Special Report - Session 1
NETWORK COMPONENTS

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Introduction

Power distribution systems are facing many challenges: ageing of components, implementation of smart grids and development of e-mobility, demand for more environmental friendly solutions… To prepare the networks of the future, new solutions and innovative network components have to be designed and implemented.

A record number of 134 papers have been selected for the Session 1 – Network Components – of CIRED 2011. About half of these papers originate from Distribution Network Operators (DNOs) and another half from manufacturers of equipment, suppliers of services to the DNOs, or research institutes. The different perspectives have been mixed in the four blocks retained for the organization of this special report and of the Main Session.

The structure of these blocks is as follows.

Block 1 Asset management (38 papers)

- General overview
- On-site tests
- Monitoring systems
- Others

Block 2 Innovative network components and solutions for Smart Grids (32 papers)

This block has been subdivided in seven categories:
- Fault current limiters (FCL) and alternatives
- Power electronics
- Electric vehicle (EV) integration
- Dynamic thermal rating
- Sensors, monitoring and communication
- Transformers
- Smart substations and testing

Block 3 Evolutions of standards and specifications, trends in network components for cable links and overhead lines (31 papers)

- Evolution in Standards
- Underground (UG) MV systems: Cables and components
- Over Head Lines (OHL) components
- Other points on LV and MV networks

Block 4 Trends in network components for substations (33 papers)

- Substations
- Transformers
- Switchgear

Only about 5 or 6 papers per block have been selected for oral presentation in the Main Session (MS), but all the papers can be presented in the Poster Session (PS). Like in the previous conferences, guided tours of the PS will be organised in order to facilitate the exchanges between authors and participants.

In addition to the Main and Poster Sessions, three Round Table (RT1a/RT5a, RT1b and RT1c) discussions and a Research and Innovation Forum (RIF) will take place within Session 1.

RT1a/RT5a is a joint Round Table organised by Session 1 and Session 5 which is entitled “Distribution networks for large cities: new components and system development issues”.

RT1b – “Components for smart grids and e-mobility” will discuss the problems and solutions related to the evolution of distribution grids, including the integration of supply for electric vehicles.

RT1c – “Internal Arc Classification - how to convert test results into personal safety on site” will present the latest developments and perspectives in this field.

Finally the authors from Block 2 who have submitted the six papers related to the development and application of Fault Current Limiters will be invited to present their papers and exchange with the audience in the RIF which will be focused on this topic.

Block 1: "Asset management"

Management of current aging networks and their evolution request an optimization of the network asset management and aging mechanisms understandings.

The 38 papers of this block have been classified into the following categories:
- Asset management (AM) – general overview
- AM currently supported by on site tests
- AM processes supported by monitoring systems
- Others

Asset Management – General overview
(4 papers)

Paper 514 – EDP – reports on how to manage millions of metering equipment and associated metering processes with the target to keep tracks of asset location, status, technical parameters operation and life cycle as well as to define new workflow. Solution used consists in a platform tool for data management and on the redesign of corporate process and workflow.

Paper 767 presents the Danish experience in the maintenance of the MV network where finally both cable technologies (PILC – XLPE) have been interconnected as in a lot of other countries. The paper focuses particularly on the importance of the transition joint in the failure rate and attempt to explain failure origins. In addition, a joint project between Danish utilities on PD measurements revealed that PD sources are distributed among three groups of components: PILC straight joints, transition joints and PILC cables.

Paper 948 reports about failures on network components which can affect the reliability of power systems. The analysis of the failure cause has a practical value since the knowledge of failure cause could help the power utilities to take remedial actions and determine appropriate method for failure reduction. An extensive cause analysis was carried out in Vattenfall distribution. Each segment of the distribution network - both LV and MV - was analyzed: OHL, UG cables, Fuses and apparatus for LV; OHL, UG cables, primary and secondary substation for the MV components. The primary causes and numbers of failures are given for the different categories.

Paper 1095 presents the so called SmartLife initiative, which is a European coordination project related to the asset management of the distribution and transmission networks. SmartLife bring together 26 European partners in both transmission system operators (TSO's) and distribution system operators (DSO's), R&D institutes and Universities in 9 countries (AT, BE, FR, IT, NL, NO, PT, ES & GB). A core group was constituted of utilities and key institutes EDF R&D, ENEL, ERDF, Iberdrola, KEMA, RTE and SINTEF under ERDF coordination. The initiative is made up of 5 groups gathering 60 experts and asset managers, 3 groups focused on the key network components (cables, accessories, OHL, transformers) will identify the critical equipment technologies and key factors generating failures, on-site diagnosis methods, health index evaluation. The 2 others are concerned with AM practices of TSO's and DSO's. The objective of SmartLife is to optimize the management of both current aging and future assets by considering ratio of network performance to renewal cost.

Fig. 1: from paper 166, after laying testing by a 250kV DAC system of a 6km long 150kV XLPE cable link

AM currently supported by on-site tests
(17 papers)

Cable and network aging (7 papers)

A few technologies are now available to assess a link before being energized either after installation or repairing. In addition to Damped AC (DAC) voltage testing, Partial Discharges (PD) and Dielectric losses measurements are more and more considered as potential tools for network assessment. Time Domain Reflectometry (TDR) method is also considered.

Paper 166 presents definition and practical application of testing procedures of DAC testing combined with sensitive PD detection for on-site testing of newly installed long length. Practical examples presented on 50 kV (12 km) and 132 kV (7.8 km) large underground circuits confirmed the interest of both continuous and damped AC test with PD measurements.

The purpose of the paper 399 is a Web database dedicated to PD measurements on the German MV network and the associated visual inspection of the located PD faults. The aim of this tool is – thanks to contributions from a large number of participants – to build up a comprehensive base in the medium term. Statistical approaches can be developed for risk assessment in accessories due to PD.

Paper 389 proposes dielectric losses measurement based upon charging current analysis when VLF voltage is applied on power cables (Hamon approximation).

As various PILC cables designs have been in operation for years in the French MV network, the paper 769 from ERDF,

with the support of EDF R&D, examines PILC components ageing (paper and impregnating compounds) and, thanks to a few tests and analysis, proposes some critical level for accessible characteristics of the insulating paper which could trigger the replacement of aged cables.

Time Domain Reflectometry – Cable Radar – is considered in paper 1070 as an interesting method on underground cables using the change of impedance all along the cable to pre-locate faults but with some restrictions in distance and unnecessary reflections mainly generated by branches. The use of a ferrite bead for suppression of high frequency signals could improve TDR measurements.

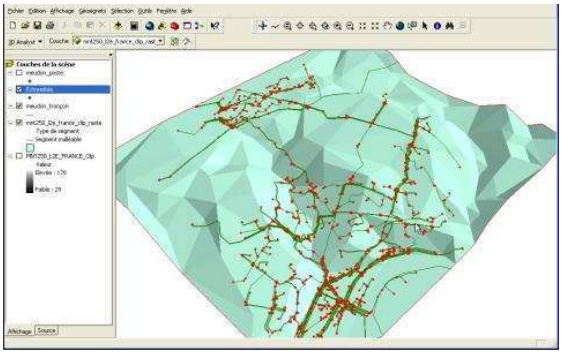

Fig. 2: from paper 1327, a new tool to get environmental data

An economic cable assessment (paper 1023), supported by qualitative – such as manufacturer, design, type, age, or utilization, cable faults, number of sections and joints – and quantitative factors like sheath testing, PD and dissipation factor measurements, points out the requirement for a multitude of information.

Health index (HI) evaluation approach, as also mentioned in SmartLife initiative (paper 1095), is proposed in paper 1327 on a specific case study in Paris area, the main issue to solve remains accurate data collection. A new "geomatic" tool was used to superpose the tracing of underground network and altitude - large interest for HI assessment of PILC underground cables.

Power Transformers (5 papers)

In distribution systems, power transformers represent a complex and critical assessment. Rapid, cost effective, non destructive diagnosis is an increasingly important area of AM. The development of non destructive methods calibrated by tests on end of life transformers can deliver a better appreciation of life time expectancy.

Non destructive methods were developed for both key components of the transformer insulation. The diagnosis on the insulating paper could be performed (paper 1030) and on-site tests can be performed on the oil (papers 24 and 831). Vibration measurement methods (paper 746) are also proposed with on line monitoring. An improved oil treatment device using HF technology can reduce time treatment (paper 231).

Paper 1030 exposes the development of a non destructive analysis of the coil insulation by determining the degree of polymerization, indicator of degradation of the paper, thanks to a portable fibre-optic probe. Following calibration and measurements trials in the laboratory, the instrument has been used in the field.

Regarding oil paper 24 relates positive results obtained with maintenance strategy based upon on site tests on oil. In addition to that it points out the need of an appropriate data management process and development of workforce skills.

Paper 831 presents an evaluation method of the components of aged transformers. Thanks to correlation analysis weak components of a transformer can be detected and corrective actions could be planned.

OHL and sub-stations (5 papers)

Visual inspection, either from helicopter or ground based, remains the most appropriate way for the condition assessment of OHL. Paper 360 presents the tool "photos-gauge". Based on a visual report, this tool allows refining the treatment of inspections. Infrared thermography is confirmed as an interesting tool for detecting hot spots in MV aerial networks (paper 252).

Paper 803 is focused on wooden poles condition assessment and proposes some new methods. The objective remains to get a better estimate of remaining lifetime with the final goal to reduce maintenance and replacement costs.

For condition assessment of aged surge-arresters in HV substations, the use of high frequency current transformer (HFCT) for PD measurements is presented in paper 1283.

Mathematical model – validated by experimental results – can be used for real time monitoring of OHL and risk assessment (Paper 1078).

AM processes supported by on-line monitoring
(13 papers)

On cable and other network components (10 papers)

The final goal of on-line monitoring is to get in real time an active management of the network based on the condition, capacity and capabilities of the assets. Paper 980 presents a general overview of on-line condition monitoring of distribution network assets.

Partial discharges measurement is more and more considered as the most judicious way to assess MV networks. With the cost of equipments decreasing (paper 1286) and improvement of the performance of PD detection, on-line condition monitoring is expected to play an increasingly vital role in the management of MV underground networks.

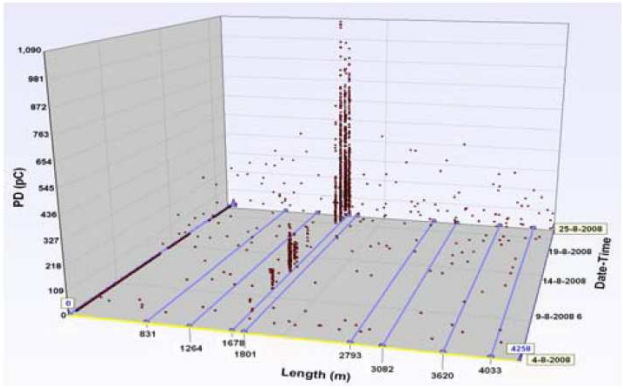

Fig. 3: from paper 875, PD activity over 3 weeks in a joint at 1678 m in an XLPE cable of 4258m, followed by a breakdown in that joint.

Although current on-line PD measurements systems performance is continuously improving, in Partial Discharge pattern recognition (paper 327), PD location (paper 994), cable mapping (papers 479, 875), still some conditions are to be met in order to target accurate replacement decision (paper 1189). It was demonstrated that in many cases there was a good correlation between PD activities and breakdowns. Even the use of PD analysis for automated failure prediction is still under evaluation (paper 907); when PD are identified and localized, there was enough time to perform repair action (paper 875) before breakdown occurs.

HFCT sensors can be used as PD detectors when placed on earth connections of terminations (in substations or switchgear). Paper 1205 describes PD monitoring on MV network in an industrial environment which makes more difficult but still possible the PD detection. On-line PD monitoring in various cases – from 6.6 kV up to 30 kV – are presented in paper 1257.

Paper 0327 presents the use of Phase Resolved Pattern identification for PD signal analysis and points out the importance of de-noising, data collection and treatment processes.

On line monitoring on switchgear (3 papers)

Discharges phenomena can create faults and false alarms in switchboards (papers 185, 862 and 1005).

Paper 1005 describes the interest of using a multi-sensor device (optical fibre signal, sound pressure and ozone detection) to detect pre-discharge phenomena. Paper 185 raise questions on the correlation between Partial Discharges signals and fault presentiment ways. Relationship between Partial discharges level and load and enhanced criticality assessment for both cables and switchgear are discussed in paper 862.

Others
(4 papers)

Paper 176 presents the very interesting experience in the use of PD sniffer for workers safety when they have to work in underground vaults. Temporary single phase to ground faults indicate insulation deterioration in non-effectively earthed distribution network (paper 441).

Paper 668 shows that based on a new proposed hidden Markov model (HMM), mechanical fault diagnosis scheme is feasible and applicable. Polymer end of life indicator using a portable fibre-optic spectroscopy probe and the Raman-spectroscopy method is described in paper 703.

Potential scope of discussion

Methods and tools for asset management of network components: what is the proper level for sharing of best practices and for collecting and sharing data about components reliability and impact of ageing? how to keep the required confidentiality in these exchanges?

On line PD monitoring: do the prospects of cost reduction and improved prediction reliability allow considering a larger deployment in the future?

Real-time monitoring of OHL: can it be used for safe overload management?

Table 1: Papers of Block 1 assigned to the Session

Paper No. Title	MS a.m.	RIF	PS
0514 (PT): Intelligently managing metering assets in a changing environment			X
0767 (DK): Service experiences in Denmark with mixed medium voltage (MV) cable systems consisting of both XLPE and PILC cables technologies			X
0948 (SE): Failure Causes of Distribution Network Components			X
1095 (FR): Outcome of SmartLife : a European coordination action in asset management of T&D networks	X		X
0166 (CH): Modern Methods of After-laying testing of Power Cables			X
0399 (DE): Evaluation of PD Measurements on MV Cable Systems by Means of a WEB Database			X
0389 (DE): Dielectric loss measurement of power cables using Hamon Approximation			X

0769 (FR): Paper-impregnated MV Cables Ageing			X
1070 (GB): Improving TDR measurement in multi-joint cable network			X
1023 (AT): Integral cable condition assessment			X
1327 (FR): Health Index : a technical indicator of underground network reliability			X
1030 (GB): Non-destructive DP analysis of kraft paper from shell-type power transformers			X
0024 (AR): Maintenance strategies to optimize the management of power transformers			X
0831 (AT): Diagnostic Measurements for the Condition Evaluation of Power Transformers			X
0746 (CN): Non-electric measurements-based on-line diagnosis method for the fault of transformer windings			X
0231 (UA): Equipment for adsorbent regeneration with application of high-power UHF electromagnetic field			X
0360 (FR): Rethinking helicopter-based inspections			X
0252 (EG): Infrared Thermography and Distribution System Maintenance in Alexandria Electricity Distribution Company			X
0803 (NO): Maintenance Cost Reduction by Improved Methods for Condition Assessment of Wood Poles			X
1283 (BR): Partial discharges measurements at field, in aged surge arresters			X
1078 (CN): Real -time monitoring of overhead transmission line and its risk assessment	X		X
0980 (GB): On-line Condition Monitoring of Distribution Network Assets - Making the Network Smarter	X		X
1286 (ES): Design and field test of low-cost online monitoring system in medium voltage underground cables			X
0327 (GB): Automatic Partial Discharge Pattern Recognition for Use in On-line Cable Condition Monitoring Systems			X
0994 (GB): Improved Algorithm for on-line Partial Discharge Location in Cables			X
0479 (GB): Improving the management of MV underground cable circuits using automated on-line cable Partial Discharge mapping			X
0875 (NL): The intriguing behaviour over time of PD's from defects in MV cables and accessories; lessons learned with SCG, an on-line monitoring system	X		X
1189 (FR): On line MV diagnostic method for failure prevention: case of application			X
0907 (GB): Data mining methods to predict failure due to partial discharge			X
1205 (GB): Detection and Location of Partial Discharge in MV cables in electrically noisy industrial environments			X
1257 (DE): On-line continuous PD monitoring for in service distribution class cables and switchgear			X
0185 (CN): Use and Problems of On-line PD Measurement Technology on Switchgear in Guangzhou Distribution System			X
0862 (GB): Location of switchgear partial discharge by panel and techniques to correlate switchgear and cable partial discharge with load and substation environment	X		X
1005 (IT): A multi sensor device for monitoring pre-discharges in medium voltage equipments			X
0176 (CA): Partial Discharge (PD) sniffer for workers' safety in underground vaults	X		X
0441 (CN): On-Line Condition Monitoring of non-effectively Earthed Distribution Network Using Transient Earth Fault Signals			X
0668 (CN): Online Monitoring and Fault Diagnostics of Mechanical Conditions of High-voltage Disconnector			X
0703 (NL): Polymer End-of-Life Indicator			X

Block 2: "Innovative network components and solutions for Smart Grids"

Innovative solutions and network components are needed for the "smart" distribution grids of the future, to cope with the high level of integration of distributed generation, and the flexibility in operation that will be required.

The 32 papers of this block have been classified into the following categories:
- Fault current limiters (FCL) and alternatives
- Power electronics
- Electric vehicle (EV) integration
- Dynamic thermal rating
- Sensors, monitoring and communication
- Transformers
- Smart substations and testing

Fault current limiters (FCL) and alternatives
(8 papers)

Massive integration of distributed generation (DG) into the networks may raise the short-circuit level above the rating of installed switchgear. One possible solution is to use fault current limiting devices located at strategic locations in the grid to maintain the short-circuit currents at an acceptable level.

The following six papers present different concepts of superconducting fault current limiters (SFCL), all using high temperature superconductors (HTS) operating at liquid nitrogen temperature.

Paper 456 reports on three trial tests launched in different UK distribution networks:
- the first trial test in ENW network is now completed (the preliminary stages were reported in paper 140 of CIRED 2009) and the lessons learnt are presented;
- a second trial test will be performed in Scottish Power network with a SFCL of same technology but larger rating (the technology used for the first 2 installations is also described in paper 352);
- a third trial will be launched in CE Electric network with a different technology (pre-saturated core FCL, also described in paper 680).

Paper 1162 reports on the first steps of the European research project ECCOFLOW. Second generation (2G) HTS conductors will be used in a three-phase resistive SFCL (rating 24 kV – 1000 A) associated to a parallel limiting air coil, in order to minimize the use of HTS material while meeting the limitation performance and the maximum allowed temperature rise. Results of preliminary simulations of the short-circuit behaviour are given. Next steps are to complete the on going measurements on the first test objects, and define the detailed design of the SFCL.

Some of the authors of the previous paper also report in paper 339 on the results of the Italian National SFCL project. Simulation studies, design and testing of a single phase SFCL (rating 9 kV – 220 A) with first generation (1G) HTS are presented. Short-circuit tests show excellent agreement with simulation results.

Paper 352 reports on the status of several SFCL projects implemented or lead by Nexans SuperConductors. For 1G HTS (BSCCO bulk material manufactured by Nexans) are mentioned the UK trials 1 and 2 (paper 456 above) and a third installation (rating 12 kV – 800 A) in a Vattenfall power station in Germany. Two new projects (ENSYSTROB in Germany, and the European ECCOFLOW also presented in paper 1162) have been launched recently to ascertain the possibilities with 2G HTS (YBCO coated conductor).

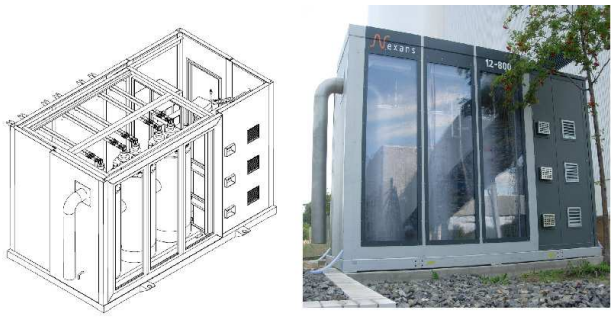

Fig. 4: from paper 352, SFCL 12-800 installed in the power station.

The technology of saturated-core SFCL is explained by the manufacturer Zenergy Power in paper 680. In this design superconductivity is used to reduce the losses in the DC coil. The concept has been tested and proven in the "Avanti" circuit of the California Energy Commission. A new oil-insulated design (Compact FCL) is introduced which will be applied in the UK trial 3 (see paper 456 above). A project of 138 kV Compact FCL is starting with American Electric Power, that will bring the advantage of a reduced voltage drop under normal load, compared to conventional air-core reactors.

Finally a hybrid type FCL is presented in the sixth paper 801. This more complex solution combines HTS, used as a trigger, reactor and fast acting switches which insert the reactor and protect the HTS component. The advantage is the reduced use of HTS material. Tests to check the reliability of this combination have been performed at the KEPCO Power Testing Center. Conditions to be met for improving the overcurrent protection coordination by using FCL are also discussed.

The paper 1256 is related to superconducting cable links. In this case fault current limitation is only a side aspect. Some breakthroughs have been achieved in the preliminary works to prepare the 6 km HTS link that is planned by a Dutch consortium. These positive results (on cryostat performance, reduction of AC losses, withstand of stresses due to fault current limitation) make confident in the successful outcome of this project.

An alternative solution to the use of FCL is proposed in paper 494. It is an innovative concept of local intelligent medium voltage circuit-breaker (iCB) that can sense very fast what will be the peak value of the fault current and decide on its ability to handle the short-circuit current. If the answer is negative, the iCB will wait for some upstream circuit-breaker feeding the fault to trip and reduce the current to a manageable value before opening. The local intelligence (combined with reclosing function) will ensure that the appropriate sequence of switching operations is performed among the involved iCBs to restore the energy supply in an optimal way. To reduce the power flows balancing transients between DG and the grid, it is shown that fast acting circuit-breakers have an advantage over conventional ones. However to compete with the FCL option this concept must be applicable for upgrading of the installed base: more studies on the transient behaviour of the conventional iCB in large and complex grid structures are under way to confirm the feasibility.

Power electronics
(5 papers)

Non specialists will find in paper 55 a clear introduction to the role that can play voltage source converters (VSC) in future grids. It is explained how VSCs can be used in conjunction with DG to control the power flows within microgrids, or as high voltage direct current (HVDC) connection of a microgrid to the utility grid in order to better control the exchanges between the two grids, and mitigate disturbances.

The next three papers are more for specialists and address several technical issues.

Paper 603 provides results of calculation and simulations of operation of modular multilevel converter (MMC) in case of dc pole to pole fault in a HVDC system. The parameters to be selected for protection against excessive overcurrents in the converter arms are explained.

Paper 1098 compares the respective merits of cascaded H-bridge (CHB) converter topology with that of MMC, for use in battery energy storage systems. It is shown that CHB with DC/DC converter has advantages in terms of components cost and efficiency.

Paper 278 presents simulations which show the advantage of H-bridge (also termed Full-bridge in paper 1098) MMC for HVDC transmission systems in terms of fault breaking capability, which can compensate the increased semiconductor losses.

Finally paper 693 makes a good transition with the next two papers on electric vehicle (EV) integration. A universal power electronic interface is described, that can be used for connection of a consumer grid (including DG) and of EV charging station to the utility grid. This interface uses back-to-back VSCs (see paper 55) for utility/consumer grids connection, and DC/DC power module for EV connection. The control strategy is explained and the simulation results show how it is possible to avoid that disturbances in one grid affect the other.

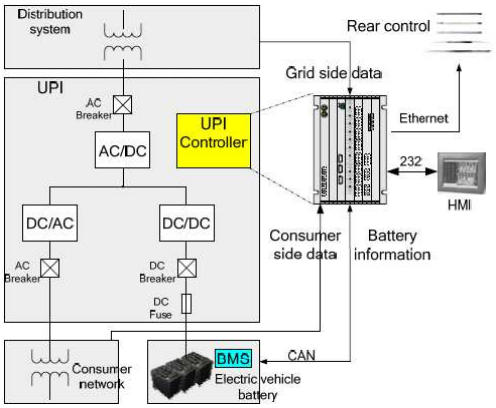

Fig. 5: from paper 693, schematic of the control system of the universal power electronic interface.

EV integration
(2 papers)

In paper 531 EDP Distribuição reviews the solutions needed to implement the infrastructure for charging electric vehicles. The concept of a universal charging station is presented, with the necessary functions. For efficient use of the available power smart protection and metering will be necessary. In a first step only slow charging will be available as fast charging needs to be adapted to a specific battery type. Therefore standardisation of batteries will be necessary before implementation of a fast charging infrastructure.

Paper 1295 is a presentation of the Green eMotion European project. The purpose is to standardize the charging infrastructure, particularly the level 3 (fast charging). Safety and interoperability requirements are to be taken into account for selecting the proper choices for the infrastructure and the coupling system between EV and charger (e.g. wireless inductive coupling).

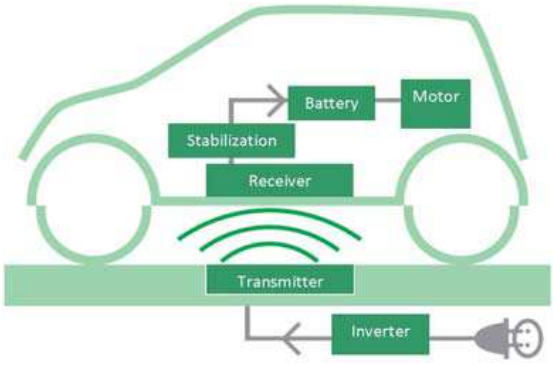

Fig. 6: from paper 1295, basic layout of a contactless battery charging system.

Dynamic thermal rating
(4 papers)

The interest of dynamic thermal rating for Smart Grids is well explained in the abstract of paper 918: "Dynamic thermal ratings have the potential to offer a cost effective alternative to network reinforcement for Distribution Network Operators looking to accommodate load growth or distributed generation connections".

A review of the state of the art in dynamic thermal rating is given in this paper 918, with special focus on the overhead lines (OHL), where the maximum current carrying capability variation can occur, depending on the ambient conditions. Direct and indirect monitoring techniques are described for OHL. Several demonstration projects are being implemented in the UK, for dynamic thermal ratings have been identified by the UK regulator, Ofgem, as a key enabling technology for the increased penetration of DG and the transition towards low carbon distribution networks.

Paper 502 reports on pilot investigations launched in Portugal to assess several systems available in the market for estimating the real-time (i.e. dynamic) current carrying capacities of OHL. Some of these systems (current and temperature sensors mounted on the conductor) are already in service and have shown a generally good agreement of measurements with the formula of IEEE 738 standard. However some notable deviations may occur depending on the local weather conditions.

Paper 1219 reports on the continuation of a work already presented at CIRED 2009. A self learning expert system (SLES) for dynamic thermal rating of power transformers has been improved and can find the optimal factors, based on a data base of historical ambient and load conditions, that best describe the thermal behaviour of power transformers: this SLES now provides a reliable dynamic thermal rating tool which allows to use more efficiently these important assets.

Finally paper 495 also reports on progresses since a previous paper at CIRED 2009. A thermal static model of gas-insulated switchgear has been refined to cover also time-dependent simulation of temperature rise. Good agreement between simulation results and measurements has been achieved. This improved model can be used not only for the design of switchgear but also for the prediction of overload capabilities. However, due to the relatively short time constant of these equipments significant overloading (in the order of 10%) can only be achieved for short durations (1 to 2 hours) of the load peak, when starting from a low base load.

Sensors, monitoring, communication
(6 papers)

In the future distribution grids will need to have more capabilities for measurement, monitoring and communication for control, like the present transmission grids.

To manage actively the power flows in the grid a first step is to measure voltages, currents and phases in the relevant nodes. Therefore it is necessary to introduce suitable voltage and current sensors in the secondary substations. The main difficulty will be the refurbishment of existing substations. Paper 1091 proposes solutions for the upgrading of the different types of substations (typically equipped with air-insulated or gas-insulated switchgear), both for measurement (voltage and current sensors) and for communication (power line carrier (PLC) couplers).

Paper 822 presents a review of the characteristics of the modern low power current and voltage sensors. This new generation of instrument transformers is well suited to the microprocessor-based relays and meters. Their main advantages over conventional current and voltage transformers are their wide range of measurement (in current, voltage, frequency) and their lower weights and costs. Voltage and current measurements can be combined in one sensor in order to reduce the size of switchgear.

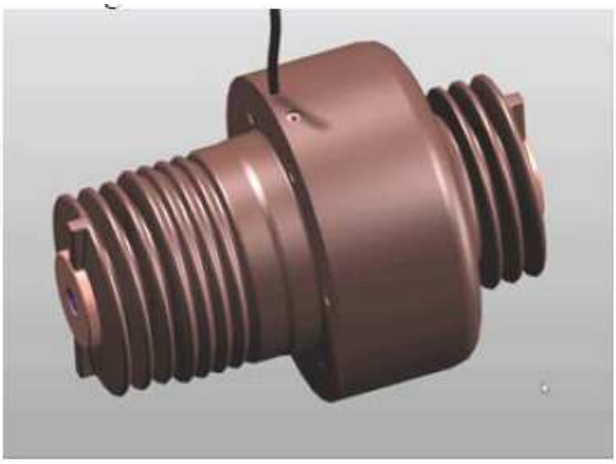

Fig. 7: from paper 822, Combined voltage and current sensors in an epoxy-resin bushing.

Condition monitoring of the different network components will also be necessary for efficient management of the future Smart Grids. Paper 223 reports on research conducted by KEPCO to study what can be imagined in this field. Feasibility of introducing different types of sensors in the various network components is presented. The main purpose is to get power quality information and self-diagnosis capability by monitoring. The example of an SF6 pole-mounted switch stuffed with all kinds of sensors shows that application to the installed base has not yet been taken into account.

Vacuum switchgear is widely used in the distribution grids, and starts to be used also in transmission and generation. For these applications the reliability stakes are very high and it can be considered to invest in a costly vacuum monitoring system. Paper 234 presents, from this point of view, a review of existing and novel pressure monitoring techniques potentially applicable to vacuum interrupters

(VI). Till now the difficulty for MV distribution vacuum switchgear has been to find a vacuum monitoring device whose cost and reliability must be consistent with those of the VI (i.e. low cost and high reliability are required), while meeting the constraints of high temperature withstand (due to the manufacturing process of VIs) and galvanic insulation.

A new range of "smart" MV vacuum circuit-breakers (VCB) is presented in paper 501. This VCB features integrated current and voltage sensors, as well as an integrated protection, control and monitoring unit, with communication means complying with IEC 61850 standard. This approach, which is rather similar to the approach for LV power circuit-breakers, can simplify specification and OEM integration into switchgear, provided that the user is ready to stop specifying and procuring independently the MV circuit-breakers, sensors and relays.

Finally paper 258 presents an innovative design rendered possible by a new type of sensors (clamp CT) associated to electronic meters. The new current transformer integrated meter (CTIM) developed by KEPCO features the following advantages over the conventional meter with external current transformers (CT):
- no wiring;
- compact design;
- no power cut for installation or replacement of the CTs.

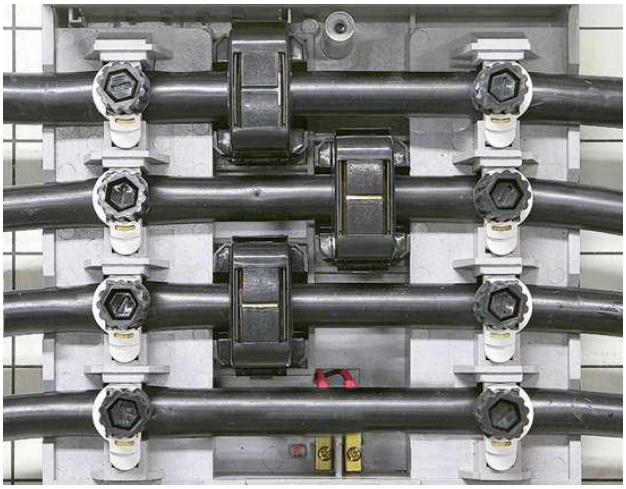

Fig. 8: from paper 258, clamp CT and voltage branch device for digital meter.

Transformers
(3 papers)

Transformers also need to evolve to meet the new requirements of Smart Grids.

Paper 1121 provides an overview of one possible future concept of distribution transformer (DT) suitable for the Smart Grids.

This DT is characterized by:
- reduced losses;
- on load voltage regulation (to control voltage on the LV network);
- condition monitoring and loss of life evaluation, with possibility of dynamic rating.

Paper 51 presents some evolutions of power transformers (PT) to better meet the demands of Smart Grids.

These new PTs will be:
- sealed, for less aging;
- environment-friendly (use of natural ester fluids);
- equipped with more efficient on-load tap changers (less wear, no oil contamination, thanks to vacuum switching) for better voltage regulation;
- fitted with intelligent monitoring, including assistance to dynamic rating.

Finally new types of transformers may become more common in the networks. This is the case of injection transformers, associated to power electronic converters, which can be used for dynamic voltage restoration in LV network, in order to increase the power quality (mitigation of voltage sags). Paper 899 proposes an improved injection transformer design, with the addition of an auxiliary coil (used as a dc reactor) to limit the transformer inrush current that is supplied by the converter.

A similar type of system is presented also in paper 1259 of Block 3, for use as a portable voltage regulator in LV networks.

Smart substations and testing
(4 papers)

Paper 130 gives an overview of the offer of modern solutions available for intelligent transformer substations ready for the Smart Grids:
- switchgear with sensors plus remote control and monitoring;
- remote terminal unit (RTU);
- communication and automation systems.

Some topics are listed as still in discussion, like:
- need for distribution transformers with automatic tap changers?
- use in overload of transformers with monitoring?

Paper 405 presents the implications for compact secondary substations (CSS) of the zone concept introduced by paper 622 in Session 3. Zone dividers can be circuit-breakers, load-break switches or disconnectors with remote communication and local intelligence for protection, control and measurement. The use of circuit-breakers as zone dividers is recommended as they allow operation in closed ring, to reduce the losses.

Smart CSS are the key nodes between zones: they are fitted with (voltage and current) sensors, fault passage indicators, ring main unit (RMU) controller, communication with the Distribution Management System (DMS). In the future the CSS controller will also take care of the transformer and the LV switchboard. Solutions must also be made available for

the upgrading of existing substations.

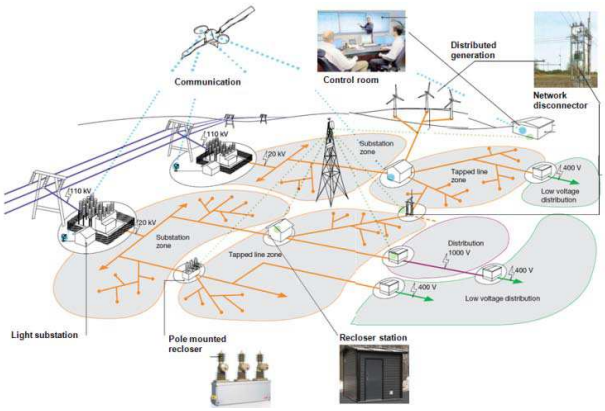

Fig. 9: from paper 405, the Zone concept.

Paper 205 reports on tests and field trials results since the presentation of the smart MV/LV substation at CIRED 2009 (paper 776).

The main features of this smart MV/LV substation are:
- control of voltage pollution;
- demand response;
- local control and monitoring;
- electricity storage system;
- step-less control of the voltage level on LV bus (smart transformer);
- bi-directional communication between home appliances and the substation.

The test results are satisfactory for the main functions of voltage control, harmonic damping and active power control.

This smart MV/LV substation has been tested at the Flex Power Grid Lab of KEMA. This laboratory is presented in paper 386, which describes the new testing facilities needed to validate the Smart Grids components. For these components must be performed, not only traditional power testing, but also digital simulation and model verification. The means of the laboratory allow reproducing the grid conditions, including in abnormal situation (e.g. high harmonic content). Examples are given of tests performed on three types of components: power electronics (grid inverters), conventional components confronted to new grid conditions (distribution transformers) and countermeasures (fault current limiters).

Potential scope of discussion

Fault current limiters: what is the potential market? How to compare the different available technologies?

Electric vehicles: what are the best solutions for safe, damage-proof and cost-effective charging stations? How to provide locally the high power needed for fast charging?

Dynamic thermal ratings: are these solutions mature enough to allow deferring network reinforcements?

Monitoring of distribution network operation: what is the proper balance between the cost of sensors (number, accuracy) and the level of information required for the network management in the presence of distributed generation?

Condition monitoring: what could be the main driver for the development of condition monitoring: the ageing of network components or the widespread availability of communication means linked with the implementation of smart grids?

New components for new network structures: will smart grids imply the implementation of innovative network structures associated with new network components?

Table 2: Papers of Block 2 assigned to the Session

Paper No. Title	MS a.m.	RIF	PS
0456 (GB): Fault Limiting Technologies in Distribution Networks		X	X
1162 (IT): The ECCOFLOW project: Design and simulations results of a Superconducting Fault Current Limiter for Operation in Electricity Networks		X	X
0339 (IT): Development and testing of innovative Fault Current Limiters for Distribution System Applications		X	X
0352 (DE): Nexans' Superconducting Fault Current Limiters for medium voltage applications - status and prospects		X	X
0680 (US): Saturated-Core Fault Current Limiter Field Experience at a Distribution Substation		X	X
0801 (KR): The Test and Installation of Medium Class (22.9kV) Hybrid type Fault Current Limiter in KEPCO Grid		X	X
1256 (NL): Breakthrough in development of superconducting cables	X		X
0494 (DE): Local Intelligent Circuit Breakers – A New Concept for the Refurbishment of Existing Distribution Network	X		X

0055 (IR): Application of Voltage Source Converters to Manage Power Flow and Enhance Operational Performance of a Microgrid			X
0603 (CN): Parameter Coordination of Modular Multilevel Converter for Robust Design during DC Pole-to-pole Fault			X
1098 (DE): Comparison of Cascaded H-Bridge Converters and Modular Multilevel Converters for the use in Medium Voltage Grid Connected Battery Energy Storage Systems			X
0278 (GB): H-Bridge modular multilevel converter for high-voltage applications			X
0693 (CN): A universal power electronic interface for distributed generation and electric vehicles	X		X
0531 (PT): Technical Solutions for Electric Vehicles Integration			X
1295 (DE): Green e-Motion - Adaption of E-Mobility Infrastructure to Mass Market Requirements	X		X
0918 (GB): Dynamic thermal ratings: The state of the art			X
0502 (PT): Increasing the operation efficiency of EDP Distribuição Overhead Power Lines			X
1219 (NL): Experiences with a Self Learning Expert System (SLES) for dynamic rating of power transformers			X
0495 (DE): Dynamic Thermal Simulation of Gas Insulated Switchgear			X
1091 (ES): Advanced sensors for the Smart Grid: how to deal with existing switchgear in secondary substations	X		X
0822 (CH): Applications of Low Power Current and Voltage Sensors			X
0223 (KR): Intelligent distribution equipment for fault anticipation of distribution network			X
0234 (GB): Pressure monitoring techniques of vacuum interrupters			X
0501 (IT): Smart eVolution, simplicity and reliability in the MV distribution network with IEC 61850			X
0258 (KR): The development of CT integrated Electronic meter			X
1121 (HU): Distribution transformers - ready for the Smart Grid			X
0051 (DE): New and innovative Smart and Green Transformer Technologies			X
0899 (ES): An improved power transformer design for dynamic voltage restoration applications			X
0130 (DE): Intelligent Transformer Substations in Modern Medium Voltage Networks as Part of "Smart Grid"			X
0405 (NO): Compact Secondary Substation in a future Medium Voltage Distribution Network	X		X
0205 (NL): Laboratory and field trial experiences with a smart MV/LV substation			X
0386 (NL): Performance evaluation of equipment under severe grid conditions			X

Block 3: "Evolutions of standards and specifications, trends in network components for cable links and overhead lines"

The 31 papers of this block have been classified into four main categories:

- Evolution in Standards
- UG MV systems: Cables and components
- Over Head Lines components
- Other points on LV and MV networks

Evolution in Standards
(7 papers)

Products developments are obviously driven by standards and vice versa. Eco-design is now more and more considered in the design of electrical and electronic equipment in Europe (paper 26). Incompatibilities are pointed out between some international standards dedicated to switchgear and their real use in DNO's. The evolution of added functions to the distribution network – Smart Grids – should impact MV network components standards.

Paper 26 presents the state of the art of regulations and standards in the field of eco-design to be applied in Europe for electrical component development. Since the early 2000's some European regulations and additional international standards have to be considered during development processes. The use of hazardous substances, energy and water consumption should eventually be

included in design process. Generalization of regulations and standards should reduce environmental impact but a reliable monitoring tool will likely be essential to follow evolution of these rules.

Four papers highlight some questions dedicated to switchgear and its environment, either regarding standard incompatibility with DNO's uses (papers 950, 971) or concerning specification (papers 87, 842).

Paper 950 reports about the impact of MV secondary substations on operating conditions and design of the switchgear. MV switchgear standards requirements seem to be more adapted to industrial networks conditions than DNO's: number of operations, service continuity due to various cable technologies and SF6 pressure indicator. Such a situation can induce some economical damages.

Paper 971 presents a study on life time estimation of SF6 MV metal enclosed switchgear according to on-site conditions in DNO's networks. Four stages are proposed: determination of temperature profile, determination of the SF6 leakage model versus temperature, model application to real conditions and lifetime deduction.

Paper 87 points out difficulty to test complete MV installation (switchgear and cable link) when installed or repaired before (re)energizing. Some clarifications in tests procedure and levels can be brought with the new IEC62271-200 standard. Cable testing operation is likely to take into account switchgear standards and vice versa.

Paper 842 presents the SYNERDIS group common specification of MV switchgear. The new specification – the structure of which is based upon IEC standard document – addresses harmonization of functional requirements for the current needs, future functions and construction design (Smart Grids), also type tests and requirements for the conformity assessment.

Paper 140 reports on basic principles of hazard and risk assessment and presents an assessment method customized for HV switchgear.

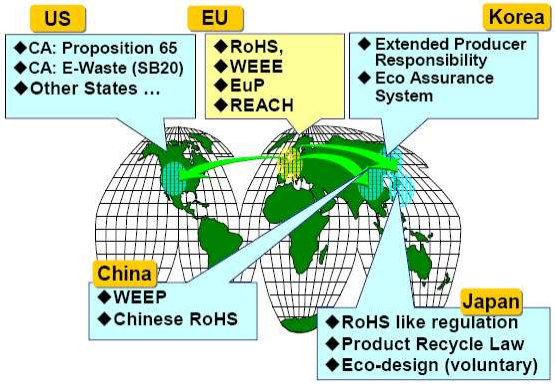

Fig10: from paper 26, Product policy spreads worldwide

Paper 1118 relates the quality policy within ESB regarding procurement of network components through the use of some key factors: quality criteria in the tender specification, factory inspections prior to contract award, routine and type tests as standard contract requirements, ongoing assessment of equipment performances.

Underground MV systems: cables and components (11 papers)

Three papers dedicated to Medium Voltage cables design or performance improvement: papers 37, 345 and 679.

Eco design or economical concerns are at the origin of the two projects presented in papers 37 and 345.

Major reasons to upgrade a 10 kV network are, as for similar experiences in Germany and China, the possible capacity increasing and investment postponement. The paper 37 proposes a 3-steps program to investigate the feasibility of upgrading a 10 kV network into a 20 kV one: theoretical study, experimental testing and field testing. A decision model is also proposed: 1) No Go, 2) only the cable but with 20 kV accessories, 3) all the system can be switched up to 20 kV.

A new insulating compound using HTPE (High performance Polypropylene Thermoplastic Elastomer) replacing XLPE, is proposed in paper 345. Authors explain the various development steps engaged since 2002. They compare the benefits of this material compared to XLPE, i.e. – some of them – recyclability (it's a thermoplastic compound), reduced production throughput time and energy consumption.

In the idea to provide information on the remaining life time of old XLPE cables generations, authors of the paper 679 present new results obtained with a 3 kHz accelerated growth of water trees in MV XLPE cables. Water trees phenomenon observed on cables from field can be compared to the one observed in cables submitted to the tests. 3 kHz test results were also compared to water trees obtained after 2 years test at 50 Hz and after 4 months at 500 Hz, authors propose this test as pre-qualification test for new cable or new insulating materials.

Polymeric materials are key components in cable design and for the expected associated electrical or mechanical performances. Four papers address this important topic under either matter with some environmental concerns (papers 982 and 203) or cable performance (papers 779 and 40).

Paper 982 presents the possible use of a new class of eco-friendly plasticizers for flexible PVC derived from renewable sources. A life cycle model, presented in paper 203, has been developed and shows an interest in cost of ownership for tree retardant XLPE compounds compared to other current compounds used in MV cable production. The model takes in consideration: cable and installation costs, expected cable life, end of life criteria, cost of repairing failure, cable losses.

Outer sheath integrity is a key parameter in the cable life

time: paper 779 proposes a methodology to evaluate the durability of HDPE sheath of electrical cables. Paper shows that PE thermal oxidation kinetics is affected by antioxidant vanishing which induces an increase in the PE sheath hydrophilic behaviour. Further step in the related study will be to build a general kinetic model for lifetime prediction of HDPE outer sheaths.

Paper 40 presents a novel nanocomposite insulating material for enhancing the performance of AC or DC power cables.

Cable accessories (4 papers)

Localized at interfaces between cables or between cable and switchgears, accessories are submitted to a lot of various constraints in electrical, mechanical, and thermo-mechanical domains. Their reliability is, apart from installation process, linked with obviously their design but also materials behaviours and operating conditions of the network.

The four papers dedicated to accessories either propose some experience from field (paper 884), present some characteristics and performance of Silicone Rubber compounds used in MV accessories (papers 100 and 341), last but not least paper 290 shows the interest of mechanical connectors use in MV accessories.

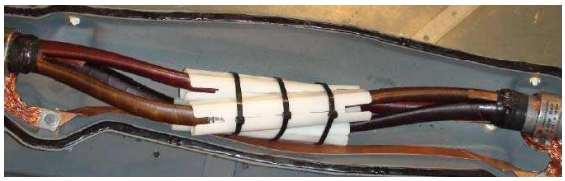

Fig.11a: from paper 884, Conductor extension when the force is about 6 kN. The potential degradation of the paper insulation is very likely in case of a cyclic load.

Fig. 11b: from paper 884, Field result: a similar joint as shown in previous Figure, which failed in service due to conductor extension.

The effect of high current loads on joints in the MV cables systems is presented in paper 884. After breakdowns in MV joints, Dutch DNO's decided to investigate their networks background. High load – and especially high cycling load – generates high mechanical forces from the conductor in the joint body (see pictures). It raises the question to reproduce in standards (type tests) conditions close to real operation service ones in a reliable and representative way.

Silicone rubbers –SiR– are among the good materials used in MV accessories, as they are well known for their hydrophobicity, ozone and UV resistance. Paper 100 presents good long duration tests results after 5.5 years at 1.5 times U0. Neither breakdown nor flashover occurred during the test.

Electrical resistivity and contact resistance of electrical conductive silicone rubbers are presented in paper 341, the electrical resistance of the interface metal/conductive silicone rubber are evaluated versus the contact pressure.

The use of mechanical connectors for MV cable accessories becomes more and more frequent; paper 290 presents the role of some key parameters in connector performance and reliability. Connector material and design, bolt material, design and number, conductor material and design, contact pressure and fastening torque are the bases of the connector reliability.

Fig. 12: from paper 290, a few representatives of MV cables and mechanical connectors

Over Head Lines and associated components
(9 papers)

Polymers are more and more used for insulators instead of porcelain and on covered conductors installed in Over Head Lines. Seven papers present the behaviour of materials used in spacers (papers 452, 1222), insulators (papers 117, 708, 1266 and 1276) and cable when faced to either polluted or coastal areas environment (paper 1073). Two papers present materials alternatives for poles (papers 392 and 1197).

Paper 117 reports on ageing effect on porcelain insulators in Alexandria area. The exposure during years to polluted and salted air impacts the electrical behaviour of the network and especially induces flashover and dielectric losses of the insulators. Cleaning is a solution to recover quite good performance.

Studies on polymeric insulators in polluted areas are presented in papers 708 and 1266, paper 1276 presents performance improvement thanks to the use of non linear polymers.

Paper 708 reports on degradation studies of various OHL components using polymers (spacers in HDPE, PE covered cables, insulators in SiR or HDPE). The results could be used in purchasing specification for a better network

reliability.

Paper 1266 presents the Iranian experience in a natural pollution test station with SiR composite insulator; neither hydrophobicity loss nor reduction of electrical and mechanical properties was observed.

Paper 1276 presents the improvement of lightning impulse voltage performance with non linear grading coating used on polymeric insulator. The grading material, using micro scaled electroceramic particles – called micro-varistors – have similar electrical properties as ZnO. The potential distribution and electrical fields were calculated with a FEM tool.

Papers 452 and 122 report on spacer used in MV OHL with covered conductors. Paper 452 presents the Iranian experience in a complete OHL design (spacers and covered cable designs) and field installation. Dielectric compatibility between spacer and covered conductor is presented in paper 1222. It shows the interest of using inner semi conductive layer to improve electrical stress control at conductor interface. Similarly paper 1073 points out interface electrical phenomena between covered conductors and the mechanical supports.

Poles are the topic of papers 392 and 1197: the first presents the interest of using pre-stressed concrete pole as an alternative to wooden and steel poles for LV, MV and HV networks; paper 1197 shows the interest for Irish networks to replace steel towers by wooden ones.

Other points on LV and MV networks
(4 papers)

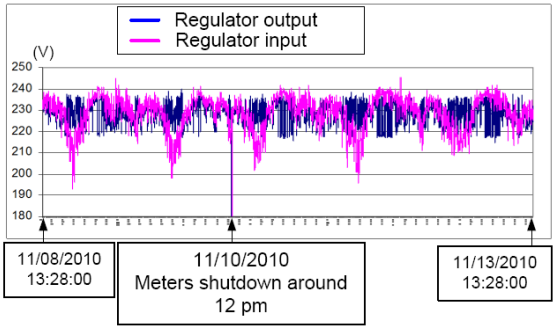

Fig. 13: from paper 1259, results of voltage measuring at entry and exit of PVRLVN in real situation

Paper 499 dedicated to technical implementation of cross bounding on underground HV line projects, shows all possible connection ways for earthing HV cable screens.

Paper 240 presents the behaviour of 30 kV OHL divested of its neutral conductor, based on simulation it was shown that distributed multi grounded neutral conductor is but an expensive way to take down power frequency earthing resistance.

Due to single phase feeding, LV networks are unbalanced, paper 781 presents some possible equipments to minimize the unbalance currents effects.

Paper 1259 reports on the Brazilian experience in the use of portable voltage regulators for the LV networks.

Potential scope of discussion

Standards and specifications: what are the necessary evolutions to cover the actual needs of Distribution Network Operators? how to ensure high quality products over the life-time of equipments?

Eco-design: will the demand for more environmental friendly solutions lead to major changes in components for cables links and overhead lines?

Cable links and OHL reliability: how to maintain OHL reliability in polluted areas? how to deal with the ageing of cable links and OHL components?

Table 3: Papers of Block 3 assigned to the Session

Paper No. Title	MS p.m.	RIF	PS
0026 (FR): State of the art of laws and standards in the field of eco-design of electrical and electronic equipment in Europe			X
0950 (BE): Incompatibility between MV switchgear conforming to the international standards and their use in DNO's substations	X		X
0971 (BE): Life time estimation of SF6 MV switchgear according to on-site conditions in DNO's			X

distribution networks			
0087 (FR): New specifications on MV switchgear for cable test features			X
0842 (FR): SYNERDIS group common specification of MV switchgear and controlgear (RMU) for MV/LV substations			X
0140 (DE): Hazard and risk assessment of HV switchgear assemblies - a vital point for product safety	X		X
1118 (IE): Treatment of Quality in Utility Specification and Procurement of Network Equipment	X		X
0037 (NL): Investigations towards the upgrading of existing 10 kV cables and accessories to an operating voltage of 20 kV	X		X
0345 (NL): Introducing High-performance Polypropylene Thermoplastic Elastomer (HPTE) insulation for MV cables in the Netherlands	X		X
0679 (BE): New Test Results with 3 kHz Accelerated Growth of Water Trees in Medium Voltage XLPE Cables			X
0982 (US): Dow Ecolibrium™ bio-based plasticizers for flexible PVC			X
0203 (GB): A Life Cycle Analysis Study of Competing MV Cable Materials			X
0779 (FR): Methodology for evaluating the durability of HDPE outer sheaths of underground electric cables			X
0040 (EG): Novel Nanocomposite Insulation Materials for the Enhancing Performance of Power Cables			X
0884 (NL): The effect of high current loads on joints in MV cable systems			X
0100 (DE): Long term behaviour of outdoor terminations made of SiR			X
0341 (DE): Electrical Resistivity and Contact Resistance of Electrically Conductive Silicones			X
0290 (DE): Reliability of mechanical connectors for medium voltage cables			X
0117 (EG): Study and Investigation of Medium Voltage Polluted Insulators In Alexandria Distribution Grid			X
0708 (BR): Degradation studies of polymeric insulators - Products performance requirements			X
1266 (IR): Assessment of in service composite insulators in very harsh coastal environment of Iran: Laboratory & Field testing			X
1276 (GB): Performance of Nonlinear Grading Coating on Polymeric Outdoor Insulators under Lightning Impulse Voltages			X
0452 (IR): Design and Installation of First 20 kV Spacer Cable in Iran			X
1222 (BR): Dielectric Compatibility of Distribution Network Spacer System			X
1073 (BR): Methodology for the utilisation of compact distribution lines in coastal areas			X
0392 (DE): Spun pre-stressed concrete poles: alternative to wooden and steel poles for low, medium, and high voltage			X
1197 (IE): Replacing Steel Towers with Wooden Poles on ESB Networks 110 kV Lines			X
0499 (PT): Technical implementation of cross bonding on underground high voltage lines projects			X
0240 (TN): Effect of missing 30 kV neutral wire on network behavior			X
0781 (FR): An alternative to the LV network reinforcements			X
1259 (BR): Portable Voltage Regulator for Low Voltage Networks			X

Block 4: "Trends in network components for substations"

The 33 papers of this block are divided between three sub-blocks:
- substations
- transformers
- switchgear

Substations
(2 papers)

Two papers are presenting new solutions proposed for respectively primary (HV/MV) and secondary (MV/LV) substations.

Indoor air insulated primary substations (also for the HV part) are already known: they are more compact than outdoor air insulated substations and easier to integrate in an urban environment. Paper 453 shows that the introduction of HV disconnecting circuit-breakers (DCB) according to the new standard IEC 62271-108 can bring more advantages. These combined functions in a single piece of equipment, together with the use of disconnecting links operable under live conditions, allow further simplification of the electrical diagram, hence a reduction in the size of the indoor primary substation. The maintenance costs are also reduced, because DCBs have a higher reliability and require less maintenance than conventional disconnectors.

Paper 477 presents two new designs of underground secondary substations, respectively for the rural and urban areas. These substations are designed and tested according to the latest edition of the IEC standard for prefabricated substations, and in addition they comply with the building codes (Eurocodes) applicable in Europe.

Transformers
(14 papers)

The first four papers present evolutions and innovations in the design of transformers.

Paper 984 reports on the development of dry-type transformers for the 72.5 kV voltage rating. The main technical challenges that have been solved are the dielectric design for solid and air insulation, the inner winding clearances and the reduction of eddy current losses. These new achievements make possible the supply of power at voltages in the 72.5 kV class in locations were it is not considered safe to use oil transformers.

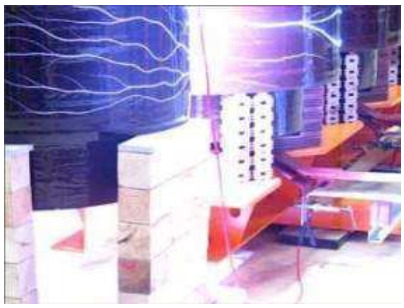

Fig. 14: from paper 984, 72.5 kV dry-type transformer tested to the limit.

Also in the field of dry-type transformers, paper 952 presents another development to push further the limits of application of this technology. In this case it is the outdoor application as pole mounted transformer, which has required a new design of the solid insulation (with no air gap between MV and LV windings, and minimum electric field at the surface of the insulation, which is not screened by a conductive coating). Also corrosion resistance of the magnetic core had to be addressed: salt fog ageing tests as well as long term outdoor tests at the KIPTS in South Africa have proven the good corrosion behaviour of this new transformer.

Paper 297 shows that the use of high temperature insulation materials (solid and oil) allows design of compact 400 kVA MV/LV distribution transformers which can be used in replacement of 200 kVA transformers without requiring a change of the supporting structure. This is an efficient way to upgrade overloaded transformer substations, in spite of the increased cost of these high temperature transformers, compared to conventional 400 kVA transformers.

Finally paper 86 introduces an improved cooling system for HV/MV power transformers. These transformers use electronically commutated DC motors for the fans, which can be controlled with a variable speed by the monitoring system. The new solution features several advantages over the conventional one (fans driven by AC asynchronous motors): less wiring and losses, more constant temperature hence less breathing, better overloading performance and, last but not least, reduced noise emission.

The next three papers put the focus on the use of amorphous magnetic material for the core of transformers, which is known as an efficient way to reduce no-load losses.

Paper 227 reports on the field trial launched by ERDF and EnBW to test amorphous metal distribution transformers (AMDT) complying with their specifications in terms of losses, noise and short-circuit withstand. This trial test campaign also aims at encouraging European manufacturers to develop cost-effective AMDTs that can demonstrate the economic viability of this technology, taking into account the total cost of ownership, which includes the present value of losses over the lifetime of the transformer.

Paper 523 compares two solutions for increasing the

efficiency of single-phase distribution transformers used in the rural areas of Brazil. The load of these transformers is low, hence the reduction of no-load losses is the target. The first solution is to use amorphous metal core, but this results in a significantly higher manufacturing cost. A second proposed solution is to use standard transformers with increased short-circuit impedance: the manufacturing cost is only slightly increased and the total costs (including capitalised losses) of both solutions seem similar. Samples of both types of transformers will be installed in the field for further technical and economic evaluation.

The third paper 1145 presents a life cycle assessment (LCA) study which has been conducted to compare standard distribution transformers and AMDTs. AMDTs use more material but generate less losses in operation, especially at low loading. Taking into account the recyclability of metals and using the global warming potential (GWP) impact as the main indicator for the LCA, it is shown that AMDTs have a significantly lower environmental impact than standard transformers, in spite of their larger use of resources and higher manufacturing cost (the total ownership costs, including capitalised losses, are comparable for both types of transformers).

The increasing use of vegetable-based dielectric fluids in transformers is the topic of the following three papers.

According to paper 1148, one main advantage of natural ester fluids (besides biodegradability, carbon neutrality and fire safety) is that they reduce the ageing of insulation paper, hence they allow operation at higher temperatures. Transformers using these fluids can thus be designed as high temperature transformers, which results in more compact and lighter transformers, lower costs and less use of materials.

Fig. 15: from paper 1148, external and internal view of the 88 kVA natural ester transformer.

Paper 39 reports on the development of a new vegetable oil fluid for transformers which does not use synthetic anti-oxidants to stabilise the oil against oxidation at high temperature. This vegetable oil is characterised by a high content of oleic acid and a refining process that keeps the natural anti-oxidant agents. This fluid presents as good or better oxidation stability than other vegetable oil fluids, and better biodegradability with lower toxicity.

Finally the results reported in paper 1253 confirm that natural ester-based dielectric fluids for transformers with high oleic content are more stable against thermal oxidation, and also that these fluids slow the ageing process of paper insulation, when compared to mineral oil.

The distribution transformers subjected to the ageing tests reported in paper 775 were filled with mineral oil and equipped with optic fibre sensors for temperature monitoring. A correlation has been established between the loss of life and some indicators of ageing, like dissolved gases in oil and degradation of the paper. A pertinent indicator of the cellulose degradation has been found to be the 2-FAL content in oil. These tests have also confirmed the good ageing behaviour of hermetically sealed oil distribution transformers.

Thermal modelling of oil transformers is the topic of paper 361, which presents thermal simulation by computational fluid dynamics (CFD) software of the heat removal from the windings of core-type power transformers. The oil flow has been properly modelled and the simulation allows to understand the reasons for poor cooling efficiency (in case of flow inversion) and to optimise the design, resulting in a significant drop of 6°C in the hot spot temperature.

The last two papers in this sub-block deal with the influence of the installation conditions of transformers.

Paper 197 reports on design and testing of a fully underground distribution transformer substation for application in large cities, when reinforcement of the LV grid is needed. Thermal modelling and testing have been important in determining a proper design of the substation and the loading capability of the transformer. Satisfactory results have been achieved at a cost that is higher than with conventional substations but acceptable for special locations with space constraints.

Paper 309 reports on the investigations performed to evaluate the influence of solar radiation on the temperature rise of transformers located outdoor. Experimental results and calculations show that the loadability can be decreased by about 15% compared to transformers located in the shade.

Switchgear
(17 papers)

New designs for switchgear are presented in the first nine papers of this sub-block.

In paper 468 ENEL introduces its new specification for SF6-insulated ring main units (RMU) which are characterized by the use of circuit-breakers instead of load-break switches for the line functions. The higher performances of circuit-breakers allow the implementation of an automated fault detection system which reduces the time needed to isolate the faulty section of a ring circuit.

In paper 1096 can be found an good example of local innovation that meets well the requirements of the new

emerging countries. Basically an automatic circuit recloser has been made vertically disconnectable to provide all the functionalities required for a circuit-breaker bay in outdoor substations for rural electrification. Modern control and communication equipment is part of the offer, which can be interesting also for other markets.

Fig. 16: from paper 1096, Integrated Switching Device in isolated position.

Paper 77 reports on the development of a specific MV gas-insulated switchgear for offshore wind farm application. Some of the special requirements that have been taken into account are the corrosion resistance (due to salinity), the vibrations withstand (for transportation) and the internal arc protection concept (due to the installation in reduced space).

In paper 489 a switchgear manufacturer shows how the life cycle assessment (LCA) tool is applied to improve the design of MV switchgear and reduce their environmental impact.

Paper 1075 gives an example of implementation of the new specifications for cable test features in MV switchgear which were presented in paper 87 of the previous block. This paper reports on the development of cable testing devices incorporated in the switchgear in order to facilitate the performance of cable tests without interfering with the cable connection. Considering the advantages of these test points in terms of safety and ease of operation they will probably tend to become a standard, rather than optional, feature for the switchgear connected by means of insulated separable connectors.

The next three papers are related to new developments in the field of solid insulated switchgear, which is considered as a possible alternative to SF6 insulated switchgear.

Paper 260 reports on the development in Korea of a MV solid insulated switchgear which is characterized by:

- the use of screened epoxy and silicone rubber solid insulation in replacement of SF6 gas;
- a modular concept which allows various configurations to be implemented by combining the different modules (disconnector, earthing switch, circuit-breaker, etc.).

Paper 333 reports on the benefits of using a pre-engineered MV metering cubicle for use with screened solid insulation switchgear. The main advantages are reduced size, harsh environment withstand without maintenance, readiness for smart metering. This type of prefabricated solution is capable of covering most applications when distribution network operators use functional specification and do not define in details which type of current and voltage transformers are to be used in the metering cubicles.

In paper 1248 is presented a new type of busbars connecting system developed for screened solid insulation switchgear. This system is characterized by a flat interface, instead of the conventional conical interface, which brings advantages in terms of compactness, ease of assembly and large positioning tolerances for the interfaces to be connected by the busbars system.

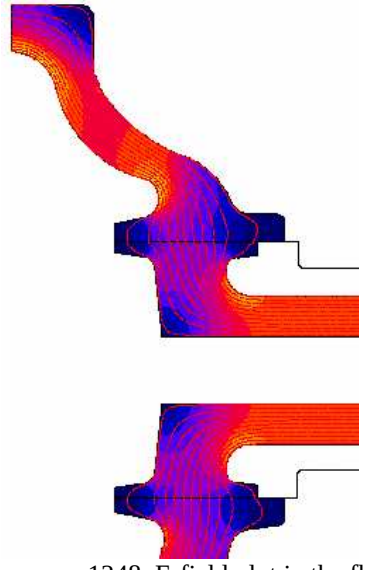

Fig. 17: from paper 1248, E-field plot in the flat interface.

A new concept of diode based capacitor switch was presented at CIRED 2007. In paper 839 are presented more test results with this device and the experience gained in a pilot installation for back-to-back capacitor switching in a 13.8 kV system. These results confirm the superiority of the diode switch concept for switching capacitor banks with reduced current and voltage transients, even when compared to synchronised switching by special vacuum circuit-breakers.

The next three papers are related to various application aspects for MV switchgear.

Paper 91 focuses on the behaviour of MV air insulated indoor switchgear depending on the installation conditions. It is important to characterize the severity of these conditions (in terms of condensation and pollution) and improve them when possible (this is often relatively easy). Accelerated ageing tests are also a way of checking the behaviour of switchgear and improving the design. Of course in the most severe cases gas insulated switchgear remains the obvious option, but air insulated switchgear is less costly and more flexible and can be selected when the installation conditions are suitable.

Paper 488 discusses the application of vacuum circuit-breakers (VCB) in inductive circuits, like MV motor switching during the start phase. This switching operation may generate overvoltages due to multiple re-ignitions and virtual current chopping. It is possible to accurately simulate these phenomena in ATP-EMTP software, with the electrical parameters describing the VCB behaviour obtained from test measurements. These simulations can then be used, for a specific application circuit, to determine the suitable overvoltage protections, such as surge arresters or RC snubbers.

Another aspect related to vacuum circuit-breaker (VCB) is discussed in paper 439, which is the bouncing behaviour of the vacuum interrupter contacts. The involved phenomena are presented and some test results are given which indicate that probably resonance effects can explain the long bouncing durations sometimes observed in no-load tests. On the other hand it is shown that no adverse effect of the contact bouncing is noted when circuit-breakers have passed successfully the type tests for short-circuit and capacitive currents switching. Therefore it is concluded that it is not relevant to define in specifications a maximum bouncing time, such as the 2 or 3 ms prescribed in China by GB 50150 for MV VCBs.

The next four papers are related to the protection against internal arc fault in MV switchgear.

Paper 1170 provides a good review of the internal arc protection topic in MV switchgear and substations. The evolution of IEC standards in this respect is presented. Some test results are also given for testing according to conditions newly defined in the next edition of IEC 62271-200 (single phase to earth fault) and also in conditions not covered by the standards (e.g. open compartment).

Paper 1137 presents solutions developed for reducing overpressure inside the switchgear room in case of internal arc, when exhaust ducts to the outside of the room are not possible. Suitable arc energy absorbers have been found effective in reducing the temperature of the exhaust gases and the pressure rise in the room: their adaptation to two types of MV switchgear (air insulated and gas insulated) is described.

Another, and possibly complementary, approach is presented in paper 385 which describes an active arc protection system. It consists in arc sensors (light and current), in a specific arc protection relay with a short operating time of 2.5 ms, and a fast acting earthing switch driven by a Thomson coil mechanism (closing time 3.5 ms). It is thus possible to short-circuit the arc in less than 10 ms, and in this way to reduce a lot the dangerous effects of the arc fault, compared to a fast acting protection by a 3-cycles (50 ms at 60 Hz) circuit-breaker.

Fig. 18: from paper 385, composition of the Arc Protection System.

In paper 1326 are reported some advances in internal arc simulation for pressure rise and structural response in the compartments subjected to an internal arc. Although simplified, the proposed method does not need to use an empiric energy transfer factor (that can vary from one configuration to another) as an adjustable parameter, and shows good agreement between calculations and test results.

In paper 492 the same authors present improvements to the thermal network method (TNM) which has been already described at the previous CIRED conference in 2009 (paper 637). This method was then successfully applied to the thermal modelling of gas insulated switchgear. For application to air insulated switchgear where convection flows are more important and variable it has been found efficient to combine it with CFD simulations on simplified geometries to get the proper velocities which are then used as parameters in the convective heat transfer elements of the TNM.

Potential scope of discussion

Transformers: what are the major technological changes that can occur in this field? dry-type insulation versus oil, high temperature materials, amorphous steel core?

Switchgear: what should be the respective applications of circuit-breakers and load-break switches in secondary substations? is there a trend towards an increased use of gas-insulated or solid-insulated switchgear in distribution networks?

Safety in the case of internal arc: how to compare the different approaches, internal arc classification of switchgear or use of personal protective equipment, passive means or active protection by fast acting devices?

Table 4: Papers of Block 4 assigned to the Session

Paper No. Title	MS p.m.	RIF	PS
0453 (SE): Innovative Compact 145/12 kV Indoor Air Insulated Substations (AIS)	X		X
0477 (FR): New underground HV/LV prefabricated substations for better integration in the environment			X
0984 (DE): Dry-type Transformers for the 72.5 kV Voltage Class			X
0952 (US): Dry-type Transformer for Pole Mounted Application	X		X
0297 (PK): Development of pole-mounted distribution transformer with aramid insulation for increased capacity and reliability of power distribution network			X
0086 (DE): New trends in noise reduction of power transformers			X
0227 (FR): Amorphous Distribution Transformers Trial Test Campaign	X		X
0523 (BR): Efficiency and Economical Viability of Countryside Transformers Based on Percent Impedance Optimization and Amorphous Core			X
1145 (CH): Life Cycle Assessment of Dry-type and Oil-immersed Distribution Transformers with Amorphous Metal Core			X
1148 (US): Sustainable Electrical Energy using Natural Ester Technology			X
0039 (ES): Oxidation stability of non inhibited vegetable transformer liquids			X
1253 (US): Aging Performance of Natural Ester-Based Dielectric Fluids for Transformer System			X
0775 (FR): Accelerated ageing for a MV/LV distribution transformer equipped with optic fibers			X
0361 (PT): CFD analysis of CORE type power transformers			X
0197 (NL): The full underground distribution transformer in practice			X
0309 (RS): The Influence of Direct Insolation on Outdoor Power Transformers Loadability			X
0468 (IT): A low-cost high performance MV RMU with circuit breakers for use in remote controlled MV-LV substations	X		X
1096 (IN): Integrated Switching Devices	X		X
0077 (ES): Evolution and development of medium voltage equipment for special wind farm applications.			X
0489 (NL): Sustainability in medium voltage switchgear			X
1075 (NL): Integrated Cable Test Facility In Compact Medium Voltage Switchgear			X
0260 (KR): Development of Solid Insulated Switchgear for Medium Voltage			X
0333 (FR): Compact metering solution withstands harsh environment			X
1248 (FR): Benefits of innovative MV interconnector system			X
0839 (SE): A diode based capacitor switch - a novel solution for power quality improvement			X
0091 (FR): Installation conditions and improved MV air insulated switchgear are key factors for an extended service life			X
0488 (DE): Switching of small inductive currents using vacuum circuit-breakers			X
0439 (DE): Performance of Vacuum Circuit-Breakers with Contact Bouncing during Closing			X
1170 (NL): Developments for maximum safety in medium voltage substations regarding internal arcs			X
1137 (DE): Solutions for Internal Arc protection acc. IEC 62271-200 with pressure relief into the switchgear room for Gas and Air insulated medium voltage switchgears			X

0385 (KR): Solution for internal arc flash hazards in air insulated switchgear			X
1326 (DE): Simplified Internal Arc-Structural simulation			X
0492 (DE): A novel approach for the thermal analysis of air insulated switchgear			X