# Session A1: HV and EHV cable systems

Chairman: Pierre ARGAUT, CIGRE SC B1, France

Rapporteur: Mohamed MAMMERI, General Cable, France

This session, comprising six papers, dealt with HV and EHV cable systems. Cable manufacturers are provided with innovative engineering approaches, regardless of the challenges that they face during project management and cable systems qualifications.

New qualifications protocols combining multiple standards have been defined. The reliability of cable systems has been demonstrated.

Paper A.1.1: Worldwide experiences and challenges with EHV XLPE cable projects 330 kV to 500 kV

Based on experiences made on more than 1,300 km underground EHV XLPE cables, the technical solutions and concepts for development, manufacturing, assembly, testing and operation have been largely confirmed.

Among two special highlights of the EHV cable technology, one of the longest 500 kV cable systems installed in Moscow (Russia) and one of the most voluminous 400 kV projects in London (UK) have been described. The Moscow project was planned in order to replace a 11 km long 500 kV double system overhead transmission line. With 10 new 400 kV cable systems in 32 km of new tunnels, the London power tunnel project reinforces the EHV network in London. For both projects, the 500 kV Moscow project and the 400 kV London project, with laminated sheath and longitudinal welded melded aluminum sheath, both with oxidized copper wire conductor, the reliability of the EHV XLPE cable system has been demonstrated. In addition, the authors address the engineering studies required for the management of such projects.

Paper A.1.2: The network connection of Niehl 3 CCPP – Germany's first 380 kV long-distance cable project since the Bewag projects in 2000

RheinEnergie, the municipal utility of Cologne, is building the third block of the Niehl CCPP, located within the Cologne harbor area. With a total length of almost 9 km, the section of the Niehl3 network connection will be the longest point-to-point 380 kV XLPE underground cable link in Germany since the two Bewag tunnel projects in Berlin in the late 1990s. Besides providing the technical particulars of this new 380 kV cable system, this paper illustrates the challenges that were faced during project planning, prequalification, construction phase and testing.

Paper A.1.3: 138 kV CABLE System Qualification to IEC 60840-2011/ICEA S-108-720-2012 / AEIC CS-9-06

The paper describes the qualification process according to multiple standards of a full 138 kV Cable system, including pre-molded accessories. Users express a preference for the cable system route via IEC and AEIC, whilst recognizing the value of the component approach (ICEA for cable and IEEE for accessories). This presents manufacturers with a considerable challenge. Consequently, a route to qualify two cable designs, outdoor terminations, oil filled and dry type GIS terminations, and straight and cross-bonded joints, was developed by G&W and Viakable. An important factor in the design of the test loop for the manufacturers was the impact of the currents required to meet the thermal requirements of the relevant standards. The expanded test loop used in the test program conducted at NEETRAC successfully met all requirements for approval under AEIC, ICEA, and IEC. The cable system approach from the latest iterations or the AEIC and IEC standards as favored by Utilities are reinforced. Careful consideration must be given before attempting to undertake such a program. Also, practical and critical limitations of IEEE 48 and IEEE 404 requirements that have been extended from the experience with Medium Voltage accessories are identified and discussed. These support current efforts underway to review the structure of these specifications.

Paper A.1.4: Qualification of a 150kV Transition joint for connecting external gas pressure three-core cable with extruded single-core cables

Transition joints for connecting two different cable types are becoming more and more common in the HV and EHV power cable systems. These joints require special attention during assembly and type testing. For design, development and qualification of such transition joints, the Cigré TB 415 "test procedures for HV transition joints" was followed. The paper highlights the aspects involved in the design, assembly and type testing of a 87/150 (170) kV transition joint between a three core External Gas-pressure Cable (EGC) and three single core extruded cables.

Paper A.1.5: PQ TEST AND FIRST 230 KV CABLE SYSTEM PROJECT IN MEXICO

The paper describes the PQ test procedure to qualification of a 230 kV cable system by 62067-2006 and ICEA S-108-720-2004 / AEIC CS -9-06 standards, using the same test loop into the Viakable facilities under the observation of the LAPEM and NEETRAC. The system comprises 29.7 km of single circuits of 1200 mm² copper conductor, XLPE insulation, smooth welded aluminum sheath, polyethylene jacket and semiconducting over layer.

This is the first cable system qualification made by a Mexican manufacturer using a power cable with smooth welded aluminum sheath. Likewise describes the first 230 kV cable system project in Mexico named “Ayotla-Chalco” installed near to Mexico City in a place subject to earthquake with characteristics of unstable soil.

The tests performed after installation include Partial Discharge (requested for the first time in 230 kV cable systems by CFE) and Voltage test. The success or the PD test after installation in the Ayotla-Chalco project is a precedent in the CFE power systems and will be a reference for future project.

Paper A.1.6: Cable installation in mountainous areas, example of a successful installation and service in the well-known touristic area of Carinthia in Austria, neat Muhldorf, a hydro power plant was extended (Reisseck ll). Since the energy generating turbine is located on the mountain site, at a level of –1600 m above ground, produced energy has to be transmitted downwards to the bottom of the valley, where a substation is distributing the power to the Austrian distribution network. The mountainous site gave rise a lot of challenges for the installation of a 220 kV cable system, which were successfully solved and are described within this paper. Indeed, regardless of all these challenges, a proper solution was found and the cable system is under operation.

# Session A2: Installation Methods

Chairman: GILLE Alain, Verbraeken Infra, Belgium

Rapporteur: RAUD Jean- Louis, SERCE, France

This session, which included five papers, was dedicated to HV installation methods. Engineers should expect increasingly important challenges in the future, because environmental or operating constraints become increasingly demanding. This Session showed that innovation is a major driver in the cable business. More than 110 delegates attended the session.

A2-1 Pump-storage plant of Linth Limmern (Swiss Alps)

Situation: This 1 GW pump storage plant has been connected to the grid via two HV AC 380 kV underground feeders consisted of six XLPE 1600 mm² copper cables laid inside a funicular tunnel. The total feeder length is 4.5 km, with horizontal or 25% incline sections.

Clamping of the cables: A detailed study of the cable clamping was required due to the stiff incline (pulling tension of max. 3.5 ton, cable weight: 27 kg/m). No harmful defects on the external semi-conductive layer have been observed, partly thanks to flat copper wires in helix used for the screen construction.

Cable laying: A specific laying bench had to be designed to fit the tunnel dimensions, the drum movements and it could be transported on road by truck.

Training of installers: They were trained in conditions mimicking the real conditions in the tunnel.

In the second half of 2014, it took 79 nights to install the 54 lengths in the tunnel. 48 joints have also been installed in the scheduled planning. In March 2015 the tests were performed on site.

All test results were on line with specifications and the installation is now ready for exploitation.

A2-2 Patuxent river crossing

Situation: The project in Maryland (US) is part of an overall Southern Maryland reliability project. Installed cable is a 230 kV 1600 mm² copper XLPE cable with a lead metallic sheath.

Installation: The project includes a segment of underground transmission line crossing the Patuxent river. As permits were difficult to obtain for submarine cables because of oyster bars on both shorelines, the only possible installation method was using HDD.

Laying: The cable pulling tension was calculated and tested and a pulling tension of 11 ton was considered to be acceptable. A specific debeading equipment has been developed in order not to affect the cable jacket.

Racking system at manhole: to avoid any sliding of the cable and to protect the sheath, a strong clamping system with spring cleats has been used. Also a section of cables was installed in direct burial snake formation between the HDD section and the manhole, allowing the longitudinal thermal expansion due to cable heat.

Induced voltage and short circuit: an adapted cross-bonding has been adopted because it was the most efficient and safe way.

A2-3 Temporary connections

Situation: The electricity supply is increasing and the maintenance activities must be performed, allowing the continuity of energy supply. One of the suggested solutions is using temporary connections made up of 138 kV insulated cables.

Characteristics of HV cables: 138 kV, 239 MVA/circuit, short-circuit of 21 kA;

Required conditions:

Development of more flexible aluminium insulated XLPE cables and of dry flexible terminations. Cables were designed to have a minimum useful life of 10 years. The reel was designed to transport, handle and store 500 m cable (weight of 5 ton).

Financial gain: compared to the overhead solution with lattice steel self-supporting structures, this solution presents a reduction of time for preparation and installation of 35% less than traditional options. It allows a reduction of accidental shutdown costs and of the environmental impact.

A2.5 Non-offset design of cables in manhole

The length of cables varies according to heating and cooling cycles. On the other hand, the expansion is 1.5 higher for 154 kV 2500 mm² aluminium cables than for 2000 mm² copper ones. The manholes must be larger for aluminium cable. Therefore, non-offset design in manhole should be considered.

Thermo-mechanical behavior of cable: a standard duct length of 300 m has been built. Different measurements have been done in ducts and at the entrance of the manholes in case of offset and non-offset design of the manhole. The results showed that a non-offset design satisfies the allowable sheath strain and that the axial force at premoulded joint is not strong.

Therefore, a smaller manhole can be adopted.

A2.6 Study on thermal backfill materials for directly buried HV cables

The importance of backfill materials: Electric energy transported by the cable depends on the surrounding soil capacity to evacuate the heat generated by the cable. In Belgium, a controlled backfill is installed in the trenches around the cable in order to evacuate this heat and avoid an accelerated ageing of the cable insulation.

Measures and laboratory tests: six materials were tested.

Grain size distribution, the relationship between the moisture and the dry density and water content were analysed. Tests in situ were performed to complete the laboratory testing.

Conclusion: three backfills were considered suitable for the evacuation of cable around HV cables. The studies showed the importance of knowing the physical and thermal parameters before the installation of the backfills. After installation, a quality control of the installation method is necessary.

# Session A3: Operating Conditions

Chairman: Saldivar Cantù Candelario, Mexico

Rapporteur: David Dubois, France

This session, comprising six papers, dealt with the operating conditions of power transmission cable systems. Up-rating the lines, retrofitting existing civil works, developing better maintenance and diagnostic methods, monitoring temperatures and predicting the available load and reducing the mounting-related fault, are different ways to improve the use of existing assets.

Paper A.3.1 presented a technical study about an indirect water pipe-forced cooling system for a 220kV underground XLPE cable line in New Zeeland. The study included the selection of water pipes with regard to thickness and material. The design constraints were very tough because of high elevation differences along the cable route. The cooling of joints appeared to be the limiting factor for the current rating. Current joint designs are not suitable for an easy indirect cooling. Putting the joint in air cooled joint chambers was suggested. Finally, the forced cooling option was not retained by the network operator because of the uncertainties about the future load of this line.

Paper A.3.2 described the installation of an auxiliary power supply in a refurbished power plant in France. New XLPE 225kV cables were pulled in an existing pipe system previously used for the plant power output through oil filled cables. Existing oil filled cable were removed from the ducts in a harsh environment. The safety of people and environmental protection were the main concerns around the site works. Working in a power station is often more difficult than in an urban environment, even though external constraints are different.

Paper A.3.3 reported on the analysis and the investigation carried out after several failures on the SCOF 154kV cable systems in Japan. The main findings were that the root cause of these failures was a mechanical degradation at the semi-stop parts in the joint boxes. This mechanism was itself due to cable core movements. X-ray photography and dissolved gas analysis were the main tools used to pinpoint and predict the potentially hazardous items. Maintenance procedures were then improved to focus on the root cause of failures. Diagnostic criteria were also sharpened.

Paper A.3.4 introduced a fibre optic intelligent distributed acoustic sensor (iDAS) technology for industry application. This technology is currently used in the oil and gas industry and for seismic profiling and flow allocation measurements. Some applications in the field of power transmission are considered.

Paper A.3.6 presented the operational records and the recent developments in DTS (Distributed Temperature Sensor) and DRS (Dynamic cable Rating System). In Japan, these technologies have been deployed for more than 15 years. Fibre Optics are laid along cable lines to monitor temperature. The cable conductor is not measured directly, but assessed through calculations carried out in real time according to IEC 60287 and IEC 60853-2. DTS makes it possible to survey seasonal soil temperature variations and has led to modified soil temperature for design. DRS provides a feature for evaluating the actual soil thermal resistivity that also varies during the year.

Paper A.3.7 explained how knowledge engineering can be applied to mitigate the infant mortality risk of HV cable system. The study was carried out by MEA in Thailand. Using different tools of failure analysis and knowledge engineering like Cause/Effect analysis and Concept/Mapping, it has been possible to better train the fitters and reduce the fault occurrence level.

# Session A4: HV AC new developments

Chairman: Y. WANG, Prysmian Group, Italy

Rapporteur: V. JOUBERT, General Cable, France

This Session consisted of six presentations on various aspects of the improvements of HVAC cable systems. Both cable material and cable manufacturers shared their latest developments to improve the safety and performance of such systems.

Paper A4.1 presented a new model for the cable insulation degassing process, allowing for better understanding and optimization of this time and capacity-consuming process. It also explored the effect of methane in the insulation on the performances of the cable.

Paper A4.2 dealt with the fire-resistant and low-smoke properties of HV cable outer sheaths. Several factors were compared in order to find the best design matching a set of criteria pertaining to the behaviour of cables in tunnels under fire conditions.

Paper A4.3 reported on the development and qualification of reduced-insulation 66/77 kV XLPE cable aimed at replacing 3-core SCFF cables without replacing the existing tubes. Higher quality control allowed for cable and accessories designed for higher-than-usual stresses to be successfully qualified.

Paper A4.4 focused on 500kV accessories for XLPE cables and shared the experience of designing, developing and qualifying 500kV joint, outdoor sealing ends and dry-type GIS sealing end.

Paper A4.5 addressed the problem of particle scattering in outdoor termination during faults, which is dangerous for both humans and other nearby terminations. Directing the pressure release can prevent such consequences.

Paper A4.6 described the development of a paperless transition joint between LLFF and XLPE-insulated cables. Through the use of a core element used to block the oil and withstand pressure changes while connecting conductors, a premoulded transition joint has been designed to be more compact and easier to install than the traditional back-to-back transitions.

# Session A5: HV cable integration in network

Chairman: Barber Kenneth; NAN Electric Cable, Australia

Rapporteur: Allais Arnaud; Nexans Research Center, France

This session, comprising five papers, dealt with HV and EHV AC Cable Systems.

Paper A.5.1 presented a new method for operating a HV network based on the Electrothermal Coordination (ETC) concept instead of the conventional steady state ampacity approach. The paper shows a case study where reliability can be increased by almost 4% by simply using the assets more efficiently. This is a very important topic, since more and more transmission circuits are created with underground cable.

Paper A.5.2 reviewed and gave guidance on the coordination required to install Cables System connections to Gas Insulated metal-enclosed Switchgear (GIS) from the implementation design to the after installation tests, through the testing performed during manufacturing and the installation works.

Paper A.5.4 showed the optimization process based on the improvement of construction sites and the reduction in the number of joints. Improvements made affecting the reliability, the duration and costs of works are linked to the increase of the cable section length and have consequences for the pulling forces during installation. Rural areas are favourable for this optimization, which is made possible by mechanised operations in civil works.

Paper A.5.5 described the simulation of partially underground links with EMT ATP. A shunt reactor has to be associated with the cable section. The simulation of the energization of mixed line with directly connected shunt reactors at voltage minimum shows risky phenomena for line operation, namely delayed current zero-crossing of the CB current.

# Session A6: HVDC Cables and Systems

Chairman: S. SWINGLER, Univ. of Southampton, UK

Rapporteur: J. SAMUEL, Nexans, France

This session, comprising five papers, dealt with the development, qualification, installation and operation of HVDC systems. Various systems were described, up to 345 kV. Although extruded AC cable systems have been developed and installed for several decades, with HVDC systems, others challenges have to be faced. Qualification of several systems as well as positive feedback from utilities showed that good progress has been made. However, further developments are expected on testing procedures for HVDC systems, on condition monitoring and fault detection, and on systems able to withstand higher voltages. Apart from extruded systems, there are also applications for which other cable systems might be more suitable.

Paper A.6.2 analysed HVDC submarine cable ratings at crossings through a 3D finite element analysis modelling method. The general design principles of submarine cable protection and relevant parameters for heat transfer were reviewed. Then the FEA model evaluated the thermal performance of four geometries. Recommendations were drawn up for crossing installation and operation.

Paper A.6.3 reported on a Transmission System Operator’s experience in manufacturing, testing, installation and operation of offshore DC connections up to 320 kV. Several HVAC and HVDC synthetic cables were installed to connect offshore wind farms in the German North Sea. High reliability was achieved. Some thoughts were given on installation, after installation testing, accurate location of the cable route and fault detection.

Paper A.6.4 described the development and qualification of DC extruded cable systems up to 345 kV. In particular, DC electrical properties of XLPE and EPDM insulation materials have been investigated. The reliability of the cable system with both pre-moulded and extruded moulded joints was assessed by type-testing up to 345 kV according to Cigré TB 496 for VSC and LCC technologies.

Paper A.6.5 reviewed the existing HVDC transmission system technologies and demonstrated that considering the complexity and diversity of the network, one single system would not be optimum. Were considered: lapped oil-filled systems lapped mass-impregnated systems, extruded systems and lapped superconductive systems. Suggestions were made on the best potential match between each of these systems and transmission needs.

Paper A.6.6 described the development of extruded HVDC cable systems. It addressed the main influence of DC stress on HVDC systems, with a focus on the main differences between AC and DC field in extruded cables and accessories, and at their interface. A scaled-model cable system rated at $^{+}/_{-}$ 150 kV was designed, produced and tested according to a program adapted from Cigré TB 496.

# Session A7: Testing and Qualification of HVDC cable systems

Chairman: E. ZACCONE, Prysmian, Italy

Rapporteur: N. BOUDINET, RTE, France

*This session, comprising six papers, dealt with the qualification of HVDC cable systems. The common point between these papers was that they all dealt with extruded HVDC cables. Extruded HVDC cables are more and more used in HVDC projects, both submarine and underground. The papers demonstrate the improvements made on XLPE HDC cable technology during these last years: increase of voltage level, increase of service temperature and increase of space charges acknowledgement.*

Paper A7.1: This paper dealt with the development and qualification of a 525 kV XLPE HVDC cable system, producing a transmissible power of 2.6 GW. This system has been designed for the VSC converter technology and with an operating conductor temperature of 70°C. Type tests and Prequalification tests were performed according to the international recommendation from Cigre TB496. This cable technology is in competition with the MI technology which is already working well at 500 kV operating voltage, especially for land application due to the availability of prefabricated joints and because it does not need lead screen use for land cables. Moreover, the operating temperature is higher than common MI HVDC cables (70°C vs 55°C).

It describes the developments of joints, particularly the prefabricated joints with a special field grading layer, as well as the terminations that are filled with SF6 gas.

Paper A7.2: The authors present here the development of a new insulation material used to develop 250 kV DC XLPE cable for LCC applications. The same material has been used for a 400 kV cable system that passed the prequalification test according to Cigre TB496 for LCC systems at 90°C. This paper dealt with the space charges characterization after a PQ test on the 400 kV XLPE HVDC cable. After the completion of prequalification tests on a 400 kV cable system, the authors have performed space charge measurements with the PEA method. The result is that the space charge accumulation and the electric field distribution in the cable insulation demonstrate a high stability.

Paper A7.3: This paper dealt with the development and prequalification tests of the HVDC cable system with an innovative, not cross-linked insulation material: P-Laser (HPTE) cable technology (based on thermoplastic PP insulation) at 320 kV operating voltage and working at 90°C on the conductor. This material was widely used for MVAC cable. The material developed shows a very good behaviour against DC electrical field (very low space charge accumulation and very high impulse strength at high temperature. A PQ test at 90°C on that 320 kV system is ongoing and at an advanced stage, according to the international recommendations made by Cigré TB496.

Paper A7.4: This paper dealt with lightning impulse requirements on HVDC cable systems when connected to OHL. The authors explained here that a good assessment of lightning impulse levels and risks is required for the cable design and testing programme. The study is based on EMTP simulations that have been performed and statistical assumptions. The value of lightning impulse depends on the characteristic of the OHL, and taking into account that it is not possible to associate the lightning level at the DC rated voltage level. Taking precaution when screening the termination, installing lighting arresters, will limit the cable impulse level. Another assumption to take into consideration is that the impulse is not the same along the cable length. A few examples are given (Nordbælt and South-West link).

Paper A7.5: This paper dealt with space charge measurements after a PQ test on a 200 kV XLPE HVDC cable system containing inorganic nano-fillers designed for VSC technology. The space charges were measured according to the PEA method, as for paper A7.2. This measurement was performed at various steps of the prequalification tests. With these space charges measured, it has been demonstrated according to the authors that two regions of the cable were polarity dependent: inner semi-conductor and middle of the insulation. These results had been also observed on the 320 kV cable system when the authors measured space charges after the PQ test according TB 496 and comfort them on the PEA method. Space charges have been stable before and after the PQ test.

Paper A7.6: This paper presented the work performed within the B1.42 Cigre WG dealing with testing recommendations for HVDC transition joints up to 500 kV. These recommendations are valid for DC transition joints between all kind of paper-insulated oil filled/mass impregnated cables, including PPL, and extruded insulation cables.

# Session A10: HVDC Transient phenomena

Chairman: L. TESTA, Prysmian Group, Spain

Rapporteur: MH. LUTON, Nexans France, France

This session, comprising six publications, deals with various transient phenomena observed in HVDC. Most of the presented studies combine experiments with simulations or calculations in order to define specific transient behaviour models. In most cases, the authors emphasize that actual measurements have to be conducted in order to confirm the initial results obtained. Transient phenomena under DC require careful attention during development, qualification and DC link design, because they may induce some possible detrimental effects. Specific space charge phenomena are observed. Thermal conditions during qualification tests need to be carefully studied in order to remain representative of the operating conditions and avoid premature failure due to thermal runaway. Polarity reversals are other transient phenomena for which specific test sequences have been developed to assess the cable system performances. Considering the grid, the impact of the transient phenomena under DC is analysed on the telegrapher's equations and the design of a DC link has to limit the effect of possible overvoltages due to faults (internal or coming from converters).

Paper A.10.1 presents the results of FEM simulations studying the influence of the temperature gradient, the duration of polarity reversals, and the activation energy on the transient electric field distribution in a 320kV typical cable structure. A "transient insulation utilization coefficient" that equals the ratio of the average electric stress vs the maximum electric stress is introduced and used to define design rules for cable insulation.

Paper A.10.2 studies the impact of temperature and field distribution according to the conductivity of HVDC insulation on the telegrapher's equations in steady state and transient operations. It is shown that in most cases, including fast transients, the equations valid for AC remain valid for DC. The author highlights in his conclusion that this approach remains to be confirmed using finite element analysis and tests on complete loops.

Paper A.10.3 deals with the transient phenomena induced on DC links in case of DC faults or internal faults in VSC type converters. This study has been conducted in the context of the France/Spain interconnection project. Resulting overvoltages during pole-to-ground faults are presented in various configurations, with or without any protection. The proposed solution to limit these induced overvoltages to acceptable values consistent with the lightning and switching withstand level of the system is to introduce surge arrestors at the terminations and to discharge the cable through a 100Ω resistance. A careful case by case analysis is recommended, as well as conducting experiments.

Paper A.10.4 presents the influence of thermal transient conditions during cable system qualification. By mean of cable leakage current and temperature measurements conducted on full-size 320kV cable loops, it is shown that without a strict control of the thermal conditions, thermal runaway may occur in the cable insulation without being representative of the operating conditions on the grid. Various methods of applying thermal insulation on the cable during testing are compared with respect to this risk, and a recommended configuration is proposed. It is also shown that electric conductivity deduced from these tests differs from the conductivity measured on lab scale samples.

Paper A.10.5 reports on study results of transient space charge phenomena obtained on 1.5mm thick XLPE insulated model cable using both simulations and PEA (Pulsed Electro Acoustic method). The study performed under negative polarity and different temperatures and dielectric stresses shows evidence of the generation of a front of negative charges, as well as a thermally activated peak of current during transient. Type tests conditions therefore require severe transient stresses when they are performed. A current-voltage model for current transient in cable geometry is also proposed.

Paper A.10.6 presents the rationales, based on previous experience with MIND cables on CSC (Current Source Converters) having led one utility to prepare a special test program dedicated to the assessment of extruded cable systems in front of polarity reversals and describes corresponding newly built laboratory facilities. Tests are ongoing.

# Session B1: Submarine Cable Technology

Chairman: M. JEROENSE, ABB AB, Sweden

Rapporteur: N. BOUDINET, RTE, France

During this Jicable conference, the subject of submarine links was widely represented, with no less than 5 sessions dedicated to submarine links and other sessions including also papers dealing with submarine projects. This session, dealing with submarine cable technology, was of a high interest, since it combined a large scope of the submarine link topics (cable, installation, maintenance).There were thus 6 papers, of which 5 were presented, dealing with cable conductor technology, cable insulation technology (extruded HVAC and HVDC), connection of various cables technologies (project application), but also installation matters, which are quite important, combining with the technology choice and fitting with the maintenance issues.

Paper B1.1 dealt with aluminium submarine cables conductors. A few years ago, aluminium conductors were still rarely used and considered to be not strong enough for submarine installation. Now, however, they are more and more used for offshore wind farms connections because they make it possible to reduce the investment price (the cable cost is directly reduced; the installation cost may also be reduced, according to this paper, since it allows longer delivery lengths).

In this paper, it is shown that aluminium conductor cables are strong enough for most submarine applications. The weak point is indeed the soldering in the cable joint (TIG welding), on which tensile tests have been performed to check the cable system strength. Various aluminium alloys have been considered regarding their electrical resistivity and mechanical properties. Corrosion is also dealt with in this paper, which gives a few tips on case of cable breakdown (the only reason for which the cable conductor is subjected to corrosion, if it contains a radial water barrier), for instance in order to seal adequately the cable ends pending repair.

Paper B1.2 was not presented.

Paper B1.3 dealt with inter-array cables in offshore wind farms. The key point of this paper is the cost reduction of renewable energy which is facing the offshore wind farms industry. Cable technology and design is thus discussed: on the voltage level (33kV or 66kV), on the cable construction (wet design or dry), on the insulation performance. The TR-XLPE insulation, which is known to be water treeing retardant, is presented in this paper and compared with other insulations such as EPR. According to the development tests performed, this insulation (TR-XLPE) could extend the service life of MV submarine cables. Moreover, an “advanced TR-XLPE” insulation has been developed, allowing the development of 66kV wet-design cables for inter-array wind farms cables.

Paper B1.4 dealt with XLPE HVDC 320 kV submarine cables. The cable manufacturer presents in this paper the qualification of its XLPE HVDC 320 kV submarine cable system. The prequalification tests were performed according to the international recommendations and a type test was also performed for submarine cable according to the international recommendations. During these tests, space charges and electrical density were checked and measured. The cable system includes external terminations, GIS termination, premoulded joints and factory joints for the submarine part. Tests at low temperature were also performed to fit with some project installation specification for the underground part.

Paper B1.5 dealt with HVAC three core cables. This Chinese cable manufacturer is presenting the cable design of the offshore wind farm connection Zhuhai-Guishan. It is a 110 kV cable with 500 mm² copper conductor cross-section. The paper also dealt with the optical fiber integration matters inside the 3-core cables assembly. Voltage withstand test after manufacturing facilities are also presented. The long length submarine cables are thus discussed in this paper, dealing with all the long length issues: insulation extrusion, FO cable integration, factory acceptance tests, etc. It has to be reminded here that the FO cable element in a 3-core cable is obviously a key component, the assembly, positioning and monitoring of which should be carefully checked during laying.

Paper B1.6 dealt with the Oslofjord project experience.

This 420 kV HVAC project, mixing XLPE cable and Oil filled cable, was brought into service in 2014. The XLPE 420 kV cable system used includes factory joint fully qualified. In this paper, project data are given and tests performed on this cable system are described. Flex fatigue tests were also performed in order to test the repair mechanical constraints. A DTS (Distributed Temperature Sensor) has been installed to monitor the temperature of all the cables end-to-end. For this purpose, optical fibers have been integrated inside the cables (multimodes FO are utilized for this 13 km length link).

Cable protection and after installation tests are also described in this paper dealing with the Oslofjord project.

# Session B2: Design of submarine lines

Chairman: U. VERCELLOTTI, CESI S.p.A. Italy

Rapporteur: M. FRANCHET, EDF R&D, France

This session, including six papers, dealt with the design of submarine lines from MV to HV levels.

Interconnection projects, allowing for the transmission of bulk quantities of energy, and the connection of the offshore facilities on medium voltage and high voltage submarine cable systems, are growing applications in the T&D sector, implementing high-capacity transmission network for efficiently moving electrical energy to consumption centres.

One of the major contributions to the development of power production systems comes from the offshore wind farms. Due to the extension and location of these wind power generation systems, large amount of submarine cables are requested to connect the individual power generating units with each other (inter-array cable) and to the mainland (power export cable).

Today, a lot of offshore wind farms have been built or are under construction. Consequently, several environmental problems related to their landing or installation (floating or under seabed), the loss reduction approach between various designs, and the choice between AC or DC transmission systems, have to be faced.

Paper B2.1 presented a comparison between DC transmission systems, AC transmission systems with various compensation schemes, and Low Frequency ones. Solutions with higher system voltage, intermittent load and dynamic rating of cables have also been addressed, focusing on AC export cables and their transmission capabilities. Based on the reduction of the frequency of the transmission system, both transmitted power and distance from the onshore connection point can be increased.

Paper B2.2 evaluated the losses in armoured and unarmoured three-phase HV cable. Relevant measurement equipment and setup, together with an appropriate data processing, have been used. The study includes the comparison of losses with various armour connections and sheath currents measurements. Discussion on measurement techniques includes armour current for unbalanced operation and the effect of semi-conducting layer covering the sheaths. Finally the conclusion drawn is that armoured cable had higher losses than unarmoured cable.

Paper B2.3 showed the world's first five-terminal DC transmission project set up in China, with information about the insulation thickness design of HVDC submarine cable, the production process and the testing phase. In particular, mechanical and electrical type tests have been performed according to CIGRE TB496 Recommendations. The Zhoushan flexible DC transmission project has been put into operation since June 2014; meanwhile, the prequalification test was still going on.

Paper B2.4 made an updated approach to design, modelling and testing of submarine dynamic MV power cables, taking into consideration global loading regime and internal mechanical stress estimation for floating offshore renewable energy (ORE). Fatigue failures risks including tensile failures, extreme axial loads sequences, as well as bending failures, have been assessed through comprehensive mechanical testing and analysis.

Paper B2.5 analysed submarine cable technologies, the landfall crossing and the thermal design of future submarine links (AC or DC) that RTE forecast in France for the coming years. The target is to define optimal technical and economical features, taking into consideration more accurate environmental data of the cable route in order to optimize the link design and to prevent unexpected hazards.

Paper B2.6 reported the results from a water aging test performed at 10 kV/mm-500 Hz of a 52 kV XLPE cable. Evaluation of HV wet designs through specific water-tree initiation and growth processes has been performed with permeation tests and water aging test at 500 Hz. Confidence has been gained that semi-wet designs can be used in special HV submarine applications.

# Session B3: Submarine cable testing & qualifications

Chairman: F. DE WILD, DNV GL, The Netherlands

Rapporteur: F.CHARLES, General Cable, France

*Thanks to the booming of submarine projects for electricity transmission as well as for distribution, operators and manufacturers are gaining experience and know-how. It is now planned to install a power cable at depths exceeding 3,000 meters, and tests have been performed in this respect, to determine precisely the mechanical stresses to be withstood by cables, to develop and test cable designs suitable for use in seismic areas. Transverse approaches make it possible to qualify a MV cable using HV recommendations and to optimize design of armours combining modelling and measurements.*

*The debates that followed the presentations show that there is still room for further investigations and R&D to face the challenges proposed by more and more stringent installation and service conditions.*

Paper B.3.1 presented a test sequence aiming at assessing the effects of high pressure on the performance of an XLPE insulated conductor. Ageing under 310 bars and 17 kV (average electrical stress of 5.9 kV/mm) was undertaken and performances were evaluated through tan δ and PD measurement, AC step test to breakdown and water-treeing test before ageing, after 120, 240, 360 and 900 days. The results of this sequence provide inputs about the effect of deep water use on XLPE insulated MV cables.

Paper B.3.2 explains the reasons why CIGRE B1 has decided to set up WG B1.43 for the purpose of developing certain recommendations for tests on submarine cables, in other words for updating ELECTRA n°171. The scope is extended, taking into consideration the evolution in the field of submarine applications: increasing water depth, floating platforms, offshore windfarms… New formula are proposed in order to establish test forces; the type tests sequence is improved, a fatigue test is introduced for dynamic cables and a set of project specific tests is proposed. The technical brochure will be published some time during the year 2015.

Paper B.3.3 No article has been received

Paper B.3.4 PG&E decided to install a new cable line in the bay east of the San Francisco peninsula. A seismic analysis led to the conclusion that the cable system has to withstand large tensile forces. The type tests sequence was set up accordingly, including a straight tension test and an offset-shape tension test, both followed by an AC HV test and a PD test. Combined with electrical and non-electrical type tests, this sequence gives confidence that the cable system will withstand the seismic conditions of the Pacific Rim.

Paper B.3.5 Despite the improvements made in mechanical protection and robustness of the cable design for a submarine cable, a fault may occur, causing expensive power outages. This paper shows the various methods that can be implemented to locate faults on long submarine power cable AC as well as DC. Advanced instruments and skilled crew are required and safety hazards have to be addressed, taking into consideration the huge amount of energy that a very long power submarine cable can store.

Paper B.3.6 presents a pioneering approach using the experience gained through HV and EHV AC projects to qualify a submarine MV cable designed for connecting Belle-Ile Island to the distribution grid. Particularly, the CIGRE brochure TB 303 was used in combination to IEC 60840 in order to assess the need for a repetition of tests. A specific “Extended Prequalification sequence” was defined, including some mechanical tests.

Paper B.3.7 tried to assess through measurements the applicability of IEC 60287-1-1 relating to losses in armour of submarine HV cables. These formulae lead to overdesigning of cables in a significant manner if the armour is not a “classic” full steel wires armour but a hybrid one. Besides, measurements highlight how interesting it is to use armour in which some steel wires are replaced with PE wires. The notable influence of a complete semi-conductive sheath on the losses was also observed.

# Session B.4: Installation of Submarine Lines

Chairman: R. D. Zhang, TenneT TSO GmbH, Germany

Rapporteur: J. Charvet, RTE, France

This session, which includes five papers (B4.5 was cancelled), gives an overview of the installation of submarine cables. Depending on a number of factors, such as the environment, the weather, etc., the installation of submarine cable is always associated with significant expenses, risks, as well as huge challenges. Any unforeseen negligence can lead to accidents and/or financial losses. Sometimes the submarine cable installation can be more expensive than the cost of cables, especially in harsh environmental conditions.

Paper B4.1 described a new installation approach to reduce costs for offshore wind farms: installing non-armoured MV and HV cables into PE pipes, an alternative to directly installed armoured cables. Pipes are sunk by filling them with brine. Once they are in a safe position, cables are installed by floating with the same brine. Long lengths of more than 10km can be reached. Furthermore, impact test were performed to demonstrate the cable protection by the pipe. Successful trials (onshore and semi offshore) are also described.

Paper B4.2 presented the experiences made during the design, production, installation and commissioning of the world's first 420kV 3-core submarine cable at Lillebaelt (DK). The paper covers all aspects linked with the cable system, from the design to the completion of the projects and the decommissioning of the existing overhead lines. The lesson learned regarding safety, surveys, and type tests were addressed.

Paper B4.3 reported experience on dynamic cable installation for the Fukushima Floating Offshore Wind Farm Demonstration Project. Static dynamic and fatigue analysis with reiterations makes it possible to design riser cable. Double layer armour twisted in opposite direction prevents cable torsion. The first stage of the project was successfully completed in 2013 and the $2^{nd}$ stage with installation of 7MW floating wind turbine is ongoing.

Paper B4.4 gave an overview of the France-Alderney-Britain (FAB) project, a 1400MW HVDC interconnector aiming at increasing the interconnection capacity between France and Great Britain, while allowing renewable generation in Alderney waters to be exported to Britain and France. The paper described the issue of cable design and protection in order to cope with the challenges linked to developing a submarine link in a highly energetic area with strong tidal currents, severe wave conditions and rocky seabed.

Paper B4.6 presented the project of the Zanzibar interconnector of 132kV submarine cable in Tanzania, in which a new 132kV XLPE insulated submarine power cable was installed in order to improve the power supply reliability and to deal with higher electricity demand in the future. A type test was performed to confirm the mechanical and electrical properties of the cable design. The cable laying work from Zanzibar Island to the mainland is performed over a distance of 37km and in a maximum water depth of 60m.

# Session B5: Submarine Cables - General

Chairman: CAMPBELL Steven; Superior Essex Energy, Atlanta, USA

Rapporteur: DOMENECH Sabina ; General Cable, France

Session B.5, which contains 6 papers (the first one was cancelled), was dedicated to Submarine Cables in general, from MV-AC to HVDC. The need to reduce costs is one of main drivers for technological development; thus a MV –AC submarine power cable with an aluminium conductor has been tested. Thermal continuous rating of a wind farm export cable has been modelled. The impact of the HVDC cable configuration on compass deviation was assessed. Different methods for predicting the thermal continuous rating of a three phase submarine cable within a J tube have been described. Water-treeing results in high voltage XLPE subsea cables with polymeric water barrier designs have been presented. Electrical performance in the wet environment and thermo-mechanical characteristics of EPR insulated cables have been explained.

Paper B5.2 explained that to move towards cost reduction, a single armoured MV-AC submarine power cable with an aluminium conductor has been developed for offshore renewable energy, interconnections between offshore platforms, islands and shore. This cable has been tested to withstand high tensile loads and holding forces during cable installation, as well as high impact forces during operation.

Paper B5.3 discusses the implication of changing the configuration of the high-voltage conductor and low-voltage return conductor in the induced magnetic fields, which has an impact on the compass deviation. Theoretical studies, backed up and verified by ship surveys, have been used to assess the impact that laying replacement low-voltage conductors alongside the existing high voltage conductors has on compass deviation.

Paper B5.4 develops a 3D Finite element analysis (FEA) used to calculate the thermal continuous rating of a three-phase submarine cable within a J tube. This method is compared to two previously published methods and concludes that the previous ones are more conservative ratings than the FEA model.

Paper B5.5 presents results from numerical calculations of water ingress in a wet designed subsea XLPE cable equipped with a two-layered outer sheath, and results from water-tree ageing at various relative humidity (RH) levels in an XLPE cable core. It concludes that the service lifetime can be very long for cable systems with two-layered sheaths.

Paper B5.6 emphasises that the EPR insulated cables, thanks to their high mechanical characteristics and thermo-mechanical performance, are suitable for modern offshore systems like wind turbines, for 66 kV submarine array cables and floating offshore platforms.

# Session B5: Submarine Cables - General

Chairman: CAMPBELL Steven; Superior Essex Energy, Atlanta, USA

Rapporteur: DOMENECH Sabina ; General Cable, France

*Session B.5, which contains 6 papers (of which the first one was cancelled) was dedicated to Submarine Cables in general, from MV-AC to HVDC. The need of cost reduction is one of the main drivers for technological development, and a MV – AC submarine power cable with an aluminum conductor has been tested. The thermal continuous rating of a wind farm export cable has been modelled. The impact of the HVDC cable configuration on compass deviation was assessed. Various methods for predicting the thermal continuous rating of a three-phase submarine cable within a J tube have been described. Water-treeing results in high voltage XLPE subsea cables with polymeric water barrier designs* have been presented. Electrical performance in the wet environment and thermo-mechanical characteristics of EPR insulated cables have been explained.

Paper B5.2. In order to move towards cost reduction, a single armored MV-AC submarine power cable with an aluminum conductor was developed for offshore renewable energy, interconnections between offshore platforms, islands and the shore. The cable has been tested to withstand high tensile loads and holding forces during cable installation, as well as high impact forces during operation.

Paper B5.3 discusses the implication of changing the configuration of the high-voltage conductor and low-voltage return conductor in the induced magnetic fields, which has an impact on the compass deviation. Theoretical studies, backed up and verified by ship surveys, have been used to assess the impact that laying replacement low-voltage conductors alongside the existing high voltage conductors has on the compass deviation.

Paper B5.4 develops a 3D Finite element analysis (FEA) used to calculate the thermal continuous rating of a three-phase submarine cable within a J tube. This method is compared to two previously published methods and concludes that the previous ones are more conservative ratings than the FEA model.

Paper B5.5 presents results from numerical calculations of water ingress in a wet designed subsea XLPE cable equipped with a two-layered outer sheath, and results from water-tree ageing at different relative humidity (RH) levels in an XLPE cable core. It concludes that the service lifetime can be very long for cable systems with two-layered sheaths.

Paper B5.6 emphasises that the EPR insulated cables, thanks to their high mechanical characteristics and thermo-mechanical performance, are suitable for modern offshore systems like wind turbines, for 66 kV submarine array cables and floating offshore platforms.

# Session B.6: Materials for HVDC Cables

Chairman: S. GUBANSKI, Chalmers University of Technology, Sweden

Rapporteur: G. TEYSSEDRE, CNRS / University of Toulouse, France

Materials are a key issue in the development of HVDC cables with extruded insulations. Whereas a track record is available now for HVAC transport using cross-linked polyethylene, new issues are raised under HVDC stress with the question of space charge effects especially associated with crosslinking residues. As formulation has to evolve in respect to current products for HVAC, the question of ageing of materials is re-activated along with optimum thermal service conditions. This is addressed on the one hand regarding thermal ageing, mechanical stress effects on static dielectric properties, and also with consideration to specific stress waveforms emitted by converters and power electronic valves switching.

Paper B6.1, with a work carried out within the framework of the new Supergrid Institute in Lyon, France, addresses pure thermal ageing of cross-linked polyethylene with accelerated isothermal ageing at 135°C on 1mm thick plates. It is shown that oxidation and chain scission occur in XLPE after 14 days of ageing

, which can affect electrical and mechanical properties. It is considered that antioxidant protects XLPE for 14 days at 135°C, the equivalent of 40 years of service life at 90°C.

Paper B6.2 proposed by Borealis addresses mechanical and physicochemical characterization under thermal ageing of commercial grade XLPE designed for HVDC cables, with a comparison between a standard product already in service and a new product with a significantly lower crosslinking degree. Both plaque and cable samples have been considered. The paper points to a long term mechanical stability when ageing at 135°C though there is a significant increase in the degree of oxidation. The new material appeared to have even better long term mechanical properties despite its lower cross-linking degree.

Paper B6.3 presents a comparison of electrical conductivity, mechanical properties, chemical analyses regarding crosslinking and by-products of materials characterized in Paper B6.2 regarding thermal stability. It is confirmed that the new product has a lower crosslinking degree and by-products content. A substantial reduction in the conductivity of material has been measured, even at high field.

Paper B6.4, proposed by Sintef, Norway, addresses the impact of DC stress on the DC conductivity of polyethylene materials. Measurements were performed on cables considering two ways of applying stresses: axial compression and tensional stresses. 12 kV XLPE insulated cables with 3.4 mm thick insulation were used. The methods to apply stress and measure conductivity in these conditions are described. It has been shown that the conductivity is apparently not dependent on the applied stress.

Paper B6.5 focuses on the characterization of nanocomposite materials made of LDPE matrix and two types of nanofillers, i.e. Al2O3 and MgO particles. Specific attention is paid to the conductivity behaviour of the materials. For both nanocomposites, a substantial reduction in conductivity, by one order of magnitude, is reported in comparison to bare LDPE. The space-charge limited current (SCLC) mechanism, which dominates the conduction process in LDPE, would cease for the nanocomposite materials.

Paper B6.6 addresses the thermo-electrical ageing of various polymers (PVC, PMMA, POM) under specific stress waveforms emitted by power electronics converters, with high frequency components up to 25kHz. This concerns relatively short term tests of a few seconds in which the specific stresses induce thermal heating of the material and hence early failure, especially when the material undergoes the glass transition temperature. Thermal heating is also predicted using FEM simulations.

# Session B8: Material for accessories and sheathing

Chairman: R. BHATTACHARYYA, Ducab, United Arab Emirates

Rapporteur: A. AIT AMAR, Nexans, France

Topic 1: Materials, New Materials and Ageing Assessment in AC and DC

This session, comprising five papers, dealt with the ageing of EPDM material used in Cold shrinkable joint and with predicting its useful life based on ageing and the thermo-oxidation reaction. The material of the stress control tube used for heat shrink accessories is deliberately chosen for a high temperature exposure.

New materials are developed for cables that can autonomously repair or mitigate damage to the sheath in order to preserve its integrity.

A new approach to tendering in a “Design contest” for new connectors was presented in order to provide for a successful implementation and a safe and reliable usage of these components

Paper B.8.1 presented an accelerated ageing procedure for predicting the useful lifetime of an external protection of a cold-shrinkable joint in EPDM rubber which can be simultaneously subjected to many complex environmental conditions during operation. Based on a combination of the intrinsic defect concept and the fracture mechanics, this method makes it possible to predict time to failure, especially when designing rubber components subjected to a thermal oxidative environment.

Paper B.8.2 described the experimental characterizations on EPDM in order to understand the effect of ageing mechanisms which lead to the modification of the properties of the insulating elastomer electric cables. The oxidation process is considered to be the main ageing mechanism of the material, as it induces an evolution of its macroscopic properties.

Paper B.8.3 described the effect of the temperature on the conductivity of stress control sleeve used in heat shrink joints. Electrical properties have been characterized at different temperatures and electrical fields. Exposure to continuous higher temperature causes thermal ageing which leads to higher conductivity due to the oxidation of the material. No critical electrical changes in tube have been observed due to a high temperature exposure.

Paper B.8.5 evaluated potential materials that are capable of being deployed in underground cable sheath to seal defects, restore cable integrity and prevent the free ingress of water. For that purpose, two routes are explored: molecular self-repair and swelling response to water exposure. Investigations are also made on hybrid materials which combine both water swelling and self- healing mechanisms.

Paper B.8.6 presented the Enexis approach to challenge manufacturers with a tendering method to come up with a solution of new insulation piercing connectors for conductor cross-sections of $1.5 mm^2$ to $25 mm^2$. The various steps of the development were presented until the qualification of the final connectors.

# Session B9: Material Performance

Chairman: Paolo MAIOLI, Prysmian SpA, Italy

Rapporteur: Petru NOTINGHER, University of Montpellier, France

Session B9 was devoted to materials, new materials and ageing assessment in ac and dc. Three papers addressing aspects related to the performance of semiconducting and insulating materials were presented.

The analysis of two grades of carbon blacks used in high voltage and extra-high voltage semicon compounds was the topic of Paper B9.1. The properties of compounds manufactured with a classic (acetylene) carbon black and a new high-conductivity (Ensaco) carbon black have been investigated. It has been concluded that the use of the new carbon black selection can lead to a reduction in carbon black loading, with a resulting improved viscosity and scorch time, retaining good dispersion and electrical properties.

Paper B9.4 analysed the effect on water-treeing of remnant mechanical stresses, frozen-in during the manufacturing process of extruded XLPE. From the experiments performed on 12 kV XLPE cables, exposed to water and different static tensions during ageing, it came out that the effect of mechanical tension is an increase in water-tree initiation sites, while the rate of water-tree growth seems to be more modestly affected. Strains lower than 2% appeared to have a minor effect on the initiation and growth of bow-tie water-trees within the insulation of the studied cables.

Paper B9.6 reported on the influence of operating conditions of cable lines in grids with extruded cable insulation. Measurements of thermal properties and resistance to partial discharges, as well as an assessment of molecular molar mass of particular insulation layers, were conducted, with samples of insulation obtained from real cables. The conclusion drawn was that the process of degradation of polyethylene insulation in MV cables was not the same over the whole cross-section of the cable. The weakest insulation layers appeared next to the boundary layers, i.e. near the semiconducting screens on the cable conductor or on the outer part of the cable insulation. In cables included in “mixed” power lines (composed of underground cables and overhead lines), the layer of insulation next to the cable conductor was found to be weaker. In contrast, for “pure” cable line runs (composed of underground cables only), the thermal and electrical properties of the insulating layers next to the metallic screen deteriorated. The obtained results were interpreted as effects of local temperature increases, depending on the fault current path.

# Session B10: Cables for the Future

Chairman: Rakowska Aleksandra, TU Poznan University of Technology, Polytechnika Poznanska, Poland

Rapporteur: Mirebeau Pierre; Nexans, France

The Session "cables for the future" included three presentations:

- Two about superconductive cables
- One about gas insulated cables

Innovations in superconductive cables concern the finalisation of the projects. Cables are no longer demonstrators; they are inserted into the network both in St Petersburg and in Essen.

Especially the cable in Essen has now been in operation for more than 1 year. There were storms, currents of more than 800A, and it has been tested in a short-circuit condition. This proved the quality of the cable system design.

The cable in St Petersburg will be put into service during the next couple of years (2017). Presently the design quality has been proven on long prototypes both in AC (200m) and DC (860m) condition.

Gas Insulated Lines have now been in operation in AC for many years, up to 420kV. They are under development tests in DC at 500kV. They will make it possible to transmit a large flow of power through a single cable system.

As a conclusion, all the cables for the future that have been presented are characterised by a large power transmission density (transmitted power divided by the footprint of the line).

# Session C1: Remaining life estimation of LV and MV cables

Chairman: N. SINISUKA, Institut Teknologi Bandung, Indonesia

Rapporteur: I.DENIZET, General Cable, France

This session, comprising six papers, dealt with several technical approaches adopted to estimate the level of degradation of LV and MV cables. The measurements described can be electrical, chemical or mechanical testing. Some studies lead to models predicting cables failures.

Paper C.1.1 describes a study on partial discharges measurement performed on aged XLPE joint which suffered from overheating in service and shows the influence of frequency on parameters such as charge magnitude, charge-phase relation, and number of PDs per cycle. A Weibull analysis shows significant differences in charge magnitude distributions.

Paper C.1.2 deals with the relation between partial discharge activity and the expected remaining life of power equipment. This calculation is performed on PILC cables and XLPE cables separately, through Weibull statistics. As a result, this study concludes that after the first detection of PD's (with SCG), the average time until a failure is 16 years for PILC and 2 months for XLPE cable (and its accessories). With a SCG warning, this is reduced to 3 years and 10 days, respectively.

Paper C.1.3 presents a study included in the European project ADVANCE (Aging Diagnostics and Prognostics of low voltage I&C cables). The objective is to evaluate the life time of cables through accelerated thermal and radiation ageing tests. Several characterization test techniques (mechanical, chemical, electrical) have been used, compared and correlated. This study highlights the difficulty to obtain reliable results with the smallest possible standard deviation.

Paper C.1.4 proposes a model to predict the cables failures based on the piecewise powerlaw non-homogeneous Poisson process and stochastic electro-thermal model. The failure causes of cables are classified into two types, random and ageing. The results show that the electro-thermal ageing life of the cables is approximately 39 years.

Paper C.1.5 explains the influence of local and global aging on the electrical performance of the insulation of cables. The performances of cables were assessed by measuring the dielectric response (Very Low Frequency (VLF) and Time Domain Spectroscopy (TDS)), by visual inspection of the generated defect, and finally by breakdown voltage analysis.

Paper C.1.6 presents key experiences and electrical testing statistics from 30+ years of non-destructive shielded MV plant electrical cable diagnostics in CANDU nuclear plants, and approximately 5+ years in US nuclear stations. A technical approach for cable aging management consists in off-line AC, over-voltage testing, off-line partial discharge testing and dielectric spectroscopy, including VLF (0.1Hz) Tan δ testing. The combined diagnostic approach can be sensitive to electrical defects, moisture degradation and bulk thermal aging.

# Session C3: Diagnosis methods

Chairman: W. BOONE, DNV GL, The Netherlands

Rapporteur: A. NAUD, RTE, France

Session C3, comprising six papers, focused on diagnosis methods applied to cable systems from LV up to EHV levels. Both online and offline solutions have been considered, offering a large panel of solutions, from the use of sensors for cable systems or accessories monitoring to partial discharge (PD) measurements. Utilities are provided with new insights and effective tools to shorten their maintenance operations, even sometimes preventing a failure through monitoring. Laboratory tests along with digital simulations strengthen the studied solutions and give additional confidence about their reliability and efficiency. Analyses of existing diagnosis methods have been carried out.

Paper C3.1 presented a new approach to HV cable system monitoring and uprating, using Localized Temperature Sensing (LTS) for cables not equipped with fibre optics in their metallic sheaths. Up to 30 LTS sensors, consisting of modified Bragg fibre optic, can be installed on the cable outer sheath, and are connected to a measuring unit at the substation. Several laboratory tests have been carried out on a 132 kV cable. At the time being, no significant differences with standard laboratory sensors have been detected. Accuracy is +/- 1°C, with 1 to 2 seconds measuring times.

Paper C3.2 introduced an innovative low-cost technique of sensing applied to cable joints monitoring. Based on an intermodal interference technique, a fibre optic (FO) has been developed for temperature sensing of electricity distribution needs. This technique is sensitive enough to detect joint failures and soil drying scenarios. Lab tests showed good agreement between thermal and optical measurements. Final accuracy of the interferometric interference system is +/- 1°C.

Paper C3.4 explained how Distributed Temperature Sensing (DTS) adapts to longer cables. Both Raman and Brillouin technologies are investigated. Insights have been provided on DTS uses, incipient faults exposition, conditions of monitoring, and performance optimisation. Both underground and subsea cables applications have been considered. The majority of the longest cables can be monitored and DTS provides valuable data, as long as parameters (length, repeatability, acquisition time, losses, technology, etc.) have been carefully selected.

Paper C3.5 reported how difficult it is to estimate the Very Low Frequency (VLF) approach effect on withstand diagnostics. Indeed, some studies suggest that VLF lower frequencies may reduce the survival probability of the cable. Lab tests of a degraded MV insulation (Water Trees), and a utility based analysis, have been carried out. As a result, there is no clear difference between failure rates on test for common VLF frequencies. The reported VLF frequency effect on simple withstand is consistent with being the result of the increased length of circuits tested, not VLF frequency.

Paper C.3.6 made a review of onsite applicable and available off-line MV diagnostics, related to their difficulties and insulation weakness targeted applications (from specific to large). PD and dielectric loss measurements and time domain reflectometry have been addressed. Even though it is possible to design an adapted method for a targeted weakness, the use of different types of measurement is strongly recommended to maximize the chances of revealing any other weakness resulting from the past life of the cable tested.

Paper C.3.7 described an online PD monitoring solution for short cable systems connecting power transformers with GIS. Synchronized PD measurements are performed using PD sensors placed on the earth connections of the cable and transformer. New numerical processing tools have been introduced efficiently to reduce background noise and discriminate more easily PD sources. An experiment on a 220 kV cable installed within a substation has been carried out, and led to the discovery of a discharge mark in the GIS compartment.

# Session C5. HV and EHV cable diagnosis

Chairman: H. TANAKA, VISCAS Corporation, Japan

Rapporteur: E. BIC – GENERAL CABLE, FRANCE

This session, comprising five papers, deals with cable diagnosis on medium, high and extra high voltage cables. Manufacturers of measuring equipment and utilities develop methods for diagnosis of cables which could be implemented during commissioning or during the service life of the cable. These diagnoses are based on partial discharge monitoring or on the dissipation factor measurement. Presently, energy supply must be interrupted. When a breakdown occurs on a cable, it is very important to locate it quickly. Manufacturers develop equipment that make it possible to locate a breakdown quickly and accurately.

Paper C5.1 shares the experience on permanent partial discharge monitoring systems gained through one year of operation on the Shanghai 500kV power cable lines. The system measures partial discharge in real time using 159 detectors and high frequency current transformer sensors. Pattern analysis makes it possible to set various levels of alarm.

Paper C5.2 explains the principle of performing damped AC voltage tests for on-site tests (after the laying test, maintenance test or diagnostic test). Examples show the experience gained on Damped AC voltage tests that can be used as a withstand test or combined with a partial discharge test and/or a dissipation factor measurement.

Paper C5.3 describes the concept of a short-term partial discharge monitoring on a 400kV XLPE cable system in Berlin. This system, on which the development of power supply of the measuring units was one of the main challenges, makes it possible to record and analyse patterns, trend files and stream files by means of high frequency current transformers set up at joint and termination locations.

Paper C5.4 presents the Line Resonance Analysis technology, which is a method designed for detecting and locating degradations on the cable by analysing the change in impedance on the line. By this way, it can locate defective locations where the cable insulation has been damaged because of thermal, electrical or mechanical stress.

Paper C5.5 explains the Time Domain Reflectometry method for monitoring high voltage cables during commissioning tests and/or during the service life of the cable. Experimental tests on medium and high voltage cables show that this could be used in order to locate with accuracy breakdowns on both AC and DC cables.

# Session C6. Maintenance

Chairman: Ray AWAD, Ray Awad Inc., Canada

Rapporteur: D.GALERON – NEXANS France

C6.1: Hydro-Québec advancements with infrared imaging for the maintenance of the underground medium voltage cable system.

MISSING

C6.2: REE's research and development projects related to predictive maintenance based on monitoring of critical parameters in high voltage underground cables.

A clear and good explanation of the topic, and a presentation of the actual system developed on site.

Interesting aspect of different parameters to be monitored (at the same time as PD) in order to have an idea about predictive maintenance.

Good presentation slides, and very good team spirit, which is probably leading to a very good and interesting study. A promising system!

C6.3: Rejuvenation of EPR-insulated medium voltage underground cables

A very interesting presentation, with a long and abundant feedback.

Leads to a clear vision about water-tree in EPR that are usually not easy to visualize.

This presentation is the result of a very large work: we can hope that it will lead to advice and proposals for the future.

C6.4: DGA diagnostic method reveals internal carbonization in oil-filled High Voltage extruded cable terminations.

The proposed analysis and the tool presented here are very attractive.

The process for DGA is performed on interesting samples. It is possible that measurements on site will not be so easy, but the results of the proposed measurements are interesting and set a certain limit value for acetylene, which can probably be a basis for future recommendations.

C6.5: Prelocating and pinpointing faults on underground Medium-Voltage cables: review of Hydro-Québec's experience

A very clear explanation of the proposed system and its implementation.

A very good system to optimize the time of fault location.

This system still seems young and the authors will find keys to improve the systems, especially by training people.

C6.6: Dielectric diagnosis of extruded cable insulation by very low frequency and spectroscopy techniques – a few case studies.

A good analysis on a very large panel, with explanation of possible reasons.

The presentation is good and the proposed process is promising.

It is a good finding for existing networks.

We hope that this very good feedback will lead to advice and interesting proposal for the future.

# Session C6 Maintenance

Chairman: Y. WANG, Prysmian Group, Italy

Rapporteur: V. JOUBERT, General Cable, France

This Session consisted of six presentations on various aspects of the improvements of HVAC cable systems. Both cable material and cable manufacturers shared their latest developments to improve the safety and performance of such systems.

Paper A4.1 presented a new model for the cable insulation degassing process, allowing for better understanding and optimization of this time and capacity-consuming process. It also explored the effect of methane in the insulation on the performances of the cable.

Paper A4.2 dealt with the fire-resistant and low-smoke properties of HV cable outer sheaths. Several factors were compared in order to find the best design matching a set of criteria pertaining to the behaviour of cables in tunnels under fire conditions.

Paper A4.3 reported on the development and qualification of reduced-insulation 66/77 kV XLPE cable aimed at replacing 3-core SCFF cables without replacing the existing tubes. Higher quality control allowed for cable and accessories designed for higher-than-usual stresses to be successfully qualified.

Paper A4.4 focused on 500kV accessories for XLPE cables and shared the experience of designing, developing and qualifying 500kV joint, outdoor sealing ends and dry-type GIS sealing end.

Paper A4.5 addressed the problem of particle scattering in outdoor termination during faults, which is dangerous for both humans and other nearby terminations. Directing the pressure release can prevent such consequences.

Paper A4.6 described the development of a paperless transition joint between LLFF and XLPE-insulated cables. Through the use of a core element used to block the oil and withstand pressure changes while connecting conductors, a premoulded transition joint has been designed to be more compact and easier to install than the traditional back-to-back transitions.

# Session C7: Modelling and Assessment

Chairman: R. MOSIER, Power Delivery Consultants, Inc., USA

Rapporteur: A. CHARMETANT, Nexans, France

This session, which included four papers, was focused on the topics of Diagnosis, Maintenance, Remaining Life Estimation, and Management. Due to the increasing reliance on computers and specialized machinery, utilities are under pressure to deliver highly reliable service. In order to do so, utility management requires answers on the health of the cable systems and on its remaining life. Engineers look for testing that can provide the most trustworthy information without overstating the weak points of the cable system.

Paper C.7.2 presented the development of a software model of aging kinetics and its validation on various ethylenic polymers (EPDM and PE) used in cables. Ultimately, this will be used to develop an understanding of the mechanisms of aging in order to adopt a universal approach for lifetime prediction and monitoring the aging of these materials on-site. Since the results showed a high correlation between the predicted and actual values over a wide temperature range, this new simulation tool will be used in the next step for the prediction of macromolecular and macroscopic changes of polymer, and ultimately lifetime predictions.

Paper C.7.3 presented a methodology for identifying local thermal stress in a cable, using time domain reflectometry (TDR). EMTP simulations showed that reflected signal amplitude could be very important when geometrical changes occur due to thermal dilatation, which demonstrates the relevance of using TDR for detecting thermal stresses. Laboratory experiments on long cable sections removed from the network after more than 20 years of operation were combined with dielectric characterization on shorter ones. These experiments showed that changes in dielectric properties can induce bias in the TDR results. This makes it necessary to discriminate between both possible causes of reflexions to decide if on-site intervention is required. The use of different signal frequencies is planned in order to make this discrimination possible.

HTS cables are very sensitive to hot points. These hot points can be due either to defects in the cable or to failure in the cryogenic cooling system. Paper C.7.4 introduced a non-destructive diagnostic methodology called TFDR with the advantages of both TDR and FDR (frequency domain reflectometry). This new methodology allows for both time localization and frequency localization of a defect. To validate this methodology, TFDR was compared with the traditional reflectometry techniques. The approach still has to be validated on real-life HTS cables under working conditions.

Paper C.7.5 presented maintenance decision models for the Java-Bali 150 kV power transmission submarine cable using Reliability, Availability, Maintainability, and Safety (RAMS). The focus of this paper was to demonstrate the applicability of RAMS to analyze maintenance planning on the operation of 150-kV submarine cables in the Java-Bali 150-kV Submarine Power Transmission system in Indonesia. A model was developed to achieve the RAMS target in maintenance strategy by choosing an effective maintenance interval and detection probability, illustrated by a case study.

# Session C8 : Improvement of cable ratings

Chairman: Francis KRÄHENBÜHL, Nexans Switzerland

Rapporteur: Frédéric BELLOT, General Cable France

This Session was dedicated to techniques aiming at improving the cable ratings of already existing networks. In fact, the ever increasing power demand resulting from city expansion or renewable energy production is giving rise to the need for an improvement of the MV cable characteristics. The current rating, as well as temperature resistance and system lifetime, have to be improved in order to meet the expectations of MV networks.

The Session started by an invited lecture on "Smart grids and insulated power cables" presented by Pierre MALLET, R&D and Innovation Director at ERDF. His requirements for cable makers was to try and introduce location tools (RFID) and/or sensors in the cables.

Paper C8.1 presented an overview of the MV cable system design in the specific context of renewable energy, in particular wind and solar applications. It underlined the importance of the right cable design for the economic viability of renewable energy projects. The conductor size, installation conditions, rated temperature and soil conditions must be thoroughly considered in order to permit the expected long-term operation of the cables.

Paper C8.2 presented the solution implemented in Dubai in order to increase the current rating of the MV grid to cope with the steadily growing power demand in such cities. For the authors, a special backfill material is a good way to increase the current rating by up to 18%.

Paper C8.3 is dealing with the lifetime extension of MV cables using a silicone-based fluid. This technology has already been presented many times in earlier Jicable conferences, but the original chemical agent caused an accelerated corrosion of aluminium conductors. The newly developed fluid contains an improved agent preventing this unwanted effect. The treated cables show a clear improvement of their impulse voltage test by up to 55%.

Paper C8.4 considered the increase of conductor temperature from the insulating material side. Using a new XLPE with increased thermal resistance allows the cable to withstand temperatures of 120°C for a rather long period of time, and therefore increases the capacity of the cable. A pilot test is currently under preparation to demonstrate the real cable characteristics in real conditions.

As a conclusion, it can be said that tools and practical means already exist for enhancing the performance of cables in networks when the increasing demand requires it. They can sometimes avoid the replacement of existing cables or make it possible to opt for more expensive cable designs.

# Session C9: Special Cables - Avionics

Chairman: J.H. Schutten, Prysmian Group R&D, Netherlands. Chairman IEC TC20

Rapporteur: A. Jeanguillaume, Draka Fileca, France

This Session dealt mainly with cables designed for the aerospace industry.

Paper C9.i was an invited lecture on the impact of the new electrical architecture of aircrafts on insulated power cables. The consequences of the increase of voltages in new aircraft types and the impact of composite body material replacing aluminium were particularly examined.

Arc tracking and partial discharge remain the main challenges, but require partly new solutions for the cables and the electrical systems.

Paper C9.1 presented a new cable family for new power supply needs in aerospace environment.

The introduction of a new voltage on board of planes had led to the introduction of new standardized DZ an AZ cable families, offering partial discharge-free products for low pressure environments. The answer to the evolution described in paper C9.i was presented.

Paper C9.2 described the validation and quantification of reliability improvements of new cable designs for LV power distribution. In particular, a case study of 600V self-sealing cables was presented.

The difficulties of proving in a scientific way the real life improvements were underlined.

Paper C9.3 was not presented. It was announced to be a report on low bending radius aerospace power feeder cables for reliable electrical architectures of more electrical aircrafts.

# Session C10: industrial and special cables

Chairman: ROVIRA Jacint, Grupo General Cables Sistemas SA, Spain

Rapporteur: BEN HASSINE Mouna, EDF R&D, France

This session, comprising five papers, dealt with the development and the qualification of industrial and special cables in order to improve their functional properties. Only three of these papers were presented.

Paper C10.1 Presented an alternative solution to Mica tape for fire-resistant cables. The aim of this study is to improve mechanical properties of low voltage fire resistant cables. This newly developped cable seems to be more environment-friendly and also less toxic. That is why these new cables will also be tested to higher voltage cable where fire performance is required.

Paper C10.2 Discussed and compared different cables design alternatives for the OGP (Oil, Gas and Petrochemical) industry. This work shows that lead and polyamide sheathed cables meet satisfactorily the specific requirements of the OGP environment.

Paper C10.3 Not presented

Paper C10.4 Analysed the Impact of an inorganic filler: Calcium Carbonate ($CaCO_3$) on the electrical, thermal and mechanical properties of the crosslinked polyethylene (XLPE). This analysis was carried out on samples under various thermal conditions. The results showed that adding inorganic filler to the XLPE cables improved its properties.

Paper C10.5 Not presented

# Session D1: Testing methods: PD measurements

Chairman: M. FENGER, PRYSMIAN GROUP, CANADA

Rapporteur: Eric SIMEON. Nexans, France

D1 - Partial Discharge Measurements in the Sub-VLF Range

By reducing the test voltage frequency, the physical stress on a potential PD defect inside a cable insulation or at interfaces in joints or terminations differs consequently from power frequency stress. By further increasing cable length, as HV export connecting offshore converters with the grid on land, the lower limit frequencies of VLF testing and cable diagnostic have to be discussed, particularly since they are worldwide accepted tools for dielectric quality control. This paper describes the PD behaviour of typical cable defects at 50 Hz in comparison with VLF test voltages of 0.1 Hz down to 0.01 Hz. All typical PD defects could be identified by their PRPD patterns for all test frequencies. The 50 Hz pattern was quite comparable to the ones at 0.1 Hz and even 0.05 Hz, 0.02 Hz and 0.01 Hz. For the PDIV, a decreasing tendency could be found for decreasing test voltage frequencies. In particular, VLF 0.1 Hz measurements are sufficiently comparable to VLF measurements with further decreased test voltage frequency.

D2 - The Application of Partial Discharge Monitored AC Voltage Acceptance Test in Beijing 500 kV Power Cable Lines

The paper introduces the acceptance test with 1.7 Uo in Beijing 500kV 6,7km-long power cable lines. A distributed Partial Discharge (PD) monitored AC voltage test method was used for this test. Performance check of the PD Monitoring system with 13 channels was completed by injection of a 10nC PD calibration signal from each cable end termination. The attenuated behaviour measured by each Partial Discharge Detector (PDD) installed on each joint along the cable line demonstrated the performance of each PDD unit, as well as the total PD measurement system. This was the first time that PD measurement criteria with no recognizable PD pattern were used in HV cable acceptance test in China: this method is now introduced.

D3 - Long-term experiences and review with offline and online PD measurements on site on EHV XLPE cable systems 330 kV to 500 kV

The experience of about 2400 tested EHV accessories during commissioning or a system assessment in about 170 assignments all around the word was cumulated over the last 12 years. The relevant standards for high-voltage cable systems (IEC 60840 / 62067) recommend an AC voltage test of the main insulation with a specified value (1.7·Uo or values according to table 4 column 11 in IEC 60840 / 62067) for 1 hour or Uo for 24 hours (‘soak-test’) is applied. In addition to the tests specified in IEC 62067, the manufacturer recommends and implements a PD measurement of all accessories after installation for voltage levels Um ≥ 362 kV.

D4 - Results of 10 years after installation tests combined with PD detection on MV cable systems

In 2004, Alliander decided to add PD measurements to their after-installation test policy, which consisted only of a voltage withstand test on the cable insulation and cable sheath in order to check the quality of the installed cable system, including cable and accessories. Before 2004, partial discharge (PD) measurements were mentioned as an option. Over the last years, dozens of accessories and a few cable parts were taken out of the tested cables, based on PD activity, measured during after installation test. In many cases, severe abnormalities were found, threatening the reliability of the cable system, but also cases were found where the reason for PD was not clear. It is also discovered that cable systems can contain PD’s in accessories but still survive the after installation test. This paper describes the experiences made with PD measurements on new installed MV extruded power cables. Besides, practical recommendations and knowledge rules developed by Alliander will be addressed. Finally, examples are given of PD behavior in relation to poor workmanship and the design of accessories.

D5 - PD Characteristics under the Aspect of Different Voltage Wave Shapes and Frequencies

The authors want to introduce the different voltage wave shapes which are currently used for offline partial discharge diagnosis and their impact on partial discharge parameters. A literature survey gives a brief overview of several recent and past publications. The main scope of this paper is about the influences of the frequency of the test voltage on partial discharge defects. Selected case studies were used to prove the effects.

D6 – On-site combination of withstand voltage testing and PD measurement for XLPE power cable accessories

# Session D2: Reliability diagnosis

Chairman: H. E. ORTON

Rapporteur: M. MUSQUIN, General Cable France

This session, comprising six papers, dealt with systems able to perform reliability diagnosis effectively, using Time Frequency Domain Reflectometry combined with Damped AC voltages, Very Low Frequencies or frequency tuned resonant technologies.

These technologies significantly reduce the complexity of measurements and the weight of equipment. They also provide the opportunity to test longer cables lengths.

Paper D.2.1 presented a method of control of instrumentation cables via Time Frequency Domain Reflectometry in South Korean nuclear power stations. This paper introduces an algorithm which optimizes parameters, including centre-frequency, bandwidth and time-duration.

Paper D.2.2 described a method of testing up to 500 kV on-site long-lengths of cable by Damped AC. It provides quality control of cables and accessories during after laying tests. In addition, maintenance testing and condition assessment were discussed.

Paper D.2.3 showed how to combine Damped AC and VLF voltage tests, that are widely used for after-laying and maintenance of MV cables, providing an optimal solution for an effective on-site test and diagnosis.

Paper D.2.4 covered condition assessment and determination of the remaining life time of MV cables in the Pacific Islands. A visual examination of failed cables indicated that the aluminium screen tape had completely corroded. The best diagnostic to detect degradations was the Reflectometry and resistance measurement of the screen.

Paper D.2.5 reported the expansion of on-site testing with frequency tuned resonant test systems, for reducing test equipment weight and longer cable lengths.

Paper D.2.6 compared various condition assessment methods for measurement on MV cables, both on-line and off-line, in order to increase the accuracy of diagnosis.

# Session D4: On-site and laboratory test (1)

Chairman: R. PLATH, Technische Universität Berlin, Germany

Rapporteur: C. MOREAU, EDF R&D, France

This session, comprising six papers, was dedicated to various considerations in relation with cable condition, laboratory test measurements and the characterisation of cables.

Paper D.4.1 has not been presented.

The knowledge of the condition of cables used in nuclear power plants is of great interest, since an abnormal ageing and/or a cable failure may lead to costly plant outage. Paper D.4.2 showed the results of laboratory forensic evaluation of MV cables with EPR insulation operating in wet environment. It points out that 0.1 Hz tangent delta measurement is relevant to identify water-tree degradation. Moreover, it proposes acceptance criteria for ranking the condition of cables and for providing guidance for their replacement (good/further study/action required).

Paper D.4.3 has reported on important measures that have to be implemented in order to reduce the error when measuring skin effect losses in power cables with large cross sections. The theoretical approach is combined with measurements and FEM simulations to reveal different set- up parameters influencing the ks factor evaluation. As a conclusion, the measurement accuracy of the ks factor may be strongly influenced by the boundary conditions of the measuring set-up, which consequently shall be considered with care.

Paper D.4.4 complemented paper D.4.3, providing further information on AC resistance measurements on long cables. In particular, it showed the effect of the cable screen design on the apparent value of the ks factor, as well as the effect of winding a cable on a drum on the apparent value of the ks factor for cables with welded aluminium sheaths.

The evaluation of the DC conductivity of HVDC cable insulation is particularly important in order to assess the performance and the stability of these insulations under various constraints. Paper D.4.5 presented a leakage current measurement test set-up and measured values of conductivity. Then experimental data were fitted to a parametric mathematical model of conductivity using different approaches combining FEM calculations and optimisation techniques. The weighted Levenberg-Marquardt algorithm-FEM identification method has provided the most accurate results.

Paper D.4.6 presented a test set-up under study/development using a hyperbaric chamber and dedicated to test cable accessories under various conditions of pressure. In particular, the design could be adapted to test accessories in water as defined in the EDF standard “Robustness test for MV joints and transition joints”.

# Session D.5: On-site and Testing Laboratory Tests 2

Chairman: B. Hennuy, Laborelec, Belgique

Rapporteur: J. Santana, Prysmian Cables & Systems, France

This session presented papers mainly related to the partial discharge measurement techniques. In high noise environments, extracting the right signal due to the discharge phenomenon is the main objective to set, since the noise level is high and blurs these signals. On-site or laboratory measurements performed during HV tests use optical fibre temperature monitoring. The paper illustrates the relationship between measurements of the DC-conductivity of the insulation cross-linked polyethylene and its chemical components.

Paper D.5.1 presented the methodology of DC-conductivity measurements in XPLE at high DC electric fields. Using the techniques described in ASTM D257 and IEC60093 allowed under controlled temperature, and applying a constant pressure on the sample, an initial modification of the electrical equilibrium was revealed between the electrodes, generating a polarization dynamic leakage current which decayed rapidly and a steady state current which remained closely linked to the electrical conductivity of the material itself. Various measurements have been made on different set-ups, showing the accuracy which could be obtained. In the case of XLPE, the cross-linked by-products have a significant influence on conductivity.

Paper D.5.3 demonstrates a technique used in the HV Laboratory for automated temperature monitoring and control systems, which is based on thermocouples or on fibre-optic cables sensor applied on a similar cable called “smart link” placed in a typical Type Test loop. This technique makes it possible to avoid using a mirror cable during a cycle temperature HV test, with thermocouples placed on the conductor.

Paper D.5.4 describes the use of fluorescent optical fibre on HV accessories with transparent or translucent pre-moulded insulation bodies for PD measurements. In parallel, this technique is compared to fiber acoustic PD sensor measurements and its advantages for opaque pre-moulded insulation bodies. These techniques are quite useful for HVDC PD measurements in an extremely noisy environment.

Paper D.5.5 shows that the use of fluorescent silicone rubber in high voltage cable accessories makes it possible to measure the developed lightning discharges by using a simple optical fiber sensor. The electrical and optical methods of PD measurements have been applied simultaneously and have demonstrated similar performances.  PD optical measurement provides good diagnosis, but outsides noises are due to the background and corona effects.

Paper D.5.6 proposed online partial discharge monitoring of power cables in high noise environment. Using various techniques for de-noising signal processing and artificial intelligence techniques, PD in high noise environments provides efficient de-noising and characterizes various activities in the recorded data.

# Session D6: Specific Testing Trends (1)

Chairman: Tiebin ZHAO, EPRI, USA

Rapporteur: Chantal FAVRIE, France

This Session presents five papers discussing a combination approach for systematic qualification tests, recommendations for performing prequalification tests based on IEC 62067, the effectiveness of commissioning test techniques, a full-scale rig to test submarine cables with combined compression and cyclic bending loads, and a tool for characterizing insulating materials for high voltage applications. One paper also discusses the Construction Products Regulation cable classifications.

Paper D6.1 addresses the issues of the differences among IEEE, AEIC and IEC standards in cable accessory and presents a combination approach for cable system qualification. The paper discusses the similarities and differences between the testing methods, test limits and test requirements in each standard. The applied AEIC/IEC combination approach form is reviewed. Risks and benefits of such an approach include complex test loops while meeting requirements of multiple standards.

Paper D6.2 provides recommendations for performing prequalification tests as required by IEC 62067. The guideline is based on the authors' experience to provide a consistent approach to enhance the effectiveness of such tests.

Paper D6.3 discusses the effectiveness of commissioning test techniques in assessing created cable defects. The paper concludes that series resonance, very low frequency, and damped AC tests demonstrate different levels of effectiveness in detecting defects as a function of voltage levels and test durations.

Paper D6.4 was missing.

Paper D6.5 describes the build full-scale rig and the test program to understand if a submarine cable can sustain combined compression and cyclic bending loads. Extreme loads from a dynamic analysis were used. The paper also discusses the potential failure modes associated with axial compression. The tests performed on a cable apply 500 load cycles with combined bending and compression. The cable is then electrically tested, dissected and visually inspected.

Paper D6.6 describes a tool using a laboratory for characterizing insulating materials (ac-XLPE, dc-XLPE and non-filled XLPE) for high voltage applications before they are used in production. The process can evaluate the electrical performance of various materials and compositions. The method includes testing thin plates by HV dc breakdown at room temperature. The test results are analysed with the Weibull function.

# Session D8: Testing evaluations

Chairman: Edward GULSKI; onsite hv solutions ag, Switzerland

Rapporteur: Martial GUILLEMIN; RTE, France

This session, comprising six contributions, dealt with Electrical and Non Electrical Testing Methods.

Utilities need warranties that cable systems in operating conditions provide the required performances for the specific applications, during the expected lifespan and for the lowest completion costs. This challenge is becoming more and more arduous with the development of subsea power cable and umbilicals. It involves innovative testing methods and top-level technology test equipment to be able to master electrical parameters of cables, especially AC resistance and PD localization (if any).

Paper D8.1 establishes a detailed measurement procedure to provide all relevant electrical parameters for subsea power umbilicals, as well as regular subsea power cables. The numeric method includes measurements of per phase impedances for all power circuits, and induced voltages and currents in all conducting materials under specific grounding conditions. The obtained values could finally be used to calibrate Finite Element Models being used for further studies such as thermal rating.

Paper D8.2 (the presenter did not show up on the session) takes stock of a current research made on XLPE cable PD localization. As the existing on-line PD testing method is based on a low frequency range (<100 MHz) and due to the weak damping effect, fault location is difficult. By using ultra-high sampling rate acquisition system, it is possible to explore a larger frequency spectrum for PD measurements. The initial findings are that the actual attenuation features of the amplitude and frequency for PD seems bigger than the theoretical attenuation, and the PD localization method needs further developments to improve its accuracy.

Paper D8.3 presents the results of a hyperbaric accelerated water-treeing test up to 310 bar, followed by AC breakdown strength measurements, that has been performed on Tree-Retardant XLPE insulated cable samples (15 kV/4,5 mm insulation thickness/wet design/blocked conductors with mastic compound). Experiments shows that, while treeing densities increase as a function of increasing pressure and ageing time, residual AC breakdown strength only remains a function of ageing time. Furthermore, it can be inferred from these results that the TRXLPE used in the study will have the reliable long-life service in deep sea submarine and umbilical applications similar to the one in the ground.

Paper D8.4 describes the challenge raised to perform type tests on a three-core submarine cable system. Due to side effects, the well-known cable procedure for medium voltage three-core to generate a three-phase heating circuit with a 3-phase transformer is not applicable. Therefore, an in-house control and software solution that compensates the mutual influence of the phases has been developed. In the same way, PD measurement on a high capacitance test assembly requires a coupling capacitor that should have the highest possible value to reduce the noise ratio. Performances of the test equipment have a significant influence on the final test result.

Paper D8.5 (the presenter did not show up on the session) reports on a first step achieved by experimenting the electromagnetic wave transmission rate in a 10 kV XLPE cable. Results show that the electromagnetic wave velocity is lower 3% than the theoretical value taken from the model used in the communication field and actually depends on the cable design.

Paper D8.6 (the presenter did not show up on the session) presents the development of a new electrical method for the AC resistance measurement of power cable conductors. This procedure is based on an electronic system including a source of about 100 mA and a small signal processing module. Comparison between measurements and theoretical predictions leads to a discrepancy of less than 0.5% for conductors whose cross-section is lower than or equal to 500 mm². Tests on larger segmental cross-section conductors are under consideration.

# Session D9 : Environment and sustainability 1

Chairman: ZHONG Lisheng, State Key Laboratory, China

Rapporteur: MOINDROT Vincent, RTE, France

Session D9, comprising five papers, focused on environmental and sustainability considerations applied to cable systems from LV up to EHV levels. EMF, diagnosis methods and thermal issues have been addressed, offering a large panel of solutions, from technical to economical or PR related ones. Utilities are provided with new insights and effective tools to strengthen their position on those formerly emerging, now well-known key subjects. Several studies have been presented, from feedback obtained to digital simulations, and give additional confidence about their reliability and efficiency.

Paper D.9.1 described the communication plan put into action at RTE about the ElectroMagnetic Fields (EMF) generated by the transmission lines, and the technical solution of mitigation installed in case of a threshold overrun according to the French government survey plan.

Paper D.9.2 reported on the analyses performed by DNV GL on power equipment failures, and described their main outcomes, which have led to improvements in design, production, testing, installation and operation of power cable systems. These improvements are all the more crucial as we rely more and more on the reliability of the grid.

Paper D.9.4 introduced a Finite Element Method (FEM) simulation of electromagnetic shielding for a 275 kV underground power system. Considering the magnetic field exposed to public area limitation, it described the technical solution to create an efficient FEM shielding.

Paper D.9.5 presented experiments made in order to determine the influence of cable system on various types of harvest. Several cable loads and bedding materials have been tested and the results have been notably used for the installation of an Extra High Voltage in a meshed Grid.

Paper D.9.6 analysed the influence of environmental parameters on the thermal rating of submarine HV cables. By means of 2D FEM simulations, it showed by example that the permeability of burial sediments could change the proportion between the different heat transfer natures (conduction or convection).

# Session D10 : Environment and sustainability (2)

Chairman: Rolf Koepfer, Sycabel, France

Rapporteur: Sophie Barbeau, Nexans, France

This session, with its six presentations, dealt with environmental and sustainability aspects of cables systems from MV up to EHV level. According to the definition of the United Nations Bruntland report, sustainable development stands for meeting the needs of present generations without jeopardizing the ability of future generations to meet their own needs – in other words, a better quality of life for everyone, now and for generations to come. It offers a vision of progress that integrates immediate and longer-term objectives, local and global action, and regards social, economic and environmental issues as inseparable and interdependent components of human progress. The main focus of the papers presented during this session was put on environmental issues and impacts of cable manufacturing and cable operation conditions. Three presentations focused on LCA methods in order to determine environmental impacts of cable manufacturing. One paper describes how to protect environment against oil leakages of fluid filled cables, one paper informs about condition assessment of MV cables in very harsh environment conditions and one paper gives results of the impact of soil moisture on cable current ratings.

Paper D.10.1 presented a life cycle assessment of extruded HVAC and HVDC power cable and one HVAC joint, focusing on the manufacturing stage. It identifies and compares the relative $CO_2$ emissions of raw materials and manufacturing processes for both cable types. Further investigations are continuing to extend the study to a cradle to grave approach.

Paper D.10.2 described the possibilities of using Life Cycle Assessment results to ecodesign MV cables. Different sheath design options are compared, and the use of recycled PE is identified as being the most interesting solution regarding environmental considerations.

Paper D.10.3 showed the possibilities of introducing circular economy concepts of MV power cables. The LIDS (Lifecycle Design Strategy) wheel principle is presented as a smart tool to improve cable design by considering circular economy aspects.

Paper D.10.4 made an outlook on a solution how to treat fluid leakage in self-contained fluid filled cables without changing the cable structure. Especially as the concerned cables have exceeded their operational life time, sheath aging and corrosion become a major concern due to the risk of soil contamination. Solution is obtained with the development of different oil types, which solidify upon exposure to air/ moisture and allow the cable to repair by itself.

Paper D.10.5 reported on condition assessment at the site of 22kV aerial bundled cables. Visual inspection and laboratory testing concluded that installation method and the exposure to harsh environmental conditions (salts spray, hydrogen sulphide, moisture, and dirt) were not the reason for failures experiences, as initially suspected. The cable quality was probably a major contributor to the mid-span cable failure.

Paper D.10.6 compared the influence on current rating calculations of XLPE insulated cables, whether the drying out of soil is taken into account or not. Regarding a full load cable, considering the soil drying or not considering it leads to differences in cable temperature simulation up to 40°C. Mainly at full load conditions, a huge influence of soil moisture on current rating has been observed.

# Session E1: Economics of cable systems

Chairman: P. PENSERINI, RTE, FRANCE

Rapporteur: Ph. GIFFARD, SYCABEL, France

This session, comprising six papers, deals with the economics of cable systems. Utilities are provided with innovative tools for reducing costs. These papers describe the influences of raw material, the life cycle of cable, maintenance, failures, installation, types of transmission. This Session makes it possible to have a clearer vision in order to avoid the pitfalls, to optimize costs and to guide the choices

Paper E.1.1 presents a new concept, “electrothermal coordination” (ETC), where the temperature of any cable in the transmission grid is calculated in order to define the dynamic ampacity of any line. ETC can be implemented in transmission systems for RT, day-ahead or grid planning purposes, taking into account market-based conditions. The description of implementation strategies is supplemented by analysing real cases. It is shown that significant operational benefits can be obtained.

Paper E.1.2 describes the results of three studies. The first one concerns technical information about copper and aluminium, the second study is about the environmental performance of both conductor materials in a Life Cycle Assessment, and the third one analyzes total costs during a Life Cycle The LCA study has discovered some indications that power cable is insufficiently recycled at the end of life, due to economic and logistic reasons. The installation design is crucial for an easy recovery of the cable, for instance the laying in ducts. From a total cost point of view, the difference between using copper and using aluminium is said to be small.

Paper E.1.3 shows the final proof of principle that the current standard 10kV 1X630 XLPE power cable can be utilized at a 20kV level for the remaining lifetime. The 10 kV cable equipped with 24kV accessories successfully withstood the severe test criteria. The results obtained after the long term test were: no signs of degradation due to the higher voltage. The next step is to perform a real life test where a 10kV cable circuit will be prepared with 24kV accessories and will be operated at 20 kV.

Paper E.1.4 makes a selection in order to choose the correct cable design with respect to application requirements. It is important to consider the total cost. Total cost should include installation, maintenance and replacement costs, and most of all safety issues.

Paper E.1.5 reports on the experience made to efficiently implement the UGL project. It states that this is not so easy! It is necessary to be aware of and integrate the constraints, opportunities and limits of the underground cable solution in order to reach an economical goal. It is important to anticipate risks and opportunities linked to the possible options for the route of the line. For a better analysis of the options, it is recommended to collect all geographic data at an early stage.

Paper E.1.6 analyzes the financial feasibility study to ensure that the DC 500 kV 3000 MW submarine connection from JAVA to Sumatra provides economic benefits, using the life cycle cost analysis (LCCA). The LCCA simulated three alternatives in order to decide which is the most profitable. The third alternative gives the best result: double cable to form positive and negative path of transmission and a spare cable will be installed.

# Session E3: Cable Ratings Calculation (2)

Chairman: L. COLLA, Prysmian Power Link Srl, Italy

Rapporteur: E. DORISON, Electricité de France, France

This session, comprising seven papers, dealt with cable ratings. The first two papers presented applications of real time thermal rating (RTTR) of cables, using Distributed Temperature Sensing (DTS) which provides, in real time, the temperature distribution all along the cable route. The following three papers dealt with thermal rating in situations not fully covered by IEC standards. The sixth paper focused on the thermo-mechanical behaviour of cables installed in empty ducts. Finally, the seventh paper was dedicated to electrical modelling of cables.

Paper E5-1 presented various methods for updating time-varying parameters of the dynamic thermal rating model from DTS readings. The paper focused on the application of the IEC analytical thermal model and presented the results of a test showing a calculated conductor temperature slightly above the measured value.

Paper E5-2 reports on the REE experience on monitoring insulated cables with DTS, in order to optimize cable ratings, particularly during transients. Experimental results were given, showing a good agreement between measured and computed (using FEM) temperatures. Two projects were introduced: the first one analyzes temperature changes between air and underground parts on a 66 kV transition overhead-underground, and the second one provides more knowledge about temperature evolution in submarine cables.

Paper E5-3 addressed the current rating of power cables installed in tunnels. The paper proposed derating factors for groups of cables presently not included in IEC 60287 and introduced a method for estimating the air temperature, taking into account the tunnel surroundings. Comparisons with FEM calculations were reported, revealing significant discrepancies for touching cables, possibly due to some IEC hypotheses which are not fulfilled.

Paper E5-5 provided ampacity derating factors for LV and MV cable installations with a large number of circuits (up to 30 circuits in PVC ducts in various configurations). Cable constructions are mostly used in North America in industrial applications. The FEM approach was implemented. Derating factors up to 44% (single layer) and 30% (multiple layers) were derived.

Paper E5-6 presented the result of the ampacity studies and suggested remedial actions in the situation where a steam pipe crosses a duct bank with HV transmission cables. These remedial actions involving close-loop gravitational water pipes seem to be both inexpensive and effective solutions in a closed system for cooling down the intersection of the steam pipe with the transmission duct bank. The paper describes a method for simulating the crossing, using calculations for a parallel arrangement, but adapting the inner temperature of the steam pipe.

Paper E5-7 described the snaking of cables in pipes left empty, modelled with an analytical calculation method. The theory (based on minimizing the total energy) has been verified by means of experimental tests. Above a critical temperature, the sinusoidal configuration becomes possible; with very high thermal rise and stiff cables, the helical configuration becomes possible. The model provides the deformation of the cable inside the pipe. The thrust and the fatigue of the cable sheath can be computed analytically.

Paper E5-8 reviewed underground cable impedance and admittance formulas, stressing a few inconsistencies in the assumptions related to some formulas. Possible solutions were described and numerical electromagnetic analysis such as NEC (frequency domain) and FDTD (finite difference time domain) were briefly introduced as a way to overcome these issues.

# Session E4: Modelling

Chairman: Nigel HAMPTON, NEETRAC, USA

Rapporteur: Minh NGUYEN TUAN, EDF R&D, France

This Session is dedicated to modelling. Three papers deal with the modelling of submarine cables. One paper focuses on transposition. One paper presents field measurements for the validation of models.

Paper E4.2 shows that transposition is an effective way for limiting induced voltages on third-party installations, in order to comply with the maximum values imposed by regulations and standards. Calculations were performed for a double 225kV cross-bonded link. The effect of transposition on currents flowing in the cores and in the screens was thoroughly studied.

Paper E4.3 presents finite element (FE) calculations on a three-core cable with twisted phases and individual screens made of twisted tapes. The aim is to study the effect of phases and screens twisting. For comparison purpose, simulations were performed 1) in 2D with grounded screens at both ends; 2) in 2D with open screens; 3) in 3D with grounded screens at both ends. Computed impedances and currents flowing in the screens reveal differences between the three cases.

Paper E4.4 presents an approach to building a transient model for an armoured two-core cable. A 2D finite element simulation was performed in order to bring the frequency response of the cable up to 150 kHz. Vector fitting was then applied to develop a state space model, which was implemented into different simulation tools. Calculations were carried out in the time domain (response to voltage/current steps) and show good agreement between the tools.

Paper E4.5 deals with the modelling of submarine armoured cables. For simplification purpose, the studied system consists in a single conductor surrounded by an armour (future work will be carried out for actual three-core cables). Simple analytical formulae for the current density are given and compared to exact formulae. It is shown through finite elements simulations that the armour made of wires can reasonably be replaced with an equivalent pipe by changing the insulation permeability and the pipe resistivity.

Paper E4.6 presents field measurements performed on a 225kV cross-bonded link in France. The purpose is to validate the existing cable models for electromagnetic transient studies and investigate potential needs for improvement. Voltage impulses were applied to excite coaxial, inter-sheath and earth-return modes. Propagation characteristics (attenuation, velocity, characteristic impedance) are assessed from the test results. These will be compared with simulations.

# Session E5 : Cable and accessories – Design, applications

Chairman: T. KVARTS, DONG Energy, Denmark

Rapporteur: M. DORY, RTE, France

This session, comprising five presentations, dealt with cable and accessories design, with the interaction of different components and materials as a common theme. The simulation of a cable system has explained the influence of heat-shrink joints and terminations on the dissipation factor of a medium voltage cable installation at very low frequency. The measurements made on the experimentation, and the mathematical model of AC resistance of submarine cables, show that a precise knowledge of the cable design is necessary to provide a correct determination of losses dissipated and accurate values of the electrical characteristic. A calculation method was studied to determinate the adiabatic behaviour of a n-metal cable screen subject to an short-circuit. Qualified solutions and instructions regarding grounding have been presented for the XLPE cables with aluminium laminated sheath. A finite element analysis was performed in order to determine the dependency of single-core cable parameters. These publications have shown that the cross between the tests, analytical and numerical calculations to better know the behaviour of cables and gives hope for future technical and economic gains.

Paper E.5.1 reported the simulated results obtained with the influence of joints on the dissipation factor Tan δ, also called loss angle. This testing is a diagnostic method to determinate the quality of the cable insulation. The simulated results are explained based on the mechanisms involved in the stress distribution in multilayer insulation systems such as joints.

Paper E.5.2 illustrated measurements, modelling and computation of armour losses in AC three core submarine cables. The experimental evidence showed that losses are definitely generated into the wire and are affected by the way in which the cable is designed (e.g. crossing pitch between cores and armour). The design of such large cables requires a precise knowledge of the structure and its electro-magnetic behaviour to pass the ordered current.

Paper E.5.3 presented a study of the behaviour of a n-metal cable screen subject to an adiabatic short-circuit. The calculation method is based on the standard IEC 60949. This study explains how to solve the case of several conductor components working in parallel. This method does not work for the moment with the common armour of three-core cables. The work is planned to be included in a revision of IEC 60949.

Paper E.5.4 was withdrawn by their authors.

Paper E.5.5 presented the XLPE cables with Aluminium Laminated Sheath. Actually, there is often a lack of information from cable suppliers regarding the importance of proper connections and the use of sufficient cross-section of grounding wires. This publication provides a qualified description of the problem and instructions about grounding.

Paper E.5.6 illustrated how metal members influence the electrical parameters of a single-core cable. In particular, magnetic steel layers are found to create an impressive level of complexity, even before non-linear permeability is introduced. The results were obtained through the application of finite element analysis (FEA). It provided a deeper insight into the way in which losses are distributed.

# Session E7:
# Material related - Special features

**Topic 2: Cables and Accessories Design - Modelling**

**Chairman: K. Leeburn; CBI Electric, African Cables Ltd, South Africa**

**Rapporteur: F. Michon, Prysmian Câbles & Systèmes, France**

This session dealt with specific and various issues, either in accessories or in cables: gradient studies regards to dimensions of premoulded stress cone or impurities in XLPE cable insulation, thermal aspects either in the accessory, in the cable or in cable environment (backfill).

Paper E.7.1 investigated factors that contribute to overheating of connectors installed in medium voltage joints. Tests made on connectors of different conductors used in North America have shown that the currently used test for joint connector evaluation is insufficient, as it revealed that it could be more than 90% of joint connectors on the network which operate at higher temperature than the cable conductor. This paper proposed that a new test procedure to qualify joint connectors should be defined.

Paper E.7.2 described with a theoretical approach the relation between premoulded stress cone expansion and gradient increase. Considering that the volume and length of the elastomeric part doesn't change notably when expanded on the cable, the outline of the surface contours are calculated by a simple method which shows a contraction of the radial dimensions, leading to an increase of the gradient.

Paper E.7.3 presented two methods to rate cables with the purpose of avoiding soil dry-out. The first one applies to direct buried cables and uses an optimization algorithm to maximize the total ampacity of the cable system whereas the second one is a new finite element based approach to cables installed in duct banks or backfills that limits the duct bank/backfill temperature. Such considerations can lead in certain cases to limit the cable conductor temperature to a lower value than its maximum permanent temperature (eg. 90°C for XLPE) in order to avoid soil dry-out.

Paper E7.4 (not presented) analysed the heat dissipation in high voltage XLPE cables. The temperature distribution of actual operating cable can be obtained through the thermal field model or the thermal circuit model. The calculations have been made in a stable cable environment fixed at 30°C. Between both approaches, the thermal field model is presented as more accurate. However, if the thermal circuit model is revised, it can be used to calculate the temperature of cables.

Paper E.7.5 reported how to increase the range taking of premoulded stress cones used in dry-type GIS and transformer terminations, taking into consideration more parameters than usually. The study has been based on a stress relief cone pressurized by mean of springs, ensuring a permanent pressure on both interfaces stress cone-epoxy insulator and stress cone-cable insulation. Calculations were made considering a minimal pressure value on interfaces, a temperature range of the termination during service, but also a temperature range during installation, leading to define more precisely the tightening of the compression springs and to have a wider range of cable diameter for each stress cone. Then the theoretical study has been confirmed by tests.

Paper E.7.6 accurately identified and simulated the exact values of the localized stresses due to impurities with sharp edges. The first necessary step was to identify the material of the impurities found in the cable which sets its permittivity. The shape and position of the impurities have been recorded using image processing and FEM. In this example the calculation has led to local gradient around sharp edges about twice the value in a clean XLPE at the same position and 37% more than max gradient on conductor shield.

# Session E8: New cable and accessories monitoring applications

Chairman: Victor SYTNIKOV, PhD, Dr Sc., R&D Center for Power Engineering – Moscow, RU

Rapporteur: Gérard LENCOT, Prysmian Cables & Systems, France

This session, comprising five papers, dealt with the monitoring of HV cable systems. The authors have demonstrated various new developments, including PD measuring techniques, acoustic signals, UHF techniques. The new techniques are more able to discriminate the interesting signal from the background noise, therefore giving more precise information about the level of faults and localization.

These technologies are also used to improve the production of HV cables.

All these technologies provide precious information for optimizing the predictive maintenance of the HV networks, and therefore reduce costs.

Paper E.8.2 presented a tool developed in Australia for the detection of partial discharges using acoustic methods. A new photonic acoustic sensor based on a fiber Bragg grating (FBG) has been shown to detect acoustic emission from PDs. This improved FBG photonic acoustic sensor exhibits a 50-60 dB gain in sensitivity when compared with a generic FBG. This sensor was able to register PDs as low as 10pC. However, some susceptibilities to 50 Hz interferences still need further investigations and improvements.

Paper E.8.3 describes an improved PD measuring technique applied to XLPE cables with UHF techniques which have the ability to locate the PD source with a high precision. This technique has been applied to the location of PD source in the pre-breakdown discharge detection test and proved that its accuracy is several tens of centimetres at most.

Paper E.8.4 shows results of on-line PD testing of HV cables, where PD phenomena are separated from noise thanks to the time-frequency map technique. Cases regarding polymeric cables, rated between 88 and 220kV, are presented and discussed, showing a clear presence of partial discharges of amplitude above or below the external noise. This contributes to the standardization of cable system commissioning and condition measurement tests, thus allowing maintenance management in the best technical-economical way.

Paper E.8.5 describes an advanced ultrasonic extrusion quality monitoring of multilayer HV cables during production. The on-line cable geometry measurements results and analyses, provided by the fast scanning/fine grained UltraScreen measurement system is playing an important role both in material saving in the production of existing cables, and in the design and the production control required to manufacture higher specification cables in the future.

Paper E.8.6 shows the results of laboratory investigation on an aged HV cable termination. The authors demonstrate that the use of PD diagnostic tests on HV lines can detect the improper cable accessories before failure. Moreover, the reliable diagnostic tests can make it possible to replace the current, time-based maintenance with a reliability-based maintenance method, which will contribute to the extension of the lifetime of valuable equipment, and the extension of the overall reconstruction cycle will result in a significant reduction of the investment costs.

# Session E9: Design of LV MV cable systems

Chairman: FALCONER Antony, Aberdare Cables, South Africa

Rapporteur: BENARD Laurent, Prysmian Câbles & Systèmes, France

This Session covered different aspects which have to be considered in order to improve so-called mature products:

- Cost reduction;
- Products easier to install, with better technical performances;
- Improvement of reliability;
- Depletion of safety risks.

Paper E.9.1 made a comparison between different metals (copper, aluminium, copper-clad aluminium and tinned copper-clad aluminium) which can be used to make flexible conductors for LV power cables. Various test carried out on prototype cables using these metals demonstrate that copper-clad aluminium is an attractive alternative to copper, providing a more economical light- weight product.

Paper E.9.2 reported results of tests performed on a device called “screen plate” which has been developed to interconnect the screens of the French medium voltage XLPE cables. The first conclusions allowed by all the tests carried out up to now are that is necessary to create a guideline for the installation of the screen plates, to modify the existing tools to make this installation and to remove PVC oversheath from the French standard NF C33-226. The definition of the qualification test program of the screen plates will be made after 2 long-term tests with thermal cycles, resistance measurements and screen short-circuits, if possible.

Paper E.9.3 analyzed the behaviour of circuit integrity cables tested to fire and water spray testing to AS/NZS 3013 standard, and identified a number of factors that improve their performance. Glass-mica tapes can provide circuit integrity during fire, depending on their chemical composition and construction, but the best results in term of fire performance, cable flexibility and ease of installation are obtained by using ceramifable insulation

Paper E.9.5 focused on the way to qualify mechanical connectors used inside the Medium Voltage Accessories to connect the cable connectors. The current way is to qualify mechanical connectors by following only the requirements of IEC 61238-1 class A. Despite the fact that connectors passed these tests, unexpected failures occurred during Accessories type tests under HD629.1 due to thermomechanical stresses not usually applied in the stand-alone connector qualification. The recommendation of the authors is to consider a system approach in order to qualify the couple accessory / mechanical connector.

Paper E.9.6 presented a study about catalyst used to increase speed of silane crosslinking polyethylene. Authors proposed an alternative to DBTDL, the most widely used catalyst, based on a di-sulfonic acid, which combines low safety risks with a better reactivity while crosslinking at room temperatures.

# Session E10 : Challenging Environment

Chairman: BEGHIN Véronique, Tractebel Engineering, Engie, Belgium

Rapporteur: COLOMBIER Serge, Prysmian Group, France

This Session included 5 papers which had four main topics. The first one was the simulation of the corrosion phenomenon on damaged LV aluminum cables in order to outline the main parameters of influence. The second topic from article E10.3 considered the efficiency of a rejuvenation fluid based on siloxane on water-tree aged cable. The article described the experimental setup and the techniques used to evaluate and compare the size of the trees and micro-voids in an un-rejuvenated and in rejuvenated cables using electronic microscopy, optical observation techniques and electrical properties. The third one was devoted to the behavior of cables materials when they are involved in a fire. Article E10.4 described the cone calorimeter as an interesting tool to evaluate the performance of a material in terms of heat release and smoke emission in order to anticipate the behavior on cables. This cone calorimeter device had also been described in article E10.5 as an interesting tool for potential toxicity of smoke generated by a cable during a fire together with de $3m^3$ chamber. The last topic was the description of a high safety, low maintenance and extreme-proof aerial and underground cable system which is very efficient, even when exposed to severe climate.

Paper E10.1: not presented

Paper E10.2 described the phenomenon and a simulation test to evaluate the parameters that can influence the corrosion of the aluminum conductors in LV cables.

Paper E10.3: The effect of a siloxane fluid as rejuvenation of water-tree aged cable was discussed.

Paper E10.4: This paper dealt with a cone calorimeter device as a good tool for cable material characterization regarding the cable behavior in a fire.

Paper E10.5: The potential lethal combustion product involved during combustion of a cable was described.

Paper E10.6: In this article, we could find the description of an aerial cable system which is very efficient, even when exposed to severe climate.

# Session F6.1: Materials, Ageing

Chairman: WALD Detlef, Eifel Kabel, Switzerland

Rapporteur: CHARRIER Dimitri, Nexans Research Center, France

F.6.1.1 The poster was there, but nobody was present.

F.6.1.2 UK. They presented a slightly commercial, new liquid antioxidant. They claimed that it is cleaner and has faster crosslinking than the other products on the market.

F.6.1.5 Presenting the database together with the utility at a certain account. Testing in the field proves to be important in order to avoid failures in the field. They pointed out certain failure modes and improvements they learned through their measurements.

F6.1.6 They showed 14,000 data points on which they developed a factor called SKIRT. The correlation between VLF tan delta and breakdown was shown and proven in the field. A prediction of life time based on this test is possible.

F6.1.8 The influence of water take-up of various blacks: this was also somehow commercial. They showed that even after compounding, the moisture remains in the semiconductive compound.

# Session F6.2: Diagnosis, maintenance, remaining life, economy.

Chairman : Hans Mayer – Consultant (Australia)

Rapporteur : Pierre Mirebeau, Nexans (France)

This F6.2 Session includes ten contributions that highlight aspects of cable system life.

- 4 posters on diagnostic techniques.
- 1 on maintenance
- 1 on remaining life
- 2 on economics

Among the 6 posters on diagnostic technique,

2 were addressing PD on line monitoring, one was about the increase of the sensitivity against the noise, and another one was a success story on finding joints ageing before any breakdown.

New diagnostic techniques were described.

- Before cable insulation, efficient sorting of contaminated pellets using a combination of X-Ray and visible light.
- During operation, monitoring of cable losses.
- During operation, distributed monitoring of noise through an optical fibre.

Maintenance was addressed by the monitoring and trending of cable losses.

The remaining life was addressed by the refined statistical data to select the links to be first addressed.

An anti-theft device using the monitoring of the screen current was presented, applied to overhead insulated cable. The experience of bad workmanship and the associated faults were described and discussed in another paper.

Finally the economics was approached through a quick and low cost overhead installation of insulated bundled cables up to 36kV.

As a whole, this Session showed the good dynamics enthusiasm and the creativity of the profession in the subject field.

# Session F9.1:
# LV, MV, HV, EHV and future cables

Chairman: JEON Seung-Ik; LS Cable & Systems Ltd, Korea

Rapporteur: BOYER Ludovic; Nexans, France

This session, including eight posters, dealt with cable system technologies from LV to HV cables, including superconductive cables and over current relays. The attendees were provided with indications to improve the cable system performances, reliability and cost. These indications include the use of smooth instead of corrugated outer screen, the use of water tree retardant polymers, the optimization of the MV protection relays settings, the development of quality control procedures, the anticipation of the cable insulation defects through simulations, the combination of energy transfer of different nature and the development and tests of innovative materials.

Paper F9.1.01 described the production and qualification processes of an HVAC cable with a smooth welded aluminium sheath presenting a lower mass and diameter when compared to a cable with a corrugated sheath. Wrinkles were avoided by processing the aluminium and outer sheath on the same line. A type test was then applied to validate a correct on field operation.

Paper F9.1.02 showed the performance of a developed additive water tree retardant XLPE insulation. Indications of the enhancement of the wet electrical performance of the material were shown. Furthermore, the developed material can be used as a component of a universal cable system, with accelerated line speed during production and the use of strippable semiconductive insulation shield.

Paper F9.1.03 analysed the influence of the behaviour of a directional over current (DOC) relay versus the variation of MV installation fault. For the various types of faults studied, it was shown that, in almost all the cases, setting the relay characteristic angle to 45 ° allowed to avoid improper operation of DOC relays

Paper F9.1.04 presented the evolution of the thermal energy of the PVC insulation of low voltage cables before and after thermal ageing using the voltage response method. Three insulation colours were aged. It was found that the variation of the computed thermal energy activation was lower than when computed using the correction factor provided in the standards. This variation may lead to an overrating of the low voltage cable insulation.

Paper F9.1.05 – not presented

Paper F9.1.06 reported the first application of a premolded joint for 275 $kV_{ac}$ XLPE cable for the Suruga-Higashishimizu line. A quality control procedure was developed to verify the proper installation. The installation was then successfully verified by the mean of a withstand voltage test and partial discharge measurements.

Paper F9.1.07 – not presented

Paper F9.1.08 Used an FEA method to evaluate the effects caused by the presence of a water filled void on the thermal and electrical behaviour of an XLPE cable. It was found that the void induced an electric field reinforcement at its vicinity, with its area spreading with the diameter of the cavity. It was also found that, due to overloading, the cavity temperature may rise above 100 °C, which could induce a vaporisation of the contained water and thus the triggering of electrical discharges.

Paper F9.1.09 experimentally confirmed the practical feasibility of high power long length hybrid energy transfer system by combining electrical energy, using superconductivity and hydrogen transfer. The confirmation was done by the test of two cable prototypes, the second having being tested with high critical currents and a sufficient voltage withstand, allowing for 135 MW total energy transfer.

Paper F9.1.10 compared the dielectric and mechanical strengths along with the thermal contraction for materials having an epoxy resin (ER) or unsaturated polyester resin (UPR) matrix and glass hollow microsphere (GHMS) or silanized glass hollow microsphere (SGM) fillers. It was shown that syntactic foam seem to be an alternative solid insulation material for superconducting cables, especially the one composed of ER matrix and SGHMS filler, although long term properties still have to be performed.

# Session F9.2: Cable and accessories Design – Modelling

Chairman: M. CHANG, Nexans, China

Rapporteur: G. PELTON, ERDF, France

In this session, 6 papers were presented by a poster, and two other only by way of an article. It covers various simulations, from thermal simulations (moisture migration and transient analysis in submarine cables), water-tree simulations, heating system heat cycles test, to switching overvoltage simulations. They use various methods, including Laplace transform and FEM. Insulator termination replacement was also presented.

The presented paper are underlined:

Paper F9.2.02 examines the effects on the electric field distribution of water-trees in polyethylene insulation. They create divergence at the roots or the tips of the trees. The impact on the electric field can varies according to the size and position of the trees, the density of the space charges and their dynamic movement.

Paper F9.2.04 presents the modelling of 3-core SL-type submarine and transient analysis using several methods and different kind of cable. It challenges the IEC equations and suggests other methods for load cycle quite different of sinusoidal shapes.

Paper F9.2.05 describes a new cable joint to FFLP cable that can be used for provisional repair in less the 6 hours. No pressing for conductor connection, no welds and pre-manufactured paper notched, are some of the elements presented in the paper

Paper F9.2.06 presents a test set for IEC heat cycle test used for underground cables quality. It describes the methods and the instruments and control circuits used to measure and monitor the temperature in the cable. It also presents some results obtained with this test sets.

Paper F9.2.09 presents the replacement by Kepco of porcelain bushing in HV termination box with safer polymeric ones having the same specification. It makes it possible to change only the insulator and not the entire termination bow, which results in faster and cheaper replacements.

Paper F9.2.10 describes a computationally light method to estimate the moisture migration in underground cables. It favours a critical heat flux to determine the limits between wet and dry zone and introduce some methods to represent its dynamic evolution.

Paper F9.2.11 describes a simple method using lumped L-C ladder to compute switching overvoltage in EHV cable lines. It can be easily self-produced instead of instead of complex Laplace transform or EMTP-RV. It then presents a comparison of the results with these different methods.

Paper F9.2.12 present a 500kV PPLP MI cable with a layer of extruded polypropylene film and two layers of the kraft paper that improves its characteristics as HVDC cable. The system with its accessories has been tested following the CIGRE recommendation.