Special Report - Session 2
POWER QUALITY AND ELECTROMAGNETIC COMPATIBILITY

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Introduction

The **scope of Session 2** has been defined by the Session Advisory Group and the Technical Committee as Power Quality (PQ), with the more general concept of electromagnetic compatibility (EMC) and with related safety problems in electricity distribution systems.

Special focus is put on voltage quality in connection with distributed generation and new technologies with particular interest in voltage level, flicker, unbalance and harmonics. This session also covers Power Quality system monitoring, electromagnetic compatibility, electromagnetic interferences and electric and magnetic field issues. Also addressed in this session are electrical safety and immunity concerns.

The aim of this special report is to present an overview of the present concerns in Power Quality and EMC, based on all selected papers of Session 2 (140 papers). The report is divided in the following four blocks:

Block 1: Electric and Magnetic Fields, Immunity, Safety and Interference
Block 2: Power Quality Issues of New Technologies
Block 3: Power Quality Simulation, System Studies, Measurement and Mitigation
Block 4: Quality of Supply, Monitoring and Big Data Analysis, Standards and Regulatory Issues

An unambiguous allocation to the blocks is not always possible and overlapping topics may appear between.

Three **Round Tables** will be organised within Session 2:

RT 1: PQ-Phenomena Related to New Technologies. Results of CIGRE/CIRED Working Group C4.24.
RT 2: How Much Is Too Much? Present Experiences and Future Challenges for Large-Scale Power Quality Monitoring.
RT 3: Network Operators Talk: Case Studies of Recent Power Quality Issues.

The **Research and Innovation Forum** is dedicated to: Recent Trends in Modelling Network Harmonic Impedance and Resonances.

CIRED will present for the first time the **Best Young Academic Award**, celebrating the 25th edition of our conference. The award will be given to the best paper of each section written by young academics. In Session 2 the award goes to Vineetha Ravindran from Luleå University of Technology for Paper No. 0237, “Characterization of Interactions between PV Systems and Energy Efficient Lighting (LED)”.

Block 1: “Electric and Magnetic Fields, Grounding, Transients and Immunity of Systems”

Electric and Magnetic Fields

In this sub block, results from electric and magnetic field measurement and simulation as well as mitigation measures (active/passive shielding) are presented.

In [B1-**0156**(EG)], besides other characteristics, the electric and magnetic field of a 20 kW roof top PV installation are presented. Measurement on the roof revealed magnetic field values of 2.2 µT. It is not clearly stated in the paper, but this value is probably a 50 Hz value, not taking the influence of DC currents into account. Close to the inverter, field values up to 48 µT were recorded. In case of the electric field 27 V/m were recorded near the power cables whereas field levels on the roof were negligible. All recorded fields were far below ICNIRP limits.

[B1-**0611**(EG)] provides some basic measurements of magnetic field density close to power cables. The tests were performed with a single-phase cable, thus resulting in rather high field values.

In [B1-**2040**(IT)] a tool for the automated identification and optimisation of parallel circuits with unknown sequence of the phases is proposed. Although the identification problem can be solved with an inverse problem, a simpler approach is preferred. Based on measurement of the individual current phasors, a so-called phase shift indicator is calculated and compared with the tabular indicators of all possible configurations. The closest match gives an estimate for the correct configuration. The disadvantage of this simple approach is the uncertainty which can be quite high, if the system has a high number of conductors or high current unbalance (presence of the neutral conductors).

In [B1-**1096**(IT)], a field mitigation system consisting of a mix of passive and active shielding systems is proposed. The two shielding methods are briefly introduced and the design choices in terms of materials and layout are presented. With the help of genetic algorithms the system is optimized with geometrical layout and compensation currents (amplitude and phase angle) as parameters. The procedure has been applied to the case of a building close to an overhead power line. It is shown that use of active loops can provide a strong mitigation of the magnetic field within the loop area. The addition of passive shielding improves the mitigation in the regions of the volume that are close to the shield itself.

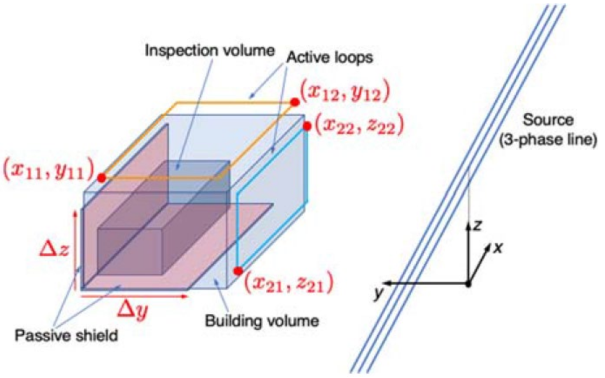

Fig. 1: *Scheme of the case study with geometrical optimisation variables indicated in red [B1-1096(IT)]*

The same author presents another study case in [B1-**1320**(IT)]. The magnetic impact of the supply of an industrial electric oven with rated current of 3000 A is analysed and mitigation measures were evaluated. Due to the fact that that the sum of the currents in the source to be shielded was not zero, ferromagnetic materials had to be used instead of simply conductive materials. The adopted solution consists of L-shaped ferromagnetic modular elements of high permeability in order to locally shift the magnetic field lines outside the worker's passage way. The solution shows a very good results and the initial value of 2500 µT is reduced below 1000 µT.

A method for a simple testing of the compliance with the requirements of Directive 2013/35 is given in [B1-**1671**(AT)]. This method is based on a zoning concept based on different groups of persons (i.e. persons with AIMD) and gives additionally simplified necessary distances or formulas for assessing the electric and magnetic fields in these zones. The main advantage of this method, which is implemented in an Austrian national guideline, is the straight systematic approach which can be performed by persons, which are not EMF experts.

Based on this method [B1-**2119**(AT)] discusses in detail the simplification formulas for magnetic field assessment. Therefore, with simple two-phase and three-phase loops all conductor configurations are simulated, while for this loops a simple formula set is presented. The method is quick and avoids underestimations, the work for 3D-modelling and documentation is reduced and a valuation tool including conservative parameter sets is easily implemented.

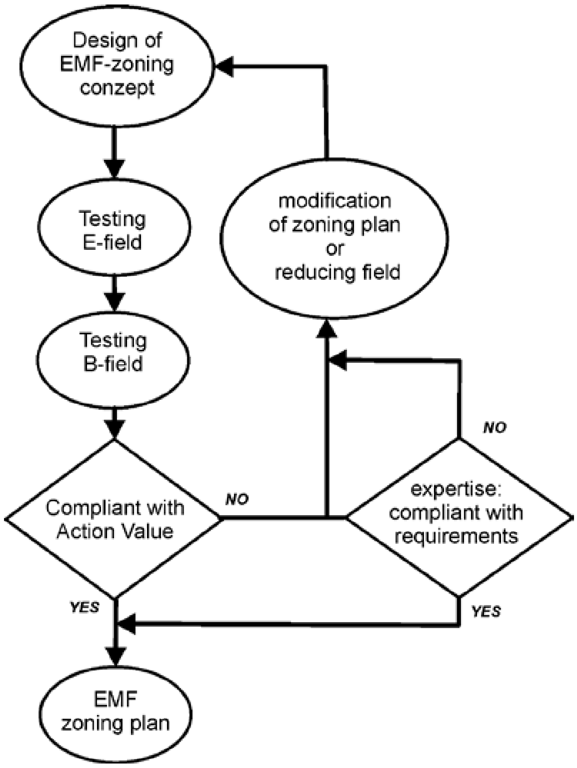

Fig. 2: *Flowchart for the elaboration of a zoning plan [B1-1671(AT)]*

The topic of EMF generated by PLC-based smart meters is presented in [B1-**1104**(AT)]. Based on measurements in representative positions in three different types of buildings, it can be concluded that the electric and magnetic fields caused by PLC-based smart meters in areas accessible for the general public are very low and the resulting personal exposure is only a small fraction of the applicable exposure limits. This confirms results presented at previous CIRED conferences. Converters emitting distortions in the range of harmonics as well as in the range of some kHz cause significantly higher levels.

Earthing Systems

The topic of introducing risk to earthing systems was in the focus of the JWG B3.35/CIRED that recently published the results. The key-findings are presented in the paper [B1-**1750**(AU)]. The authors conclude that traditional safety criteria, in order to meet societally tolerable risk exposure targets, must rely upon the low likelihood of the coincidence of an earth fault and a person being in a position to receive a hazardous voltage. Based upon the analysis undertaken by the working group it is recommended that asset owners, engineering offices and standards setting bodies work toward the explicit inclusion of quantified risk analysis (QRA) within earthing design processes and communicate clearly the fact that the application of QRA is able to produce three key outcomes:

- Reduction of waste where traditional approaches produce overly conservative requirements.
- Reduction of 'risk of fatality' from earthing related (indirect) electric shock where such reduction is justified.
- Provide a measure of risk that allows broad comparison and understanding by non-specialists.

A new WG B3.54 dealing with earthing systems was launched recently. The task is to survey different approaches for testing and monitoring of earthing systems around the world, compare practical and theoretical approaches and develop recommendations for standardisation. The relevant input regarding earthing system testing in Australia is summarized in [B1-**1415**(AU)]. In addition, results from a survey which was conducted recently in North America, are presented.

In assessing the earthing performance it is often necessary to measure the 'strength' of the associated distribution earthing network. The 'strength' of an earthing system or network is best described by ascertaining the level of hazard created by an imposed earth fault and where those hazards will occur. In [B1-**1383**(AU)] it has been shown that the strength of these networks is aligned with the age of the power system network. Older networks consistently demonstrate lower earthing impedance than younger nearby networks, sometimes an order of magnitude lower. This trend appears to be being driven by the increasing use of plastic piping by water authorities.

[B1-**0367**(PT)] describes the challenges in the design of a 40 MW PV power plant. Due to the large area covered, large variations of the soil conductivity were observed. Despite of these challenges, the study resulted in very surgical measures to improve the plant's earthing grid. The earthing resistance and touch and step voltages were measured on site, validating the results of the design.

Cross-bonding, i.e. the special bonding in which the metallic sheaths of different phase power cables in successive minor sections are cross-connected in such a way so as to attain partial or full cancellation of induced currents on the metallic sheaths is described in [B1-**2091**(GR)]. In a case study, long medium voltage cables of a wind park are analysed. Cross-bonding with two major sections and five minor sections succeeds to reduce the sheath current and cable power losses significantly.

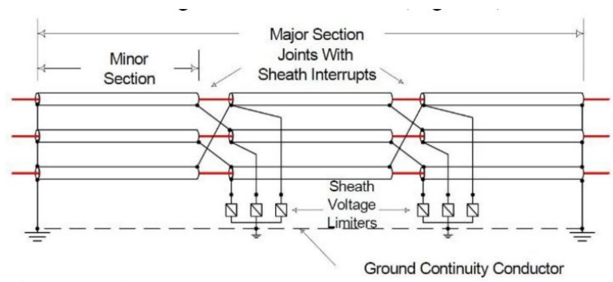

Fig. 3: *Implementation of cross-bonding [B1-2019(GR)]*

The authors of [B1-**0550**(UK)] performed measurements of earth fault current and potential rise on a live 11 kV system. A variable resistor was switched between phase and earth, high enough to prevent earth fault protection from operation. The resulting phase-to-earth voltage depression and currents were measured at the load point; analysis yields the overall zero sequence impedance of the system (including soil-return paths) and the resulting maximum earth-fault current at that point.

The overvoltage protection of a transformer is analysed in detail in paper [B1-**0628**(IR)]. Different locations for lightning strikes have been investigated. It is shown that the installation of arresters provides a significant improvement. An interesting fact mentioned is the increase of earth resistance due to lowering of the groundwater level.

Defining a distribution network as a global earthing system (GES) can simplify the design requirements when adding new substations to a network. Examples often cited include cable networks in dense-urban or city-centre locations, and large industrial areas. A far greater proportion of a network may supply small towns and villages, and these are often discounted as GES due to reduced geographical coverage or lower substation density. In [B1-**0822**(UK)] two small networks, fed from a common source substation, have been examined in detail to see if any GES characteristics may be observed. Although techniques such as the Ellipse Method may be used to classify GES, insufficient substation density may limit its use for small networks and the contribution of underground cables with electrode effect cannot be ignored. There is good agreement between the predicted earth potential rise from the simplified UK power networks design tool and more detailed models. The results are generally conservative.

The impact of stray currents on the corrosion rate of earthing systems is analysed in [B1-**1700**(FR)]. Special focus is put on DC railway systems as source of those currents. In practical, necessary simplifications and parametric studies are recommended to provide a realistic corrosion current estimation according to soil resistance inputs. As the process comes with a lot of uncertainties and simplifications, some safety margin should be taken into account for decision.

Permanent monitoring of a TT-LV system is described in [B1-**1213**(US)]. A 9-channel Power Quality recorder is used, providing information about poor earthing and dangerous safety conditions during a ground fault. The method is able to differentiate ground faults from other Power Quality phenomena, “catching” intermittent ground faults and verifying the integrity of the ground connection

Switching Transients

Switching of capacitive currents with vacuum breakers might end up in the situation of NSDD (non-sustained disruptive discharge). NSDD is a voltage breakdown after the vacuum circuit-breaker breaking the capacitive current which will not cause the recovery of power frequency or capacitive current in main circuit. This phenomenon is investigated in paper [B1-**0699**(CN)] by testing a 40.5 kV breaker in detail. Although the impact of NSDD on the vacuum circuit-breaker itself is not very serious, it’s a serious transient Power Quality problem affecting the other sensitive electrical equipment connected to the bus.

In addition [B1-**2095**(IR)] deals with switching transients. Voltage disturbances in a 63 kV substation due to switching of its upstream 400 kV substation in 12 km distance are simulated with EMTP. Four different switching scenarios are investigated: switching of a shunt reactor, switching of a transformer and two short circuit scenarios. The effect on the downstream 63 kV substation is evaluated. Due to the distance between the substations and the presence of surge arresters, no harmful overvoltages were observed.

Immunity of Devices and Systems

[B1-**0763**(DE)] summarizes the results of a comprehensive immunity assessment of household appliances with respect to harmonics from 2 kHz to 150 kHz. The tests are based on the effective immunity standard IEC 61000-4-19 using test levels according to Class 3. A set of 55 representative devices has been tested for short-term effects, 20 devices for long-term effects. The results show that a considerable share of devices is sensitive to supraharmonics. Most common short-term effects are audible noise at frequencies below 20 kHz and light flicker. The significant number of observed malfunctions suggests that the EMC coordination does not work properly yet for present household appliances. The results are an important contribution to the ongoing standardisation activities. Besides re-thinking the test levels and class definition given in IEC 61000-4-19, a discussion about additional requirements for the input impedance characteristic of devices in the frequency range 2-150 kHz should be triggered.

The immunity of LED street lamps for voltage dips, short interruptions, voltage fluctuations and supraharmonics is determined in [B1-**0765**(SE)]. The most critical disturbance is the short interruption, lasting 250 cycles. All tested lamps failed in that case. However, the extinguishing time is unpredictable and more research is needed for understanding the mechanisms behind this. Voltage dips with remaining voltage above 40 % are non-critical in most cases. Supra- and interharmonics led to small measurable modulation in light intensity, which was visible only in one case.

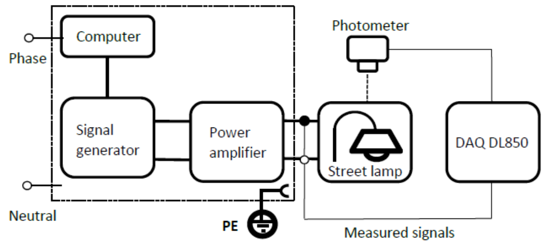

Fig. 4: *LED street lamp testing setup [B1-0765(SE)]*

The influence of temperature and voltage fluctuation on illuminance, active power and temperature of LED lamps was tested by the authors of [B1-**0035**(SE)]. Based on the results for voltage variation, no significant differences of the parameters studied have been observed. On the other hand, according to the results about environmental thermal variations it is concluded that the illuminance increases with low temperatures.

Given the increasing need for measurement and control at lower levels in the power grid, the reliable operation of secondary systems in Ring Main Units (RMU) is becoming increasingly important. By the tests that the authors of [B1-**1231**(NL)] carried out, it is shown that it is possible to perform an integral test of EMC performance of intelligent Ring Main Unit systems. To determine the EMC capabilities of the complete RMU system, a test procedure to test the EMC capabilities under several load and short circuit conditions was designed. An extra cable was connected to the RMU to simulate short circuits at a certain distance. In all cases, no malfunctions of the secondary systems due to the electromagnetic transients, caused by switching, were observed.

It is well known that PLC communication is strongly affected by noise, especially from power electronic devices. In [B1-**1624**(PT)] the influence of noise and distance in PLC PRIME communication in a smart grid composed of a smart meter and a data concentrator in a laboratory environment has been studied. The spectrum of noise introduced artificially in the test grid is presented in Fig. 5.

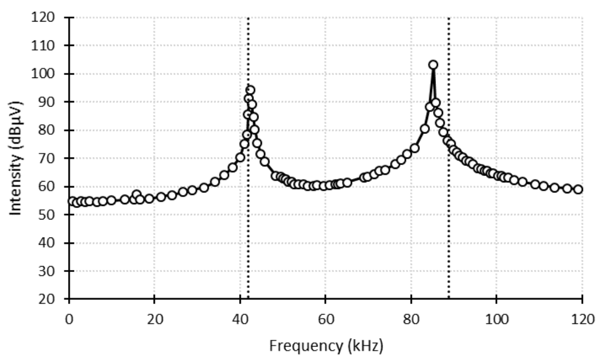

Fig. 5: *Spectrum of generated noise [B1-1624(PT)]*

The impact of the operation of a power conditioning system in an ungrounded LV grid on protection is analysed in [B1-**0519**(KR)]. In Korea, many industry sites operate ungrounded grids and use grounded voltage transformer for ground fault detection. The harmonic emission of the inverter of the power conditioning system includes amongst others zero sequence components. This may lead to erroneous measurement, malfunction of the protection relay and overheating of the equipment. Methods to reduce these adverse effects include increasing the wattage of the damping resistors in the open delta winding of the voltage transformer resistors, adjusting the various parasitic capacitors in the system and adding interconnection transformers.

Harmonic Performance of Measurement and Power Transformer

The transfer characteristic of voltage transformers is essential for evaluation of harmonic measurement in power systems. Although the accuracy for the fundamental frequency is high, the behaviour in case of harmonics can differ significantly. This is especially true for capacitive voltage transformers. In [B1-**0226**(CN)] an experimental platform for the measurement of the frequency response of high voltage and medium voltage oil-immersed CVTs is described. Comprehensive experimental results show that the parameters of the same type of oil-immersed CVTs from the same manufacturer are consistent under similar environmental conditions. By comparison of measurement and simulation, an optimal model for the key parameter estimation was established by the least square method.

Inductive MV voltage transformers are in the focus of [B1-**2230**(UK)] and [B1-**1168**(UK)]. In the first paper, a test system for on-site measurement of the complex frequency characteristics is presented. The method is based on a set of distorted input signals with different fundamental frequencies and FFT analysis of the measured waveform. It was observed experimentally that good results in agreement with the standard swept–sine technique could be achieved at ±10 V input levels, which allows a measurement to be performed using low-voltage portable equipment. In the second paper, the frequency response of VTs rated 11 kV respectively 33 kV between 100 Hz and 2500 Hz was analysed. The results show an increasing attenuation with higher frequencies but no dedicated resonance peak as found in other published cases.

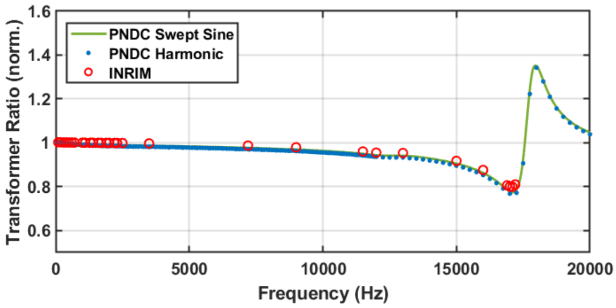

Fig. 6: *Transformer ratio measurement, comparing measurements from INRIM (red) with a swept-sine measurement at PNDC (green), and the harmonic superposition method (blue) [B1-2230(UK)]*

Ferro-resonance is a nonlinear dynamic phenomenon that appears in the electric power system between the non-linear inductance of VTs and system capacities, excited by a sinusoidal voltage source. This effect is studied experimentally in [B1-**1619**(BA)]. In a test without damping devices, the measurement at the open-delta winding of the VT clearly shows the undamped oscillation with a frequency around 20 Hz. Additional tests with a damping device show a significant improvement.

A comparison of dry type transformer derating methods is given in [B1-**0965**(BE)]. The method of harmonic-losses-factor and K-factor are investigated and the relation between these factors and the total current distortion is determined. This evaluation is based on real life measurements on multiple transformers with different load levels so representing a real industrial relevance.

A simplified model for the analysis of the influence of DC stray currents on ultra-high voltage transformers is presented in [B1-**0843**(CN)]. Those DC currents can have their origin in variations of the geomagnetic field (GIC, geomagnetic induced currents) or in HVDC installations. The application of a 3-D model of the transformer's magnetic circuit requires high computational effort. In this paper, an equivalent axisymmetric two-dimensional model of an UHV transformer is established and the influence of the meshing of the model is investigated. The simulation results show that the axisymmetric two-dimensional model of the transformer is small in scale, less affected by meshing, and effectively reduces the computational burden of DC bias analysis.

Potential Scope of Discussion

Further research about active and passive shielding could end up in general planning guidelines, allowing decisions whether passive or active mitigation methods are more efficient and economically competitive.

Table 1: Papers of Block 1 assigned to the Session

Paper No.	Title	MS a.m.	RIF	PS
0035	Temperature and voltage distortion analysis in LED lamps			X
0156	Impact of Installation Photovoltaic Cells on Electromagnetic Fields and Electrical Parameters			X
0226	Frequency Response Test and Key Parameter Estimation of Oil-immersed Capacitive Voltage Transformer			X
0367	40 MW Photovoltaic Power Plant's Earthing System Design – New Challenges for an Integrated Methodology			X
0519	Analysis of effects of harmonics generated by PCS on the protection devices of ungrounded distribution systems			X
0550	Measurement of Earth Fault Current and Earth Potential Rise on Live HV Systems	X		X
0611	Underground Power Cables Magnetic Field effects on Human Health			X
0628	Analyzing And Investigation of Lightning Overvoltage on Distribution Transformers Considering Case Study in SOLTANIH-ZANJAN			X
0699	Influence of NSDD phenomenon on power quality after breaking of vacuum circuit-breaker			X
0763	Immunity Assessment of Household Appliances in the Frequency Range from 2 to 150 kHz	X		X
0765	Light intensity immunity performance of LED street lamps under power quality disturbances			X
0822	Global Earthing System Characterisation of an Actual UK Distribution Network			X
0843	Fast Calculation of DC Biased UHV Transformer			X
0965	Derating method for dry type power transformers based on current distortion parameters			X
1096	Active and passive shield for aerial power lines	X		X
1104	Assessment of EMF-Exposure in Residences due to PLC-based Smart Metering			X
1168	Understanding the harmonic performance of voltage transformers for distribution system power quality monitoring	X		X
1213	Identifying ground faults on a TT grounded system with a 9 channel PQ analyser			X
1231	Towards an integral EMC test of intelligent Ring Main Units			X
1320	Magnetic shielding of power supply of electric glass oven			X
1383	How the observed declining strength of Distribution Earthing Networks will impact the risk exposure of power utilities			X
1415	Earthing System Testing Methods - Historic Approaches & Recent Developments			X
1619	Experimental Investigation of Ferroresonance and Mitigation Measures in 35 kV Isolated Networks			X
1624	Assessment of Smart Meter Communication Over PLC PRIME in a Laboratory Simulating a Real Grid			X
1671	Occupational EMF-Exposure: A Simple Guide for Testing Compliance with Requirements of Directive 2013/35/EU	X		X
1700	Estimation of stray current impact on electrical earthing systems			X
1750	Earthing design incorporating risk quantification – an expensive overhead or key decision-making tool?	X		X
2040	Identification and Optimization of the Sequence of Parallel Conductors Using an Automatic Tool			X

2091	Case study of the implementation of cross-bonding to underground long medium voltage cables in wind parks			X
2095	Switching analysis of a transmission substation and its effect on the downstream sub-transmission substation: A Case study			X
2119	Simplified Magnetic Field Evaluation for Workers with Conductor Loops			X
2230	New methodology for on-site measurement of Voltage Transformer magnitude and phase ratio as a function of frequency			X

BLOCK 2: "Power Quality Issues of New Technologies"

This block gives a summary of the papers dealing with Power Quality issues of new technologies, analysis and mitigation methods. Also in this year's conference this block is quite balanced. It is divided into five subsections. The subsection renewables is mainly dedicated to PV, as the number of contributions dealing with wind energy is quite low. There is a good balance of contributions originating from universities and research programs, rather than from utilities. As an increasing share of EV contributions is observed, indicating that both unbalance and flicker will occur and disturb end users employing more and more sensitive loads, Power Quality is still remaining very important.

Grids

Hybrid grids have become a new trend in both distribution and transmission lines. The Power Quality in this kind of grid has not been addressed or considered compared to the traditional AC grids. In paper [B2-**0527**(FR)] a detailed Power Quality assessment for a typical AC/DC hybrid microgrid is presented. In order to do so, a demonstrator consisting of an AC bus of 10 kV and a DC bus of 560 V is built. AC and DC grids are connected and controlled by a three-phase power controller which can create a virtual impedance droop to realise an average distribution of power flow (Fig. 7).

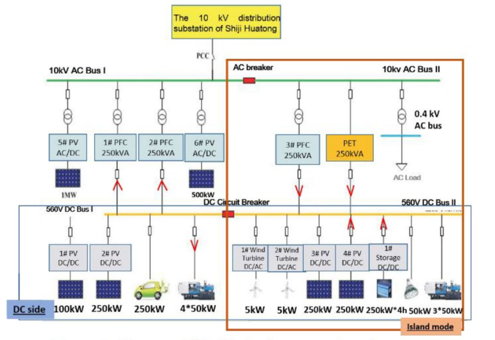

Fig. 7: *Shangyu AC/DC hybrid microgrid configuration [B2-0527(FR)]*

Simulations, on-site tests and measurements have been carried out to verify AC voltage harmonics and DC voltage ripple, voltage unbalance and harmonics. The equivalent dynamic impedance of power electronic interfaced converters is also evaluated. Similar to the AC power systems, the DC voltage also contains AC components because DC loads are composed of power electronic converters as well. So the impact of conducted disturbances on DC loads should be studied in the future.

The authors of [B2-**1022**(CH)] analyse the impact of the massive expansion of renewables and heat pumps in the Swiss distribution grid. Since all these types of loads are equipped with power electronic convertors, the injection of non-sinusoidal currents will affect the frequency-dependent grid impedance and create harmonic voltage drops, possibly beyond the limits of the EN 50160 standard. The study analyses the impact of three main operating states of heat pumps: high power state, low power state and no load condition. Because the inverters of the large heat pumps cause significant variations of the 15th order harmonic current, the corresponding harmonic voltage drop is observed with respect to the impact of an active harmonic filter. Since the grid impedance in distribution grids is dominated by locally connected devices, it can vary strongly between two measuring points. The influence of a device can be the better observed, the closer the measuring equipment is located to this device. It is concluded that, in conditions that the grid presents multiple non-linear loads injecting current harmonics in the grid, the corrective effect of an active harmonic filter is limited at remote grid points.

The research presented in [B2-**1513**(JP)] investigates harmonic characteristics of grid-connected inverters under different switching frequencies and grid configurations by experimental analysis. Therefore, the circuit and control parameters were scaled down from an actual 6.6 kV and 1 MVA system to an experimental 200 V and 4.2 kVA system. The characteristics of harmonic voltages by changing the switching frequency of an inverter from 4 kHz to 10 kHz are analysed under series resonant conditions. Characteristic harmonic voltages are investigated by changing the switching frequency of the inverter and the experimental results demonstrated that the harmonic voltage of the distribution line can be amplified under the condition that the inverter's switching frequency corresponds to the series resonance frequency in the distribution system.

In contribution [B2-**1814**(DE)], the authors are highlighting the impact of the increased use of renewable energy resources in public grids. Since these power electronics produce harmonic currents and inject them into the grid, the significant influence on the Power Quality in the grid is discussed. Three main goals have been identified, namely performing a representative set of measurements to detect external influences on harmonic emission measurements, suggesting improved methods to determine harmonic emission limits in the planning level and finally the evaluation of the possibilities and limits for an active control. It is shown that the voltage distortion and the harmonic impedances at the POC are the main impact factors to increase the harmonic emission. Applications of the methods showed better utilisation of the existing harmonic hosting capacity of the network in comparison with the currently applied methods.

In contribution [B2-**0599**(EG)] the control of a Dynamic Voltage Restorer (DVR) to enhance the Power Quality of a stand-alone hybrid RES system is discussed. The controller proposed in this article is a PI controller based on cuckoo search optimisation technique, called CS optimisation technique. For the validation of the model, two test cases, namely a three-phase fault and a severe voltage dip, are investigated to analyse the impact of/on the quality of DVR based PI-CS controller. It is shown that disturbances applied to the proposed system are avoided by the DVR, while the hybrid RES-system continues its normal operation. The results have shown the ability of DVR to compensate the disturbances occurring in the system, with improvement in voltage, current and power waveforms of the generation sources. The implementation of the Hybrid system with DVR gives an advantage that can ameliorate the Power Quality of off-grid hybrid power systems.

The authors of paper [B2-**1859**(KR)] propose the modelling of a thyristor voltage regulator (TVR) using fast switching semiconductors and voltage control method for long distribution lines. A method of circuit design and a control method for a single-phase TVR are introduced. Using a line drop control method, a constant voltage range control can be implemented, although voltage range may be out of range of sudden voltage change.

A real time optimisation algorithm based on an artificial neural network, developed to optimize the performance of series and parallel inverters for unified Power Quality conditioners (UPQC), is presented in [B2-**2097**(IR)]. The control strategy is based on a neural network controller with PI controller, keeping the DC-link current of UPQC converter constant and generating a proper harmonic mitigating current by determining the duty cycle of the converters. A self-tuning ANN controller consisting of input, output and hidden layers is used to achieve a fast tracking capability of the PWM converter controller. A comprehensive analysis has been conducted for two different scenarios: the first one on the harmonics elimination capability without voltage dip compensation and the second one with voltage dip compensation.

The authors of paper [B2-**2321**(IT)] describe the microgrid implemented in the Campus of Politecnico di Milano. The project aims at creating a microgrid, including all the loads of the Campus, a combined cooling, heating and power plant, two GenSets and different distributed PV plants. The microgrid will achieve further improvements beyond electricity self-consumption. The network components require very reliable and fast controllers. The simplified architecture of the microgrid is divided into five layers which are extendedly described. Finally the paper closes with an overview of possible economic savings from three main aspects, namely the continuity of supply, the provision of ancillary services and the reduction of peaks of power withdrawn from the external grid.

The paper [B2-**0738**(IR)] presents the results of field measurements during a week in spring for both grid-connected and islanded mode of Power Quality indices and energy flow for a single customer microgrid. This grid includes a 15 kWp photovoltaic system as its source of energy. Only the critical loads of the building including lighting, computers and network are fed by the microgrid as an intelligent UPS. A battery bank is included in the system which allows operating this microgrid both in grid-connected and islanding mode. The analysis of the Power Quality parameters during a field measurement at the PCC is discussed. It can be concluded that all measured data were in acceptable range and it shows that this UPS operated microgrid has no Power Quality issue for the distribution grid. However, it should be mentioned that in this study the behaviour of the microgrid regarding the distribution network is considered for a period of four days in March when the sun radiation is like the average of the year and the weather was mild.

In paper [B2-**0222**(EG)] a novel compensating circuit, composed of capacitors, IGBT switch, and a diode bridge is designed and integrated in a Solid Oxide Fuel Cell connected to a microgrid via a Cuk (buck/boost) convertor and a grid connected convertor. All elements are analysed and modelled in MATLAB/Simulink. It is shown that the compensating circuit (FACT) device is designed to provide continuous supply of load demand in a distributed generation system fed by a Solid Oxide Fuel Cell.

Renewables

The paper [B2-**0105**(IR)] presents an investigation on the effect of switching frequency of a static converter of a grid-connected distributed generation resource on the increase of supraharmonic propagation and reduction of the accuracy of smart meters in LV grids. The studied system has been derived from a real LV network, which is connected to the PCC via a 250 m feeder. The LV distribution grid supplies a linear load and a solar system and a passive filter for reactive compensation. An advanced measurement infrastructure (AMI) is analysed. The system was simulated in MATLAB/Simulink in real-time mode. Switching frequency of the static converter of the distributed generation resource was varied over a wide frequency band. It is shown that the excessive increase in switching frequency could cause a 0.88% error in the smart meters.

Paper [B2-**0959**(CN)] investigates the response of rotor overvoltage in double fed induction generator (DFIG) wind turbines under recurring grid faults in order to improve the low voltage ride through (LVRT) capability. The impacts of multi-characteristics of dip events, especially dip duration and the time interval between two adjacent dips on the rotor overvoltage of DFIG, are analysed and presented. Both symmetrical and asymmetrical dips were analysed. It is concluded that under recurring voltage dips, dip duration and the time interval between two adjacent dips, greatly affect the rotor overvoltage of DFIG.

It is commonly known that high dynamic interactions among inverter-based power system components may generate dynamic oscillations. These are leading to harmonic disturbances. Most Power Quality related problems can be detected and investigated within preliminary analyses by use of power system and component simulation. However, modelling of high dynamic effects is mostly simplified or neglected. The contribution [B2-**1572**(DE)] describes a Hardware-in-the-Loop (HIL) testbed for high frequency interdependency issues of inverter-based generation in order to tackle the problem of HF modelling. Current testing and validation of the prospective power system conditions are improved by introducing an appropriate PHIL-based testing system. The paper introduces a concept to overcome current limitations and operational bandwidth limitations of such systems.

Paper [B2-**0370**(SE)] studies the impact of single and three-phase connected PV on the overvoltage in a LV distribution grid, based on a statistic analysis of grid impedance data in POC. The probability of overvoltage is assessed using Monte Carlo simulations to obtain customers and phases with PV combinations for the observed network. It is shown that the voltage rise due to single-phase connected PV can be up to six times higher than in case of three-phase connected PV. Next to grid-reinforcement, other solutions such as active power control and curtailment can be used. Coordinated connection of single-phase PV on LV distribution grids also helps in reducing both unbalance and overvoltages.

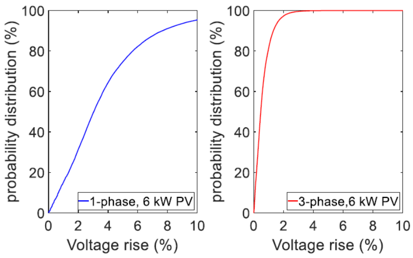

Fig. 8: *Single and three-phase probability distribution functions for the calculated voltage rise with each PV size of 6,000 W and up to 10 % permissible voltage rise [B2-0370(SE)]*

The authors of paper [B2-**0404**(SE)] present the analysis of harmonics in LV networks in the framework of the increasing amounts of PV installations. The focus is put on the practice of aggregation of the harmonic emissions from multiple sources of harmonics. Challenges such as the time dependency and power yield variations and their mutual interactions are analysed using a transfer-impedance matrix. The most important conclusion is that there is no need to place strict requirements on harmonic emissions from small PV installations or to do studies on their impact on the waveform distortion with every new installation.

In contrast to the previous one, the objective of paper [B2-**0562**(BA)] is to analyse the impact of a PV plant on the distribution grid in terms of voltage quality. It considers the dependence between the strength of the grid and PV plant rated power due to the DG penetration, based on a case study.

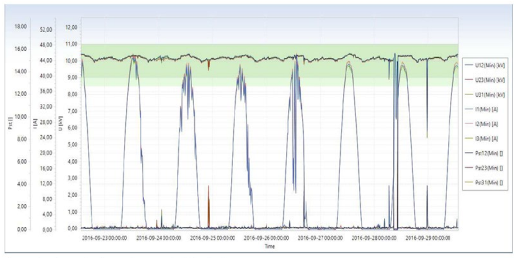

Fig. 9: *Value of U, I and Pst after PV plant connection [B2-0562(BA)]*

The case study refers to a PV plant with rated power of 1MWp connected to MV grid rated voltage of 10 kV. Fig. 9 shows that the Pst value after PV plant connection is negligible compared to the period before PV plant connection. A great value of Pst is obtained for a period when a failure occurred and voltage was zero. If that period is excluded, maximum short-term flicker values were up to 4. But, in accordance with the standard, for 95% of the week the maximum Plt value was less than 1.70%.

As is known, dynamic voltage restorers (DVR) protect against voltage dips and swells. Paper [B2-**0841**(EG)] investigates the performance and analysis of three-phase DVR based on the synchronous reference frame theory. A separately excited DVR based on a controlled PV-DC-link has been designed to mitigate voltage dips and swells up to ± 30%, based on the assumption that there is a sufficient and constant DC power available at the input of the PV inverter. It is shown that the proper operation of the inverter and its control method, which is the core of this system, and depends on the space vector pulse width modulation method, has a linear operation. The success of the control system is based on the detection of dip /swell occurrence and the calculation of reference vector voltage.

Since in Slovenia energy metering on yearly base is used for PV on the one hand, and at the same time subsidises are given for the integration of heat pumps, the combination of both has a serious impact on grid quality. In contribution [B2-**1356**(SI)] the Power Quality related aspects due to the integration of PVs and heat pumps are described in a separate way. Where the impact of harmonics is analysed in case of PV installations, current unbalance due to the use of heat pumps is discussed. As a conclusion, PV inverters are not compliant with the Slovenian rules for connection and extra care should be taken regarding balanced connection to the grid when using heat pumps, due to the unbalance they can create.

The authors of [B2-**1802**(CZ)] describe the impact of photovoltaic power plant inverter firmware on voltage quality parameters, more specific, the flicker levels in low voltage distribution grids. It is shown that the high level of flicker is caused by rapid changes of the active power generated by the inverters. However, there is no direct relation between the level and the frequency of the active power changes and the level of the instantaneous flicker presented in Fig. 10, since the flicker is caused by the contribution of the inverters used. It is also concluded that common, off-the-shelf Power Quality analysers detect exceeding of the flicker limits, but without the possibility to conclusively identify the cause.

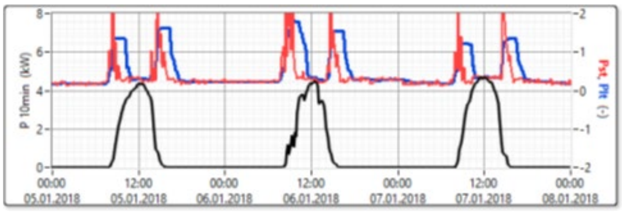

Fig. 10: *The inverter PL1 and Pst, Plt waveform for a 3-day interval, the aggregation interval of 10 min [B2-1802(CZ)]*

Measurements should be conducted by Power Quality analysers with a short aggregation time of max 10 ms (in case of 50 Hz supply), since this will record the rapid active power amplitude changes and rapid power sign changes.

The study performed in [B2-**1888**(FI)] presents the behaviour of active and reactive power with several time averages considering separately measured loads and solar power plants from the viewpoint of measurements in the real environment of a modern office building including EVs and other loads such as elevators. The measurements of the pilot building enabled to study the correlation between Fryze's reactive power expression to both current and voltage distortion. The influence of each time average is analysed. It is found that the 1 hour average distinctly differs from the other averages. Finally, fundamental frequency reactive power was noted to remarkably deviate from Fryze's reactive power and distortion correlated noticeably with the magnitude of active power.

Electric Vehicles

The paper [B2-**0916**(CA)] addresses the impact of fast charging stations implemented in Quebec and discusses the results of the tests performed in IREQ's laboratories on the impact on Power Quality of two different models of fast charging stations. The charging stations under test require a three-phase 480 V AC power supply. The Power Quality impact evaluation tests included the monitoring of the power supply of each charging station during idle periods (no EV charge) and during EV charging periods based on a three-stage process, namely the start-up, full charge and end of charging process. For reasons of coherence, homogeneity, uniformity and regularity, several EV charging sequences, of different EVs have been carried out and monitored. As a result, Power Quality parameters exceeding the thresholds suggested by standards during idle periods of charging stations were acceptable during charging periods and lower than the standards limits during both active and passive periods.

The paper [B2-**0092**(CN)] focuses on the qualitative and quantitative analysis of harmonic issues caused by high integration of electric vehicles. The harmonic current injected by the EV charger (which is acting as a nonlinear load), especially in cases of fast charging stations, significantly influences the long period safe and stable operation of the distribution network. The fast charge-discharge behaviour of EV users is often coupled with car types, battery characteristics and driving habits. Especially, the latter leads to a relationship between charge-discharge power and consequently the harmonic current behaviour. Since the main topology of electric vehicles chargers influences the harmonic behaviour of EV fast charging stations, two types of chargers are analysed in this contribution, namely an uncontrolled rectifier combined with a DC/DC converter (type 1) and a PWM rectifier combined with a DC/DC converter (type 2). The main conclusions drawn are summarized in two main points. First the topology of an EV charger determines the harmonic characteristics and is more pronounced for the uncontrolled rectifier, while the THD(I) decreases with increasing EV connections (Fig. 11).

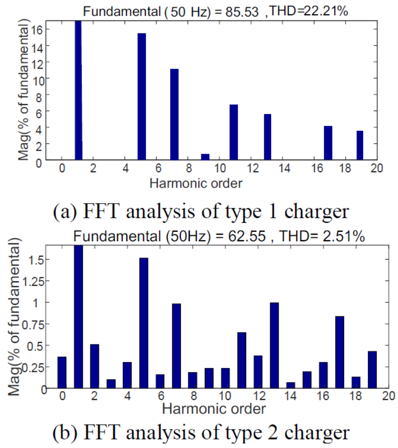

Fig. 11: *FFT analysis of different EV charger topologies [B2-0092(CN)]*

The authors of paper [B2-**0667**(FR)] describe the methodology developed for the simulation of phenomena observed when connecting a 3 kW single-phase slow domestic charger of an electric vehicle to the LV distribution network. The description of the modelling is discussed and simulations have been performed using EMTP for different impedance values of the LV residential network with typical high R/X ratios. Next to that both RFI input filter and PFC boost converter are modelled in order to complete the simulation model. In order to validate the model, lab experiments were performed. In the considered case, it is shown that instabilities occur when the impedance of the upstream network has a very high value. These findings were also found back during the on-site tests made in a laboratory.

The authors of paper [B2-**0958**(DE)] emphasize the new challenges for grid operators due to the shift in power systems from large power stations towards smaller decentralized generation units. Due to the massive integration of these decentralized units, elevated harmonic distortion levels, inducing additional losses and causing malfunctioning of control devices, occur. In this paper, EV charging stations are envisaged. Segmentation is used to pre-process the measured signals in order to detect measurements with significant deviations from their expected value. A new method for detecting Power Quality issues and identifying their underlying causes, based on historical data, is proposed. The presented Object Detection Algorithm (ODA) method is able to identify Power Quality disturbances based on the visual patterns within spectrograms. The main objectives of the approach are the abilities to process large datasets, to detect multiple Power Quality disturbances simultaneously and to link the identified disturbances to a corresponding cause.

These short term challenges for the distribution networks due to the rapidly increasing penetration with EVs are also discussed in paper [B2-**1074**(CH)], where the effect of EV charging stations on the Power Quality of the distribution grid has been analysed in accordance to the EN 50160. The most relevant effects of EVs on the distribution grid, such as possible overloading of cables and transformers and especially voltage problems due to asymmetrical loading, are highlighted. Based on the evaluation of the measurements, it is shown that charging of EVs has no significant impact on the voltage quality at the points of common coupling mainly due to the high short-circuit power compared to the respective power ratings of the EV chargers. The evaluation of the current harmonics is shown in Fig. 12 and illustrates that all values comply with these technical rules. This can be explained by the high short-circuit power at the PCC in relation to the ordered power rating.

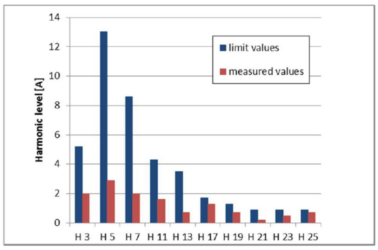

Fig. 12: *The evaluation of the current harmonics [B2-1074(CH)]*

With the increasing penetration of EVs in LV distribution networks voltage quality issues potentially could be caused. In [B2-**1032**(ES)] mitigation strategies are proposed to eliminate voltage oscillations of the most relevant decentralized charging controls. This paper studies, analyses and compares different strategies to mitigate the voltage oscillations that the most relevant EVs decentralized smart charging controls introduce in LV networks. As it is shown, most of the strategies (random delay, hysteresis comparison and sample time strategy) are able to diminish and eliminate voltage oscillations when implementing an EV decentralized charging control in LV networks (Fig. 13). However, the effectiveness of all strategies depends on the charging control and the LV network where they are implemented.

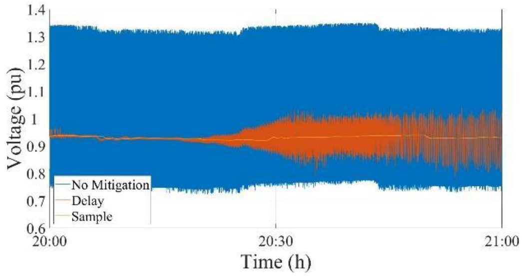

Fig. 13: *Load balancing control results [B2-1032(ES)]*

Also paper [B2-**1409**(CN)] discusses the nonlinear load behaviour of EV chargers which will, in case of large scale use, endanger the safe and stable operation of the power grid and power equipment. This study is based on the actual measured data obtained by the charging monitoring system in order to analyse the harmonic characteristics of current and voltage in the dynamic process of charging. In order to obtain training data, this paper uses simulation data as training data to train the harmonic model of an EV charging station. An equivalent model of an electric vehicle charger based on SOC of the battery is discussed, and a data-driven harmonic modelling method for EV charging stations is proposed. The suggested method only needs to know the measured data of the PCC of the EV charging station, and does not need to go into its specific parameters and structure.

In paper [B2-**1170**(UK)] it is shown that the emerging application of V2G applications of plug-in electric vehicles enables to provide energy and/or ancillary services by communicating with power grids. Due to the connection of EVs to the grid, both current and voltage individual harmonics, total harmonic distortion (THD) and total demand distortion (TDD) of the network will be affected. The paper explores methods for improving Power Quality and reducing harmonics in a distribution network via proper sizing of active power filters and/or adapting control schemes of EVs in V2G mode. As a conclusion, the V2G mode appears to worsen harmonic current content at the PCC, but at the other hand improved the voltage rms value.

Since Norway has the highest number of EVs per capita in the world, the authors of [B2-**1554**(NO)] describe some observed causes for EV-charging issues, as well as some indication on their observed frequency since, in contrast to most EU countries, the LV distribution grid is operated in IT. Consequently, ground faults will not be detected or switched off and may affect the proper functioning of EV chargers. More than 10% of EV chargers have reported some type of charging problems, and many of these are linked towards the charging system falsely identifying a ground fault as a dangerous network condition.

The last contribution of this section [B2-**2234**(CZ)] focuses on the flow of active and reactive power of chargers measured on the charger cable connection (both AC and DC chargers) and its impact on the distribution grid, including the impact of harmonic currents and load conditions on the voltage asymmetry of the distribution grid. Based on measurements and calculations, it is possible that an EV charger can be connected to the distribution grid or the grid connection should be reinforced. Other influences, as also mentioned in [B2-**1074**(CH)], can be neglected, based on measurements performed during analysis.

LEDs

The growing numbers of LED lamps in the distribution network may increase the harmonic levels in the network or can have negative impacts on other equipment connected to the same network. The authors of [B2-**0009**(EG)] analysed the harmonic profiles of various common types of LED lamps and made a comparative study about which types of LED lamps could mitigate the harmonics generated by other lighting systems, including incandescent lamps.

Fig. 14: *Voltage and current waveforms for a 6W LED lamp [B2-0009(EG)]*

It can be concluded that most LED lamps have a high current harmonic content (Fig. 14) and may cause harmonics standard violation. However, due to non-linearity characteristics of power electronic converters, each lamp has a different harmonic profile. When connected together, these harmonics can mitigate each other. So far the variety and allocation of these lamps randomly decreased the overall THD in the electricity distribution network.

The authors of paper [B2-**0237**(SE)] describe the possible interactions between grid-connected PV systems and energy efficient LED lighting systems in terms of their Power Quality parameters and this for different combinations of the inverter and LED lamp types under different grid conditions. These combinations are tested in a controlled laboratory environment; consequently parameters like the operating power of inverter, grid impedance, and grid background distortion were controllable. Harmonic interaction occurs in both directions, between PV and LED as well as background distortion. Even harmonic voltage distortion can potentially affect light intensity. In case of interharmonic emissions, the direction of the interaction is outward from PV towards grid or LED, while concerning supraharmonics, it depends very much on the system impedances. Finally, voltage variations create electrical stress on LED lamps entailing light intensity and harmonic spectrum variations.

Where the former paper showed the LED flicker sensitivity due to voltage variations, the contribution [B2-**0675**(BE)] analyses more specifically the flicker problem and its relation to harmonics by using the Compact Flicker Degree (CFD) method. In this method, the light waveform is taken into account. The light intensity is converted into an electrical voltage. The spectrum of the waveform is determined, depending on the frequency and the eye sensitivity.

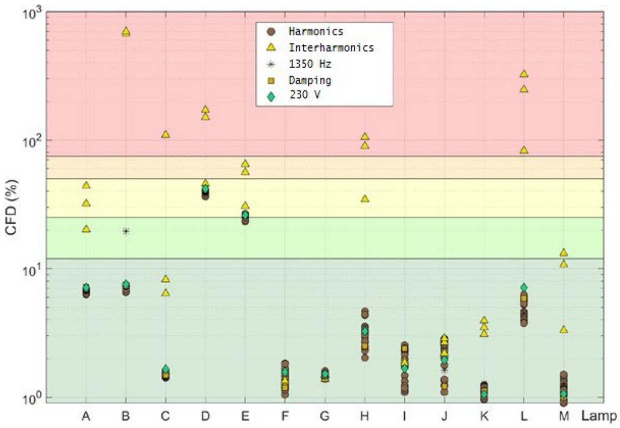

Fig. 15: *Influence of (inter)harmonics on the flicker behaviour of different LED [B2-0675(BE)]*

Researched interharmonic frequencies are the used typical RC-signals. The lab results showed that especially interharmonics have a large influence on the optical flicker behaviour of the LED (Fig. 15), based on the CDF evaluation method.

The authors of paper [B2-**0960**(EG)] are also analysing the flicker effect on LED-systems, but now from the perspective of voltage variations and with respect to the standardisation methods. Different types and technologies of lamps are analysed. It is shown that CFL types have a light flicker percentage of moderate level as compared to LEDs and the latter units having operating times up to 10000 hours have a higher flicker percentage than the identical ones having no operating time. From the experimental procedure with the previous practical issues for the actual LED production with standards evaluation, low power LED units have a low flicker percentage and consequently a low Flicker Index.

The paper [B2-**1527**(FI)] discusses the impact of replacing standard TL lamps with LEDs, both as LED-tube but also as a complete new lighting system. It is observed that the removal of the compensation capacitors in TL lamps not only decreases the phase difference significantly but also decreases the current harmonic spectrum from 14% to 12%. It can be concluded that special attention is required for the additional passive compensation devices when replaced with LEDs. The PFC circuit of the LEDs controls the power factor close to 1, but the effect of separate capacitors is beyond control. The active power is reduced but the apparent power and rms current remains almost unchanged. Therefore, with the defective replacement practice LEDs may cause more issues than benefits and the expected energy efficiency is lost.

The development of a significant and strategic replacement program of the existing PL by the new LED technology by EDP Distribuição with respect to the Power Quality impact is presented in [B2-**1561**(PT)]. In order to perform the analysis, a Power Quality monitoring is carried out in several MV/LV secondary substations, starting some weeks before replacement and ending some weeks after it. The conventional PLs were fully replaced by LED technology lamps. It is shown that there are no significant changes in the voltage harmonic spectrum, after the replacement that could be attributed to LED lighting. As obvious finding, the absorbed current, and consequently the active power decreases with the use of LED lamps on the other hand the reactive power also decreased but became more capacitive.

The paper [B2-**1895**(BE)] presents a complete model of a compact fluorescent lamp and the design of its components with the aim to model the harmonics produced by CLFs in the domain from 2 up to 150 kHz. The paper describes the decomposed CLF in distinguished parts, starting with the EMI filter, a diode rectifier, and its active power factor correction followed by a half-bridge and a tank circuit, are used to obtain a high-frequency current needed to feed the lamp properly. This allows for deriving a mathematical time domain model. It has been demonstrated that the results obtained by a simplified model are close to the ones obtained with the complete model. Finally, these models are validated and compared with experimental measurements gathered from the Panda data base.

Storage

In paper [B2-**0963**(AT)] an energy storage system for peak load shaving and its impact on flicker level, voltage unbalance and voltage level are studied for the case of a rural network. Traditionally either grid reinforcement or new transformer stations are used to solve Power Quality problems in the distribution grid. However, local grid storage systems also give the possibility to solve Power Quality problems on local base. It is shown that the local, decentralized grid storage system supports the grid by using a controlled active power exchange system. This system must allow that in times of high consumption, energy storage should support the grid by providing power and in the times of low consumption the grid storage should recharge. Fig. 16 shows the impact of the local storage system including a peak-load-function in combination with a fast response time. This system allows limiting the load and flattening the load gradients resulting in a lower flicker level as well as a higher and stable voltage level.

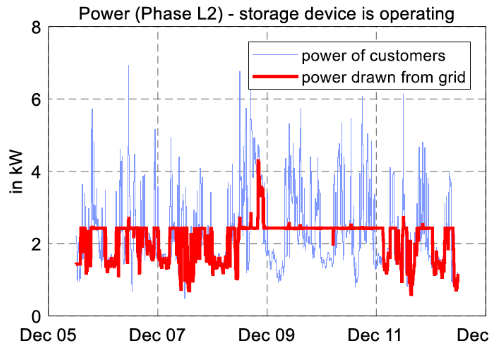

Fig. 16: *Overlay of consumed power of customers and power drawn from the grid influenced by grid storage device [B2-0963(AT)]*

The authors of paper [B2-**0287**(EG)] present the modelling of a battery storage system provided with a supercapacitor as a backup based on a switched filter compensator (SFC) scheme to ensure energy efficient battery charging. The system comprises a Li-Ion battery provided with supercapacitor (C1) that is connected to the DC side to settle frequent charging problems and absorb energy during the regenerative breaking while the SFC topology is connected to the AC bus for reduction of THD, limitation of inrush currents and ensuring energy sustainability of the AC side during fast charging of Li-Ion batteries. Two scenarios for examining the introduced topology are presented, including changing in the SOC of battery storage, and analysis of THD.

Potential Scope of Discussion

Upcoming integration of EVs leads to increased Power Quality related problems in the grid with relation to hosting capacity, unbalance, flicker and both LF and HF emissions in the grid. Consequently, the distribution networks starts suffering through the use of EVs much more than nowadays through PV inverters. It is recommended to analyse and monitor charging stations including the integration of distributed charging points for EVs in order to obtain sufficient information for a reliable assessment of their impact on both hosting capacity and Power Quality related issues.

In contrast to former CIRED conferences, the interest for the impact of wind turbines on new technological evolutions is rather low. However, wind power plants still may have a significant impact on power system operation such as voltage variations and flicker effects. Also here, intensified monitoring and publication of results is recommended.

LED technology is massively increasing in modern electricity distribution networks. Due to their low DC power, power electronic converters are needed to control these types of lamps, creating various harmonics profiles and causing negative impacts on electrical equipment in electricity distribution networks. Therefore, future evaluations of the massive integration of this type of loads and their interaction on both linear and nonlinear loads and sources must be considered.

Table 2: Papers of Block 2 assigned to the Session

Paper No.	Title	MS a.m.	RIF/ RT	PS
0009	Passive Mitigation Technique for the Harmonics Caused by LED Lamps			X
0092	Harmonic Analysis of Electrical Vehicle Fast-charging Station Considered Uncertainty of Load			X
0105	Investigating Increased Error of Measurement Meters in Smart Grids in Presence of high frequency harmonics (Supra-Harmonic) of distributed generation sources			X
0222	Novel Circuit to Compensate the Effect of Source Open Circuit Fault in Distributed Generation System			X
0237	Characterization of Interactions between PV systems and energy efficient lighting (LED) in a mixed installation	X		X
0287	A Robust D-FACTS Based Metaheuristic Control System for Battery Charging Scheme			X
0370	Overvoltage due to single-phase and three-phase connected PV	X		X
0404	Impact of PV on Harmonics in Low-Voltage Networks			X
0527	Power Quality Assessment for AC/DC Hybrid Network Based on New Modelling Methods and On-Site Measurements	X		X
0562	Influence of PV plant 1 MWp connected on MV overhead line on voltage quality in PCC – case study			X
0599	Optimal Control of DVR to enhance the power quality of PV/Wind/Fuel cell hybrid system feeding a new community			X
0667	Description of the low frequency phenomena involved when connecting a 3 kW EV charger to the distribution network: modelling, validation and perspectives.			X
0675	Interharmonics and LED flicker: an assessment by CFD			X
0738	Power Quality Assessment of a Single Customer Micro Grid-Case Study			X
0841	PV Based Dynamic Voltage Restorer for Power Quality Enhancement in Distribution System			X
0916	Impact of Fast Charging Stations on Power Quality	X		X
0958	Object Detection Based Power Quality Expert System for an Electric Vehicle Infrastructure			X
0959	Response of Rotor Over-Voltage in DFIG Based Wind Generator under Recurring Voltage Sags			X
0960	Light flicker Performance of Low power LED Units			X
0963	Power Quality improvement in a rural grid by grid storage system	X		
1022	Harmonic analysis and mitigation in distribution grids with high penetration of power inverters		RT3	X
1032	Strategies for Voltage Oscillation Mitigation in LV Distribution Networks with EV Smart Charging control			X
1074	Impact of Fast Charging and Home Charging Infrastructure for Electric Vehicles on the Power Quality of the Distribution Grid			X
1170	An evaluation of V2G for distribution network harmonic suppression			X
1356	A Practical Case of Power Quality Issues Operating a Small Rooftop PV Plant in Conjunction with a Household Heat Pump			X
1409	A Data-driven Harmonic Modeling Method for Electric Vehicle Charging Stations			X
1513	An Analysis of Harmonic Disturbances in Distribution Systems Caused by Grid-Connected Inverters: Experimental Verification of High-Order Harmonic Resonance		X	X

1527	The Impact of LED Lighting Systems to the Power Quality and Recommendations for Installation Methods to Achieve the Expected Energy Efficiency			X
1554	Charging problems in EV paradise			X
1561	LED technology in Public Lighting – Analysis of the impact in power quality in the low voltage grid distribution			X
1572	Power Hardware-in-the-Loop Testbed for High Frequency Interdependency Issues of Inverter-Based Generation			X
1802	How Photovoltaic Inverter Firmware Could Affect PQ			X
1814	Impact of Renewable Generation on the harmonic distortion in distribution networks: Key Findings of the German research project NetzHarmonie			X
1859	Design and Control Strategy of Thyristor Voltage Regulator for Distribution Line Voltage Regulation for Expansion of Distributed Power Supply			X
1888	Solar power plant in a modern office building: Power and power quality considerations			X
1895	Modelling of harmonics produced by Compact Fluorescent Lamps in the frequency range 2-150 kHz	X		X
2097	Artificial neural network based UPQC controller for power quality improvement in Micro-grids			X
2234	E-mobility impact on supply in distribution grid			X
2321	Designing a Microgrid to Improve Continuity of Service and Flexibility the Case of Politecnico di Milano Leonardo Campus			X

BLOCK 3: "Power Quality Simulations, System Studies, Measurement and Mitigation"

This block contains papers dealing with simulation-based and/or measurement-based studies dedicated to specific Power Quality aspects. Moreover, it covers methods and devices for mitigation purposes. A third group of papers allocated to this block discusses different aspects of instrumentation and advanced methods based on artificial intelligence for efficient analysis of measured data.

The dominating share of papers is dedicated to medium and low voltage networks. Several papers also address high and extra high voltage networks, which underlines the fact that Power Quality is a system issue not only limited to a certain voltage level or the distribution network.

Distortion is considered by more than 60% of the papers in this block. Most of them are dedicated to harmonics, while higher frequency distortion in the range 2-150 kHz, also referred to as supraharmonics, is addressed only in a few papers. The second most important phenomena are events, namely voltage dips, which are discussed in about 15% of the papers. Remaining papers are related to unbalance, transients and supply voltage magnitude.

The most important subject addressed in this block is network harmonic impedance including resonances. Therefore it has been decided to dedicate the RIF session specifically to this subject. Measurement surveys, mainly with regard to harmonics and harmonic source location are two further significant topics. Remaining papers in this block are related to the design of equipment, mainly for mitigation purposes, as well as new algorithms and data analysis tools based on artificial intelligence.

Compared to the conference two years ago, some topics like resonances and network impedance as well as mitigation methods remain important in this year's conference. Some other topics, like sophisticated data analysis techniques based on artificial intelligence or harmonic source identification, have increased in importance over the last two years.

Measurement-Based System Studies

This section includes nine papers, mainly dealing with harmonic aspects, especially harmonic cancellation effects. One paper discusses typical disturbance levels in LV distribution networks, while the remaining papers present measurement surveys on the zero-sequence currents in HV/EHV networks, the current gradient at LV customer terminals and the typical voltage bands in MV networks.

The authors of [B3-**0582**(EG)] analyse the correlation between voltage THD and load current for a set of 18 sites with different customer configuration, namely industrial, commercial and residential. Measurements have been taken as 3-second-values over a day once in 2017 and once in 2018. For the majority of sites a negative correlation is observed, which means a reduction of voltage THD in case of increasing load current. According to the authors, cancellation between single-phase and three-phase equipment is the main reason. A comparison between both years shows no significant change.

[B3-**0053**(EG)] studies the impact of capacitor bank placement and open point location in a radial MV distribution network on losses and harmonics. Based on simulations and validated by measurements it has been found that in the considered network existing capacitor banks were not required anymore due to the less inductive characteristics of the customers. By removing them from the network and reallocating the open points, power losses and total harmonic distortion could be significantly reduced.

[B3-**1627**(CN)] discusses high harmonic distortion levels in MV distribution networks, which are caused by capacitor banks. Due to a low series reactance of only 1%, the de-tuning is not yet effective at lower harmonics, which introduces significant resonances especially at the 5th harmonic order. A voltage THD of up to 9.6% resulting in an excessive noise of up to 95dB was measured. Increasing the reactance ratio to 5% could effectively remove the resonance and consequently the problem with a resulting voltage THD as low as 0.8%.

Paper [B3-**0074**(EG)] also studies harmonic cancellation effects between different types of equipment. Based on the measurement of harmonic emission of 56 commonly used appliances in Egypt, the potential for harmonic cancellation is analysed based on harmonic phasor (magnitude and phase angle). The authors prove that the use of equipment of different brands results in a good harmonic cancellation without the need of any additional mitigation equipment. On the other hand, the use of many similar appliances should be avoided and it is recommended to develop guidelines on how appliances should be chosen in order to optimize the harmonic cancellation. The paper also presents a synchronised measurement at different aggregation levels in a residential area.

The authors of [B3-**1431**(JP)] present a comprehensive analysis of the cancellation between LV single-phase loads and MV three-phase loads for 5th and 7th harmonics due to the difference in their harmonic phase angles. The main reason for the study is the decreasing trend for voltage harmonics, especially of 5th and 7th order, in the Japanese distribution networks with lower levels during the day, when more appliances are used. Based on measurements of 86 MV customers a model for the cancellation of 5th and 7th harmonic current is developed, which proves the harmonic cancellation between the two load groups. The authors discuss the results with regard to harmonic limits, which should provide the necessary balance for an effective cancellation and should not be too strict for the MV three-phase loads (industrial and commercial areas). The possible impact of tightening regulations on 5th harmonic feeder current is shown in Fig. 17 below.

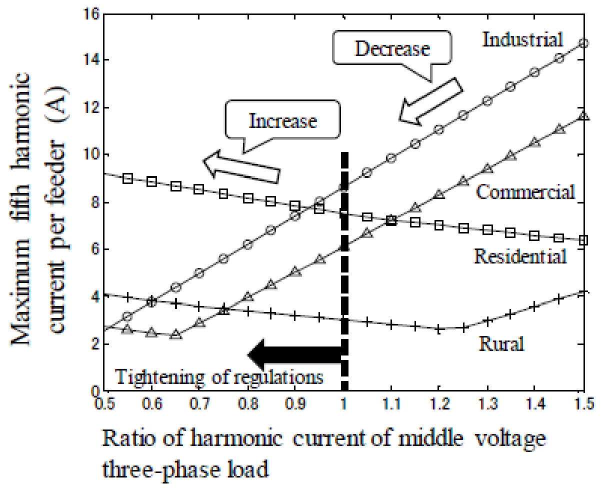

Fig. 17: *Impact of changes in regulations on the 5th harmonic feeder current of different areal feeders [B3-1431(JP)]*

Paper [B3-**0055**(SE)] presents a survey of disturbance levels in the frequency range 2-150 kHz (supraharmonics) in eight different LV networks in Europe, Asia and North America for durations between 118 and 246 days. Based on a statistical analysis of 2-kHz-bands it is shown that the 90%-percentiles are within a range between 0.09% and 0.56% (cf. Fig. 18). There is a significant dispersion between the sites regarding the variation characteristic, the magnitudes and the frequencies of the dominating emission. Clear daily patterns are identified for several sites.

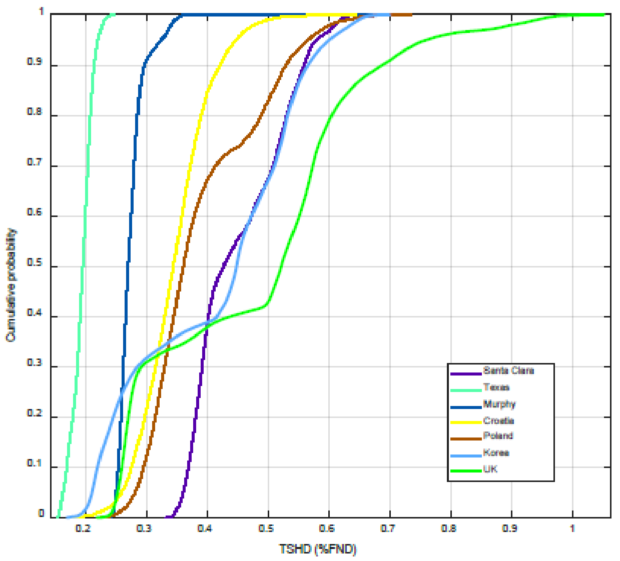

Fig. 18: *CDF plot of the Total supraharmonic distortion (TSHD) at several sites, measured for a duration up to nine months [B3-0055(SE)]*

Due to the close neighbourhood over longer distances, an influence from transmission systems to railway systems by inductive coupling might occur for zero-sequence currents. Virtually no knowledge exists about realistic levels of those currents in the transmission system. The authors of paper [B3-**1229**(NL)] address this issue by performing measurements in two 150-kV-branches and four 380-kV-branches in order to determine present levels of zero-sequence currents and their characteristics. To assess the reliability of results, a comprehensive measurement uncertainty analysis has been carried out beforehand. While the zero-sequence current in the 150-kV-branches is almost constant at levels around 5 A, the current in the 380-kV- branches depends significantly on the magnitude of the positive-sequence current. The levels of the zero-sequence currents are well below the values that are presently assumed for simulation-based interference studies.

The paper [B3-**1025**(CZ)] performs a comprehensive analysis of measurements of supply voltage variations in Czech MV networks. The main objective is to investigate, if due to the increasing penetration of DER in LV and MV networks, the used transformer ratios for the MV/LV transformers are still suitable or should be changed. The supply voltage variation has been analysed for weekly measurements at 54 MV busbars and 22 MV feeder ends. Based on the measurements for two different transformer types and their respective tap changer positions, the authors calculated the suitability of the different transformer types and conclude that 22/0.4kV transformers are more suitable for the Czech networks, as the MV voltage is mostly maintained at about 22.8 kV and those transformers enable a wider range of possible tap positions without exceeding the voltage band limits in the LV networks compared to 22/0.42 kV transformers.

Several studies have shown that the accuracy of energy meters can be significantly influenced by high gradients of the current. In order to obtain a first overview of current gradients, which has to be expected for low voltage customers, the paper [B3-**1078**(DE)] presents the results of one-week measurements at 95 customer terminals, where 47 of them are households. Based on two approaches, one in frequency domain and one in time domain, the authors estimate the current gradient. The majority of gradients are below 0.1A/µs, where a significant deviation between different types of customers could not be observed.

Resonances and Network Harmonic Impedance

This section includes seven papers. Mostly the impact of either wind turbine generators or the placement of capacitor banks and filters in the harmonic range is discussed. Two papers introduce models to study the impedance considering multiple voltage levels and one paper presents a resonance study in the frequency range above 2 kHz.

Paper [B3-**0830**(UK)] develops a simplified generic model of a voltage source converter representing a wind turbine generator. Based on a modified IEEE 34 bus system the impact of different configurations regarding capacitor banks and number of wind turbines is simulated. The frequency scans show a significant impact of the capacitor banks on the parallel resonances. The authors underline that modelling the impact of wind turbines on the network impedance is essential for reliable harmonic distortion studies.

The authors of paper [B3-**2052**(US)] study the effect of distributed harmonic filters on the network impedance in three MV distribution feeders using a simulation. The harmonic filters are aimed to replace traditional non-detuned capacitor banks, which can likely cause resonances. The filters are tuned to the 4.7th interharmonic based on a filter design spreadsheet developed by the authors. It is observed that the change of capacitor banks to filters reduces the impedance for 5th and 7th harmonic, while it increases it slightly for harmonics of order 9 and above. However the transition to filters reduced in general the harmonic levels in the grid compared to the base case with capacitor banks.

Paper [B3-**1191**(IR)] discusses the optimized placement of capacitor banks in MV overhead line feeders in order to avoid unwanted resonances. The proposed methodology is based on initial measurements of the harmonic levels followed by a simulation of the feeder with the capacitor bank installed. In case the resonance frequency is similar or close to the existing harmonics, the location of the capacitor bank is changed or it is split into multiple smaller ones until the risk of triggering the resonance is significantly reduced. The method is illustrated by a practical example, where a 600 kvar capacitor bank has been split into two 300 kvar capacitor banks, which shifted the first parallel resonance from 4.6th interharmonic to 6.4th interharmonic and consequently the risk of high 5th harmonic voltages has been reduced.

In [B3-**1795**(SI)] the authors study the impact of changing customer configurations on the impedance at three PCCs of a MV benchmark network. Therefore a whole week of different operating conditions/states has been synthesised. The analysis shows that in particular at frequencies close to the resonance frequency of the system significant variations of the network impedance in case of operating state changes have to be expected. In a second step the harmonic voltages are analysed with respect to the harmonic contribution of the individual customers. The paper provides input for the ongoing activities of the CIGRE/CIRED WG C4.42.

The authors of [B3-**0930**(SE)] have developed a comprehensive network model covering all voltage levels from LV to EHV (400 kV). It is intended for the analysis of switching transients and the harmonic propagation in power systems. The simulation network is freely available and proposed to be used in the CIGRE WG C4.46. The paper explains the element models used and identifies present limitations. The application of the network is illustrated by several case studies including the impact of changes in the grid, namely the total length of cables and different N-1 scenarios, on the network impedance. It is shown that especially the total share of cables at 400-kV-level has a significant impact on the location and the rise of the first parallel resonance.

In paper [B3-**2306**(NL)] the authors study the impact of different aggregate models of the underlying MV distribution system on the simulation of network impedance in HV networks. This is of special importance, as usually the responsible network operator of the HV system is different from the network operator of the MV system and it is therefore virtually impossible for the HV system operator to obtain sufficient detailed information about the MV system. The paper compares four different types of models to represent an aggregate of the MV network. The parameters of the MV network models are identified based on a clustering of the Dutch MV network in seven generalised MV feeders. Significant differences have been found, where the more complex "type 2 model" provides more accurate and reliable results, which is illustrated by an example network (Fig. 19).

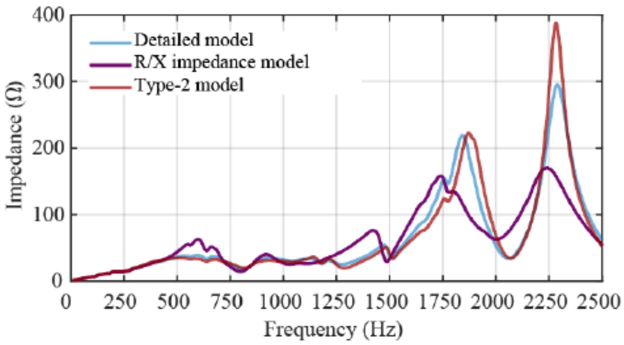

Fig. 19: *Magnitude of harmonic impedances of the detailed, R/X impedance and Type-2 load models [B3-2306(NL)]*

The authors of [B3-**0984**(GE)] analyse resonance amplifications at frequencies above 2 kHz in two different LV networks. Based on synchronized measurements at the substation busbar and the affected junction box the frequency-dependent transfer ratio in downstream direction has been determined. The location of the resonance depends on the operating conditions of the load connected to the junction box and has its maximum at 10 kHz with an amplification factor of 2.2 for single-phase injection (see Fig. 20) and up to 4 for three-phase injection at the LV busbar.

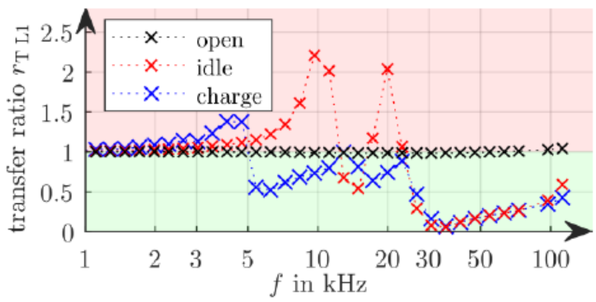

Fig. 20: *Transfer ratio of the low voltage cable under different load conditions of a connected fast charging station and single-phase injection [B3-0984(GE)]*

Along with the measurements also a significant coupling between the phases could be observed, which is caused by the connected three-phase devices. Based on the network data a detailed three-phase four-wire simulation model has been developed. The simulation results compare very well to the measurements. The resonance is caused by the interaction of line inductance and capacitance of a device connected to the junction box.

Harmonic Source Location and Propagation

This section includes five papers. One paper presents a measurement-based model to study the propagation of harmonics in MV networks while the other papers deal with different aspects of identifying harmonic sources and determine their contribution to the voltage distortion.

The authors of paper [B3-**0416**(AT)] present a large-scale simulation of harmonic propagation in a real MV distribution network, where the models of upstream background distortion and harmonic emission of downstream LV networks are parametrized based on real harmonic measurements. For the LV networks the individual characteristic of different customer categories, like households, industry or commercial customers, is taken into account. The authors compare two commonly used simulation approaches for diversity between multiple harmonic sources: one uses only harmonic current magnitudes and the summation exponent recommended by IEC, the second one is based on the real complex harmonic phasors. Results are exemplarily presented for 5^{th} and 7^{th} harmonic and they compare well with the real measurements taken in the considered MV network. In case insufficient accurate information on harmonic phase angles exists, the approach based on summation exponent provides more reliable results.

Paper [B3-**0426**(CN)] describes an easy-to-apply method to identify harmonic sources based on measurement data from Power Quality monitors, which does not require information about topology of grid or harmonic impedances. The method is based on the analysis of the relation between nodal harmonic voltage and harmonic currents in the connected branches. In a first step, the suspicious feeders are identified based on an assessment of the active harmonic power flow. In the second step, the mutual information between branch current and nodal voltage is calculated based on applying the principle of joint entropy and the result is compared with a threshold. For all suspicious feeders the correlation coefficients are calculated as well. The method is validated based on a simulation using the IEEE 13 bus test system and based on measurement data taken at a three winding transformer to which a wind farm and a railway supply network are connected.

Paper [B3-**0475**(CN)] develops a method for harmonic source location especially dedicated to radial distribution networks. The main objective is to improve the placement of harmonic filters. The method requires knowledge about the system as it is based on the analysis of the level of coupling between different nodes based on the admittance matrix. Singular value decomposition is applied to decompose the impact of harmonic sources at each bus and to obtain optimal filter positions based on modifying the respective node admittances. The method is validated using a 13 bus test system and it has been shown that a much more effective reduction of harmonic voltages can be achieved by the proposed method (Fig. 21).

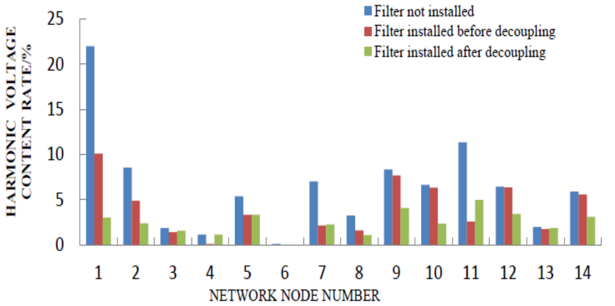

Fig. 21: *Comparison of the total distortion rate of harmonic voltages at each node of the filter grid before and after decoupling [B3-0475(CN)]*

Paper [B3-**1062**(CN)] proposes a method based on an improved independent component analysis to identify utility-side and customer-side impedances based on measurements. The authors emphasize that the identification of customer-side impedance is important for the accuracy of the calculation of customer emission in case the customer installation contains harmonic filters, which reduce the customer-side impedance to values in the range of the utility-side impedance at the considered frequencies. In this case the customer-side cannot be neglected anymore. The application of the proposed method is illustrated by a simulation example. The comparison with three other methods proves the good performance of the proposed method.

In paper [B3-**1512**(SI)] a MV benchmark network is used to compare three different methods for the identification of the harmonic contribution of different customers to the harmonic voltage at a single point in the network. The method disaggregates the harmonic voltage in a network part (background), in a part that belongs to a considered customer installations and a part which is caused by all other customer installations. In spite of differences between the methods, the authors come to the conclusion that all three methods are suitable to realistically determine the contribution of a customer to the harmonic distortion in the network.

Voltage Dips and Interruptions

This section contains five papers, where four deal with different aspects of voltage dips and one paper with the simulation of outage performance of a MV feeder.

Recently, for the detection of voltage dips methods based on empirical mode decomposition have been introduced. The authors of paper [B3-**0483**(CN)] identify the prior definition of level of noise and number of ensemble trails as significant disadvantage of the method, as it requires respective expert knowledge. The authors propose an improved method, which adaptively selects the required parameters by analysing the signal-to-noise ratio and the correlation between the signal and the obtained decomposition functions. A laboratory setup has been used to compare the results of the improved method with the original method and the results obtained with a Power Quality monitor.

In paper [B3-**0985**(IT)] two machine learning tools are developed to support the classification of voltage dips for the Italian Power Quality monitoring system QUEEN. The first tool detects the origin of the fault (MV/HV), but requires a manual feature extraction, which is time-consuming. The second tool automatizes the feature extraction by applying a convolutional neural network. Even if the detection rate is slightly higher with the manual feature extraction, efficiency and flexibility of automatic feature extraction brings a significant improvement. Moreover the neural network is used to differentiate between "true" and "false" voltage dips, the latter originating from voltage instrument transformer saturation (cf. Fig. 22).

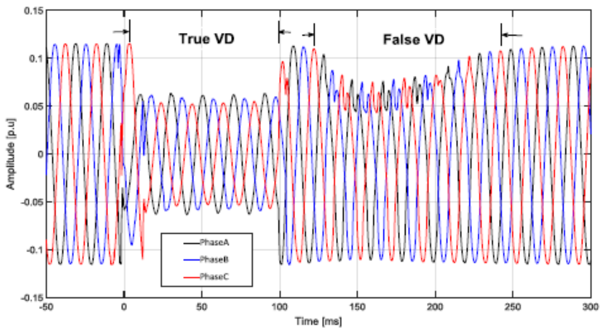

Fig. 22: *Line to line voltage waveform associated to a "true" and "false" voltage dip sequence [B3-0985(IT)]*

For both objectives, detection of origin and true/false dips the total accuracy of the new machine learning based approaches is 86% and 80% respectively.

The authors of paper [B3-**0485**(CN)] propose an improvement of existing indices for evaluating the impact of voltage dips based on application of improved analytic hierarchy process method. Both a grid side and a user side index are calculated taking appropriate weighting for different residual voltage vs. duration combinations into account. Finally the indices are combined to a comprehensive index. The application is illustrated for a 110 kV substation.

Based on a real distribution network paper [B3-**0937**(IR)] analyses the dip performance at the connection points of different sensitive customers connected to the network using Monte Carlo simulation. The simulation is parameterized based on a dip measurement campaign of more than 4.5 years. Finally for each sensitive load the dip performance is calculated, which forms an important basis to decide if mitigation measures are required.

The authors of paper [B3-**1930**(IR)] developed a MATLAB toolbox specifically dedicated to distribution system studies. A specific MV feeder is studied with regard to its interruption performance based on commonly known parameters as SAIDI, SAIFI and ENS. Reliability parameters of the different network components are calculated based on the outage statistics gathered by the dispatching centre over four years. Finally several field measures to optimize the performance of the feeder, like replacement of insulators, placement of additional fuses and tree trimming have been implemented. Moreover, the best positions for reclosers and automatic sectionalisers have been obtained by analytical optimisation. The measures could significantly improve the interruption performance of the feeder, which is shown by the decrease of the above mentioned indices (SAIFI, SAIDI, ENS) by up to about 50%.

Mitigation of Power Quality Disturbances

This section contains eight papers, with most of them discussing strategies and equipment for mitigating harmonic distortion and unbalance. The improvement of sensitivity against voltage dips and the analytical calculation of DC link trajectories are studied for adjustable speed drives. The damping of interarea oscillations is also covered by the papers in this section.

The authors of paper [B3-**0213**(EG)] propose a mitigation device that combines series voltage compensator with two different filter circuits, one to reduce low order harmonics and one to reduce higher order harmonics (Fig. 23).

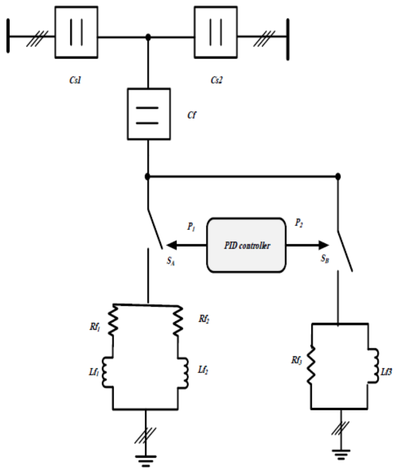

Fig. 23: *Circuit layout of the proposed device [B3-0213(EG)]*

Both filters are controlled by electronic switches. The application of the device is illustrated by several simulations. It is shown that besides the effective filtering of harmonics power losses in the network can also be significantly reduced due to the improvement of the voltage profile.

The authors of paper [B3-**0086**(EG)] describe a C-type filter circuit, which is able to improve power factor and reduce harmonic distortion at the same time. A comprehensive index representing the annual electricity cost savings is developed and used as an objective function for the optimisation of the filter parameters based on the dragonfly algorithm. A simplified test system derived from IEEE 519-1992 containing nonlinear loads, induction motors and linear loads is used to illustrate the application of the algorithm. Besides a considerable reduction of harmonic currents, annual savings for electricity equivalent to about 70 T€ could be achieved with a return of investment period for the filter device of less than a year.

Measurements of 3rd and 5th current harmonic at 20 different LV networks with different costumer types (commercial/residential, office, industry) are presented in paper [B3-**1228**(IR)]. In order to decrease the 3rd harmonic currents the authors design a filter circuit, assess its efficiency by a simulation and perform a field trail based on a prototype. Particular attention has been put on the proper tuning of the filter in order to reduce the impact of existing background distortion. The measurements of the field trail show, that the filter can reduce the 3rd harmonic current and consequently the 3rd harmonic voltage by about 25%, while the impact of 3rd harmonic background voltage is still small.

Due to the rapid development of high-speed electric railways the Chinese power supply system faces increasing challenges with regard to negative sequence currents and harmonics caused by the unbalanced connection of the railway supply and the increasing amount of power electronics. Paper [B3-**0155**(CN)] presents a railway power conditioner (RPC), mainly dedicated to the mitigation of negative sequence unbalance. The authors describe in detail the topology and control strategy for the device, which utilises quasi-resonant controllers for mitigating odd harmonics up to 17th order. The performance is verified in a simulation as well as by an experimental setup of the RPC as downscaled version of 20 kW. In order to cope with capacity restrictions of the RPC and ensure the priority for unbalance mitigation, individual harmonic controllers can be automatically deactivated if required.

Another device designed for unbalance mitigation, but dedicated to three-phase four-wire LV distribution networks, is described in paper [B3-**1641**(FI)]. Its application focuses mainly on weak networks with low short-circuit power. Rather than minimizing the negative sequence unbalance the main goal of the “interconnected star-phase balancer” is to minimize the deviation in supply voltage magnitude between the phases. Besides the unbalance mitigation the authors show, by laboratory tests, that the device improves the short-circuit current and is able to reduce the flicker levels (Fig. 24).

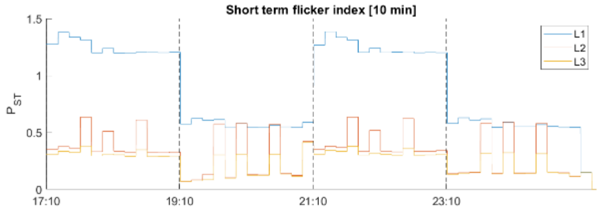

***Fig. 24:** Short-term flicker in flicker mitigation test (segments 1 and 3: balancer OFF; segments 2 and 4: balancer ON) [B3-1641(FI)]*

To generalise the results of the measurements, in particular the impact on increase of short-circuit current, the authors performed initial simulations representing different characteristics of public LV networks.

Adjustable speed drives (ASD) are widely used and their number is expected to grow continuously. ASD are usually sensitive to voltage events, like swells or dips. The authors of paper [B3-**0123**(EG)] compare two mitigation methods to improve the susceptibility of ASD, namely dynamic voltage restorer and dynamic voltage restorer including an ultracapacitor, by a set of simulations. While the behaviour of both methods is similar in case of a voltage swell, it significantly differs for a voltage dip caused by a three-phase ground fault. Based on the results the authors recommend the use of the dynamic voltage restorer with ultracapacitor.

The authors of paper [B-**0134**(EG)] study power system oscillations between two supply areas interconnected by two 220 km long lines transferring a power of 413 MW from area 1 to area 2. Efficient damping of the oscillations is achieved by introducing thyristor controlled braking resistors at the bus bars in both areas to which the lines are connected. A novel fuzzy logic algorithm is introduced to control the dynamic braking resistors. The proposed method is validated by time-domain simulations of three different case studies.

The main components of a typical electric power train application are a passive bridge rectifier and a machine inverter, which provides the frequency variable voltage to the connected drive. In order to optimize the application and analyse occurring problems, nowadays the system, namely the DC link behaviour, is studied by numerical simulations, which are time-intensive and do not allow detailed insight into the impact of individual parameters. Therefore the authors of paper [B3-**1799**(DE)] develop an analytical method based on state space description and approximation of input signals by Fourier series. The analytical method is limited to states, where the DC-link inductor is operated in continuous current mode. The comparison with a numerical simulation shows a good match.

Instrumentation and Data Analysis Techniques

This section contains six papers, three of them dealing with different aspects of instrumentation to measure Power Quality parameters and its accuracy. The remaining three papers describe the application of artificial intelligence and machine learning on the analysis of measured data in order to turn it into useful information for the network operator.

Many of the existing Power Quality instruments are still not capable of performing measurements in the frequency range 2-150 kHz (supraharmonics). Therefore, the authors of paper [B3-**0647**(FR)] have developed a versatile testing platform for generating and acquiring signals in the range

2-150 kHz. It can be used for calibration of Power Quality instruments as well as grid measurements. Besides standard waveforms of e.g. sine, square or rectangular shape, the platform is also able to generate signals with one or several higher frequency components (each specified by amplitude and phase angle) as well as to replay signals that have been acquired in real networks.

In order to enable LV customers to monitor their energy consumption and Power Quality parameters, paper [B3-**0677**(ES)] proposes a low-cost open-source Power Quality monitor, which can be installed in almost every installation and that complies with IEC 61000-4-30. Besides magnitudes of voltage and current, active and reactive power and active energy it can also monitor power frequency, harmonics and voltage events. The authors illustrate different ways of graphical representation, which are included in the Web-interface by an example measurement of a household for several months.

As already identified in [B3-1078(DE)], the accuracy of energy meters can be affected by the sensors used. The authors of paper [B3-**1239**(DE)] build on this issue and perform a detailed study of the impact of the Rogowski coil integrators, in particular its clipping, on the measurement accuracy of power under non-sinusoidal conditions. Based on analytical calculations and circuit simulations of a controlled rectifier bridge the impact of different parameters is analysed. One important finding is that a firing angle of 90°, which generates the highest harmonic content and which is part of the normative required testing conditions, represents a best case where no impact on the measured power is observed (Fig. 25).

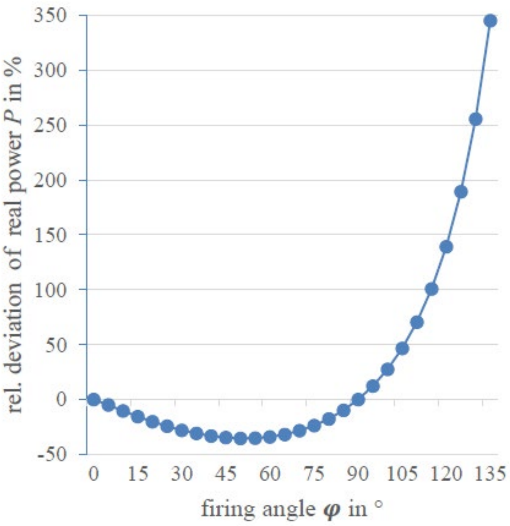

Fig. 25: *Relative deviation of real power P in % as a function of the firing angle (I_{rms} = 10 A, 300 kHz Bessel filter, clipping at 325 mV) [B3-1239(DE)]*

Consequently the test conditions should be revised. The paper finishes with a laboratory comparison of the performance of three real meters.

The number of Power Quality monitors and measurement data increases vastly. The authors of paper [B3-**1535**(NO)] use 7616 time series of real measurements from nine different sites and develop a method for incipient fault prediction based on gradient boosted decision trees. While interruptions are easy to predict with a true positive rate of 95%, the prediction of earth faults and voltage dips is more challenging. The study considers forecast horizons of maximum 40 seconds, but indications exist that forecast horizons of up to few minutes can also be realistic.

A practical model to estimate distribution line (DL) conditions by means of a multi-label extreme learning machine is presented in [B3-**0119**(KR)]. For extraction and classification techniques, the presented research focuses on an interactive modelling approach to suitably classify the types of Power Quality disturbances and DL conditions. Therefore, the condition learning structure for different aggregation levels in the distribution system are defined in this work. Several mathematical models of Power Quality waveforms referenced by the IEEE-1159-2009 Power Quality standard are used to train the model. The model verified that voltage and current waveforms can be classified into fluctuation classes and also provided current patterns reflecting load changes.

The authors of paper [B3-**2049**(DE)] study the performance of three different machine learning regression methods for the prediction of voltage and current characteristics. As the feature set is of crucial importance for the performance of the methods, three different feature sets are developed based on a total of eleven features. The comparison is based on 1-second measurements of voltage and current at an industrial site. Significantly better performance could be observed for currents compared to voltages, where support vector regression (SVR) using feature extraction based on sequential random k-nearest neighbours (SRKNN) provided the best prediction results. The best performing methods for voltage and current have been further optimized and application is illustrated for an eight week measurement, where the first six weeks have been used for training.

Potential Scope of Discussion

One of the major challenges for many different applications is the accurate determination of the network harmonic impedance. It is e.g. required for realistic simulation of harmonic levels in the power system and the determination of the contribution of a customer installation to the harmonic voltages. Both applications received also increasing attention in the last years, where the second one is closely related to harmonic source identification, which is also an important subject of this year's conference.

Due to the increased number of Power Quality monitors, the amount of measurement data is growing vastly and new methods for turning the existing data into useful information are required. The application of artificial intelligence and machine learning, in order to extract this information, seems very promising and is expected to increase in importance in the future.

Mitigation seems to be still an important issue in many countries and is addressed similarly in the research by network operators and universities. Especially the location and optimisation of harmonic filters as well as their combination with additional features is discussed this year.

Finally the impact of distorted signals on the accuracy of smart meters receives attention, as the number of meter manufacturers is large and the quality between them can differ significantly. It has to be ensured that phenomena like distortion in the frequency range 2-150 kHz or the gradient of the current waveform have no adverse impact on the correct function of these meters in the future. There is an indication that existing test conditions could be improved to reflect the real conditions in the networks more realistically.

Table 3: Papers of Block 3 assigned to the Session

Paper No.	Title	MS p.m.	RIF	PS
0053	Practical Case Study of Capacitor Oversizing in MV Distribution Networks using ETAP and Network Analyzer			X
0055	Variations of supraharmonic emissions in low voltage networks			
0074	Harmonics Cancellation in the Residential Distribution Networks			X
0086	Optimal Harmonic Passive Filters for Power Factor Correction, Harmonic Mitigation and Electricity Bill Reduction Using Dragonfly Algorithm			X
0119	Empirical end-device disturbance recognition by waveform feature learning models			X
0123	Fault Ride Through in PMSM Drive Based on Dynamic Voltage Restorer and Ultracapacitor			X
0134	Inter-Area Power Oscillations Mitigation for Electrical Systems Via Novel Fuzzy Control Based Braking Resistor Model			
0155	Railway Power Conditioner With Parallel Quasi-resonant Controller			X
0213	Enhancement of Distribution Networks Performance Using Power Filter/Compensator			X
0416	Modelling the propagation of harmonic voltages in large medium voltage distribution networks	X		X
0426	A Multiple Harmonic Source Localization Method based on Data Analysis			X
0475	Multi –harmonic source decoupling algorithm and treatment in the radial distribution network			X
0483	Application of adaptive EEMD method in voltage sag detection			X
0485	Comprehensive Evaluation of Voltage Sags Based on Grid and Device Sensitivity Analysis			X
0582	Analysis of Harmonic Distortion Levels on Alexandria Distribution Network			X
0647	Design of versatile waveform platform for supraharmonic testing and calibration			X
0677	Efficient open-source power quality analyser and smart meter			X
0830	Impact of Distributed Energy Resources on resonance conditions and harmonic amplification in distribution systems		X	X
0930	A power system model for resonance studies		X	X
0937	Stochastic Analysis of Transient Voltage Dip in Distribution System			X
0984	Measurements and Simulation of Supraharmonic Resonances in Public Low Voltage Networks	X		X
0985	A Machine Learning Based Tool for Voltage Dip Classification	X		X
1025	Voltage variation in MV distribution networks and its impact on selection of MV/LV transformation ratio			X
1062	Harmonic Emission Level Assessment Considering the Influence of Filters in Harmonic Source Side			X
1078	Survey of Current Gradient at Public Low Voltage Customer Terminals in Germany			
1191	Determining the impedance-frequency characteristic of the network in capacitor placement studies by prioritizing the harmonic pollution of feeders under different loads			X
1228	Analysis and design of harmonic filter for commercial and official substations in Lorestan Province Electricity Distribution Network			X
1229	Measurement and analysis of zero-sequence current levels during normal operation			X
1239	Simulations in GNU Octave to Analyse the Behaviour of Rogowski Coil Integrators for Measurement of Nonsinusoidal Currents			X
1431	Characteristics of Fifth and Seventh Harmonics in Japanese Electric Power Distribution System	X		X
1512	A Network-Wide Evaluation of Single-Point Harmonic Contributions from Customer Installations: Comparison of Different Methods			X

1535	Incipient Fault Prediction in Power Quality Monitoring	X		X
1627	Research on the Typical Problem of Shunt Capacitors Excessive Noise Caused by Harmonics Based on Field Measurements			X
1641	Characterization and Laboratory Performance Testing of Interconnected Star Phase Balancer	X		X
1795	Temporal Variations of System Operation Conditions and Continuous Assessment of Low-Order Harmonic Emissions from Customer Installations		X	X
1799	An analytic investigation of the dc link trajectories in electric power train applications			X
1930	Distribution System Reliability Modelling and Optimization of city Outskirts: Case Study of Polebaba Feeder			X
2049	PQ prediction by way of parallel computing - benchmark and sensitivity analysis for classical ML approaches			X
2052	Assessment of Distributed Harmonic Filters on Grid Voltage Quality			X
2306	Impact of distribution network modelling on harmonic impedance in the HV grid		X	X

Block 4: "Quality of Supply, Monitoring and Big Data Analysis, Standards and Regulatory Issues"

Monitoring of Power Quality in the distribution system is gaining importance. On the one hand the increased use of inverters leads to new Power Quality phenomena and issues, on the other hand an increasing number of sensitive loads and processes are employed by business and residential customers. As the quantity of Power Quality information is continuously increasing, efficient monitoring systems, the mining of Power Quality data and the prediction of trends using adequate indices are of strategic importance for distribution system operators. Regarding future intelligent distribution grids, the availability of reliable real-time data and fast communication systems will be critical for a reliable and cost-efficient operation of the grid.

Monitoring and Big Data Analysis

Distribution System Operators employ more and more Advanced Distribution Management Systems that include monitoring and control functionalities. Monitoring is employed to improve the "visibility" of the MV and LV networks. The increased availability of real-time measurements and fast communication technologies permits an improved state estimation and enhanced monitoring. Power Quality monitoring plays an important role in ensuring quality of supply. In active network management flexible loads and generation will be employed to improve the supply reliability. Big data analysis is needed to analyse and structure large volumes of data and to recognize patterns, correlations and trends. Together with machine learning and artificial intelligence tasks like operation status detection and fault prediction can be approached more efficiently. Several papers in this subsection focus on Power Quality monitoring of harmonic levels. The triplen harmonics have increased largely over the past years due to the massive deployment of non-linear household equipment. Even after the expected adjustment of the limits in EN 50160 for the 15th and 21th harmonic to 1.0 and 0.75, respectively, the triplen harmonics will remain a major challenge to the grid.

This subsection comprises eight papers presenting results of monitoring campaigns, potential applications of Power Quality monitoring as well as the use of big data analysis and machine learning for problem identification.

[B4-**0023**(NL)] presents an overview of the Power Quality monitoring activities of Enexis in its HV, MV and LV networks. In this context, the Power Quality monitoring program on the national level in the Netherlands going on in the Enexis MV and LV networks is also referred to. Trends based on records of the last four years and field measurements are presented. The results show that the majority of the Power Quality complaints are received from households including an increasing number of customers with PV-installations. Analysis indicates that 70% of the reported Power Quality problems originate in the network itself. Fig. 26 represents the repartition among the different phenomena. The national Power Quality monitoring program shows that the main Power Quality parameter that violates the standard limit is the 15th harmonic. As it does not cause any exceptional problems for the customer, the Dutch standardisation committee has already accepted the proposal for the increment, which will be adopted soon in the Gridcode.

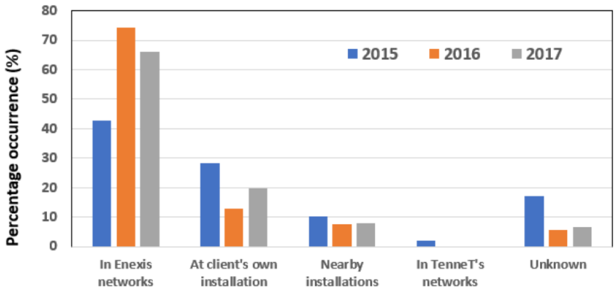

***Fig. 26:** Distribution of the origin of PQ problems (in %) [B4-0023(NL)]*

[B4-**0366**(SE)] presents levels of harmonic voltage distortion at low voltage customers, which have been measured during 2017 and 2018. Phase-to-neutral voltages have been recorded at 163 locations. Apart from four locations, all measurements have been performed in Europe with a portable power-quality monitor for a period between one hour and one day per location. The highest 10-min-values have been used for comparison to EN 50160. Although this does not comply with the one week period of EN 50160, this survey can give a good indication about typical voltage harmonic levels near the terminals of low voltage equipment.

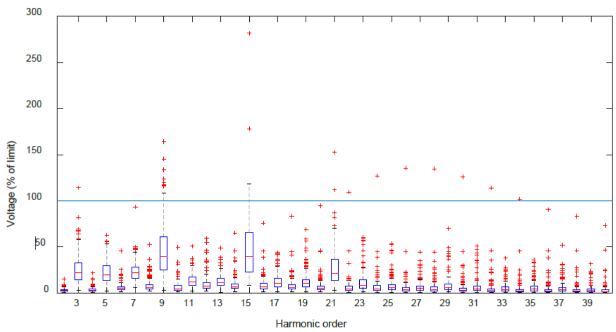

***Fig. 27:** Harmonic levels at all locations as a percentage of the limits [B4-0366(SE)]*

The 75th percentile is well below the limit (20% or less) for all but a few harmonics (3, 5, 7, 9, 15 and 21). The proposed new limits for harmonics 15 and 21 would make a larger margin available at those frequencies, but not solve the challenges with harmonic 9. In spite of the limitations of the survey conducted, the results of this paper clearly indicate that the harmonic levels in documents like EN 50160 and IEC 61000-2-2 should not be used as typical harmonic levels. The authors encourage system operators and regulators to make measurements of harmonic levels in low-voltage grids available for comparison with other surveys.

General Power Quality levels in Danish distribution grids have been analysed in measurement campaigns since 2009. [B4-**0538**(DK)] focusses on the rms voltage flicker and harmonics up to the 25th. The analysis extends to the angle of the 5th harmonic voltage, in order to compare it to the less stringent requirements possible to use in EN/IEC 61000-3-12. 63 different sites are included, which cover a variety as large as possible regarding i.e. distance from transformer, composition, age, consumer types and number of consumers. Analysis of the measurements suggests that supply voltage and flicker levels as well as distortion, except from triplen harmonics, are generally not an issue. Of all harmonics the 9th and the 15th are the harmonics closest to the limits. The second part of the paper deals with the 5th harmonic angle and analyses measured values in order to assess the special conditions related to EN/IEC 61000-3-12. For equipment connected to the grid >16 A and ≤ 75 A per phase, relaxed requirements can be applied for angles of the 5th harmonic current being within 90-150 and 150-210 degrees respectively under the assumption, that these are uncommon areas for a distortion. As can be seen from Fig. 28 there is a rather large variation in the phase angle of the 5th harmonic. The 5th harmonic angle does not have a clearly identifiable area across the various measurement sites. Of all the sites measured, only about 20% support the relaxation in EN/IEC 61000-3-12, while about 40% do not support it. Therefore, the author concludes, that the general rule of relaxation does not appear to be valid.

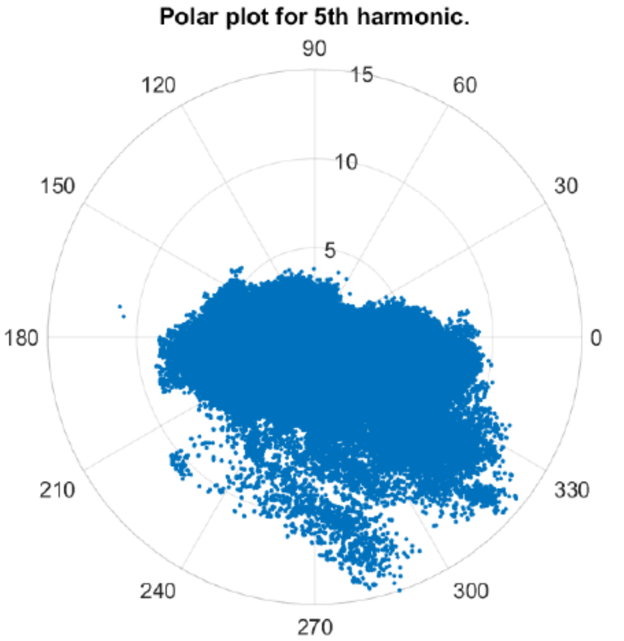

Fig. 28: *5th harmonic voltage in phase A across all sites. [B4-0538(DK)]*

[B4-**0652**(SE)] presents the results of a long-term Power Quality survey carried out at three Swedish medium voltage substations. The paper focusses on harmonic voltage distortion and analyses possible correlations with meteorological data. Site 1 is close to several wind parks, site 2 close to domestic and industrial loads and site 3 close to wind parks, domestic and industrial loads. The measurement duration is eight, six and five years, respectively. Differences over the years, seasonal, daily and variations with wind speed and temperature are analysed. Results indicate that there are significant differences between sites and over the years. Fig. 29 and Fig. 30 show the average value of the 5th harmonic for the three sites for two years. As trends and correlations seem to vary largely, more long-term monitoring data are needed to gain better understanding.

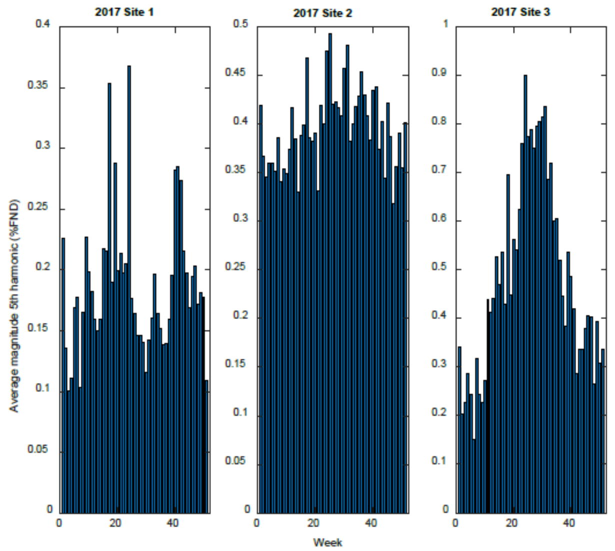

Fig. 29: *Average value of 5th harmonic calculated per week during 2017 at each site [B4-0652(SE)]*

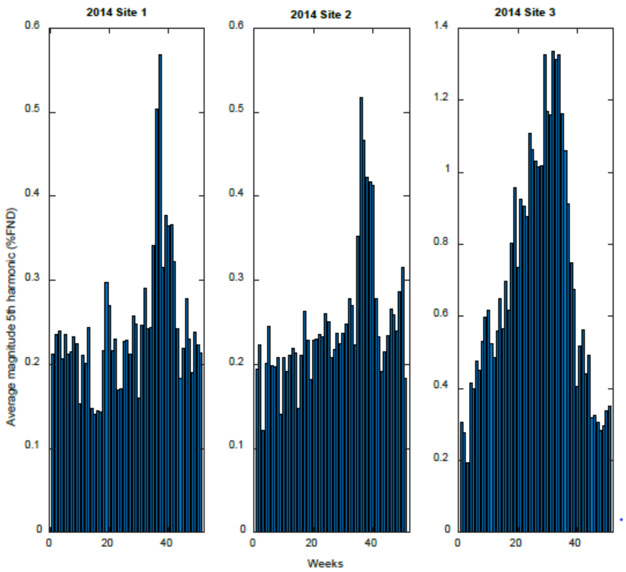

Fig. 30: *Average value of 5th harmonic calculated per week during 2014 at each site [B4-0652(SE)]*

[B4-**0724**(IR)] studies the effects of harmonic distortion on performance of transformers. Iranian utilities usually refer to IEEE Standard 519, which allows a maximum harmonic distortion (THD) of 5%, which is reported to be exceeded in many cases. In the grid of Mashhad Electric Energy Distribution Company most transformers and consumers > 30 kW are equipped with smart meters. In this paper data of about 1500 transformers are analysed, covering commercial, industrial and rural networks, and compared for peak, off-peak and shoulder time.

Improving network operation and maintenance are the goals of an ongoing project for monitoring distribution transformers and their associated low voltage networks. [B4-**1608**(ES)] presents the challenges and benefits of the project. Monitoring of secondary transformers is realised by low-cost devices, which are not fully compliant to IEC 61000-4-30, but deliver useful features for energy and Power Quality monitoring. Each installation consists of a Power Quality device with voltage and current connectors and an external temperature probe for measuring the indoor temperature. The monitoring system is used to improve the analysis of LV and MV faults. Recently, the challenge to estimate the temperature and aging of oil-immersed transformers has been tackled. Transformer ageing is estimated based on IEC 60076-7 weighting up the calculated temperature rise according to EN 50464-3 by the effect of harmonics and current unbalance. Ambient and top-oil temperatures as well as hot-spot temperatures are estimated and average aging across the period is calculated. The data can be stored for weeks in the device or downloaded by MODBUS or FTP. The model will be validated using on-site temperature measurements of top-oil temperature. Future collaborations with transformer suppliers for intensive in-factory tests are envisaged.

[B4-**0744**(FI)] gives an overview how IEC 61850-9-2 standard based raw data streamed from the Sundom Smart Grid can be processed and utilised for Power Quality monitoring and analytics applications. Digitalisation also enables several other parallel applications, since the same data stream can be used for several targets when the connectivity, interoperability and data quality are sufficient. Future big data analytics could utilise calculations, which are integrated into Intelligent Electronic Devices (IEDs) and send pre-processed values by Generic Object Oriented Substation Event (GOOSE) messages. A data analytics platform called DAGR for Power Quality monitoring has been developed as a proof of concept that big data processing can be handled in real-time. The Sundom Smart Grid consists of one primary HV/MV substation and four secondary MV/LV substations, in total 20 IEDs are sending IEC 61850-9-2 sampled value (SV) streams with a sampling rate of 4 kHz, as well as GOOSE data to a centralised server. The following parameters are computed every ten periods: power, reactive power, frequency, total and fundamental signal rms, THD and current and voltage harmonics up to the 40th. A multi-threading avoiding concurrency issue by design is used for efficient processing. Data coming from each sample value stream is copied in its corresponding ring buffer. Fig. 31 shows the batch processing of the raw data, which permits improving the performance. Tests confirmed, that the implementation can handle up to 10 SV streams on a Raspberry Pi 3, which would be half the size required for Sundom Smart Grid.

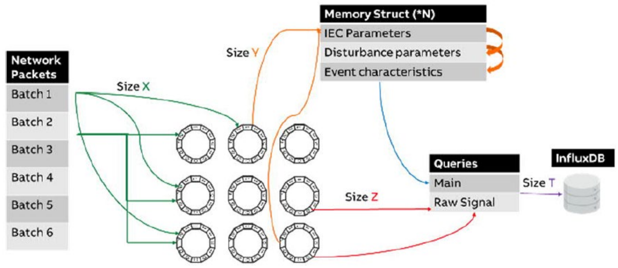

Fig. 31: *Batch processing of the raw data [B4-0744(FI)]*

The authors of [B4-**0713**(CN)] deal with operation status prediction for Power Quality compensatory equipment. Power Quality data from the monitoring system of the power supply company are used in order to feed an algorithm. Voltage deviation, three-phase voltage unbalance, total harmonic distortion rate and long-term voltage flicker are the input of a Probabilistic Neural Network (PNN) supervised learning algorithm, whose output is the operation status of the compensatory equipment on the customer site. The proposed method is verified by measured data from a 35 kV substation, where a photovoltaic power station with a static var generator (SVG) is connected. Data from three days are used for training; afterwards data from six days including the training data are used to verify the method. The reported accuracy of classification for the case study is more than 95%. Some misclassifications are done due to the time delay between the SVG starting and working effectively. The authors state, that the method can provide data support for the management of compensatory equipment and improvement of compensation scheme.

Power Quality Standards

With respect to the ongoing and rapid changes in power systems at all voltage levels, such as the increase of power electronics in generation and non-linear loads, Power Quality standards have to evolve to reflect these changes and to keep up with the needs of all players in the distribution grid. A topic of high interest is the allocation of an adequate share of the compatibility level for voltage distortion to the customers at the planning stage. As power electronics are on the rise in generation and storage, these installations have to be part of the allocation process. The determination of fair and justifiable limits for emissions already in the planning stage is one of the challenges to be addressed in the field of Power Quality. Several paper review and compare current standards regarding harmonic voltage limits and harmonic allocation. Also addressed in this context is the network harmonic impedance in the higher frequency range. Furthermore, the effects of ageing of equipment as well as prolonged periods with extreme temperatures with respect to limits in standardisation, the implications of the IEC 61850 standard on Power Quality monitoring and the need to redefine EMC standardisation regarding reliable NarrowBand Power Line Communications are discussed.

This subsection comprises eleven papers presenting an update on standards and corresponding measurement methods.

[B4-**1393**(DE)] deals with new challenges for the determination of emission limits for customer installations and gives an overview of the activities of CIGRE JWG C4.40/CIRED on the revision of the IEC reports 61000-3-6, 61000-3-7, 61000-3-13 and 61000-3-14. The transition to power electronics based generation acting as disturbance sources similar to customers requires including them in the allocation process. Envisaged modifications and extensions are presented as basis for discussion with relevant stakeholders. The EMC concept is based on the probabilistic coordination between the disturbance level resulting from the emissions of all connected devices and the immunity levels of these devices. The compatibility level in LV corresponds to the sum of global contributions of all voltage levels. Emission limits of customers are determined by sharing the global contribution between all customer installations connected to this voltage level. The major proposed changes are: The dedicated consideration of energy producing installations while providing the flexibility to define more strict emission limits compared to consuming installations, the consideration of existing background levels and a significant simplification of the emission limit calculation for customer installations connected to LV networks.

An overview of Chinese harmonic standards and their development is presented in [B4-**0635**(CN)]. The first Chinese harmonic standard "Quality of Electric Energy Supply Harmonics in Public Supply Network" was released in 1993. GB/T 14549 mainly referred to UK harmonic standards. Successively standards on harmonic limits, planning and monitoring assessment as well as management and supervision have been developed. In order to keep up with the development of the Chinese power grid revision of GB/T 14549 concerning harmonic voltage limits and the harmonic allocation method are two important challenges.

Methods for harmonic responsibility quantification are reviewed in [B4-**0902**(CN)]. Estimating the harmonic contribution of various loads is a key prerequisite for a harmonic control scheme to minimize harmonic pollution in the grid. The paper reviews the existing indices, methods and algorithms for multi-harmonic source responsibility quantification. In conclusion the authors point out that further development of indices to estimate the harmonic contribution in multi harmonic source systems is required to enable harmonic control schemes. Furthermore, multi-harmonic source quantification methods should take into account several harmonic feeders on a bus and changes of the harmonic impedance during the evaluation period.

In [B4-**0331**(KR)] harmonic allocation methodologies and emission limits of IEC 61000-3-6 and IEEE Standard 519 are compared. Unfortunately, the comparison on the basis of an IEEE 123 network topology system, which is referred to in the conclusion is not presented in the paper.

Current and voltage distortions in the range of 2 kHz to 150 kHz so-called supraharmonics and rapid voltage changes (RVCs) are Power Quality parameters which have been researched for several years. However, a standard measurement method for rapid voltage changes has only recently been published and a standard measurement method for supraharmonics is still missing. [B4-**0551**(ES)] reviews measurement methods for both phenomena alongside with the status of international standards and the most recent scientific work. The measurement method for RVCs defined in the IEC 61000-4-30 standard is based on the calculation of the rms voltage computed over one-cycle intervals. Drawbacks reported in literature include the lack of threshold for RVC detection, missing consideration of the rate of change of voltage relevant for flicker and a minimum aggregation time to separate consecutive events. However, authors consider the proposed method as an important step towards standardisation of RVC measurement. Supraharmonics still lack a unique measurement method needed for the definition of compatibility levels. Regarding supraharmonics the IEC 61000-4-30 standard on Power Quality measurement methods proposes different methods in its Annex C. The authors briefly present and discuss these and other measurement methods proposed in research papers.

Measurement methods in the frequency range from 9 kHz to 150 kHz are reviewed and compared in [B4-**1574**(DE)] taking into account performance requirements for implementation in Power Quality instruments as well as compatibility and accuracy with CISPR 16 receivers. Existing EMC standards regarding compatibility levels and emission limits refer to CISPR 16-1-1 and specify receiver settings for measurements. As emissions in this frequency range are rapidly increasing in the grid, assessment and measurement of these disturbances in the grid is an urgent need as has been addressed in IEC 61000-4-30 Ed. 3. The authors provide a comprehensive comparison of measurement methods for voltage distortion specified in Annex C of IEC 61000-4-30 Ed. 3 and Annex B of IEC 61000-4-7 Ed. 2.1 (Fig. 32). Furthermore, they propose a new digital DFT-based CISPR compatible measurement method for Power Quality instruments. The new method is designed to be modular in order to permit the implementation of classes A and S for different types of applications based on the same measurement principles.

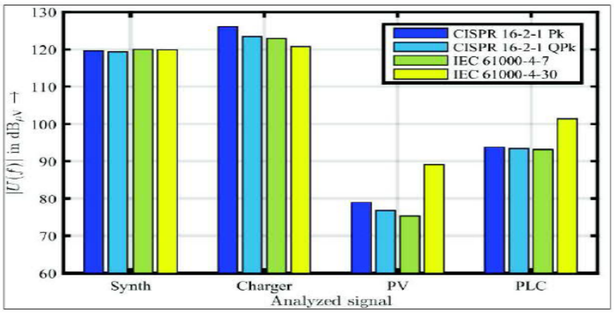

Fig. 32: Comparison of test methods [B4-1574(DE)]

Suitability of test procedures in IEC 61000-3-2 for assessing harmonic emission of modern mass-market equipment is analysed in [B4-**1407**(DE)]. IEC 61000-3-2 specifies harmonic emission limits for equipment with input currents below or equal to 16 A per phase. As the share of power electronic equipment with self-commutated circuits has largely increased in comparison to classical line-commutated topologies, it is analysed, if test conditions in IEC 61000-3-2 reflecting the worst case for classical equipment are still suitable today. The paper presents a comprehensive survey of the sensitivity of harmonic emission of more than 150 classical and modern devices for two different supply voltage waveforms (sinusoidal and flat-top) and for three different supply voltage magnitudes. The analysis suggests that modern power electronic devices especially with active-PFC behave significantly different from classical devices and are much more sensitive to voltage distortions (Fig. 33). A first idea for a revised test procedure for assessing compliance with emission limits taking into account the characteristics of modern devices is proposed.

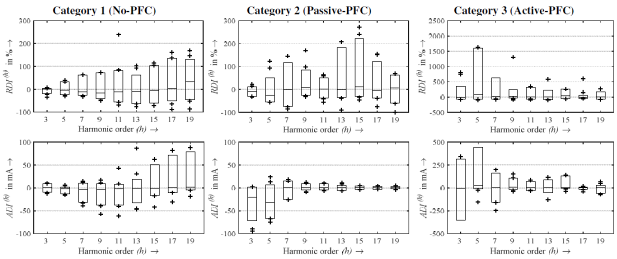

***Fig. 33:** Impact of flat-top voltage waveform on harmonic current emission for different topology categories (nominal rms voltage) [B4-1407(DE)]*

[B4-**1398**(DE)] presents the results of a measurement campaign in four European countries with the aim to identify typical ranges of the frequency-dependant network impedance in the frequency range 2-9 kHz. As the network impedance is generally unknown in the planning stage, it has to be estimated based on realistic assumptions. Especially in the frequency range above 2 kHz the linear extrapolation of the short circuit impedance seems to be too conservative and could lead to an inefficient utilisation of the grid. IEC 61000-4-7 proposes a reference impedance for testing appliances in the frequency range 2-9 kHz based on a reference short circuit power based on IEC/TR, which is still rather conservative. As the 3rd edition of the AT/CH/CZ/GE rules for assessment of network disturbances for customer installations shall be extended to the frequency range 2-9 kHz, the authors of the paper aim to develop a realistic, reliable and widely accepted assumption for the network impedance in this frequency range. In total 198 single loop impedance measurements have been conducted. Fig. 34 shows the measured loop impedance in comparison to IEC 61000-4-7.

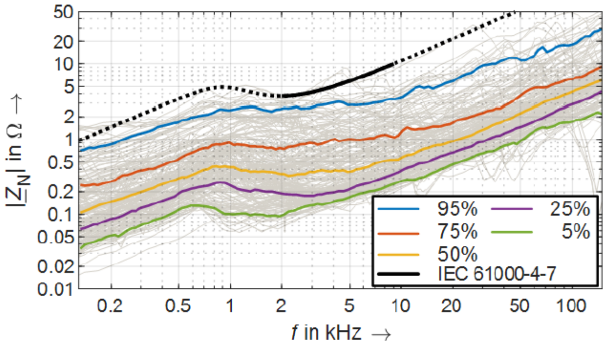

***Fig. 34:** All measured loop impedances in comparison with IEC 61000-4-7 reference impedance including selected percentile curves [B4-1398(DE)]*

The measured loop impedance can vary about two decades and can be up to factor 100 smaller than the IEC 61000-4-7 reference impedance. The proposed impedance approach is based on an appropriate scaling of the IEC 61000-4-7 reference impedance by the short circuit power at the connection point of the customer installation. The reference impedance Z_{ref} for frequency f is linearized in the considered frequency range 2-9 kHz, which leads to an error in the range of -15% to +5%. Afterwards, the linearized impedance is scaled with the ratio of reference short circuit power (S_{sc} ref) and the real short circuit power at the connection point (S_{sc}). In order to keep the dependency flexible, a reduction factor r is introduced. r=0 means, that the short circuit impedance has highest impact on the impedance. Following a similar probabilistic approach as for the determination of the reference impedance in IEC 60725, a reduction factor r=0.25 is proposed. For this value 90% of the measured impedances are below the respective estimated impedance. The authors emphasize, that more research is needed to improve understanding and knowledge about the network impedance above 2 kHz.

[B4-**0521**(CN)] discusses the potential significance of climate change and extreme climate events on the emissions of electrical devices and potential implications for standards. In Shanghai complaints of residential customers regarding Power Quality issues have significantly increased alongside with the rising use of sensitive electronic devices since 2013. Therefore, utilities urgently need to control the Power Quality status of devices like inverter-driven air conditioners, which are responsible for harmonic emissions and have become a concern to electric utilities. The authors compare the results of Power Quality tests for inverter-driven air conditioners in an enthalpy difference lap with the IEC 61000-3-2 standard. Temperature requirements for harmonic tests for air conditioners in the standard are 30°C±2°C and 15°C±2°C. In the lab scenarios with an outdoor temperature with a constant value of 35°C and 40°C have been compared to the scenario with 30°C for a typical inverter-driven air conditioner.

[B4-**1353**(US)] highlights the new international standard IEC 61850 for substation communication, which has a significant impact on Power Quality monitoring and recording functions. IEC 61850 has been designed to support the development and availability of a wide variety of applications in substation protection, automation, monitoring and control. It defines both how data is represented in the system model and how devices and applications exchange data with each other. Services are defined which allow the development of distributed systems for Power Quality monitoring and recording and the more efficient use of multifunctional Intelligent Electronic Devices (IEDs) following the changes in IEC 61850 Edition 2. Power Quality monitoring functions are covered by a dedicated group of logical nodes – Q. This group of logical nodes refers to the modelling of Power Quality events detection and analysis functions. It allows a new approach to detection and recording of Power Quality events with a sampling rate of 256 samples per cycle. Time synchronisation is achieved over the Ethernet according to IEC 61850-9-3 with accuracy better than one microsecond. The Power Quality monitoring system architecture can be implemented completely distributed or hybrid. Fig. 35 shows the scheme of hybrid architecture. Testing of Power Quality monitoring devices and systems requires a set of specialised IEC 61850 Power Quality related tools.

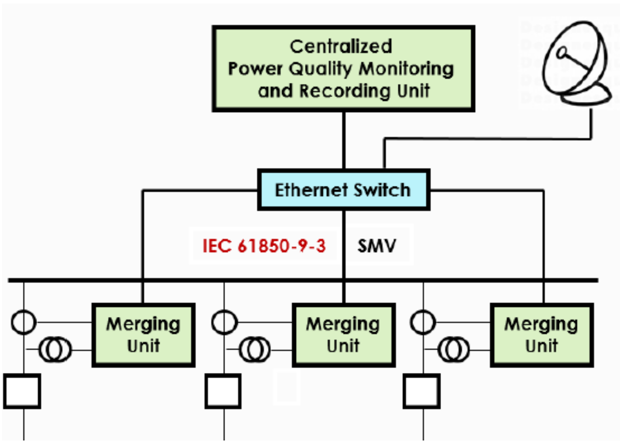

Fig. 35: *Merging units based hybrid system architecture [B4-1353(US)]*

In [B4-**1911**(ES)] the need to redefine EMC standardisation is discussed. Power spectral density limits for non-intentional emissions are analysed with respect to reliable NarrowBand Power Line Communications (NB-PLC). Use of NarrowBand PLC for Automated Metering Infrastructure is increasingly deployed worldwide. The authors investigate how the performance of the communications channel can be ensured. In these channels Non-Intentional Emissions (NIE) throughout low voltage grids represent the main adverse influence. In the last years various limits for compatibility levels have been studied in EMC standards. In this paper three curves proposed to derive compatibility levels have been evaluated. The results indicate that the proposed curves are not sufficient to allow the communications of all tested NB-PLC devices. The approach of traditional EMS standards is to establish peak and quasi-peak limitations, which are not enough to ensure the coexistence of NB-PLC communications devices with NIE sources. The authors conclude that NIE limits must define values for the total injected power in the bands of interest where telecommunication devices are involved.

Quality of Supply and Regulatory Issues

Quality of supply is a topic which is still receiving increasing attention. Several papers in this subsection address voltage dips as a major challenge for sensitive industrial processes. Assessment of industrial processes regarding process immunity time is complex as it has to take into account the different components and their connections. Several papers highlight the effects of voltage dips on industrial customers and propose methodologies to assess process immunity and deal with customer complaints. Continuity of supply has been involved in price regulation in many countries for several years. In comparison voltage events have been considered for regulation more recently and only few European countries have included voltage events into regulation so far. From a regulatory point of view EN 50160 is not comprehensive for voltage events and the amendment of further specifications is suggested.

Nine papers dealing with supply quality and regulatory issues have been summarized in this subsection including three papers from Brazil.

The authors of [B4-**0058**(CN)] propose the GANTT chart as tool to determine the PIT of industrial processes. PIT depends on the immunity of components and their connection. The GANTT chart can be used to describe the connection between the components and to determine the critical path. The immunity of components is modelled by an immunity time constant (ITC) corresponding to the duration of a subtask in the GANTT chart. PIT is then calculated taking into account the critical path and minimum cumulative time in the GANTT chart. The results of modelling by GANTT chart have been compared to measurements for the case of an escalator under different types of voltage dips.

In [B4-**0737**(IN)] a new approach of Power Quality assessment for key consumer installations is presented. Tata Power has begun to set up a Power Quality monitoring system in Mumbai by installing Power Quality meters on 110 kV, 22 kV and 11 kV bus sections of substations which feed key customers. Voltage dip events are monitored monthly and afterwards the reasons for these events are mapped. As about 34% of the faults are transients beyond the control of the interconnecting utility, a case study at three key customers has been conducted. After analysing the impact of dips on the customer installations, optimum network re-configuration of the Tata Power network and localised solutions at the customer sites to reduce the impact of grid disturbances on customers are analysed. A key mitigation measure resulting from this study on utility side is bus sectionalisation of the 110 kV system. As compensation equipment at grid level is too costly, this is addressed at local/consumer level. On the customer side the chosen mitigation measures are customer specific and include UPS and LV ride through for critical motor/variable frequency drive contactors. As result of this analysis recommendations to reduce the impact of dips at the customer premises involving utility and consumers are given.

Power Quality concerns of customers are also discussed in [B4-**0739**(IN)]. Tata Power Mumbai follows a methodology to address consumer concerns beyond the boundary of the meter. Key customers with Power Quality complaints that are not caused by Power Quality issues in the grid are identified for behind the meter services in terms of Power Quality assessment behind the meter. A process is started, through which the customer is supported to find the root cause of the problem, and receives recommendations for mitigating Power Quality concerns. The paper presents a case study for a company in the hospitality sector. The approach enables customers to understand Power Quality concerns within their premise and to engage in measures to mitigate the problem.

A thermal power plant is taken as research scenario for the influence of voltage dips on process parameters in [B4-**1389**(CN)]. The shutdown of thermal power units caused by voltage dips is increasing in China. Low voltage ride-through capability is insufficient for many auxiliary units in thermal power plants. Therefore, a case study for a thermal power plant has been conducted based on the concept of process immunity time (PIT). The effects of energy storage links and process time constants on process parameters during voltage dips are analysed. Appropriate energy compensation is used as mitigation measure to ensure, that the process does not break the lower limit. In case of the thermal power plant, compensation with a battery pack on the DC bus side has been found to be the most economical measure.

Frequent voltage dip events with a significant impact on the process lines of a petrochemical plant in Malaysia are investigated in [B4-**1796**(MY)] Tripping of AC contactors resulted in long downtime and high losses. The authors analyse, how the immunity levels of AC contactors evolve over time. The tests were conducted in 2014 and 2018 at the site and benchmarked against the Malaysian standard MS IEC 61000-4-11 voltage tolerance-curve. From the test results it is observed, that the equipment under tests does not comply with the MS IEC 61000-4-11 and that it is obviously a challenge for manufacturers to comply with existing Power Quality standards. Furthermore, three out of five contactors show weakening immunity levels after four years, two contactors show mixed results. Fig. 36 summarizes resulting immunity levels for 2014 and 2018. The authors recommend to industry to continuously evaluate contactor immunity at pre-determined periods to assess the performance over time. For the specific plant an ultra-capacitor based ride through protection scheme is proposed.

AC Contactor	2014 Immunity Level	2018 Immunity Level
C1	a) 50% for 20ms b) 60% for 1s	a) 55% for 1s
C2	a) 10% for 20ms b) 50% for 400ms c) 60% for 1s	a) 5% for 20ms b) 60% for 1s
C3	a) 40% for 20ms b) 60% for 1s	a) 70% for 1s
C4	a) 50% for 20ms b) 60% for 500ms c) 70% for 1s	a) 0% for 20ms b) 45% for 40ms c) 55% for 200ms d) 70% for 500ms e) 80% for 1s
C5	a) 65% for 1s	a) 70% for 1s

Fig. 36: *Summary of Immunity Levels [B4-1796(MY)]*

[B4-**0542**(CZ)] focusses on aspects of voltage event assessment to be considered in the context of voltage regulation. Long-term monitoring at 46 MV sites for the period from 2010 to 2017 has been analysed. About 8.5% of the dips are major voltage dips according to the indicative responsibility-sharing curve (cf. 5th CEER Benchmarking Report), whereas 75% of recorded voltage dips are transient dips with duration below 0.1 second. In the context of voltage quality regulation the impact of voltage dip assessment has to be considered and clear rules have to be set. This covers the effect of the time-aggregation interval, counting of event clusters and the choice of a reference voltage-tolerance curve to delimit major events. Because of the large number of transient dips the method used for dip sequence counting has a significant impact on the total number of voltage dips. Fig. 37 presents the effect of aggregation and removal of dip sequences in HV substations. In conclusion a clear definition of measurement method is required for voltage quality regulation.

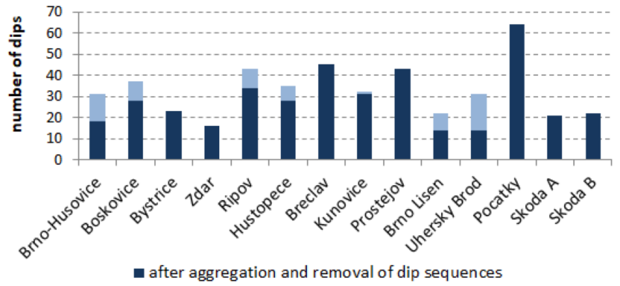

Fig. 37: Effect of aggregation and removal of dip sequences in HV substations (2015) [B4-0542(CZ)]

Three papers have been submitted, which discuss different aspects of Power Quality and regulation in Brazil from the viewpoint of regulator, distribution system operator and research institution. An evaluation of the regulation of continuity in Brazil had already been presented for CIRED 2017 in Glasgow.

[B4-**2072**(BR)] describes the regulatory mechanisms implemented in Brazil and their effects focussing on the incentives and penalty approaches to improve service quality related to continuity of power supply. The Brazilian Electricity Regulatory Agency (ANEEL) sets specific annual limits for average duration (DEC) and frequency (FEC) of outages similar to SAIDI and SAIFI. The limits are specific for consumers from a certain region. Fig. 38 highlights the development of DEC and FEC and the deviation from limits from 2001 to 2018. As average duration did not continuously improve as a response to regulation, new mechanisms were implemented form 2015 on. Selected distributors had to submit action plans aiming at improving poor continuity indicators. Additionally, the renewal of the concession contracts for a group of distributors was under the condition of new clauses focussing on the enhancement of service continuity. However, monitoring of the indicators is the basis for assessment of service quality and measures for its improvement.

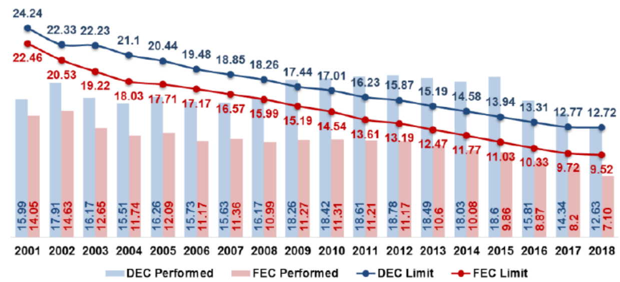

Fig. 38: DEC (hours) and FEC (number of outages) in Brazil (average from concession holders) [B4-2072(BR)]

In [B4-**2265**(BR)] the Brazilian regulation of reliability is discussed from the point of view of a network operator. The authors highlight the main mechanisms of regulation of supply quality and present a proposal for improvement. Two regulatory mechanisms are discussed. Firstly, the monetary reimbursement for customers, who are subject to interruptions above the established limits and secondly, the incentive or penalty of the regulator at the time of the distribution tariff definition related to the performance of the distribution company. Regarding the reimbursement scheme, the authors present a proposal for adequacy and a simulation of the effects. The current regulation is simplified and the average reimbursement value is increased by adopting maximum limits for duration (DMIC) of interruptions as parameters for a monthly reimbursement calculation.

[B4-**2145**(BR)] presents a new approach for the forecast of steady-state voltage problems. It has been observed, that simulations of power flow and consequently voltage levels are not sufficient for a good prediction of regions and customers where the steady-state voltage levels are not complying with limits. The Brazilian Electricity Regulatory Agency (ANEEL) defines the steady-state voltage limits and the distribution companies are obliged to carry out steady-state voltage measurements in a random sample of customers. Additionally, measurements have to be performed, if customers complain about voltage quality problems. Using the data collected during a measurement campaign for load curve for a random sample of customers, power flow calculations have been conducted. However, there are no measurements available along the distribution feeders or MV/LV transformers. The prediction of steady-state voltage problems could be improved by adding socio-economic data together with statistical and machine learning techniques.

Potential Scope of Discussion

The development in the grid is much faster, as in the past. New components like inverter based generation and electronic household equipment become relevant for Power Quality and entail new phenomena and compatibility issues. Regulation and standardisation have to keep up with this process in order to set an adequate framework for the co-ordination of all players and components in the electric grid.

The allocation of an adequate share of the compatibility level for voltage distortion to the customers and the determination of fair and justifiable limits for emissions already in the planning stage is one of the challenges to be addressed in the field of Power Quality. As power electronics are on the rise in generation and storage, these installations have to be involved in the allocation process. Further research topics are multi-harmonic source location and new indices as a basis for harmonic control schemes.

In recent years, current and voltage distortions in the range of 2 kHz to 150 kHz (supraharmonics) as well as rapid voltage changes (RVCs) are Power Quality parameters which have been of high interest regarding research. A standard measurement method for supraharmonics is still a research topic, which should be addressed. Furthermore, more research is needed to regarding the network harmonic impedance, in particular in the frequency range above 2 kHz.

Distribution grid operators face the challenge to apply smart monitoring systems in meaningful ways to optimize planning and operation of the grid. Comprehensive Power Quality monitoring with efficient data analytics will be a key element to enable optimal operation of the distribution grid while maintaining supply quality. Big data analytics and machine learning will play an important role in this process. The use of flexibilities in the grid is required by different players with different goals. However, as the electricity grid is the backbone of modern infrastructure, flexibilities will have to be allocated by regulators in a way to maintain and support the reliable and cost-efficient operation of the grid.

Paper No.	Title	MS p.m.	RIF	PS
0023	Power quality performances of Enexis grids – an overview			X
0058	Calculation of Process Immunity Time with Gantt Chart	X		X
0331	Comparisons of IEC/TR 61000-3-6 and IEEE Std 519 in the MV Systems			X
0366	Typical harmonic levels and spectra with low-voltage customers			X
0521	The experimental evaluation and monitoring for power quality status of inverter-driven air conditioners according to climate change			X
0538	Empirical measurements of Power Quality in Danish low voltage systems	X		X
0542	Voltage dip assessment in context of voltage quality regulation			X
0551	Methods for the Evaluation of New Power Quality Parameters: a Review of Rapid Voltage Changes and Supraharmonics			X
0635	Issues on the Application of Chinese Harmonic Standard GB/T 14549			X
0652	Long-term power quality measurements in medium voltage networks			X
0713	Determination the Switching State of Compensatory Equipment Based on Monitor Data Analysis			X
0724	Evaluation of Harmonic Impacts on Distribution Transformers in Mashhad Based on Smart Meter Data			X
0737	Power Quality Assessment of Key Consumer Installation - Interruption statistics of Grid Disturbances			X
0739	Deciphering Power Quality Concerns Of Consumer – Beyond the Meter			X
0744	Advanced Utilization of Big Data for Real-time Monitoring and Data Analytics	X		X
0902	Review on Harmonic Impact Assessment Indices and Methods of Multiple Harmonic Sources		X	X
1353	"Impact of IEC 61850 on Power Quality Monitoring and Recording			X
1389	Influence of Voltage Sag on Process Parameters and the Control Measures for a Process of Auxiliary Engine in Thermal Power Plant			X
1393	New challenges for the determination of emission limits for customer installations - Activities of CIGRE JWG C4.40/CIRED on the revision of IEC reports 61000-3-6, 61000-3-7, 61000-3-13, 61000-3-14			X
1398	Survey of network impedance in the frequency range 2-9 kHz in public low voltage networks in AT/CH/CZ/GE	X		X
1407	Suitability of test procedures in IEC 61000-3-2 for assessing harmonic emission of modern mass-market equipment	X		X
1574	Application aspects and measurement methods in the frequency range from 2 kHz to 150 kHz			X
1608	Large scale PQ, temperature and energy monitoring in secondary substations.			X
1796	Operation Effect to Voltage Sag Immunity Levels of AC Contactors at Petrochemical Plant in Pahang, Malaysia			X
1911	The Need to Redefine EMC Standardization: Power Spectral Density Limits of Non-Intentional Emissions for Reliable NB-PLC Communications	X		X
2072	Service Quality in the Brazilian Electricity Distribution Sector: Challenges, Regulatory Approaches and Results			X
2145	Forecast of steady-state voltage problems considering simulation and socio-environmental information			X
2265	Proposal to improve the Brazilian regulation on the electric energy reliability			X