012	Novel Power System Reliability Indices Calculation Method				S5
1158	Reliability improvement by optimizing MV substation configuration in combination with remote controlled switches				S5
1161	Benefits of voltage measurements with smart meters			X	
1166	Mismatch in electromagnetic compatibility standards and regulations			X	
1173	Assessing the Service Quality Provided by Electricity Distribution Utilities			X	
1178	New methods for distribution network monitoring with smart meters - Verifying data in network information systems				S5
1298	Clustering of Smart Meter Data for Data Compression and Fast Power Flow Computation		X	X	
1401	Efficient Power Quality Analysis of Big Data (Case Study for a Distribution Network Operator)	X		X	
1407	NEQUAL - Web-based Voltage Quality Monitoring in Switzerland			X	
1422	Dynamic Intelligent Compression for Power Quality Analysers			X	
1582	Power Quality Analysis for DG in Smart City Buzios			X	
1620	Modelling of simultaneous fault to Reliability enhancement in distribution system				S5
1625	Case study: Assessment of Power Quality in practice			X	
1654	Why network coherent data is smart			X	
1657	Coastal Distribution Network Power Quality Measurement			X	