Session A1: HV and EHV cable systems

Chairman: AWAD Ray; Independent Consultant, Canada

Rapporteur: LSTELLA Romain; Prysmian, France

Paper A.1.1: North American Experience of HV and EHV Extruded Cable Systems

Paper A.1.1 presents results of a survey regarding reliability of the HV (69-150 kV) and EHV (230-400 kV) underground extruded cable systems in North America. These results are extending the findings of the CIGRE Technical Brochure 379 issued in 2009, which is currently one of the main reference document dealing with performances of the underground HV and EHV cable systems. The aim was first to focus on extruded cable systems, to readjust the type of requested data to better depict reliability of the cable systems in North America than in the previous CIGRE results. Also, it was on purpose to enlarge actors of the survey to utility as well as to cable manufacturers.

Collection of data from more than 40 entities allowed a statistical analysis of the source of failure (type of component); failure rates by system voltage class expressed per 1000 conductor miles and per year; and a general life cycle analysis through Weibull (Bathtub curve) analysis. The failure rates in service presented here are lower than those reported in the CIGRE brochure. Readers shall take care to properly handle units between metric and imperial to compare the reported data from different survey on the same basis.

Paper A.1.2: EHV Cables in Subsea Road Tunnels – Vision or Reality?

Paper A.1.2 introduces the analyses carried out to assess the most optimized configuration to combine the construction of 16 km long Norwegian subsea road tunnel including six 420 kV underground insulated cables.

Applying for a multi-functional subsea tunnel has strong synergy effects such as rationalizing territorial resources and lowering environmental impact.

Focus is made on two cost efficient solutions which comply with tunnel and cable regulations: Below road Shoulder and Physical Barrier.

A comparison of both tunnel configurations was made through cost, traffic incident, traffic capacity, fire risk, exposure to electromagnetic fields, cable maintenance and ampacity analyses.

Paper A.1.3: Experiences and Challenges with the 420 kV XLPE Cable Systems of the London Power Tunnels Project

Paper A.1.3 describes the main features of the 400 kV XLPE cable system of the London Power Tunnels Project, and underlines all the challenges faced to fulfill the technical specification. This project consists in the replacement of old oil filled circuits installed 60 years ago right underneath London city, which were obsolete and no longer reliable. It encompasses the design, manufacture, delivery, installation and commissioning in three distinct stages of ten 400 kV circuits made of 2500mm² oxidized copper conductor (196km of cable overall) in ventilated tunnels of diameter range from 3 to 4m for a total tunnel length of 32km right at depth between 30 to 60m.

Installation constraints was one of the main challenge, dealing with cable system of large conductor section and cable span of approximately 1,1 km to lay in flat vertical and flexible formation, with access and feeding through vertical shaft, according to best practice of CIGRE Technical Brochures 194 and 669.Another challenge was the implementation of a cross bonding scheme to fulfill ampacity requirement without any earthing grid accessible inside the tunnels, together with a 63kA/1s short circuit specification was also a design challenge, requiring a specific arrangement of the bonding cable and SVL to protect the screen interruption at joints from potential rises.

Despite the system provided was already qualified according to IEC 62067, further specific qualification tests were requested and performed to prove the cable system comply with ampacity requirement and can handle such stringent installation conditions.

Finally, all the circuits were successfully commissioned, the latest in 2017, through on-site AC resonant test at 260 kV for 1 hour against PD measurements.

Paper A.1.4: Topography scanning as a part of process monitoring in power cable insulation process

Paper A.1.4 presents an innovative method to permanently monitor the quality of the XLPE cable core, one step further towards smart manufacturing. It consists in a topographic scanner measuring the core surface with laser displacements sensors providing accurate data reporting of the core surface through more than 3000 measurement points around the circumference of the cable.

This technic allows to detect geometrical defects due to the thermomechanical constraints experienced by the compound during the different phases of the manufacturing process. It gives also the possibility to detect local surface defect such as scratches, scorched material occurring because of an unintended contact during the manufacturing process for example.

Scanned cores are 3D modelled and analyzed within a two phases defect detection system, and measurements checked against data library along with deep learning method.

The main assets of such a system is to provide better control on manufacturing parameters in live time and also to allow short time preventive maintenance as soon as slight deviations are measured.

Paper A.1.5: Refurbishment of the Copenhagen Transmission Grid – Project Planning and Execution

Paper A.1.5 describes the main features of a 10,9 km long 132 kV XLPE single circuit cable system in Denmark. This link is supposed to interconnect two nodes in the grid to take over power transmission during later power take out of part of the grid as part of a grid refurbishment program.

The link runs along both urban and rural areas, leading to several site installation constraints. It was planned to cross a Natura 2000 area, among other type of constraints, but tunnel was not deemed a viable option. Therefore, attention was paid to the optimum cable route, anyhow leading to the execution of several horizontal drillings.

Despite tight deadlines with regards to such complexes multiple civil construction work types, the circuit was successfully commissioned in March 2019, through on-site AC resonant test at 1,7 U0 for 1 hour against PD measurements.

Paper A.1.6: Electrical and physical characterization of a 138 kV XLPE insulated cable with 12 years' service life

Paper A.1.6 highlights results of an ageing investigation test carried out on a 138 kV crosslinked polyethylene (XLPE) insulated cable sample. Commonwealth Edison experienced an external damage on a 138 kV cable system in the US after 12 years in service, and decided to make the most of this unfortunate event to extract a 100m sample in order to proceed to investigation tests in accordance with the ICEA standard.

The test program included electrical tests with partial discharge, AC voltage, dissipation factor, lightning impulse, VR measurement on semiconducting shield, as well as physical tests through visual inspection, physical characterization, hot creep measurements, gel content determination, tensile testing, thermos-oxidative ageing, degree of crystallinity.

It turned out the 12 years old sample passed successfully all the tests according to ICEA standards, and the reported performances are found similar as to any piece of cable right after production with equivalent design, proving the reliability of such technology.

Session A2: Design of HV and EHV cable systems

Chairman: TYRBERG Andreas; NKT, Sweden

Rapporteur: TEYSSEDRE Gilbert; Laplace-CNRS, France

This session, comprising six papers, dealt with HV and EHV cable systems. Cable manufacturers are provided with innovative engineering approaches, addressing different challenges linked to network rationalization, and cable and accessories design and optimization.

Paper A.2.1: Standardization and Optimization of High Voltage Cables Design

Presented by H. Alghofaili, the paper describes the electric power transmission system of National Grid Saudi Arabia. The network of underground cables ranges from MV (13.8kV) to EHV (380kV) with a backbone with voltage rating of 110kV to 380kV. Prior to 2003, the network was operated by four individual utility companies, with high voltage underground cable network at 3 different voltage ratings: 110, 115 & 132kV. National Grid initiated a study to standardize, optimize and unify the cables sizes and designs. Appropriate ways were looked into to optimize the design by implementing the relevant international standards and taking into consideration feedback from the maintenance and projects about existing cables. Details on cables designs were given.

Paper A.2.2: Hybrid analytical / finite-elements model to design optimal HVDC joint bays

B. Salamé presented a hybrid model to study the thermal behavior of HVDC joints, joint bay and soil. This model couples a 2D axisymmetric finite-element model of the cable and the joint, with an analytical model of the joint bay and soil, based on IEC 60287 standard. This approach allows simulating the heat sources and heat transfer in the layers of cables and joints, while considering the longitudinal heat flow towards metallic parts. Coupling finite-elements with analytical formulas allows obtaining accurate results without defining a full 3D model, i.e. at low computational cost. The simulation results are validated by experimental results of laboratory tests. This hybrid model provides a fast and accurate numerical prediction of HVDC cables and joints temperatures in real operating conditions. It ensures optimized joint bays design without degrading their performance.

Paper A.2.3: Thermal analysis of 3-core SL-type cables with jacket around each core using the IEC standard

Several issues related to the calculation of the steady state and transient rating of 3-core submarine cables with a metallic screen and a jacket around each core were addressed by L. Dario Ramirez. Nowadays, such cables are frequently used in submarine installations. Whereas there is no provision in the IEC Standard to model such cables. The proposed equations for the thermal conditions are validated and benchmarked using 2D models in software applications that use analytical and/or finite element analyses.

Paper A.2.4: Asymmetric joints for extruded and fluid-filled cables - Traditional use and new applications

P. Tsakonas presented a panel of designs of asymmetric joints, i.e. joints to connect two cables of different geometry. There are many types of design for this component. In this paper, an overview was given of the compact 1-piece prefabricated asymmetric joint with plug-in installation technology and some example were presented of the plug-in asymmetric joint application in performed projects.

Paper A.2.5: Retrofitting HV External Gas Pressure Cable Systems

J. van Rossum presented the project for the coming years of TSO TenneT to replace the 110 kV and 150 kV external gas-pressure cable systems in the Netherlands, with extruded cable systems making use of the existing steel pipe infrastructure, so called retrofitting. The paper described the development for a 150 kV retrofit cable system, compatible with the External Gas Pressure cable system as existing in the Netherlands, and comprises description of the cable designs, production of pilot lengths, report on real-scale pulling tests, type test, PQ test and other tests.

Paper A.2.6: Hornsea projects 1 and 2 - Design and Optimisation of the Cables for the World Largest Offshore Wind Farms

M. Zouraraki gave an outstanding paper on experiences with the design, production, installation and commissioning of the world's two largest offshore wind farms. These challenging ground-breaking projects push the limit of a cabled HVAC transmission system to almost 200 km in length. Through extensive electrical system analysis and detailed project cable engineering the longest 220 kV cable connection to an offshore wind farm in the world was conceived and built. This paper covers all aspects in relation to the export cable system from the onshore substation to the offshore substations including the array cable systems from the offshore substations to the wind turbines.

Session A4: Operational experiences of HV and EHV cable systems

Chairman: THUNBERG Erik; SVK (Svenska kraftnät), Sweden

Rapporteur: LIEMANS Didier; Nexans, Belgium

This session, comprising five papers, dealt with feedback of experiences of HV and EHV cable systems (some good, some bad), but even bad experience is learning, and shared to the Jicable community.

Paper A.4.1: Strategies for maintenance and repair of EHV cable systems

This paper considers the ways of reducing the out-of-service time of 380kV cable systems, which can be significantly longer than for overhead lines. A part of the work is to prevent failures on cable systems, by a good accessibility, by inspection, maintenance and monitoring. Additionally, a good Repair Preparedness Plan is necessary to reduce the repair time in case of failure. This plan includes communication, access to cable route, availability of the spare parts, availability of the repair team, and implication of civil works

Paper A.4.3: Failure Experience on 380 kV Joints and Terminations in Saudi Arabia Transmission Network

This paper summarizes the most common mistakes that lead to EHV accessories failures, based on incidents which occurred on Saudi Arabian transmission network Two study cases of accessories failures are reported (one joint and one termination), with the observations, testing and remedial actions applied. For terminations, this paper explains that failure path is different depending of the stress cone material (EPDM or SiR)

Paper A.4.4: Qualification and experiences with large 400 kV XLPE cable systems installed on the Arabian Peninsula

This paper summarizes the extended qualification tests for of 2500mm² cu 400kV cable system according to customer specification for Arabian Peninsula. In total, the projects contain more than 700km of cable and more than 1300 joints. Experience feedback reports only one commissioning test which laid to a failure of a joint (due to flooding in joint pit during installation work), and one failure of a GIS termination in service, due to civil works after commissioning, (heavy gravels placed on cable bend below the termination caused an axial movement of the cable). No other incident was reported, which shows the maturity of the technology for big projects.

Paper A.4.5: Degradation of silicone insulating fluids in cable sealing ends

Due to some performance issues on cable sealing ends on UK networks, this paper analyses the possible degradation causes of silicone oil (polysiloxane liquid) in outdoor cable sealing ends. Finite elements studies computed the electrical stresses and temperatures reached in the sealing ends, and more particularly in the silicone oil. The temperatures and electrical stresses values obtained should not lead to oil decomposition over a short number of years. This paper also gives information of the measurement techniques to detect products generated by possible chemical changes in the silicon oil

Paper A.4.6: Investigation and Mitigation of HV Cable Joint Failures in Thailand Metropolis

This paper reports a series of 115kV joints failures during voltage test or soak test after installation. Causes of failure have been investigated. Lack of space in the manholes (crowded with lot of cables) increasing the risk of mounting errors, difficult to keep straight shape of the joints, high water depth, work under time pressure seem to be the causes of breakdowns. Problem was solved by using another type of joint, which seems to be better suitable for this difficult mounting environment, allowing more deviations.
Causes of breakdown (80%) are also the different type of joints used, and jointers are not familiar with them (installation technique and tools)

Session A5: HV and EHV Submarine Cables

Chairman: COLLA Luigi; Prysmian Group, Italy

Rapporteur: CHARLES Fabien; Prysmian Group, France

This session foresees designing activities of HV and EHV submarine cables from different perspectives. From different aspects of corrosion and mitigation of its effects, manufacturing process including a newly developed degassing process, return on experience in China with XLPE technology from 35 kV AC to 500 kV AC leading to DC projects up to ± 320 kV and a ± 525 kV cable system under PQ-test, monitoring of ships crossing a power cable using DAS signals and ML techniques to the development and tests of a light armored cable making possible installation of EHV AC and DC cables up to a depth of 3000 m.

Paper A.1.1: Corrosion, we just have to live with it

Corrosion is becoming more and more a predominant concern in cable systems. This article provides examples of consequences of corrosion of cables and underlines how interaction between components inside the cable and between the cable and its environment is impacting the corrosion risk (pH influence). The main conclusion is mentioned in the title, we have to live with corrosion, mitigating its effects and keeping in mind that a very small detail may have huge consequences.

Paper A.1.2: Study on Degassing Process of the World's First 500 kV XLPE Insulated AC Submarine Cable

Manufacturing of reliable submarine EHV cables on large lengths has to be addressed by industry to fulfil market expectations. Not only equipment design, parameters adjustment and material cleanliness are cautiously managed but a new degassing process based on "heat convection" was designed. Simulations and post-manufacturing controls show that the degassing process is suitable for manufacturing of large lengths of submarine EHV cable with tick insulation, particularly for the first worldwide 500 kV submarine cable.

Paper A.1.3: Research and Application of XLPE Insulated AC and DC Submarine Cables in China

XLPE has become the preferred technology for submarine cable connection in China during the last decade. Benefitting from experience from pioneering this technology through designing, manufacturing and installing 3-core cable for optimizing purposes at 35 kV, 110 kV and later 220 kV, further developments were made possible for DC applications. Three projects at ± 160 kV, ± 200 kV and ± 320 kV respectively were implemented. Then the first single-core submarine 500 kV AC cable project was performed in China and a ± 525 kV DC cable system is currently under PQ-test.

Paper A.1.4: Not received

Paper A.1.5: Toward Detecting Ship Characteristics and Movements using DAS and Machine Learning

This paper investigates if detection of ships crossing a submarine power cable using DAS (Distributed Acoustic Sensing) signals and ML (Machine Learning) techniques is feasible. Tests performed and further analysis on 2 type of ML algorithms, CNN (Convolutional Neural Networks) and SVM (Support Vector Machines). The data collected in the article show that it is possible to detect a ship crossing a power cable from DAS signals and using ML techniques. SVM appears more suitable in this respect for smaller datasets with fewer samples.

Paper A.1.5: Light Armor Cables for Submarine Deep Water Power Application

One major limitation to reach depth about 3000 m with HV submarine cable is the ratio "tensile strength to linear weight" of the cable. This paper put forward the use of strengthening components made of composite material embedded in a polyethylene jacket. A test sequence considering stresses encountered at such a depth was performed successfully. This technology gives perspective to reach very deep installation of HV submarine cables up to 3000 m albeit a de-rating of about 8,5% at hot spots.

Session A6: HVDC submarine cables

Chairman: DOEDENS Espen; Nexans Norway, Norway

Rapporteur: CORLU Yannis ; Rte, France

General Comments about the Session :

This Session consisted of five presentations on various key considerations of HVDC submarine projects. Challenges have to be faced during all the phases of these projects: from preliminary studies to the maintenance, through testing, production and installation phases.

First it is necessary to make the right choice of cable technology and design to answer the specific project constraints, such as mechanical constraints, temperature limitations. Then the testing phase before and during production should assess the quality of the cable system. The installation phase shall also be controlled from the transpooling of cables to commissioning tests where a relevant monitoring can prevent defects.

Paper A.6.0: Special Communication

This paper presented the main challenges faced during the 4 years of the construction of the offshore part of the NEMO Link project. The cable route and burial protection tool had to be carefully chosen because of the different natures of sea beds, their mobility and crossings. Because of the history of this area of the world, an exceptionally high frequency of debris, including UXOs, had to be removed, their frequency making it impossible to do micro re-routing. During the construction, the cable was damaged 3 times, 2 of which were caused by fishing trawlers. To prevent new damages of this nature, it was decided to increase the number of guard vessels, and improve the communication with local authorities and fishermen.

Paper A.6.1: Qualification, installation and commissioning of world's first DC 400 kV XLPE cable system

This paper presented the main aspects of the NEMO Link project, the world's first DC 400 kV XLPE cable system in operation. It covered the description of the cable route and of the cable system, the project schedule, and the summary of the main tests performed to assess the quality of the cable system (type tests and manufacturing tests). A special attention was paid to type tests with extra heating cycles at temperature of 105°C, above the maximum operating temperature of 90°C. Then the load out and installation phases were presented, both for offshore and onshore parts, with a highlight on the damages due to fishing trawlers and theirs localization thanks to integrated optical fiber monitoring and reparation. Finally the main aspects of the commissioning tests were presented.

Paper A.6.3: Design features of HVDC cables crossing the German North Sea EEZ

This paper dealt with thermal biding constraints in the German North Sea Exclusive Economic Zone for HVDC cable systems, and its impact on cable sizing of subsea MIND and extruded HVDC cables which could be installed there for interconnectors crossing. These constraints limit the maximum temperature rise above the cables to 2 degrees Kelvin at 200 mm and 300 mm sediment depths (2K Criteria). First, the calculation methods were presented, before being applied to two scenarios of cable sizing with MIND and extruded cables. The results showed that free capacity is available. This could be used to tackle potential constraints along the cable route, such as crossings.

Paper A.6.4: UK to Iceland HVDC Interconnector: Key Project Considerations

The paper provided some reasoning for the main aspects of the UK to Iceland HVDC Interconnector: the choice of cable and the installation methodology as well as the approaches to environmental constraints or the impact of fault finding, spares strategy and disaster recovery in order to, in the end, secure the installation and maximise the availability of the link. A challenge about armouring solutions is also faced to prevent damage during the installation.

Paper A.6.5: Continuous monitoring of HVDC Power cables with integrated fibre optic cables

This paper presented the use of integrated fibre optic cables to continuously monitor the cable in NEMO Link project. In the past it has been impossible to identify the cause of damage to HVDC power cables from installation or subsequent fishing or anchor damage as the primary damage may not have caused an immediate failure. By continuously monitoring the majority of the Single Mode fibres in both cables during transpooling, cable laying, trenching and pre-energisation periods when no voltage is applied, mechanical interference causing increased OTDR losses or breaks can be observed and alarms raised. External mechanical damage can thus be noted and cross-referenced against activities such as fishing for the most likely culprit to be identified fast. Through having

this extra layer of quality assurance, the cable supplier can be sure no external mechanical damage had been experienced by the cable whilst the monitoring is on.

Session A8: Development and testing of DC cable systems

Chairman: TANAKA Hideo; Furukawa Electric, Japan

Rapporteur: REMY Christian; Prysmian, France

General Comments about the Session: The six papers presented in the session are about studies of the space charges dynamics, development of non-destructive measurement of space charges, the extension of PQ testing protocol from extruded to lapped 500 kV DC cables, the conversion of AC MV cables for MV DC applications and a historical review of the development of insulation material s of HV and EHV DC applications, from 80 kV to 640 kV DC.

Paper A8.1: Influence of Relaxation Polarization on Charge Transportation in a Cable Geometry

The study looks at the effect of polarisation on the charge transportation of LDPE in a cable configuration, with similar electrical gradient and thermal drop. Even if the polarisation has an impact on the charge transportation the steady electrical field distribution is not impacted, only the transient (lag effect). The field distortion ratio (field with vs. without polarisation) is higher for the higher thermal gradient and is higher close to the electrodes.

Paper A8.2: Recommendation of Pre-Qualification Test for the DC 500 kV MI-PPLP cable

The paper proposes a PQ test protocol for MI cables for which only a Type Test is currently requested (Electra 189). The PQ protocol is derived from the IEC 62895 standard defining the PQ test on extruded cables, bending test and side-wall pressure test are added for taking into consideration mechanical weaknesses of MI PPLP insulation. A 500 kV MI-PPLP cable has been successfully prequalified and will be used for the Dangjin C/S Pyeongtaek C/S link

Paper A8.3 Twenty years of extruded HVDC cables from a material supplier's perspective

This paper reports the development of insulation compounds for extruded HVDC and EHVDC cables. Two phases can be distinguished; The first phase was characterised by a focus on developing polymers with reduced numbers of space charge carriers and resulted in the qualification of 320 kV DC cable systems. The second phase, towards higher power transmission capabilities through higher voltages, has been focused on developing insulation materials with reduced DC conductivity and appropriated mechanical characteristics. The outcome of this phase is the successful TT and PQ of 640 kV DC cables.

Paper A8.4 Application of extruded MVAC cables for DC Power Transmission

The study deals with the conversion of MVAC cables to MVDC cables, and shows that a standard 12/20 kV AC cable can be used as a 55 kV DC cable and increases the power transmission by 350 %. A PQ test, with standard 20 kV AC cable and accessories, at 55 kV DC, derived from Cigré Recommendation n° 496, with polarity inversions has been completed. Testing arrangement and protocol are described

Paper A8.5 Follow up of space charge distributions in HVDC cable during a Pre-Qualification test using the Pulse Electro-Acoustic technique and the Thermal Step Method

The evolution of space charges and electrical field distortion during a PQ test is monitored with Pulse Electro-Acoustic (PEA) and Thermal Step Method (TSM) and more particularly during load cycles and high loads at positive and negative polarities and during zero load (Cigré 496 testing sequence). It is shown that despite a small amount of space charges the highest electrical stress is located close to the inner semiconducting screen and that the highest evolutions of space charges are seen during the high load sequences. Good sensitivity of both PEA and TSM has to be noticed.

Paper A8.6 Development and set-up of a non-intrusive technique for measuring space charges in specimens of DC cables

The paper deals with the development of a non-destructive measurement, by TSM, of space charges directly inside the cable without removing the cable sheath. For a correct TSM measurement a current pulse of 800 A for 50/100 ms is necessary. For this purpose, a multicellular Buck DC/DC converter has been developed. The design and tests of this converter and its ancillary equipments are presented. The TSM results obtained with this converter are discussed.

Session A9: Qualification of HV DC cable systems

Chairman: JEROENSE Marc; MarCable Consulting AB, Sweden

Rapporteur: PAILLER Benjamin; RTE, France

General Comments about the Session: To develop more powerful and over longer and longer distances obliged the cable market to develop HVDC cable system more powerful. All the papers within this session described the development and testing of extruded cable system.

Paper A.9.1: Investigation and Qualification of ±320 kV HVDC cable systems for VSC and LCC applications

In this paper, it is described how the HVDC phenomena were investigated in order to develop a 320 kV HVDC XLPE underground cable system. Presence of charge spaces in insulation and a resistive field distribution are challenges that has to be managed when developing an HVDC cable system. After having carried out simulations, full size prototypes were manufactured to perform PQ (ongoing) and Type test according to Cigré Technical Brochure 496 for VSC and LCC applications.

Paper A.9.2: PQ Test of Extruded HVDC 525- kV-Underground Cables: Results and Conclusion

The German TSOs put in place a system of prequalification in order to prove the feasibility of a 525kV underground extruded cable system meeting the cable demand for "German corridors". This system includes a PQ test according to TB496 and project specific requirements (way of installing the test loop, DTS, conductor temperature and temperature drop through the insulation…) to simulate the installation and operation conditions on the cable route. 5 testing loops were launched.

Paper A.9.3: Qualification of 400 and 525 kV HVDC XLPE cable systems including a multitude of accessory configurations

This paper dealt with the development and qualification of a 525 kV XLPE HVDC cable system for land application and 400 kV XLPE HVDC cable system for submarine application. A submarine cable system was designed for a maximum water depth of 500 m. Both systems were designed for the VSC converter technology and with an operating conductor temperature of 70°C (one PQ loop was performed at 75°C). They includes as well different accessories needed to build an entire link.
Type tests and Prequalification tests were performed according to the international recommendation from Cigré TB496. For land cable system, PQ test was also performed in agreement with the IEC 62895.

Paper A.9.4: Performance evaluation of 525 kV and 640 kV extruded DC cable systems

The authors present here the investigation and development of 525 kV and 640 kV XLPE HVDC cable system. Increasing the voltage allows to increase the power capacity per cable and in addition the losses will be reduced. When developing this two level voltages, different challenges linked with HVDC properties were to be faced such as the thermal runaway, the electrical field inversion and electrical stresses at accessories interface. For the latter, a Field Gradient Material (FGM) connecting the inner and outer deflectors of the premoulded sleeve was used.
PQ and type tests were eventually performed on both voltage levels according to Cigré recommendation TB496 for VSC application. A PQ and TT were additionally performed on 320 kV cable system with a conductor temperature up to 80°C.

Paper A.9.5: Development of 350 kV and 525 kV HVDC extruded cable system

This paper dealt with the development and qualification of a 350 kV and 525 kV XLPE HVDC cable system for submarine application and with a conductor temperature of 90°C. The first step was to prequalify a 350kV cable system according to TB496 for LCC application. From there, investigation tests were performed on a 525 kV cable system using the same insulation system. Once done, the cable supplier decided to start a PQ test according to TB496 for VSC application. This PQ is ongoing (foreseen to be completed by the end of 2019) and includes factory joint, premoulded and repair joints, GIS and outdoor terminations.

Paper A.9.6: 270 kV DC Extruded Land Cable Systems for LCC Power Transmission

This paper described the development of a 270kV extruded cable system used to replace old oil fluid cable system installed on IFA2000 underground part. The difficulty was the use of an XLPE technology with a LCC typology that uses polarity reversal to change the power direction. To validate the system development type test and PQ test according to TB496 and IEC62895 plus additional impulses were performed.

Session A10: Testing for DC cable

Chairman: Ronald PLATH ; Technische Universität Berlin, Germany

Rapporteur: Adrian DUMONT ; Prysmian Group, France

This session supported by six papers dealt with the different aspects of DC testing. For the laboratory testing part, the following items have been discussed: possible test setups for superimposed voltage test, long DC duration tests with more realistic layout of the cable, temperature drop controlled across the insulation of the cable, PD measurement for DC cable. Regarding onsite testing, the following items have been discussed: DC transformers and configurations to be used, fault location, discharge of long cable length, fault location.

Paper A.10.1: Superimposed voltage tests on DC cable

This paper presents the state of the art in term of equipment and test configuration being used today in the world to perform superimposed voltage tests as part of qualification of HVDC cable systems.

The use of a spark gap coupling presents the advantage of being a compact solution but can be difficult to set up in the case of same polarity for DC voltage and superimposed impulse; moreover, DC cable/GIS will be completed discharge during the superimposed impulse LI/SI. The use of a capacitive coupling avoids this last phenomenon and any coupling issue but will decrease the impulse generator efficiency and is more expensive and heavier than the spark gap solution.

To protect the DC generator from the impulse stress, an adapted protection resistor shall be used: water resistance, wire wound resistor or build up from film resistor. To measure the superimposed voltage impulse applied to the cable system, the use of a composite measuring system – divider and data acquisition – is presented with a detailed explanation of the calculation part.

Paper A.10.2: Cost-effective and practical solutions for testing HVDC cable systems

This paper deals with two important aspects while talking about qualification of HVDC cable systems: temperature drop across cable insulation and test configuration for performing superimposed voltage tests.

Temperature drop across cable insulation is an important requirement for testing HVDC cable systems. One solution here described for the control of the temperature drop through the insulation during electrical testing is the use of heating transformer producing an induced current into the conductor for the conductor temperature regulation and the use of resistive heating belts for the insulation screen temperature regulation. With an appropriate software, the resistive heating belt solution allows to compensate for ambient temperature changes, offering also flexibility in case of hot spot; all of this leading to a decrease of delay due to invalid thermal cycles.

As required by HVDC standard as part of the qualification process of a complete system, superimposed voltage impulses can be performed using two configurations: spark gap coupling and blocking capacitor coupling. The paper presents with data the pros and cons of each configuration.

Paper A.10.3: Testing experience on extruded cable systems up to 525 kV DC in the first third party worldwide laboratory.

This paper presents a 525kV HVDC long duration test campaign performed on 4 complete cable systems (extruded cable, accessories and terminations) according to a German TSO specification. In order to fulfill this ad hoc qualification procedure, the cable systems were not tested only indoor as per CIGRE TB 496 but mainly underground with pipelines, joint bays and urban tunnels as per real network situation.

Advices are given regarding the preparation and the execution of the test and a question is raised regarding the inclusion of DTS equipment into the future standards for temperature control throughout the complete cable lengths for future DC PQT test if real conditions installations were to be required. A point is also made on the two possible test setups for superimposed voltage tests at the end of the long duration tests: spark gap or coupling capacitor.

Regarding visual inspection of the different components of the cable system at the end of the qualification tests, the paper raises a point on the fact that standards do not have defined measurable criterias.

Paper A.10.4: Enhancing the Effectiveness of Partial Discharge Measurements on HVDC Cables by Use of Pulsed X-Ray.

This paper presents a study on performing PD measurements using X-rays on polymer insulated HVDC cables. The experiment has been performed on a short length of HV cable on which an EPR slip-on joint has been installed with a default inserted on the insulation of the cable ends.

With DC voltage applied, the repetition rate of the partial discharge can be very low, making it difficult to truly observe the presence or not of PD inside the cable system. Using X-ray generator, it enhances PD measurement because it leads to slightly higher charges magnitudes that can be easier to detect. By coupling PD measurement with radiation measurement, the precision is increased but the risk of double count exists.

Despite interesting results, this study reminds that it covers only one defect and it could be interesting to covers other common defects. Moreover, investigations regarding the impact of ionizing radiation on the cable insulation material should be made to guarantee that no alterative effects occur on the cable system during the measurements.

Paper A.10.5: Modular DC test system for testing long DC cables including a fault location system.

This paper presents a compact and modulable DC transformer up to 2200kV with 400kV modules for laboratory testing and onsite testing.

In order to meet the latest HVDC standards, polarity reversal shall be performed in last than two minutes using discharge resistor. Protective components shall also protect the transformer during superimposed impulse tests such as protective resistor / damping resistor combined with spark gap or capacitor coupling. For onsite testing, to avoid long discharging time while testing long cable length, a discharge resistor using water with controlled ohmic resistance value could be used.

One of the main issue with breakdowns on the network is the localization of them. The paper also presents a software based on TDR methodology and included into the voltage divider to localize its position at the time the fault occurred.

Paper A.10.6: Safe discharge of high cable capacitance under HV DC stress.

This paper first describes the main principle of fault locating procedures highlighting the fact that this operation must be performed with a de-energized cable that is then charged. At the end of the fault location procedure, the cable must be de-energized again by discharging it and then grounding it to the earth. Such operation can take time as you should reach a not-dangerous touch voltage before grounding.

The paper presents then a combined discharge and grounding device made of resistor compartment modules that would allow to safely and rapidly discharge a cable when needed during fault location operation. A continuous monitoring of the resistor value allows the switch off the high voltage in case of faulty resistor.

Session B1: Materials and characterization (A)

Chairman: GAO Jinghui; Xi'an Jiaotong University, China

Rapporteur: CAPON Guillaume; Nexans, France

General Comments about the Session : This session B1, including 5 papers, mainly focuses on materials, new materials and ageing assessment in AC and DC. As the HVAC and HVDC cable are developing towards larger cross-section and higher voltage, it poses great challenge on the properties and characterization of materials in the cable systems. The materials based on the current technology needs to be revaluated including the aging assessment based on the new requirement. Also, the emerging new material developing has attract much attention.

Paper B.1.3: Leakage current behaviours under high electric field in polymer minicables

This paper reports different families of leakage current behaviour that were observed in model cables for various insulation materials under different test regimes. Measurements were performed on minicables with fully-degassed DC XLPE, partial-degassed DC XLPE and non-DC XLPE at isothermal state and normal/abnormal thermal cycles, and the stability and reliability for the materials have thus been evaluated. It is pointed out that model cables are a convenient way to simulate the whole set of parameters at once in a somewhat realistic manner, and an ideal technique to select the best materials with high reliability. Some of the tested insulation systems appeared to be favourable and acceptable, when showing a continuous decrease of leakage current with time.

Paper B.1.4: Investigation of the PD behaviour of boundary surfaces with alternative PD-detection methods for AC and DC application

The authors describe a test arrangement for investigating the partial discharge (PD) behaviour at interfaces, in particular of silicone rubber and XLPE insulating materials. The test setup is flexible enough to investigate further aspects such as the influence of heat, different mechanical pressures or the behaviour of the interfaces after a certain ageing process. It is suggested that the PD behaviour and the associated PD-inception voltage vary with surface roughness and for greases quality (moisture content) on the interface. The corresponding tests were performed with alternating voltage and direct voltage.

Paper B.1.5: Space Charge Properties of XLPE and PDMS Dual-dielectric with Graphene Coating

This presentation reports the space charge distribution of layered samples of XLPE/PDMS with and without graphene coating at DC electric field of 10kV/mm and 40kV/mm. For specimens coated with graphene, the charge injection into the bulk is prevented and heterocharge remains blocked near the electrode itself, and the induced charge at polymer interface migrates close to the cathode at high electric field. In contrast, the one without graphene coating has heterocharge accumulation near the opposite-electrode at high electric field.

Paper B.1.6: HVDC dielectric material comparison from cable characterizations as a mean for material selection

The present paper aims at describing the measurement methods applied to mock-up cables in order to evaluate their dielectrics. The focus is on leakage current and temperature measurements together with the processing based upon them to assist in the selection of the more appropriate material. The comparison of the dielectric materials of model cables is made under the assumption of a capacitive electric field distribution. The limitation arises when the conductive current cannot be determined due to complementary transient phenomenon. In such case, the follow up of the current evolution versus time and with complementary measurement techniques such as space charges measurements would be more appropriate.

Paper B.1.1 : cancelled prior to the exhibition

Paper B.1.2 : did not show to present the work

Session B2: Materials and characterization

Chairman: RAKOWSKA Aleksandra ; Poznan University of Technology, Poland

Rapporteur: CHARRIER Dimitri; Nexans Research Center, France

General Comments about the Session : Materials, New Materials and Ageing Assessment in AC and DC

Paper B.2.1: Interface Polarization Characteristics of Water-Tree Aged Cables based on Polarization and Depolarization Current Method

This work is interested in looking at asymmetrical behavior of DC Polarization and Depolarization Currents of accelerated AC water-tree aged XLPE cables. Because there is an empirical relationship between tree formations and DC response. Accelerated AC water-tree ageing is performed with 3 mm deep pinholes.

Paper B.2.2: A study on partial discharge and bubble behavior in oil gap on oil-impregnated paper insulation system

The paper deals with partial discharges simultaneously coupled with optical measurements for detecting defects in oil impregnated papers. A special test cell is presented. Measurements are performed on both impulsion and steady voltages. Bubbles are present when partial discharges occur confirmed by PD and optical measurements.

Paper B.2.3: Study on Degassing Efficiency of Crosslinked Polyethylene High Voltage Cable

This work presents methane degassing both experiments and calculations on XLPE slices taken from cables.

Paper B.2.4: Studies of diffusion of byproducts formed by the peroxide-induced cross-linking of polyethylene

Predictive models based on simulations allow to calculate solubility, diffusion coefficients of atoms (He) and small molecules (N_2, O_2, CH_4, C_3H_8) in an amorphous polymer for simplicity. A comparison between simulations and experiments is done, while in reality there is indeed crystallinity.

Paper B.2.5: The effect of mechanical pressure on the electrical resistivity and water transport capabilities of a semi-conductive superabsorbent tape

Radial and axial electrical resistivity of semi-conductive tapes are looked with the humidity content and pressure. Tapes are usually made of a tri-layer design, formed by a CB tissue, a glue and a superabsorbent polymer. A volume electrical resistivity test cell is presented and allows to generate different situations of moisture content and pressure found in real subsea cables. Measurements showed axial conductivity is almost unaffected by the pressure. This is explained by the fact the CB tissue is not affected by the pressure.

Session B3: Fire performance

Chairman: VERCELLOTI Uberto; CESI, Italy

Rapporteur: COLOMBIER Serge; Prysmian Câbles & Systèmes, France

General Comments about the Session :

Due to public presence and/or critic infrastructures and devices to protect, cables are very often required to have specific fire performances. It can be fire propagation behavior, in order to not contribute the fire propagation inside the building and or fire-resistant cable for the one that have to maintain their integrity during the fire allowing security systems to work properly. For such fire performances, specific fire retardant materials have to be used. The mechanicals and thermal characteristics of these fire improved materials are often lower than the ones of the current not fire improved materials. Nevertheless, in order to guarantee the functionality of the cable it is fundamental to design properly these high fire performance materials.

This session explains the main problems encountered with these fire retardant materials and how it has been possible to solve having the right formulation and cable design. Different cables type is treated from LV to HV, EHV, HCDC cables and also network components.

Paper B.3.1: Products Construction Regulation: do HVAC and DC cable have to answer?

This special communication describes how fire safety technologies and new regulation are affecting HV EHC HVDC cables links. After an overview of consequences on HV installation of European regulation and especially Construction Products Regulation (CPR), and through a series of experiences done it is proposed some technical solution to address TSO’s new need and specification.

Paper B.3.2: ElecLink Cable Fire Performance and Bespoke Fire Test

Under the EU Construction Product Regulation, the 320kV ElecLink HVDC interconnector cable shall comply with the EU Fire classification defined inEN13501. It is needed to achieve a B2sa s1a a1 classification. This paper firstly outlines the project cable fire performance requirements, subsequently describes the design challenge and finally the associated performance tests and results.

Paper B.3.3: LSZH sheath cracking in harsh environment

This paper discusses the LSOH sheath cracking issue faced in harsh environment. The ambient temperature during summer can reach very high temperatures and the external sheath a cable fully expose to such condition can reach temperature as high as 70°C causing a loss of the mechanicals properties of the material and formation of cracks. This paper examines different experiments performed to observe the sheath cracking issue.

Paper B.3.4: Current ratings and installation considerations for Fire Resistant Wiring Systems

This paper examines the effects of fire temperatures on the ability for Fire Resistant wiring systems to carry the sufficient load current necessary in order to maintain integrity to ensure the functional operation of connected equipment for the required time.

Paper B.3.5: A Study of Smoke Release of Complete Cables and components of the cable

Not presented.

Session B4: New materials (A)

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

Chairman: GUSTAFSSON Anders ; Borealis, Sweden

Rapporteur: SAMUEL Jorice ; Nexans, Norway

General Comments about the Session : The 5 papers presented in this session described developments at different stages of several potential alternatives to XLPE for AC and DC applications.

Paper B.4.1: Enhanced Performance Thermoplastic Insulation Systems

This paper described two development strategies : thermoplastic insulation systems based on PE and PP blends, and composite insulation compounds based on hexagonal boron nitride. A broad range of properties has been evaluated and promising candidates have been identified. In particular, mapping of PP blends with respect to their electrical and mechanical performance has been shown. Selected blends provide major improvements of the breakdown strength and thermal stability with no corruption of the mechanical performance. Hexagonal boron nitride introduction into these blends under certain conditions provides a 25% increase in electrical breakdown strength while maintaining mechanical properties.

Paper B.4.2: Development of a thermoplastic insulation system for medium voltage cables

The authors developed an insulation system fully thermoplastic, based on polypropylene, for MV cables. Several properties have been verified and demonstrated a performance comparable to XLPE compounds, or even better for some aspects. In particular, good resistance against water tree propagation has been demonstrated in laboratory test, as well as a mechanical behavior enabling installation down to – 20°C. Theoretical calculated ampacity is in the same range.

Paper B.4.3: Comparison of characteristics and behaviour of XLPE and P-laser MV-cable

The authors shared results from verification tests consisting in a comparison of MV cables (630 mm^2 Al 6/10 kV) insulated with XLPE and a thermoplastic elastomer based on polypropylene. Both provided similar performance as far as ampacity in air, overbending at various temperatures, short-circuit and shrinkage performance are concerned. As a conclusion, Enexis decided to open the possibility for utilization of this thermoplastic elastomer in its MV-network.

Paper B.4.4: A polystyrene pinning crosslinked polyethylene for potential application in HVDC cable insulation

This paper suggests the inclusion of polystyrene into XLPE to form a polymer pinning structure, aimed at HVDC cable insulation. The results showed that addition of PS could enhance the DC breakdown strength and decrease the DC conductivity compared to XLPE at the test temperature range. The space charge behavior is also promising. Based on design parameters as well as experimental results, a simulation of electric field distribution for 320kV and 525 kV cables was performed and discussed.

Paper B.4.5: Performance of a strippable thermoplastic medium voltage cable

This paper brings attention to the semiconductive screens and addresses the challenges of having a strippable screen for medium voltage that will give a good performance on the cable at – 20 °C and at + 105 °C, and including short circuit behaviour at 250 °C. This paper is seen in conjunction with Paper B.4.2. Cable prototypes up to 35 kV were produced and tested according to IEC 60502. Strip force, volume resistivity of the screens, AC breakdown strength, transmission capacity and long term thermo-mechanical performance at lab scale have been assessed. A piece of cable has also been installed and a long-term evaluation has started under real network conditions one year ago.

Session B5: New Materials (B)

Chairman: CASIRAGHI Flavio ; Prysmian SpA, Italy

Rapporteur: SAHYOUN Jihane ; Nexans, France

Session B5, comprising six papers, was devoted to materials, new materials and ageing assessment in AC and DC. The session addressed the recent developments in materials and their performances, i.e; Tree Retardant XLPE for Wet HV cables, fully-crosslinked XLPE for HVDC, modified Liquid Silicon Rubber for HVDC accessories, Self-healing fluids for FFC and modified XLPE (along with a screw design) for HV cables.

Paper B.5.1: Advancements in TR-XLPE Insulation Technology to Enable Use in High Voltage Cable Applications

The paper reviewed the development history in Tree-Retardant XLPE insulation in dry/wet environments. It was shown that the 3rd generation demonstrate 6X improvement in ACLT performance over other TRXLPEs, while maintaining the low dissipation factor characteristics. When aged in wet and high electrical stress aging conditions, cable samples retained about 65% of their initial AC breakdown strength. Authors propose to consider the use of the latest TRXLPE generation in "Wet" HV cable designs, up to 150kV.

Paper B.5.2: Fully-crosslinked XLPE with low conductivity for DC insulation

Authors suggested that the insulation conductivity behavior cannot only be dominated by crosslinking residues content, but additional factors including chemical interactions, polymer morphology and charge injection/accumulation processes. When compared to a commercial low-cure HVDC insulation XLPE-1, the presented fully-crosslinked XLPE-2 showed a comparable DC breakdown strength along with a low conductivity. Successful type test with a full-size 320kV HVDC cable (550kV type test in progress) using XLPE-2 address the possible use of this material for HVDC insulation.

Paper B.5.3: Formula and preparation of special rubber sheath material for Rolling Stock Cables

Missing presenter

Paper B.5.4: Development of Novel Liquid Silicone Rubber solutions for HVDC Cable Accessories

Modified liquid silicone rubbers (LSR) characterizations by means of cure data, mechanical properties, volume resistivity, DC conductivity and breakdown strength were discussed in this paper. Optimizing the modification method of LSR induced a positive impact on the tear strength. Post curing seemed to decrease the modification effectiveness, yet, it could be corrected through the formulation method. These rubber solutions with a variable volume resistivity, might allow matching the accessory conductivity to that of the XLPE insulation while preserving good mechanical properties and dielectric strength.

Paper B.5.5: Recent Developments to Improve the degassing and long run extrusion performance of HV Cables

It was reported that the development of a novel XLPE compound along with a new screw design result in a significant improvement in scorch-resistance and eliminate stagnation points. Consequently, the extrusion run time was increased up to 20 days, delivering about 140ton of XLPE insulation. The quality of the produced 1200mm^2 110 kV cable was confirmed by testing the final drum in a full 220kV Type Test, with elevated stress for Tan δ measurement ($2U_0$). The novel XLPE exhibited significantly lower degassing burden and the heat resistant insulation semiconductive screen enabled increasing the degassing temperature from 70 to 80°C.

Paper B.5.6: Self-healing dielectric fluids for Fluid Filled Cables: from lab to circuits

This paper focused on the recent improvements in self-healing fluids for FFC, i.e. testing instrument and formulation (dielectric host and fully dispersed catalyst). Two testing rigs were designed to evaluate SHF performance in open air and backfill conditions. The SHF allowed reducing the leak rate from 24 to 7.5l/month without containment and from 38 down to 3l/month with containment. Authors presented further refinements of the SHF formulation to improve both self-healing performance and electrical properties. Further advances in the scaling production to carry out circuit trials are ongoing.

Session B6: Ageing and lifetime (A)

Chairman: MONTANARI Gian Carlo ; Texas University, Austin, USA

Rapporteur: MIREBEAU Pierre ; Nexans, France

General Comments about the Session : The session "ageing and lifetime (A)" included 6 papers 3 of them from USA, 1 from China, 1 from Norway and 1 from France. It showed that the ageing and life time of a long product, i.e. a cable system, is a difficult subject where many valid approaches are in progress. There is no common operational conclusion for the time being and further work is necessary.

Paper B.6.1: Extracting optimal value from a medium voltage (MV) Qualification (wet ageing) Test?

This paper examined in depth the ageing data of cables (from standard CENELEC wet ageing tests), and joints. It showed that the most scattered ageing results are the ones of the joint, as their manual installation impacts their performance. It is to be noted that the same qualified reference cable was used for all ageing tests of joints. The discussion pointed out that depending on the technology, some joints may present water trees after ageing tests.

Paper B.6.2: Implementation of Ageing Laws and Cable Models to Estimate Service Life for MV Cable Designs using Laboratory Endurance Tests

This paper collated 124 data sets of Accelerated Cable Life Tests (ACLT) that are in the public domain. Through a statistical approach it evaluates the effect of electrical stress, operating temperature, cable length, cable jacket and water presence. The discussion regarded the application of the results to maintenance operations.

Paper B.6.3: Can Cables Last 100 Years?

This paper investigated what happens after the design lifetime of 40years. The authors have not been able to find any contradicting science to suggest cables cannot last 100years or longer time.
The discussion addressed how to detect and remove and abnormally stressed length of cable, out of a long healthy aged cable link.

Paper B.6.4: Lifetime prediction based on electro-thermal aging test and electric field simulation of a new ac 500 kV submarine cable

This paper addressed ageing tests performed on slab immersed in oil and applied the results to a 500kV AC cable.
The discussion addressed the validity of the tests performed on the slabs, specially the compatibility between oil and XLPE.

Paper B.6.5: Aging of oil impregnated insulation paper of subsea HV cables in decades of service

In this paper, a 300mm² HVAC 300kV oil filled cable in service since 1957 and a 800mm² HVDC 250kV Mass Impregnated cable were dissected. Not any significant degradation was detected.
The discussion addressed the service conditions of the cables. They were actually heavily loaded, specially the HVAC cable that was actually operated at 90C.

Paper B.6.6: Dielectric spectroscopy response and Mechanical properties of XLPE mini-cable aged under thermal stresses

In this paper, traditional XLPE insulating material has been aged in air during more than 100 days. Temperature were ranging from 70°C to 110°C. Changes have been detected, Markers have been identified, but there was not any significant ageing.
Discussion addressed the influence of the semi-conductive layer.

Session B7: Materials, New Materials and Ageing Assessment in AC and DC

Chairman: ISUS Daniel; Prysmian, Spain

Rapporteur: CHRÉTIEN Antoine; Rte, France

General Comments about the Session: Several insulation materials (XLPE, EPDM, etc.) were tested under various ageing conditions (thermal, AC/DC electrical ageing, etc.) to assess the material's properties evolution. Phenomena such as oxidative degradation, water-treeing, water sorption, space charge, crystallinity were studied.

Paper B.7.1: Thermal-electrical aging of selected polymeric LVAC cables under DC voltage stress

This article compares the failure behavior of several insulation materials (PVC, halogen-free, silicon-based, TPE & poly-olefin) subject to thermal, mechanical and DC voltage stress. Ageing is performed on insulated conductors put inside a water tank with a temperature of 80°C over 2500 h. Failure criterion can be either an electrical breakdown or a reduction of insulation resistance under 10 MΩ. It concludes that failure behavior is specific to each insulation material; for instance silicon-based samples displayed a failure behavior dependent on the insulation thickness and the bending radius.

Paper B.7.2: Phased propagation characteristics of water trees in XLPE cables during the accelerated water tree aging experiment

This study is dedicated to better understanding the process of water trees propagation. Cable samples with pinhole defects were subjected to an accelerated water tree aging experiment. It concludes that water trees first propagate rapidly (initial stage), then slowly (stagnation stage) and then rapidly again (late stage). The reduction of propagation rate can be explained by the decrease of local electric field in the zone where water trees form a mass of voids that eventually tend to get interconnected, thus reducing the electric field at the water trees tips. And then, when the void density is high, their shape may become irregular, thus enhancing the electric field, and making the water trees grow again.

Paper B.7.3: Influence of Thermal Ageing on Water Sorption in EPDM Rubbers

This study assessed the water transport properties of EPDM after thermal ageing in air-ventilated ovens at 150°C, 160°C and 170°C. It showed that these properties are mainly driven by an oxidation criteria that can either be the carbonyl content or the compound density. Indeed, the oxidative process leads to the formation of various carbonyl species and a significant increase in density. Regarding water transport properties, thermal ageing tends to increase water solubility while decreasing water diffusivity. Permeability being the product of both quantities, it remains somewhat constant regardless the oxidation state.

Based on a comparison of two EPDM compounds, this study also showed that adding sulphur into the formulation helps stabilizing EPDMs against thermal oxidation.

Paper B.7.4: Assessment of the impact of the electrical stress on the ageing for a HVDC model cable

This study aimed to compare the electrical and physico-chemical evolutions of a model cable system subjected to thermoelectrical or thermal stress for a long period of time, using IR spectroscopy, DSC (differential scanning calorimeter), and PEA (Pulsed Electro-Acoustic). The sample was a model cable extruded on a laboratory CCV using HVDC XLPE grade material. Thermal stress was shown to raise the conductivity and thus the FEF in the short term, but lower it in the long term. This is especially the case when electrical stress is added to thermal stress, probably because thermoelectrical stress drives charges, and thus decreases the density of ions that are present in the insulation; a process that cannot be achieved by thermal stress alone. However, no breakdown occurred during tests, therefore these electrical characterizations cannot be linked to material dielectric performance.

Paper B.7.5: Estimation of chemical changes of thermally aged XLPE cable insulator

Unlike wet design cables, for which water tree degradation is the main chemical ageing process, XLPE cables equipped with a water barrier suffer primarily from oxidative degradation due to heat and exposure to oxygen. This process can lead to hardening the insulator and ultimately to cracks. Based on DSC (differential scanning calorimeter), FT-IR spectrometry, and X-ray diffraction, both the antioxidant content and the crystallinity were measured during thermal ageing of a cable sample. It concludes that thermal stress tends to hasten the kinetic of

antioxidant consumption and raise the insulator’s crystallinity. These ageing process are local (radially dependent) and highly depend on the manufacturing parameters.

Session B8: Dynamic cables and mechanical design

Chairman: SALES Lluis ; Prysmian, Spain

Rapporteur: LAURE Emmanuelle ; RTE, France

This session, comprising five papers, dealt with dynamic cables and mechanical design. Whereas dynamic cables are well-known in Oil&Gas industry, the emergence of floating wind farms highlights the need for clear guidelines in terms of analysis and testing of these cables, in accordance with new challenges of renewable energies. The papers are proposing some modelling and analysis methodologies that are of great interest for the development of this technology.

Paper B.8.1: Full Scale Fatigue Test on Dynamic Submarine Power Cable

This paper presents modelling and testing performed on a 10kV dynamic cable for an Oil&Gas project in Madura Strait East Java. On one hand, 4600 load cases were simulated for 3D Finite Element Analysis to verify the prototype complies with extremes, and 200 millions of cycles were simulated for fatigue. On the other hand, one full scale fatigue test was performed, with 1,5 millions of cycle simulated. Both approaches demonstrate that the cable design can achieve expected service lifetime. Monitoring using DAS was also used, showing some possibilities in dynamic field.

Paper B.8.3: An Experimental and Modelling Approach for Assessing Dynamic Cable Capability to Withstand Operational Constraints

This paper presents the work to be performed in the OMDYN2 project and the methodology intended to be used in this project. One principal point of this project is to assess if there is some coupling between mechanical and thermo-electrical constraints applied to dynamic cables. In operational conditions, dynamic cables undergo these three constraints simultaneously whereas for now, they are designed and tested taking these constraints separately. OMDYN2 project will also look at modelling and biofouling issues.

Paper B.8.4: Large HVAC export cables under tensile loading

This article studies the mechanical behavior of one large HVAC cable, 245kV, 1800mm² Al, single armoured, when exposed to tensile loads. Three different methods have been studied and compared: analytical formula, 3D Finite Element Analysis (of 1m of cable) and full-scale testing on a cable sample of 45m. It shows good agreement between 3D FEA and experimental results, both with regards to elongation response and tension-twist behavior, thus demonstrating that 3D FEA can be a powerful modelling tool.

Paper B.8.5: Load and fatigue evaluation for 66 kV floating offshore wind submarine dynamic power cable

The model sensitivity and convergence for a semi-submersible platform, with a 5 MW turbine and a 66 kV double-armoured 300 mm² Cu power cable are explored regarding metocean conditions, computational parameters. A lowered Lazy Wave cable configuration is chosen as most suitable design, providing a compromise between hang-off tensions and induced bending stresses. The paper provides methodology to assess the cable design, with a focus on ULS case.

Paper B.8.6: A new time-domain model-based diagnosis method for assessing the offshore floating wind turbine umbilical state of health

This paper investigates cable electrical health state by monitoring estimated capacitances of multi-wire transmission line models. A pulse generator and a high frequency acquisition system have been specially designed in order to efficiently sensitize the model parameters in operating conditions. The output-error identification approach is exploited to select the “best” model structure, i.e. to optimize its parameterization and its granularity, using experimental data obtained with an 8 MW 500-m long submarine power cable. Then, a sensibility analysis shows that the proposed method allows to detect and localize a breakdown of the cable moisture barrier dealing with a relative increase of more than 8% of the cable distributed capacitance.

Session B9: Submarine cables current rating

Chairman: STØLAN Ronny; Nexans, Norway

Rapporteur: JOUBERT Vincent; Prysmian, France

General Comments about the Session: This session addressed several aspects of the submarine cable design. Papers dealt with several stages of the design process: modeling, experimental losses measurement, design optimization and local site condictions.

Paper B.9.1: Accurate measurement of losses in three core armoured cables

The first presentation focused on the accuracy of impedance measurement in three core armored cables. Because the equations of IEC 60287 only give an approximate level of losses in the armors, it is becoming more and more common to perform measurements on actual cables. It should however be stressed that the error budget of such measurements can be relatively high, to the point where the uncertainty can become higher than the actual armor losses.

Paper B.9.2: Analysis of an array of wires in a low-frequency time-harmonic magnetic field

The most common method for accurately computing armor losses in three core armored cable is to use a Finite Element Model. Usual methods typically necessitate to build a 3D model with a sufficient length of cable and fine meshing, which can create computationally-challenging models.
The alternative method presented in this paper uses the Method of Moments to be able to avoid meshing the air and to be able to represent wires as a 1D line. This results in dramatically reduced computing times with little reduction in accuracy.

Paper B.9.3: Research on improving the ampacity of high voltage single core submarine cable

This paper presented the results of a practical study performed for a submarine cable project. By replacing a number of steel wires with copper wires in the armor of a single core cable, a higher ampacity was reached without having to increase the cables conductor cross-section, while still maintaining acceptable mechanical characteristics.

Paper B.9.5: Towards optimum construction of HV AC cables

This paper showed the work and experimentations conducted in order to optimize a cable.
It describes the protocol that was establish to perform measurement on several cable designs, in order to minimize losses, and the challenges that have to be addressed in order to obtain accurate values.

Paper B.9.6: Seabed soil controls on the design and lifetime performance of marine HV cables

Finally, an overview of the seabed conditions affecting HV cables circuits ampacity was presented. Seabed conditions are generally uncertain and can vary with time. A summary of the temperatures historically reached at various locations around Britain was shown, with discussion on how this would affect the cable conductor temperature.
It was also suggested that convection, which can occur in water-saturated seabed soils, can be a significant way for heat to be transferred, and that taking it into account could allow for higher ratings.

Session B10: Submarine Cables testing

Chairman: TROLLI Alessandro; Prysmian, Italy

Rapporteur: FRANCHET Maud; EDF R&D, France

General Comments about the Session :

This session, including five papers, deals with testing of submarine cables from MV to HV levels.

Interconnection projects, allowing 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 is coming 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 among them (inter-array cable) and to the mainland (power export cable). To ensure a good reliability of such cable systems, appropriate testing is needed all the more than any failure on the submarine cable will involve expansive and time consuming repairs.

Paper B.10.1: After Installation Testing of Inter-array Cables at Offshore Wind Farms using Damped AC Voltages

Paper B10.1 deals with after installation testing of inter-array cables at offshore wind farms. The paper focused on partial discharge damped AC voltage testing. Results of concrete cases are exposed, where some faults have been detected before commissioning thanks to the proposed method. Testing after installation before commissioning could help identify upcoming failures and by consequence save money.

Paper B.10.2: Full Scale Wet Age Testing of XLPE Insulated Power Cables in Salt Water

Paper B10.2 presents results of full scale accelerated testing on 66kV wet XLPE insulated cables in saline conditions. Tests have been made at both 50Hz and 500Hz and compared with results obtained for the same MV insulation system in tap water. According to these results, this cable design meet the requirements of the current standards in terms of residual breakdown strength. Moisture content and microscopic analysis have also been carried out in order to assess the effect of ageing. Good agreement between moisture tests and modelling have been met. The analysis showed evidence of electrical ageing after 6 months but with no significant growth of water trees after 12 and 24 months.

This raises the question of making tests at 500 Hz instead of full scale state which are much more complex to implement. To answer this question some more investigations are needed.

Paper B.10.3: On-Site Testing of 66 kV Subsea Array Cables for Off-Shore Windfarms

Paper B10.3 analyses test voltage methods appropriate for evaluating the dielectric integrity of 66kV array cables after installation. The preferred method here proposed is based on resonant test circuit, especially ACRF (frequency tuned resonant circuit) which is able to generate stresses similar to the one experienced in service. This system is modular and can be used for cables length of 25 to 40 km. Such system can be installed in the offshore substation but must be off-shore qualified.

Paper B.10.5: Bend Stiffness of submarine cables – an experimental and numerical investigation

Paper B10.5 studies the non-linear bend stiffness of submarine cables. A test rig based on the four-point bend method has been developed. Measurements are used to calibrate a numerical model which take into account the temperature dependant visco-elastic shear deformation in the bitumen layer. Results have demonstrate the non-linear response of the cable and strong temperature effects. Taking into account such hysteretic moment-curvature relationship instead of a simple constant bend stiffness can give more realistic results.

This article raised a particular interest of the audience especially regarding manufacturing and installation issues.

Paper B.10.6: Conditioning of High Voltage XLPE Cables in Salt Walter – A Review of Ion Diffusion and Impact onWater Treeing

Paper B10.6 addresses the impact of ionic impurities in cable insulation and mechanisms of NaCl diffusion in cable materials. Diffusion measurement techniques are described and some recommendations are made. This review is put in perspective with the recent recommendations given by the CIGRE technical Brochure TB 722, which opens several questions on the impact of ionic diffusion on insulation ageing and on preconditioning and test protocols.

This is a literature review. No real tests have been done for now.

Session C1: Distribution network diagnostic and maintenance

Chairman: WALD Detlef; Eifelkabel, Switzerland

Rapporteur: MOREAU Christophe ; EDF R&D, France

Session C.1 was dedicated to diagnostic and maintenance of distribution network underground cable links.

Paper C.1.1: PD alarm – Lightweight automated diagnostic device for online detection and location of partial discharges on non-shielded accessories of a medium voltage distribution network

Hydro-Québec Distribution (HQD) operates more than 12000km of medium voltage underground distribution lines with more than 600000 accessories. It is of great importance to detect and locate accessories with partial discharges (PD) prior to any failure. To do so, HQD inspects its underground equipment by means of thermography and PD detection.

This paper is focused on online PD detection and location. It describes the approach and the different research stages that leads to the development of the PD Alarm device. An important part of the research has been dedicated to the design of the differential antennas. Finally, the chosen concept consists in a narrow band 18MHz differential antenna associated with a converter board and a microcomputer. The system has been tested in laboratory and onsite. On 167 components tested onsite PD Alarm identified PDs without giving any false positives or false negatives. It has to be noted that this system is dedicated to be used only on non-shielded components.

Paper C.1.2: New approach for evaluating the condition of cable systems and estimation of remaining life time of MV underground power cables

This paper addresses the question of estimation of remaining life time of medium voltage power cables. Based on a large database of Tan Delta and Partial Discharge measurements performed by KEPCO (Korean Electric Power Corporation) a new data treatment is proposed. The aim is to improve the methodology of remaining life time estimation already developed by KEPCO. The new methodology builds a vector which module (R-value) is based on several characteristics of Tan Delta patterns. Methodology applied to data base results is such that cable failure are likely to occur for highest R-values. So, for these cables R-values can be used for asset management (showing similarities with Health Index approach). The applicability of the algorithm to different cable designs will be further studied.

Paper C.1.3: Comparative Investigations of PD-Behaviour on an Artificial Accessory Failure under medium Voltage AC and Damped AC (DAC)

The aim of this paper is to compare PD characteristics obtained on MV accessories with 50 Hz AC and Damped AC (DAC) test methods. Knowing that most of the failures of MV accessories observed on site are initiated by bad workmanship of assembly, the authors have tested an artificial defect type (cable termination without field control at the outer semi-conductive layer) with the 2 test methods.

With tested defects, no significant differences was shown on PD-inception voltage between DAC and AC test voltages. This work opens possibilities of comparative studies between AC and DAC test on various type of accessories and defects.

Paper C.1.4: Operating Extruded Distribution Cable Systems at Elevating Temperatures

The authors notice first that the difference between operating temperature specified for a cable system and operating temperature actually occurring on site is quite important. Moreover, recent service experience reports failures when cable systems operate above 70°C. So, the authors question the ability of a complete cable system (cable and accessories) to operate at the highest specified temperatures. The analysis of requirements of standards and specified tests shows several reasons to be cautious about operating extruded distribution cables at elevated temperatures (above 70°C or 90°C). At last, complementary tests and associated requirements as well as more comprehensive ampacity calculations are recommended for new cable systems (including connectors, materials and accessories) to mitigate the risk of failure.

Paper C.1.5: Reducing cost throughout the power cable network with Online Condition Monitoring using Integrated SMART-SENSING

This paper reports an application of a Distributed Acoustic Sensing (DAS) system used on fibre optic cables on export or subsea power cables. It has shown ability to detect and locate accurately (+- 10m) a short circuit on a 15km long power cable, saving repair costs.

As another application, endangering situations (for example third part damage due to mechanical digging activity) when the system is permanently connected to the fibre optic cables can be detected.

Paper C.1.6: Proposition of New Diagnostic Features for VLF Tan Delta Measurements in Order to Improve Their Interpretative Value

Offline diagnostic of MV underground links based on the measurement of VLF Tan Delta is widely practiced nowadays. Criteria in use in terms of condition assessment are generally issued or adapted from IEEE 400.2.

Based on the author's experience and database of measurements, this paper explores the potential of making use of the currently unexploited information that may lie in the detailed very low frequency (VLF) Tan δ numbers recorded during tests. The analysis takes also into account an additional criteria called TUTU (Tip-up of the Tip-up) which relates to the difference in mean Tan δ evolution from 0.5 U0 to U0 vs from U0 to 1.5 U0.

Different patterns of VLF Tan δ vs applied voltage are identified, discussed and associated with cable or joint degradation. New advanced diagnostics features for VLF Tan δ measurements are proposed. In order to take fully advantage of the proposed new methodology it is only necessary to perform an additional VLF Tan δ measurement at 0.5Uo after the usual voltage steps (0.5 U0, U0 and 1.5 U0).

Session C2 - offline diagnostic and maintenance

Chairman: TESTA Luigi; Prysmian, Italy

Rapporteur: LEEMANS Pieter; Elia, Belgium

General Comments about the Session : This session, comprising six papers, dealt with offline diagnostic and maintenance. Different techniques VLF, tan delta in time domain and frequency domain spectroscopy, fault localization,…in this domain were presented during the session.

Paper C2-1: Low Frequency Dielectric Spectroscopy Applications to Aged Medium Voltage Cable Diagnostics

The paper describes the technique of low frequency dielectric spectroscopy (LFDS) based dielectric loss diagnostics on aged MV cable systems and its advantages over 'conventional' fixed frequency 0.1Hz (VLF) tan delta measurements. The FDDS methodology is explained for application on oil paper cables and extruded cables and illustrated with a case example of a 15 kV rated XLPE cable with severe water-treeing and 25 kV rated XLPE cable with shield mechanical damage / corrosion. For the assessment of the results, a practical guide is included in the report.

Paper C2-2: Methods and experience of Very Low Frequency (VLF) diagnostic testing to support asset management of critical MV circuits

Utilities find that the small footprint, ready availability of VLF (very low frequency) voltage sources, and well-established condition assessment criteria are beneficial when undertaking condition based maintenance. In this paper, the application of VLF diagnostic testing coupled with other complimentary techniques is addressed in order to support the asset management of critical Medium Voltage (MV) cable circuits. Circuits are considered critical when the risk of failure profile and related consequences are significantly different to traditional distribution applications. The approach could differentiate about the prior knowledge of the cable circuit (new cable circuits – existing cables with and without diagnostic record) and the source of criticality.

Paper C2-3: Development of a method for the localization of PD-Faults in high voltage cables with UHF sensors

Faults in cable accessories can occur during the manufacturing process but, most likely during assembly and installation. The aim is to develop a smart on-site PD-fault localization system with capacitive UHF-sensors. In the paper, the technology Ultra-High-Frequency (UHF) sensors is described. During investigation, an artificial fault was reliably detected and a smart application of UHF sensors in combination with computer-aided super-positioning system was developed for detection a 110 kV cable termination in laboratory conditions.

Paper C2-4: Partial Discharge measurements during AC voltage test: a fast and effective method for the site commissioning of long EHV XLPE cable systems

The aim of the present work is to describe the process and procedures used in a Partial Discharge (PD) investigation on a long HV cable system during the AC withstand test. The design of the PD measurement system, the analysis of the results, the comparison of the PD data in the detection points on a double 230 kV system is presented together with the outcome of the test. The PD measurements have been carried out on the cable accessories, equipped with inductive sensor permanently installed on it by design. The PD results show 3 phenomena: noise from the RTS, external surface discharges and corona effects. Questions about the synchronization of the sensors, total execution time of the PD measurements,…were treated during the session.

Paper C2-5: Condition based maintenance of HV cable line using damped AC technique - a case study

Damped AC (DAC) technique is one of PD measurement methods which is capable to locate the PD sources and execute conventional PD measurement on existing cable systems. By the application of this method, the critical sections of the entire cable line can be pinpointed. In the paper, a case study is presented about an almost 30-year-old HV cable line, which were tested by DAC technique five times between 2012 to 2019. The results of the results of the PD-measurements (e.g. PDEV and PD level) of the different diagnose tests were presented and compared and have initiated the replacement of the porcelain terminations. Also, after the re-routing of the cable, PD measurements were performed as an acceptance test. Questions about the min. required level of sensitivity and the repeatability of the DAC test were answered by the presenter.

Paper C2-6: Diagnostic of Underground Cable Systems Based on the Combination of Time Domain Dielectric Spectroscopy (TDDS) and VLF Tan Delta

Dielectric loss measurement, as a testing approach for performing condition assessment of underground cable systems, poses a number of challenges in terms of interpretation, related to the fact that it constitutes a "global"

measurement. As for example, with the current tools and diagnostic features available, the use of dielectric loss measurements does not allow yet discriminating between the various types of degradation that may be present. The presentation discuss the concepts of dielectric spectroscopy, the benefit of performing Time Domain Dielectric Spectroscopy (TDDS) in order to improve the diagnostic interpretative information, including possibilities to discriminate problems with cable vs problems with joints. A new interpretative grid will be proposed, that includes classical and new “advanced” diagnostic features for VLF Tan δ along with a number of new proposed TDDS diagnostic features. During the Q&A the advantages of time domain vs. frequency domain DS were discussed.

Session C3: Online diagnostic and maintenance

Chairman: BOONE Wim; DNV GL, the Netherlands

Rapporteur: TANZEGHTI Houssam; Enedis, France

General Comments about the Session: This session was dedicated to diagnosis, monitoring and remaining life estimation. Most of the papers focused on partial discharge measurement and monitoring of underground cable system. The optics fibre is also a methods presented in some papers in order to make temperature measurement. There is also acoustic or optical methods to perform monitoring.

Paper C.3.1: Investigation of temperature effect on partial discharge patterns in high voltage XLPE insulated cables

The online partial discharge detection has been used as one of the most important method for asset management in high voltage cable systems. The effect of the temperature on partial discharge patterns is discussed in this paper, based on the experimental tests on two samples. It was demonstrated that the higher temperature of the cable insulation leads to a decrease in the partial discharge pulses amplitude.

Paper C.3.2: Performance of the Partial discharge equipment and the future of online monitoring system in National Grid SA network

This paper present the use of partial discharge equipment in National Grid SA network. It start with a history of the partial discharge tests. A discussion between different partial discharge methods was discussed and National Grid SA network give some recommendations based on their own experience.

Paper C.3.3: Belgian experience with the commissioning and operation of a monitoring system on a 380 kV AC cable system

This paper present the experience of the installation and commissioning of a system of a partial discharge monitoring on a 10 km underground, 380 kV AC cable line in Belgium. The design and the installation of this systems were discussed in this paper. This system monitors the condition of the entire cable and all of its accessories in real time and the system simultaneously performs measurement of the cable shield current as well as the condition of sheath voltage limiters. Then the paper describes the software technologies associated with the partial discharge acquisition unit and the power supply solution used in the PDM. The return of experience is also presented.

Paper C.3.4: High voltage outdoor terminations with integrated optical partial discharge measurement

This paper presents a brief introduction to the physics behind the optical partial discharge detection technique. More precisely this paper describe the development of an original solution of optical partial discharge measurement special prototype based on a conventional oil filled termination for the voltage class 145 kV. A simultaneous measurement of the electrical and optical partial discharge channel was performed. and show similar results.

Paper C.3.5: In-service Partial Discharge Measurements on Power Cable Terminations

This paper first describes the various types of cable terminations and termination failures encountered in transmission and distribution networks in SPPG. Then the paper introduces a portable in-service non-conventional electromagnetic partial discharge measurement system. The procedures to locate partial discharge, to identify the defect using frequency spectrum, PD clustering, PD patterns, PD pulses, time-of-flight measurement techniques, as well as with the help of GIS on-line PD Monitoring system, are proposed.

Paper C.3.6: Integral sensing of HV cable joints - monitor operation and predict failures early

This paper discusses the real life pilot installation of three joints equipped with sensing technologies: an acoustic sensing system (DAS) and a distributed temperature sensing (DTS). This paper describe the pilot installation.

Session C5: Interfaces an modelling of DC cable systems

Chairman: KIM Jeongtae; Dept. of Electrical Eng., Daejin University, Korea

Rapporteur: BOYER Ludovic; SuperGrid Institute, France

General Comments about the Session:

The session C5 on the subject of "Interfaces and modelling of DC cable systems" was composed of four presentations. The study results from the first two presentations were based on electromagnetic transient simulations while for the two last papers, it was supported by the use of finite element methods and analytic modeling.

Both the content of the papers and the presentations were globally very good.

Paper C.5.1: Overvoltages experienced by DC cables within an HVDC transmission system in a rigid bipolar configuration

This presentation was a special communication from Cigré JWG B4/B1/C4. it proposed an evaluation of characteristic overvoltage transients in the rigid bipolar configuration. The selected electromagnetic transient simulation results highlighted the different performance related to transient voltage stresses occurring in symmetrical monopolar schemes. Related findings would help stakeholders to develop an understanding of the rigid bipolar configuration, and therefore to contribute to ongoing discussions within the community.

Comments from the audience:

As it is important for the impact study on cables, are computation of rise time of the transients done and reported? Close to the defect rise time is sharp but magnitude is lower than far away from the cable. The comment was taken as an input for future work in the group.

During a fault, is the healthy cable under risk? This is being evaluated in the JWG. However, it was reminded that tests results have been published on previous conferences and that reproducing such slow transients in laboratory is difficult.

Are sensitivity studies dealing with the cable parameters performed? Sensitivity on insulation thickness for instance are taken into account.

What about studies on LCC type converters? Focus is on MMC as the subject of LCC as already been addressed.

Paper C.5.2: Approach for a comprehensive definition of the electrical interface between HVDC converter and cable

For high voltage direct current (HVDC) projects, it is important to describe the electrical interface between converter and cable system thoroughly. The interface in this respect is defined by continuous and transient voltage and current parameters. The actual stress levels and wave shapes occurring in an HVDC cable system differ from standard test parameters. In this paper, a set of parameters is derived based on the analysis of occurring transients utilizing electromagnetic transient simulations. Since the stress levels depend on both cable system and converter design, an iterative procedure to derive project specific values is proposed.

Comments from the audience:

The difference between rated and ripple voltage is taken into account during operation. Is it taken into account during qualification tests? Yes, it is. The presentation highlighted that the definition of U0 can be misleading

Paper C.5.3: Modeling of the Thermoelectric Performance of a ±320 kV HVDC Underground Cable System

For this presentation, analytical and finite element modeling based methods were used to examine the thermoelectric performance of a ±320 kV HVDC underground cable system. The study was performed for both cable and joint in either steady-state or transient conditions in order to analyze the different phases of a long term pre-qualification (PQ) test. The presented results facilitate the theoretical assessment of the cable system actual performance prior to its real PQ test.

Comments from the audience:

How to incorporate space charge phenomenon in the analytical calculations? The models are based on the Maxwell equations, meaning that the materials are considered to be defect free.

Is verification with experiments, like measurement of leakage currents planned? PEA method is being currently used in testing to verify the results from simulation and complete them with addition of more detailled models if needed.

Paper C.5.4: Disruptive modelling of HVDC insulation system electrical properties from ab-initio material analysis

In the frame of simulation of the electrical properties of HVDC cable insulation, a new model approach based on Markov model and local evolution was presented. The aim was to simulate the electrical properties of the cable insulation by considering both influencing physical and chemical heterogeneities and to highlight the impact of micro-structure modification over time on these electrical properties. The proposed model is stochastic and is based on local interaction calculation instead of global criteria. Its main strengths are the simulation of DC electrical behavior of polymers only from physical and chemical material analysis and simulation of system evolution with a faster solving time.

Comments from the audience:

What is the next step? Take into account the ageing of the materials

Session C6: Cable rating
(Cables and Accessories – design and modelling)

Chairman: DU PLESSIS Thinus, DNV GL, The Netherlands.

Rapporteur: LESUR Frédéric, Nexans, France.

Four papers and a special communication (report of a CIGRE working group) were the material of this session, attended by approximately 85 delegates. The current rating is an essential step in the design process of a cable system. Many calculation analytical elements are provided by international standards, but complex configurations are covered by more sophisticated tools such as FEM applications. They often deal with specific environmental conditions and bring solutions to hot spots. The session was a wide overview of efforts made to outreach the existing methods, to model and simulate, to get experimental data to consolidate the background and to verify the quality of the calculation from a validated technical baseline. Finally, the best is yet to come with great prospects of dynamic rating applications, for which the reliability of the current rating calculation is a key input data.

Paper E.7.19: **Pure Mathematical DLR Model for Implementation in Embedded IT Systems – Modelling Principles and Accuracy**

The paper presents the Danish transmission system operator's development of Dynamic Line Rating algorithm which allows full integration with the SCADA system. When fully developed. the model can be directly built into the SCADA system. thereby allowing SCADA-integration of the operational criteria set out by the DLR. The DLR algorithm is based on a bilinear autoregressive moving average (ARMA) model representing the dynamics of the cables. The model shows good accuracy compared to the expected results obtained via IEC methods.

Paper C.6.2: **Ampacity calculation of multiple independent cable systems in ventilated tunnels**

In 2017, the standard IEC 60287-2-3 for the calculation of the current rating of cables installed in ventilated tunnels was published, however, the method is not suited for applications with multiple independent cable circuits. A new and extended analytical method was developed to allow for the calculation of multiple different cable systems or other heat sources in ventilated tunnels. The numerical method consists of a thermal network representing axially connected slices of the tunnel cross sections.

Paper C.6.3: **Extended approach for calculating thermal stress and ampacity of high voltage cable systems based on experimental data**

Thermal rating calculations of high voltage cable systems are normally performed using either analytical or numerical methods. Nevertheless, both methods face problems through simplifications, approximations or the insufficient modelling of the surrounding soil. The High Voltage Test Laboratory Graz Ltd. is currently developing an extended approach, which combines these methods for higher accuracy. The research so far shows, that a more detailed modelling of the surrounding soil as well as an increased region to be discretized can improve accuracy.

Paper C.6.4: **Novel Cooling Technique for Cables Crossing a Road Ramp**

The aim of this study is to perform ampacity calculations for a cable system consisting of three duct banks installed at a depth ranging from 20 to 29 feet crossing a 50 feet wide ramp, with 3 feet depth from the existing ground and 35 feet center-to-center separation. There are six cables in a duct bank, in order to assure required cable rating, the design team is planning to drill three 5' OD boreholes horizontally crossing the ramp with air flowing through the boreholes to take away the heat generated by the cable circuits crossing the ramp. The paper discussed the assumptions, the model and the results.

Paper C.6.6: **Overview of CIGRÉ WG B1.56 regarding the verification of cable current ratings** (Special communication)

To ensure that calculation tools compute the current rating of a power cable in a trustworthy manner, a set of 11 case studies is provided where MV. HV. AC and DC cable systems are considered in land and submarine applications. 40+ guidance points were developed which provide clarifications, additions, or changes to the existing IEC standards for current ratings to ensure that individual cable specialists using different tools, techniques or computer software can find the same, consistent current rating in similar cases. In this paper, key learning points are shared and a new CIGRE Technical Brochure (TB) is announced.

Session C7: Cable rating (armour losses and dynamic effects)

Chairman: MOUTASSEM Wael; USi, USA

Rapporteur: GODARD Alexandre; RTE, France

General Comments about the Session: This session, comprising five papers, dealt with the modelling of complex phenomena not fully covered by IEC standards such as armour losses for HVAC submarine cable systems, thermoelectric rating calculations for HVDC systems and prediction algorithm for underground cable temperature. In order to move further on these topics, authors introduced several methodologies including 3D finite elements approaches, laboratory measurements and other innovative engineering approaches, to overcome these challenges.

Paper C.7.2: DC Cable Thermoelectric Rating Design

The paper presented several failure mechanisms occurring for HVDC cable interconnectors operating at or being designed above 320kV and where rating calculation no longer only depends on the conventional IEC 60287 but also gets constrained by insulation thermoelectric limits. Qualitative understanding of these failure mechanisms and associated mathematical models are provided by authors to deal with these thermoelectric aspects.

Paper C.7.3: Endowing a configurable and computationally light underground cable temperature prediction algorithm with real-time rating capabilities

The paper presented simplifications to a temperature prediction algorithm for underground cables initially developed some years ago. The methodology principles are presented and results illustrated successes in accounting for variation in ambient temperature, which can include the effect of external heat sources, and accounting for moisture content variation and moisture migration.

Paper C.7.4: Fast Modelling of armour losses in 3D validated by measurements

The paper presented modelling of losses of armoured submarine cables using 3D Finite Elements. The FEM models were based on measured magnetic properties of the armour material and the use of a coarse mesh in order to shorten the calculation time. The modelled total losses and screen currents were confronted and validated against measurements performed on long cable samples and also compared to IEC 60287 calculations. The 3D models predicted total losses lower than IEC and also a different distribution of losses between the screen and the armour than IEC.

Paper C.7.5: An electrical method for measuring the complex magnetic permeability of steel wires

The paper described a method for the measurement of the complex valued relative magnetic permeability of steel wires. Fundamental conditions of the set-up, the configuration of the electromagnetic field (also compared to more standard measurement methods), as well as the applicability of the results for loss calculations within steel wire cable armouring are discussed.

Paper C.7.6: Parametric analysis of three-core submarine power cables by means of simplified 3D FEM simulations

The paper addressed the design, modelling and evaluation of impedance and power losses in submarine cable through parametric analysis and simplified 3D FEM simulations. The authors evaluated the impact on the evaluation of these parameters according the modelling approach selected comparing 3D FEM models to 2D FEM model. Results showed that the relative twisting between phases and armor has an important influence on these topics, leading in some circumstances to numerical values far from being similar to those obtained through 2D FEM approaches.

Session C8 : Modelling of HV and EHV cable systems

Chairman: **PILGRIM** James; Univ. Southampton, UK

Rapporteur: **BARATON** Philippe; EDF R&D, France

General Comments about the Session :

The sessions deals with modelling of cables systems. The session has had a good success with approximately fifty people in the room. Fives paper have been presented covering thermal, electrical and chemical modelling.

Paper C8.1: 3D FEM analysis of armour loss in three core submarine cables

This paper deals with the calculation of the electrical losses in the three conductive components of the three-phase submarine cables (Conductor, lead sheath, armour) using 2D and 3D finite element models and compares the results obtained with the analytical model proposed by the IEC 60287. A first modeling shows that the 2D model leads to get a good estimate of these losses with shorter computation time. This model FEM 2D is then used to evaluate the factors λ1 and λ2 of the IEC according to the size of the conductor and to compare them with those suggested by the IEC. The authors show that in all cases the values of these losses are lower than the IEC's values. The last modeling concerns the evolution of the factors λ1 and λ2 as a function of the thickness of the lead sheath. The authors confirm the trend stated by the IEC that the thicker the screen is, stronger are the losses in the sheath and consequently weaker are the losses in the armour. The authors show again, that the loss values evaluated by their model are lower than those of the IEC.

Paper C8.2: Impact of Laying Conditions on Temperature Distribution in HVDC Cables Based on Numerical Simulations

This paper deals with thermal modeling of HVDC cables. The first part is the presentation of an analytical model and its comparison with a numerical model. The agreement between us is considered satisfactory for simple configuration. Nevertheless, numerical modeling allowing to study more realistic cases, it has been chosen by authors to perform several influence studies as : influence of the laying depth, influence of the distance between cables, influence of the soil surface temperature, influence of the current, influence of the soil moisture and finally influence of bedding materials. The mains results are the finding of a homogeneous variation of the temperature of the cable for parameters like laying depth, distance of conductors soil surface temperature, and vice versa the finding of inhomogeneous variations for the others parameters.

Paper C8.5 Numerical analysis of methane degassing from XLPE Insulated cable: role of cable conductor

The purpose of this paper is to present a numerical modeling of methane degassing in a cross-linked polyethylene insulation (XLPE) cable. Based on experimental data on a 66kV cable, the study consists of evaluating with both an axisymmetric 2D model and an inverse method the coefficients of diffusion of the inner, central and outer parts of the XLPE insulation layer. The knowledge of these parameters leads to deduce the time evolution of the methane's concentration in the 3 parts of the insulation layer. The inverse calculation results shows that the diffusion coefficient of the conductor is comparable to the other cable components. The study shows that a non-negligible part of the methane is transferred to the conductor. For example, after 8 days of degassing process, the remaining methane within the polymer is less than 50% of the global remaining methane in the cable.

Paper C8.6: Transient overvoltage distribution in sectionalized screens of HV joints

The aim of this publication is the study of the type of bonding lead cable used for connect cable's screen to Surge Voltage Limiters in case of sectionalized links. The authors study unipolar and coaxial configurations and show that the unipolar configuration leads in a first hand to higher over voltages (x3) , and in an other hand, are equivalent to extend the length of the link (x5 to x12 depending on the length).

Paper C8.7: Estimation of the Remaining Life Time of Oil-Filled Cable Systems Based on Mathematical Modelling their Electrical Insulation Ageing Process

The authors present an original mathematical model of ageing of oil filled cable insulation. This model focus on the degradation of the impregnated paper dielectric et take into account particularly the effect of the temperature on the tangent delta indicator. According to the authors this new model is more general than the previous ones. In this paper an application of this model is carried out on a 220 kV 5-circuit cable system. The mains results show than the remaining service life of the central circuit is shorter than the peripheral circuits, due to hotter temperature conditions.

Session C9: Development of accessories

Chairman: UZELAC Milan ; G&W Electric, USA

Rapporteur: SALAME Basil ; Nexans, France

General Comments about the Session : This session, comprising four papers, dealt with HV connectors, joints and terminations design, testing and maintenance. The main topics discussed were the thermomechanical and electrical stress control at the joint, the arc phenomena in cable terminations and the introduction of digital technologies in the power industry asset management.

Paper C.9.2: Analysis and Testing of Internal Arc Phenomena in Gas Insulated Outdoor HVDC Cable Termination up to ± 640 kV

In this paper NKT investigates the impact of internal arc event. This is supported by high-current arc tests performed by KEMA B.V. with the aim to simulate an internal fault in HVDC cable terminations up to ±640 kV. Successful results confirm the robustness of the HVDC cable terminations.
Besides, authors present the points to take into consideration when designing the termination for internal arc robustness and raise an awareness about the lack of an international standard regulating the internal arc test requirements for HVDC cable terminations.

Paper C.9.4: Technical evolution of high power EHV systems 2500 mm² aluminum screwed connectors according to IEC 61238-1 and safety of 420 kV AC oil filled terminations

Nexans developed a new screwed connector for 2500 mm² Milliken Aluminum conductors. A safe (no risk of fire) and reliable solution that doesn't need any specific tool to be installed. The current capability has been validated using a scope of tests aligned with IEC 61238-1.
Moreover a new blast proof termination or anti-explosion system has been developed to reduce the hazard when safety distances regarding electric installation are reduced. The system reliability was confirmed by the internal arcing and the normal short-circuit tests.

Paper C.9.5: Development of Augmented Reality (AR) application for cable terminations and joints

In this paper G&W Electric explores a possible customized application of Augmented Reality (AR) technology for maintenance of power cable terminations and joints. It will be used both in the training facilities and in the field. Authors discuss some of the major challenges related to developing virtual platform with menus, commands and logic behind it, and the ways they can be overcome.

Paper C.9.6: Qualification of a 220 kV transition joint to connect MI pipe-type cable with extruded single-core cables

Under the request of the French transmission system operator, Nexans designed and qualified a new 220 kV dry transition joint to connect paper insulated MI pipe-type cables to single core XLPE-cables. This joint design can be used either for low or high-pressure oil filled cables or for gas pressurized cables of the different types.
This paper details the joint design and the tests performed as per IEC 62067, CIGRE TB 415 and RTE specification to qualify it.

Session C10: Dry type accessories

Chairman: MAMMERI Mohammed; Prysmian, Italy

Rapporteur: AIT AMAR Abdellatif; Nexans, France

Six papers were presented during the session with a specific focus on dry accessories and different topics such as the modeling and calculations in HVDC dry terminations, design of dry accessories especially for terminations with different designs.

Paper C10.1: **Electro-thermal simulation methodology for HVDC cable GIS termination**
This study explained how mastering the electric field distribution under DC voltage application is a key element in high voltage insulation design. Indeed, the electric field distribution is more complex to predict as the field depends simultaneously on the permittivities and conductivities of the insulating materials. In this paper a simulation methodology for HVDC GIS/cable termination is proposed under different operating conditions considering all the materials properties and their dependence on temperature and electric field.

Paper C10.2: **A unique dry 145 kV prefabricated one-piece self-supporting outdoor cable-termination**
The contribution introduced a new type of dry cable prefabricated termination qualified according to IEC 60840 up to a rated voltage of 145 kV. The design is based on a conventional self-supporting fluid filled outdoor cable termination where the fluid is replaced with a soft rubber (gel), no filling in the field is needed, and the stress relief cone is relatively long compared to a conventional stress relief cone for the same voltage.

Paper C10.3: **Design and Qualification of 500 kV dry terminations and joints for extruded cables**
This paper highlights a design approach for 500 kV rated terminations and joints, provides underlying reasoning and describes steps undertaken in qualification and testing of these accessories. The author exposed how this design philosophy translated in selection of the materials, product design, manufacturing and field challenges and development and implementation of testing programs of the cable system with the different type of accessories and their results.

Paper C10.4: **New generation of dry type high voltage termination**
The subject described the development of a new type of dry type termination that was developed for voltage classes up to 170 kV. This novel solution is based on a new insulation material which behaves like a gel and is specifically developed for high-voltage cable accessories. The development, design and performance are explained in detail and the paper concludes with the summary about the already conducted type tests and the relevant operation experience.

Paper C10.5: **Development of Self-supporting Dry Type Outdoor Terminations for 100 kV Extruded Underground Cable Connection in AIS Substation**
A design of dry Self-Supporting Outdoor termination has been designed, tested and qualified. As a prefabricated accessory, main components are electrically tested in factory before delivery. The SSO terminations have been subjected to enhanced extended development and qualification tests. The time to install the termination is short and can be further reduced by pre-installing the plug-in in factory. The SSO termination can be installed to retrofit an existing fluid-filled termination.

Paper C10.6: **A High Voltage Dry Type Outdoor Cable Termination**
A new principle of dry type outdoor cable termination combining two filed control methods from different HV products and designs which are established in the HV technology has been described: the capacitive field grading and geometric field grading. Furthermore, the development and proof of concept for other types of dry type cable terminations for oil, gas and indoor application will be investigated.

Session D1: Non-Electrical Tests

Chairman: KVARTS Thomas; Orsted Wind Power as, Denmark

Rapporteur: CALVERAS Daniel; Prysmian Group, Spain

This session, comprising six papers, dealt with Non-Electrical tests for LV and HV/EHV cables. Cable manufacturers are provided with innovative methodologies to be used in their cable project developments.

Paper D.1.1: Test Regimes for HV and EHV Cable Connectors

This paper introduces the final report TB 758 of the CIGRE WG B1.46 proposing test regimes for connectors for high voltage (HV) and extra high voltage (EHV) cables. As there is no IEC standard for testing HV/EHV connectors, the task of the WG was to review existing cable connector designs, collect available experimental data, service conditions and performance of connectors in the field, including highly loaded systems, and propose thermal and mechanical tests with special attention to connectors for large cable conductors.

Paper D.1.3: Full-scale compression capacity test of an offshore power cable

This paper describes a full-scale test designed to trigger lateral buckling failure in the cable cross-section of a static power cable. The main purpose of the test is to estimate the compression capacity of the cable and gain a better understanding of local buckling phenomena for power cables in compression.

Paper D.1.4: A calorimetric measuring system for measurement of loss in high voltage cable conductors

A calorimetric measuring system for measuring the ratio between AC and DC resistance, R_{AC}/R_{DC}, of high voltage power cable conductors has been designed and constructed. An uncertainty analysis predicts that the ratio R_{AC}/R_{DC} at 90 ºC of a 2500 mm^2 cable of low loss design can be measured with an uncertainty of 1,0%. But the uncertainty of an actual measurement was larger due to unresolved sources of uncertainty.

The influence of the temperature of the cable ends relative to the ambient temperature and its uncertainty contribution need to be further investigated.

Paper D.1.5: Curative maintenance to be accounted for in compliance tests

RTE, French TSO, is in charge of development, operation and maintenance of the HV network in France including HV connections of offshore wind farms.

Curative maintenance shall be taken into account at early stages of project that is to say when setting parameters and cover repair loads, RTE has worked on the calculation method and proposed to upgrade the CIGRE's formula, including how to take into account the added mass of a rigid joint.

Paper D.1.6: Relevant accelerated corrosion tests for buried low voltage power cables

This study proposes a specific accelerated ageing procedure as a corrosion test for low voltage power cables in a salted atmosphere. This test emphasizes the fast consumption of zinc and thus the weakness of the galvanized steel tape after a long period of time, leading to a possible reduction of neutral diameter. Some other materials proposed for the new design should allow a much longer lifespan of the power cable thanks to a better compatibility between screen and neutral in the cable exposed to a very stringent corrosion procedure.

Paper D.1.7: Online monitoring of the cross-linking process of XLPE-insulated power cables during cable production using ultrasound.

In material investigations, the relationship between the degree of cross-linking and the sound velocity of the XLPE has already been demonstrated. Based on this, the cables samples are scanned with ultrasound. From the determined wall thicknesses and the measured sound propagation time, the sound velocities of the different cable core samples are calculated. As a result, the cross-linking of a cable insulation system can be evaluated by focusing the sound velocity. The increasing trend of the sound velocity with decreasing cross-linking goes with the results of the material investigations.

Session D2: Onsite and laboratory tests

Chairman: CLASEN Geir; Nexans Norway, Norway

Rapporteur: DUBOIS David; Nexans France, France

General Comments about the Session:

During this session 5 papers were presented. Testing is the essence of confidence and reliability. This applies to the whole life of a system, from design and development to the maintenance and extension with different technology when products are no longer developed but still exhibit good operation service. Proven test procedures and innovation are part of the testing evolution and these papers are addressing some major concerns of the utilities.

Paper D.2.2 Cable system commissioning update

After having shown a comprehensive list of possible defect types in MV cable systems the authors are reporting several experiences where 50/60Hz-with-PD-measurements commissioning tests have shown their superiority against VLF with tan delta tests to detect potential failures in MV (up to 35kV) cable systems.
The need for suitable and efficient commissioning test including PD measurement is recalled.

Paper D.2.3: Air insulated factory routine test system for HV accessories up to 550kV

SF_6 is still the most commonly used gas for filling up empty compartment of gas-filled type of accessories. The authors have carried out theoretical and experimental studies aiming at replacing this gas known for its green-house contribution by pressurised air. There are claiming that further to their studies compressed air could be a substitute to SF_6 for the pressurisation of coupling devices for the routine test of extra high voltage polymeric accessories.

Paper D.2.4: Sensitive and selective partial discharge measurement method for DC and AC cable joints

A PD measurement method is presented. It is based on PD discrimination by capacitive bridge and exhaustive PD collection. This is peculiarly applicable to PD measurement under DC voltage whose main characteristic is a low repetition rate. It could also be used as a discrimination method for AC application. The PD measurement presented method is suitable for development test monitoring, for monitoring on site / in service some issues must be solved.

Paper D.2.5: Performing of type test for the qualification of three-core submarine cable and accessories for connections of offshore wind farms

A type test was carried out on a 3-phase submarine system as per CIGRE TB 490 and IEC 60840. The cable had the magnetic armour on. Three phase heating current was used. Land cable and submarine cables were tested in the same test loop, owing thermal insulation on the land system to achieve the rated conductor temperature for both cable designs.

Paper D.2.6: 138kV transition joint between High-Pressure Fluid Filled and XLPE cables

USA still have a lot of Pipe-Type cable systems in service, some of them being up to 70 years old. To allow the network expansion and its maintenance a 138kV transition joint with XLPE cable has been developed and qualified as per a type test program including electrical, mechanical and thermomechanical aspects.
Short-circuit test on the joint were carried out as well. The service record of this quite new accessory type is excellent. Performance tests have demonstrated a comfortable design margin.
Likely the market will soon ask same type of joint at the 230kV and 345kV levels.

Session D3: Partial Discharge Methods and Measurement

Chairman: FENGER Mark ; Prysmian Group, Canada

Rapporteur: CASTELLON Jérôme ; University of Montpellier, France

General Comments about the Session : In this session, followed by around 80 attendees, five papers dealing with « Partial Discharge Methods and Measurement » have been presented by utilities, academia and test companies. Mainly, the presentations were focused on PD measurements techniques applied directly to power cable mostly under AC stress. Towards these presentations, PD measurement are mainly used as a diagnostic and defects localization tool for cable lengths. Chairman and Rapporter highlight the numerous questions asked to the authors and voluntary limited to 4 questions per presentation.

Paper D.3.1: Fifteen Years Damped AC On-site Testing and Diagnosis of Transmission Power Cables

Based on the international experiences as collected in the last 15 years at different power grids this contribution focuses on the use of DAC for after-laying testing and diagnosis of all types of transmission power cables. In particular supported by practical examples different important aspect of testing new connections as well as condition assessment of service aged power cables will be mentioned in this paper. Following her presentation, discussions arose around PD sensitivity and PD assessment when testing new cables.

Paper D.3.2: Partial discharge inception voltage and magnitude under AC and DC voltage supply

In this paper, the ratio between partial discharge inception voltage, PDIV, under AC and DC voltage supply is estimated by an analytical model. Despite the simplifying assumptions, the experimental results confirm that the PDIV in DC can be much higher than in AC, for the same defect, especially at room temperature. However, depending on material conductivity and the rate of variation of conductivity with temperature, the PDIV in DC can become lower than that in AC, at least for the typical XLPE materials used from HV AC and DC cables. Hence, PD can incept and extinct during operation as a function of cable loading, posing reliability problems for a cable insulation system that have to be taken care both at the design and at the commissioning stage. Regarding PD amplitude, this paper shows that the delay time distribution of firing electrons is the main cause of the difference between PD amplitude values measured in DC and AC. Questions were related to the influence of conductivity on PD behavior under DC.

Paper D.3.3: Application of PD monitored Voltage Withstand Test Method for High Voltage Power Cable Lines

Several key application aspects of PD monitored AC voltage withstand test method were discussed in the paper. A distributed PD measurement system together with a PD free AC voltage resonant test system, were used for such a test. PD detectors were installed alone the cable line at each cable joint and terminations. In order to make the PD level showed on each measuring channel comparable, a consistency of PD level for all PD detector units had to be checked. PD activities were monitored and all PD data were stored from the beginning of voltage regulation to the whole period of voltage test. No PD activity with recognizable PD pattern should be acceptable, which might be the recommended PD criteria of such a test. The absolute value of PD level was not so critical in the recommendations of this paper. The questions were realized to the duration of the withstand test and if the test should be interupted if PD is detected.

Paper D.3.4: Non destructive after laying test with PD localization

The paper describes the insights and thoughts to gain more knowledge from the after laying test of high voltage cable circuits. For improving the quality of Tennet cable grid, Tennet is looking for after laying and diagnostic test methods which are non-destructive and provide information about possible discharges within the cable system. The presentations discussed not stressing dielectrically beyond the point of the inception voltage of PD activity. Additionally, by not testing until breakdown the damage control and repair can be done in an improved way. Also a better root cause analysis can be done since the fault location is not completely destroyed due to a breakdown. In this paper more clarification is given on basis of a practical case study. The presentation generated considerable and animated discussions on acceptance testing practices of new cables.

Paper D.3.5: partial discharge localization of gas pressure cable routes through double sided-synchronous-multi point-measurement

The scope of this paper dealt with a detection method that allows the localization of PD events within an investigated cable route. To obtain a sufficient signal to noise ratio, despite high cable attenuation and cable lengths greater than 2 km, a redesigned measurement setup as well as corresponding measurement data was presented. Following the presentation, discussions arose on the influence of dielectric temperature on the PD magnitudes detected.

Session D4.1: Partial Discharge Methods and Measurement – Equipment

Topic 3: Testing Methods: Electrical and non Electrical

Chairman: KIM Jung Nyun; LS Cable, Korea

Rapporteur: SANTANA José; Prysmian Câbles & Systèmes, France

General Comments about the Session : very interesting session where we have regarding Partial Discharge measurement several approach. We have a field testing approach, new equipment experienced, up to 500kV testing qualification of equipment's and numerical model of phenomena interpretations.

Paper D.4.1: Optimized test setup and decoupling strategy for onsite partial discharge measurements

The advantages of pd measurements have led to a frequent implementation into after-installation AC-tests for high voltage cable systems. Both the technology for providing the test voltage and the pd measurement devices and techniques have undergone a constant improvement process. However, a main aspect of improvement is often left unconsidered: Optimizing the existing and field-tested equipment with adequate arrangements at the test site can increase the sensitivity of the measurements greatly. To achieve this, the measurement frequency has to be taken into account as well as high voltage and earth connection components including their dampening characteristics.

One the solution is to use high frequency current transformer (HFCT) at the screen wires. Laboratory test was done to compare rigid tubes and flexible tubes connections, with increasing measuring frequencies giving greats information's about the PD setup.

When changing setup integration frequency, it is needed to calibrate another time the PD device.

Differences been noted regarding the lengths of the connections between the cross-bonding joints to link box.

Paper D.4.2: Innovative PD Site Location Optimized for FAT in the Cable Industry

To measure PD detector been used since decades like using TDR methods. The theory of PD site location is described and discussed. A novel method introducing an innovative PD cable location procedure enabling fast, easy and accurate triggering on the PD pulse in the well-established Pulse Diagram (charge over phase) is presented. This approach ensures easy and accurate triggering of the investigated PD pulse and its reflections. Several practical examples of fault location in field are presented and discussed, including difficult failure localization, less than 20 meters from the far end of the cable. In conclusion, a reference is drawn to a new innovative approach enabling users to accurately discriminate failures located at the near and far end of the cable.

The use of this new oscilloscope approach, give accurate and clean PD measurement using advanced signal processing averaging function optimized for SL

Failure location is automatically calculated based on the propagation speed calculated during calibration step. It was detected a failure near or far from cable 240m length end, but limited to less than 20 from the cable ends.

Approach about the white noise, it uses fences of signal mathematical processing to avoid it.

Paper A.1.3: HV withstand test for a 500kV Power Cable Project Using 8 modular variable Frequency Resonant Test

This paper introduced the acceptance test in a 500kV long power cable test project. Based on the initial test parameters calculation, Eight modular type of AC resonant HV systems made in Germany were used with connection of two systems in series to reach higher voltage, then four in parallel to reach higher current based on China State Grid Cable Test Standard.This was the first time to use eight modular resonant systems in one test worldwide. Based on the Series & Parallel connection technology, not only the eight reactors, but also all exciting

transformer, all variable control systems had also to be interconnected each other to setup a communicating and controlling network. One control unit was acted as a master, all other units were acted as slaves in the network. Four diesel generators were used as power supply for the eight modular test systems. The tests were performed by SINDIA Instruments Co., Ltd. in Dec. 2017. One cable joint in phase A was broken down at applied voltage, all other phases of the cable lines passed the voltage withstand test.

This paper relates experience about test setup, with use of 8 resonant system connected in serie & parallel permit to increase the long power cable link up to 15,8km cross-bonding system project. This system increases the voltage and the capacitive current, but reaching as much as possible a higher quality factor Q value around 139 in this case.

Paper A.1.4: Procedures to qualify PD measuring instruments to use in the insulation condition of cable systems

Insulation condition of equipment and materials installed in HVAC and HVDC grids is evaluated using online PD measurements by means of PD analysers operating in the HF range (< 30 MHz). To achieve homogenous and comparable results during on line measurements, calibration of PD quantities and characterization of built in diagnostic tools of PD analysers according to standardized procedures are needed. This paper presents procedures to qualify PD measuring instruments used for insulation condition.

Monitoring PD calibrated using HF transformers been used, but discrimination of the PD is not easy and to ensure a qualification of the PD measured. For that, it is used a testing setup using different modules.

The sensitive factor requirement of 15 pC/mV is needed to reach a better accuracy of the results, by mathematical model to analyses transient signal. Two variables of the PD pulses amplitude and equivalent frequency is analyzed to detect and eliminate the electric noise.

This experience has leaded to review, qualify and have a good interpretation about the nature and the origin of the PD pulses sources against noise.

Paper A.1.5: Partial discharge propagation in high voltage XLPE insulated cables – measurement and modeling

The goal of this study is to develop a numerical tool that would allow for prediction of certain characteristics of high voltage (HV) cables necessary for commissioning testing. These characteristics describe both: power frequency and high frequency PD performance. This document summarizes the results of the measurement of a PD pulse propagation in a high voltage 230 kV cable and an attempt to model the propagation of such pulse using FEM. The results of the simulations show attenuation of the HV cable which agrees with the results of the measurement and the results previously published.

The author would challenge himself presenting the result of is numerical model. To achieve it, detection of PD pulses injected on a HV cable screen been done using PD sensors connected to an oscilloscope.

Developed numerical model, where 2-axisymetric model taking advantage of the cable concentricity. 230kV Cable model about 20m been modelized with finite element model. Several simulations been done which permit to compare the real measurement’s and the calculated model, and to get information’s about High permittivity of the semi-conductive layers effect like decreasing propagation and increasing attenuation and dispersion.

Session D6: Interaction of the Cable System with the Environment

Chairman: GILLE Alain ; Verbraeken Infra, Belgium

Rapporteur: DENIZET Isabelle ; Prysmian Group, France

This session deals with different topics related the existing interactions between cables links and their environment.

The main subjects developed are :

- Recyclability of the cable components
- Accurate models to measure soil thermal resistivity and optimize the ampacity calculation,
- Development of new backfill material with high thermal conductivity
- And a development of new aerial lines using insulated cables with enhanced characteristics

Paper D.6.1: No paper

Paper D.6.2: Recycled XLPE from cable waste

Today in cables, metal can be recycled but what about plastic materials ? This paper deals with solutions to recycle XLPE and reintroduce it in cable applications. First of all, to separate materials from cables, two initial methods can be used : Shredding (fast but difficult to separate the materials from each other) and Stripping (clean process but with low capacity). Six different recycled XLPE (flakes or powder) are described and analyzed. They can be re-used in compounds. In terms of applications, prototypes like cable drum, cable channel…have been done.

Paper D.6.3: Enhanced adoption of the two-zone model to implement the drying out of soil in ampacity calculations of directly buried cable systems for different types of soil

Due to heat injection of power cable, soil properties are modified. A method to implement the dry out of soil in ampacity calculation is proposed. The bedding is divided in two zones : dry and wet. A continuous function to describe the dependency of the thermal conductivity of the soil on the temperature within the bedding is used.

Probe extraction and examination, test field in laboratory and numerical modeling have been performed. Stationary and dynamic conditions are taken into account.

The resulting relation between the temperature inside the bedding and the heat conductivity of the soil is a continuous function which can be seen as a refinement of the two zone models.

Paper D.6.4: Fluidized and Self Compacting Backfill with High Thermal Conductivity for Underground Insulated Cable Systems

This paper presents an R&D study on the development of a fluidized, low thermal resistivity backfill to apply on underground cable systems.

This includes first of all the selection of specific materials based with a appropriate properties. Main ones are density, granulometry and of course thermal conductivity. Volcanic materials are good candidates. Appropriate binders have also to be selected. In a second step, an evaluation of the characteristics of the new backfill and developments of laboratory procedures to evaluate the performances are detailed. To conclude, an example of cost benefits is shown : the use of this new backfill allows a 11% of cost benefit in a global cost of 138 kV cable link implantation.

Paper D.6.5: MV self-supported insulated cables, a reliable and eco-friendly solution for protected and forest areas

This paper presents a development project to implement MV insulated aerial lines in particular in forest areas. In these areas, different environmental constraints are encountered (hard wind, temperatures, fauna…) and insulated cables show advantages (maintenance budget, number of incident with Avifauna, reduced ROW…) The system approach covers insulated MV cables and all accessories associated (messengers, joints and terminations, clamps, tower design, sectorization and derivation). The main challenges are the weight of bundle cables, climatic aging, design of clamps…A pilot installation has already been implemented.

Paper D.6.6: Estimation of the thermal resistivity of backfill materials using a practical approach

In this work, a model for thermal conductivity calculation of backfill material with only geotechnical index properties as input parameters is presented. The objectives are mainly increased focus of utilization, security of supply, higher capacity and obtaining accurate calculation tools.

Some laboratory experiments were performed on steady state. The model gives results on transient state. The results show that calculated values agrees with measured datas . The accuracy from transient-state experiments is about 15% compared to model results whereas results from steady-state experiments are within 10% of accuracy.

Session D7: System considerations for sustainability

Chairman: ZHONG Lisheng ; Xi'an Jiaotong University, China

Rapporteur: SARTIEAUX Anne-Catherine ; Nexans, Belgium

General Comments about the Session: Sustainability is the key word in this session. Discussions will turn around how HV cable systems interact with their environment. How can we adapt cable designs to be more eco-friendly? Can we limit pollution in case of breakdown or maintenance on HV accessories? What are the consequences on cable assets of the increasing large disturbances in the world? Can we use and validate temperature rises with calculations? Why is Vietnam a good candidate for growing HVDC links?

Paper D.7.1: Special communication – Eco Designs in Power Cables – a Case Study

Due to the DSO and TSO paying more attention to the sustainability aspects of power cables, ECO designs are on the rise. The Lifecycle Design Strategy identifies the product modifications that could make a power cable more eco-effective throughout its whole life span. This paper presents a qualitative method to compare a traditional and an alternative eco-design. A comparison of designs is made for a single core medium voltage cable and the case study of a 50kV project is described.

Paper D.7.2: Qualification of a fully dry 225kV cable system from outdoor terminations to GIS & transformer terminations

This paper describes the qualification of a fully dry 225kV cable system demonstrating the feasibility of fluid free cable systems. It cancels the risk to contribute to greenhouse effect or to soil pollution in case of maintenance mistake or in case of any malfunction. The tested cable system consisted in a cable, a joint, a GIS termination inner cone design, a GIS termination outer cone design, an outdoor termination and a transformer termination. The prequalification test and type test (IEC 62067 and IEC 62271-209) were successfully completed. The transformer termination, type tested in a separate loop, was mounted in a back to back configuration in a stainless-steel enclosure.

Paper D.7.3: Behaviour of Cable Systems under Large Disturbances – Status Report

The paper details the findings from earthquakes, bush fires, storms and ice storms and shares how these events have affected cable assets. It is important to work on a planning and design modifications prior to installation: it will minimize and even prevent the disruption of an underground power system. For example, seismic impacts can be limited by performing a detailed foundation design study. Bush fires impacts due to broken overhead conductors sparking when striking the ground are to be reduced using advanced resonant earthing systems incorporating Ground Fault Neutralisers (GFN). No reported cases of damage on buried cable circuit. Ice storms can cause important damages on overhead lines, in this case underground cables can take over.

Paper D.7.4: Long Term Temperature Measurements Compared with Transient Calculation acc. To IEC 60853-2

HelWin1 DC cable system has been installed in UNESCO Wadden Sea natural reserve with the permit requirement of a very limited thermal impact of 2K increase limit compared to the undisturbed soil in a depth of 30 cm below surface. To attain this, design calculations according IEC 60287 and IEC 60853-2 were carried out and temperature monitoring was installed to validate these calculations. This paper shows the results of the measurement campaign : the 2K-limit was never transgressed. The calculations gave sufficient accuracy for cable design even at transient conditions. Soil data and load profiles being conservative, it gives a safety margin for the cable design and environmental footprint.

Paper D.7.5: Prospects for HVDC links in the electricity network of Vietnam

Vietnam is a rapidly developing country: the primary sources of energy will shortly change and thus the electrical grid of Vietnam will need to deeply evolve and strengthen. The demand in energy is estimated to twice as of today in a twelve-year span. The split in energy sources is clearly a coal-fired thermal power supply with a stable capacity of hydropower over the coming years and renewable energies showing an upward trend. Vietnam has a huge hydropower potential which accounts for almost half of the total installed capacity of the country. However, coal-fired power plants constitute the main development strategy due to lower investment costs and shorter construction time but is not in line with COP21 CO_2 emission reduction targets. Besides these two power supplies, Vietnam has also a major potential for renewable energy – wind and solar, but with a major disadvantage being indeterminate and difficult to predict. The introduction of these renewables energies must go with a strong transmission and distribution grid with strong interconnections to neighbouring power markets. Hydraulic energy storage could be a solution, using batteries another one. HVDC energy links will most probably be integrated as a way to stabilize the network.

Session D8 : Risk Assessment and management of cable systems

Chairman: SMIT Jacco ; TenneT, The Netherlands

Rapporteur: DURCIK Elie ; EDF, France

General Comments about the Session : This session, which included six papers, was dedicated to last experiences and new methods which could be implemented to improve the risk assessment and management of cable systems. This topic is very large and covers all levels of tension and cable technologies, and all stakelholders are involved by this topic (manufacturers, sub-manufacturers, suppliers, legislators,…). More than 70 delegates attended the session.

Paper D8.1: Risk management in the presence of partial discharges in HV joints by means of periodic monitoring

Internal partial discharges (PDs) are dangerous because the time to breakdown is short and not predictable, but there are some cases where a proper knowledge of the PDs patterns, the accessories and cables designs, and a suitable PDs measuring equipment and personnel, may allow a certain time of extra service with controlled risks, making possible the programmed replacement of the accessories with PDs. This paper presents an eight-month real case on 66 kV cable joints maintained energized with quite severe PDs, and the associated risk management plan that allowed a controlled service life until the removal of the joints, as well as the results of the autopsy performed on the joints, and their link to the measured patterns. The importance of the measurement methods, training for jointers, on-site quality protocol and documentation is pointed out.

Paper D8.2: Challenges of cable engineering from offshore to onshore and project to operation

As one of the German TSOs, TenneT TSO has installed more than 4,000 km of EHV cables, especially HVDC cables in the German offshore and coastal areas for offshore grid connection projects in the last ten years. Approximately 2,000 km HVAC and 3,000 to 4,000 km HVDC cables will be realized in different grid extension projects in the grid regulation zone of TenneT Germany until 2025 additionally. This paper gives an overview about the challenges in the field of cable engineering from offshore to onshore projects and further from projects to Operation. Quality Assurance (QA) and Quality Control (QC) are essential issues for TSO but at another side the risk, performance and cost shall be balanced in order to keep the energy as affordable. Available monitoring systems are reviewed and compared, and other tools are presented, like Third Party Damage Probability Assessment, RPP (Repair Preparedness Plan) and SLA (Service Level Agreement).

Paper D8.3: Quality Control of HVDC Cables - The next industry challenge

HVDC cable systems will see a large increase in manufactured quantity, voltage and power levels and grid criticality. With decreasing design margins due to higher stresses and temperatures there is a need for increased and additional Quality Assurance and Quality Control. New technologies are created faster than organisations like CIGRE, IEC and IEEE can catch up with in terms of internationally agreed upon recommendations and standards. This article describes in a logical manner the increasingly challenging industrial environment that leads to this conclusion. By comparing some historical HVAC facts, compelling suggestions are made for directions and areas of additional Quality Assurance and Quality Control methods. In particular, specific areas of attention for (extruded) HVDC cable systems are Conductivity, Compatibility and Chemical composition. For example, under DC voltage, the electric field is controlled by the conductivity and the permittivity. The conductivity is strongly dependent on temperature, electric field, time and chemical constitution, but today standards and recommendations do not control the conductivity or the parameters influencing the conductivity. The proper QA and QC methods that are needed are best developed by cable manufacturers, because they have the deepest knowledge of the peculiarities of their newest products. Considering the huge economic and social values ahead there is no time for waiting; and therefore implementation of new QA and QC should happen directly with the introduction of the new technology. It should be part of the development phase.

Paper D8.4: Enhanced Overvoltage Protection for Reliability beyond the First Decade

Within the first few years of operation, the AC breakdown (ACBD) voltage of new cable insulation is quite high, but typically drops within the first decade to a fraction of the original value. Adequate overvoltage protection is essential for long solid dielectric insulation service life and case studies indicate that cable could significantly benefit from better protection. In particular, one utility-scale study involving thousands of kilometers presented indicates that, as part of a condition-based reliability program, moving from a 50 % to 97 % compliance with better overvoltage protection yields a correlated 36 % improvement in reliability and show how a combination of

improved overvoltage protection and the removal of discrete defects can significantly improve cable reliability and therefore extending its useful life for decades. 2 additional case studies point out the impacts of fault location or switching transients on existing defects. The paper ends up with some recommendations to deal with aging problems on cables in relation with the risk of transients.

Paper D8.5: European Subsea Cable Association: providing technical advice to manage the life cycle of subsea cables

This paper presents and summarizes the organization and role of the European Subsea Cables Association (ESCA), which is an organisation of submarine cable owners, operators and suppliers primarily aimed at promoting marine safety and protecting subsea cable installation, maintenance and operation in European and surrounding waters, and which up to now has published 19 guidelines covering technical issues but also topics such as stakeholder management. Technical guidelines are a helpful tool to manage subsea cable projects over the life time of a cable. They help establish good practice and cost effectiveness. Nevertheless, they are challenged by differently by national legislation's. This paper gives an overview of the existing technical guidelines and topics addressed by the European Subsea Cables Association (ESCA). It is supported by an example for using a guideline (use of guideline N°6) on proximities between the assets of transmission system operators, telecoms, and wind farms.

Paper D8.6: Application of a Combined Technical Approach for Medium Voltage Cable Aging Management at South Texas Project Nuclear Operating Company

The guiding objective of an MV cable test program is to reduce the risk of unplanned (in-service) failures, whilst balancing safety, regulatory, operational and financial considerations. Since 2012 the South Texas Project Nuclear Operating Company has adopted a more comprehensive technical approach for MV cable aging management than the sole VLF (0.1Hz) tan δ test commonly used by other operators. The core methodology relies on the combination of off-line PD monitored 60 Hz withstand testing, advanced off-line 60 Hz diagnostic PD testing, frequency domain dielectric spectroscopy and VLF tan δ testing. This approach provides significant benefits to minimize the risk of 'false positive' and 'false negative' diagnostic testing results, improves reliability, improves the allocation of funds for maintenance, addresses anomalous diagnostics results, and enhances project planning. This paper discusses the technical, regulatory, economic and risk management rationales for adopting this combined technical approach. The program has led to reduced spending on cable replacement and a robust, risk-informed protocol for shifting un-planned to planned work. These improvements have substantially increased plant confidence stepping into a renewed licensed state of operation from 40 to 60 years.

Session D9: Maintenance of cable systems

Chairman: ZHANG Roland Dongping ; TenneT TSO GmbH, Germany

Rapporteur: CHARVET Jean ; RTE, France

During this session, recent developments and valuable findings concerning various Condition Assessment techniques were shared and considerations for safe maintenance works were addressed.

Paper D.9-1: Condition Assessment of Aged Medium Voltage Network Cables

Findings from two off-line testing programs on MW cable networks in Australia were presented with a focus on PD and DDF (tan delta) measurements. Asset Management rationale behind the test program, test equipment and methodologies used, summaries of the results obtained and establishment of a remedial works program was explained. The authors advocate the advantage of having a combined approach of Asset Management objectives and well implemented test programs for condition assessment of aged MV cables.

Paper D.9.2: O&M and Design Challenges of Floating Wind Farm Power Cables

Current status and future development of floating offshore wind farm cable connection in France were presented. Design challenges such as taking into consideration the effect of marine growth on the dynamic cable, and having a suitable test program was explained. Specific condition assessment for this type of cable, and issues regarding preparation for repair and potential disconnection from wind turbines were addressed.

Paper D.9.3: Safe and non-destructive Verification of Absence of Voltage (VAT) prior to maintenance works on long cable lengths

The principle of Verification of Absence of Voltage (VAT) under French standard was presented, based on spiking the cable, and thus destroying cable insulation. The intention of the authors is to propose a non-destructive safe and clear identification of the cable link which is grounded, conductor and screen. Development and tests of a method based on kHz range voltage injection and current detection into conductors and screens was discussed. Tests were partially successful and showed that further mitigation measures needs to be implemented.

Paper D.9.4: Towards Active Cable Reburial Monitoring using Distributed Fiber-Optic Sensing over 40 km of a High Voltage Marine Interconnector

Results, analysis and learnings from Distributed Temperature Sensing (DTS) and Distributed Acoustic Sensing (DAS) measurements acquired on a section of Skagerrak 4 subsea cable were presented. Correlation between cold spots, areas of higher acoustic levels and exposed cable locations were found. Follow-up and confirmation of re-burial operation could also be performed. The authors conclude to an effective monitoring tool, which give best results together with a good understanding of ambient environmental conditions.

Paper D.9.5: Location of Micro Leaks in FFLP Cables with Bi Directional Bridge

A methodology for locating micro-leaks in FFLP cables was presented. It is based on the measurement of leaks at the ends and use a bi-directional technique. The developed technique can evaluate the existence of more than one leak, estimate its positions, and it was successfully tested on a line in São Paulo (Brazil). The authors emphasize that the technique is robust, does not require to inject a tracer that remains within the insulation and most importantly can be applied on live cables.

Paper D.9.7: DGA (Dissolved Gas Analysis) Value in Detecting and Locating Potential Problems in Laminar Dielectric Cable Systems

The application of Dissolved Gas Analysis to HPFF cable systems was presented. Measurements of acetylene concentration of about 50 ppm was demonstrated to reveal some paper damage in a termination, with the extent of damage depending on acetylene levels. Concentration Lab tests and Field findings made the authors conclude that DGA is an economical, effective and easy-to-apply diagnostic technique to assess the condition of laminar dielectric systems.

Session D10: Management of data received from diagnostic tests and monitoring systems

Chairman: PENSERINI Paul ; RTE, France

Rapporteur: CHANIOLLEAU Julia ; RTE, France

This session presented how the developments of diagnostic tests, monitoring systems and algorithms to manage the data generate information for decision making tools for electrical Asset Management. These new approaches will enable condition based maintenance, based on the calculation of indicators of the cable health; to reduce the repair time by discriminating automatically the section in fault; and to optimize the design of network architectures.

Paper D.10.1: Asset Management of MV Cables using Data Driven Health Indices for Water Treeing

Paper D.10.1 exposed how Water Tree assessment can estimate the health of the cable's dielectric and its remaining life. The diagnostic tests on more than 450 samples, by Wafer method or Hot Oil Method, showed that failures cannot only be correlated to water tree growth in the insulation. An accurate Cable Health Indicator has to take into account more information on the water tree data (length and density) and the cable system meta data (cable generation as material and construction design, age, previous failures, neutral condition) to enable decision making based on "relative prioritization" of the condition of cables.

Paper D.10.2: A new algorithm to define a health index for HV and MV polymeric cables

Paper D.10.2 described a new approach to evaluate the cable system's condition. The novelty of this indicator is to attribute more weight on the fast aging mechanisms (i.e. partial discharge amplitude) compared to the slow aging mechanisms (i.e. dissipating factor, hot spots) in order to reflect the emergency of the maintenance action needed. The reliability of each subsystem (cable, termination and joint) is calculated separately and an alarm can be triggered even if only one component is subjected to failure. On line measurement on the whole cable system could be used to calculate an updated or "dynamic health index" (DHI) in order to plan automatically appropriate maintenance actions at the right time.

Paper D.10.3: Cable Management Optical Systems (CAMOS)

Paper D.10.3 presented how Optical Current Transformer (OCT); because they do not require any power supply, are free from maintenance and can be easily connected to substation interrogators; can monitor key information regarding the health of a cable system in normal condition in order to trigger preventive maintenance actions (current measurements of the earthing cable system) and to discriminate and locate point of failure. A 12 km pilot installation in Denmark is experimenting the possibilities of this type of monitoring.

Paper D.10.4: Large Scale Monitoring of Extruded Cables - Review of TSO's Needs and Options

Paper D.10.4 explained that in order to minimize OPEX/CAPEX and ensure a reliable network, the optimal monitoring solution for cable system has to fulfill 3 goals: indicate when maintenance is needed on the component; calculate the cable rating online; evaluate the remaining lifetime of a cable. As none of the monitoring technique available on the market gives a full overview about the cable condition, data from different monitoring solutions need to be combined. Standardization of data structure produced by monitoring could improve the efficiency of data analyses.

Paper D.10.5: Multilevel design approach for industrial distribution network optimization

Paper D.10.5 presented a multi-level design algorithm for MV distribution networks that takes into account the constraints related to the cable, the trenches and the accessories. The tool can be set either to minimize the CAPEX or the total cost of ownership (TCO) depending on the need of the user. The TCO approach takes into account the overall losses over 20 years based on the load. The application of this process on real case studies showed that a reduction of 15% of the overall cost to build could be obtained while reducing long term risk of failures. One optimization result is to select bigger cross-sections, longer cable lengths and use transition boxes.

Session E1: Sheath bonding and parallel circuit

Chairman: MOSIER Rachel; Power Delivery Consultants, USA

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

General Comments about the Session: Whether it is for insulation coordination studies, electromagnetic interference issues or thermal rating, the need to assess sheath currents and voltages is always there. The papers show that existing methods for power frequency concerns are reliable and can be used to deal with non-standard cases, which are likely to be found on the actual network.

Paper E1.1: Capacitive and Inductive Coupling in Cable Systems – Comparative Study between Calculation Methods

In this paper, a comparison is made between three methods for the calculation of sheath currents and voltages at power frequency: CIM method, EMTP software and FEM. Calculations were performed for a 150 kV link, in solid bonding, single-point bonding and cross-bonding configurations. A good agreement is shown between the three methods. CIM method has the benefit of simplicity, but does not consider capacitive coupling. FEM should be limited to complex cases.

Paper E1.2: Sheath circulating currents calculation in asymmetrical installation schemes for power frequency models

This paper presents calculations of sheath currents on a 220 kV cross-bonded link in non-standard configurations. The impact of unequal minor sections length and changes in laying conditions is studied, for single and double circuits. Results show that sheath losses assessed through IEC standard methods can be underestimated. When the link is not balanced or not uniform, an accurate calculation of the ampacity, e.g. by CIM method, is therefore recommended.

Paper E1.3: An updated method for evaluating current sharing between parallel single-core cables: Case studies and correlation with field measurements

The IEC 60287 standard provides methods for the calculation of the permissible current rating of cables in the conditions of steady-state operation. Part 1-3 focuses on the current sharing between parallel single-core cables and the calculation of circulating current losses. The matrix algebra method has been improved and extended to wider configurations. Case studies illustrate the given refinements, and lead to recommendations for operation in the grid. Then, the results of a bachelor thesis are reported, based on the study of circuits installed in a 110 kV substation, with calculations in good accordance with the measured values.

Paper E1.4: Induced Sheath Voltages and Currents in Cross-Bonded Power Cables with Consideration of Improper Connections of the Bonding Leads

This paper presents calculations of sheath currents and voltages at power frequency on a 132 kV cross-bonded link. A comparison is made with field measurements performed at every joint along the link. The effect of wrong sheath bonding, earth resistance and contact resistance is also studied. Calculations show that when these resistances increase, the induced voltages also increase.

Paper E1.5: A practical method to compute the metallic sheath circulating current for non-standard cases

This paper presents calculations of sheath currents at power frequency on cross-bonded links. The circulating current is obtained by dividing the induced voltage along all minor sections by the sheath impedance. A first case study with unbalanced minor sections shows good agreement with IEC 60287 formulae. A second realistic case study is then presented, with unbalanced minor sections composed of different types of cables laid in various conditions.

Session E2: Monitoring of lapped insulation and remaining life evaluation of transmission cable systems

Chairman: ZENGER Walter; USI, USA

Rapporteur: BELE William; RTE, France

General Comments about the Session: The overall developments in HV and EHV transmissions present a number of challenges, one of them being the need for an efficient monitoring and assessment of the remaining life of installed assets. This session, comprising six papers, presented some innovative solutions to monitor insulated cables, and better understand the phenomena responsible for ageing of such cables. Throughout the different papers the whole lifecycle of the cable is covered, from design considerations, to testing sequences, monitoring of installed assets and even lab studies of key parameters leading to premature ageing or cable failures.

Paper E.2.1: Condition Assessment of Pipe-Type Joints Utilizing Limited-Angle Computed Tomography X-Ray Technology

This paper presents a solution which provides three dimensional and computed tomography images of pipe-type joints, created for inspection purposes. The proposed solution takes the form of a transportable gantry, which by use of high energy X-Ray generation, digital imaging detectors and imaging software allows to detect flaws within the joint, directly on site, and with the feeder fully energized. While previous imaging methods only provided 2D visualization, the designed application quickly gives a 3D overview of the inspected object, with the possibility to move through the reconstructed image for volumetric inspections. In this paper the authors present the development process of their innovation, from lab testing to field testing, where the true performance of the design can be tested, notably in narrow and encumbered areas where 360° turn around the joint are not feasible.

Paper E.2.2: A Study on Partial Discharge Pattern Analysis for HVDC MI-PPLP Cables

This paper describes the partial discharge pattern analysis for HVDC MI-PPLP cables. It is first presented the partial discharge measurement hardware and software that were developed for HVDC cables, which comprises 3 analysis modes: Frequency Analysis; Pulse Analysis and Time Difference Analysis. With those instruments, partial discharges were measured and analyzed during positive and negative load cycles on MI-PPLP cables. The paper shows that partial discharges are more frequently generated during the cooling period, but present a relatively low repetition rate. The average partial discharge magnitude is almost similar between the negative and positive load cycles, even though they are more frequent during negative cycles.

Paper E.2.3: How Can Life Assessment and Diagnostic Monitoring Influence the Choice of MV to EHVDC Cables for Interconnected Grids

This paper discusses some of the challenges related to the design and long-term reliability of HVDC cables, and proposes a two-step approach to better face them. The first step concerns cable design and testing, for which an highlight into key ageing parameters is given, and trends for failure mechanisms explanations are provided. For this study a combined electrical-statistical and thermal modelling approach was used and shows that three critical parameters chosen appropriately can lead to an improved design and potentially to costs reductions. The second step addresses model informed monitoring systems that should be used to ensure reliability and integrity of the cable system on the long term. It was also argued the potential economic advantages that such monitoring could provide, notably through allowing overload while knowing the consequences for reliability.

Paper E.2.4: Chemical ageing of subsea mass impregnated insulation cable paper

This paper presents the outcome of ageing experiment tests performed on different types of mass impregnated cables, while applying varying tests conditions. The varying tests parameters were the temperature (70, 90, 110 and 130 ºC) the humidity level (0.1 and 1 wt %) and the type of insulation paper (Paper A and Paper B). Six outtakes at each temperature were made, with the humidity and the paper type changing. After each outtake the degree of polymerization was measured to establish the ageing of the sample. The experiment clearly shows the impact of humidity level on the paper ageing criterion, as it appears higher initial humidity greatly accelerates degradation. The impact of higher temperatures as an ageing accelerator parameter is also highlighted through this experiment.

Paper E.2.5: Water tree Degradation on Long Term Operated 60 kV Class XLPE Cables Decommissioned from Actual Power Grid

This paper presents the outcomes of pre-breakdown tests performed on 60kV class underground XLPE cables. The chosen samples, with up to 40-year of operation, were decommissioned from the grid, where some of them might have been exposed to water tree degradation. The purpose of the experiment being to understand the electrical insulation capability and the cause of the degradation of the selected samples. The experiment has revealed a large scattering in terms of electrical insulation capability within the tested samples. While some of them had insulation performances close to that of their initial stage, others have fairly low electrical insulation capability caused by a water tree, with about a tenth of their initial capability.

Paper E.2.6: Power cables and accessories survey - learnings from type tests, tests after installation and in-service failures

This paper presents a study on the failures happening during pre-qualification, type testing and after installation tests of power cables and accessories from DNV GL's KEMA laboratories. A total of 1007 tests carried out over 26 years were evaluated for type tests and prequalification tests, and were used as a database to extract statistics and learnings. The same process was applied for after installation tests, with more than 1300 tests over 22 years. The analysis provides an insight into the causes of failures, and gives an overview of the differences in performance between types of components i.e. between cables, accessories, various voltage classes as well as underground vs. submarine cables.

Session E3: Challenges for integrated optical fibres

Chairman: OTTERSBERG Heiner ; Prysmian Group, Germany

Rapporteur: LOUDIERE Nathan ; Rte, France

General Comments about the Session : This session, which includes five papers, gives an overview

Paper E.3.1: Model-based predictive control for use in RTTR temperature sensing systems of high voltage cables

This paper presents a model-based on analytical methods for the transient calculation of underground power cable, for use in fibre optic distributed temperature sensing (DTS) systems with real time thermal rating (RTTR). Such a prediction system is highly dependent on different parameters such as: correct modeling of the soil with thermal resistance and thermal capacity, consideration of mutual heating between power cables, of cable conduits, of backfills, of the fibre optic position. This model-based predictive control is used to determine theses parameters and adapt them in order to eliminate the possible uncertainties.

Paper E.3.2: Combined distributed fibre optic sensing: the revolution in managing and reducing risks and costs of offshore power cable

Power cable failures have led to significant financial losses in the last 15 years in the offshore wind industry. In order to manage and reduce these risks, distributed fibre optic sensing (DFOS) systems are set up. By measuring the backscattered light and with the right instrumentations, several DFOS have been implemented: Temperature measurement, through Distributed Temperature System (DTS) to prevent hot spot failure and localizes faults or real time thermal rating (RTTR) to manage the load; Acoustic sensing, through Distributed Acoustic Sensing (DAS) to provide fault location; and Strain measurement, through Distributed Strain Sensing (DSS) to monitor the bending and tension during installation or operation, and to track a failure. Properly defined and specified, it becomes possible to reliably deploy them, and have an efficient way of monitoring and managing offshore power cables.

Paper E.3.3: Inherently safe designs of fibre optic cables integrated in three-core submarine power cables

In recent years, integrated fibre optic cable (FOC) has been the roots of several faults on large three-core submarine cables. Studies have been carried out to determine the causes of these errors, and to assess its causes. This paper shows, through means of calculations, that the energy induced in the metallic parts of some FOC designs could be the cause of electrical breakdown of three-core submarine cables in case part of the FOC is damaged. Inherently safe designs of integrated fibre optic cables are then presented, with three main guidelines: the jacket of the FOC has to be sufficiently semiconducting; the resistivity of the metallic part of the FOC has to be high; the ends of all metallic parts of the FOC shall be solidly grounded.

Paper E.3.4: Fibre optic related failure modes of submarine power cables

In this paper, an overview is given of fibre optic related failure modes for FOCs used in submarine power cables. This includes describing how FOCs are generally integrated in submarine power cables, the materials and bonding method used for FOCs, the manufacturing techniques for the integration of FOCs in submarine power cables, and the consideration for submarine power cable accessories. An overview and explanation of the experienced stresses and resulting couplings between the FOC and other submarine cable components during different lifecycle phases is provided, such as manufacturing, handling and transportations, installation, operation and testing. Finally, this paper presents the several FOC failure modes, from deformation failure to oversheath integrity and metallic tube failure. It also provides recommendations for submarine power cables, to safely and reliably include FOCs.

Paper E.3.5:

No article has been received.

Paper E.3.6: Electromagnetic coupling in HV and EHV three-core submarine cables during test and operation

The Fibre Optic Cable (FOC) integrated in the three-core power cables used as wind farm export cables is not considered as a system element in the design. Thus, in CIGRE TB490 for instance, there are no design verification tests as a system component for the FOC. This paper analyse the electromagnetic phenomena related to the FOC, through the study of the overall system during test and operation. Special attention is given to several design elements and parameters, such as the FOC or sheath designs, the grounding schemes, the AC voltage levels and power frequency, the length of the cable system or the interfaces between different cable designs.

Session E4: Monitoring of mechanical issues

Chairman: **MAIOLI** Paolo; Prysmian SpA, Italy

Rapporteur: **CABAU** Matthieu; RTE, France

General Comments about the Session:

This session, comprising 6 papers, dealt with the latest approaches for monitoring and diagnostics on power cables, combined with elaborated algorithms. The goals are various, from determination of the depth of burial of subsea cables with DTS, to fault location and Partial Discharge detection with fibre optics acoustic sensors or soft fault location with reflectometry, always trying to reach larger ranges.

Paper E.4.1: Determination of the Depth of Burial of Submarine Power Cables from Temperature Measurements in Real-Time

This paper discusses how the depth of burial of a submarine cable can be calculated and monitored from DTS and load data in real-time and along the entire length of the cable. The performance of the method is demonstrated using field data.

Paper E.4.2: Experiences with depth of burial monitoring in the North Sea using Distributed Temperature Sensing

Paper E4.2 shows the results of a software model that uses the data of a distributed temperature sensing (DTS) device to calculate the actual burial depth of an offshore submarine cable. The results show that it is possible to calculate the actual burial depth using DTS and a software model, but there are also factors that can limit the usability of the model which are discussed in this paper.

Paper E.4.3: Fault Localisation with Distributed Acoustic Sensing (DAS) – Service Experience

New system design and installation methods makes it difficult to perform fault localisation with traditional methods. Distributed Acoustic Sensing (DAS) was found a viable option however limited experience is freely available. The paper presents the use of DAS for fault localisation on three different cables where both successful and less successful cases are presented, with useful learnings each time.

Paper E.4.4: Ultra-Long Reach Fibre Distributed Acoustic Sensing for Power Cable Monitoring

This paper reports the furthest reach to the author's knowledge of a Distributed fibre-optic Acoustic Sensing (DAS) system on passive fibre, which reaches 125km. This is achieved by using a commercial DAS system optimized for long reach measurements in combination with 3 different fibres types spliced together. Together it enables the reported long reach with a suitable SNR for power cable applications.

Paper E.4.5: Online chafing fault diagnosis and characterization in twisted pair cables based on multi-carrier reflectometry and genetic optimization algorithms

This paper proposes to develop methods and models to detect soft faults (e.g. insulation damage, chafing, pinching, etc.) and characterize them based on inverse problems combined with the genetic algorithm and the well-known reflectometry technique in an aeronautical twisted pair cable.

Paper E.4.6: Non-electric detection of internal discharges in High-Voltage Cable Accessories

This paper evaluated optical and acoustical measurements of partial discharges in laboratory models of MV cable terminations and cable joints under AC and DC conditions. It was shown that both non-electrical methods are able to reliably detect internal discharges with satisfying sensitivity and stability, similar to conventional electrical detection. Successful integration of the optical sensors in the cable accessories was demonstrated.

Session E5: Non PD health assessment

Chairman: ORTON Harry; Consultant, Canada

Rapporteur: COUTURIER Nicolas; RTE, France

General Comments about the Session:

This session consisted of 5 presentations about new technics and actual projects to assess cable system health without partial discharge sensors. 4 papers were dedicated to cross-bonding analysis, and one to joint X-ray analysis.

Paper E5.1: Belgian experience with a sheath current monitoring system installed on a critical 150 kV cable

Elia has installed an online sheath current monitoring system on two critical 150 kV HVAC cable systems. The goal of this pilot project is to investigate the possibility of such system to replace periodic sheath measurements, detect bad connections in link boxes and verify the correct functionality of the cross bonding system. Experiment measurements and theoretical results match.

Paper E5.2: Real time monitoring of EHV cable system

AEML-TB has decided to upgrade its maintenance policy for buried EHV cables in urban environment. A global safeguarding procedure has been implemented with all the new technologies available. Among others: DTS, DAS, sheath current monitoring, but also ground patrolling and Augmented Reality for cable route inspection.

Paper E5.4: Condition assessment of cross-bonded HV cable system

The presentation deals with possible improper functionalities of HV cable connections with cross-bonding systems. Several cross-bonding faults are simulated to study the impact on sheath currents and current rating. In particular, it is shown that a sheath to ground damage resistance above 0.5 Ω results in a derating of less than 5%.

Paper E5.5: Cable sheath diagnosis in cross bonding cables systems

Generic method is presented for detecting defects in cable sheaths in CB configuration. Three types of defects are studied in this paper: open circuit fault in sheath loop, two phase short circuit in linkboxes (breakdown between sectionalized sheaths) and flooding in linkboxes. The criterion developed is studied on a real double circuit cable system in order to show the influence of varying the load of each one of the parallel lines.

Paper E5.6: Visualization based on HDR Image Processing for X-ray Inspection of Power Transmission Cable Joints

X-ray inspection methods can sometime be used for on-site joint inspection, but with a very poor contrast due to high absorption by metallic parts. A new technic is here proposed, based on High Dynamic Range (HDR) image processing with a multi-scale contrast adjustment.

Session E6: Materials

Chairman: Marco ALBERTINI, Prysmian SpA, Italy

Rapporteur: Petru NOTINGHER, University of Montpellier/CNRS, France

The E6 session included ten papers concerning cable material properties and evolution: electrical trees inception and development, space charge behavior, partial discharge analysis, self-repair materials and cable ageing management.

Paper E6.5: *Study of inception mechanism of electrical trees from bow-tie trees*
KATAKAI Shoshi, HIWATASHI Shigeo, SUZUKI Hiroshi; Sumitomo Electric Industries, Ltd., Hitachi, Japan
SUZUKI Kozo, MASHIO Shoji; Sumitomo Electric Industries, Ltd., Tokyo, Japan

The appearance of electrical trees from bow-tie trees and the relationship between the length of this type of water trees and the breakdown strength of XLPE-insulated cables was addressed. Calculations of the electric field in cable insulation were made through different models and assumptions regarding the permittivity and resistivity values and distributions. The results were widely discussed and interpreted to explain the initiation of the breakdown process. Assuming that breakdown occurs when the electrical stress at the tip of the bow-tie tree becomes equal to the tree inception stress, comparisons between experimental data and calculated values were presented. The authors proposed estimation curves of the breakdown voltage of 275 kV and 500 kV XLPE cables with respect to the lengths of the bow-tie trees, based on values calculated with the presented models.

Paper E6.6: *Manhole Monitoring via IoT and GIS*
KANGKUN Watchara, TUNGDUANGDEE Paphawee; Metropolitan Electricity Authority, Bangkok, Thailand

The paper presented a case study concerning the monitoring of manholes by the Metropolitan Electricity Authority (electricity supplier of Bangkok, Nonthaburi, and Samut Prakan in Thailand). The proposed system includes IoT devices and a procedure to transfer data to a Geographic Information System (GIS) and to display it interactively via a management dashboard. The different parts of the system and of the data collecting platform were described.

Paper E6.7: *The Propagation Retardation of Electrical Tree in XLPE under Negative Impulse Superimposed AC Voltage*
ZHOU Kai, LI Zerui, CHEN Shijia, ZHU Guangya, HUANG Yonglu; College of Electrical Engineering and Information Technology, Sichuan University, Chengdu, China

Paper E6.7 investigated, using a microscope based real-time digital imaging system, the characteristics of electrical trees developing under ac voltage to which negative impulses are superposed. A simulation model set up according to the microscopic images was presented, the electric field distribution being calculated with respect to the experimentally-observed dimensions and shape of the trees. The propagation mechanism of the electrical trees was analyzed through the calculated electric field distributions.

Paper E6.8: *Space Charge Behavior in Polyethylene under Elevating Stepwise DC Voltage*
OGURA Kotaro, MIYAKE Hiroaki, TANAKA Yasuhiro; Tokyo City University, Japan

The relationship between space charge accumulation and breakdown of LDPE and XLPE samples was studied under step-wise dc voltage with various voltage increase rates. The space charge distributions when applying a constant voltage to an XLPE/Semicon structure at high temperature for a relatively long time were also observed. On one hand, it has been found that, when a stepwise elevating voltage was applied to the sample, injected charges accumulated near electrodes and reduced the field at the electrode/insulator interfaces, thus lowering the probability of subsequent charge injection. On the other hand, the authors concluded from the presented results that the charge is less likely to accumulate following a stepwise increase of the applied voltage as compared to the application of a constant electric field.

Paper E6.9: *Space charge behaviours of PP-based nanocomposites for HVDC cable insulation varying with temperatures*
HOU Zhaohao, DU Boxue, LI Zhonglei, LI Jin, HAN Chenlei, HAN Tao, XIAO Meng; Tianjin University, China

Paper E6.9 reported results concerning space charge behavior and dc breakdown strength of PP-based nanocomposites manufactured in the shape of films with thicknesses of 70 µm to 180 µm. In particular, it has been found that, in the temperature range between 30 to 90°C, PP/ULDPE films with a content of 0.01 wt % graphene nanoplatelets show interesting performance in term of electric distortion factor due to space charge (6 to 24) and breakdown strength (360 to 420 kV/mm). The probable mechanisms leading to the observed results were discussed.

Paper E6.10: *Suppressing Space Charge Accumulation in XLPE with Voltage Stabilizer*
HAN Chenlei, DU Boxue, LI Zhonglei, HOU Zhaohao, LIU Chang, LI Jin, HAN Tao, XIAO Meng; Tianjin University, China

The effects of different voltage stabilizers on XLPE samples were investigated by conductivity measurements, PEA measurements, breakdown tests and surface potential decay. It was shown that the voltage stabilizers could improve the dc conductivity characteristics of XLPE, decrease space charge accumulation at 90°C and improve breakdown strength at 90°C. The results were discussed by considering the effect of the stabilizers on the injected "hot" carriers and of the changes they induce in the trap level distribution.

Paper E6.11: *Advanced cable self-repair materials for subsea and underground cables*
BASU Susmit, GERMAN Ian, RHODES Rhys, STEVENS Gary C., THOMAS Janet; Gnosys Global Ltd, Guildford, United Kingdom

Paper 6.11 proposed approaches aimed to autonomously resolve defects in cables. They are based, on one hand, on a waterswelling hydrophilic thermoplastic elastomer (h-TPE) that operates on a similar concept to currently used water blocking tapes, and on the other hand on an intrinsic self-healing material (SHM) that can autonomously repair the polymer network in the wake of damage. The properties and the efficiency of the proposed technologies were studied on minicable prototypes systems in order to assess their potentiality for being implemented in real cable systems.

Paper E6.12: *Comparative Analysis on Partial Discharge Inception Voltage in Interfacial Void Models with Different Materials for AC XLPE Cable Joints*
YOON Sung-Ho, SON Hyeong-Wook, KIM Jeong-Tae; Daejin University, Pocheon, Republic of Korea

The study assessed PDIVs through experimental set-ups embedding model voids to simulating void defects able to occur at insulating interfaces and at the semiconductor interface of AC XLPE extra-high voltage transmission cable joints. Breakdown voltages were also calculated using Paschen's law. The authors showed that experimental PDIV values and calculated breakdown voltage values tended to be quite identical regarding metal electrodes. However, the EPDM-semiconductor case was slightly different from the general tendency, and this was assumed to result from the effect of carbon black clusters in the EPDM-semiconductor.

Paper E6.13: *Effects of switching impulse voltage on characteristics of electrical trees within silicone rubber*

HUI Baojun, FU Mingli, HOU Shuai, ZHANG Yifan, LI Xiaolin; Electric Power Research Institute, CSG, Guangzhou, China, PENG Yunshun, XU Man; Xi'an Jiaotong University, China

In order to study the effects of switching impulse voltage caused by the closing action on the initiation and growth of electrical trees in silicone rubber, the authors of paper E6.13 conducted a series of tests during which ac voltage, switching impulse voltage and their combination have been applied on samples and the developed electrical trees have been analyzed. The results showed that the electrical tree shapes varied depending on the applied voltage, and switching impulse voltage would destroy the silicone rubber electrical branch root channel, promoting the growth rate of electrical trees and shortening the breakdown time.

Paper E6.15: *Innovation in cable ageing management for nuclear safety in long-term operation of generation II and III reactors*
MARQUE Gregory; EDF R&D, Moret-sur-Loing, France

Paper E6.15 presented the TeaM Cables project – European Tools and Methodologies for an efficient ageing management of Nuclear Power Plant (NPP) cables, which is a EU-funded research project aiming at providing NPP operators with a novel methodology for NPP cable ageing management, and includes 13 partners. The aim is to develop cable ageing models and algorithms, methodologies for non-destructive testing techniques and a tool integrating all the models developed and providing the residual lifetime of cables. The approach, the partners, the funding and the expect results were detailed.

Session E7 Poster session: Diagnosis, Monitoring, Testing Methods, Cables and Accessories, Emerging Technologies

Chairman: **BASCOM III** Earle C. (Rusty); Electrical Consulting Engineers, P.C., USA

Rapporteur: **LAGOMARSINI** Clara; Nexans, France

General Comments about the Session: The session presented a wide range of subjects related to cables diagnosis and monitoring, testing methods specifically related to partial discharge, accessories development and testing and simulation techniques. An overall comment about the covered subjects it is difficult to give, due to the diversified topics treated in the session. We found particularly interesting the exposure and contents of posters E7.2, E7.8 and E7.14

Paper E.7.2: The development of intelligent self-driving monitoring system for 345kV underground transmission line in tunnel

The poster presented in detail a monitoring system for underground power cable system in tunnels through an intelligent self-driving system transmitting real time thermal images.

Paper E.7.3: Study on Water Tree Degradation Diagnosis for Dry-cured and Extruded Three-layer 6-6 kV XLPE Cables with Penetrated Water Tree

The poster presented the details on accelerated water-treeing test performed for dry current and extruded three-layer E E type 6.6 XLPE cables removed after approximately 20 years of operation. Degradation diagnostic results were also presented and discussed by the author.

Paper E.7.5: On-site Application of the VHF Partial Discharge Detection Method for the Underground Power Cable Terminations

Synthetic presentation of a method for signal detection in the VHF/UHF wideband employed as high frequency measuring system for frequencies up to 400MHz for noise reduction in partial discharge measurement.

Paper E.7.8: Discovery of a New Degradation Mechanism of Self-Contained Fluid-Filled Cables (SCFF or SCOF) and Development of Diagnostic Technology

New deterioration process for SCOF cables joints and terminations due to dissolved copper compounds in the oil was estimated and verified. An interesting relationship between dissolved copper compound in the oil and the state of deterioration of the insulation was derived.

Paper E.7.10: Effect of air density factors on performance of EHV cable terminations during lightning transients

Not present

Paper E.7.11: Standardization of sample preparation for mechanical tests on cable Insulation and sheathing materials

Not present

Paper E.7.14: Integrated Testing and Diagnosis of Distribution Cables using Damped AC and Very Low Frequency Voltages

The paper accurately described a multimode system for MV cables testing combining DAC and VLF sinus voltage test and diagnosis (PD and tanδ) in a single test system solution. Practical application examples were also presented and discussed.

Paper E.7. 15: Evolution of MV Extruded Cable Designs Used in the US from 1996 to 2014

Refreshing of industry knowledge on medium voltage underground cable construction and usage. The study can provide a perspective of present day cable accessories and employment in US.

Paper E.7.16: How cables fail Œ Debunking the myths and reinforcing the fundamentals to ensure long cable life

Presentation on findings on cable system failures categories. Based on the results obtained on a utility case, it was shown that PD assessment can provide optimal direction to improve the reliability of new and aged cables at a lower cost

Paper E.7.17: New Generation of Accessories for EHVDC extruded power transmission applications

Development and testing of joints and terminations for 525/600kv HVDC extruded. The design criteria and the methodologies defined to define a solution for this application were presented

Paper E.7.18: Ampacity calculation of multi-system cable crossings at 40 MVA frequency converter station Mendrisio

On this work, calculation of cable rating at several complex cable crossings around the new 40MVA substation Memdrisio was possible through a new implemented method for cable rating calculations in case of multiple crossing

Paper E.7.19: Pure Mathematical DLR Model for Implementation in Embedded IT Systems Œ Modelling Principles and Accuracy

Presentation of a developed RTTR software enabling DTS system to detrrmime in real time the temperatures of cables and soil layers along a hv cable route

Paper E.7.20: Basic Engineering for Overhead Insulated Transmission Line

Simple and basics considerations related to overhead transmission lines in comparison to underground networks.

Paper E.7.21: A study of field enhancement from semiconductive protrusions in power cables

The paper aimed calculating through a pure mathematical approach electric field enhancement from semiconductor protrusion in extruded HV cables.

Paper E.7.22: Cable Degassing, Strand Filling Mastic and Cable Defects

Location and characterisation of cable manufacturing defects and relationship between strand filler and cable defects were analyzed. Examples of field located cables defects with offline 50/60 Hz PD tests were presented.

Session E9: Nuclear and LV cables diagnostic and remaining life evaluation

Chairman: FABIANI Davide; UNIBO, Italy

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

This session, comprising six papers, dealt with Nuclear and LV cables diagnostic and remaining life evaluation.

Paper E9.1: AGING ASSESSMENT OF XLPE LV CABLES USED IN NUCLEAR POWER PLANTS

This paper investigates the evolution of electrical and physico-chemical properties of low-voltage power XLPE insulated cables (stabilized unfilled materials specially made for this project) for nuclear application subjected to both temperature and radiation aging. Electrical response is evaluated by the means of the dielectric spectroscopy technique while the physico-chemical and mechanical changes are analyzed at different material scales. In conclusion, used techniques are shown to be appropriate for the evaluation of the radiochemical aging development on LV cables, suggesting the effectiveness of dielectric spectroscopy as a non-destructive technique for on-site cable diagnosis.

Paper E.9.3: Detection of Vibration Faults of I&C Cables via Time-Frequency Domain Reflectometry

This paper presents a method to detect local faults caused by vibrational stress using time-frequency domain reflectometry (TFDR) technique. The TFDR result, validated by experiments, is compared with conventional method. The TFDR is expected to contribute to the safe operation of NPP by detecting vibration faults.

Paper E.9.4: LOW FREQUENCY DIELECTRIC SPECTROSCOPY AS A CONDITION MONITORING TECHNIQUE FOR LOW VOLTAGE CABLE IN NUCLEAR PLANTS

This project shows the ability of low frequency domain spectroscopy (LFDS) to monitor aging in thermally aged cables. The electrical tests conducted in this study and the Frequency based results indicate that LFDS measurements can be sensitive enough to global aging effects in multiconductor LV cable insulation.

Paper E.9.5: CONDITION MONITORING OF THERMALLY AGED LOW VOLTAGE CABLES WITH POLARIZATION-DEPOLARIZATION CURRENT TESTING

This project shows the ability of Polarization Depolarization Current (PDC) to monitor aging in thermally aged cables. In fact, PDC testing was found to be appropriate to reduce the time to obtain reliable data in the low frequency range in comparison to FDDS testing.

Paper E.9.6: Low-voltage cable systems: aluminium conductor corrosion and online monitoring

This paper looks into degradation mechanisms, in particular corrosion of aluminium conductors, a phenomenon that may, for instance, occur in case a damage is inflicted to a cable without directly causing a loss of connection. Secondly, the presence of high peak currents with short duration are being measured in the field. The research aims at creating better understanding of the relation between the occurrence of peak currents and subsequent failures in the connection. Warning signals will give opportunity to conduct preventive maintenance if so desired.

Paper E.9.7: A MULTISCALE ANALYSIS ON K1 QUALIFIED CABLES, TAKEN ON NUCLEAR POWER PLANTS, FACE TO THERMAL AGEING, IRRADIATION AND ACCIDENTAL CONDITIONS (LOCA)

The objective of this study is to characterise the behaviour of a series of K1 qualified cables based on EPR (Ethylene Propylene Rubber) insulation, which have been sampled from French nuclear power plants after more than 30 years of operation. The purpose is to verify that these cables exhibit good behaviour in the face of thermal ageing (TA), irradiation (IA 500 kGy) and finally to test their resistance to a LOCA (Loss of Coolant Accident). A multi-scale examination demonstrates the good resistance of these different K1 qualified cables face to thermal ageing, irradiation and LOCA conditions. Tests performed showed that they retain their functional properties during and after the LOCA, even after more than 30 years of service in the nuclear plants completed by additional thermal ageing and irradiation.

Session F2: Young Researcher's Contest

Chairman: JEROENSE Marc; MJ MarCable Consulting AB, Sweden

Rapporteur: TEYSSEDRE Gilbert; CNRS / Laplace, University P. Sabatier, France

The YRC contest has been settled to stimulate participation of Young Researchers into the conference. The Jury was composed of Marc JEROENSE (Sweden), JeongTae KIM (Korea), Peter MORSHUIS (Netherlands), Petru NOTINGHER (France), Harry ORTON (Canada), Yuriy SERDYUK (Sweden), Gilbert TEYSSEDRE (France), and Lisheng ZHONG (China). A total of 28 abstracts were selected after examination by the Jury. 23 of them were still in competition at the beginning of the conference. The YRC prices were awarded considering the quality of the papers and the presentations given in the Poster session. After deliberation, the following awards were given:

1st Prize: Raphaël GUFFOND, Nexans Lyon (F2.17), for an original work on the modelling of electrical history effect on semicrystalline polymer conductivity;

2nd Prize: Markus SCHEDEL, Univ. Darmstadt (F2.9), for practical application on research carried out on physical properties of bedding materials for HV energy cables.

3rd Prize: Laurie KIRKCALDY, Univ. Southampton (F2.11), for a contribution on partial discharge detection using distributed acoustic sensing

The topics if the papers addressed in the competition are briefly given below:

Modelling

Two papers were concerned with thermal modelling, F2.1 resorting to methodology using lumped element methods, and F2.2 who investigated the impact and depth and thermal properties of the soil on the temperature distribution in 3-core XLPE insulated cables. Regarding modelling of losses in submarine ac cables, new methodologies are proposed in F2.21, while the impact of semicons is investigated in F2-22 through FEM. The evolution of the apparent conductivity in polyethylene materials with temperature/time was modelled considering an evolution of the microstructure and phase contents in an outstanding paper (F2.17).

Materials and Physics

In F2.3, the contribution to morphology change on the dielectric response is discussed based on polypropylene nanocomposites. A physical model for the transport of holes in semi-crystalline materials is proposed in F2.10. The DC conductivity is measured under non-isothermal conditions in F2.6. Graphite-filled silicone materials are analyzed from the standpoint of mechanical properties in F2.28.

Cables and systems design

The papers presented are from very different standpoints. The question of screen arrangement of cables, particularly the link between earthing method and failure mode is analyzed in F2.12. Transition materials and related field distribution is analyzed for joints between cables of different nature in F2.20. Important physical properties of bedding materials for HV cables installation are evaluated in F2.9. Finally an economical and risk of thermal failure study of mismatching wind power source and cable capacity is proposed in F2.5.

Development of diagnostic techniques

Two papers address partial discharges detection and analysis technologies: F2.11 deals with distributed acoustic sensing along cables; F2.14 addresses methodologies for PD identification. Impedance spectroscopy is applied to probe longitudinal interfaces between materials in F2.7. Finally time and frequency-domain analyzed are compared in F2-13 for fault localization in cables.

Ageing assessment - Failure

Two papers are concerned with intrinsic aging of materials under irradiation, one directly by impedance spectroscopy (F2.8), the other (F2.19) at cable scale by reflectometry. F2.24 addresses, mostly by modelling, the impact of surface state of materials on their space charge and field distribution in cable insulation. Breakdown measurements complete the work. The impact of renewable energies introduction on MV cable ageing is discussed in F2.25. How hydrodynamic loads impact life of submarine cables is treated in F2.23. Finally, the electrical stresses on cable sheets and consequences of breakdown are discussed in F2.15.

Poster Session: Cable Systems

Chairmann: Christian Frohne, Nexans, Germany

Rapporteur: Dominik Häring, Südkabel GmbH, Germany

Date: 25th of June, 2019, 14:30 – 16:00

Place: Room F (Galerie Le Nôtre)

In total 15 papers were accepted as a part of poster session ‚Cable Systems'. During the poster session seven contributions were presented and discussed by the authors.

Paper F6.1 was not provided and presented.

Paper F6.2 was not presented during the poster session. The paper deals with the modelling and testing of temporary protective ground (TPG) cables with focus on high fault current applications. The paper shows testing procedures of different parallel TPG configurations. Test results are presented and discussed under consideration of thermal failure phenomena and thermo-mechanical forces. A system model of TPG under high current fault conditions is developed. Test parameters are integrated in the system model. A validation of the system model results by comparison to test results is shown. Possibilities for the application of the system model to other failure scenarios are outlined.

Paper F6.3 deals with the systematic investigation of quality checks on low (LV) and medium (MV) voltage cables from the perspective of a dutch distribution system operator (DSO). Applied test procedures for LV and MV cables are presented. Specific test results and related deviations to normative and DSO requirements are discussed. Deviations are evaluated in terms of system reliability. Corrective measures are indicated with cable manufactures.

Paper F6.4 was not provided and presented.

Paper F6.5 was not provided and presented.

Paper F6.6 describes the development process of XLPE medium voltage cables with sector shaped conductors. Main differences between three core round and three core sector-shaped medium voltage cables are shown. An electrical field study of both cable configurations is described. A comprehensive and comparative test procedure is described and the obtained results are discussed. Key figures of a pilot operation of the developed cable are given.

Paper F6.7 deals with the problems of overhead communication lines and describes a systematic communication approach to public from the perspective of a Utility in Thailand. The paper gives an example regarding the sensitive understanding of public to underground cable installation in

metropolitan regions. The paper describes a systematic approach and application for a transparent communication to all stakeholders with regard to construction, timeline of the projects, impacts on environment, and beneficial outcome for undergrounding of communication cables. The applied communication procedure leads to a higher acceptance for undergrounding cables and an accelerated execution of ongoing projects.

Paper F6.8 discusses the electrical field distribution of HVDC MI and PPLP cables. Specific differences between both cable types are addressed. Main characteristics of the considered cable types are presented. Fundamental basics for evaluation of electrical field distribution under DC applications are given. Electrical field distribution of MI HVDC cable type under consideration of various thermal system boundaries are calculated and presented. A numeric system model considering layer configuration of PPLP insulation system is developed and described. Results of field calculations with focus and various thermal system boundaries and polarity reversal operation is shown. Differences between MI and PPLP field distributions are evaluated and discussed.

Paper F6.9 was not provided and presented.

Paper F6.10 deals with the investigation of buffer layer ablation on high voltage XLPE cables in corrugated aluminium sheath constructions. Theoretical failure mechanisms for buffer layer ablation and resulting consequences are described. A systematic evaluation approach is given in terms of visual investigation and system modelling. Additionally, a testing procedure reproducing buffer layer ablation with focus on electric discharge ablation and elctrocehmical corrosion ablation is developed and applied. Fundamental coherences are derived and discussed.

Paper F6.11 was not presented during the poster session. The paper deals with the optimization of high voltage cable system under consideration of technical and economic parameters. A mathematical model approach to describe physical cable and cable system parameters is developed and applied. An exemplary case study for a high voltage cable system is presented. Two different cable designs for a copper conductor and aluminium conductor cable are considered. Simulation results are shown and discussed.

Paper F6.12 was not presented during the poster session. The paper studies on the dynamic and fatigue system behaviour of dynamic cables for floating offshore wind turbines. A systematic evaluation approach considering the local conditions and system requirements is given. Measuring results of a 5 MW cable are shown and compared to simulation results. On the base of obtained measuring results, the fatigue damage rate and expected lifetime is derived. Obtained results are transferred and analyzed on a 7 MW cable application.

Paper F6.13 was not presented during the poster session. The paper gives an overview of an integral organization of submarine cable owners, operators, and suppliers. Beside the general description of the organization, the cooperation with third party organisations, such as marine industry, fishing industry, and regulators is given. The paper indicates the outcome from the cooperation.

Paper F6.14 describes a development process of extruded HVDC cable systems. The paper discusses two different evaluation approaches with a nano-filled and non-filled XLPE compound for LCC and VSC system applications. An overview of fundamental investigations on nano-filled XLPE material is shown. Testing procedure of a 250 kV HVDC cable and outdoor sealing ends for LCC applications according to CIGRE recommendation is presented. Furthermore, description of a HVDC cable system for VSC applications is described. Development tests on a 150 kV and 320 kV cable system are shown. A pre-qualification test procedure of a 320 kV HVDC cable system according to VSC test protocol is described.

Paper F6.15 deals with power cables and their interaction to fire performance. The paper gives an overview of the latest requirements and regulations for power cables under fire conditions. A general classification and description of cable sheath constructions are described in relation to their reaction to fire performance. Cable designs for recently certified cable constructions and solutions matching legal requirements by consideration of new cable oversheathing compounds from CD IEC 60840 ED5 are shown. Test procedures and results with notified bodies are presented.