Special Report - Session 1
NETWORK COMPONENTS

Chairman Pierre MALLET
France
pierre.mallet@erdf.fr

Special Rapporteur Yves PARASIE
France
yves.parasie@nexans.com

Special Rapporteur Philippe PICOT
France
philippe.picot@schneider-electric.com

Introduction

Session 1 deals with all aspects related to the components used in the electricity distribution networks: cables, overhead lines, primary and secondary substations, transformers, switchgear and their control, protection and monitoring systems, new active power electronics devices. It covers topics related to the life cycle optimisation of assets from design through installation, operation and maintenance to the end of life management, as well as new solutions for diagnosis and monitoring. The session also covers environmental aspects including eco-design and life cycle analysis, standardisation, ergonomics and the safety of both the operating staff and the public. It aims at providing an overview of the state-of-the-art in component design and proposals for future components, including the ones needed for smart grids and e-mobility. This session is an opportunity for DSO and manufacturers to share their objectives.

129 papers have been selected for the Session 1 – Network Components – of CIRED 2015. They have been organized in four blocks, which are the same for both this special report and the Main Session.

The structure retained for these blocks is as follows.

Block 1 Diagnosis and maintenance of network components – Part 1: Cables and lines (34 papers):

- Phenomena studies and diagnostic measurement methods;
- Proposed methods and tools in asset management of cables and distribution lines;
- Specific solutions or methods to be applied in line rating and standards.

Block 2 Diagnosis and maintenance of network components – Part 2: Substations (30 papers):

- General methods and tools;
- Transformers;
- Switchgear.

Block 3 Innovation in Network Components – Part 1: Cables and Lines (30 papers):

- Design tools;
- Smart Grids solutions and applications in smart metering or power quality improvement;
- Communication systems.

Block 4 Innovation in Network Components – Part 2: Substations (35 papers):

- Substations;
- Transformers;
- Switchgear;
- Modelling and simulation;
- Storage and LVDC distribution.

6 papers per block have been selected for oral presentation in the Main Session (MS), but all the papers can be presented in the interactive Poster Session (PS).

In addition to the Main and Poster Sessions, three Round Table (RT2, RT4 and RT6) discussions and a Research and Innovation Forum (RIF) will take place within Session 1.

RT2 – "Telecommunication Solutions for Smart Grids" will put the focus on this important aspect of the evolution of distribution networks.

RT4 – "SF6 Substitution: Alternative Gases and Mixtures", a topic for the first time addressed in CIRED, will show that new technical solutions have reached the capability to replace SF6 for MV GIS.

RT6 – "Smart secondary substations – Technology development and distribution system benefit" will present the first results of the CIRED WG on this subject.

Finally 6 papers, presenting various aspects of the topic "Data analytics for asset management of network components", have been selected for oral presentation and exchanges with the audience during the RIF.

Block 1: "Diagnosis and maintenance of network components – Part 1: Cables and lines"

The first block is focused on methods and tools for cables and lines assets management.
The 34 concerned papers were split within 3 sub-blocks:

- Mechanism or phenomenon studies and diagnostic measurement methods (14p.) for assets management of cables and lines
- Proposed methods and tools in asset management on cables and distribution lines assessment methods and solutions (14p.)
- Some specific solutions or method to be applied in line ratings and some standards (6p.)

Sub-Block 1.1: Mechanism or phenomenon studies and diagnostic measurements methods (14 papers)

For a few years, various diagnostic methods are applied on distribution networks. On MV underground lines, tan delta (TD) and partial discharges (PD) measurements seem to be the way to assess the insulation condition in off-line situation.

Four papers are partly illustrating the application of tan delta measurements on insulation, two on the network in off line situation, and two on cable samples new or removed from network.

A five years off line diagnostic experience on MV cable is presented in **Paper 0999**. This method was deployed in a quite large scale on the French network impacting maintenance program and pointed out some new criteria – as water penetration in cables - and tools to be studied. Finally, the use of such diagnostic method requires specific skills.

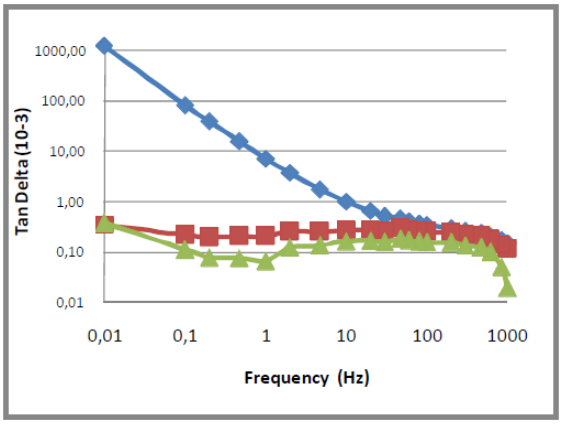
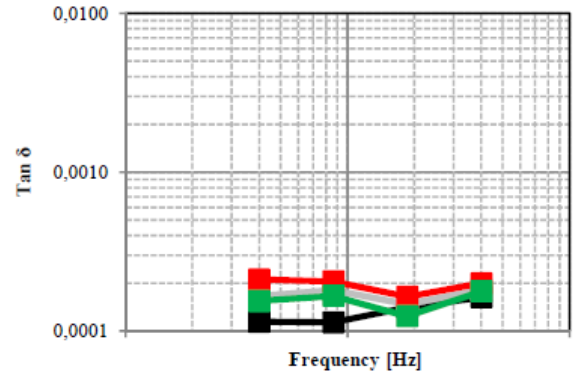


Figure 7 from Paper 0999: Frequency TD value dependence vs degradation level

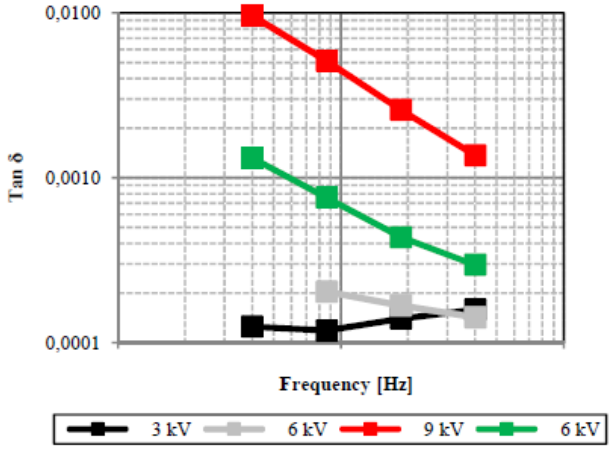
Similarly, since 2001 in Denmark **Paper 0471**, the tan delta diagnostic method was applied on 86 sections of MV cables installed between 1982 and 2010. All cables sections were ranked from bad cables with leakage current at normal operating voltage up to good cables with low losses. It mentions the relationship between the missing water barrier in the cable and its lifetime.

The remaining lifetime estimation of MV PILC cables is the aim of **Paper 1522** by performing a long-lasting ageing experiment on either new or old cables (45 years of service). Both TD and PD measurements were performed during the tests. With a proposed ageing model mainly tan delta based, a cable remaining lifetime can be determined.

In MV distribution links, the critical parts are more often localized on accessories and more precisely on joints, **Paper 0486** describes a simple method based on using an insulation tester to reveal if joints with low resistance are present in the cable link. A 30 meters sample with a HS joint was removed from a wet design 20 years old XLPE MV link presenting high level of PD and TD network. In association with water trees examination on cable sample, some polarization and depolarization currents measurements, tan-delta at various frequencies were applied to cable sample including joints. From the results it can be concluded that insulation tester can provide sufficient accuracy and resolution to be used in MV XLPE links, and by using reliable criteria can reveal a joint as high tan delta origin. Regarding the use of PD measurement, the Egyptian **Paper 0104**, confirms that it could be a good solution for on-site diagnosis of MV power cables network.



a) Measured dielectric losses in 2010



b) Measured dielectric losses in 2014

Figure 6 from Paper 0471: Measured dielectric losses on one phase in a cable section in 2010 and 2014

Still in cable area, the three following papers are describing ageing phenomenon on cables components, the first one **Paper 0896** is addressing polypropylene insulated cables and joints degradation when exposed to high temperature at emergency overload. A high temperature ageing test program with voltage application was engaged on cable with joint systems. Although the cable may support high temperature level, the critical point remains the joints.

All electrical and physical characteristics should be taken in consideration for the emergency operating temperature. PILC cables are exceeding their predicted service lifetime and continue to operate in normal conditions as far as the lead sheath ageing remained acceptable. **Paper 0547** examines the structure of the PILC lead sheath, as grain size, in old cables – more than 50 years old – and new one. The evaluation of the grain growth of the lead enables the application of a replacement criterion for this kind of cables.

Cables installation conditions, and pulling forces precisely, are not considered as premature ageing parameters for LV and MV cables, it's the topic of the Belgian **Paper 1188**. A too high pulling force applied to the cables during laying may impact – LV cables more than MV cables – outer sheath thickness variations and consequently the dielectric test results.

Condition monitoring of high and medium voltage cable systems is well established, at present interest shifts to investigate condition assessment of Low Voltage network, **Paper 0510** examine the characterization of intermittent faults in LV underground cable systems. Artificially damaged LV cables sections have been tested on water ingress in labs. A few electrical phenomena were observed and analyzed. PD occurred over the surface of cable insulation, inducing carbonization of the insulation and short circuits. The obtained results contribute to a better understanding of the degradation mechanism and represent a step towards to condition monitoring in LV grids.

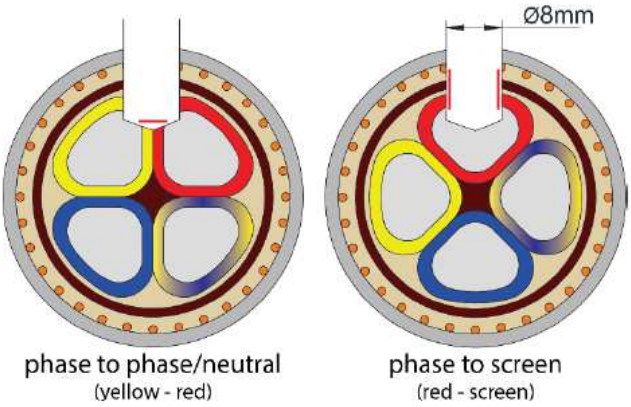


Figure 2 from Paper 0510: Artificial damage types (degradation is expected at the locations indicated by a red line)

In LV cables domain, a new method to estimate the remaining life of Low Voltage aerial bundle cable networks is proposed in the Iranian paper, **Paper 0112**. ABC cables are affected by some factors as mechanical damages, moisture penetration in cable insulation, non-standard clamps and weather conditions. The cable insulation is considered as a good indicator for calculating the remaining life of ABC. Based upon experiments in labs, the ABC insulation breakdown level is equivalent to the remaining lifetime of the cable.

The three following are dedicated to overhead line (OHL) connectors and insulators. Investigations on the long-term behavior of current carrying fittings for high temperature low sag (HTLS) conductors are described in the **German Paper 0729**. Through long term tests on HTLS conductors with connectors, it points out the connectors as the weakest points of the links. Furthermore the evaluation of compression type connections with an electric model was presented.

The inspection of insulating systems used in OHL is a matter of concerns. The used methodology could be adapted to the voltage level. Brazilian **Paper 0665** addresses the real time automated diagnosis of insulating system employing ultrasonic inspection. Tests are performed in labs on a single insulator supporting an energized cable. The emitted noise is then analyzed and treated according the Fast Fourier Transformation (FFT). The results obtained can be used to identify defect in the insulator samples.

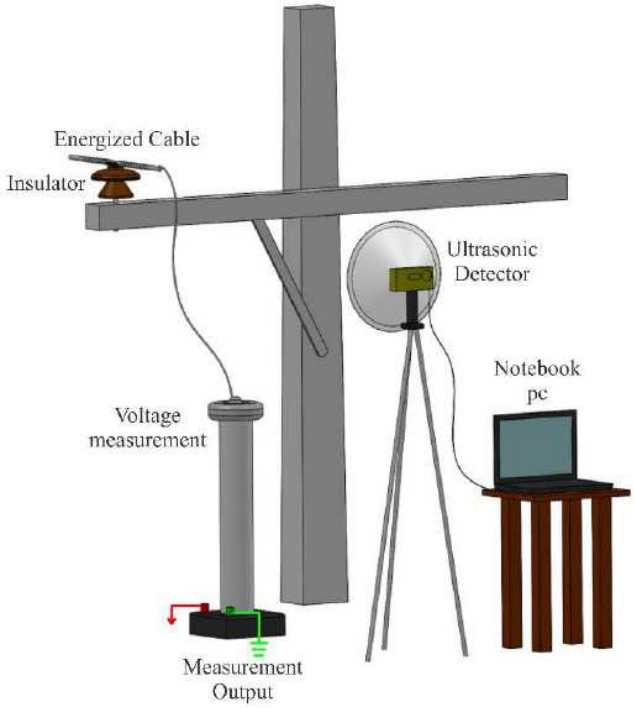


Figure 6 from Paper 0665: Laboratory set up

In the UK **Paper 1010**, the contamination level of high voltage insulators by pollution is considered. The methodology here proposed is based on the use of X-Band microwave radiometry. The microwave radiometer described measures energy emitted from the contamination

layer and could provide a safe, reliable contactless monitoring method effective under dry conditions. This experiment was first applied on glass planes with an artificial pollution layer laid on the sample surfaces respecting the IEC standard.

Analysis of cable failures data is more often limited to the ratio between failures number versus considered cable length, the Chinese **Paper 0199** proposes a probabilistic study of the influencing factors on distribution cable failures using Cox Proportional Hazard Model (Cox PHM). Among a lot of considered parameters, installation method, manufacturer origin and cable length were significant and positively correlated with failures. This model can be used in the processes of procurement, design and installation method.

More generally regarding the network, the French **Paper 0788** introduces some methods and presents some results regarding "On line diagnostic on HV/MV substations". Some diagnostic systems based upon PD measurement were installed in two HV/MV substations. It describes the main architecture of the diagnostic systems under experimentation and presents some field and simulation results focusing on the measurement of self extinguishing faults and research of solutions for their localization

Sub-Block 1.2: Proposed methods and tools in asset management on cables and distribution lines assessment methods and solutions (14 papers)

This sub-block will be cut in three parts:

- Underground networks
- Aerial networks, including OHL
- Some specific case to face networks reliability improvement

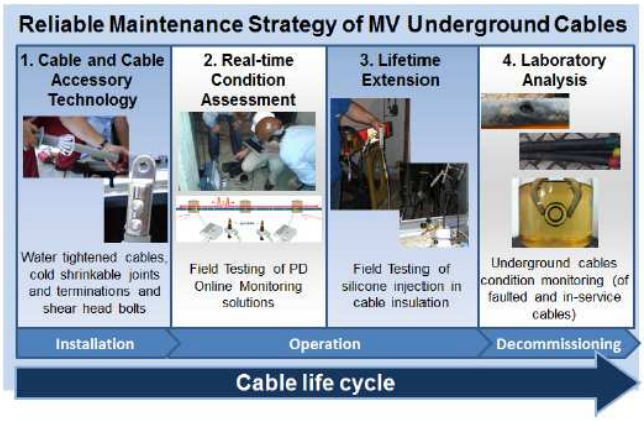


Figure 1 from Paper 0252: EDP Distribuição's approach to the MV underground cables' life cycle

After considering some methodologies for cable or networks assessments, the following papers expose the solutions or strategies to improve network reliability. The Portuguese **Paper 0252** presents an integrated approach to the maintenance strategy of the Medium Voltage underground grid of Lisbon area. This assessment, completed through pilot projects and innovative tests, included cable design, accessories technology selection, cable and accessories failures analysis. On-line monitoring solutions for network diagnostic improve asset managers' decisions.

Some specific devices are proposed to assist the asset manager in his duty. The Dutch **Paper 1044** is devoted to Smart Cable Guard (SCG) device as a very interesting tool for On-Line monitoring activities. SCG may localize PD's and faults in MV cables networks with high accuracy.

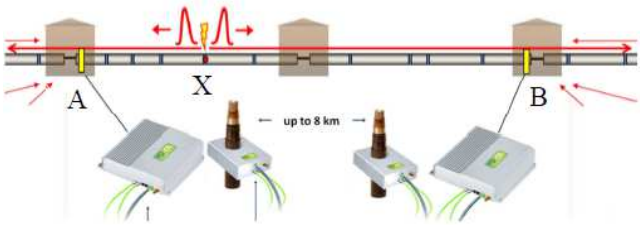


Figure 1 from Paper 1044: Typical SCG set-up with left (location A and right (location B) a sensor and a dedicated industrial computer with wireless or LAN internet connection

The cost effectiveness of PD sensors could be an issue in the development, the goal of the Finish **Paper 1200** is to develop a low-cost, sensitive and robust sensor solution for continuous on-line PD monitoring. The proposed High Frequency Current Transformer (HFCT) device is based on ferrite. Sensitivity, amplitude response, pass band transfer impedance, high current saturation on developed sensors and commercial available ones were compared. Back to MV joints and their risk of PD production when installation processes is not fully under control.

A specific PD's sensor can be inserted within the joint during its installation. The Swiss-Italian **Paper 0508** presents a new MV joint type with an embedded sensor with suitable characteristics – bandwidth and sensitivity – for the monitoring of the partial discharges activity. Some experimental results on various joint technologies are presented.

Cable and joints localization on the underground networks could be an important issue to solve properly and efficiently. The use of RFID markers installed on the cables during the laying operations could be one solution. This is what the French **Paper 0514** proposes.

The question of ageing bare OHL assets management in the Malaysian distribution is presented in **Paper 1376**. Starting from key objectives parameters, such as customer satisfaction index, SAIDI and loss reduction ratio, a structured asset management strategy and initiatives were put in place. Some technologies were used to monitor ageing MV bare OHL as i) Infra Red thermography, ii) Ultrasound detection, iii) Aerial scanning and Inspection.

Some countries are more exposed than others to severe and frequent weather events. In Brazil, the design of the distribution OHL subject to high impact but low probability

events may be a challenge. The Brazilian **Paper 1353** exposes the results of the statistical analysis of weather which may impact the OHL structure inducing new designs of the OHL supports and components.

Similarly to the Brazil case, i.e. extreme weather events in forest environment impacting OHL, the Portuguese **Paper 0246** proposes the concept of the Risk Management Buffer as an innovative solution of safety corridor design. This solution provides to the HV and MV OHL adequate resilience to the effect of falling or agitation of trees. The deployment of such methodology in areas where a cost benefit analysis is achieved must involve and guarantee benefits for all the parties.

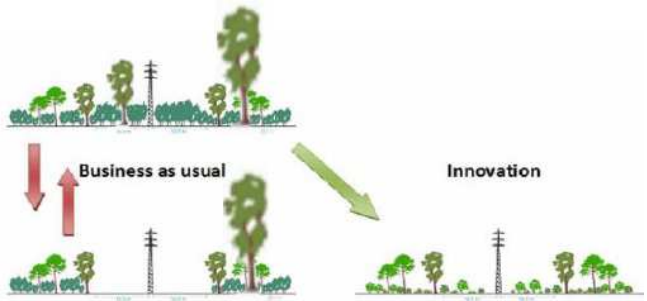


Figure 3 from Paper 0246: Corridor Management

As mentioned in the sub-block 1.2, air pollution can affect the reliability of the OHL: in Brazil the use of covered conductors with polymeric spacer cable systems is presented in the Brazilian **Paper 0166** as an interesting solution. In this paper experiments on various spacer designs are indicated, erosion and tracking tests with leakage current measurements are performed.

After weather events, birds may also provoke – apart their own electrocution – outages of power supply, this topic is addressed in the two following papers by proposing solutions to avoid such sad event.

Figure 11 from Paper 1288: Bird-friendly support structure with insulated cross arms

The first one, a Portuguese **Paper 0241** is related to stork activities in the vicinity of MV networks. The most efficient solution was to install some micro electrical shock system applied to specific metallic structures.

In the Hungarian **Paper 1288**, the DSO use rigid-type covers which induce numerous failures as: flash-overs, discoloration of phase conductors, broken insulators. Some bird-friendly new designs supports are presented and tested.

Design of MV overhead distribution lines is affected by many considerations: the **Paper 0899** relates the South African experiences with respect to insulation coordination of medium voltage power lines.

Whatever the event occurred – weather or maintenance – affecting the distribution networks, DSO should be in the situation to minimize time duration to restore the power supply, the Portuguese **Paper 0311** details some solutions to be used in crisis situation. Three solutions are dedicated to OHL with emergency pole kit to be applied in various cases as steel pole solution, gantry solution when angle in the OHL or broken concrete pole extension. An emergency cable kit (ECK) is envisioned to by-pass MV faulted circuits, directly laid on ground or attached to an aerial support. A MV/LV mobile generator was designed to provide energy in crisis situation.

Figure 4 from Paper 0311: Gantry solution being vertically placed

The Dutch **Paper 0027** updates the upgrading 10 kV cable connections to 20 kV. Tests were performed in labs on 10 kV XLPE cables with both 10 and 20 kV accessories (11 types). After long duration tests, conclusion is that upgrading is possible, provided that only the joint type is used passed successfully the long term test.

Sub-Block 1.3: Some specific solutions or method to be applied in line ratings and some standards (6 papers)

The first three papers are addressing the line ratings assessments. Electrical losses in the armor of 3 cores submarine cables are impacting the submarine link rating. These losses are calculated during the cable design process using the IEC 60287-1-1 formulae.

The French **Paper 1001** proposes a comparison study between IEC standard and FEM calculation. In all studied cases, the FEM calculated losses are lower than the one calculated with IEC formulae. Nevertheless the FEM model must be improved by considering hysteresis losses, in addition some other armor designs should also be considered.

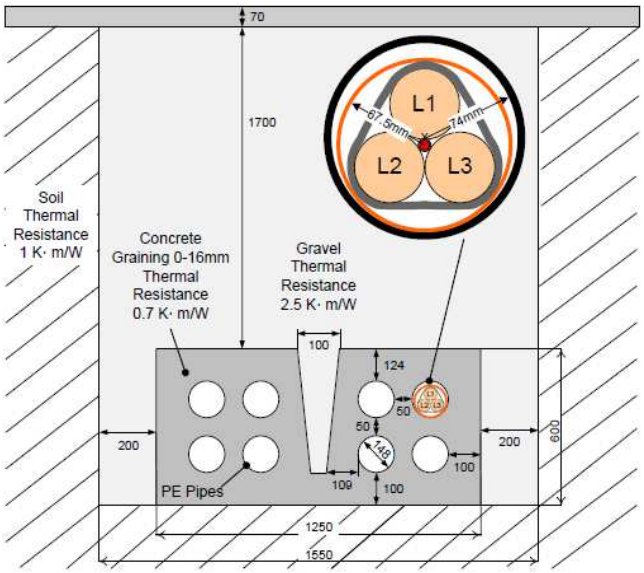


Figure 2 from Paper 1150: standard duct bank with three-core cable

The Swiss **Paper 1150** examines the modeling and pilot project associated to high voltage cables configuration in existing duct banks under new regulations regarding magnetic field emissions. The challenge is to fit and operate three-core HV cables in duct bank designed for single core cables thanks to theoretical modeling considering thermal and mechanical constraints.

The challenge is also to maximize the global power rating of the line. In distribution OHL domain, the Spanish **Paper 1076** different dynamic line rating systems have been developed. The aim of these systems is to estimate the current rating for available capacity evaluation. A few systems were tested and uncertainty levels evaluated. Results show that the uncertainty decreases with temperature and tension based systems when the conductor temperature increases.

Cables components have definitely impact of its rating performances, the two following papers are dedicated to conductor metal nature.

Spanish **Paper 0401** introduces a new generation of micro alloyed copper conductors in place of ACSR conductors. According to the authors, such type o conductor may challenge ACSR with a reduced Life Cycle cost, a competitive upgrade of existing lines, better performance in extreme weather conditions and finally a reduction in corona losses.

Similarly, the Dutch **Paper 0026** exposes copper in comparison with aluminium as common material in conductors of LV and MV cables.

Potential scope of discussions (papers selected for oral presentation)

- Do other measurement programs confirm the results of the Danish XLPE cables test campaign? (paper 0471)
- What are the best solutions for condition assessment of XLPE cable joints? (paper 0486)
- Which factors can generate premature ageing of cables? (paper 1188)
- Will cables incorporate embedded sensors in the future? (paper 0508)
- What are the best solutions to manage ageing overhead lines? (paper 1376)
- Which components are needed in emergency kits? (paper 0311).

Table 1: Papers of Block 1 assigned to the Session

Paper No. Title	MS a.m.	RIF	PS
0999: MV Cable off line diagnostic at ERDF: Feedback over 5 years global deployment experience			X
0471: Insulation condition of dry-cured XLPE cables measured over a period of 13years	X		X
1522: Essential strategies for the remaining lifetime estimation of the MV cable systems		X	X
0486: Condition assessment of XLPE MV cable joints by using an insulation tester	X		X
0104: Advanced solution for on-site diagnosis of medium voltage power cables network			X
0896: Degradation characteristics of the polypropylene-insulated cables and joints at emergency overload			X
0547: Ageing of the lead sheath of MV PILC cables			X
1188: Influence of pulling forces on premature ageing of LV and MV cables	X		X
0510: Characterization of intermittent faults in Low-Voltage underground cable systems			X
0112: Presenting a new method to estimate the remaining life of aerial bundled cable network			X
0729: Investigations on the long-term behavior of current carrying fittings for high temperature low sag conductors			X
0665:Real time automated diagnosis of insulating system employing ultrasound inspection			X
1010: High Voltage insulator contamination level monitoring with X-Band microwave radiometer			X
0199: A probabilistic study of the influencing factors on distribution cable failures using COX proportional hazard model		X	X
0788: On line diagnostic in ERDF HV/MV substations: Method and results of network experimentations			X
0252: Using new technology and assessment methods to a reliable maintenance strategy of MV cables			X
1044: Smart cable guard – A tool for on line monitoring and location of PD's and faults in MV cables – its application and business case			X
1200: Novel sensor solutions for on-line PD monitoring			X
0508: New cable accessory with embedded sensor to check partial discharge activity	X		X
0514: Accurate mapping thanks to RFID markers			X
1376: Managing ageing bare overhead line assets in TNB distribution network	X		X
1353: Design challenges for distribution overhead lines subject to high impact low probability events			X
0246: Innovative solution of safety corridor design for overhead lines: Increasing resilience to extreme weather events while providing environmental benefits			X
0166: Alternatives for the use of spacer cable system in medium and high polluted areas			X
0241: Eco-Networks – Innovative solutions to mitigate stork's activities in the vicinity of the electric distribution network			X
1288: Bird protection of Medium Voltage power lines			X
0899:Insulation coordination of Medium Voltage powerlines: South African experiences			X
0311: Emergency kits for distribution networks	X		X
0027: Upgrading of 10 kV cable connections to 20 kV in the Netherlands			X
1001: Armour loss measurements in three-core medium voltage cables: comparison with IEC standards and FEM calculation			X
1150: Fitting of high voltage cables in existing duct banks under new regulations: theoretical modelling and pilot project			X
1076: Analysis of dynamic line rating system configurations in a distribution line			X
0401: New generation of micro-alloyed copper conductors to face distribution system operators challenges			X
0026: Copper in comparison with aluminium as common material in conductors of LV and MV cables			X

Block 2: "Diagnosis and maintenance of network components – Part 2: Substations"

This block is organized in three sub-blocks as follows:
- General methods and tools applicable to different types of components;
- Transformers;
- Switchgear.

Sub-block 2.1: General methods and tools
(8 papers)

The two complementary papers 0472 and 0217 introduce the application of the theory of evidence to manage the uncertainty in the condition assessment of network components. Paper 0472 presents a method which has been developed and experimented in cooperation with several German DNOs. The results from visual inspections and simple measurements are recorded in uniform inspection checklists and used as base data for the condition assessment. It is shown that the deviations due to the subjectivity of inspectors can be reduced by training, tools (like fault catalogues) and, most effectively, by additional measurements. Combination of these multiple data, which are characterized by different levels of uncertainty, is made possible by the theory of evidence (or Dempster-Shafer theory) and provides a condition index with good credibility (i.e. low uncertainty) that can be used as a sound basis for maintenance decision-making.

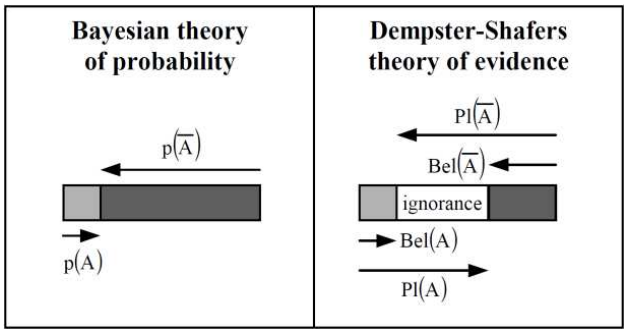


Figure 3 from paper 0472: Basic idea of the theory of evidence

Paper 0217 illustrates how this approach can be applied to MV GIS substations. In this case the results of visual inspections are complemented by measurements related to partial discharges, temperature-rise and mechanical characteristics. These incoming data are aggregated by using the theory of evidence, taking into account their respective uncertainties. Finally a mapping of the condition indexes, and the associated uncertainties, can be provided to the asset manager for the different substations.

In paper 1604 PLN Indonesia describes the DREAM (DistRibution Enterprise Asset Management) process which has been implemented as a pilot project in the Bali region. This SAP tool manages both Time Based Maintenance and Condition Based Maintenance for transformers and distribution lines through a Health Index system that determines the next steps to be taken (such as inspection or corrective actions) on the basis of results of the condition assessment activities.

A group of three papers (0328, 0466 and 0476) provides updated information on the new asset management tools tested by EDP Distribuição in Portugal (cf. previous presentation of paper 0589 at CIRED 2013). Paper 0328 reports on several pilot projects launched to evaluate on-line monitoring solutions that could help to implement preventive maintenance on network components. Different types of innovative connected sensors have been tested for power transformers, primary and secondary substations: these experiments have allowed identification of the most interesting sets of variables to be monitored, and of those without any real interest. Paper 0466 focuses specifically on the remote monitoring system installed in secondary substations and describes the different types of smart sensors, the system architecture for communication of data and the man-machine interface implemented in the SCADA platform for efficient data management. Finally paper 0476 presents an innovative condition monitoring system for power transformers, which is based on the measurement of characteristic electrical values in operation (on-load excitation current Park's vector). This real-time system, which does not require installation of intrusive sensors, has proven its effectiveness versus the conventional annual diagnostic approach, and will be applied in more substations.

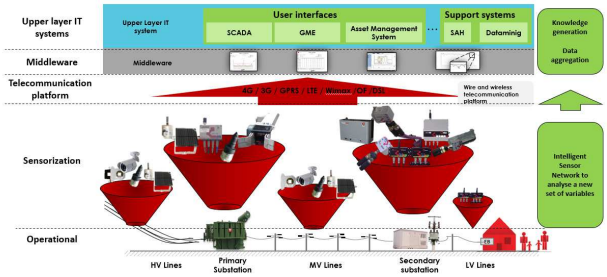


Figure 3 from paper 0328: Smart Sensor architecture to connect the sensors network to the upper layer system

Paper 0669 from Germany explains how the condition assessment of distribution substations can be improved by the installation of smart sensors and processing of the data provided by these sensors. Temperature and humidity, in addition to current, voltage and oil temperature, are monitored continuously as they have been identified as the main ageing factors, notably for the newly introduced secondary equipment of smart substations. A specific clustering methodology is applied to histograms of relative frequencies for temperature and humidity values and allows classification of the substations in groups, corresponding to different ageing stresses and need for maintenance. A field test is on-going to confirm the correlation between failures and operational stresses revealed by the measurement data.

Finally paper 1074 presents the statistical methods applied

by East Japan Railway Company to process the data from the on-line monitoring system (MICS: Maintenance Information Collected System) in order to grasp the changes in the condition of substation equipment. It has been found effective to follow the residuals between measured data and predicted data generated by a model based on the analysis of past MICS data. This new method has confirmed its ability to detect at an early stage abnormal data (generated for checking): more work remains to be done to find the optimal values of some statistical parameters in order to improve the sensitivity while avoiding false alarms.

Sub-block 2.2: Transformers
(12 papers)

In the continuation of previous publications (cf. paper 0064 at CIRED 2013) paper 0024 presents the latest developments of the methodology retained by EDENOR in Argentina for the condition assessment of its power transformers. Results from different diagnostic tools, notably oil analysis, are processed by an algorithm built upon the experience of the company's specialists, and a Health Index is generated for each transformer. Taking into account the criticality of the transformers in the network, and their probability of failure, a map of risks is established for the entire fleet of power transformers, which is used for defining the maintenance strategy (e.g. relocation of some vulnerable transformers in less critical network locations).

Along the same line paper 0054 presents a (similar in principle) IT-based tool developed by the manufacturer Maschinenfabrik Reinhausen GmbH for the asset management of a fleet of power transformers. Data from on-line monitoring and off-line diagnostics are aggregated to build the Health Index for each transformer. Taking into account the criticality (risk) for a specific transformer in case of failure, the priority order for maintenance activities is determined.

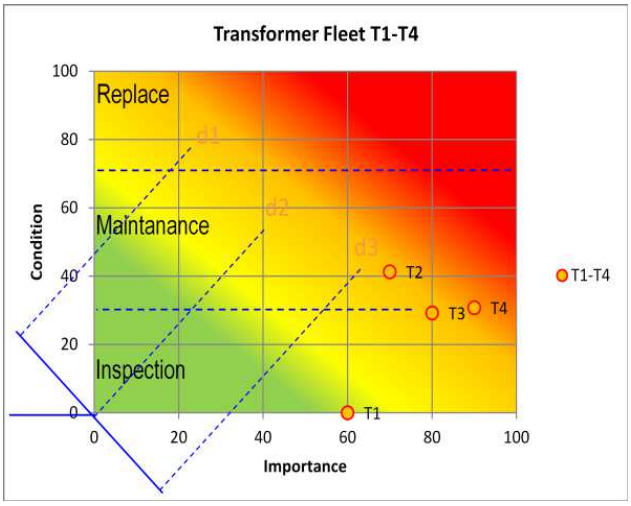


Figure 7 from paper 0054: Transformer fleet maintenance prioritization

In paper 1572 TNB in Malaysia describes their new ARMS (Asset Retirement Management System) process, which has been applied first to distribution transformers. The main differences between ARMS and the previous process lie in the systematic post-mortem analysis performed to understand the failure modes and root causes, and the use of a total life cycle cost analysis (LCCA) tool to decide between refurbishment and scrap of failed transformers. Implementation of the new ARMS process has resulted in a reduction in the amount of write-off (by about 40%) and a significant increase in the proportion of refurbished transformers (from 5-10% to more than 60%).

Different aspects of transformers' ageing are addressed in the following two papers. Paper 0749 describes the new testing facility that EDF R&D and ERDF have decided to build in order to perform accelerated ageing tests on distribution transformers. The "thermal image" system that will be included in this facility is an innovative feature that should enable to check the validity of empirical ageing laws and to correlate ageing with the chemical tracers.

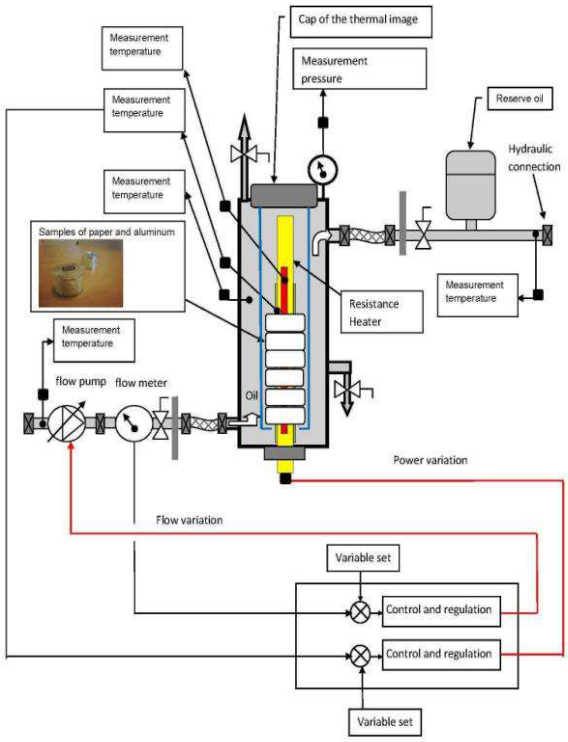


Figure 5 from paper 0749: "Thermal image" system

Paper 0612 draws attention to the potential issues that may arise from the oil reclaiming process applied to power transformers. Depending on the type of fuller's earth (activated bentonite clay) used as adsorbent for the oil purification, it has been found that reclaimed oil can become corrosive according to the DIN 51353 test. It is therefore recommended to perform a full set of tests on the reclaimed oil, including the DIN 51353 corrosive sulphur test, to prevent possible serious problems.

The next three papers deal with diagnosis tools for

transformers. Paper 0695 presents the results of experimental ageing tests which have been performed to check the feasibility of using the methanol content in oil as a marker of the degradation of the insulating paper. It has been found that methanol is a promising marker able to provide early warning about the degradation of cellulose insulation. It is more efficient than 2-FAL at this stage but methanol content tends to stabilize when the degradation of paper becomes important: it is proposed to use it in complement of 2-FAL marker analysis in order to cover properly the full range of the paper ageing process.

Paper 0374, from the environmental and industrial measurement specialist Vaisala in Finland, indicates the benefits that can be gained from real-time monitoring of the moisture content in the oil of power transformers. Capacitive sensors give direct information about the relative moisture saturation percentage, from which can be derived the water concentration in ppm when the water solubility characteristics of the oil are known. Moisture measurements from oil samples are affected by major uncertainties due to the handling of the samples, and also due to the loading history of the transformer before the sampling is done (hysteresis of the moisture content versus temperature): real-time monitoring measurements are not affected by these uncertainties and can provide useful guidance for the maintenance and operation of power transformers.

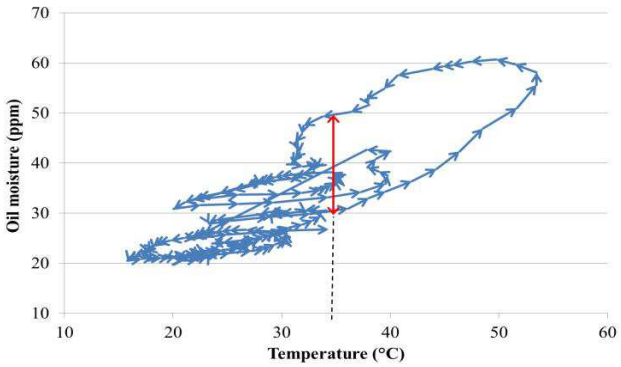


Figure 3 from paper 0374: Oil moisture plotted as function of temperature (variation of moisture at 35°C is highlighted with a red arrowed line)

A new type of expert system for power transformer fault diagnosis based on Dissolved Gas Analysis (DGA) results is presented in paper 1651. The ontology model based on OWL programming language has some advantages over other expert systems in terms of knowledge representation and extraction of hidden content in the knowledge. This model is able to integrate data from heterogeneous sources and provides accurate automated diagnosis of fault types.

The last four papers of this sub-block are related to various aspects of the adaptation of transformers to the flexibility requirements for the smart grids.

Paper 0419 introduces the concept of “soft sensors” incorporated in smart meters located at the LV side of distribution transformers. Thanks to thermal and electrical models of the transformer embedded in the software of the smart meter, it is possible to derive from the LV measurements information relative to the transformer and to the MV system, such as oil temperature, ageing rate, MV voltage values and energy flows. This could be an economically interesting solution for managing the smart grids, also on the MV distribution network (without using many MV sensors).

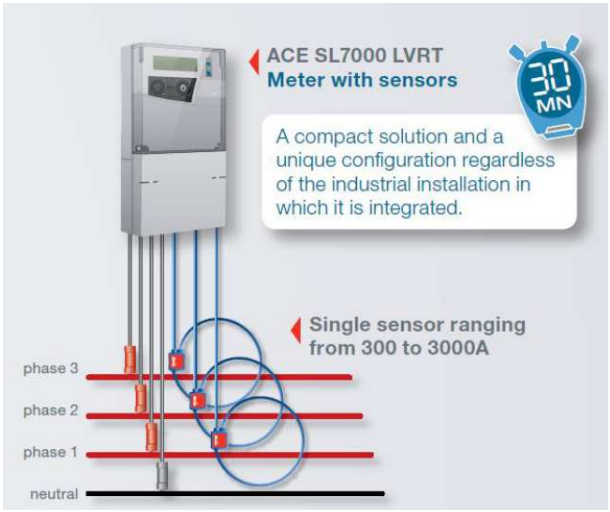


Figure 1 from paper 0419: Distribution transformer meter

In order to check the capability of transformers to meet future load scenarios (e.g. EV charging) it is necessary to evaluate their thermal parameters. Paper 1488 presents a method for estimating the parameters of the simplified IEC thermal model of transformers for which heat run tests data are not available. Based on furan analysis and load data, the average hot-spot temperature can be derived from the degree of polymerization of the paper insulation. The thermal parameters estimated for the transformer can then be used for predicting its remaining lifetime for any arbitrary load scenario.

The results of a survey conducted on several power transformers from Scottish Power Energy Networks are reported in paper 0987. It has been found that the inspected transformers were currently low loaded and that significant load increases could be applied to cope with the foreseeable evolution of networks (more electrical heating, electrical vehicles, solar energy) without excessive ageing. In order to be able to steer the power transformers safely and efficiently close to their limits, it is proposed to implement a real time thermal rating (aka dynamic rating) system, of which the principle and advantages are explained.

Finally paper 1283 presents investigations performed by EDF and the manufacturer Alstom in order to confirm the feasibility to upgrade 70 MVA power transformers to 100 MVA ratings. Numerical simulations and tests have shown that the 70 MVA design has good thermal margins and can be boosted up to 100 MVA with an enhanced

cooling system and by using thermo-stabilized paper for the solid insulation. Besides thermal aspects other points have been checked (leakage flux, capabilities of auxiliaries) and found satisfactory for operation at the upgraded rating. This will give more flexibility to ERDF for managing its fleet of power transformers which has ten times more 70 MVA units than 100 MVA ones.

Sub-block 2.3: Switchgear
(10 papers)

The first three papers of this sub-block present new methods for condition monitoring of MV switchgear.

Paper 0968 provides a comprehensive review of the monitoring options available for MV switchgear. Following an approach similar to that of the IEEE Std C37.10.1 "Guide for the Selection of Monitoring for Circuit Breakers", the paper lists the potential failure modes for MV circuit-breakers and identifies those representing the highest risk levels. For these failure modes the various available monitoring options are reviewed and assessed in terms of accuracy and cost. It is shown that, for the majority of the critical failure modes, now mature and efficient condition monitoring options are available. However it is stated that more research is still needed to improve the effectiveness of the monitoring systems for operating mechanisms and insulation.

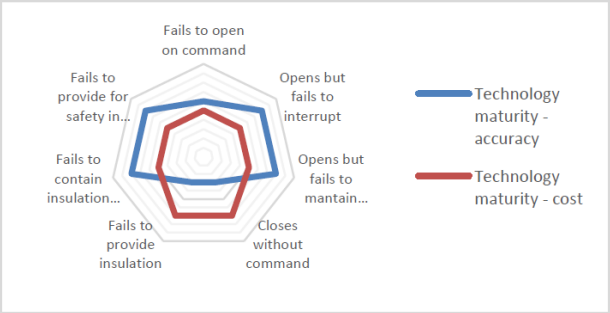


Figure 2 from paper 0968: Summary of technology maturity (in terms of accuracy and cost) for condition monitoring of MV switchgear

Paper 0358 describes an improved thermal monitoring system for MV switchgear. Algorithms have been developed to process the real time measured data (temperature and current) according to a thermal model of the switchgear in order to define a dynamic temperature limit (versus a fixed one) that is able to provide an early warning of abnormal conditions in the switchgear, even at low values of load current.

Paper 1436 reports about tests performed on a solid dielectric MV recloser to compare different types of partial discharge (PD) monitoring sensors. It has been found that low cost sensors, such as the built-in capacitive divider for voltage indication, can have a sufficient sensitivity for PD activity. However in field conditions it is necessary to use de-noising techniques, such as the principle of coincidence (gating concept), in order to suppress the back-ground electromagnetic disturbances and cross-talking between phases: long-term on-line tests are planned to further improve the system of external noise elimination.

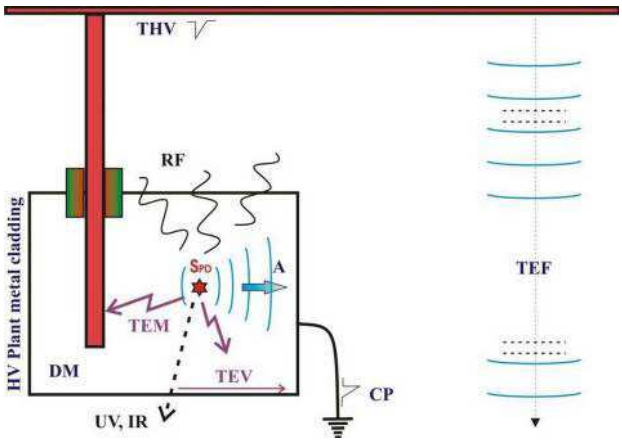


Figure 1 from paper 1436: Physical phenomena of PD occurrence: Electrical (THV transient high voltage, TEF transient electrical field, CP current pulse, TEV transient earth voltage, TEM transient electromagnetic, RF radio frequency wave); Acoustical (acoustic wave); Optical (UV and IR radiation); Chemical (decomposition of the material)

The next three papers are focussing on the climatic conditions inside secondary substations.

Paper 0144 reports on measurements performed in the Netherlands to assess the indoor conditions of MV/LV transformer substations. It has been found that in a significant percentage of cases the inner climate of substations is not suitable for long life duration of the MV switchgear, as condensation frequently occurs, which leads to damages to the mechanisms and to the MV insulation (if GIS switchgear are not used). The most effective actions for improving the inner climate and preventing condensation have been identified and are summarized in the following three basic rules: 1) every floor has to be 100 % air tight (vapor-tight and waterproof); 2) walls of substations without a MV-LV transformer require an Rc of at least 1 W/K.m; 3) MV-installations should not be placed in front of or nearby vents.

Along the same line paper 0342 from Portugal shows that reducing the openings area of MV/LV substations according to the average load of the transformer is a simple and effective way of improving the internal climate in substations and preventing early failures of air insulated MV switchgear. A practical table has been established for the different types of substations to determine which percentage of the ventilation area should be obstructed, depending on the rating and the load of transformers.

Paper 1515 describes how some underground MV/LV substations in the city of Buenos Aires have been modified, in order to prevent flooding of the substations in case of heavy rains. The retained solution (raised ventilation

chimneys from the side-walk, water-proof transformer and man-hole covers) has proven effective in reducing the risk of flooding, while maintaining a sufficient level of natural ventilation, and is relatively low cost and easy to implement: it has already been applied to 294 substations located in flood-risk areas.

The following three papers take up different aspects of the end of life or retrofit of MV switchgear.

Paper 0552 addresses the topic of the replacement strategy for aged MV switchgear for which spare parts are no longer available. In some cases the lack of spare parts will forbid maintenance activities: the probability of failure will increase rapidly and necessitate fast replacement of the switchgear. However inspection results can be used to refine the analysis and establish health indexes for the aged components: several sub-populations can be distinguished, with different remaining life estimation and different requirements in terms of critical maintenance (requiring specific spare parts). It is then possible to focus replacement on the high risk components only and perform maintenance or adaptation activities to extend the operational life of the other ones.

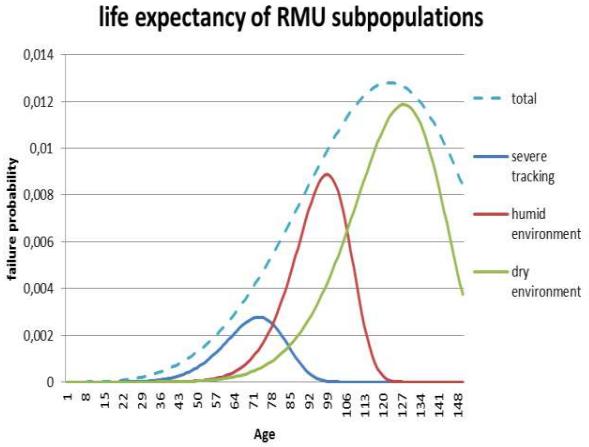


Figure 10 from paper 0552: Sub-populations based on inspections

Paper 1461 discusses the question of the end of life of vacuum interrupters (VI), which was already approached in previous CIRED conferences (cf. papers 0705 at CIRED 2009, and 0156 at CIRED 2007). Investigations have been carried out on a significant number of VI samples (from different manufacturers) removed from service after an operation life of more than 20 or 25 years. It was found out that the vacuum level inside these VIs was similar to that of new VIs, which confirms that vacuum interrupters are sealed for life, with no measurable leakage rate when operated in normal conditions. The other tests performed on these VIs (voltage withstand and breaking tests) were also satisfactory: indeed it was found that many of these VIs did little switching during their service life and so were still internally in new condition. Eventually it is concluded that vacuum interrupters, after having passed the early failures stage in the "bath-tub" curve, have a design life expected to exceed 100 years (provided of course that their mechanical and switching duties are low, and would not reach their endurance limits before, in terms of number of operations and accumulated interrupted current).

Paper 1420 presents a novel concept for retrofit of old MV switchgear, called "retrofill". The idea is to insert and connect inside the circuit-breaker (CB) compartment of the old cubicle the new drawout CB within its own new racking cradle. A patented system for designed-to-order links allows to connect, by clamping, the old spouts of the switchgear to the bushings of the new cradle. Some of the claimed benefits of the new "retrofill" concept: 1) the modern CB & cradle compartment system provides safe and state-of-the-art interlocking and operation of the drawout CB (e.g. remote motorized racking in and out of the CB is possible); 2) no need to know in details the design of interlocking and interchangeability of the old switchgear (unlike when the new CB uses the same design of truck as the old one); 3) possibly the new CB & compartment assemblies can be reused in case a complete renewal of the line-up is eventually decided.

The last paper 1630 in this block discusses the different options which can be considered when converting the neutral grounding method of a MV system from solidly earthed neutral to resonant grounded neutral, regarding the overvoltage protection of transformers by surge arresters. The best option is to replace existing surge arresters by surge arresters rated for resonant earthed system, but this is also the most costly. A comparatively low cost alternative, with same overvoltage protection efficiency, is to connect a fourth arrester (with low continuous voltage rating) in series with the earth connections of the existing arresters, in the so-called "Neptune" configuration. In this case the temporary overvoltage capability of the existing arresters needs to be checked, but it is usually found to be sufficient.

Potential scope of discussion (papers selected for oral presentation)

- Feasibility of robust health index assessment with limited investment in diagnosis (inspections, measurements) (0472).
- New markers available for ageing of well-known oil and paper insulation system (0695).
- Dynamic rating safe and reliable enough for effective application in distribution networks (0987).
- Maturity of solutions for condition monitoring of MV switchgear in the fields of operating mechanisms and partial discharges (0968).
- Impact of environment conditions in secondary substations on MV switchgear and auxiliary equipment life expectancy (0144).
- Keeping in service aged components with acceptable risk level (0552).

Table 2: Papers of Block 2 assigned to the Session

Paper No. Title	MS a.m.	RIF	PS
0472: Condition assessment of distribution grids using uncertainty theory	X		X
0217: System-Approach for Realistic Condition Assessment of High-Voltage Gas-Insulated Substations			X
1604: Managing performance, cost and risk of distribution asset through CBM method: study case in PT PLN Indonesia			X
0328: EDP Distribuição's asset management tool supported by real time monitoring			X
0466: Using smart sensors in the remote condition monitoring of secondary distribution substations			X
0476: Non-intrusive solution for Power Transformers real time monitoring using an hybrid Park's Vector and model-based approach		X	X
0669: Classification of Distribution Substations by Operational and Environmental Stresses Leading to Failure of Equipment		X	X
1074: Condition monitoring of electric equipment in railway substation by analyzing maintenance data collected from MICS (Maintenance Information Collected System)		X	X
0024: Condition Assessment of Power Transformers: A Practical Methodology Approach			X
0054: Integrated transformer fleet management (ITFM) system		X	X
1572: TNB Approach on Managing Asset Retirement for Distribution Transformers			X
0749: Accelerated ageing test of distribution transformers			X
0612: Fuller´s earth as the cause of oil corrosiveness after the oil reclaiming process			X
0695: Methanol as new ageing marker of oil-filled transformer insulation	X		X
0374: Transformer's moisture assessment with online monitoring			X
1651: Transformer fault diagnosis based on ontology and dissolved gas analysis			X
0419: Soft sensor for distribution transformers: thermal and electrical models			X
1488: Strategy for assessment of distribution transformer lifetime under EV scenarios			X
0987: Dynamic rating to support safe loading of distribution transformers	X		X
1283: A case of increasing the overload capability of transformer			X
0968: Medium-voltage equipment monitoring and diagnostics: Technological maturity makes concepts compatible with expectations	X		X
0358: Data model for overheat prediction of medium-voltage switchgear			X
1436: New method for in-service partial discharge measurement on solid dielectric switch			X
0144: Improving the inner climate of MV substations	X		X
0342: Dynamic ventilation of secondary substation: increase or decrease the openings?			X
1515: Construction of waterproof underground substations M.V./L.V.			X
0552: Optimisation of replacement of ageing MV switchgear due to lack of spare parts	X		X
1461: A field check on the condition of vacuum interrupters after long periods of service			X
1420: Innovative retrofit solution brings safety and reliability upgrade to aged switchgear installed base			X
1630: Modification of the arrester arrangement when converting the method of neutral treatment			X

Block 3: "Innovation in Network Components – Part 1: Cables and Lines"

This third block presents some design tools to be applied on cables and lines (3 papers)
A second part (16 papers) will propose some Smart Grids solutions and various applications in smart metering or power quality improvement.
The third part (11 papers) will be devoted to communication systems required by the smart grids

Sub-Block 3.1: Design tools for cables and lines (3 papers)

Type testing on cable and accessories is an unavoidable process for all power transmission and distribution systems qualification. The Dutch **Paper 0303** presents an overview of the main standards currently applied on EHV, HV and MV systems for 20 years, demonstrating – if it was necessary – the importance of testing the desired combination of cables and accessories before installation.

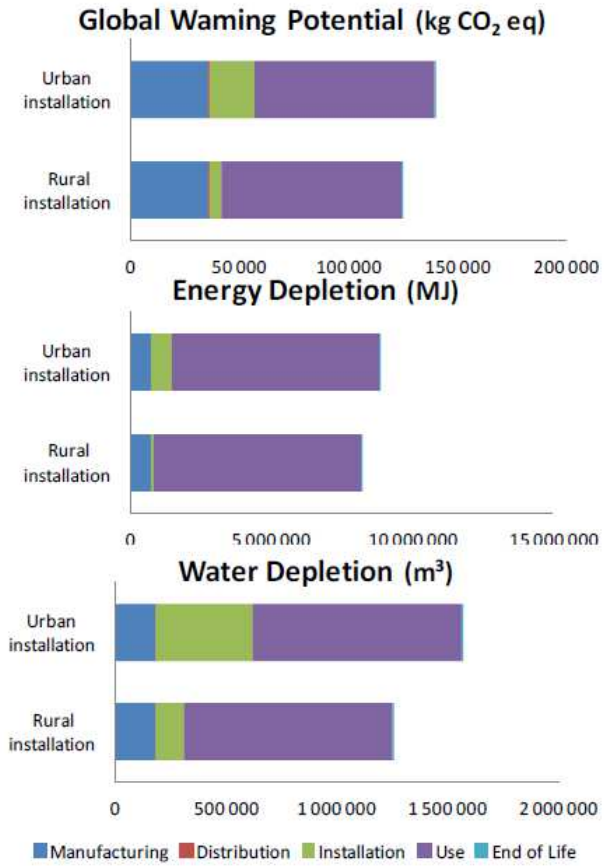


Figure 4 from Paper 1333: Life cycle impact comparison between rural and urban installation for 240 mm² MV cable

Life Cycle Assessment (LCA) is the topic addressed by the French **Paper 1333**. LCA is impacted by two parameters, the cable cross section selection and the installation type. Two MV cables cross-sections aluminum, 240mm² and 150 mm², are considered. Global warming, Energy & Water Depletion are significantly reduced from -25% up to – 36% with 240mm² compared to 150 mm², and from -8% to -25 % in rural installation compared to urban zone.

The Czech **Paper 1041** proposes a 3-DOF model for modeling the dynamic behavior of an OHL stretched wire. The cases study shows wire with constant icing and constant wind blowing. The practical result is the development of new tool for OHL designers providing limiting mechanical forces and limiting clearance under the line.

Sub-Block 3.2: Smart Grids solutions (16 papers)

Smart grids require some sensors. The **Paper 1101** depicts the actual need of sensors in the French Distribution network for Smart Grid applications. Several sensors were selected in order to carry out functional and laboratory tests. The four tested sensors use some basic principles. For voltage measurements, sensors are capacitive (sensor 1) or resistive (sensor 2) divider type, for current measurements Rogowski coil (sensor 3) or Hall effect (in sensor 4 including a CT) sensors are selected. These four sensors were tested within two testing facilities. The good performance and limitations of these sensors were observed.

Paper 1016 reports on field tests on MV cable accessories – indoor termination and plug-in connector - with integrated sensors for current and voltage measurement in combination with a special tele-control equipment as an alternative to conventional transducer technology in medium voltage grids. Concerning economical aspects, in addition to the hardware costs for accessories and telecontrol technology, costs for installation, maintenance and process control connection must be considered. According to the authors, apart installation time duration which should take little more time, no maintenance or recalibration is required, the operating expenses are not different from that of conventional transducers.

The Iranian **Paper 0959** presents the design and manufacturing a current transmitter for smart grids applications on MV systems. Based on Hall effect, this CT sensor design considers the impact of the electrical field, thermal and saturation effects on measurements. A prototype model has been manufactured and tested during nine months on 20 kV network.

The objective of **Paper 0769** is to present tests carried out for the French VENTEEA smart grid demonstration project, and, more precisely, a specific focus on an innovative MV fault detector. Three measurement sensors – one per phase – are installed on the MV OHL with a processing unit on the ground. Then a series of fifty faults – downstream and upstream the detectors were created by means of a mobile circuit breaker. Current measurements were carried out in the various configurations. These tests enabled i) to check the fault detectors installation on MV OHL, ii) to put in service the detector system, iii) to validate sensor behavior under real various conditions, iv) to test

functional performances of the fault detector with different fault parameters.

Standardization for the current and voltage measurements in electrical networks by IEC and CENELEC is the topic addressed in **Paper 1215.** The former IEC Series 60044-X is now replaced for conventional type of instrument transformers by the new IEC Series 61869-X. Concerning new technologies using mostly optical Faraday and Pockels effects, or passive sensors using low power current sensors, Rogowski sensors or R/C divider, the standardization work is in progress.

The accuracy of instrument voltage transformers is very important for a proper operation. In line of this topic, **Paper 1295** proposes design criteria and a survey on the precision and reproducibility of a new model-based calibration approach.

Following up the information presented at CIRED 2013 (Paper 0742) about the 3 concentric three phases superconducting MV Cable AMPACITY project, **Paper 0678** updates this project situation. After installation operations in last 2013 term, the commissioning tests were successfully performed in December 2013 with PD measurements at 20 kV, loss factor at 10, 15 and 20 kV. Finally a voltage withstand test was applied on each phase at 30 kV – one hour. On March 2014 the HTS system was connected to the grid.

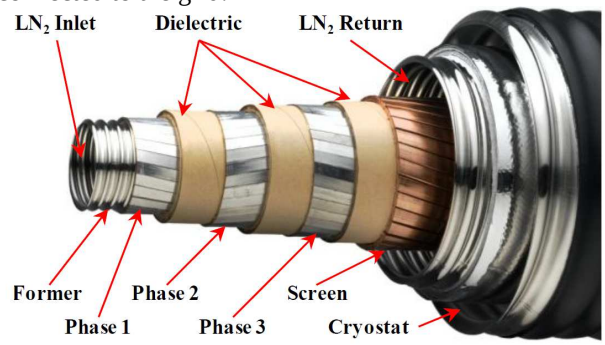


Figure 2 from paper 0678: Concentric HTS Cable design

Fault current limiters can play an important role in networks designs, either using superconducting components or magnets. Three papers will present new projects of field testing installation. A first superconducting FCL was installed in Italy in March 2012. The results of the grid field-testing and 3-phase fault event are presented **Paper 1256**. The SFCL is a resistive-type BSCCO-based 9kV/3,4MVA and installed as a single-feeder fault protection in a substation of Milan urban area. Thanks to this first successful installation and operations, the DSO is now considering protecting four different feeders at 9kV in the same substation with upgraded SFCL to be developed up to 9kV/16,5MVA.

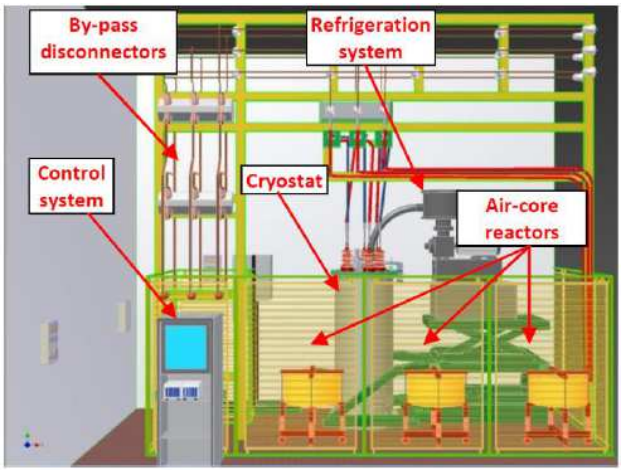


Figure 1 from Paper 1256: General sketch of the FCL grid installation

Two superconducting FCL, part of the FlexDGrid project, will be installed in Western Power Distribution Grid in UK by mid 2015. These two SFCL, resistive-type YBCO based are described in **Paper 0985**. They will be introduced in the 11 kV bus ties in order to improve the short circuit strength. The operating current of the two devices is 1600 A and 1050 A, respectively. In both applications the prospective peak short circuit current will be limited from about 20 kA to below 10 kA.

After the feasibility study – see Paper 0505 of CIRED 2013 – **Paper 0223** describes the development of circuit parameters to predict the performance of a new permanent magnet biased FCL being developed for application in the 11 kV network. A comparison is made between the selected saturated iron core inductors FCL with a conventional Current Limiting Reactor (CLR). The power delivery advantage is shown with the pre-saturated FCL for the commercial power class of 20 MVA.

Integration of dispersed and fluctuating photovoltaic and wind energies causes voltage rise problems especially in rural grids with low load density and long distribution lines. In order to achieve an efficient supply with electrical energy **Paper 1230** presents Line Voltage Regulator (LVR) for voltage adjustments in MV Grids. The LVR is based on a circuit which adds or subtracts an additional voltage U_B to the non regulated voltage U_L. A transformer is used as a variable voltage source. A pilot installation of an 8 MVA LVR was realized in the 20 kV grid of Westnetz in Austria.

In the same line, **Paper 1512** describes the field trial of a power electronic device which regulates the voltage on the LV network to mitigate customer voltage issues. The device is equipped with a shunt current source - providing reactive capability and harmonic current compensation – and a series voltage source providing voltage regulation and harmonic voltage compensation. The power rating of the tested device is 50 kVA per phase, 150 kVA in total at 230 V AC nominal voltage.

As the two previous papers, voltage regulation is the aim of the German **Paper 0130**. Initially designed to be used within the power system as a control device, Voltage Regulating Distribution Transformers can also be applied as generating unit transformers in e.g. wind power plants or as switching element in variable shunt reactor (VSR) providing enhanced capabilities of the generation units with respect to applicable voltage ranges for continuous operations and reactive power supply. The paper describes both applications and a done certification process for VRDT and VSR.

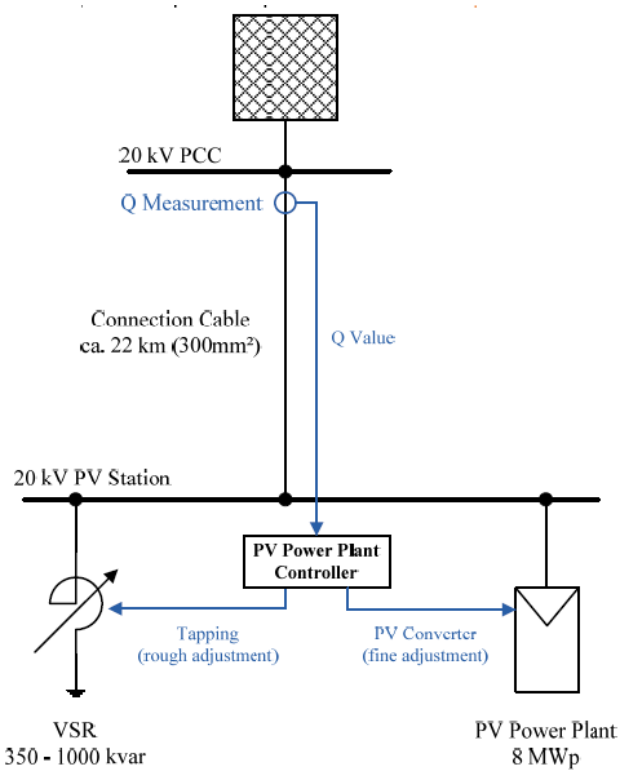


Figure 4 from Paper 0130: case of application PV park

Paper 1093 proposes an improved passive-damped LCL filter to be used as interface between the grid-connected voltage-source converters (VSC) and the utility grid. The proposed filter replaces the LCL filter capacitor with a traditional C-type filter with the resonant circuit tuned in such a way that switching harmonics due to pulse width modulation are to be cancelled. Since the tuned circuit of the C-type filter suppresses the switching harmonics more effectively, the total inductance of the filter can be reduced. Additionally, the rating of the damping resistor is lower, compared with conventional passive-damped LCL filter. To verify the benefits of the proposed filter, a comparison with the conventional LCL filter is made in terms of losses and ratings when both the filters are designed under the same condition.

Smart meter installation in small territories can have different outcomes and challenges than the expected results in larger territories. **In Paper 1361**, the EDF SEI examines these outcomes and challenges on some of their overseas regions to better understand the acceptance of smart metering across island communities. As energy consumption savings and peak load shaving are key objective of the local DSO, smart meter could be a solution and it's technically feasible. Associated results of the experiment are the reduced life span of smart meters under the Caribbean climate and the impact on professional skills and work forces training needs.

Similarly EDP points out in **Paper 1165** the smart meters reliability due to the use of not completely mature and complex electronic components. A reliability prediction method was applied and a test procedure is proposed. To predict the smart meters reliability, EDP collected information through the three following steps: i) computations to predict the reliability of the meters, ii) information collected from the field, iii) labs tests.

Sub-Block 3.3: Communication systems in Smart Grids (11 papers)

The Swedish **Paper 0912** describes DSO's experience from planning and installation of a system for improved monitoring and communication with a secondary substation. The technical solution is based on a Swedish supplier concept. An automatic switch-over functionality has also been implemented together with MV switchgear. Radio planning of mobile communication, development of system architecture and a requirement specification are all important parts, but the major challenge of this project proved to be the installation. New technology, a large number of companies involved and new requirements on the staff's competence level were some of the challenges.

The iniGrid project, presented in the Austrian **Paper 0713,** addresses the development of cost effective components for medium and low voltage network, as well as their secure integration and roll out into power systems. One central application within this context will be the development and integration of Smart Breakers, which aim is to provide load monitoring and control functions for decentralized applications. Base on this idea, the supplier provides a generic concept for integrating this technology into power grid control systems, while IT-security is an increasingly important concern that necessitates continuous research work. Finally, within the research project both technological developments and conceptual investigations will be proven in field trials both in labs as well as real world scenarios.

Smart area Aachen project is introduced in **Paper 0521**. The project "Communication infrastructure for Innovative Equipment" will build the basis of open communication for all other joint projects. The project will provide an extension of the IEC 61850 standard. The knowledge and recommendations from this project will be used for further development of the industrial partnership. The results will be published in national and international conferences and standardization processes.

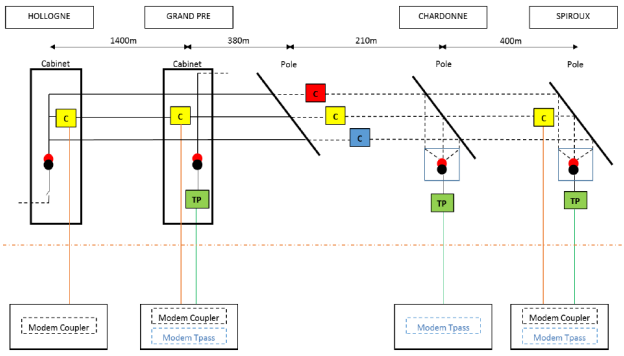


Figure 1 from Paper 0543: Marche-en-Famenne field trial setup (C=Coupler; TP=Tpass)

Paper 0543 presents the field trial realized in Belgium by a consortium gathering DSO, supplier and university representatives. The current results of this field trial show that the collaboration of every members of the consortium resulted in a functioning measurement setup capable of analyzing the performance of G3-PLC on the MV line over long periods of time. This paper shows that in the case of the considered field trial, G3-PLC communication is functional on MV lines in the FCC band. However, further steps have to be taken to study the possibilities that G3-PLC on MV lines can offer to DSOs. Indeed, for the G3-PLC to be of any practical use for DSO on MV lines, further studies have to be realized. The next steps of these analyses will be to correlate the performance with the load present at different points on the line, to further study the performance evolution over longer periods of time (seasons for instance), to take into account practical needs to better fit the test parameters with real practical telecommunication needs. Another aspect of the field trial that needs to be studied is to ensure that the parameters used for the transmission are compliant with EMC regulations. Steps to measure the electromagnetic radiation are ongoing and will be taken into account.

MV Broadband Powerline Communications (MVBPL) is a robust communication solution with good performance and economy for the support of distribution automation applications. The Spanish **Paper 0691** describes the use of MVBPL as part of the Iberdrola communication network for smart metering and smart grid applications. It demonstrates the scalability, performance and economy of the MVBPL communication system in comparison with commercial 2G/3G radio networks. In the financial analysis some basic variables must be taken in account as i) the share of the transformer stations with MVBPL or 2G/3G as part of the total commercial roll out, ii) cluster size ; the number of transformer stations with MVBPL devices. Clustering the MVBPL allows i) to get a high performance solution, ii) to get a lower total cost of ownership and iii) to improve the Net Present Value.

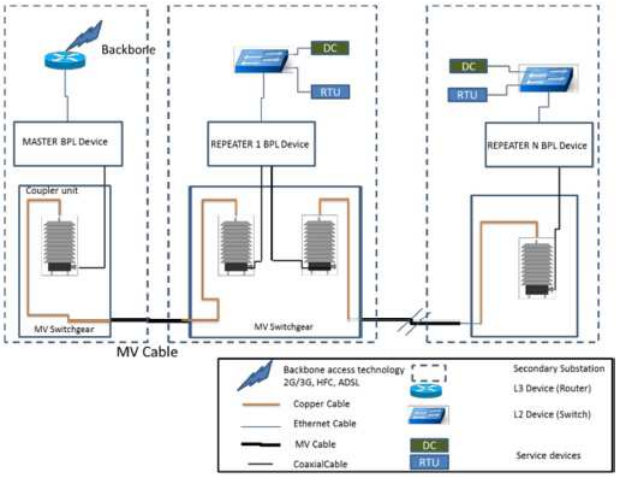


Figure 3 from Paper 0691: Network elements in the MVBPL Cluster

In the intent to use the transmission and distribution power lines as a communication channel, much attention has been provided in the modeling of the transmission media used for the propagation of the signals that transmit the information. Most of this effort has been applied in the broadband propagation characteristics, due to higher bandwidth and the use of higher frequencies that can avoid some interference. In the Spanish **Paper 0313**, it is proposed a method to better understand parameter differences between line characterization in the different frequencies of interest for PLC applicable to analytically determine the channel model, by analyzing the effects of reflections due to the nodes and branch lines impedance mismatches that are present at the distribution power lines. Nowadays such methodology is empirically determined, so this new approach intends to facilitate the modeling methodology prior to its implementation.

In a PLC based AMI system a crucial role on overall system performance and KPI fulfillment is played by the reliability of the communication on distribution line. Typical PLC communication architecture is based on concentrators, normally installed into secondary substations, and PLC nodes spread over the distribution network, normally near the customer premises. Capability of a PLC node to setup a connection with its concentrator is conventionally named reachability. Reachability of a node on distribution line strongly depends on electrical parameters that are not easy to measure such as cables attenuation, loads impedance, narrow band/wide band noise and, often, unknown network topology, which, in addition, are not stable across the hours, days, weeks and seasons. Aim of the Italian **Paper 0720** is to detail ELVIS, an integrated handheld device able to perform all the needed measurement as well as to act as a PLC node in order to allow performing many PLC communication diagnostic functions in a simple, guided and safe way due to its integrated wireless communication capabilities and APP based MMI.

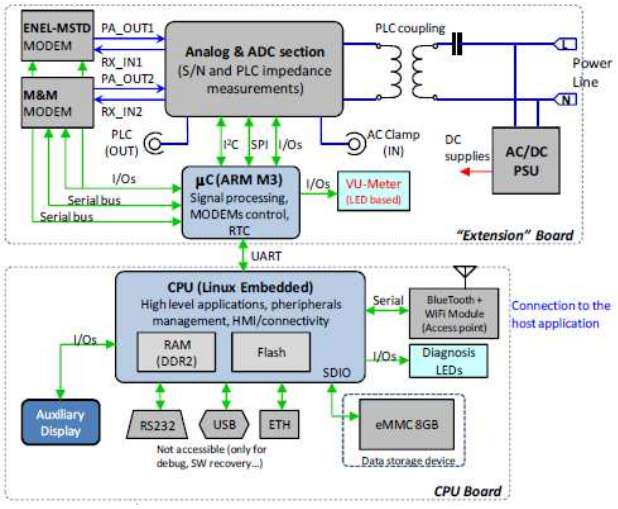


Figure 1 from Paper 0720: device general architecture

Historically, automation investments in MV distribution network were focused mainly on energy availability. Since a decade, the emergence of new applications such as distributed generation for instance, induces new challenges regarding voltage plan control, including in the LV network, leading to an increasing need for LV monitoring and control. As a consequence, sensors have to be installed into the LV pillar of an MV/LV substation, and mainly as retrofitting of existing substations. Wireless sensors have to be considered as the only possibility in most of the cases. **Paper 0638** describes the multiple advantages of wireless sensors for LV monitoring in an MV/LV substation. In a first part, wiring and upgrading simplification are analyzed. In a second part some possible architecture are proposed, showing the easiness of installation and the openness of the solutions. Different standards of wireless protocols and systems are compared. A last part demonstrates the feasibility with an example of architecture based on Zigbee standard communication systems. It will show that a standard created for the residential market could be used in an industrial harsh environment.

The Croatian **Paper 1018** deals with interoperability and interchangeability requirements for metering equipment with respect to different communication protocols, modulation techniques and interfaces. It describes the GSM/GPRS communicator that supports both IEC 62056-21 and IEC 62056-31 communication protocols as well as the additional function of IEC 62056-21 to IEC 62056-31 conversion and vice versa.

The Brazilian **Paper 1477** aims to conduct a discussion on the main physical media used in communications networks in Smart Grids considering PMU applications. To achieve it, a comparison of the security implications of the major physical means and technologies used in communication networks based on IP is performed. To perform this comparison, is first conducted a study of the existing vulnerabilities in a network data communication. From this, an assessment of physical media, protocols and routing technologies used under the security context of communication will be held.

The telecommunications sector is crossing a strategic time in France with the deployment of next generation infrastructure, both fixed and mobile with 4G. This is for the fixed part of the gradual renewal of the historic copper local loop by a fiber optic infrastructure (FTTH). This renewal began in the mid-2000s in very dense areas, is gradually extending today to less dense areas. This is a site of considerable infrastructure of over 20 billion €. In rural areas France is populated with a lot of small cities and villages that represent 40% of the population. On way to reach these small cities and villages by optical cables to implement Very High Bit Rate is to use medium voltage power lines mainly operated by ERDF in France for which a few millions of medium voltage towers could be used. The French **Paper 1646** presents the different solutions that are under development or will be implemented on these lines to get reliable installations with the minimum adverse effects or overload increase on the towers when high speed wind or a combination of wind and ice increase dramatically the cable strains on the towers.

Potential scope of discussion (papers selected for oral presentation)

- What are the consequences of life cycle environmental impact assessment on cable design and installation? (paper 1333)
- Which sensors are needed for smart grids applications? (paper 1101)
- Will superconducting cables become a widespread solution in the near future? (paper 0678)
- Advantages, drawbacks and maturity level of superconducting fault current limiters? (paper 1256)
- What is the best solution for voltage regulation in MV grids? (paper 1230)
- What are the main challenges faced when implementing secondary substation monitoring and communication? (paper 0912)

Table 3: Papers of Block 3 assigned to the Session

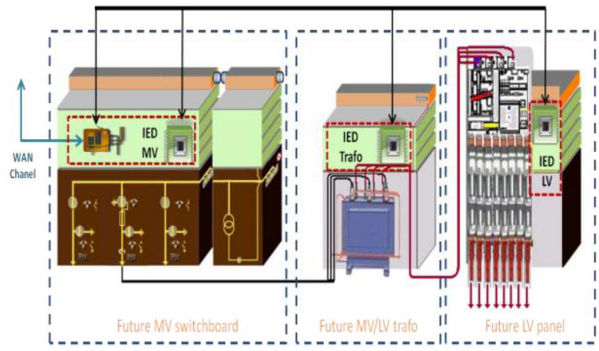
Paper No. Title	MS p.m.	RIF	PS
0303: Type testing cable and accessories, a must			X
1333: Quantification of MV cables environmental impact using life cycle assessment	X		X
1041: Overhead line mechanical behaviour – Dynamical model			X
1101: Sensors in the French distribution network for smart grid applications	X		X
1016: Smart cable accessories for the measurement of state variables in medium voltage networks			X
0959: Designing and manufacturing current transmitter on MV systems for smart grid applications			X
0769: Tests of innovative fault detectors for the French distribution network			X
1215: Standardization in the field of Current and Voltage measurements			X
1295: Accuracy of voltage transformers – Design criteria and a survey on the precision and reproducibility of a new model-based calibration approach			X
0678: AMPACITY project – Update on world's first superconducting cable and fault current limiter installation in a German city center	X		X
1256: Fault current limitation – Results of the first grid field-testing and 3-phases fault event on the first Italian superconducting Fault Current Limiter	X		X
0985: Commercial application of superconducting fault current limiters in the western power distribution grid in the UK			X
0223: Full scale 11 kV Fault Current Limiter for the distribution grid based upon zero power consumption ceramic ferrite permanent magnets			X
1230: Line voltage regulator for voltage adjustment in MV grids	X		X
1512: A comparison of field results with modeled behavior for a power electronics regulator used to manage dynamic voltage variation on a feeder with high PV content			X
0130: Increase of the grid integration of decentralized power plants by the application of certified grid regulation units in secondary substations and power generation units			X
1093: Improved Passive-Damped LCL Filter to enhance stability in grid-connected Voltage-Source Converters			X
1361: EDF evaluates smart metering in Martinique – Expectations & local review			X
1165: Reliability prediction methods – The procedure used by EDP			X
0912: Secondary substation monitoring and communication – A pilot project in Stockholm	X		X
0713: Secure integration and Rollout of IEC 61850-based smart components within the iniGrid project			X
0521: Smart area Aachen – Communication infrastructure for innovative equipment			X
0543: Field trial deployment for the evaluation of G3-PLC performance in the medium voltage grid			X
0691: MVBPL – Reliable, future proof and cost efficient			X
0313: Consideration of DER in the PLC communication channel			X
0720: ELVIS (Enel Low Voltage Identification System) – Improving narrowband PLC communication performance by means of electrical characteristics measurement of distribution line			X
0638: Wireless connection in distribution substation			X
1018: Communicator with the additional function of conversion of communication protocols			X
1477: Security aspects on PMU data communication based on IP networks in smart grids			X
1646: Vey high bit rate in rural areas thanks to ADSS solutions on aerial medium voltage line			X

Block 4: "Innovation in Network Components – Part 2: Substations"

This block is organized in five sub-blocks as follows:
- Substations;
- Transformers;
- Switchgear;
- Modelling and simulation;
- Storage and LVDC distribution.

Sub block 4.1: Substations
(5 papers)

Paper 1027 explains the approach retained by EDF and ERDF for the development of a new generation of smart secondary substations. After the smart meters (Linky), the smart MV/LV substations have now become another essential brick of the smart grids, and synergies must be found between them (e.g. substations should benefit from the Linky infrastructure for network applications). A gradual development process has been chosen (first a development market to refine the requirements and solutions with selected manufacturers, then the series market) with a focus first on control-command, sensors and MV switchgear (evolutions of transformers and LV panels will be considered at a later stage). The selected architecture for the integration of intelligence in substations, through the so-called EMIS (Equipment of the Modular type for Instrumentation and Supervision) equipment is presented in the image below.



The "Intelligent Electronic Devices" (IED) are distributed close to the sensors in order to limit cabling: this implies renewal of the power equipment (MV switchgear, transformer, LV panel) for retrofit of existing substations. The control-command equipment EMIS is modular (in order to be "future-proof") and embeds a set of functions which can be divided in five families (network, service, system, security and communication). Voltage and current sensors are tested and evaluated at the new Concept Grid laboratory of EDF. To take into account cyber-security and bandwidth concerns a hybrid solution has been chosen for communication: proprietary systems for the "critical" channel, operated telecoms for the "non-critical" channel. The considered time frame is the following: development market phase from 2015 to 2017 (three years), roll-out of the series market for the targeted generation of smart secondary substations from 2018.

The next three papers are related to the design of prefabricated substations.

Paper 0538 describes the methodology applied for the design and manufacture of prefabricated HV and LV installations (E-house) for industrial applications. These types of substations are not directly covered by the existing IEC standard applicable to prefabricated substations used in distribution networks, but the approach remains based on standardized solutions which have been validated or type-tested. The functional analysis of the E-house is used as a guideline for reviewing the design of the envelope (based on modules), the electrical installation inside and the checks which have to be performed to make sure that what has not been type tested will perform according to the specifications. It is also shown how the requirements for embedded monitoring functions to help the condition based maintenance of these installations are taken into account from the design stage.

Paper 0951 explains how the use of virtual testing by means of standardized numerical simulation tools allows the development and validation of customized substations for specific applications, like renewable farms, to be performed efficiently and economically, with a limited recourse to actual physical testing.

Paper 0212 introduces a new GRP (Glass-fibre Reinforced Polyester) material considered for the envelope of prefabricated substations. In comparison with the conventional steel or concrete materials the most interesting properties of GRP are: 1) light weight for a given structural strength; 2) high thermal insulation; 3) resistance to corrosion. Some points of attention to be addressed properly for the application of GRP for substation enclosures are the UV resistance and the reduced thermal inertia.

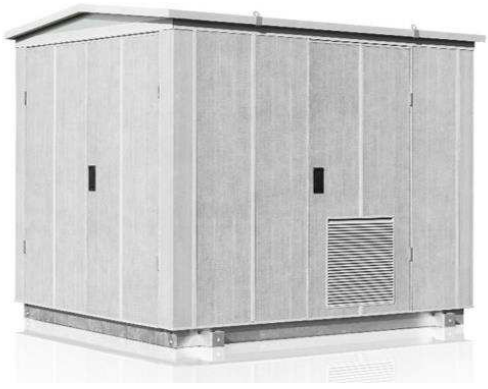


Figure 4 from paper 0212: Proposed modular CSS made of GRP

Finally paper 0610 presents a cooling solution based on the "Canadian well" principle that can be advantageously applied in climates where the maximum load conditions for transformer substations occur when the ambient air

temperature is also at its maximum (like Spain). Geothermal cooling is achieved by forcing the ventilation air through underground pipes (not used by cables): typical pipe lengths of 50 to 100 m and diameters of 150 to 200 mm, buried at 1 to 2 m depth, have been found suitable for efficient transformer substations cooling in these severe conditions.

Sub block 4.2: Transformers
(5 papers)

As an introduction to this sub-block, paper 0424 presents the current standardization activities of the IEC TC 14 in the field of power and distribution transformers. A general review of the on-going work program of the Technical Committee 14 is provided, with a special focus on a topic of interest for the CIRED community: the development of the future "Energy efficiency" standard IEC 60076-20. A second committee draft (CD) of this document will be published in 2015: the different ways to define the efficiency index of transformers, as well as the minimum levels being considered, are introduced.

The next two papers are dealing with the European Regulation No 548/2014 recently issued to implement the 2009 Ecodesign Directive in the field of transformers. Paper 1299 explains that as from July 1st 2015 the transformers covered by this Regulation will have to comply with maximum values of no-load and load losses, or minimum values of the Peak Efficiency Index (PEI). These transformers will be heavier and costlier than the current standard C0Bk transformers, but it is shown that, if the losses during the usage phase are taken into account, the new designs complying with the Regulation can be economically, as well as environmentally, beneficial.

One of the consequences of the new Regulation is the need to accurately measure the losses of power transformers. In paper 1538 VSL, the national metrology institute of the Netherlands, presents the new specific facilities that they are developing for the calibration of transformer loss measurement (TLM) systems. The components and system approaches for TLM calibration are explained: the system approach is more complex but preferable. The facilities for complete on-site system calibration of TLM are currently being developed and expected to be ready in 2016.

The last two papers in this sub-block are related to the use of natural esters in oil transformers.

Paper 0784 reports on the introduction of natural esters filled distribution transformers in the network of Tata Power in Mumbai city. The main advantages of natural esters versus mineral oil are better biodegradability, lower risk of fire and higher admissible temperature rises. To take benefit from this last point it is considered in the future to increase the temperature limits for the transformers used by Tata Power, which will result in a reduction of the footprint and total cost of ownership (in spite of some increase in the load losses).

In paper 1533 the supplier of natural esters Cargill reports on oxidation ageing tests performed on samples of transformer paper and pressboard insulation impregnated by natural esters. It has been found that the dielectric creep withstand performance of the samples could be adversely affected by air oxidation (when prolonged over 30 days, up to 180 days in 40°C dry air oven) contrarily to samples impregnated by mineral oils. Recommendations are therefore made regarding the manufacturing and repair processes for transformers using natural esters insulation in order to prevent significant losses of the insulating properties due to oxidation ageing of the paper insulation.

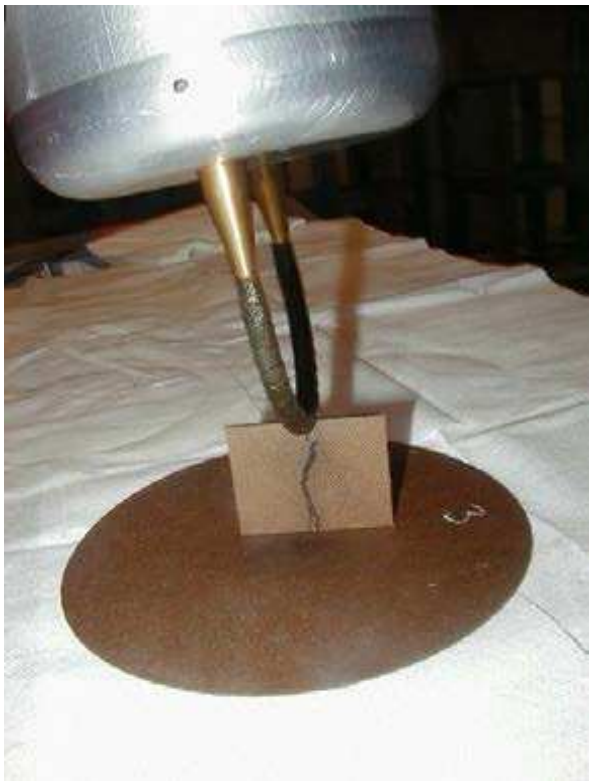


Figure 3 from paper 1533: Creep test specimen

Sub block 4.3: Switchgear
(15 papers)

The first four papers of this sub-block are related to the topic "SF6 Substitution: Alternative Gases and Mixtures" that will be discussed in the round table 4 on June 16th, for the first time in CIRED.

Paper 0230 from Alstom Grid presents a new possible alternative to SF6 in HV switchgear, which consists in a mixture of the 3M Novec 4710 fluid (from the FluoroNitriles family, FN) for 4 to 10% of the volume, and carbon dioxide CO2 for the balance. Because of the low percentage of fluorinated component in the mixture, the GWP per mass unit of gas is reduced by about 98% in comparison with SF6, to typical values in the order of 300 to 500. The dielectric and thermal properties of the mixture are sufficiently close to those of SF6 to allow keeping

similar design and technology for the HV switchgear using this alternative. The current interruption capability of the new gas (for circuit-breaker application) is still under investigation, but promising results are reported. No timeline for industrial application is indicated at this stage.

Paper 0587, from ABB, EWZ and 3M, introduces another SF6 alternative applicable to MV primary gas-insulated switchgear (GIS), based on a C5 FluoroKetone (FK) equally developed by 3M. Compared to the FN family the FK family is characterized by much lower GWP (close to 1), but also less stability. Like FN, FK have a relatively high boiling point (26°C for C5) and so have to be used in mixtures (in this case dry air is used as carrier gas) with a sufficiently reduced partial pressure to remain gaseous at low temperatures. FK application is limited to dielectric insulation (no arc switching), but this is sufficient for MV primary GIS which typically use vacuum interrupters for switching. The investigations performed on the new FK-based alternative gas have shown that the properties are sufficiently close to SF6, so that only slight modifications of design are necessary. A further step will be achieved soon with the implementation of a pilot substation in the EWZ network: this will allow gathering more information in the coming years on the behaviour of the new gas and its stability in the conditions of MV primary GIS application.

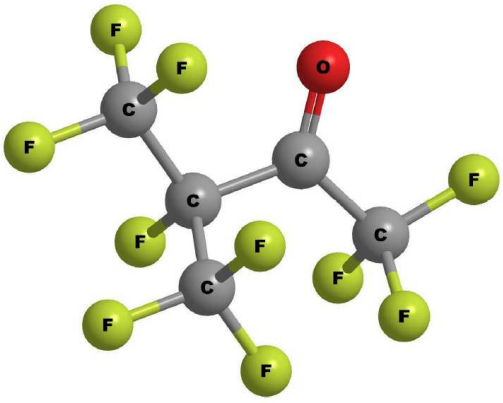


Figure 1 from paper 0587: C5 fluoroketone 3M Novec 5110 Fluid

Paper 0926, also from ABB, provides a comparison, based on both theoretical and experimental results, of the dielectric performances achievable in a typical secondary distribution GIS (RMU) for SF6, air and the C5 FK-air mixture introduced in the previous paper. Although for a mixture suitable for application down to -25°C the dielectric performance is significantly lower than that of SF6, it is shown that some design improvements can be applied to achieve the rated insulation level with the alternative gas. Typically a RMU design suitable for 12 kV (75 kV BIL) rating with air insulation can be used for 24 kV (125 kV BIL) rating with the very low GWP C5 FK-air mixture suitable for -25°C minimum operating temperature.

Finally, paper 0493, from Schneider Electric, presents a list of candidate alternative gases for the replacement of SF6 and proposes validation steps to be followed for selecting the most suitable alternative. In addition to the main technical performances (dielectric, thermal) a special focus should be made also on the properties of stability, compatibility with materials and toxicity (of the gas itself and of its decomposition products). The corresponding validation tests program represents a long term effort, and it is considered that at this stage the ideal candidate has not been found yet. However a compromise solution seems achievable, possibly with a somewhat revised target in terms of GWP reduction.

Based on these four papers it is possible to identify a number of questions raised by the challenge of finding a low GWP alternative to SF6 for HV and MV switchgear application. These questions will certainly generate interesting discussions in the round table dedicated to this topic.

A not limitative list is proposed hereafter:

- What are the real environmental stakes and the reasonable targets in terms of GWP reduction (divided by 100, by 10,000 … trade-off between GWP and stability of the fluorinated gas to be considered)?
- How long can it take in our era of “principle of precaution” to validate a new artificial gas for switchgear application?
- What is the best approach to be followed: several initiatives in competition (proprietary solutions, patents) or coordinated effort at the level of the industry, with the active involvement of users, to determine one standardized alternative?
- What would be the economical impact of a possible EU regulation banning SF6 in secondary distribution GIS, depending on whether a natural or artificial gas alternative is retained?

New designs of switchgear are presented in the next five papers.

In paper 0058 Ormazabal goes one step further in the elaboration of the solution proposed, for secondary distribution MV switchgear, at the previous CIRED conference (cf. paper 0095 at CIRED 2013): a combination of vacuum circuit-breaker (CB) and SF6 load-break switch (LBS). In the last version of this concept the combination of CB and LBS is operated and mechanically synchronized by a single driving mechanism. The resulting 3-positions circuit-breaker and earthing switch assembly makes best use of the respective advantages of vacuum and SF6 switching techniques, while keeping the simplicity of operation of a single 3-positions device.

The next paper 0057, from the same manufacturer, introduces a new design of cable testing facility developed for application in secondary distribution MV GIS switchgear. An integrated switch-selector dedicated to cable testing is provided, which is interlocked with the main

switch-disconnector and earthing switch. This new concept presents the following advantages over the conventional cable testing systems (either "British" or "French" types): 1) no risk of affecting the condition of the main earthing system; 2) no need for specific tool for voltage injection.

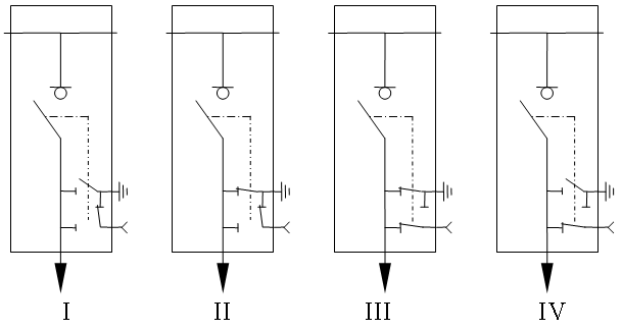


Figure 5 from paper 057: Sequence of operations for voltage injection

Paper 1503 presents the design adaptations performed by G&W on a solid insulation submersible vacuum fault interrupter in order to provide a visible break for visual confirmation of the "open" state. A glass window has been overmoulded in the epoxy resin enclosure in order to make visible the blades of the disconnect switch inserted in series with the vacuum interrupter. This innovative switchgear is the first of its kind to be produced and the solutions found to the design challenges (water tightness, dielectric performance) are explained.

Paper 0789 describes a new development by Ensto Novexia: a pole-mounted SF6 switch-disconnector for connection to 24 kV 630 A overhead networks using insulated cables. In order to facilitate the installation and eliminate exposed bare live parts the following solutions have been retained: 1) auxiliary voltage transformer integrated within the SF6 tank; 2) use of screened separable connectors and surge arresters directly plugged in the connectors.

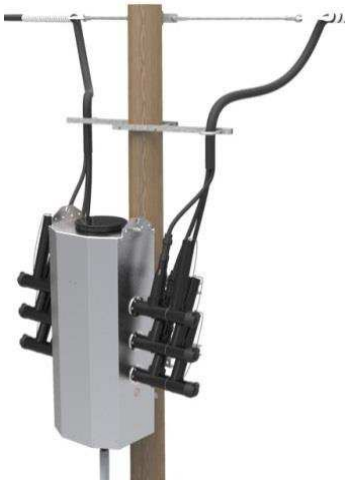


Figure 6 from paper 0789: Addition of an internal transformer and the connecting solution

Paper 1212 reports on the design and testing of a new ABB vacuum generator circuit-breaker for ratings of 15 kV – 50 kA – 4000 A. The breaking duties for generator circuit-breakers are significantly more demanding than those of distribution circuit-breakers according to the IEC 62271-100 standard: higher d.c. component (possibility of delayed current zeros), steeper transient recovery voltages (TRV), larger fault currents under out-of-phase conditions. To meet these requirements specific solutions must be applied in order to get the best possible performance from the vacuum interrupters. In this case optimized transverse magnetic field (TMF) arc controls have been selected because their relatively high arc voltage helps in reducing the d.c. component and getting earlier current zero crossing. Also a robust auto-reclosing spring-operated drive mechanism has been chosen in order to get a fast opening of contacts, which helps in sustaining the high values of TRV after a short arcing time.

The next two papers deal with sensors, either for measurement or for condition monitoring.

Paper 0529 specifically focuses on the measurement system which has been integrated in a MV recloser in order to provide accurate voltage and current values for the new "smart grids" applications (like energy and power flow management, power quality monitoring, etc.). The measurement system includes notably: low power electronic instrument transformers, junction box and electronic relay for the recloser control and protection. The measurement uncertainty of the whole system has been assessed experimentally and by simulation according to the procedures defined in the IEEE P1878 standard: the results are consistent and the voltage ratio error for rms measurement at the fundamental frequency is better than 0.2%.

Paper 0128 introduces the concept of applying a continuous vacuum monitoring (CVM) system to the vacuum interrupters (VI) of MV vacuum circuit-breakers (VCB). The proposed solution is based on the detection of partial discharges occurring inside the energized VI when the vacuum has been lost: it has the advantage of being applicable to standard VIs, without adversely affecting their reliability which is excellent (MTTF in the order of 40,000 years, cf. CIRED 2007 paper 0156). Special care is given to the signal processing algorithm in order to make sure that other possible sources of PDs in the vicinity of the VCB will not generate false alarms. A reliability analysis is presented that shows that CVM significantly improves the availability and functional safety of VCBs, while avoiding the recommended yearly hipot testing as condition check of the VIs.

The next two papers are related to the specific topic of MV vacuum circuit-breakers (VCB) operating mechanisms.

Paper 0777 discusses the respective advantages of the two main technologies used for MV VCB drive mechanisms,

spring-operated mechanisms and magnetic actuators, in terms of reliability. Clearly magnetic actuators have an advantage in terms of mechanical endurance, and are the most suitable solution for multiple fast auto-reclosing sequences. Therefore they are preferable for automatic circuit reclosers and special applications where the VCBs are subjected to very frequent switching duties (exceeding 10,000 operations in a 30 years lifetime, corresponding to the class M2 of extended mechanical endurance according to the IEC 62271-100 standard). For the majority of MV VCB applications, which fall within the classes M1 or M2, spring-operated mechanisms are preferable in spite of their lower mechanical endurance because their reliability is not affected by the relatively high constant failure rates of the electronic components and storage capacitors which are necessary for the control of magnetic actuators.

Paper 0978 explains the basic concepts of MV VCB spring-operated mechanisms, and how the output torque of the mechanism can be adapted to the load represented by the vacuum interrupter poles by adjusting the four-bar linkage kinematics and the closing cam profile. Tests performed on three different VCBs show that the one fitted with the mechanism having the best matching (output/load) characteristics performs much better in short-circuit closing and breaking, due to reduced tendency to contacts welding. It is noted that proper design of the operating mechanism is also an important factor (not usually reported in the literature) to prevent contacts welding in vacuum interrupters.

The last two papers in this sub-block describe solutions which reduce the switching transients in the network.

Paper 0519 explains the benefits that can be expected from the controlled switching of circuit-breakers in MV networks. Controlled switching is already well known and applied in HV networks to reduce the electrical transients at energizing of sensitive loads like capacitor banks or power transformers. The same benefits can be obtained in MV networks, with in addition an increased lifespan for the equipment and a better adjusted protection scheme. The functionalities of the controlled switching device (CSD), a controller for MV circuit-breakers, are presented and the switching strategies explained for different applications, like for instance the connection of a distributed energy resources (DER) step-up transformer with minimum magnetizing inrush current. This CSD controller can also provide advanced condition monitoring of the circuit-breaker, as it is regularly checking its behaviour and timing. The introduction of more offers for MV circuit-breakers with independently operated poles would be necessary to take full benefit of CSD controllers.

Finally paper 0778 follows up on the research work presented by ABB in previous CIRED conferences (2007 and 2011) by describing the industrialized solution for a MV capacitor bank “diode switch”. The DS1 product combines a hybrid solid-state switching technology with controlled switching to provide almost transient-free operation of capacitor banks, even in back-to-back configuration. The new switch is presently being field tested in a pilot installation to confirm its effectiveness and reliability.

Figure 4 from paper 0778: DS1 main assembly

Sub block 4.4: Modelling and simulation
(6 papers)

In the wake of paper 0463 presented at CIRED 2013, paper 1090 reports on the continuation of the experimental, modelling and simulation work performed to improve the thermal design of gas-insulated switchgear (GIS) where SF6 would be replaced by air as an insulating medium. The thermal properties of air being inferior to those of SF6, design changes are necessary to maintain the temperature-rise values within the limits defined by the standards, if same dimensions and ratings are to be kept. Thanks to the available thermal modelling and simulation tools it is possible to gain useful insight on the thermal exchanges inside the GIS and identify the most efficient design improvements.

Paper 0517 presents the methodology retained by the Schneider Electric simulation experts to predict the internal arc behaviour of switchgear configurations which have not been actually type tested for internal arc classification (IAC) according to IEC 62271-200. The criteria for accuracy of computational fluid dynamics (CFD) simulations have been defined and it is shown that accuracy better than 10% is achievable between actual pressure measurements and simulation results, which is sufficient in practice as the arc energy itself may vary by about +/- 10% between identical internal arc tests. The transient pressure field mapping provided by the CFD solver is exported to a structural solver that computes the transient response of the enclosure. The guidelines for proper coupling between the two simulation tools are explained and highlighted in order to ensure a correct prediction of the enclosure mechanical withstand.

Paper 0739 presents a practical approach to mitigating some internal arc effects which are not taken into account in most standards, like the pressure rise in the switchgear room. A rule of thumb is proposed for estimating this pressure rise, depending on the arc current and duration, and the room

volume. This provides a valid indication of what can be expected in case of internal arc in air insulated switchgear, without any arc energy absorber system. It is also shown that some arc energy absorber schemes, like ceramic honeycomb blocks arranged in exhaust gas ducts, can very efficiently reduce the pressure rise in switchgear rooms: use of such solutions is recommended in applications where it is not possible to provide pressure relief flaps to the outside of the room.

Paper 0371 illustrates how modern numerical simulation tools can be used in the development of MV switchgear. In the particular case described, the short-circuit withstand of bushings have been evaluated against the electrodynamic forces generated by the currents, by coupling electromagnetic simulation (to determine the density of Lorentz forces) and structural simulation (to check the corresponding deformations and stresses in materials). Simulation results are accurate enough to identify the design weaknesses and correct them before going for actual testing, thus saving development time.

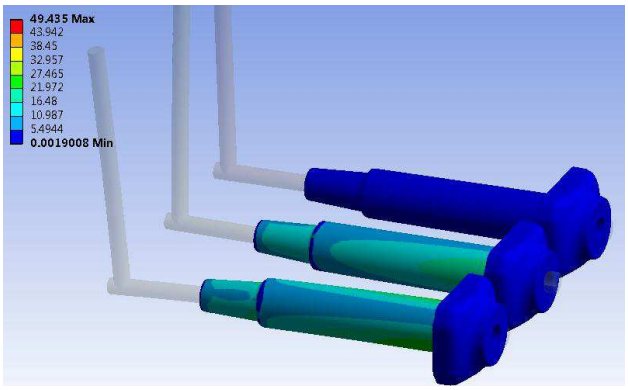


Figure 5 from paper 0371: Stresses corresponding to the forces seen on insulator during STC tests

Paper 1339 shows how complex interactions between electromagnetic and mechanical domains can be adequately modelled by coupled magneto-mechanical 3D transient finite elements simulation. In the case of the LV windings of power transformers the stresses distribution under short-circuit conditions has been found to be more severe than expected from the static Lorentz forces distribution, due to mechanical resonance effects: the insights gained by the use of such powerful simulation tools allow to better design and optimize the cost of power transformers.

Finally paper 0421 presents an implementation of the hardware in the loop (HIL) simulation technique to optimize the control strategy for a MV recloser magnetic actuator. The HIL test bench coupled with optimization software has been used to determine the best control strategy for minimizing the over-travel and back-travel at opening, while maintaining a sufficient opening speed.

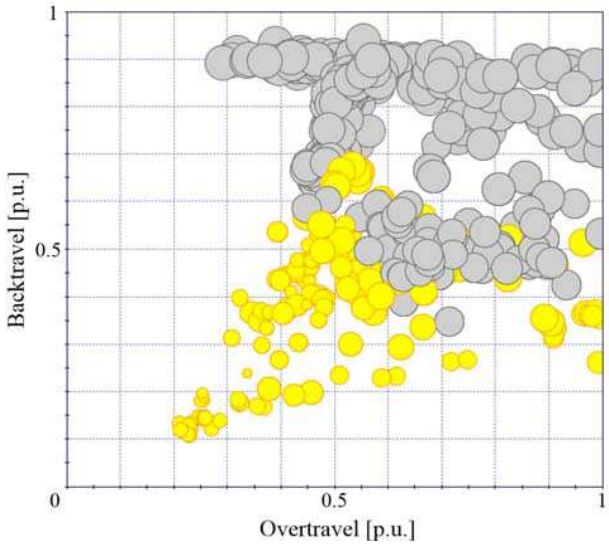


Figure 8 from paper 0421: Hardware in the Loop Optimization of MV Reclosers Opening Operation

Sub block 4.5: Storage and LVDC distribution
(4 papers)

Following up on the information presented at CIRED 2013 (paper 0781) about the first electric storage system installed in ENEL Distribuzione (ED) network, paper 0149 reports on the behaviour and site acceptance tests results of four additional electric energy storage systems (EESS), from different manufacturers, which have been installed in 2014 and 2015. Overall the results are satisfactory, in terms of efficiency, active/reactive power capability and frequency regulation, showing that the EESS technology (with Li-ion battery storage) has reached a good development level. However significant differences have been found in the consumption of the auxiliary services, and some ICT issues have been encountered for the remote management of EESS through ED remote terminal units.

Paper 0775 presents the experimentation that will be launched by EDF on a 1 MW – 500 kWh energy storage system to be used primarily for power frequency regulation. The system has been installed in the 20 kV network of the experimental Concept Grid platform in order to study its behaviour under normal and also simulated abnormal conditions. Points of special interest are the management of the state of charge of the battery, and the confirmation of its useful service life (10 years expected) for the number of discharges and micro-discharges needed for the frequency control application.

Figure 1 from paper 0775: Picture of the battery and the inverter at the EDF concept grid platform

The last two papers deal with different pilot projects of LVDC distribution in Finland, in the continuation of what has been presented at the previous conference (cf. paper 0776 of CIRED 2013).

Paper 0874 reports on the lessons learned from the 2nd LVDC pilot implemented in the distribution network of Elenia Oy. For rural areas with limited power to be distributed over relatively long distances, it is expected that LVDC (750 V) cable system can be a good solution for the replacement of MV branch lines. Experience from this pilot installation confirms the improvement in terms of power availability to the consumers, the available energy storage in DC capacitors being sufficient to ride through short supply interruptions (due to auto-reclosing sequences in the MV network). In the future battery storage will be added to the LVDC pilot in order to confirm its ability to operate in islanded mode.

This is the subject of the last paper 1120 (from the authors of the CIRED 2013 paper 0776) which refers to the first LVDC pilot distribution network implemented in Finland, and more specifically to the battery energy storage system (BESS) that has been connected to this installation. Connection of the BESS has been made directly at the level of the grid-tie rectifying converter, without using a dedicated converter. The designs of the battery system, from battery cells to DC components, and of the control system are presented. The battery system has been in operation since October 2014 and experiences from the operation, as well as measurement data, are continuously collected to better understand how to make best use of this type of solution.

Potential scope of discussion (papers selected for oral presentation)

- Requirements and architecture of future smart secondary substations (1027).
- Impact of the new “Energy efficiency” standard IEC 60076-20 on existing and foreseeable technologies for transformers (0424).
- Respective merits of specific cable testing facilities in MV switchgear and direct access to the cable conductor (0057).
- Future fields of application of power electronics in MV networks: solid-state switching, voltage regulation, etc. (0778).
- Convergence of IEEE and IEC standards in the domain of internal arc protection for MV switchgear (0739).
- Operational life of batteries and suitability for large scale deployment of storage in the networks (0775).

Table 4: Papers of Block 4 assigned to the Session

Paper No. Title	MS p.m.	RT4	PS
1027: Towards a new generation of secondary substations on French distribution networks to accommodate smart grids requirements	X		X
0538: Contribution of the HV/LV prefabricated substation standard and practices to the robustness of the prefabricated HV E-houses.			X
0951: Virtual assessment of customized (non-standard) substation solutions for renewable applications			X
0212: New material for Compact Secondary Substation enclosures			X
0610: Distribution Transformer Cooling using the geothermal energy from the underground electric pipelines			X
0424: IEC TC 14 Activities for the Distribution Area with IEC ACTAD	X		X
1299: EcoDesign of Dry Transformers			X
1538: Impact of the Ecodesign Directive on Traceability in Power Transformer Loss Measurements			X
0784: Compact, Safe and Eco-friendly Substations for Mumbai City			X
1533: Oxidation aging and resulting dielectric performance of a natural ester insulation system for transformers			X
0230: Alternative gas to SF6 for use in High Voltage Switchgear: g3		X	X
0587: Alternative gas insulation in medium-voltage switchgear		X	X
0926: Dielectric properties of gases suitable for secondary medium voltage switchgear		X	X
0493: Validation methods of SF6 alternative gas		X	X
0058: New generation of circuit-breaker switchgear			X
0057: New generation of switchgear with cable testing facilities	X		X
1503: A novel way of implementing visible break in a Solid Dielectric Switch			X
0789: Integrated installation of a switch with no exposed live parts for MV overhead insulated networks			X
1212: A three-phase generator vacuum circuit breaker based on vacuum interrupter technology has been established for the application in generator circuits up to 15kV - 50kA			X
0529: High accuracy measurement capabilities integrated into reclosers for MV power networks			X
0128: Continuous Vacuum Monitor for Air Insulated Vacuum Circuit Breakers			X
0777: Impact of Operating Mechanism type on MV Vacuum Circuit Breaker Reliability			X
0978: The Research and Optimum Design for Vacuum Circuit Breaker with Spring Mechanism			X
0519: Benefits of Controlled Switching of Medium Voltage Circuit Breakers			X
0778: Switching technology evolution: The solid state contribution to the capacitive switching control	X		X
1090: Thermal design of future medium voltage switchgear			X
0517: Modeling & simulation extrapolated internal arc test results: A coupled fluid-structural transient methodology.			X
0739: Internal arcs: Pressure rise versus cooling methods in air insulated MV switchgear	X		X
0371: New computational framework for analyzing of short-time withstand current effects in a switchgear design			X
1339: Dynamic mechanical behaviour of a low voltage transformer winding under short circuit conditions			X
0421: Hardware in the Loop Multi-Objective Optimization of Medium Voltage Switching Devices			X
0149: Performances comparison inside the Electric Energy Storage Systems of Enel Distribuzione			X
0775: Primary frequency control by using a 1 MW battery: study at grid scale on the Concept Grid EDF platform	X		X
0874: LVDC Pilot Implementation in Public Distribution Network			X
1120: Implementing a Battery Energy Storage System with a Converterless Direct Connection to a LVDC Distribution Network			X