SPECIAL REPORT FOR SC B1 Insulated Cables

Special Reporters
Florian AINHIRN
Jacco SMIT
Søren KRÜGER OLSEN
Alexandra BURGOS MELGUIZO
Ivan JOVANOVIC

SESSION PAPERS

Session Papers focussed on a number of Subjects – referred to as 'Preferential Subjects' – selected in advance by the 16 Study Committees of CIGRE and available in the Call for Papers.
Session Papers are selected through a two-phase review process – abstracts and full Papers.
Have a look at the Technical Programme - the list of selected Papers for the Session, and so have an overview of subjects that will be discussed. It is updated as Full Papers review proceeds.

FORMAT OF CIGRE SESSIONS

At CIGRE Sessions authors are given the opportunity to present their Paper during half-day specific meetings – the Poster Sessions.
Four days are also dedicated to 'Group Discussion Meetings' organised by Study Committees. Four meetings run simultaneously each day from Tuesday to Friday, under the presidency of the Study Committee Chairs. The purpose of these meetings is the discussion of the Session Papers on the basis of "Special Reports" which incorporate the gist of the Session Papers and raise a number of questions for discussion.
For fruitful discussions delegates are strongly encouraged to read the Papers before the Session.
The set of Session Papers is made available for downloading to all duly registered delegates before the Session through their private account on the registration's portal. Papers are also readable on the Session smartphones application on site in Paris.
Follow our Session latest news and General Programme - by regularly visiting our website.

INTRODUCTION TO SC B1

Study Committee (SC) B1 is responsible for AC and DC insulated power cable systems for power transmission, distribution and generation connections on land and in submarine applications, as well as for power cable systems associated with micro-grids and the integration of distributed resources.
Within its technical field of activity, Study Committee B1 addresses theory, design, application, manufacture, installation, testing, operation, maintenance and diagnostic techniques.

For the 2024 Group Discussion Meeting, three preferential subjects were proposed to stimulate discussion considering the strategic directions:

PS1 - Learning from experiences
PS2 - Future functionalities and applications
PS3 - Towards sustainability

A total of 85 papers have been accepted and published.

PARTICIPATING IN THE 2024 PARIS SESSION

You are invited to participate in discussing this Special Report at the SC B1 session held on Thursday August 29th starting at 08:45 in Amphitheatre Bleue at the Palais de Congress de Paris.

The reporters have compiled up to 16 questions, these are not specifically aimed at the papers' authors, but are synthesised from common issues and trends identified in across the papers. This provides the opportunity for a broader response and participation in the discussion session.

We encourage you to share your views or experiences *in response to the specific questions* in this report.

Procedure for contributions.

1. Contributors should **upload your contribution** on the **registrations portal** – "Contributions to Group Discussion Meetings" section - using your existing account and own credentials **before 10th August 2024, 18.00 CET** for a prior screening and a good organization of the Group Discussion Meeting. **Important points;**
    - Access to contribution uploading is given only to duly registered delegates.
    - As a consequence, **registration to CIGRE Session** should be finalized before uploading contribution(s) online.
    - Register now for the Session **registrations**
    - Contributions uploading will be open at start of June.
2. Special Reporters will review the prepared contributions (Power point presentation with max 3 slides and a written word file with max 1000 words pr contribution). A guide for contributors as well as templates and sample pages will be available on the Paris session 2024 webpage.
   Important notice: No commercial names are to be included in presentation or the written summary (even TSO/DSO names).
   Any recommendations or changes to the contributions will be provided to the contributors by the Special reporters directly on the Registration platform between **10th of August and 16th of August 2024**. Contributors are encouraged to visit their account on the **registrations** portal to see the result of this review.
3. All contributors with accepted/finalised contributions will be contacted by the Special reporters of SC B1 by email between **10th of August and 16th of August 2024**, to finalize the presentation and receive the instructions regarding the session.

   Important note:
    - All contributions must be uploaded prior to the Conference in Paris.
    - Last minute changes to the contributions will not be granted.

4. It is expected that the questions relevant to the three Preferential Subjects will attract many prepared contributions. The number of contributions for each Preferential Subject (PS1, PS2 and PS3) may need to be limited. The selection will be based on relevance, quality and time of submission of the contribution.
5. There will be a virtual meeting with for the contributors with SC Chairman, Secretary and Special Reporters to be given instructions and possibility to ask questions. The details about the meeting will be posted at the website of SC B1: CIGRE SC B1 > Home

There might be the opportunity for spontaneous contributions during the session, which will only be verbal with no slides. Attendees who provide a spontaneous contribution, are encouraged to summarise their contribution as a short written response for the Proceedings. This text is required to be forwarded within two weeks after the SC B1 Session by **Tuesday September 10th 2024** to be considered in the proceedings. The written summaries shall be sent to SC B1 Secretary (Matthieu Cabau, matthieu.cabau@rte-france.com).

No new contributions will be accepted after the 10th August 2024, 18.00 CET.

Authors of SC B1 Session papers are required to present their papers during the **SC B5 Poster Session scheduled for Tuesday 27th August 2024, (**09:00 – 12:00). Template and instructions on poster preparation are available on the CIGRE 2024 Session website. Posters will be displayed on digital screens. **A draft copy of the poster must be uploaded to the ConfTool platform by Wednesday 31st July** for review by the poster session convener. A final version, incorporating any requested changes, must be uploaded by **Friday 16th August 2024**. It should be noted that authors will **not** have the possibility to upload their own file on the day of the Poster Session. If the author(s) cannot attend the Poster Session, he/she or the relevant National Committee is requested to send a substitute.

KEY DATES FOR SC B1

Day	Date	Time	Room	Description
Wednesday	2024-07-31	EOB	N/A	Deadline for upload of Posters
Monday	2024-08-05	15:30	N/A	Virtual contributors' meeting with SC Chairman, Secretary and Special Reporters
Saturday	2024-08-10	EOB	N/A	Deadline for submission of the prepared contributions
Friday	2024-08-16	EOB	N/A	Deadline for informing the contributors about the outcome of the review. At acceptance a time slot will be distributed.
Thursday	2024-08-22	EOB	N/A	Authors informed that their contributions will be included in the Discussion session, with a time slot
Monday	2024-08-26	16:00– 18:00	TBD	HV DC cables, TB 852 & 853
Tuesday	2024-08-27	09:00 - 12:00	Halle Ternes	SC B1 Poster Session where all authors of the accepted papers are invited to present an e-poster. This is an opportunity to meet authors and discuss papers.
Thursday	2024-08-29	08:45 – 12:30 & 14:00 – 18:00	Amphitheatre Bleue	SC B1 Group Discussion meeting. Prepared contributions and the Special Report will be presented and discussed.
Thursday	2024-09-12	EOB	N/A	Deadline for submission of written spontaneous contributions.

1 PS 1: Learning from experiences

- Design, manufacturing, installation techniques, maintenance and operation
- Quality, monitoring, condition assessment, diagnostic testing, fault location
- Lessons learned from permitting, consent and safety issues from design to implementation.

This preferential subject attracted 56 (60 – 4 non-accepted) contributions, which was the most of any preferential subject in Study Committee B1 and generated six discussion questions.

1.1 PS1 Paper Summaries

Paper No. 10168 (B1-PS1): The submission presents a methodology for measuring armor losses in three-phase AC submarine cables with magnetic armor. The methodology was tested experimentally, and the obtained results were compared to a 3D FEM analysis and to IEC 60287-1-1.

Paper No. 10169 (B1-PS1): This submission addresses the problem of inconsistency of impedances of submarine cable terminals, test lines and test equipment when using frequency domain reflection for defect localization in submarine cables. This problem is addressed by developing an impedance matching method, which is shown to effectively reduce the amplitude of reflection peaks generated by the impedance mismatch and improve defect detection sensitivity and potentially also extend the detectable distance.

Paper No. 10170 (B1-PS1): This paper reports about a three core XLPE insulated 500 kV AC submarine cable to transmit 1 GW wind power. Special regard is on calculation of losses. A type test was successfully performed. Furthermore, details about the installation process are given.

Paper No. 10303 (B1-PS1): This paper presents the work performed on FEM modelling of a submarine HVDC cable design to study its bending stiffness at ambient temperature. The contribution to the total bending stiffness of the bitumen embedded on the armour wires is widely investigated, in a first stage by determining its viscoelastic properties using a dynamic rheometer, and in a second stage by implementing those parameters into the FEM model.

Paper No. 10354 (B1-PS1): Measurements of screen currents and it exposes cases of study where on-site measurements are understood with simulations that correspond with the anomalies detected. After analysing the situation, tests were performed on the installation, verifying what was previously supposed.

Paper No. 10355 (B1-PS1): The paper discussed a dynamic export submarine cable design and qualifications processes, including the use of FEM models to confirm design requirements of certain system accessories.

Paper No. 10356 (B1-PS1): The paper describes the installation of a new 132 kV cable system from the Italian mainland to the island of Elba. - including all the environmental concerns taken in relation to mitigation of the impact on the ecosystem from the burial of the submarine cable and reduction on magnetic fields onshore.

Paper No. 10357 (B1-PS1): The paper describes the design and sea-trial of a 525 kV Mass impregnated paper DC cable at large installation depth of 1600 m with a composite armour design.

Paper No. 10416 (B1-PS1): This paper describes PD testing techniques for medium voltage cables. It highlights the need for increased resilience and safety in the medium voltage cable network to cope with the increasing amount of renewable energy sources connected via these cables. The feasibility of online PD measurements to gain an understanding of the condition of a circuit and establish a health index is explored. Two practical examples are given which have been verified by offline measurements and fault investigations.

Paper No. 10519 (B1-PS1): The paper describes an alternative approach to UXO's in relation to submarine cable projects. Instead of the usual approach of doing UXO investigations followed by clearance of possible UXO's and thereby avoid the worst-case scenario - the paper proposes to assess the factual UXO risk and include the risk that the UXO mitigation exposes to people at sea in the assessment. A second approach to perform a cost benefit assessment of UXO mitigation is also presented.

Paper No. 10530 (B1-PS1): The paper deals with a DSOs experience on the thermal evaluation of medium and high voltage cable systems. For this purpose, a special software and measuring device were developed in-house and used in the field. Three cases are presented. The study contrasts normal and abnormal temperatures and tries to provide an explanation using “cost optimised” instrumentation to allow the monitoring a large number of circuits.

Paper No. 10540 (B1-PS1): This paper presents a study attempting to develop electromechanical test techniques to examine the appropriateness of a sequential testing approach outlined in CIGRE TB862 f static and dynamic mechanical stress on 66kV XLPE cable insulation and associated electrical tree characteristics.

Paper No. 10586 (B1-PS1): The paper describes the results of a practical test set-up with ground penetrating radar (GPR). In the paper the working principle of GPR and the test bench are described. During the practical tests with 5 different GPR systems, the influence of the surface, propagation speed, duct material and soil conductivity are analysed. A comparison between GPR technologies is made.

Paper No. 10587 (B1-PS1): Case study of fault location and repair for the 400 kV ESMA I cable. The fault location is based on TDR measurements and the impact of actual laying cable date is shown. The paper shows the actual challenges with cable damage by external parties and the benefit of having actual as installed measurements of the cable.

Paper No. 10588 (B1-PS1): The paper presents a new method for measuring partial discharge activities on high voltage cable systems during periods of time in which overvoltages occur, e.g. during switching events. This new method was tested in the laboratory has been verified in the field in several installations throughout 2 years. The obtained results are analysed, and comparison is made to traditional PD measurement techniques.

Paper No. 10589 (B1-PS1): This submission looks at the numerous obstacles the authors encountered during the installation of a 66 kV line, their solutions and the lessons learned. The paper provides general information on the challenges encountered during the installation of underground cables and addresses those encountered during the construction of a project. It is proposed to describe in more detail the impact of the changed routing on the circuit.

Paper No. 10591 (B1-PS1): The paper presents the importance of safe work and environmental protection in areas where challenges such as access restriction due to environmental issues and tourism is discussed. The paper tries to give guidance for projects where environmental and permissions aspects are crucial. Learning experience gained on the requesting and implementation of permits and consents during the cable laying process are shown on the example of the Ibiza Formentera Power Link project.

Paper No. 10597 (B1-PS1): For an offshore windfarm, a Brillouin type distributed temperature sensing (DTS) system is in operation on 220 kV submarine and underground cables. Three cases are presented where the calculated conductor temperature from the DTS measurement at a certain location started to deviate from the expected conductor temperature based on the measured current. The discovery led to further investigation into causes of moisture migration in the soil along the onshore route.

Paper No. 10665 (B1-PS1): The paper focuses on guidance for cable repair near watercourses balancing environmental aspects and the need for a speedy repair. The work is based on a case study of the Craighall Sandpark legacy cable circuit repair and key lessons learnt and opportunities are discussed.

Paper no. 10695 (B1-PS1): Results of Pre-qualification testing and various Type Tests for an AC 400kV Submarine Cable System are shared. The testing is performed in compliance with the international standard IEC 62067, as well as Cigre TB 490 and 623.

Paper No. 10759 (B1-PS1): In the paper, the bend stiffness of a dynamic submarine cable under axial tension has been studied by experimental tests and numerical analysis. The bend stiffness of a cable is one of the important characteristics of a dynamic cable, which is important for maintaining the stability and fatigue performance of the cable during installation and operation.

Paper No. 10760 (B1-PS1): The paper presents failure statistics of insulated cables in three highly urban and similar areas under the concession of the transmission and distribution energy utilities located in two major cities of Brazil. The analysis period comprises spans 11 years, from 2012 to 2022.

Paper No. 10761 (B1-PS1): Several innovative and unusual solutions have been developed during the initial feasibility studies and basic and executive designs to overcome difficulties in relation to designing underground cable routes in congested areas. One of the innovations in the development of the design/management was the BIM (Building Information Modelling) methodology.

Paper No. 10762 (B1-PS1): The paper presents the difficulties encountered in locating a fault in a Columbian 220 kV underground section of a transmission line and to carry out the necessary repairs to restore the system's operation. It presents learned experiences about the improvements implemented to prevent and mitigate risks of similar accidents on other existing lines and in new projects.

Paper No. 10763 (B1-PS1): The objective of the paper is to share the experiences regarding installation of high-voltage underground cables in São Paulo, Brazil's largest city. The paper aims to illustrate the challenges and complexities associated with cable installation, operation, and maintenance.

Paper No. 10787 (B1-PS1): The paper presents a study of over voltages in medium-voltage (MV) cable networks in Russia. According to cable line (CL) damage statistics, there is a tendency for group damage in modern distribution networks. The root cause of damage may be overvoltage during switching carried out to eliminate the original fault. A mechanism for limiting over voltages using a surge arrester (SA) is considered.

Paper No. 10879 (B1-PS1): In this study, the development of a 500kV-class LCC (Line Commutated Converter) HVDC PMJ (Pre-Moulded Joint) was presented. The insulation material applied to the PMJ Unit, used EPDM (Ethylene Propylene Diene Rubber) as a base polymer. By adding inactive inorganic fillers, space charge characteristics were improved, and compounds with excellent mechanical and electrical properties were developed through the addition of various additive agents.

Paper No. 10892 (B1-PS1): The paper presents a thermal evaluation of HVDC cable systems under fault conditions. It studies the temperature increase due to fault radial current flowing through the semiconductive sheath of a cable system connection with a joint between a semiconductive sheath and an insulated sheath cable system.
The study is performed through EMTP equivalent circuits to define the value of currents and FEM models to evaluate the temperature increase.
The increase of temperature due to such current is assessed as not significant.

Paper No. 10950 (B1-PS1): The paper deals with the high overvoltage appearing in the sheath of a cable, under fault and transient conditions, in areas of soil with high electrical resistivity. It includes the study of the effects of adding an earth continuity conductor to a 420 kV cross-bonded underground cable system using an EMT-type software.

Paper No. 11085 (B1-PS1): This paper reports a dynamic analysis to evaluate mechanical deformation caused by a salt mine blasting and estimates potential impact on the electrical and mechanical performance of a 525 kV DC cable and joint system. The study was performed using finite element simulations. The paper concludes that the overall deformations of the cable and joint system are within manufacturing tolerance and have minimum impact on mechanical and electrical performance of the evaluated system.

Paper No. 11167 (B1-PS1): The paper provides a complete analysis of the cycle of temporary cable connection systems. It proposes a cost-effective approach balancing between no testing or including a complete high-voltage test after each installation.

Paper No. 11173 (B1-PS1): This paper deals with the importance of quality assurance after detecting an increase in faults in cables and accessories. This increase in faults is due to the dynamic loads in the systems, because of the energy transition, and to the increasing demand for land and submarine cables and the emergence of new materials and technologies.

Paper No. 11176 (B1-PS1): This paper provides a holistic analysis and evaluation of the construction activities for high voltage cable systems from a sustainability point of view.

Paper No. 11181 (B1-PS1): This paper brings the challenge of carrying the testing process from the lab to the field, due to the commission of extra-long cables. Resonant Test Systems are presented as the most powerful and reliable technology today available on the marked, for this purpose. The paper focus on Health, Safety and Environment topics in minimizing risk of harm to people and environment

Paper No. 11188 (B1-PS1): The paper gives an overview of the steps necessary to include the Building Information Modelling methodology in the realization of HV cable projects, including the current limitations of this methodology for this end.

Paper No. 11193 (B1-PS1): This paper describes use case of passive optical sensors applied for condition monitoring of 400 kV cable in the joint bays. Field installation considerations, and lessons learned are presented and analysed. Methods for analysing and utilizing obtained data are divided into analytical and statistical groups, and each was discussed in regard to cable and joint health, and the actionable options for asset management.

Paper No. 11258 (B1-PS1): Two year update of failure statistics of installed cables (2012-2021), from Reliability Advisory Group of Study Committee B1.

Paper No. 11275 (B1-PS1): The paper presents one novel option for end-of-life assessment of specific 66 kV “wet” XLPE cable design, with large population still in operation in Japan. The approach of the method uses pre-breakdown discharge detection tests on cables retired from service, simulations, and accelerated water tree analysis. The results are then used for the age-based health assessment of the remaining cables in operation.

Paper No. 11279 (B1-PS1): This paper provides the methodology for development of Y-joints as an asset management option for replacing HPFF and SCFF cables with solid dielectric cables. A case study of 275 kV HPFF project was presented, including special installation considerations, and development and application of special tools. Paper also provides information on savings in construction costs, time and manpower, and other benefits from this approach.

Paper No. 11307 (B1-PS1): In this paper authors analyse the influence of higher harmonics on the cable current rating and propose a method combining IEC rating calculations to obtain better results. The case study presented in the paper shows errors that can happen and be avoided.

Paper No. 11308 (B1-PS1): The paper discusses combination of Overhead and Underground lines in siphon systems, and related risks for the cables and accessories, which requires special considerations for cable bonding schemes. The induced voltages in different bonding configurations and simulated, and results are evaluated and compared. Paper concludes that in siphon systems direct bonding creates high stresses in the equipment and recommends use of cross bonding.

Paper No. 11311 (B1-PS1): The paper presents 3D thermo-electromechanical analysis of 3-core rigid repair submarine joint. Comparison is performed versus 2D analysis, and the findings and deviations in the results are pointed out. Main differences are shown in cables with mild steel armour, and the potential gap in estimating maximum temperature.

Paper No. 11354 (B1-PS1): The authors present results for FEM electrostatic field analysis of heat shrink cable terminations in coupled configurations. Results show increased electrical stress values comparing to singular cable termination. Paper provides some recommendations for the layout based on these results.

Paper No. 11356 (B1-PS1): This paper presents and examines use of Artificial Intelligence as a predictive maintenance tool for power cables. Two AI models were discussed and tried out, decision tree, and neural network model, in order to map the data and obtain health index.

Paper No. 11368 (B1-PS1): The paper presents two cases of challenging cable installations in the refineries. Higher reliability, power savings, and lower maintenance costs are discussed, and installation methods are analysed from those points.

Paper No. 11468 (B1-PS1): High voltage underground cables often face induced voltages and circulating currents in their sheaths due to magnetic fields. To mitigate these effects, methods like cross bonding, solid bonding, and single-point bonding are recommended by IEEE and CIGRE standards. Single-point bonding requires an Earth Continuity Conductor (ECC), which adds costs and risks. An alternative, single-sheath bonding, directly bonds the central cable sheath at both ends while grounding the outer sheath through a Surge Voltage Limiter (SVL). This method, validated through simulations and field tests, eliminates the need for ECC, reduces costs, and maintains cable performance with minimal induced circulating currents.

Paper No. 11568 (B1-PS1): Viking Link, the world's longest HVDC power cable, spans 761 km between Denmark and Britain, facing potential cable faults despite protective measures. Time Domain Reflectometry (TDR) is crucial for fault detection and preventative maintenance but exhibits limitations with longer cables, affecting accuracy and sensitivity. The paper discusses these limitations, emphasizing the need for skilled personnel and suitable equipment. Additionally, it introduces Murray Bridge techniques as a complementary fault detection method, showcasing improved accuracy and faster fault location on the Viking Link.

Paper No. 11572 (B1-PS1): The paper addresses the need for accurate estimation of electromagnetic fields (EMF) emitted by 3-core AC cables used in offshore wind farms. Simple analytical formulas often overestimate magnetic fields, particularly when considering cable features like helical layup or magnetic armor. More advanced estimation methods, including 3D FEM models, offer improved accuracy but still present challenges, especially in shallow burial scenarios or with floating offshore generation. The authors advocate for using accurate formulas alongside 3D FEM models, providing worked examples for easy replication and validation. This approach eliminates the need for margins of inaccuracy, simplifies documentation, and ensures that potential biological effects can be adequately assessed.

Paper No. 11580 (B1-PS1): Denmark's offshore wind expansion requires rigorous monitoring of transmission cables for renewable energy goals. This research introduces a data-driven model leveraging cable load and temperature response correlation to detect changes in soil conditions and cable integrity. Tested with data from the Danish Transmission System Operator, the model proves effective in monitoring laying conditions, with potential wider applications.

Paper No. 11755 (B1-PS1): The paper emphasizes the importance of overvoltage testing for HVDC cable systems prior to operation, citing specific voltage parameters outlined in TB 841. It details the components and requirements of an onsite HVDC test system, including a compact yet powerful DC source and discharge resistor concepts based on water resistance. Additionally, considerations for power ratings, voltage ratings, and dielectric insulation for system components are discussed. The paper also addresses worst-case scenarios during system breakdowns and highlights the need for wind resistance during installation and testing phases.

Paper No. 11802 (B1-PS1): The paper discusses the evolution of monitoring technologies for offshore power cables, including Distributed Fiber Optic Sensing (DFOS), which has been widely used for static cable monitoring. With the emergence of floating offshore wind farms, dynamic power cables have become essential, facing significant mechanical forces that can impact their lifespan. Through the European Interreg AFLOWT project, a one-month monitoring campaign was conducted using DFOS technologies such as Distributed Acoustic Sensor (DAS) and Brillouin Distributed Temperature Sensor (DTS), aiming to address the mechanical challenges faced by dynamic cables. Results showed that DFOS technology, despite challenges with loose-tube fibers in dynamic cables, effectively tracked strain variations over time, offering insights into mechanical behaviors and potential early failure detection, suggesting its suitability for monitoring floating offshore wind farm cables.

Paper No. 11827 (B1-PS1): The paper describes a structured approach to failure investigation on power cable systems and includes a couple of real-life examples. The importance of proper and structured failure investigations for the improvement and prevention of recurrence is explained - and concluded in the paper.

Paper No. 11849 (B1-PS1): The paper discusses the installation of insulated power cables in France, particularly in galleries, tunnels, or shafts, which are commonly used in urban areas like Paris. However, these open locations are susceptible to theft, especially of essential components like the earth continuity conductor (ecc), leading to reliability risks for the underground cable system. To address this issue, proposals such as changing screen earthing schemes or concealing the ecc are considered, although some solutions may increase induced voltage on metallic screens, requiring careful simulation using EMTP software. Simulations reveal differences between calculated distances using analytical formulas and more complex simulations, suggesting that while analytical formulas are generally sufficient for design, specific software may be needed for unusual configurations.

Paper No. 11885 (B1-PS1): This study conducted a root cause analysis at a wind farm following an early failure in the medium-voltage network, revealing multiple defects in the insulated cables. The findings underscore the importance of considering design and installation factors to prevent overheating and ensure reliability in onshore renewable energy projects.

Paper No. 11892 (B1-PS1): In recent years, high-voltage crosslinked polyethylene cables with corrugated aluminum sheath have experienced a new type of defect known as the buffer layer defect, which poses a serious risk to cable integrity. To address detection challenges, three types of distributed optical fibers are embedded as sensors in defective cables, allowing for temperature distribution detection using Brillouin and Raman scattering sensing techniques. A comprehensive detection system is developed and tested, with distributed optical fiber temperature detection showing significant advantages in terms of online detection, defect location, sensitivity, and efficiency over other methods. Further research into the potential of optical fiber embedded in the buffer layer could provide an ideal solution for early defect warning.

Paper No 11897 (B1-PS1): Until recently, underground transmission networks, especially in major US cities, heavily relied on high-pressure fluid-filled (HPFF) cable systems, but there's been a shift towards cross-linked polyethylene (XLPE) insulation in recent decades. While some utilities have begun replacing older HPFF circuits with XLPE ones, the transition faces challenges due to the reliability and longevity of existing HPFF systems, alongside the complexities and costs of installing new circuits. This paper outlines the development and qualification of a new 138 kV HPFF-XLPE transition joint design and its first field installation in a Western US utility, addressing the demand for seamless connections between the two insulation materials.

1.2 PS1 Discussion

A significant portion of the papers focuses on the technical aspects of submarine cables, which are crucial for the transmission of power, particularly from offshore renewable energy sources like wind farms. Innovative methodologies for quantifying losses in these cables are described, which is vital for ensuring efficiency and reliability.

The use of Finite Element Method (FEM) modeling emerges as a powerful tool in understanding and predicting the behaviour of power cables under various conditions. FEM allows researchers and engineers to simulate the physical characteristics of cables, such as bending stiffness, which is particularly relevant for submarine cables that must withstand the dynamic forces of ocean currents and tides. This modelling is also used to refine design requirements, ensuring that cables are both robust and efficient. In addition, FEM analysis is extensively used for rating and loss calculation of cables for both land and submarine cables.

Installation and monitoring challenges are examined, with environmental impacts being a significant concern. The laying of submarine cables must be done with minimal disturbance to marine ecosystems, and the papers discuss strategies to achieve this. Ground-penetrating radar (GPR) technology is highlighted as a method for detecting underground cables, which aids in avoiding damage during other subsurface activities. Issues to tackle Unexploded Ordnance (UXO) are a real threat to submarine cable installations and methods are shown to mitigate dangers of UXO

Innovations in risk mitigation and reliability improvement are presented, such as the application of distributed temperature sensing (DTS) systems. These systems provide real-time temperature profiles along the length of the cable, which can be used to detect hotspots indicative of potential issues. Other methods for using integrated fibres also includes Distributed Acoustic Sensing to allow for more close supervision of mechanical challenges in particular for dynamic cables. Building Information Modelling (BIM) is introduced as a transformative approach to cable route design, allowing for the integration of various data sources to optimize the installation process and reduce the risk of future problems.

Quality assurance and sustainability are emphasized as critical components in the construction and operation of high-voltage cable systems. With the energy transition driving an increased demand for cables, ensuring that these systems are built to last and can be sustainably managed throughout their lifecycle is more important than ever. Some papers propose new methods for assessing the end-of-life of cables, which is essential for planning replacements and recycling materials.
The potential of Artificial Intelligence (AI) in predictive maintenance is also explored, which could revolutionize the way cable health is monitored and managed. Use of digital transformation (in processes and assets) as a “handle” to optimize a part or the complete life cycle

The development of new testing techniques is covered, offering more accurate and efficient ways to ensure cable integrity before and after installation. The integration of different types of cables within the same network presents unique challenges, and the papers discuss approaches to harmonize these systems for seamless operation.

For fault location challenges of impedance matching, a technique used to pinpoint defects within the cable system, thereby enhancing the ability to conduct targeted repairs and reduce downtime. Also the importance of performing TDR of the installed circuits to enhance fault location techniques. Murray Bridge is also a useful tool for fault location for extreme cable lengths.

Several papers discuss various issues with screen currents, cable bonding schemes with focus on induced voltages and currents. Several cases of cable failures has been reported and care must be taken in the complete system design.

Finally, the document addresses the need for precise electromagnetic field (EMF) estimation for offshore cables, which has implications for both environmental impact and human health. Monitoring technologies for dynamic cables in floating offshore wind farms are considered essential for the burgeoning industry, as these cables experience unique stresses that require specialized attention. The importance of structured failure investigations is underscored, as learning from past incidents is key to preventing future failures and ensuring the reliability of cable systems

1.3 PS1 Questions

PS1-Q1: With more and more renewable energy production connected to the grid with varying loads, what concerns are seen for cable system reliability onshore and offshore? Will the varying load and for some periods higher loads than seen before cause an increase in failure rate? What kind of extra quality assurance measures (system design, cable supply and after installation) should be implemented to ensure the underground and submarine cables are reliable long term?

PS1-Q2: Planning of cable routes in urban areas becomes more and more difficult as the major cities grow and various utilities are expanding at the same time. What issues are encountered and how could they be handled in future projects?

PS1-Q3: What are the next steps towards submarine power cables without lead sheaths as a water barrier? What materials and water barrier designs could be considered? Is it likely that water retardant XLPE will be widely used for higher voltages and how should these be qualified for long term performance?

PS1-Q4: Temporary cable system connections are more needed each day and a testing strategy along its life cycle is needed. Does the strategy depend on the age of the system or its different components? How does the manufacturer guaranty apply in these temporary systems? Do they give any instructions about the policy that should be applied in order to keep a high level of reliability?

PS1-Q5: The implementation of BIM in electrical installations requires the development of open standards and evolutions of the current version of IFC (Industry Foundation Classes) format. What could the utilities do to push in this direction?

PS1-Q6: Partial discharge monitoring has been one of the main tools for condition assessment, safety and predictive maintenance of the cable systems. What are the experiences of different methods – continuous vs. periodic, online vs. offline? How does the alternative PD equipment like optical sensors compare to the traditional ones like HFCTs? What are some of the pros and cons, and lessons learned?

2 PS 2: Future functionalities and applications

- Innovative cables and systems, exploring the limits of both land and submarine cables,
- Role and requirements of power cables in tomorrow's grids,
- Prospective impacts from the Internet of Things, Big Data and Industry 4.0 and Robotics on power cable systems.

This preferential subject attracted **20** (21-1 non-accepted) contributions.

2.1 PS2 Paper Summaries

Paper No. 10134 (B1-PS2): The emergence of medium voltage direct current (MVDC) electric networks offers significant advantages over medium voltage alternating current (MVAC) systems, including higher efficiency and greater flexibility in power flow. This paper addresses challenges associated with MVDC system development, proposing a detailed qualification procedure for MVDC cable systems to ensure reliability and performance. The protocol encompasses essential tests such as type tests and transient overvoltage assessments, focusing on factors like electrical field distribution and thermal stability. By outlining these procedures, the paper aims to facilitate wider acceptance and implementation of MVDC technology in various applications.

Paper No. 10172 (B1-PS2): The paper proposes a design optimization algorithm for balancing three-phase currents on a coaxial HTS cable. This algorithm is then used to design a 5 m long 10 kV @ 1 kA 3-phase HTS coaxial cable, with modelling suggesting a significant improvement in the imbalance ratio. This is followed by a demonstration of a manufactured HTS cable with results not as good as those modelled.

Paper No. 10328 (B1-PS2): The paper discusses about the use of high temperature of superconducting cables as transmission power cables due to its advantages against XLPE power cables. Example of a 230 kV line is shown, with focus on installation vs cost.

Paper No. 10331 (B1-PS2): The paper presents the development of a FEM ampacity calculation for the case of a 3-core cables, and suggests that an error of the interpretation of IEC 60287 is present is one of the cases of TB 880. Large focus on T2 estimations.

Paper No. 10405 (B1-PS2): The submission summarizes existing maximum operating temperatures for XLPE-insulated power cables within different national standards and IEC. It also provides a literature review on research that has been done on higher operating temperatures for XLPE insulated power cables. Furthermore, the submission gives a set of statements, why it might be possible to increase the maximum operating temperature of XLPE insulated cables beyond 90°C and a proposal how to further proceed.

Paper No. 10520 (B1-PS2): This paper summarizes the work of CIGRE WG B1/B3/D1.79 on recommendations for dielectric strength testing of HVDC GIS cable joints. The paper focuses on multiphysical simulations and recommendations of the CIGRE technical brochure. The paper aims to provide an insight into the challenges of HVDC testing of GIS cable joints and the explanations for testing such systems.

Paper No. 10577 (B1-PS2): This paper presents field experience of the use of temporary connections in cable systems. The Paper describes special considerations and particularly thermomechanical development tests of a cable system for high voltage substation connections to temporary switchgear during construction.

Paper No. 10775 (B1-PS2): The paper investigates the factors influencing the current rating of cables installed in J-tubes deployed in offshore wind farms. Parameters such as J-tube diameter, intensity of solar radiation, ambient temperature, length of air-filled tube section and wind velocity are considered.

Paper No. 10786 (B1-PS2): Assessment of the technical and economic feasibility of the use of 10 kV High-Temperature Superconducting AC Cable Lines has been carried out as an alternative option to provide power supply to consumers compared to the complex reconstruction of a 110 kV substation.

Paper No. 10817 (B1-PS2): An operational floating demonstration project was equipped with a Distributed Acoustic Sensing (DAS) device to gather data on strain variations along the full cable length. Experiments have shown a good correlation between the intensity of strain variations in the fiber and bending or movement intensity of the cable. This allows DAS to be used for evaluating strain variations along a dynamic cable trajectory.

Paper No. 10951 (B1-PS2): This paper describes approaches to perform thermal rating calculations, based on finite element analysis as well as thermal equivalent circuits. It reflects the load profiles in contrast to steady state assumptions. It illustrates where the differences of the approaches are and which parameters influence the calculation results. This is done in comparison to real DTS measurements.

Paper No. 11050 (B1-PS2): In this paper, current ratings of DC export cables are analysed under different load assumptions. Under special consideration is the cross-connection of wind farms on the AC side of the converters. Thus, the existing export cables can be utilized and optimized in a favourable manner. The optimization is also expressed in a carbon footprint of the different results

Paper No. 11080 (B1-PS2): The work gives a good guidance on aspects to consider during qualification to verify the adequacy of the cable system design for very deep-water applications. This in addition to the standard approach reported in the current TB 490 and TB 632. The additional test results and methodologies may be useful to cover those aspects worthy of note considering the new challenges of high laying depths.

Paper No. 11179 (B1-PS2): This paper describes a system for early detection of civil works near critical infrastructures like high voltage cables using Distributed Acoustic Sensing (DAS) system. This system identifies and classifies potential threats, improving accuracy and speed by filtering background noise and using machine learning for real-time monitoring and alerts.

Paper No. 11329 (B1-PS2): Several methods of cable ampacity calculations with variable loads under dryout conditions are compared in this paper. The authors simulated examples from conservative to progressive, with significant difference in results.

Paper No. 11426 (B1-PS2): The paper provides an overview of high temperature superconducting (HTS) cables as an alternative for traditional underground cables in densely populated urban areas. The authors present the case study of 110 kV, 500 MVA HTS cable implementation in Munich, Germany. Paper presents installation procedure, test setup and the results from the field.

Paper No. 11430 (B1-PS2): This paper explains a digital twin concept, where cable line is monitored and measured in real time in order to predict performance issues. The paper presents a case study of a digital twin utilized on 110 kV cable installed in the grid. Also described in the paper is the implementation on newly developed energy harvesting system that powers up the data collection.

Paper No. 11454 (B1-PS2): This paper presents an overview of the best practices and methods used to prevent issues in submarine and underground cables. It discusses repairs, outlines the costs of different failures and how they can be prevented.

Paper No. 11634 (B1-PS2): This paper contributes to the evolving HVDC cable market by studying electrical properties like space charge and DC conductivity under anticipated future requirements, including higher operating temperatures and polarity reversal conditions. Most electrical testing is conducted at elevated temperatures (90-95°C), addressing the need for insulation materials to withstand such conditions even in VSC schemes. New electrical testing sequences on small-scale specimens aim to understand insulation material behavior independently of accessories or other cable components, ensuring long-term cable performance. Through various preconditioning treatments and measurement starting conditions, the study demonstrates the robustness of the insulation system under different scenarios, paving the way for continued adaptation and full cable system qualification.

Paper No. 11886 (B1-PS2): The emergence of floating photovoltaics (FPV) offers a solution for areas with limited land availability, complementing the development of offshore wind power. In regions like the Belgian North Sea, where wind and solar resources exhibit temporal complementarity, integrating offshore floating PV (OFPV) with existing offshore wind farms shows promise for optimizing

transmission capacity utilization. Simulation studies indicate that this hybrid approach can significantly increase transmitted renewable power while minimizing curtailment, leading to more efficient utilization of offshore connection infrastructure.

2.2 PS2 Discussion

The contributions of PS 2 outline various innovative approaches and challenges in electrical power transmission systems. Firstly, they delve into the utilization of temporary HV cable connections for substation renovation, emphasizing the need for compact, flexible solutions that can operate for extended periods without service disruption. Testing focuses on coordination between cables, plug-out capability, and reusability, requiring close collaboration between manufacturers and system owners to ensure proof of concept. Additionally, it discusses the quest for higher reliability underground transmission systems, driven by urban and industrial expansion and the demand for uninterrupted power supply. Research efforts prioritize performance enhancement through engineering best practices, monitoring technologies, and contingency maintenance strategies to mitigate failure rates and optimize CAPEX and OPEX investments.

Another area of focus is the development of medium voltage direct current (MVDC) electric networks, offering advantages over traditional MVAC systems such as increased efficiency and flexibility in power flow control. However, challenges like the lack of international standards and cost considerations must be addressed to achieve wider industry acceptance. Proposed qualification procedures for MVDC cable systems aim to address these challenges by outlining essential tests and criteria for cable design and performance evaluation, paving the way for enhanced reliability and performance across various applications, including wind power and offshore gas rigs.

Furthermore, the contributions explore advancements in high temperature superconducting (HTS) cables as a viable alternative to conventional XLPE cables, particularly in urban environments with space constraints and high infrastructure presence. The development of novel two-section three-phase coaxial HTS cable concepts demonstrates efforts to optimize design parameters and reduce current imbalance, enhancing cable performance and stability. Additionally, initiatives like the SuperLink project in Munich showcase the practical implementation of HTS cable technology, aiming to increase energy transmission capacity while minimizing construction efforts and operational costs. These innovations underscore ongoing efforts to improve the efficiency, reliability, and sustainability of electrical power transmission systems in response to evolving industry demands and challenges.

Multiple contributions address insulation materials, specifically XLPE. From the reconsideration of conventional operating temperature limits for XLPE insulated power cables, challenging the longstanding 90°C threshold established by IEC standards, over thermal aging of insulation materials and electrical behavior at interfaces, and propose steps to potentially extend XLPE cable functionality in the future. Additionally, studies focus on understanding electrical properties like space charge and DC conductivity under higher operating temperatures and polarity reversal conditions, aiming to ensure the robustness and long-term performance of insulation systems under future power system requirements.

Cable rating is a major topic in this years contributions, delving into various aspects of underground cable systems, particularly in the context of offshore renewable energy projects, focusing on wind and solar power generation. It begins by exploring the factors influencing cable ratings in offshore wind farms, such as wind velocity, air temperature, J-tube diameter, and other environmental parameters. Moving forward, the integration of offshore solar power systems, specifically floating photovoltaics (FPV), with offshore wind farms is discussed. It highlights the potential for increased transmission capacity and minimized curtailment of renewable power generation by combining offshore wind and solar energy resources.

Furthermore, advancements in cable rating methods are explored, particularly considering dynamic factors like time-varying cable current and partial drying of soil around cable ducts. Existing rating

methods that account for these dynamic variables and proposes analytical and numerical approaches to optimize cable ratings in offshore environments are addressed. The potential increase in revenue resulting from optimized cable ratings is highlighted, emphasizing the financial benefits of accurately assessing cable capacity in offshore renewable energy projects.
Additionally, the contributions address the challenges and opportunities associated with the development of digital twins for power cable systems. The concept of creating digital replicas of underground cable networks to enable continuous monitoring and analysis of cable condition, load flows, and lifetime consumption events is presented. By integrating sensors along cable routes and utilizing energy harvesting systems, digital twins can provide real-time data on cable performance, facilitating proactive maintenance and optimization strategies. A prototype of a digital twin system tested on a real 110-kV cable installed in a city grid, showcasing the potential for advanced monitoring and control of underground cable systems in urban environments is given.

In summary, preferential subject 2 underscores the importance of technological innovation and data-driven approaches in optimizing cable systems for underground and offshore renewable energy projects. By considering dynamic factors, integrating complementary energy resources, and leveraging digital twin technology, the contributions of PS 2 enhance the efficiency, reliability, and sustainability of power cable systems in onshore and offshore environments, contributing to the ongoing transition towards renewable energy sources.

2.3 PS2 Questions

PS2-Q1: With regards to off-shore power generation, what are challenges to combine e.g. photovoltaics, wind farms and wave energy from cable system perspective?

PS2-Q2: Choices can be made between the use of DC or AC on-shore cable systems, what and how are choices made with respect to reliability, performance and application?

PS2-Q3: For HVDC testing and material research are performed at higher testing temperatures, how to align and correlate (new) test methods in order to show the robustness of such HVDC cable system?

PS2-Q4: What role do testing and qualification procedures play in ensuring the reliability, efficiency, and safety of modern cable systems, including high temperature superconducting (HTS) cables, deep-water HVAC submarine cables, and temporary cable solutions? Is there a higher need for testing today then there was 10 or 20 years ago?

PS2-Q5: How do advancements in cable rating methodologies and thermal modelling techniques contribute to improving the efficiency, reliability, and cost-effectiveness of power cable systems? Given the higher losses and the accelerated ageing, when and why does it make sense to push the thermal limits of power cable systems?

PS2-Q6: How does the concept of a digital twin enhance the monitoring, maintenance, and decision-making processes for power cable systems? What are the requirements (e.g. monitoring systems and sensors) to establish such digital twins and what potential benefits does continuous data analysis offer in terms of grid stability and resource allocation?

3 PS 3: Towards sustainability

- Experience with technical sides of environmental challenges for current and future cable systems,
- Technical impacts of recycling, roadmap to net zero, Lifecycle of system with upgrading and uprating, inclusion of new technologies such as Hydrogen
- Projects and initiatives to promote access to affordable, reliable, sustainable distribution and transmission cable systems for all

This preferential subject attracted **9** contributions.

3.1 PS3 Paper Summaries

Paper No. 10332 (B1-PS3): The paper gives a literature review on the topic of recycling cross-linked polyethylene, e.g. from cable scratch material. Focus on mechanical and chemical recycling, where they conclude that mechanical recycling is the preferred choice today, but it has its limitations so chemical recycling could be a complementary strategy to a total circular solution for XLPE waste.

Paper No. 10333 (B1-PS3): The contribution describes a chemistry cured XLPE and conventional peroxide-only cured XLPE. The XLPE material and the production processes are described in high detail. Furthermore, the materials are used in the production of 110 kV and 400 kV cables.

Paper No. 10358 (B1-PS3): This paper describes an approach to cable design that involves the scoring on 6 different criteria to get a sustainability scorecard that might be taken into account both by manufacturer and customer when selecting cable design/installation. It aims to inspire to get ever improving manufacturing processes to lower carbon emissions.

Paper No. 10622 (B1-PS3): The electric power industry is expanding rapidly, amongst others due to new green energy incentives and the need is arising to replace SF6, a gas with high global warming potential used in GIS substations. SF6 alternatives like fluoroketone and fluoronitrile mixtures, natural gases, and synthetic air are being considered, leading to the development of new GIS cable terminations that meet the technical requirements of these gases.

Paper No. 10724 (B1-PS3): Pressurized Air Cables (PAC) are essentially gas-insulated lines which use pressurized air for insulation between a HV conductor and its coaxial enclosure tube. The paper concerns High-voltage AC and BIL tests on PAC that have been carried out according to IEC62271-204 on a 145 kV PAC including all main components of a pressurized air cable system.

Paper No. 10952 (B1-PS3): This paper describes that one successful TT of 525kV DC cable system with alternative gas (SF6 free) filled Termination and describes the need for rigorous control over of interfacial quality of cable surface by the innovative way.

Paper No. 11002 (B1-PS3): This paper describes an intelligent link box solution integrating Partial Discharge, water, humidity, temperature and cover sensors for an early detection of issues/faults in HV cable connection systems. The system is able to identify issues through continuous monitoring, reporting and sending relevant alarms to users.

Paper No. 11285 (B1-PS3): This paper tackles important topic of replacing ageing HPFF cable infrastructure in existing pipes. It describes novel cable design, customized pulling procedure of the cable, lining of the pipe, and special installation method of the joints in small vaults.

Paper No. 11896 (B1-PS3): This study explores the integration of small and scattered renewable energy power plants into Italy's transmission grid via a new 36 kV standard solution introduced by the Transmission System Operator (TSO). Standardized 36 kV cable lines, engineered to withstand national transmission grid fault current levels, serve as the primary infrastructure for linking these plants to High Voltage (HV) and Extreme High Voltage (EHV) substations. Through an analysis of current distribution among cables and thermal validation using software simulations, the study provides insights into the feasibility and efficiency of this integration approach.

3.2 PS3 Discussion

The electric power industry is undergoing significant growth driven by market expansion and a shift towards more sustainable energy sources. This transition is demanding high voltage equipment to be more environmentally friendly. A key focus is replacing sulfur hexafluoride (SF6), used in gas-insulated

switchgear (GIS) for decades due to its excellent technical performance but high global warming potential (GWP).

Several alternative gases are being considered to replace SF6, including fluoroketone mixtures (C5-FK), fluoronitrile mixtures (C4-FN), natural gases, and synthetic air. These alternatives require high voltage equipment to meet new technical requirements, such as dielectric strength, operational gas pressure, material compatibility, leakage influence, thermal conductivity, and gas handling procedures. These requirements impact GIS design and the equipment connected to GIS, such as cable terminations.

A new generation of dry-type, plug-in GIS cable terminations has been developed to meet these technical requirements using alternative gases like C4-FN and pressurized dry air. These terminations are more compact than required by IEC 62271-209, reducing cable compartment length and costs while increasing workspace. The standardized inner contour of these terminations allows flexibility in sourcing and integrating components from various manufacturers, benefiting new installations, repairs, and testing activities.

Innovative solutions for high voltage cable connections have been developed, including new methods for on-site cable surface preparation and quality control. HVDC type tests with GIS cable terminations containing replacement gases have been successful, demonstrating environmental benefits and cost reductions.

XLPE cables keep replacing HPFF (HPOF) cables. New construction methods have been developed to mitigate costs and improve efficiency, including the use of movable support structures and hydraulic machines for quick cable removal and packaging. Pressurized air cables (PAC) are another innovation, using pressurized air for insulation, offering higher current ratings, lower losses, and fireproof enclosures.

Crosslinked polyethylene (XLPE) is widely used for cable insulation due to its electrical and mechanical properties. However, its crosslinked nature makes recycling challenging, leading to landfilling or incineration of most XLPE waste. The wire and cable industry is exploring circularity options to manage startup materials, scrap, and plastic waste. Strategies for recycling crosslinked materials, such as XLPE, involve transforming these thermoset materials into thermoplastic substances, aligning with circular economy principles.

A new XLPE formulation technology has been developed to reduce peroxide byproducts and degassing times while maintaining targeted crosslinking levels. This technology offers significant sustainability benefits by reducing greenhouse gas emissions from cable processing and improving scorch retardancy, reducing material waste.

The integration of renewable energy sources is crucial for decarbonization efforts. A new 36 kV standard solution introduced by the Italian Transmission System Operator (TSO) facilitates the integration of small and scattered RES power plants into the transmission grid. Standardized 36 kV cable lines with designed screens and sheaths ensure compatibility with fault current levels, enhancing the connection process to HV and EHV substations.

Link boxes, crucial for HV cable systems, feature sheath voltage limiters to mitigate overvoltages. An economical and user-friendly early alarm system has been developed to continuously monitor various parameters like induced currents, voltages, water ingress, and partial discharge levels. This system integrates with the Supervisory Control and Data Acquisition (SCADA) system, providing alerts to operators before catastrophic failures occur, improving reliability and reducing shutdown times.

Measurable criteria for assessing the sustainability of medium and high voltage power cables, such as carbon footprint, recyclability and transmission efficiency, are becoming increasingly important. Systems are needed that allow easy comparison and fair and reproducible grading of products based on their sustainability performance and promote environmentally friendly cable solutions. This should help

the cable industry to significantly reduce its environmental impact, optimize resource use and promote innovation in sustainable cable development.

3.3 PS3 Questions

PS3-Q1: There is no dedicated certification system in Europe that enables the sustainability aspects of high voltage cable construction to be assessed. How does the design and engineering phase affect to this topic? Should the whole cycle of life considered from the planning to the dismantling? Are there any initiatives in the different countries?

PS3-Q2: Large portions of underground transmission networks are based on legacy Oil-filled (OF) cable technologies, namely HPFF and SCLF. Asset managers are looking for options to maintain reliable power supply, and gradually replace ageing OF circuits in sustainable way by utilizing existing corridors and infrastructure, while minimizing construction costs, and disruption to the public. What are some of the main strategies and technologies deployed today for the replacement of HPFF pipe-type cables, terminations and joints? How are those strategies different for SCLF replacements? What new products and services need to be developed to facilitate this transition?

PS3-Q3: As global economy is moving away from fossil fuels towards sustainable renewable energy, unprecedented number of new electric power lines will need to be built to support the transition. Concept of a ‘digital twin’ provides an option to continuously monitor power lines, analyze parameters in real time, and predict possible performance issues and ageing under higher and different loading patterns.
How the concept of a digital twin can be feasibly scaled up, and implemented in new installations? What are the barriers? Is the new standardization work required? Can the digital twin be implemented on existing HPFF and SCLF lines, and what would be the benefits?