Special Report - Session 2
POWER QUALITY AND ELECTROMAGNETIC COMPATIBILITY

Chairman Herwig RENNER
Austria
herwig.renner@tugraz.at

Special Rapporteur Jan DESMET
Belgium
janj.desmet@UGent.be

Special Rapporteur Britta HEIMBACH
Switzerland
britta.heimbach@ewz.ch

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 (voltage level, flicker, unbalance and harmonics). This session will also look at power quality system monitoring, electromagnetic compatibility, electromagnetic interferences and electric and magnetic fields issues. Also addressed in this session are electrical safety and immunity concerns.
The aim of this special report is to present a synthesis of the present concerns in PQ and EMC, based on all selected papers of session 2 (107 papers) and related papers from other sessions, (16 papers). The report is divided in the following 4 blocks:

Block 1: Electric and magnetic fields, safety and interference
Block 2: Power quality issues of distributed generation and EV
Block 3: Power quality measurement, analysis and mitigation methods
Block 4: Power quality system monitoring, data mining, economic and regulatory issues

Especially for block 2 and 3 an unambiguous allocation of the contributions is not possible and topical overlapping may appear to some extent. Block 2 is organised according to the type of equipment while block 3 is segmented with respect to power quality phenomena.

One **Round Table** will be organised within session 2:
"Power Quality Aspects of Solar Power (RT 12)", presenting results from the CIGRE working group C4/C6.29.
The **Research and Innovation Forum** is dedicated to supra-harmonics.

Block 1: "Electric and magnetic fields, safety and interference"

Electric and Magnetic Field with Mains Frequency

In this sub block, results from electric and magnetic field measurement and simulation are presented.

In [B1-0092(EG)] measurements have revealed that the electric and magnetic field emission levels of dry type distribution transformers exceed those of oil insulated transformers. A rather unexpected correlation between electric field emission and loading of the transformer is observed but not explained in the paper. A relationship between measured magnetic and electrical field and load balance for distribution transformers is presented in [B1-0237(EG)]. There is a clear reduction of the intensity of the magnetic field down to approximately a third after measures which were decreasing unbalance and improving the quality of the ground system.

Two papers present measurement campaigns in substations and close to power lines. Results from Brazil [B1-1254(BR)] show that, for general public exposure, the power system assets in the country were in compliance with ICNIRP reference levels (4,17kV/m, 200 µT @60 Hz) in more than 98% of the facilities where measurements and calculations were performed (more than 3800 measurements at power lines, more than 2000 measurements in substations). However, in case of occupational exposure by the electric field more than 10% of the power lines and substations were found to exceed the reference levels of ICNIRP (8,33 kV/m @60 Hz. On the other hand, only 4 out of 1798 substation measurements revealed a violation of the occupational magnetic field limit. Evaluation in Serbia [B1-1292(RS)] is made on directive 2013/35/EU.

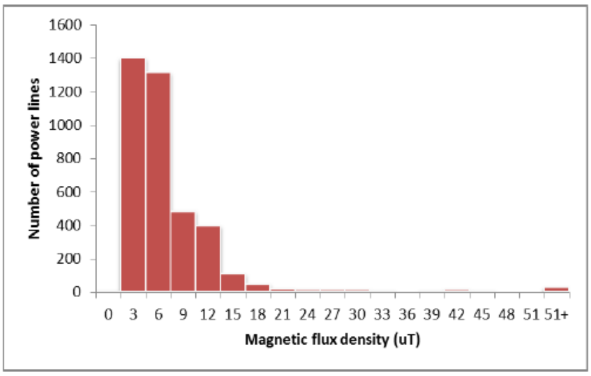


Fig. 1: Magnetic fields frequency distribution (general public exposure) in power lines [B1-1254(BR)]

The directive defines 'action levels' as operational levels established for the purpose of simplifying the process of demonstrating the compliance with relevant exposure limit values. Based on measurements in different 110kV/MV substations, it can be concluded that the occupational electric field exposure is lower than the action levels of 10 kV/m. Measured values of magnetic flux density as well as extrapolated maximum values at rated load, are significantly lower than the low action levels of 1000µT.

In the following three contributions, shielding of magnetic fields is discussed. In [B1-0487(IT)] a new concept of multilayer shield proposed. The innovation is related to the reduction of the local magnetic flux leakage in the interface area among neighboured plates. The multilayer plates are made of aluminium and grain oriented electrical steel. Especially for tangential field component the shielding factor is significantly improved by factor 2. Paper [B1-1029(IT)] deals with the problem of non-completely closed shields. Usually open shields are fixed on the separation walls between sources and sensitive installations inside the substation or inside the room to be protected. The obtained results show the capability of open shields to get the required performance using flaps to provide a reduction of the local field increase due to edge effects. A case study to improve shielding is presented in [B1-1230(IT)]. Measurements after installation of a simple shield have shown a reduction of field level in a bedroom above a substation. However, extrapolation from actual to rated load resulted in levels above 4 µT. Therefore, the authors proposed an optimized, complex shape instead of simple plane metal sheet.

High frequency Electric and Magnetic Field

In 1998 ICNIRP published guidelines providing reference values for the frequency range from 1 Hz up to 10 MHz to protect against stimulation of sensory cells and nerves from induced currents. Modern power electronic devices providing high efficiency are operating circuits in the frequency-range of some ten kHz. PLC based smart metering systems in Europe are typically operated according to EN 50065-1 in the CENELEC-A band (9-95 kHz). In future the communication will probably be extended to a higher frequency range, i.e. the FCC band (154-500 kHz).

Emission of a smart meter using G1 PLC and G3 PLC is investigated in [B1-0152(FR)]. The electromagnetic field levels are quite constant for a given distance to the cable and decrease as the square of the distance. At 10cm, the maximum value of electric field is 3.3V/m and the maximum value of magnetic induction is 99nT, corresponding respectively to 3.8% and 1.6% of the reference levels of the European recommendation. Similar measurements were performed by the authors of [B1-0166(BE)]. Close to an overhead bundle preassembled cable and a non-insulated line carrying G3-PLC smart meter signals, the magnetic field produced is well below the lower limits (5 and 1.5 A/m in the CENELEC-A and FCC-2 bands respectively) of the European Council recommendation 1999/519/CE.

The assessment of EMF-exposure caused by PLC-signals is discussed in [B1-0595(AT)]. Application of the weighted peak method as calculations simply summing the weighted spectrum components are resulting in ten-fold higher exposure quotients. The relevance of EMF-exposure from smart metering signals is almost negligible as the exposure quotient is typical below 0.1% for magnetic field and 0.3% for electric field. Both levels are significantly lower than 10% of very low level domestic exposure.

It can be concluded that the electric and magnetic field exposure in the immediate vicinity of a smart using PLC technology and power cables will hardly produce problems.

Paper Field [B1-1285(CH)] deals with possible of PV inverters and PLC. A method is presented to assess interferences with the help of frequency scans of equivalent circuits modelling LV grid components, active infeed converters and loads. The proposed method was successfully evaluated on the basis of simulations and measurements realised on a simple laboratory setup. The results put emphasis on the role played by inverter EMC filter in PLC signal attenuation. Further investigations based on the developed methodology will be realised together with the DSO and the smart grid equipment supplier, in order to evaluate more advanced PLC modulation schemes and targeted EMC filtering.

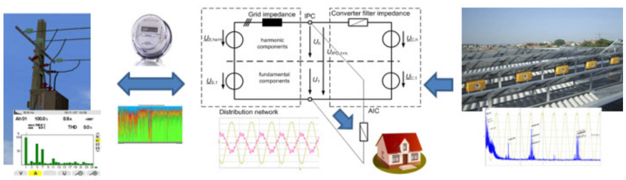


Fig. 2: Case study EM Interferences between PLC and DEG

Mains Frequency Interference

Several ways of interference (inductive, conductive and capacitive) are in the focus of paper [B1-0433(EG)]. The influence of the soil resistance as important parameter for inductive interference is highlighted.

In this paper [B1-1294(HR)] guidelines are given for assessing the risk of electrocution due to influenced or induced voltages. A study case is presented for the impact of a double circuit 220 kV line on a parallel 20 kV overhead line. The results from calculation and measurement are presented. The measured capacitive coupled voltage reached a value of 820 V while in the simulation a value of 5680 V was reached. An explanation for the difference is not provided. The magnetically induced voltage is rather low with 13.8 V simulated and 15.8 V measured. In addition to the assessment of risk, additional safety and security measures at work are given to prevent the risk and the negative impact of a close parallel line. [B1-1297(BR)] evaluates the effect of the electromagnetic coupling between a conventional 69 kV line and a compact overhead distribution line rated 11.4 kV sharing the same structures. Simulations were performed considering steady state conditions, the occurrence of faults on the high-voltage line and transmission line energization. The electromagnetic coupling between the lines can cause high transient overvoltages in the distribution line requiring measures to ensure safety to costumers' devices and maintenance staff. The installation of properly selected surge protective devices on the low voltage line can limit the overvoltages caused by short-circuits and transmission line energization. In [B1-1303(BR)] the calculated transient overvoltages of the previous paper are analysed by means of FEM. The simulations show that electrical stresses occur on covered cables in the distribution lines, at the interface with the spacer and along all low voltage cables.

Earthing systems

The main objective of an earthing grid evaluation and design work is to ensure the safety of people in a substation and its surroundings against electrocution in non-live areas. This is closely related to earth resistance and global earthing systems (GES) as defined in BS EN 50522 (interconnected underground cable shields, conducting grounded installations and earthing systems which resemble a global earthing system). In current design guidelines, connections between earthing systems of different substations by cable shields are not always taken into account.

Calculations and measurements presented in [S3-0295(FI)] show that the resulting impedance was typically 50-80% lower than the secondary substations' individual earthing resistances. This means that there is great potential for savings in the earthing network without risking the safety. Results from earth resistance measurements are presented in [B1-0299(UK)]. They have analysed a sample of twenty case study sites. For each substation earth impedance was calculated, using a simplified approach based on the conservative assumption that only a single cable is providing a contribution. However, the corresponding measured values were significantly lower. A novel calculation method is proposed which uses the minimum impedance provided by a network. It's based on the concept of effective length of a single cable, extended to a complete area. Comparison of the earth impedance calculated from the effective area method with measured values from the twenty test sites indicates that the method may provide a reasonable and generally conservative prediction of the network earth impedance contribution. The approach may be optimistic at substations which are part of a modern polymeric cable network. Further calculations based on a sparse network have been made which appear to be more applicable to semi-rural networks.

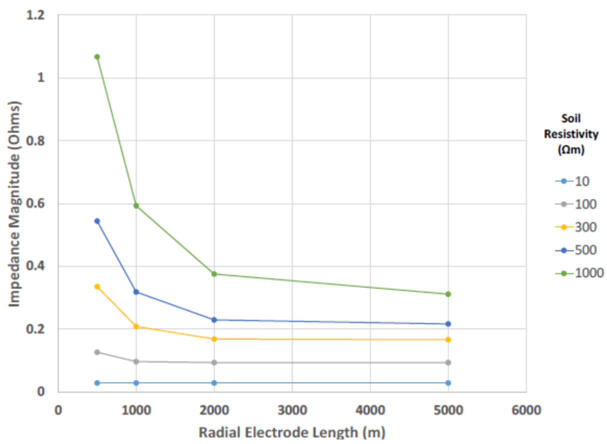


Fig. 1: Calculated Earth Impedance Magnitude for Cable Network Approximation [B1-0299(UK)]

A validation of their developed methodology of simulating grounding systems is presented by the authors of [B1-0452(PT)]. Generally a good correlation between measured and simulated grounding potential rise for 6 investigated sub stations was found. Only one substation presented a significant error (>10%) in the simulated grounding impedance. Further analysis shows that no significant difference exists between the results for the substations that had their soil model designed using multiple 1D Wenner profiles or the ones with the more complex 2D/3D geo-electrical survey. However, a critical point in the comparison is the accuracy of the measurement.

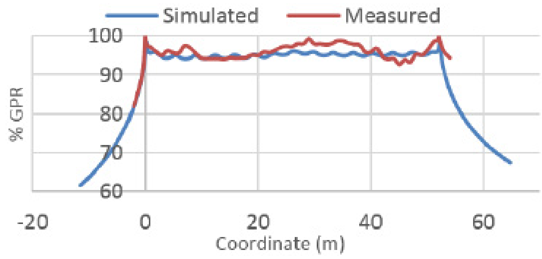


Fig. 2: Case study 1: Substation E [B1-0452(PT)]

A comparison of a simple, analytical approach and a FEM simulation of multi-layered soil is presented in [S1-1108(CZ). From the overall results, it may be said that the first approach in most cases will lead to an overestimation of the earthing resistance. However, in the case that the upper layer has a better conductivity than the lower layer, the simplified approach may lead to an underestimation with an increased potential safety hazard.

In paper [B1-1261(NL)] a comprehensive overview on LV earthing configurations and the relevant Dutch standards is given. From the discussion of the paper it can be concluded that TN earthing system provides a safer earth route than TT configuration. In TT system, customer needs to install an earth electrode and should check its functionality regularly while in a TN system the network operator is responsible for an adequate earthing system. In case the customer's installation fulfils the standard guidelines, the network operator must guarantee that the installation is safe too against any external network fault. As a consequence the network operator should conduct periodic control checks at different network connection points to estimate the change of circuit impedance that might occur because of network modifications. Also, proper remedy measures should be taken if the circuit impedance is found higher than 0.5 ohm. According to the contributions it can be stated, that the modern methods used for simulation and design of grounding systems meet the requirements generally good.

A statistical approach for risk estimation is introduced in [B1-1065(AU)]. Electrocution due to indirect contact with metalwork during earth fault events is a low-probability high-consequence risk scenario. A cursory examination of the efficacy of past earthing practices would have difficulty discerning if an adequate level of safety has been achieved for workers and the public. The probability of fatality due to indirect contact with a fault voltage may be expressed by the product of the probability of ventricular fibrillation (depending on touch voltage, series resistance, …) and the probability that a person will be present and in contact with an item at the same time that the item is affected by a fault. The paper demonstrates how earthing related shock risk quantification supports the design process and is able to provide objective yet defensible design criteria and their range of applicability. The joint CIGRE/CIRED working group B3.35 is currently investigating the topic and will give recommendations for incorporating probabilistic risk analysis in international earthing standards.

The importance to take into account the correct impedance of grounding transformers in isolated or partially compensated MV grids is highlighted in [B1-0653(HR)]. In the investigated study case the grounding transformer causes a reduction of resistive and inductive current. This can lead to unreliable relay protection. Under certain conditions, the harmonics content in the earth fault current can lead to a violation of the upper limits of residual current and touch voltage.

The authors of [B1-1062(DE)] present a method to determine the residual earth fault current in A MV system in case of a single phase earth fault by using the voltages (incl. harmonics) measured in the faultless network. It is shown that harmonic current sources $I_{S(\nu)}$ have to be used to include the influence of the feeding HV network. Discrepancies result from the imprecision of the input parameters and from the simplification of influencing factors. Series resonances with a frequency close to characteristic harmonics can lead to significantly increased residual earth fault currents. Thus fault location and fault impedance have a crucial influence. A distant earth fault can lead to a shift of the resonances of the network impedance and cause certain harmonics in the residual earth fault current to either rise or fall. The same authors provide a practical application of their method in [S3-0564(AT)].

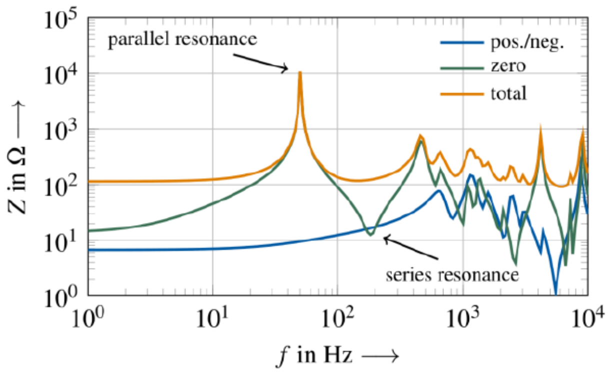


Fig. 3: Frequency dependent network impedance for positive/ negative and zero sequence system and the total impedance as seen from the voltage source U_q of an exemplary network [B1-1062(DE)]

Two contributions deal with lightning. Paper [B1-1005(PT)] analyses the transient behaviour of a pole mounted MV/LV transformer regarding lightning strikes in MV and the LV distribution networks. The effect of surge arresters installed at the terminals of the transformer was analysed with the help of transient simulations. The results indicate that ZnO arresters installed at the MV terminals of are only effective in protecting the MV windings against lightning strikes in the MV distribution network, leaving the LV windings unprotected. As a consequence the installation of surge arresters at the LV terminal is recommended. The effect of indirect lightning strikes on MV lines is investigated in paper [B1-1352(IR)]. Based on results of measured soil resistivity in different parts of the feeder, simulation within the measured conductivity of the earth in the values of 0.01 and 0.001 were performed. The results show that an increased earth resistance significantly increases the induced over-voltages

Potential scope of discussion

The topic of electric and magnetic fields seems to stagnate in the recent years. Standards for public and occupational exposure are obviously accepted and monitoring campaigns indicate that limits are not exceeded in a large majority of cases. However, for special situations (close vicinity of power installation or poor substation design) mitigation measures are necessary. Economical and technical evaluation and comparison of passive shielding methods and active shielding (active field compensation) would be helpful to support engineers in that situation.

In the area of earthing simulation significant improvements have been achieved during the last years, documented in CIRED contribution to session 2. Nevertheless, some measurement results indicate that in some cases safety requirements are exceeded, probably at the expense of investment costs. With regard to this point, also the probabilistic approach as presented by CIGRE/CIRED working group B3.35 could be a solution, which probably has to be researched further to be widely accepted.

Table 1: Papers of Block 1 assigned to the Session

Paper No. Title		MS a.m.	RIF	PS	other sessions
0092:	Comparison between Magnetic and Electric Fields Levels due to the Operation of Dry and Oil Distribution Transformers			X	
0152:	Electromagnetic Field Level in the Immediate Vicinity of a Linky Meter			X	
0166:	Exposure to the Electromagnetic Fields Generated by Power Lines Carrying Smart Metering RF Signals			X	
0237:	The Effect of Unbalanced Loads in Distribution Transformers and Ground Network on Electric and Magnetic Fields			X	
0295	Earthing Systems Connected via Metallic Screens of the 20 kV Underground Cables in Non-Urban Areas				S3
0299:	Estimation of Substation Earth Impedance in a Global Earthing System			X	
0433:	Electromagnetic AC Interface Between High Voltage Overhead Lines and Pipelines Sharing The Same Corridor			X	
0452:	Validation of an Integrated Methodology for Design of Grounding Systems through Field Measurements	X		X	
0487:	Multilayer Magnetic Shielding: an Innovative Overlapping Structure			X	
0564	Why does the Earth Fault Detection Method based on 3rd Harmonic work in Large Meshed 110-kV-Networks				S3
0595:	Assessment of EMF-Exposure in residential buildings caused by smart metering systems using PLC	X		X	
0653:	The Influence of Grounding Transformer on Ground Fault Current in MV Networks			X	
1005:	Using Low Voltage Surge Protection Devices for Lightning Protection of 15/0.4 kV Pole Mounted Distribution Transformers			X	
1029:	High Performance Magnetic Shielding Solution for ELF Sources	X		X	
1062:	New Model for the calculation of Harmonics in the Residual Earth Fault Current of Medium Voltage Systems	X		X	
1065:	Making Risk Based Earthing Design Accessible and Effective.	X		X	
1108	Sensitivity Analysis of Earthing System Impedance for Single and Multilayered Soil				S1
1230:	Magnetic Field in an Apartment Located above 10/0.4 kV Substation: Levels and Mitigation Techniques			X	
1254:	Electric and Magnetic Fields from Power Grids in Brazil: Regulation and Monitoring			X	
1261:	Ensuring Public Safety Through Proper Earthing In Low Voltage Networks			X	
1285:	Electromagnetic Interferences in Smart Grid Applications: a case study of PLC Smart Meters with PV Energy Generation	X		X	
1292:	Levels of Electric and Magnetic Fields inside 110/X kV Substations			X	
1294	Hazards and Protective Measures at Work on 20 kV Line in Close Vicinity to Parallel 220 kV Line			X	
1297:	Assessment of the Electromagnetic Coupling Between Lines of Different Voltages Sharing the Same Structures			X	
1303:	Analysis of Magnetic Coupling Lines with Shared Structure Using Technique of Finite Elements			X	
1352.	Investigation of Lossy Ground in Lightning Induced Overvoltage at Presence of Surge Arresters in CST Software			X	

BLOCK 2: Power quality issues of distributed generation and Electric Vehicles

Photovoltaics

The increasing use of solar power connected to the public grid and the associated concern for deteriorating power quality triggered the formation of a joint working group with the aim to describe and quantify this impact. Contribution [B2-0351(US)] gives an overview of findings, recommendations and open issues of the most important PQ related aspects. This contribution is given by the joint working group C4/C6.29 “Power quality aspects of solar power”, formed to examine the power quality aspects of solar power. During the last 4 years this working group has studied, analyzed and discussed the impact of such PV installations on low, medium and high voltage networks with respect to power quality. As a conclusion, the connection of PV installations will have a potential impact on the voltage and current quality in the grid. Key findings from each of the power quality phenomena have been summarized here. For each of the disturbances, the emission by PV installations is characterized, as much as possible, based on existing installations. A decision about possible negative impacts can be made most likely only on a case by case basis. The CIGRE survey of utilities experiences with respect to PQ related issues for PV installations, performed by the above mentioned working group, is given in contribution [B2 – 0456(DE)]. Due to the huge increase in the amount of solar power connected to the networks last decade in many countries of the world such a survey is needed to increase the insight into PQ related problems. This trend is expected to continue and even grow during the coming years. Different concerns have been raised with the connection of solar power, especially their potential impact on the voltage and current quality. It is recommended to intensify the monitoring of PV installations in order to obtain sufficient information for a reliable assessment of its impact on PQ. A round table discussion during the CIRED conference is dedicated to the results of the mentioned working group.

Paper [B2-0002(IR)] describes the emission and immunity of the harmonics in the frequency range of 2-150 kHz resulting from the switching frequency of the static convertor of a 100 kW solar power plant connected to the distribution network through a low voltage feeder. Six harmonic measurement devices are located in each bus. In order to ensure the maximum power extraction in the solar power plant, the increased conductivity algorithm has been used. The simulation is done in Simulink/Matlab software and the results show that in the optimum witching frequency the spread of supra-harmonics was in the frequency range of 2-20 kHz with a large amplitude around 20 kHz (switching frequency). The spread of supra-harmonics up to 150 kHz was neglect able.

In paper [B2–0357(SE)] the negative-sequence voltage unbalance for increasing numbers of single-phase photovoltaic inverters connected to low-voltage distribution networks is calculated on a very comprehensive way using the transfer impedance matrix. Moreover, a stochastic method is applied to estimate the voltage unbalance. The method has been applied to a 6 and 28-customer network for the connection of 6 kW single-phase PV installations. Next to that also the hosting capacity for each network has also been estimated. It is observed that it is likely that with the connection of PV installations the voltage unbalance (Fig. 5) will reach 1% when they are connected randomly, but the probability of exceeding the limit of 2% is low. It is also shown that the simplified approach used here, calculating the transfer impedance matrix using a commercial power-system analysis package, can provide useful information for making investment decisions by network operators.

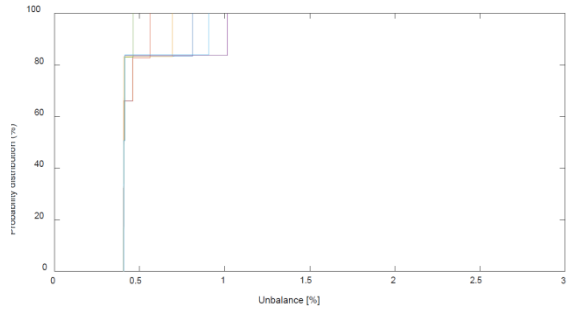


Fig. 4: Probability distribution function of the voltage unbalance for one PV installation at random busbars and phases in a 6-customer network; the different colors refer to different customers [B2 – 0357(SE)]

In the paper [B2-0492(EG)] the flicker behaviour in Egyptian distribution networks, caused by PV systems is discussed. Due to the increasing penetration of PV systems in the electric network, power quality is becoming of crucial importance for the further deployment of renewable generation. The irregular solar radiation is considered to be one of the main drawbacks of the large-scale application of photovoltaics in distribution networks. Especially in case of (fast) moving clouds, short irradiance fluctuations, which can produce voltage fluctuations in power networks, will occur. A distribution network with more than 600 kW of PV installations with different capacities is observed. Measurements were carried out at the point of common coupling to determine the effect of PVs on distribution networks and comparing the results with the technical requirements for connecting PV systems to low voltage distribution networks.

A control strategy for reactive power and harmonic compensation for PV systems is demonstrated in [B2-1009(IR)]. In order to analyse this concept, an equivalent electric model presented in the literature is used to implement the photovoltaic system. The photovoltaic system is connected to the power grid with a DC/DC step-up converter and DC/AC full-bridge inverter. The equivalent model including nine panels connected in series constitutes the implemented photovoltaic system. In non-linear loads, low-frequency synchronous reference frame methods cannot eliminate higher order harmonics which appear in the grid current. In this study, it is proven using a mathematical analytical approach to compensate reactive power and eliminate current harmonic of a non-linear load with active power injection. Simulation results are presented in order to verify the suggested control approach and the system feasibility.

In paper [B2-0078(BE)], a study of the control-command process of a photovoltaic conversion chain in order to evaluate its impact on the power line channel transfer function using MatLab/Simulink has been proposed. In order to test the efficiency of the photovoltaic array modelling based on the single diode model, a comparison between simulations and measurement is realized (Fig. 4).

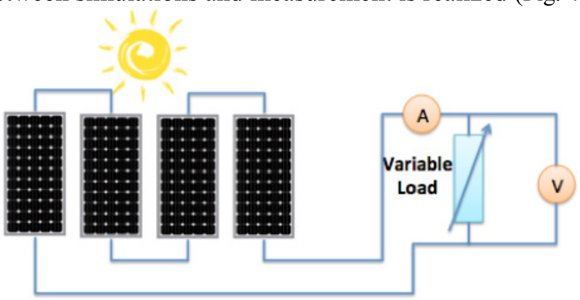


Fig. 5: Measurement setup used for the validation of the PV array modelling [B2-0078(BE)]

The input impedance of the chain obtained in both cases has been used to study its impact on the powerline of a realistic distribution network topology. It has been observed that the mechanism of control-command leads to more important variations in the shape of the impedance and induce more peaks and drops in the shape of the transfer function in comparison with the simulations without control-command procedure. It is shown that this is an important observation because, in a context of data communication, these variations change the PLC communication performance and can cause trouble during the transfer of data.

The intermittency and unpredictability of PV leads to new challenges to the electricity distribution network service providers, as described in paper [B2-0132(EG)]. The demand for a solution to the electricity shortage lead to an increased number of grid connected PV. However, the distribution networks suffer through PV inverters since they are potentially able to cause harmonic problems. Measurement campaigns are performed to show the impact of the harmonic distortion in the network before and after the installation of PV systems also to assure there is a match with the IEC standard. Moreover the influence of temperature variations on the output power of PV installation was monitored under the climatic condition in upper Egypt and is discussed. This paper shows the effect of temperature on the monthly and yearly yield by PV.

Windfarms

In [B2-0045(IR)] a back to back converter of a wind unit connected to the low voltage network were simulated using real time Matlab/Simulink with respect to stability. Results show that the wind power plant causes the frequency oscillations of approx. 0.02 Hz. However the distortion of network voltage increases, but stays within the permitted limit determined in the IEC and IEEE standards. The noise in the voltage waveform is very high and cannot be overlooked.

In [B2-0097(EG)] the integration of large-scale wind turbine generators on static VAR compensators is discussed. They may have significant impacts on power system operation such as system frequency, voltage profile, stability and reliability. This paper studies the stability and since with reactive power compensation, the integration of wind farms based on induction generators may lead to the voltage collapse in the system. It is shown that dynamic reactive power compensation at the point of common coupling is successful in maintaining the system voltage at acceptable level and increases stability of the system.

Paper [B2-0241(CZ)] summarizes the results of short-term voltage quality measurements in medium voltage distribution grids of the MV wind power plants and were in compliance with the standard EN 50 160. The measurements were made in grids on supply territory of the utility E.ON Czech Republic in the years 2013 to 2016. It is shown that the operation of wind farms has an impact on voltage changes as well as flicker severity, but the effect of individual wind farms is different. Power flows of individual wind power plants were also evaluated and mutually compared to find the pattern of their performance in various year seasons and in a larger extent in delivery points at the end of long MV feeders. As expected, power production varies greatly during a year. Maximum active power flows closely coincides with maximum reactive power flows.

By the help of the vector analysis, paper [B2-0191(CN)] studied the impact of voltage sag with different characteristics of grid voltage sag events including magnitude, deration, phase angle jump and varying phase point on wave on the rotor over-voltage of the double fed induction generator (DFIG) of a wind generator using the stator flux analysis.

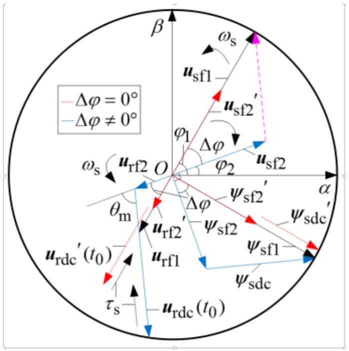


Fig. 6 Space vector diagram of DFIG with phase angle jump [B2-0191(CN)]

This is required to have low voltage ride-through capability during sag event to maintain power system stability. The influence principle of phase angle jump with varying point on wave is presented (Fig. 6). It is shown that vector analysis method is a good approach to relate voltage sag features, stator flux and rotor voltage for symmetrical and unsymmetrical voltage sags. Considering the practical constraints of phase angle jump, the general variation rules of DFIG rotor over-voltage caused by phase angle jump with varying point on wave in voltages sag are validated by simulation.

Several papers deal with harmonic emission of windparks. In paper [B2-0227(BE)] harmonic computations for four different configurations of wind turbines are presented. The paper is focused on small wind turbines (<100 kW) and their impact on the LV distribution grid, with respect to harmonics. A throughout discussion of the models developed to study by simulation the disturbances produced by small wind turbines is presented. In a second part, due to the power converters chain, harmonics will be found on the grid side and discussed. Since there are three different sources of harmonics observed, a deeper insight is given. Finally the paper presents several simulation results. These simulations study the impact of the active power on the level of disturbances.

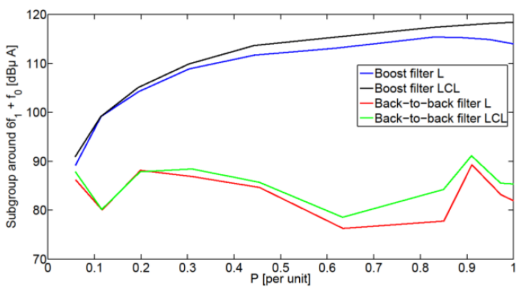
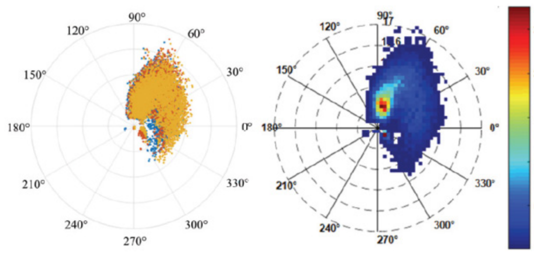


Fig. 7 Quadratic sum of the current interharmonics around $6f_1 + f_0$ in function of the active power [B2-0227(BE)]

The level of disturbances seems to increase with the active power for the harmonics around the switching frequency of the inverter and for the interharmonics linked to the rotor speed while it decreases for higher order harmonics. All results presented in this paper are based on models which should be checked through experiments on a real grid.

The main objective of paper [B2–0457(DE)] is to give a detailed and comprehensive characterization of the harmonic currents within a typical wind park installation. Especially their impact on the voltage harmonics at the connection point with the grid is investigated. The wind park, consisting of 6 similar type 4 turbines with a total rated power of 12 MW, is connected to a 110kV/20kV substation via a 10km MV cable. Both, a long-term measurement of almost 2 months in order to monitor the typical behaviour of harmonics under uninfluenced conditions, and a short-term measurement where turbines have been switched and controlled according to a defined schedule were made. In addition transient analysis was performed for acquiring raw waveform data during the short-term measurements. In the course of the same measurement campaign the performance of the windfarm with type 4 wind turbines has been tested for frequency and voltage control [S4-0731(DE)]. Through reduction of the active power in the case of over frequency, the windfarm could contribute to system stability, whereas the voltage level in the surrounding grid can be stabilized by voltage dependent control of the reactive power of the windfarm. This contribution will be presented in session 4.



$PR^{(7)} = 0.87$; $\varphi^{(7)} = 58.1$

Fig. 8: Example of the prevailing phase angle and ratio for the 7th harmonic of a wind turbine in the test set-up [B2–0457(DE)]

All wind turbines behave similar, but differ partly to the distortion current values provided by the manufacturer. This conclusion also confirms that there are some location specific conditions, particularly frequency dependent grid impedance components.

In paper [B2-0927(DE)] a standard passive harmonic scheme is proposed for majority of wind farm connections. The design of harmonic filters required for harmonic voltage compliance depends on the characteristics of the network, which are usually not exactly known and are subject to uncertainties. Network conditions may change considerably from those that a harmonic filter was originally designed for. Four steps were considered: Establish extent of issue, data clustering (also see Fig. 9), filter optimization and filter selection.

The solution discussed includes connections of C-type harmonic filters at the 33 and 132kV voltage levels. This study demonstrated that a standardized harmonic filter scheme could be considered at a very early stage when a connection offer is made to a wind farm developer. In this way, all the costs and risks associated with power quality requirements can be considered and evaluated at early stage of wind farm construction.

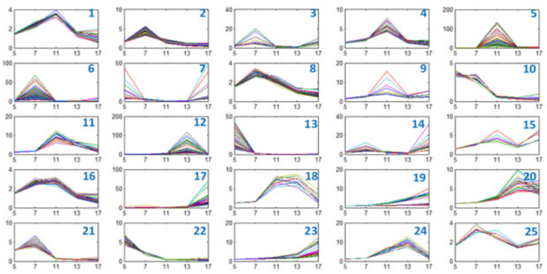


Fig. 9: Network clusters. X Axis: Harmonic order and YAxis: HDGF [B2-0927(DE)]

The harmonic emission and immunity in the frequency range (2-150 KHz) resulting from a full power frequency converter of a wind turbine as described in [B2-0047(IR)] is analysed in the presence of capacitor banks. The current distortion of the capacitor exceeds the limits of the standard. The maximum generated supra-harmonics value can be observed in the frequency of 3500 Hz and 6750 Hz. The harmonics will cause the severe heating of the capacitor bank.

A wind farm based consisting of double fed induction machines has been simulated and analysed in [B2-0058(EG)] using Matlab/Simulink environment. Two-level PWM for both grid side and motor side convertors produce rather high distortion of the grid current and voltage while three-level space vector modulation techniques for the same convertors result in reduced THD values at all operating points. The harmonic content decreases by changing switching techniques and converter topologies. Even at over speed the THD of grid current decreases under all conditions. This is roughly a 60% decrease in grid current harmonics and 64% decrease in grid voltage harmonics.

Electric Vehicles

The paper [B2-0834(DE)] presents the results of detailed in-situ measurements of electric vehicle charging processes at a common connection point. The measurements used a newly developed power quality meter, which records every power quality index value and all harmonics of voltage and current up to 150 kHz in 10-cycle averages. Through an examination of the volatility of the current and current harmonics of electric vehicles, a recommendation for 10-second averaging intervals is established (Fig. 10). Regarding higher frequency current harmonics, no significant content is measurable beyond 50 kHz. Finally, an estimation for the resulting data sizes is given when different averaging intervals and other aggregations are applied.

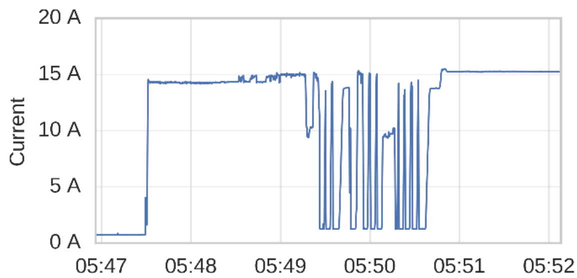


Fig. 10 Start of a charging process (Friday morning) in 10-cycle averages [B2-0834(DE)]

The increase of distributed energy resources (DER), distributed storage, flexible load and plug-in-electrical vehicles (PEVs) brings distribution systems opportunities and challenges. Paper [B2-0285(BR)] presents a methodology developed for dynamic setting changing of distribution voltage regulators under normal operating conditions or in reconfigurations that allows the quickly mode adjust of operation of the drivers for different operating conditions. Uncontrolled charging may occur coincidentally with the peak hours while the photovoltaic and wind generation may occur coincidentally with the off-peak hours and will affect or even deteriorate the operation performance of distribution systems dramatically. Step voltage regulators (VR) need to have their settings previously evaluated for these different operating conditions. In a system with little ability to manoeuvre or charge transfer, the AHVC method, basically, operates in the improvement of voltage levels according to the seasonality of load and the different load levels that occur during the day. However for systems with more possibilities for transfer of loads between feeders, these configuration changes are perceived by the SCADA system, by monitoring key and the change in the load profile of the regulators. If the equipment is not prepared for an operation in reverse flow, the adjustment mechanism can take control of the regulator, maintaining a range of appropriate regulation without violating the constraints. The presented control who is developed can be embedded in an intelligent control system that will be part of a so-called "intelligent voltage regulator".

A decent charging station network coverage has been identified in paper [B2-1074(NL)] as the essential enabler for the adoption of plug in hybrid vehicles. Therefore, the availability of ultra-fast charging stations is not only a technical prerequisite but also a key enabler for the consumer acceptance to bring electric mobility to the next level. This article introduces an advanced converter harmonic model that can be used to study harmonic resonance when the ultra-fast charging station is connected to the medium voltage (MV) grid. A small demonstration network is created to verify the effectiveness of the converter harmonic model in the harmonic resonance interaction study compared with the traditional ideal current source model approach. A case study is performed on the Dutch Bronsbergen MV grid when an ultra-fast charging station is connected. The harmonic resonance is calculated with both the ideal current source model and the converter harmonic model. This contribution highlights the risk of harmonic resonance when a voltage source converter such as used for the ultra-fast charging station is introduced in a MV grid. The advanced converter harmonic model delivers the required level of insight for the distribution network operators (DNOs) when it comes to large scale integration of EV chargers in the future.

Grid interaction and hosting capacity

Paper [B2-0076(FR)] describes different nonlinear load modelling approaches in force for power quality assessment. For harmonic issues caused by conventional disturbance sources based on thyristor power electronic installations, the equivalent multi-frequency current source method can be used. However, for supra harmonic issues and disturbances (f > 2 kHz) caused by new inverter technologies, it is recommended to use time and frequency hybrid simulation with embedded local time domain models for main nonlinear devices. The described model well reproduce disturbance spectra and represent the disturbance interaction among different sources. The simulation in the case study verified the on-site observation as well as identified one of the potential HF disturbance magnifications which may be further deteriorated by aging issues of customer appliances. In Fig. 11, input currents of the charger (a) (b) are near the results obtained from equivalent current source modelling method (with or without the PV inverter), and curves (c) (d) from proposed local time domain model. The equivalent current source method leads to important errors.

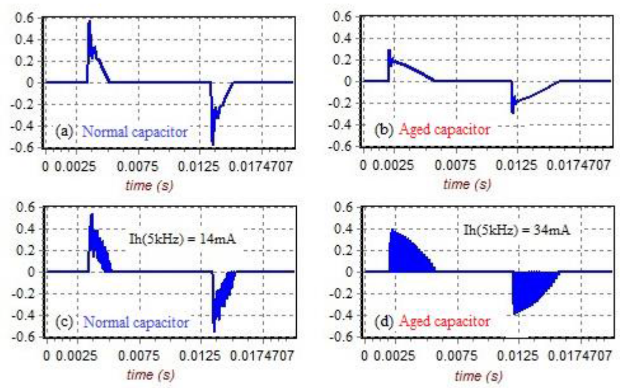


Fig. 11: Charger input currents in A simulated with local time domain models for different working states [B2-0076(FR)]

The paper [B2-0178(SE)] proposes a comprehensive set of performance indicators, such as voltage variations, overvoltages, harmonics etc. that should be used when evaluating the hosting capacity of a system. Descriptions are given for the most relevant phenomena and how they should be quantified and measured. The suggested time resolution for the data has been 1 hour, 10 min and 3 s, based on what is available already in standard meters. The use of 100, 99 or 95-percentile values have an impact on the hosting capacity. It is also shown that based on the statistical overvoltage index used, the hosting capacity of a wind turbine of 1 and 2.3 MW, for statistical overvoltage indices of 100 and 99%, respectively. In contrast to the EN 50160, which is used throughout Europe, a statistical overvoltage value of 95% is used. So there must be a push for the use of 100% values in regulation, which may limit unnecessarily the amount of renewable energy sources that can be connected.

It is well known that low voltage network are not designed for two-way flow of electricity, consequently local voltage rises due to excess solar generation feeding energy back into the supply network is commonly experienced. In paper [B2-0324(BE)] the implementation of an optimized battery storage system that could be implemented at LV-grids is discussed. Different evaluation methods are considered, but generally for a residential building a battery bank of approximately 1 kWh/MWh consumption can enlarge both the self-consumption and self-sufficiency from 30% in an solar system without storage, to approximately 60% with small battery capacity. Larger storage capacity means greater decongestion of the grid, but it will not contribute to a proportionate increase of both ratios is shown in Fig. 12. Next to that, the influence of the location of the storage system is evaluated, which points out that integrating storage at the end of the feeder would lead to considerable decongestion. Anyway, decentralized and centralized systems contribute to reduced voltage congestion. Centralized systems start charging earlier and faster, compared to decentralized storage and consequently they are more capable of handling problems with respect to overproduction. Decentralized systems on the other hand use the battery system to optimize the residential building resulting in longer decongestion.
The contribution [S4-1227(UK)] deals with an economical distributed control scheme for operations in the low voltage grid with a high penetration of photovoltaic installations. Rather than curtailment, battery storage followed by reactive power control is presented. Also simulations were carried to show successful overvoltage mitigation.

Paper [S5-0026(AU)] deals with the increase of the hosting capacity for PV on low voltage grids. The last two contributions are complementary to paper [B2-0324(BE)] and will presented in session 4 respectively 5.

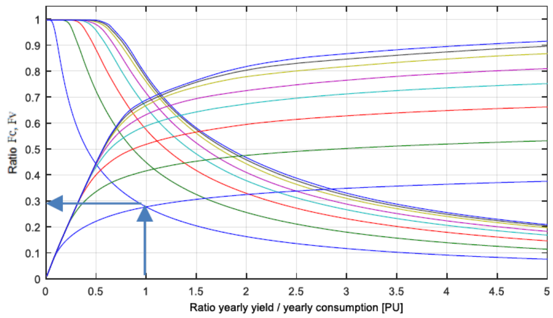


Fig. 12: F_C and F_V in function of the size of the PV-installation for different effective storage capacities from 0 to 5 kWh/MWh with a cycle efficiency of 81% for an individual building [B2-0324(BE)]

In the contribution [B2-0662(BE)] describes the control algorithms for stabilizing the grid voltage due to distributed generation, since they cause voltage unbalance problems and over voltages. The need for power quality improving control strategies of grid-connected inverters emerges with the increasing share of single-phase distributed generation units in low voltage grids. Some control strategies require three-phase four-wire inverter topologies. The simplest way to connect the fourth wire is by connecting it to the mid-point of the dc-bus. This sometimes causes challenges in the stabilization of the mid-point. In this article two algorithms for stabilizing the midpoint of a three-phase four-wire inverter are proposed. Both algorithms are described in detail and validated experimentally. The results showed that both algorithms perform well under perturbations and are able to maintain the midpoint potential close to zero while the quality of the injected currents is not deteriorated. It was also found that both algorithms are able to maintain the midpoint potential stable while the quality of the injected currents is kept within the IEC limits.

A power quality analysis of a regional Chinese network is discussed in contribution [B2-0754(CN)]. The regional network consists of several area networks connected to the main network through 500kV stations. In recent years, renewable energy in these rural areas has developed rapidly and electrified railway traffic traction in urban areas is developing rapidly. Both cause a significant impact on the power quality of the power supply system and even the main transmission network. Chinese harmonic standards for power system planning are introduced. Next to that, the parameters of the minimum operation mode and the power supply capacity in harmonic planning are also discussed. With the present standards, the determination principles and calculation procedures of the two parameters are proposed, to deal with the rapid development of the power grid.

Harmonic emission assessment in high voltage networks containing renewable power plants is challenging. This paper [B2-0891(SA)] gives a scientific methodology readily accessible to engineers to validate the compliance to grid code requirement set by the distribution system operator. Since harmonic phasors record coherently all over the network it can cause an impractical volume of data. The opportunity to improve existing methodologies by application of the prevailing angle in a harmonic phasor can be used as an approach to significant reduction of data. The evaluations of these results are demonstrated with respect to grid compliance in a network with a number of interconnected renewable power plants. It is shown that the unrelated dynamic nature of the different non-linear energy sources does compromise the practical application of the prevailing harmonic phase angle. As a conclusion, aggregation of harmonic phasors vastly reduces the volume of data required for harmonic emissions assessment. This enables a practical engineer to conduct a harmonic emission assessment over longer periods without compromising data integrity.

The research presented in [B2-997(CH)] discusses voltage instabilities caused by inverters in weak grids. The stability of pulse-width modulation inverters is strongly related to the short-circuit power, and especially to the frequency dependent grid impedance at the point of common coupling. It is shown, based on two cases that inverters can lead to unstable behaviour in a weak grid, independent of the nominal voltage level. With a set of field measurements, it is also shown in Fig. 13, that the frequency dependent grid impedance is highly influenced by the number and type of connected inverters. As shown, commercial power-grid simulation tools are not able to predict this kind of instability.

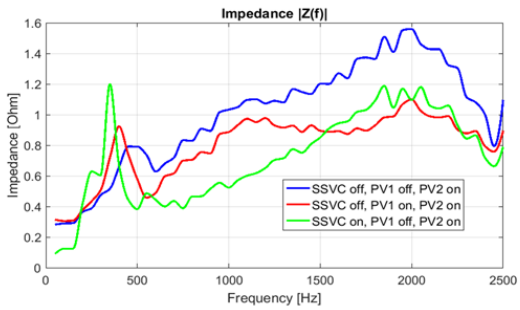


Fig. 13: Change of the frequency dependent grid impedance related to the amount of connected PV systems and the upstream (SSVC) [B2-997(CH)]

As a conclusion, it is stated that the parameters of the control circuit for the current curve form should be optimized using the real frequency dependent grid impedance at the foreseen connection points. Inverters should be tested and qualified not only by using a proper voltage source but also with a disturbed voltage. For this, the limits for EN50160 might be a good approach for a voltage distortion in the test lab.

The aim of paper [B2-1047(ES)] is to demonstrate the dynamic behaviour of renewable plant for grid code requirements regarding both voltage and reactive power.

In this contribution it is shown that for big amplitude grid voltage variations are the most critical point regarding dynamic behaviour of generally of renewable power plants. Both hybrid static synchronous compensators or mechanical switching capacitors or reactor are considered as subsystem to meet the requirements of the grid code by analysing the step response of the system and by voltage control actions. To be adequate, switching transients of the mechanical switching capacitor and reactors applied for voltage control are taking into account. The results show that a Hybrid-STATCOM System can meet the requirements applied, and as a result, the installation cost for network support resources could be considerably reduced.

Paper [S3-0554(DK)] focusses on distributed voltage control coordination between renewable generation plants in medium voltage distribution grids. It is shown that voltage regulation leads to satisfactory results however reactive power provision increases the power losses significantly. A real-time coordination concept with on-line signal exchange between the assets can reduce power losses to a measurable extent. This contribution is complementary to paper [B2-1047(ES)] and will be presented in Session 3.

With respect to issues with voltage level especially in rural grids with high penetration of distributed generation [S1-0207(DE)] of Session 1 proposes an innovative technology for a line voltage regulator for LV networks which operates with a magnetic controller inductor.

The changing system dynamics and growth of distributed generation demand for solutions to control the voltage unbalance in order to ensure reliable and stable supply. There is a variety of options currently being investigated by DNOs, manufacturers and universities. In this context [S4–0889(SI)] presents the contribution of the Slovenian DNO Elektro Gorenjska to the EU FP7 project titled “Increasing the penetration of renewable energy sources in the distribution grid by developing control strategies and using ancillary services” (INCREASE). Different sets of voltage control strategies for an on load tap changer (OLTC) were deployed, tested and evaluated including integrated OLTC voltage control, overlaying network OLTC control and local PV droop control. This contribution will be presented in Session 4.

In [S4–1049(GB)] the impact of the increased penetration of distributed generation in LV networks for voltage management is investigated for the Scottish Power network. Three fields of action have been identified; updating policy documents, in order to incorporate the application of voltage optimization into network design and operation, updating voltage control relays and the deployment of voltage regulating transformers. A case study analysing different options is presented. This contribution will be presented in Session 4.

The paper [S4-0233(FR)] deals with the reactive power control for voltage regulation in low voltage grids. Three different situations of regulation are analysed:

- the business as usual, so no reactive control,
- the tan-phi=-0.33 and
- a Q=f(U) solution.

It is shown that a certain number of prerequisites should be met in order to create an optimal solution. This contribution will be presented in Session 4.

Potential scope of discussion

Massive integration of PV leads to increased PQ related problems in the grid with relation to unbalance, flicker and both LF and HF emissions in the grid. Consequently the distribution networks suffer through PV inverters. It is recommended to intensify the monitoring of PV installations in order to obtain sufficient information for a reliable assessment of its impact on PQ.

Wind power plants may have a significant impact on power system operation such as voltage sags and phase jumps. As wind power already has a significant share of total power generation in many countries, the systems will have to contribute more and more to stability and reliability with regard to voltage level and system frequency. Using stabilisations systems can increase grid quality. Also here intensified monitoring and publication of results is recommended.

Since it is well known that low voltage networks are not designed for two-way energy flow not only the impact of distributed generation, but also electric vehicles must be considered. Storage capacity provided in order to balance RES yield also will be used in future grids to provide hosting capacity and operational flexibility. Dynamic setpoint adaption of distribution voltage regulators can improve the operation performance of distribution systems and possibly increase the hosting capacity for distributed generation.

Table 2: Papers of Block 2 assigned to the Session

Paper No.	Title	MS a.m.	RIF	PS	other sessions
0002	Evaluating Emission and Immunity of Harmonics in Frequency Range of 2-150 KHz Caused by Switching of static convertor in solar power plant			X	
0026	Increase the hosting capacity of 4-wire Low Voltage supply network for embedded solar generators by optimising solar generator and load placement on the three supply phases				S5
0045	Evaluating Noise and DC Offset due to Inter-Harmonics and Supra-Harmonics Caused by Back to Back Converter of (DFIG) Generator in AC Distribution Network			X	
0047	Capacitor Bank Behaviour of Cement Factory in Presence of Supra-Harmonics Resulted from Switching Full Power Frequency Converter of Generator (PMSG Harmonic)			X	
0058	Comparison Between Types of DFIG Converter with Various Switching Techniques			X	
0076	How to deal with electromagnetic disturbances caused by new inverter technologies connected to public network	X		X	
0078	Impact of control-command of a photovoltaic conversion chain on the power line channel transfer function in the narrowband PLC frequency range		X	X	
0097	Comparative Performance of Wind Energy Conversion System (WECS) With PI controller Using Heuristic Optimization Algorithms			X	
0132	The Impact of Grid-Connected Photovoltaic System on Power Quality Indices and its Output Variations with Temperature			X	
0178	Performance Indicators for Quantifying the Ability of the Grid to Host Renewable Electricity Production			X	
0191	Impact of PAJ with Varying POW in Voltage Sag on Rotor Over-Voltage in DFIG based Wind Generator			X	
0207	Line Voltage Regulator Based on Magnetic-Controlled Inductors for Low Voltage Grids				S1
0227	Harmonic Disturbances up to 150 kHz Produced by Small Wind Turbines on the LV Distribution Grid			X	
0233	Using LV Distributed Generation's Reactive Power for Voltage Regulation				S4
0241	Impact of Wind Power Plants on the Distribution Grid			X	
0285	Smart Voltage Regulator to Active Voltage Level Management of Distribution Networks			X	
0324	Decongestion of the Distribution Grid via Optimized Location of PV-Battery Systems			X	
0351	Power Quality aspects of Solar Power - results from CIGRE JWG C4/C6.29			X	
0357	Voltage Unbalance due to Single-Phase PV	X		X	
0456	CIGRE C4/C6.29: Survey of DSO Experiences on Power Quality Issues Related to Solar Power			X	
0457	Harmonic and interharmonic characterisation of a 12-MW-windpark based on field measurements	X		X	
0492	Flicker in Distribution Networks Due to Photovoltaic systems			X	
0554	Distributed voltage control coordination between renewable generation plants in MV distribution grids				S3
0662	DC Bus Voltage Balancing Controllers for Split DC Link Four-Wire Inverters and Their Impact on the Quality of the Injected Currents			X	

0731	Contribution of a Wind Park to Voltage and System Stability: Results of a Measurement Campaign				S4
0754	Power Quality Analysis of the Zhangjiakou Regional Network in China			X	
0834	Detailed Power Quality Measurement of Electric Vehicle Charging Infrastructure		X	X	
0889	Voltage Quality Provision in Low Voltage Networks with high Penetration of Renewable Production				S4
0891	Harmonic emission assessment on a Distribution network using the prevailing phase angle	X		X	
0927	Standard Passive Harmonic Filter for Wind Farm Connections	X		X	
0997	Measurement of voltage instabilities caused by inverters in weak grids	X		X	
1009	A Control Strategy for Reactive Power and Harmonic Compensation of Grid Connected Photovoltaic System			X	
1047	Hybrid Statcom Solutions in Renewable Systems			X	
1049	Voltage Regulating Distribution Transformers for LV Network Voltage Control and System Efficiency				S4
1074	Ultra-Fast Charging Station Harmonic Resonance Analysis In the Dutch MV Grid: Application of Power Converter Harmonic Model		X	X	
1227	Economical Distributed Voltage Control in Low-Voltage Networks with High Penetration of Photovoltaic Units				S4

BLOCK 3: Power quality measurement, analysis and mitigation methods

This block gives a summary of the papers dealing with Power Quality measurement, analysis and mitigation methods. In this year's conference this block is quite balanced divided in the four mentioned subtopics. Most of the papers originate from universities and not from utilities. As an increasing share of industries and businesses are relying on sensitive high-tech processes and residential customers employ more and more sensitive loads, Power Quality is still becoming more important.

Voltage Variations and Flicker

Disturbances of voltage as sags and flicker are among the key causes of customer interruptions. The origin and propagation of theses phenomena is an important topic for customers as well as utilities. This knowledge sets the ground for targeted mitigation measures and a fair share of responsibility between utilities and customers. Furthermore, the growing penetration of distributed energy resources and flexible loads lead to varying voltages in feeders which can exceed the permissible voltage range defined by EN 50160.

The air compressor analysed in paper [B3-1132(CN)] usually driven by an induction motor is a typical fluctuating mechanical load, which can easily bring power quality problems to power grid, such as voltage fluctuation and flicker. The analysis of the working voltage and current data of a 7.5 kW three phase induction motor loaded by an air compressor is performed. It is shown that frequency components of 37.5 Hz and 62.5 Hz in voltages and currents are generated when the air compressor motor is running. The inter-harmonic spectrum and variation curves during the working process of that 7.5 kW air compressor motor are calculated and shown in the graph below.

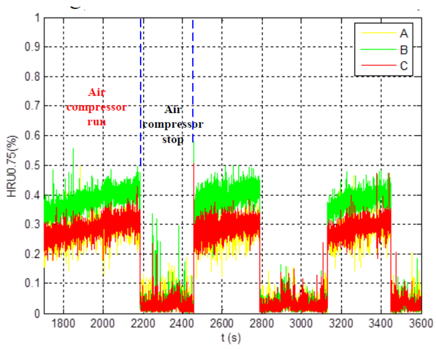


Fig. 14: Variation curves of the 37.5 Hz interharmonic voltages when air compressor motor running and stopped [B3-1132(CN)]

The variation curve of voltage fluctuation and flicker brought by interharmonics is also calculated in this paper. Furthermore, the model of air compressor motor is built to study the interharmonics mechanism and has found out frequency of 37.5 Hz and 62.5 Hz interharmonic voltage sources can be produced in the motor stator windings when the air compressor motor is running and meanwhile the same frequency interharmonic currents are appeared. Finally, the equivalent circuit diagram of the air compressor motor in power grid considered interharmonics, has been given.

Paper [B3-0747(NL)] proposes a method for the determination of flicker contribution based on synchronised measurements of RMS voltages and currents. Averaging and time aggregation, as usually is done by using the short or long term flicker coefficient, is avoided. Based on the synchronized measurement results, flicker emission of individual installations is derived by ranking the amplitude of the registered rapid voltage changes (RVCs). Alternatively the disturbance source can be determined based on the sign of RMS voltage and current changes during these events. The latter of the two is found to be more appropriate due to higher sensitivity. Once the individual RVCs are assigned to substations, the frequency and percentile values of magnitudes of individual events can be used to determine the contribution of an individual substation to the flicker level over the observed time interval. The performance of the method was demonstrated using measurement data from PMUs with power quality functionality in a 50 kV network. It was shown that the results are in good agreement with the characterisation based on instantaneous flicker coefficients.

In paper [S3-1026(NL)], an on-load tap changer based smart solution is verified. The field trial revealed that redundancy and cyber security are the main concerns for distribution system operator. The paper will be presented in Session 3.

Low Frequency Harmonics up to 2 kHz

In [B3-0621(BR)] the impact of a change in lamp technology from predominantly CFL to LED on the system is analysed. LED lamps could replace fluorescent lamps in Brazil over the next years. Therefore, the harmonic generation from LED lamps and the effect of voltage sags on LED lamps as well as their thermal properties are investigated. The individual testing of different CFL and LED lamps showed that 40% of the CFL and 60% of the LED lamps do not comply with all requirements of national standards energy quality. For a group of ten different CFL lamps a reduction of the THD by 12% was observed in comparison to 30.6% for ten different LED lamps. The gradual exchange of CFL bulb groups by LED bulb groups led to a gradual increase of the power factor and a decrease in consumed power, in current and in THD. The impact due to the change in lamp technology was 30.3% improvement for the power factor, 45.6% reduction in power consumption and 80.3% in THD.

In paper [BE-0376(BE)] accurate calculations to assess harmonic pollution in MV grids are performed. The proposed and new method to fine-tune a simulation model is presented. It allows calculating harmonic power levels for all MV feeders and HV/MV transformers based on measurements done in the field. A case study has been done to evaluate the method, whereas the results between simulation and measurements are given in the graph below. In order to have good results, a two-week measurement campaign was conducted. During the whole duration of the measurement campaign, the full waveform was sampled. The harmonic simulation model adaptation for this analysis of the MV grid was modelled in NEPLAN. The models are supplied by the DNO and the HV/MV transformer, the MV busbar and 11 MV feeders. Load flow calculations are executed at 50 Hz using the CIGRE method. The proposed method shows, using the results of a measurement campaign, one can determine harmonic pollution levels where compliance of Kirchoff's law is more or less valid. The fine-tuned model is tested by simulating different scenarios, such as the closing of the busbar coupler and the addition of a MV capacitor bank on the busbar. These scenarios were reproduced and measured in reality and were used to check coherence with the simulation results.

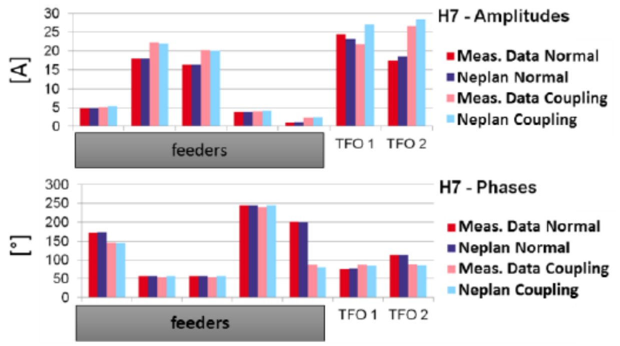


Fig. 15: Simulation results for H7 currents [A]: normal situation and situation with busbar coupler closed.

[B3-652(IR)] presents a study of the harmonic congestion produced by base transceiver stations (BTS) for mobile communication. In Iran more than 3000 BTS are connected to the distribution grid and inject harmonic currents due to the use of single phase rectifiers to feed batteries and amplifiers. Twelve stations with different types of rectifiers and distance from the supply station have been selected for measurement and analysis. The measurements indicate that Power Quality parameters especially for voltage total harmonic distortion THD and 3rd and 5th harmonic do not comply with the limits according to IEEE-519. For one of the problematic BTS a hybrid passive filter has been designed to reduce THD of the injected current.

In paper [B3-1337(IR)] a new novel method to analyse harmonics in electrical power distribution network by using artificial neural networks is presented. In this research artificial neural networks have been used for fast and efficiently predicting the harmonics of a power distribution network. The research highlights the importance of focusing on various power quality parameters to achieve sustainable availability of quality supply Problems related to harmonics faced by power utilities can be avoided by efficiently estimating or predicting the harmonics using artificial intelligence techniques with high accuracy as shown in the paper.

Related to the rising penetration of non-linear loads in modern networks [S3-0190(UK)], proposes an extension to conventional static load models. By incorporating the effects of harmonic distortion, load models can be improved to reproduce network conditions by simulation. The contribution is presented in Session 3.

The authors of paper [B3-534(CN)] have analysed the harmonic influence of high speed railway's traction load on power grids. Especially harmonic and negative sequence voltages are observed. Several simplifications are done in order to make a static polynomial model, which is presented in the paper. Quantitative and qualitative analysis are done and filter solutions given. It is concluded that third order harmonics are exceeded over the whole supply system.

In [B3-0341(IR)] an optimization algorithm for the output voltage multilevel inverters is presented. Using a particle swarm optimization algorithm, the total harmonic distortion (THD) of the staircase output voltage is optimized. This is achieved with an increased number of switching angles for each level and by optimizing the voltage magnitude input of the DC voltages of the inverter. A simulation in MATLAB/SIMULINK has been conducted for a 7-level inverter, which shows an improvement of the THD.

Resonances and network impedance

[B3-0346(SI)] studies the impact of different HVDC technologies on reactive power control and voltage profile regulation and the level of harmonic distortion. Simulation results of reactive power control and voltage regulation with LCC (line-commutated converters) and VSC (voltage-source converters) technology are presented. Filtering of the harmonics in the output is required by both technologies, but to a lesser extent for VSC technology. The study shows, that a thorough analysis of the impedance-frequency characteristics at the respective locations have to be carried out, as resonance points are moved by the installation of HVDC systems. The strongest influence has been detected for the harmonic filters of the LCC system.

In [B3-0408(BE)] a method to improve simulation of ripple control signal behaviour and performance in medium voltage grids is presented. Through several measurement campaigns the impedance of the actual medium voltage grids was investigated for the fundamental and the signal frequencies. For different types of loads typical ratios KN of fundamental to signal frequency impedance were found (Fig. 16). The simulation model was expanded in order to take into account the measured impedance of the loads at signal frequency. Thereby the model is able to produce reliable signal attenuations along the medium voltage feeders. The authors recommend taking special care when modelling decentralized generation units.

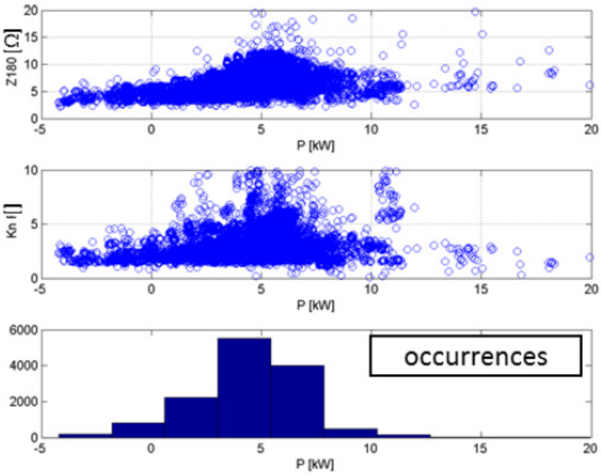


Fig. 16: Measurements of impedance at signal frequency Z_{180}, factor K_N and occurrence of measurement points over consumed power for typical households [B3-0408(BE)]

Measurements indicate that resonances below 2 kHz occur in residential networks, which has not been expected in the past. [B3-0460(DE)] presents a detailed study of the harmonic impedance of a low voltage network based on measurements and simulations. Measurements show, that the resonance frequency is around 500 Hz for different locations in the grid, which is close to the mains signalling frequency of 482 Hz for this grid (Fig. 17). The simulations indicate that the resonance is most likely caused by distributed capacitances of power electronic devices applied in households. Specific frequency-dependent simulation models of the loads have been developed and implemented for each household.

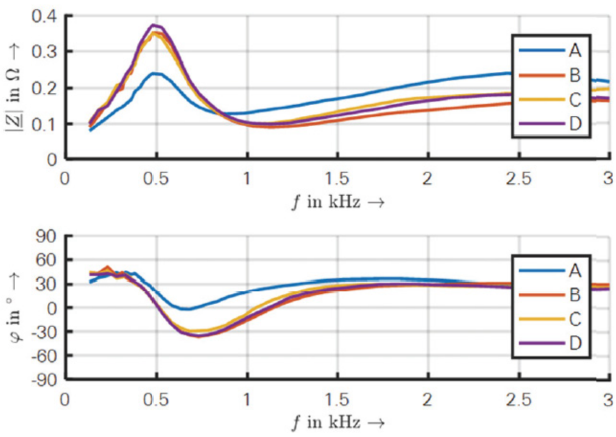


Fig. 17: Network harmonic impedance (phase 1) at different locations (low voltage busbar A, junction boxes B-D) [B3-0460(DE)]

The authors recommend taking into account resonances already at the planning stage of distribution grids. Following the results of the study, a resonance factor has been introduced in the equations for calculating harmonic emission limits in the ongoing revision of relevant rules and guidelines for assessment of network disturbances in Germany, Austria and Switzerland.

Paper [B3-0807(CH)] describes the identification methods for resonance problems in networks in presence of harmonic pollution. Harmonics propagation in power systems gained interest again, since the use of power line communication has an increasing interest. In HV networks, current trend of burying cables changes resonance frequencies. However, in LV distribution systems, due to distributed generation; both harmonic current content increases, while PLC can be disturbed or interfered. In this analysis, the most important elements of power systems are modelled in the frequency domain, so frequency scan and Resonance Mode Analysis methods can be performed. Two network types are analysed to point out the specificities of each network level: the first one is an EHV/HV network and the second one is a part of a MV/LV distribution system. It is shown that with this method the network behaviour in a large frequency bandwidth can be predicted. Recent network impedance measurements contribute to the validation of this method by showing the same trends and resonance frequencies close to the ones visible in the simulation results. Based on recent experience, it is important to understand these effects in order to maintain the functionality of PLC and ripple control systems. The modelling framework summarized and applied in this paper will help the DSOs to do so early in the planning process.

[B3-0790(EG)] discusses a simulation that has been carried out in order to investigate and compare the occurrence of ferroresonance phenomena for conventional, low-loss and amorphous transformers in cable grids.

High Frequency Phenomena above 2 kHz

Power quality measurements in a single house, which can be considered as microgrid, are discussed in [B3-0240(SE)]. The microgrid consists of one residential house that can operate in grid-connected or grid-disconnected (islanded) modes. During the year the microgrid was disconnected from the main grid most of the time. Since in a household a great number of non-linear loads are connected, both harmonics and super harmonic will occur on regular base (Fig. 18).

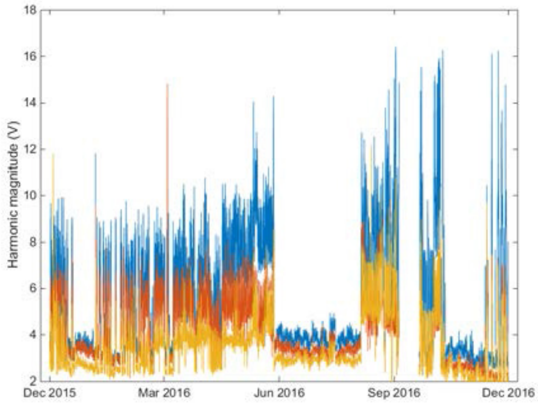


Fig. 18: The one hour average of the total harmonic distortion measured during one year. Different colours indicate the phases

Also unbalance and flicker can occur. Especially in case of island operation the frequency variations are more noticeable. Several power quality indices have been analysed and in most cases a deterioration of the power quality index is seen as the microgrid is islanded:

- increase in harmonic voltage
- increase in supra-harmonic voltage
- large increase in frequency variation
- slight increase in voltage unbalance

Analogue, in paper [B3-0458(DE)], household equipment is also investigated, more specific a survey of the emission of high frequency components (the so called supra-harmonics) is studied. The number of devices with high frequency switching circuits is growing constantly caused by increased efficiency or power factor of the devices. The devices of interest in this study are usually equipped with switching power supplies who are working in the domain up to 50 kHz, since the third harmonic will be below the 150 kHz and consequently, they do not have to fulfil the CISPR requirements for emission.

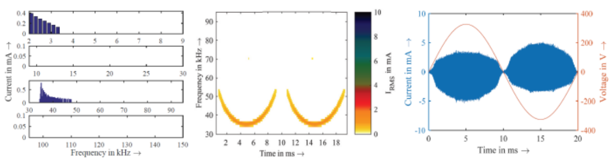


Fig. 19 : Frequency (left), time-frequency (middle) and time (right) representation of an household equipment [B3-0458(DE)]

This paper introduces a set of criteria for classification of this frequency domain in order to help the standardization organizations and to have a better insight in the working domain. The performed study contains the results of more than 120 household appliances, where the results are summarized in the paper. It is also shown that more than 50% of the tested devices have an identifiable supra-harmonic emission.

A harmonic analysis of streetlamps is performed in [B3-0493(EG)]. Harmonics are one of power quality issues which are generated in any non-linear loads. For street lighting, high-pressure sodium lamps are currently the main lamps used. The study analyses the transition from high pressure sodium lamps of different power to LED lamps, since they are a more energy-efficient alternative. Measurements carried out to high-pressure sodium lamps with electronic ballast and LED lamps and compared with IEC61000-3-2 limits. It can be concluded that measured harmonic values are less than the limits given in IEC61000-3-2.

Similar work is presented in [B3-0627(BR)]. It describes a case study of harmonic analysis of a lighting technology application. The assessment in quality of energy resulting from the implementation of residential artificial lighting and public lighting technologies is performed in the Smart City Búzios, Rio de Janeiro State, Brazil. Measurements are made with compact fluorescent lamps, LED lamps and sodium vapour lamps. The simulation of Búzios network was carried out with help of HarmZs, software. Eight application scenarios of lamps and luminaires were made, and the voltage distortion generated in the 13.8 kV network was checked. It was shown that the LED technology has advantages with regard to reduction of distortions as compared to other technologies, for residential lighting or public roads. In addition, this work seeks to communicate to professionals in the field, the importance of considering in the implementation of efficiency projects with the use of new lighting technologies, the possible effects of these equipment on harmonic distortions in the electrical network and effects on equipment and installations already in operation;

Paper [B3-1012(SI)] discusses the measurement results of high frequency disturbances in the Slovenian network. Therefore the researchers performed on-site electromagnetic compatibility testing in substations. The method for measurement of high frequency disturbances and usefulness of such measurement in substations is presented. Measured overvoltage with its characteristics corresponds to the damped oscillatory wave and ring wave, both with respect to the IEC standards. Overvoltage is measured in control rooms or relay kiosks in enclosures of secondary circuits of current transformers) cores and voltage transformers windings between the terminal of the circuit to the terminal of the equipotential bonding system (Fig. 20) or directly to the earthing terminal. The need for establishing the criteria for electromagnetic compatibility assessment is indicated. From the results of the measured overvoltage, it is evident that quite great differences exist in measured amplitudes despite similarly designed substations´ earthing system and equipotential bonding system, which clearly shows that the improved criterion is indeed necessary.

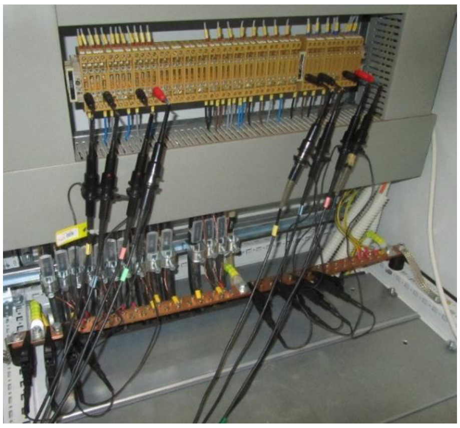


Fig. 20: The principle of high voltage probes connection

Paper [B3-1359(BE)] deals with the power conversion harmonics of nowadays loads. It states that reproducible emission measurements between 2 and 150 kHz are a challenge, since several parameters have their influence on its behaviour. Different parameters were analysed with the aim to validate their influence. Basically it's the type of the emitting source and supply voltage (including grid impedance) as can found back in the graph below.

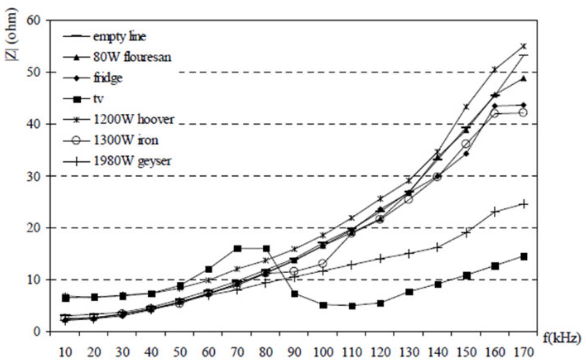


Fig. 21: Measured grid impedance with different loads [B3-1359(BE)]

Measurement inconsistencies due to unbalance

[B3-1267(UK)] presents an analysis aimed at resolving inconsistencies in three-phase current measurements. Current measurements made at distribution substations in low voltage networks often show significant inconsistency as compared to the expectation, that any unbalance between phase currents in four-wire distribution circuits will equal the neutral current. The causes and effects of these inconsistencies are investigated in the paper using measurements form a low voltage feeder. In the analysis compared harmonics were found to be the main cause of the inconsistencies. Temporal averaging of the data was shown not to be a major cause for inconsistency in calculating the unbalance current. The feeder selected for the analysis did not have any further connections to the neutral. More generally a number of additional current paths though neutral conductors connected at link boxes and between ground electrodes have to be considered. The authors point out, that these effects need further investigation.

Mitigation Methods (Active Filters, Dynamic Voltage Restorers)

Flexible mitigation measures are an important issue to cope with the growing challenges by PQ phenomena. Several papers have been submitted, which propose mitigation measures to ensure the stable operation of the distribution grid as well as sensitive customer processes.

[B3-0101(US)] focuses on the use of FACTS solutions to address distribution voltage sag and swell problems. FACTS devices like STATCOM and SVC can be designed to quickly restore of the voltage and to reduce the impact of sags and swells on the distribution system. In case of problems with power interruptions some type of uninterruptible power supply (UPS) is required. If the utility has taken all possible measures, the industrial customer has to gather data over an extended period in order to be able to assess the economic impact of power quality mitigation. Businesses, where power quality mitigation is economically advantageous have a common set of characteristics, including a load greater than 10 MVA, computerized process controls and a high facility utilization rate.

With the objective of mitigating Power Quality problems, [B3-0707(IR)] investigates the range of application of a new topology for a dynamic voltage restorer (DVR). The proposed topology is a matrix converter, which is a switching device converting AC to AC with different frequencies and magnitudes without using a DC link and energy storing elements. A three phase to single phase matrix converter could be applied to mitigate voltage sags and swells and harmonics in balanced and unbalanced conditions .In the paper the stability of a matrix converter is analysed and the stability range is discussed.

[B3-0821(CN)] proposes a low voltage ride through (LVRT) system to ensure the normal operation of an inverter during voltage sags. The shutdown of thermal power plants caused by voltage sags has occurred several times in China endangering the stability of the power system and entailing substantial economic losses. Research on the process including immunity time of sensitive equipment has indicated that under-voltage tripping of the inverter during voltage sag is the cause of coal feeder shutdown. The influence factors of voltage sags on the AC-DC-AC inverter are analysed and a LVRT system using DC support technology is proposed (Fig. 22). Using batteries the LVRT system provides DC voltage for the inverter's DC bus. Experimental and field data have shown that the system meets the requirements of voltage sag protections.

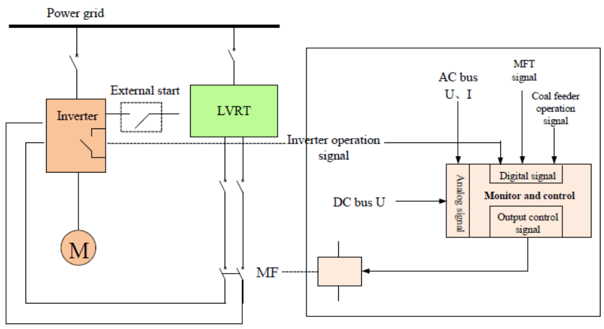


Fig. 22: Logic control of LVRT system [B3-0821(CN)]

In order to stabilize the voltage in distribution systems without interruption, a new generation of voltage regulation distribution transformers (VRDT) is presented in [B3-0881(DE)]. A resistor based switching principle is applied in combination with arc quenching by vacuum technology, which minimizes losses. The voltage level is constantly monitored by a control unit. As soon as the voltage leaves the specified range for a predefined time, the tap position is adjusted under load. A case study for two VRDTs of different ratings has been successfully conducted.

Paper [S1-0348(DE)] contributes to the implementation of transformers with on-load tap-changers to facilitate integration of renewable energy sources. In order to facilitate the voltage changes by the OLTCs, some intelligence as presented is needed to determine when which actions are appropriate. This contribution will be presented in Session 1.

Two related papers discuss the design and optimization of a shunt active power filter to selectively mitigate harmonics and improve the power factor. A Power Quality second order generalized integrator based control technique is presented in [B3-0203(EG)], which is employed to generate an in-phase sinusoidal current with a non-ideal grid voltage. In order to minimize digital implementation delays and parameter uncertainties [B3-0201(EG)] proposes a self-tuning indirect adaptive current controller based on model predictive control theory and system identification.

Potential scope of discussion

Voltage disturbances and flicker are important topics for customers as well as utilities. The assessment of origin and propagation of these phenomena is a key issue in power quality analysis. In future, GPS synchronised power quality measurement (PMUs with enhanced PQ functionality) could provide data, allowing the exact determination of disturbance origin and propagation. The development of appropriate methods and algorithms will be a challenging task for the next years.

In low voltage networks unexpected resonances in the harmonic range below 2 kHz are more frequently observed by distribution system operators. Measurements and simulations indicate that distributed capacitances of power electronic equipment applied in street lightning and by residential customers are involved in this phenomenon. Amplification of specific harmonic orders or ripple control signals and sudden changes in harmonic voltages and currents can indicate resonance issues. Taking into account the harmonic network impedance in planning of large installations concerned and monitoring shifts in selected networks is recommended.

The massive and fast change in lamp technology to LED will influence the system. CLF replacement by LED lamps over the next years will lead to harmonics and even shift to higher frequency components in the domain above 2 kHz. A confirmed knowledge about nowadays current and future current emission and immunity characteristics of all equipment must be considered. Next to that, the growing number of grid connected inverters used for distributed generation will influence harmonic emission and create background distortion. The problem of interaction of different devices in the high frequency domain (secondary emission) needs to be investigated furthermore in the future.

Table 3: Papers of Block 3 assigned to the Session

Paper No.	Title	MS p.m.	RIF	PS	other sessions
0101	Distribution System Power Quality: How FACTS on the Distribution System are Being Used to Improve Customer Power Quality			X	
0190	Enhanced ZIP Load Modelling for the Analysis of Harmonic Distortion under Conservation Voltage Reduction				S3
0201	Self-Tuning Indirect Adaptive Current Control of Shunt Active Power Filters in Electric Power Distribution Systems			X	
0203	Design and Implementation of a Single-Phase Shunt Active Power Filter based on PQ Theory for Current Harmonic Compensation in Electric Distribution Networks			X	
0240	Harmonic Measurements in a Single House Microgrid		X	X	
0341	THD Minimization of Multilevel Inverter with Optimized both DC Sources Magnitude and Switching Angels			X	
0348	Beyond Grid Integration of Renewables - Voltage Regulation Distribution Transformers (VRDT) in Public Grids, at Industrial Sites, and as Part of Generation Units				S1
0346	HVDC Technology and Power Quality Issues in Slovenian Transmission System - Technical Study			X	
0376	A new method to assess harmonic grid congestion in MV-networks			X	
0408	Advanced ripple control signal calculation tools for DNO’s	X		X	
0458	Survey of Supraharmonic Emission of Household Appliances		X	X	
0460	Analysis of Resonances in Residential Low Voltage Networks caused by Consumer Electronics	X		X	
0493	HARMONIC ANALYSIS OF STREET LIGHTING LAMPS			X	
0534	Analysis of Harmonic Effect of High-Speed Electric Railway's Connection to Grid			X	
0621	A power quality analysis and thermal properties of the system associated with the change of fluorescent lamps for LED lamps			X	
0627	Harmonic Analysis of Lighting Technology Application – Case Study in Distribution Network: Smart City Buzios			X	
0652	Measurement and Analysis of Base Transceiver Stations Power Quality Parameters and Assessment of its Unfavourable Effects on IRAN Distribution Systems			X	
0707	Performance and Stability Study of a Triple Dynamic Voltage Restorer (DVR) Based on Matrix Converter			X	
0747	Determination of Flicker Contributions Based on Synchronised Measurements of Rapid RMS Changes	X		X	
0790	Study and Comparison of the Effect of Conventional‹Low Losses and Amorphous Transformers on the Ferroresonance Occurrence in Electric Distribution Networks			X	
0807	Use of a complete Frequency Scan and Resance Mode Analysis to identify Resonance problems in power networks in presence of Harmonic pollution			X	
0821	Research of Process Immunity Time of Boiler Coal Feeding system in thermal power plant and solution to Volatge Sags	X		X	
0881	A New Generation Voltage Regulation Distribution Transformer with an On Load Tap Changer for Power Quality Improvement in the Electrical Distribution Systems			X	
1012	Measurement of High Frequency Disturbances in Slovenian Substations	X		X	
1026	Coordinated Voltage Control in LV Grid with Solar PVs: Development, Verification and Field Trial				S3
1132	Interharmonics analysis of a 7.5k W air compressor motor			X	
1267	Resolving Inconsistencies in Three-phase Current Measurements	X		X	
1337	A New Novel Method of Harmonic Analysis in Power Distribution Networks using Artificial Intelligence			X	
1359	Discussion on Preconditions for Reproducible Measurements on Power Conversion Harmonics Between 2 and 150 kHz		X	X	

Block 4: "Power Quality Monitoring Systems, Data Mining, Economic 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 is of strategic importance for distribution system operators. Regarding future intelligent distribution grids, the availability of reliable real-time data will be of critical for a reliable operation of the grid.

Design and Functionalities of Power Quality Monitoring Systems

In the past decades efforts have been made regarding the standardisation of measured quantities and measurement methods for PQ instruments. There is still a gap regarding the standardisation of the interface between PQ instruments and PQ management systems. This is of high importance to enable non-proprietary solutions and guarantee interoperability of PQ monitoring systems. In the context of smart substations the interface between PQ monitoring and protection has to be resolved and a robust and independent process-level network has to be established. Furthermore, specific tools and functionalities are developed for monitoring systems, in order to use the data for PQ improvement. 6 papers present new approaches regarding design and new functionalities based on monitored Power Quality data.

[B4-0066(CA)] presents the results of a condition based maintenance system (MILES) using a new fault location technique based on voltage dip monitoring (Fig. 23). The system is based on the voltage drop-based fault location (VDFL) technique, which has been presented in two former CIRED publications (2007, 2011). This fault location technique uses triangulation to limit the number of fault location and advanced fuzzy logic to identify the cause of faults. The measured amplitude of the arc voltage produced during a fault in conjunction with other information as weather, faulted phases, repetitions and duration of the fault are used to identify the cause. The MILES system has been deployed on 40 feeders and has shown a very good potential for permanent and temporary fault location on overhead radial distribution system.

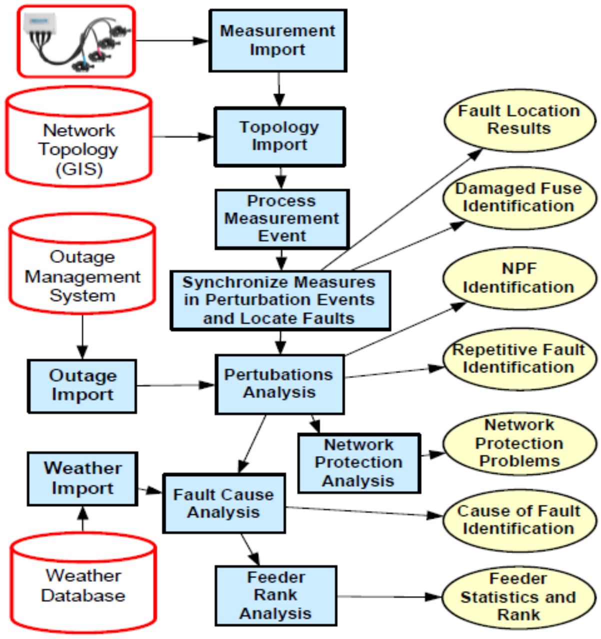


Fig. 23: MILES Process Analysis, Data Requirements and Results [B4-0066(CA)]

[B4-0421(PT)] presents support tools and a Power Quality monitoring platform that have been developed by the distribution system operator in order to promote the improvement of the Portuguese power quality monitoring program. The program has the goal to ensure a high level of Quality of Service according to EN 50160 and the Portuguese Quality of Service Regulation Code. The program implementation has led to building up a wealth of Power Quality data and results alongside with challenges related to the quantity of data and compatibility with sources as well as data analysis. At the management level security and transparency have to be guaranteed. Fig. 24 shows the topology of the Power Quality monitoring platform. In the paper the development of tools for fast and reliable analysis is discussed, these include a warning system on data quality and Power Quality limits violation, application of Power Quality indices as well as improvement of the Power Quality management process. Complementary to this paper [S6-1015(PT)] addresses the evolution of the quality of supply in the Portuguese distribution system over the last years as a result of a package of targeted measures.

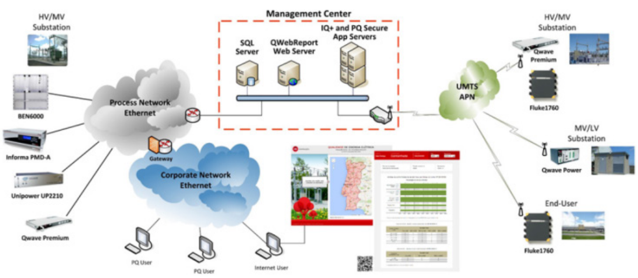


Fig. 24: EDP D's monitoring platform [B4-0421(PT)]

[B4-0573(CN)] describes the design of a Power Quality monitoring system for an IEC 61850 based smart substation with a sampling rate of 12.8 kHz. The sampling rate exceeds the limit of 4 kHz allowed for protection and control components in order to support high-resolution Power Quality monitoring. A novel Power Quality monitoring device has been developed, which is able to support digitized samples input with sampling rates of 4 kHz and 12.8 kHz. This device can monitor multiple points and PQ indices and periodically transmits a PQDIF file to a wide-area monitoring system. The key issue of implementing the system is the design of a robust and independent process-level network. Prioritized virtual LAN has been chosen to isolate irrelevant equipment and avoid congestion. The design for a smart substation has been successfully applied for the first time in a 110 kV substation supplying the metro of Shanghai, where it is highly important to have real-time Power Quality monitoring and long-term evaluation of harmonics.

[B4-0645(IT)] deals with a set of global standards Enel has developed for power quality instruments and systems in order to enable a non-proprietary solution for power quality monitoring and analysis. The first standard harmonizes the physical properties of PQ instruments, whereas the second standard addresses the interface between PQ instruments and PQ management system by defining communication protocols and formats. Depending on the reliability and performance of the communication network two solutions have been foreseen, upload of data packed in PQDIF files to a central location and access to the data kept in an embedded database in the PQ instrument through HTTP requests. The third standard describes the architecture of the QP management system in order to take advantage of the embedded database in PQ instruments and to guarantee interoperability between PQ management systems in different countries. The overall scheme of a global PQ management system is shown in Fig. 25. Due to country regulations regarding power quality, it is expected that Romania is the first country where a fully compliant PQ management system will be ready by the end of 2018.

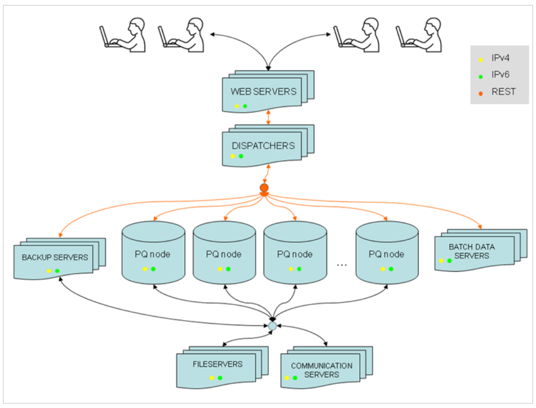


Fig. 25: Architecture of a global PQMS [B4-0645(IT)]

Power Quality Monitoring and Data Mining

Advanced DMS systems in MV networks are gaining ground. 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 residential customers and businesses. Distribution system operators employ PQ monitoring systems in order to analyse the current situation in the grid and to find the origin of PQ issues. Regulatory requirements regarding Power Quality monitoring are a further driving force. This subsection comprises 9 papers presenting results of monitoring campaigns and the use of monitored data for problem identification.

[B4-0106(CZ)] presents results of long-term voltage swell monitoring in the Czech Grid on all voltage levels. Voltage swell monitoring is regarded as important by the authors as it provides information about power system performance and identification of potential problems. The annual number of voltage swell was about six times less in the MV than in HV networks. In the LV network voltage swells were very rare at the monitored points. A detailed analysis was performed to find a pattern of swell occurrence and to identify the causes of these events. It was found that long swells correlate with maximum voltage limit exceeding and therefore identify problems with the settings of voltage regulation parameters.

The impact of a large number of distributed energy sources on voltage quality parameters is analysed in [B4-0111(CZ)]. Thirty representative LV distribution grids with connected PV plants were chosen and two voltage quality measurements were performed for each grid according to EN50160, one at the LV side of the substation and one at the PV plant. The analysis of the measurements has shown over voltages caused by the operation of PV plants. Flicker was detected in 53% of LV grids and problems with the 15th harmonic in 7% of the grids. For flicker and harmonics, however, the influence of the operation of PV plants is not clear. The authors recommend introducing new and stricter conditions for the connection of distributed energy sources to the distribution network.

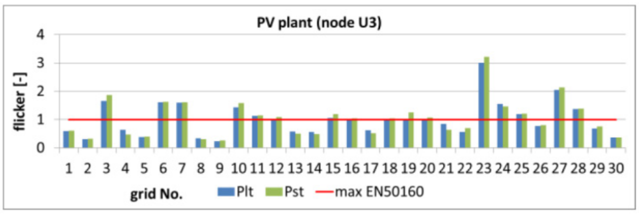


Fig. 26: Evaluation of flicker (PV plant) [B4-0111(CZ)]

[B4-0146(DK)] presents the results of a measurement campaign carried out at eleven Danish MV industrial customers with the goal to analyse the occurrence and the impact of voltage swells and voltage dips and to identify measures that can be taken by distribution system operators. Measurements have been conducted at eleven sites for six to twelve month. Fig. 27 shows the categorized voltage changes and the immunity curves for industrial equipment. The analysis revealed that only 2.4% of the recorded rapid voltage changes outside the immunity ranges were caused by events within the distribution grid.

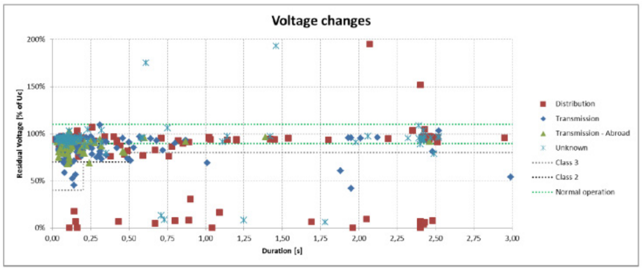


Fig. 27: Registered voltage changes, except of those caused by the customer themselves [B4-0146(DK)]

[B4-0148(CZ)] analyses the impact of the operation of customers with large loads on the voltage quality parameters in medium voltage distribution grids. 45 measurements have been conducted at the low voltage side of the customer substations of 15 customer sites in the course of three years. The analysis showed that the flicker level exceeds the limit particularly for one customer with a relatively low short circuit power at the delivery point. Correlating the flicker intensity to the current intensity revealed that the flicker was caused by the customer's operation. In this case the distribution system operator is going to build a new substation. In the meantime the process of the customer has been adjusted, in order to minimize the flicker. The authors recommend performing a connectivity study before connecting industrial plants to the network and to take into account future reserve power increase for approximately ten years.

The authors of [S4-1055(PT)] deal with one of the biggest issues regarding DG high penetration the behaviour of the invertors in case of voltage dips since they can cause the disconnection of DG, which, in turn, can possibly affect the system's stability and security. The study is based on real network case. This contribution is complementary to both [B4-0146(DK)] and [B4-0148(CZ)] and will presented is Session 4.

[B4-0246(EE)] presents the results of measurements of voltage dips and swells in low voltage networks in Estonia. The magnitude and duration of the voltage variations is analysed and their origin and responsibility issues are discussed. The measurements were carried out at the point of common coupling on the low voltage side according to the earlier IEC classification. The results of the measurements are shown in a scattered diagram as magnitude-duration plot alongside with the voltage dip tolerance (ITIC) in Fig. 28. Different categories of voltage variations are discussed together with their potential origin and possible mitigation measures. As a conclusion in case of problems the authors recommend to install permanent monitoring of voltage events at the point of common coupling of customers in order to fairly share the responsibility between the network operator and the customer.

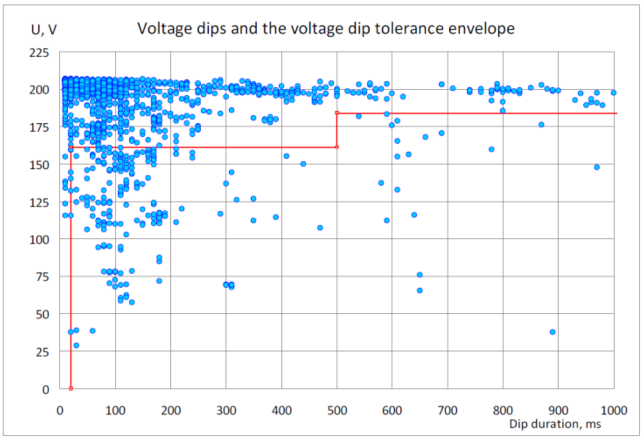


Fig. 28: Voltage dips and the voltage dip tolerance envelope [B4-0246(EE)]

[B4-0679(US)] gives an overview over publicly accessible online power quality monitoring databases. Data from different data sources are available in a new cloud based online-system, which are free for educational institutions. These include solar data, wind data, a library of disturbance waveforms including the cause of the disturbance and a power quality waveform library displaying common power quality conditions and events.

The approach of the Portuguese distribution system operator to improve the Quality of Service indicator MAIFI (Momentary Average Interruption Frequency Index) in medium voltage networks by mitigating the effects of short interruptions and avoiding sustained interruptions is described in [B4-0465(PT)]. Data from different sources including weather conditions, type of fault, fault locations provided by the distribution management system and fault indicators installed on medium voltage lines are aggregated and a diagnosis report including information about the possible zone and cause of the fault is automatically generated (Fig. 29). This report is send to a maintenance team in order to identify the location of the potential failure. The first results of this approach indicate that operational cost savings are derived from reducing the areas, which have to be inspected in order to find the root causes of momentary interruptions. Furthermore, sustained interruptions can be avoided, which leads to an improvement of the indicators SAIDI and SAIFI.

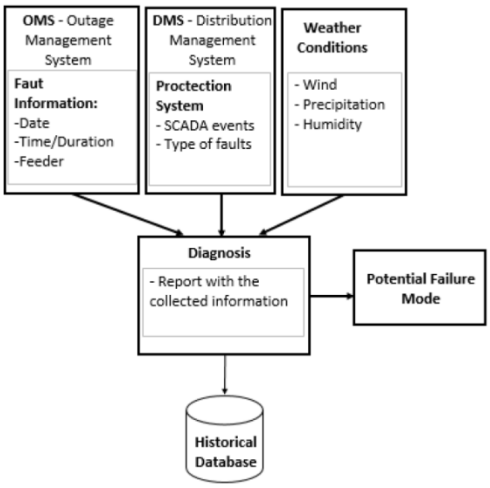
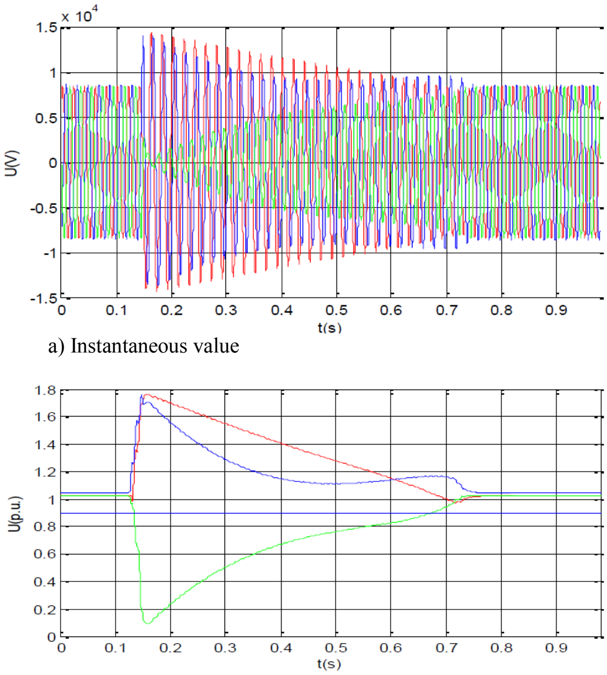


Fig. 29: Flowchart of the proposed methodology [B4-0465(PT)]

In [B4-0776(CN)] a method for identification and recognition of voltage sag disturbance sources using fuzzy comprehensive evaluation is proposed, which can deal with large sample data. An index set for the evaluation of the sources has been selected, which consists of three-phase unbalance factor, duration ratio and increments of the second harmonic. Afterwards the weight of the evaluation indices is calculated based on an analytic hierarchy process. A novel estimation criterion is proposed in order to establish fuzzy membership functions for each index. The method has been verified by application to simulated and measured data. The presented estimation criterion improves the accuracy of source identification by reducing the influence of sample errors.

Research on the classification of voltage sag sources based on events recorded by online Power Quality monitoring systems is presented in [B4-0907(CN)]. An accurate classification of voltage sag sources is essential for designing effective and efficient mitigation and management strategies. For a comprehensive classification of voltage sag sources, eight categories including short circuit faults, transformer energizing, induction motor starting, lightning faults, self-extinguishing faults and multistage voltage sags are introduced and analysed in detail. For the voltage sag events recorded by online Power Quality monitoring systems both the instantaneous and the RMS value of the waveform of the typical recorded event are given for each category of voltage sag sources. Furthermore, the causes and the waveform characteristics are analysed and summarized for each category. Statistical results for 369 voltage sag events are discussed. With 80.22%, short circuit fault has been identified as main cause of voltage sag events. The aim of the paper is to provide a theoretical basis for the detection and identification of voltage sag sources.



a) Instantaneous value

b) RMS value

Fig. 30: Recorded waveform of a voltage sag due to self-extinguishing faults [B4-0907(CN)]

Trends in Power Quality Indices

As the quantity of Power Quality information is continuously increasing, the in-depth mining of Power Quality data and the prediction of trends using adequate indices is gaining importance for distribution system operators. In the future the reliability and operation efficiency of the grid will depend on a comprehensive evaluation of the actual condition of the grid and a reliable forecast of trends. Power Quality indices have to be adapted to new types of grids. For benchmarking purposes the definition and interpretation of indices has to follow precise and generally applicable rules. 5 papers dealing with trends in Power Quality indices have been submitted in this subsection.

[B4-0336(CZ)] highlights the problem of variations in calculation methodology for continuity indicators SAIDI, SAIFI and CAIDI which are used for quality comparison. The calculation methodology for each indicator can vary for each country and distribution system operator. Model examples are presented for different types of failures. The paper introduces the calculation methodology for the Czech Republic that could be standardized through the EU. Short-term interruptions do not yet have to be reported to the regulator, but are already monitored in many countries. As they can be dangerous to sensitive customers they have been analysed by a series of wide area measurements on the low voltage level and an average value of short-term interruption rate 5.3 and MAIFI 3.6 was defined. The authors also point out the need to standardize the calculation methodology for short-term interruptions between member states of the EU and distribution system operators.

[B4-0120(CN)] deals with the prediction of Power Quality indices through the analysis of monitoring data. The proposed method is based on support vector machine, feature selection and cluster analysis. By the use of this method the prediction accuracy can be improved significantly. A case analysis is presented for a sample 35kV substation. The sample data include Power Quality as well as the corresponding weather, date type and other associated data. The voltage deviation data set is selected for analysis. The prediction of the voltage deviation for twelve continuous hours has been carried out for 61 days, an example is shown in Fig. 32. The average relative error using the proposed method is 5.22% compared to 20.01% using the Time Series Algorithm.

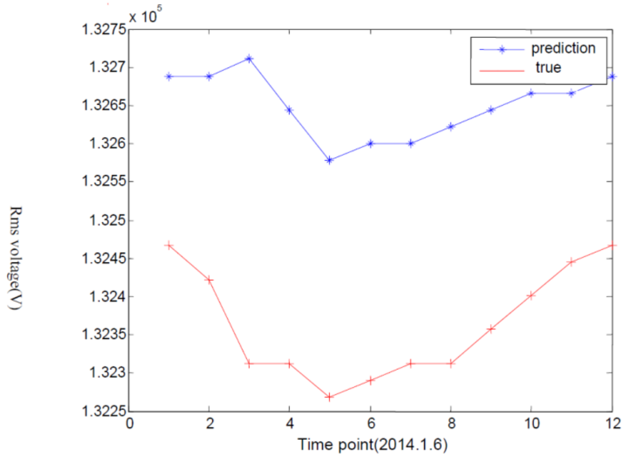


Fig. 31: Prediction results of the proposed method [B4-0120(CN)]

[B4-0488(EG)] points out the need for an Unified Power Quality Index (UPQI) to summarize the overall level of Power Quality disturbances and to aggregate the large quantity of data generated by Power Quality monitoring. This index can be used to determine sites with priority for Power Quality improvements, represent the level of Power Quality across large networks and for benchmarking utility performance against standards or other utilities. The authors propose an UPQI, which aggregates information on continuous Power Quality disturbances such as voltage level, unbalance, harmonics and flicker (Fig. 33). In a first step 95% cumulative probability values are applied for calculating the individual disturbance indices for each site. The indices are then normalized by dividing them by their standard limits and aggregated for each disturbance type, reducing the number of indices to five. The UPQI for each site is determined based on the exceeding value. Space aggregation across monitored sites for utilities can be accomplished by combining the individual values for each disturbance of all sites or by calculating the 95% cumulative probability value for the UPQI at each site.

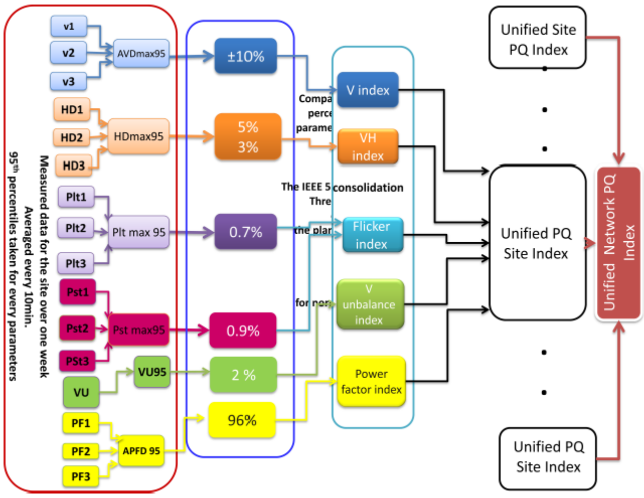


Fig. 32: Framework of the proposed UPQI [B4-0488(EG)]

In [B4-0505(IR)] a strategy is presented to select a limited number of measurement points by categorizing loads by region, type and transformer capacity. The main part of the paper deals with global power quality indices for comparison of different points in the grid to enable constant monitoring of power quality. For this purpose two strategies are used the combination of single indices of each power quality disturbance and combination of all indices at specific points. Two indices for combination of all indices have been defined and measured. An improved unified power quality index UPQI taking into account values in the neighbourhood of permissible values an index named K_{margin}, which is a paragon of indices margins. The results for the case study have shown that the harmonic injection of residential loads is higher than for industrial loads, which means, that monitoring of industrial loads is not sufficient.

[B4-0693(CN)] proposes a novel set of reliability indices, which are designed to assess the reliability of urban microgrids. Whereas the traditional indices SAIFI, SAIDI, ASAI and ENSI reflect the average supply reliability of the system, the proposed reliability indices for microgrids take into account a weight for important customers for each load point. Furthermore a new index called Energy Storage Optimization Degree (ESOD) is introduced in order to assess the effects of an energy storage system on reliability and economic efficiency. It is defined as the average improvement of a micro grid reliability index divided by the rated capacity. In a case study the impact of energy storage and two different load shedding strategy on the traditional and new reliability indices is analysed. The second load shedding strategy takes the importance of load points into account and cuts ordinary load points before important load points in ascending order according to load weight. The results show, that the results for the traditional and new reliability indices differ considerably. The new indices allow considering the heterogeneous importance of loads in a microgrid. The results show, that reliability increases with storage capacity with a greater marginal contribution for low values. The load shedding strategy has a considerable influence on the new indices, which is dominant as compared to storage utilization (Fig. 34).

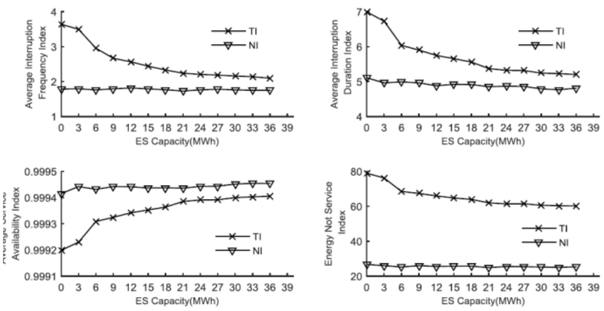


Fig. 33: Impact of energy storage size on traditional and new reliability indices with load shedding strategy prioritizing important loads.

Economic Aspects and Regulatory Issues

In many countries quality of supply is already regulated and different economic incentives are created to guarantee that quality standards are met. In future it is expected that voltage quality issues will also be covered by the regulation. The introduction of the monitoring of short interruptions has already been put into practice and is expected in more countries. In this respect the specification of the standard EN 50160 regarding voltage dips and swells is an important issue. This subsection comprises 7 papers highlighting unresolved issues and proposing innovative solutions.

[B4-0129(IR)] discusses the problem of current unbalances affecting LV grids. Whereas distribution system operators are responsible for providing symmetrical voltages at the point of coupling and for equal distribution of single-phase customers, three-phase customers are responsible for equal distribution of their single-phase loads. In order to order to make the customers fulfil the limits set for current unbalance, the paper proposes an unbalanced current based tariff based on both amplitude and angular unbalance.

In [B4-531(ID)] the effects of harmonics generated by a 20 kV arc furnace customer in Indonesia on the distribution grid and transformers regarding losses and lifetime are discussed and economically assessed. The authors recommend the application of a harmonic penalty tariff per harmonic order for customers which exceed the permissible standard values.

[B4-0676(BR)] presents an evaluation of the regulation of continuity in Brazil. In 2010 the regulation changed from imposing penalties on the electricity distributors for violation of collective continuity indicators like SAIDI and SAIFI to rewards payed by utilities for individual consumers. These rewards are based on individual continuity indicators per consumer unit or connection point and aim to compensate the effects of the violation for the affected consumers. The rewards take into account the severity and recurrence of the violation. The authors note, that it was a challenge to define adequate reward values. From 2010 to 2015 the total amount of individual rewards payed to consumers was almost equal to the simulated penalty according to the former regulation. From 2007 to 2015 the standard limits for SAIDI and SAIFI have been continuously reduced (Fig. 35). During this period SAIDI remained relatively constant, whereas SAIFI improved. Data from 2016 suggest an improvement of SAIDI and SAIFI at adequate level.

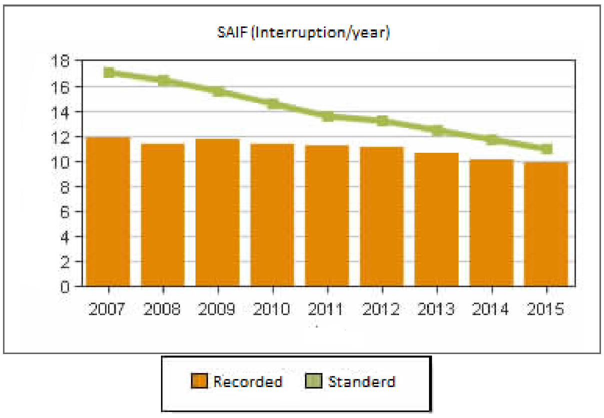


Fig. 34: Evolution of SAIFI in Brazil from 2007 to 2015 [B4-0676(BR)]

The new version of Performance Standards (2016) in Romania for power distribution and transmission services and a new revision of the Metering Code (2015) are discussed in [B4-0791(RO)]. The goal of the performance standards is to ensure the quality of service and to target investments to areas with Power Quality problems. For this purpose performance indicators alongside with provisions for their monitoring and recording are established. Taking into account the high penetration of renewable production in Romania, connection rules and Power Quality analysis of generation nodes are of essential importance. The new Metering Code integrates the new ICT capabilities in order to enable communication and access to relevant data. Furthermore the Metering Code revision makes intelligent metering systems the fundament of the Romanian Smart Grid Concept.

The Dutch Regulator has requested the network operators to prepare a proposal for a regulatory framework regarding voltage dips. [B4-0734(NL)] presents an initial proposal for the MV grid. Based on their impact on aggregated customers, voltage dips are divided into three clusters. At first weighting factors are determined from the measured relative power loss at the HV/MV substation after each phase-phase dip collected from six substations during four years. For regulatory purposes three clusters cA, cB, cC are formed by classifying the effects of the voltage dips as small, medium and big, respectively. For each type of dip (1-, 2-, 3-phase dips) the average number occurring in each cluster is predicted based on the statistical evaluation of the measured data (see Fig. 36). For the dips belonging to the cluster with small effect, the end-users are expected to choose adequate equipment to ride through these dips. For the dips belonging to the clusters medium and big the number of dips can be limited to an objective number to indicate the minimum quality of supply beyond which the network operator should investigate the problem.

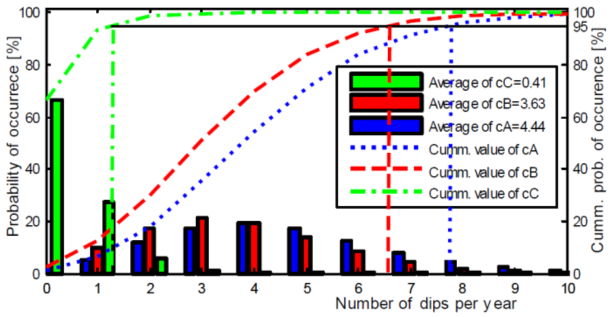


Fig. 35: Probability distribution and cumulative function of average voltage dip occurrences for the three clusters voltage dips [B4-0734(NL)]

[B4-1266(NL)] gives an overview over the methodology which is applied to deal with customer's complaints in the Netherlands. This complaint handling procedure was developed following the national level guidelines, which request efficient handling and full transparency to the customer. Furthermore, examples for typical Power Quality complaints and the process of handling with them are given. One example is spontaneous switching-off of PV inverters, which may occur due to the fact, that over and under voltage limits are not harmonized in different countries of the world. Power Quality monitoring data from the last four years indicate, that harmonic voltage levels are slowly increasing while the 15th and 21st harmonic voltage levels are regularly surpassed. New values for these harmonic voltage levels have been suggested to the Dutch standardizing committee.

An approach to optimize the investment level by determining a cost versus quality of service characteristic is presented in [B4-1241(BR)]. The study focusses on the installation of automatic reclosers in medium voltage distribution grids as possible measure in order to be able to clearly allocate the specific costs and improvements of the quality of service. A computational tool is used to determine the optimal positions for the installation of reclosers taking into account both normally open and normally closed devices. The tool determines the best combination for a given number of automatic reclosers maximizing the relationship between the reduction in quality of service indices (SAIDI, SAIFI and Energy Not Supplied ENS) versus equipment costs. A case study has been carried out for two distribution substations considering the relevant events for 2014 to calculate the failure rates and service time for each block of the medium voltage network. In a first step the allocation of a given number of reclosers in the network is optimized and the quality-of-service indices are calculated. On the base of this analysis the marginal costs of quality improvement are determined (Fig. 37). Finally, the results are discussed comparing the perspective of the utility with the point of view of the customer relating to costs of energy not supplied (CENS). The authors conclude that the current reliability levels are not in accordance with those required by the society and that investments are not being made at the optimum quality level.

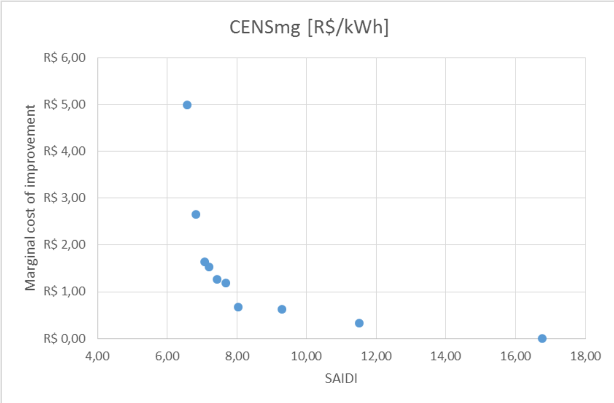


Fig. 36: Marginal Costs of Improvement dependent on SAIDI [B4-1241(BR)]

Potential scope of discussion

Smart distribution grid management systems are on the rise globally. Distribution system operators have the goal to minimize costs for the integration of distributed generation, electro mobility and use flexibility in the grid in a strategic manner. With this development goes the need for thorough PQ monitoring in order to enable optimal operation of distribution grid while maintaining reliability and respecting PQ boundaries. Data analytics and efficient data mining are keys in this process. In this respect, new concepts for unified PQ indices and fast and comprehensive visualization and forecast of the PQ in wide area distribution grids are of great interest.

This development entrains two issues, which have to be tackled from in advance. Electricity is the backbone of modern infrastructure, which requires its permanent availability for 24 hours on each and every day. Through the development of smart grids, a massive amount of new components, both hardware and software, will be integrated into the system. Even under the assumptions of an extremely high reliability of these components, overall reliability will decrease merely with the number of components if no countermeasures are taken. It is recommended to take into account the technical measures for guaranteeing a sufficient reliability in smart grids and their economic impact in the planning phase. Furthermore, the immunity of smart distribution grids against adverse external interference remains an issue, which has to be solved in the next years. The computerization of components (IoT), increasing reliance on properly working software and the large amount of data traffic will make the distribution grid more vulnerable. For this reason cyber-security must become a key element of grid design.

Paper No.	Title	MS p.m.	RIF	PS	other session
0066	Using Voltage Sag Measurements for Advanced Fault Location and Condition Based Maintenance	X		X	
0106	Evaluation of Long-term Voltage Swells Monitoring in the Distribution System			X	
0111	Analysis of Voltage Quality Parameters in LV Distribution Grids with Connected DES			X	
0120	Prediction of Power Quality Indicators Based on Clustering Analysis and Support Vector Machine			X	
0129	Unbalanced Current Based Tariff			X	
0146	Voltage Dips and Swells in Danish Distribution Grids			X	
0148	Analysis of Voltage Quality Parameters in MV distribution grid			X	
0246	Voltage Dips in Low Voltage Networks of Estonia			X	
0336	Evaluation of Long and Short Interruptions Indices of Power Supply in the Czech Republic			X	
0421	EDP Distribuição's Development of Support Tools and Platforms for Power Quality Management and Analysis			X	
0465	An approach to reduce MAIFI – the Quality of Service Indicator for Momentary Interruptions – the experience of the Portuguese DSO			X	
0488	Unified Power Quality Index for Electrical Network in Alexandria-Case Study	X		X	
0505	A New Power Quality Observation Algorithm to Power Distribution Network			X	
0531	Harmonics Penalty Tariff Design for Arc Furnace Customer			X	
0573	The Design and Application of Power Quality Monitoring System for the Smart Substation Based on IEC 61850			X	
0645	Enel Global Solution for Power Quality Monitoring and Analysis	X		X	
0676	Impacts of the Change in the Regulation of Brazil: Penalty for Violation of Continuity Indicators Versus Reward to Consumers.	X		X	
0679	New Publicly-Accessible Online Power Quality Monitoring Databases			X	
0693	Studies on Reliability Assessment Indices and Method for Micro Grid			X	
0734	Regulation and Classification of Voltage Dips	X		X	
0776	Classification of Voltage Sag Disturbance Sources Using Fuzzy Comprehensive Evaluation Method			X	
0791	Performance Standards Applied to Romanian TSO and DSO			X	
0907	Research on Classification of Voltage Sag Sources Based on Recorded Events			X	
1015	Evolution of the Quality of Supply in the Portuguese Distribution System				S6
1055	Distributed Generation at Distribution System Level Resilience to Voltage Dips - a Real Case				S4
1241	An Experience in Determining a Cost versus Quality of Service Characteristic in order to Define Optimal Investment Level	X		X	
1266	Dealing with Customer's Complaints Regarding PQ Issues - from DNO perspective			X	

SESSION 2 - Power quality and electromagnetic compatibility

Block 1 : Electric and magnetic fields, safety and interference

0092 **Comparison between magnetic and electric fields levels due to the operation of dry and oil distribution transformers**
G Abdel Salam, *South Cairo Electricity Distribution Company, Egypt*

0152 **Electromagnetic field level in the immediate vicinity of a linky meter**
D Picard, J Legrand, *CentraleSupélec GeePs, France*

0166 **Exposure to the electromagnetic fields generated by power lines carrying smart metering RF signals**
W Pirard, B Vatovez, P Bernard, *ISSeP, Belgium*

0237 **The effect of unbalanced loads in distribution transformers and ground network on electromagnetic fields**
M A Mahmoud, *North Delta Electricity Distribution Company, Egypt,* K Youssef, *Improving Energy Efficiency of Lighting & Building Applicence Project, Egypt*

0299 **Estimation of substation earth impedance in a global earthing system**
M Davies, R Weller, *Edif ERA, United Kingdom,* S Tucker, *UK Power Networks, United Kingdom*

0433 **Electromagnetic AC interface between high voltage overhead lines and pipelines sharing the same corridor**
A Anany, *North Delta Distribution Co, Egypt*

0452 **Validation of an integrated methodology for design of grounding systems through field measurements**
C Cardoso, L Rocha, A Leiria, *EDP Labelec, Portugal,* P Teixeira, *EDP Distribuição, Portugal*

0487 **Multilayer magnetic shielding: an innovative overlapping structure**
A Canova, *Politecnico di Torino, Italy*

0595 **Assessment of EMF-Exposure in residential buildings caused by smart metering systems using PLC**
A Abart, *Netz OÖ GmbH, Austria,* M Flohberger, *EnergieAG OÖ, Telekom, Austria,* R Hirtler, *ESF Vienna, Austria*

0653 **The influence of grounding transformer on ground fault current in MV networks**
H Opacak, T Calic, S Jergovic, *HEP Elektroistra, Croatia*

1005 **Using low voltage surge protection devices for lightning protection of 15/0.4 kV pole mounted distribution transformers**
F O Resende, *INESC TEC, Portugal,* J A Peças Lopes, *INESC TEC, Portugal/FEUP, Portugal*

1029 **High performance magnetic shielding solution for ELF sources**
A Canova, L Giaccone, *Politecnico di Torino, Italy*

1062 **New model for the calculation of harmonics in the residual earth fault current of medium voltage systems**
K Frowein, P Schegner, *TU Dresden, Germany,* U Schmidt, *HS Zittau/Goerlitz, Germany,* G Druml, *Sprecher Automation GmbH, Austria*

1065 **Making risk based earthing design accessible and effective**
W Carman, *Bill Carman Consulting ,Australia*

1230 **Magnetic field in an apartment located above 10/0.4 kV substation: levels and mitigation techniques**
M Grbic, *Electrical Engineering Institute "Nikola Tesla", Serbia,* A Canova, L Giaccone, *Politecnico di Torino, Italy*

1254 **Electric and magnetic fields from power grids in Brazil: regulation and monitoring**
D Vieira, C A C Mattar, H Lamin, *ANEEL, Brazil*

1261 **Ensuring public safety through proper earthing in low voltage networks**
S Bhattacharyya, *Enexis, Netherlands,* S Cobben, *TU Eindhoven, Netherlands*

1285 **Electromagnetic interferences in smart grid applications: a case study of PLC smart meters with PV energy generation**
D Roggo, R Horta, L Capponi, *HES-SO Valais-Wallis, Switzerland,* L Eggenschwiler, *HES-SO Fribourg, Switzerland,* C Pellodi, F Decorvet, *Services Industriels de Genève, Switzerland,* F Buholzer, *Landis+Gyr, Swizerland*

1292 **Levels of electric and magnetic fields inside 110/X kV substations**
M Grbic, A Pavlovic, D Hrvic, B Vulevic, *Nikola Tesla Electrical Engineering Institute, Serbia*

1294 **Hazards and protective measures at work on 20kV line in close vicinity to parallel 220kV line**
D Milun, *HEP ODS d.o.o., Croatia*

1297 **Assessment of the electromagnetic coupling between lines of different voltages sharing the same structures**
L Moraes, G Lopes, A Violin, E Wanderley Neto, *Federal University of Itajubá, Brazil,* A Piantini, *IEE/ University of São Paulo, Brazil,* G Ferraz, R Salustiano, R Capelini, *HVEX, Brazil,* J Campos, *ENERGISA, Brazil*

1303 **Analysis of magnetic coupling lines with shared structure using technique of finite elements**
M Lasmar, L Batista, E Tavares, *Federal University of Itajubá, Brazil,* G Ferraz, R Capelini, R Salustiano, *HVEX, Brazil,* J Campos, *ENERGISA, Brazil*

1352 **Investigation of lossy ground in lightning induced overvoltage at presence of surge arrester in CST software**
M Mehdi Khademi, M Hajizadeh, M Zakeri Ziyarati, *Hormozgan electrical distribution company, Iran*

Block 2 : Power quality issues of distributed generation and EV

0002 **Evaluating emission and immunity of harmonics in frequency range of 2-150 KHz caused by switching of static convertor in solar power plant**
J B Noshahr, B M Kalesar, *Ardebil Province Electricity Distribution Company, Iran*

0045 **Evaluating noise and DC offset due to inter-harmonics and supra-harmonics caused by back to back converter of (DFIG) generator in AC distribution network**
A Alizade, J B Noshahr, *Province Electricity Distribution Company, Iran*

0047 **Capacitor bank behaviour of cement factory in presence of supra-harmonics resulted from switching full power frequency converter of generator (PMSG Harmonic)**
B Mohamadi Kalesar, J Behkesh Moshahr, *Ardabal Province Electricity Distribution Company, Iran*

0058 **Comparison between types of DFIG converter with various switching techniques**
M N F Nashed, *Research Institute, Egypt*

0076 **How to deal with electromagnetic disturbances caused by new inverter technologies connected to public network**
X Yang, L Bertin, *EDF R&D, France*

0078 **Impact of control-command process in a photovoltaic conversion chain on the power line channel transfer function in the narrowband PLC frequency range**
C Wawrzyniak, V Moeyaert, F Vallée, *UMONS, Belgium*

0097 **Comparative performance of Wind Energy Conversion System (WECS) with PI controller using heuristic optimization algorithms**
H E Keshta, E M Saied, F M Bendary, *Benha University, Egypt,* A A Ali, *Helwan University, Egypt*

0132 **The impact of grid - connected photovoltaic system on power quality indices and it's output variations with temperature**
N Ahmed, A Sedky, A Fatehy, M Foda, *MEEDC, Egypt*

0178 **Performance indicators for quantifying the ability of the grid to host renewable electricity production**
O Lennerhag, G Pinares, M H J Bollen, *STRI AB, Sweden,* G Foskolos, T Gafurov*, MälarEnergi, Sweden*

0191 **Impact of PAJ with varying POW in voltage sag on rotor over-voltage in DFIG based wind generator**
J Ren, X-Y Xiao, Y-F Liu, Z-X Zheng, *Sichuan University, China,* W-B Chen, *Nanjing Golden Cooperate Information & Automation Technology Co. Ltd., China*

0227 **Harmonic disturbances up to 150 kHz produced by small wind turbines on the LV distribution grid**
C Leroi, E De Jaeger, *Université Catholique de Louvain, Belgium,* M Bekemans, *Thales Alenia Space, Belgium*

0241 **Impact of wind power plant operation on MV distribution grids**
M Tesarova, R Vykuka, *University of West Bohemia, Czech Republic,* M Kaspirek, *E.ON Distribution, Czech Republic*

0285 Smart voltage regulator to active voltage level management of distribution networks
L Neves Canha, *UFSM, Brazil,* P R Pereira, *UNISINOS, Brazil,* M Antunes, *CEEE-D, Brazil*

0324 Decongestion of the distribution grid via optimized location of PV-battery systems
J Van Ryckeghem, T Delerue, A Bottenberg, J Desmet, *Ghent University, Belgium,* J Rens, *North-West University, South Africa*

0351 Power quality aspects of solar power - results from CIGRE JWG C4/C6.29
J Smith, *EPRI, United States,* S Rönnberg, M Bollen, *Luleå University of Technology, Sweden,* J Meyer, A M Blanco, *TU Dresden, Germany,* K L Koo, *PB World, United Kingdom,* D Mushamalirwa, *Alstom, Germany*

0357 Voltage unbalance due to single-phase photovoltaic inverters
D Schwanz, S Rönnberg, M Bollen, *Luleå University of Technology, Sweden*

0456 CIGRE C4/C6.29: survey of utilities experiences on power quality issues related to solar power
J Meyer, A-M Blanco, *Technische Universitaet Dresden, Germany,* Sarah Rönnberg, Math Bollen, *Luleå University of Technology, Sweden,* J Smith, *Electric Power Research Institute (EPRI), United States*

0457 Harmonic, interharmonic and supraharmonic characterisation of a 12-MW-wind park based on field measurements
A-M Blanco, J Meyer, *Technische Universitaet Dresden, Germany,* B Heimbach, B Wartmann, M Mangani, M Oeschger, *EWZ, Switzerland*

0492 Flicker in distribution networks due to photovoltaic systems
H Karawia, M Mahmoud, M Sami, *AEDC, Egypt*

0662 DC bus voltage balancing controllers for split DC-link four-wire inverters and their impact on the quality of the injected currents
D Bozalakov, B Meersman, A Bottenberg, J Desmet, L Vandevelde, *Gent University, Belgium,* J Rens, *North-West University, South Africa*

0754 Power quality analysis of the Zhangjiakou Regional Network in China
C Ding, Y Zhang, *Tsinghua University, China,* X Li, J Ding, *State Grid Jibei Electric Economic Research Institute, China,* S Wei, L Wang, *Sien Electrical Engineering Co Ltd, China*

0834 Detailed power quality measurement of electric vehicle charging infrastructure
C Kattmann, K Rudion, S Tenbohlen, *University of Stuttgart, Germany*

0891 Harmonic emission assessment on a distribution network: the opportunity for the prevailing angle in harmonic phasors
B Peterson, J Rens, *North West University, South Africa,* J Desmet, *Ghent University, Belgium*

0927 Standard passive harmonic filter for wind farm connections
A Kazerooni, L Koo, *WSP | Parsons Brinckerhoff, United Kingdom,* C Brozio, Z Emin, *Power System Consultants, United Kingdom,* E Chalmers, *SP Energy Networks, United Kingdom*

0997 Measurement of voltage instabilities caused by inverters in weak grids
M Höckel, A Gut, S Schori, *BFH, Switzerland,* M Arnal, *BKW, Switzerland,* R Schild, *KWO, Switzerland,* P Steinmann, *ABB, Switzerland*

1009 A control strategy for reactive power and harmonic compensation of three-phase grid connected photovoltaic system
M T Hagh, M Jadidbonab, M Jedari, *University of Tabriz, Iran*

1047 Hybrid statcom solutions in renewable systems
E Perez, S Rementeria, *Arteche, Spain,* Aitor Laka, *Ingeteam Power Technology, Spain*

1074 Ultra fast charging station harmonic resonance analysis in the Dutch MV grid: application of power converter harmonic model
Y Sun, V Cuk, J F G Cobben, *TU Eindhoven, Netherlands,* E De Jong, *DNV GL, Netherlands*

Block 3 : Power quality measurement, analysis and mitigation methods

0101 How facts on the distribution system are being used to improve customer power quality
J Diaz de Leon II, B Lieblick, *AMSC, United States,* E Wylie, *AMSC, United Kingdom*

0201 Self-tuning indirect adaptive current control of shunt active power filters in electric power distribution systems
M Monfared, H Gholami-Khesht, S Alishahi, *MEEDC Iran,* M Zabihi, *Scandic Informatics and Techniques AB, Sweden*

0203 **Design and implementation of a single-phase shunt active power filter based on PQ theory for current harmonic compensation in electric distribution networks**
M Monfared, M-S Karbasforooshan, S Alishahi, *MEEDC, Iran,* N Nakhodchi, *Scandic Informatics & Techniques AB, Sweden*

0240 **Power quality measurements in a single house microgrid**
S Rönnberg, M Bollen, J Nömm, *Luleå University of Technology, Sweden*

0341 **THD minimization of multilevel inverter with optimized both DC sources magnitude and switching angels**
M T Hagh, F N Mazgar, S Roozbehani, *UOT, Iran,* A Jalilian, *Kermanshah Elect. Dist Co, Iran*

0346 **HVDC technology and power quality issues in Slovenian transmission system - technical study**
L Herman, A Bozicek, B Blazic, I Papic, *University of Ljubljana, Slovenia*

0376 **A new method to assess harmonic grid congestion in MV-networks**
S Uytterhoeven, Q Antoine, *Laborelec, Belgium,* P Vermeyen, *Eandis, Belgium*

0408 **Advanced ripple control signal calculation tools for DNO's**
S Uytterhoeven, D Empain, *Laborelec, Belgium,* P Vermeyen, *Eandis, Belgium*

0458 **Survey of supraharmonic emission of household appliances**
A Grevener, J Meyer, *Technische Universitaet Dresden, Germany,* S Rönnberg, M Bollen, *Luleå University of Technology, Sweden,* J Myrzik, *Technische Universitaet Dortmund, Germany*

0460 **Harmonic resonances in residential low voltage networks caused by consumer electronics**
J Meyer, R Stiegler, P Schegner, *Technische Universitaet Dresden, Germany,* I Röder, A Belger, *NRM Netzdienste Rhein-Main GmbH, Germany*

0493 **Harmonic analysis of street lighting lamps**
H Karawia, M El hoseiny, M Mahmoud, *AECD, Egypt*

0534 **Analysis of harmonic influence by high-speed electric railway's connection with power grid**
F Zhao, L Liu, *Shenyang Institute of Engineering, China,* F Sun, *Electric Power Research Institute of State Grid Liaoning Electric Power Co Ltd., China*

0621 **A power quality analysis and thermal properties of the system associated with the change of fluorescent lamps for LED lamps**
L Oliveira, M Fortes, D Carvalho, R Tomaz, A Fragoso, A Queiroz, *UFF, Brazil*

0627 **Harmonic analysis of lighting technology application - case study in distribution network: smart city buzios**
A Paula, A Fragoso, M Fortes, V Ferreira, A E Pereira, *UFF, Brazil*

0652 **Measurement and analysis of base transceiver stations power quality parameters and assessment of its unfavourable effects on Iran distribution systems**
K Roshan Milani, B Adham, *Electricity Distribution Company of East Azarbaijan province, Iran,* M R Banaei, F Mohajel Kazemi, *Azarbaijan Shahid Madani University, Iran*

0707 **Performance and stability study of a triple Dynamic Voltage Restorer (DVR) based on matrix converter**
R Ghazi, M R Alami, *Ferdowsi University of Mashhad, Iran,* M R Mozayeni, *Khorasan Razavi Electric Energy Distribution Company, Iran*

0747 **Determination of flicker contributions based on synchronised measurements of rapid RMS changes**
V Cuk, F Ni, S Xue, *TU Eindhoven, Netherlands,* A Jongepier, *Enduris B.V., Netherlands,* H van den Brom, G Rietveld, M Acanski, *VSL,Netherlands,* S Cobben, *Alliander, Netherlands/TU Eindhoven, Netherlands*

0790 **Study and comparison of the effect of conventional, low losses and amorphous transformers on the ferroresonance occurrence in electric distribution networks**
M Hajizadeh, I Safinejad, N Amirshekari, *Hormozgan Electric Power Distribution Company, Iran*

0807 **Frequency scans and resonance mode analysis for resonance problems identification in power networks in presence of harmonic pollution**
L Eggenschwiler, O Galland, P Favre-Perrod, *HES-SO Fribourg, Switzerland,* D Chollet, F Décorvet, *Services Industriels de Lausanne, Lausanne, Switzerland,* D Roggo, *HES-SO Valais, Switzerland*

0821 **Research of process immunity time of boiler coal feeding system in thermal power plant and solution to volatge sags**
L Wang, *Golden Cooperate Co., Ltd, China,* X Zhu, *NUAA, China,* H Zhang, Y Zhao, Z Zhu, *Shenzhen Power Supply Co.Ltd, China,* M Fan, *CEPRI, China,* Z Zheng, *Sichuan University, China*

0881 **A new generation voltage regulation distribution transformer with an on load tap changer for power quality improvement in the electrical distribution systems**
S Mokkapaty, J Weiss, F Schalow, *SBG Transformers, Germany,* J Declercq, *SGB-SMIT Group, Netherlands*

1012 The measurement of high frequency disturbances in Slovenian substations
U M Peterlin, T Živic, *Milan Vidmar Electric Power Research Institute, Slovenia*

1132 Interharmonics analysis of a 7.5kW air compressor motor
M Zhiyuan, M W Xiong, L Le, X Zhong, *Electric Power Test & Research Institute of Guangzhou Power Supply Bureau Ltd., China*

1267 Resolving inconsistencies in three-phase current measurements
A Urquhart, M Thomson, *Loughborough University, United Kingdom*

1337 A new novel method of harmonic analysis in power distribution networks using artificial intelligence
M Fayyazi, *Ardebil Electricity Distribution Company, Iran,* A Akbari Majd, *Mohaghegh University, Iran*

1359 Discussion on preconditions for reproducible measurements on power conversion harmonics between 2 and 150 kHz
J Knockaert, B Vanseveren, J Desmet, *Ghent University Lemcko, Belgium*

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M Tremblay, B Fazio, D Valiquette, *Hydro-Québec, Canada*

0106 Evaluation of long-term voltage swells monitoring in the distribution system
M Tesarova, *University of West Bohemia, Czech Republic,* M Kaspirek, *E.ON Distribution, Czech Republic*

0111 Analysis of voltage quality parameters in LV distribution grids with connected DES
M Kaspirek, L Mikulas, *E.ON Distribution, Czech Republic,* D Mezera, *E.ON Czech Republic, Czech Republic*

0120 Power quality index's predication based on cluster analysis and support vector machine
J Song, J Zhou, A Pan, *State Grid Shanghai EPRI, China,* Z Xie, X Yang, *Shanghai University of Electric Power, China*

0129 Unbalanced current based tariff
H Arghavani, *Tehran Electricity Power Distribution (TBTB) co., Iran,* M Peyravi, *Tehran University, Iran*

0146 Voltage dips and swells in Danish distribution grids
H Hansen, M Erleng, *Danish Energy Association, Denmark*

0148 Analysis of voltage quality parameters in MV distribution grid
M Kaspirek, L Mikulas, *E.ON Distribution, Czech Republic,* D Mezera, *E.ON Czech Republic, Czech Republic,* K Prochazka, *EGC Energoconsult, Czech Republic,* P Santarius, P Krejci, *VSB - TU Ostrava, Czech Republic*

0246 Voltage dips and swells in low voltage networks of Estonia
T Vinnal, M Jarkovoi, L Kütt, H Mõlder, *Tallinn University of Technology, Estonia*

0336 Evaluation of long and short interruptions indices of power supply in the Czech Republic
K Prochazka, F Broz, *EGC CB s.r.o., Czech Republic,* J Sefranek, *Energy Regulatory Office, Czech Republic,* M Konc, *CEZ Distribuce, Czech Republic,* M Kaspirek, *E.ON Ceska Republika, Czech Republic,* J Hradecky, *REdistribuce, Czech Republic*

0421 EDP Distribuição's development of support tools and platforms for power quality management and analysis
F Gonçalves, A Lebre, P Veloso, F Bastião, N Melo, *EDP Distribuição, Portugal*

0465 An approach to reduce MAIFI - the quality of service indicator for momentary interruptions - the experience of the Portuguese DSO
M Couto, J Pascoal, J Dias Matos, J Antunes, *EDP Distribuição, Portugal*

0488 Unified power quality index for electrical network in Alexandria-case study
H Karawia, M Mahmoud, *AEDC, Egypt*

0505 A new power quality observation algorithm to power distribution network
M Youhannaei, M E Honarmand, J Talebi, A Sharifi, *Gilian Electric Power Co., Iran,* H Mokhtari, *Sharif university of technology, Iran*

0531 Harmonics penalty tariff design for arc furnace customer
M Rusli, M Ihsan, *PLN, Indonesia*

0573 **The design and application of power quality monitoring system for the smart substation based on IEC 61850**
L Luo, S Chen, *State Grid Shanghai EPRI, China,* Y Yang, S Yuan, *State Grid SMEPC, China,* H Luo, *Hunan University, China,* Y Hu, *XJ Electric, SGCC, China*

0645 **Enel global solution for power quality monitoring and analysis**
J M Romero Gordon, *Endesa, Spain,* C Noce, *Enel SpA., Italy*

0676 **Impacts of the change in regulation in Brazil: penalty simulation for violation of collective interruption indications versus compensation for consumers**
A D S Barbosa, P L Carvalho, *ANEEL, Brazil*

0679 **New publicly-accessible online power quality monitoring databases**
K Kittredge, D Sabin, B Todd, *Electrotek Concepts, United States*

0693 **Reliability assessment indices and method for urban microgrid.**
T Ma, J Wu, *Beijing jiaotong University, China,* X Niu, *EDF holding limited company, China*

0734 **Regulation and classification of voltage dips**
L Weldemariam, V Cuk, S Cobben, *TU/Eindhoven, Netherlands,* J van Waes, *Movaris Energy, Netherlands*

0776 **Classification of voltage sag disturbance sources using fuzzy comprehensive evaluation method**
C Li, J Yang, Y Xu, Y Wu, P Wei, *North China Electric Power University, China*

0791 **Performance standards applied to Romanian TSO and DSO**
D Stanescu, D Federenciuc, *Electrica, Romania,* M Albu, S Gheorghe, *Universitatea Politehnica Bucuresti, Romania,* D Ilisiu, C Stanescu, *Transelectrica, Romania*

0907 **Research on classification of voltage sag sources based on recorded events**
P Wei, Y Xu, Y Wu, C Li, *North China Electric Power University, China*

1241 **An experience in determining a cost versus quality of service characteristic in order to define optimal investment level**
I O Cryillo, M A Pelegrini, G Quiroga, *Sinapsis Inovação em Energia, Brazil,* C F M Almeida, C M V Tahan, M R Gouvea, *University São Paulo, Brazil*

1266 **Dealing with customer's complaints regarding PQ issues - from DNO perspective**
S Bhattacharyya, *Enexis, Netherlands,* S Cobben, *TU Eindhoven, Netherlands*