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SPECIAL REPORT FOR SC B1
(Insulated Cables)

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INTRODUCTION

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, applications, manufacture, installation, testing, operation, maintenance and diagnostic techniques.

The strategic directions given by the Cigre Technical Committee serve as a basis for the performed work.

For the 2018 Group Discussion Session, three preferential subjects were proposed to stimulate discussion in the light of the strategic directions. A total of 41 papers has been published.

PAPER SUMMARIES, DISCUSSIONS AND QUESTIONS ON EACH PREFERENTIAL SUBJECT

1. Preferential Subject No. 1

The title for PS1 is **Recent experiences with underground and submarine AC and DC cable systems**. The subject involves the following sub-items:
• Design, manufacturing, installation techniques, and operation
• Advances in testing and relevant experience
• Safety, Health, Environmental and Quality considerations
• Lessons learnt from permitting, consent, and implementation

This preferential subject attracted 23 contributions.

1.1 Papers for Preferential Subject No. 1

B1-101: This paper describes the development of a 72 kV dry-type branched joint. It is designed for

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easy assembly as an off-shore joint and is conducive to extension and simplified jointing work on-site in the future. The insulation is mostly epoxy insulation and pre-molded joint bodies. Many analyses and performance tests for various applications were carried out, including AC and impulse voltage tests, heat shock test and qualification test, under conditions more severe than actual use; the results indicated acceptable performance. It is expected that the proposed points can be applied in off-shore wind farms and underground cable systems in the very near future.

B1-102: This paper describes methodologies to reduce the out-of-service time of 380 kV underground cable systems during the repair work following system failures. Several topics relating to the remedial works after system failures were reviewed. It was proposed that the out-of-service time could be reduced drastically if the Repair Preparedness Plan (RPP) were optimized. Two actual failure cases were reviewed, and it has been shown that, depending on the conditions affecting the work, the necessary out-of-service time varies dramatically. Several proposed ways of reducing the out-of-service time, including improvements to the cable route design, system design, accessibility to the cable route, availability of spare parts and site workers, protection against outer injury, and system redundancy, were investigated and were found to reduce the out-of-service time successfully.

B1-103: Cancelled

B1-104: This paper describes in detail the magnetic field from a cable system. Magnetic field measurements were carried out on a 138 kV full size cable with three types of shielding. Magnetic field simulations were carried out and verified with theoretical calculations. The impact of this magnetic field on the transmission capacity is important and it was evaluated both experimentally and theoretically. Furthermore, various magnetic-field-reduction strategies were evaluated in terms of the magnetic field reduction, the impact on the transmission capacity, and the cost. Moreover, guidelines for method selection in future projects were proposed.

B1-105: This paper describes the results of experimental measurements and 3D analysis of the magnetic field from cable systems. An infinitely long shielding plate was considered theoretically in a general 2D analysis with special attention given to the limited dimensions of the electrical contact between metal plates for shielding. Magnetic field measurements under balanced and imbalanced three-phase conductor currents were carried out on three cables laid in flat formation with aluminum plates. The experimental measurements and the 3D simulation results were compared and the following conclusions were drawn. (1) Good electric contact is necessary for good field reduction because of the leakage flux at the interfaces between plates. (2) Imbalanced three-phase currents reduce the shielding effect. (3) The edge of the aluminum plate does not influence the shielding effect but it is recommended that they are grounded to prevent short-circuit accidents.

B1-106: This paper describes an on-site AC voltage test for extruded cable systems based on the use of a frequency-tuned resonant test system (ACRF). A 14 km-long 220 kV XLPE cable system with 22 joints was tested using the ACRF test system in combination with partial discharge (PD) measurements. The results showed that the PD signals increased from pC to nC and one joint failed. Thus, the authors recommend the incorporation of PD measurements into after installation AC voltage tests in the IEC 60840 and IEC 62067 standards.

B1-107: This paper reports on the construction of underground cable systems that supply power to the Barra area in Rio de Janeiro, Brazil, where the Olympic Park was constructed for the 2016 Summer Olympic Games. To cope with the need to secure a power supply, two transmission circuits, separate power sources, and separate routes were introduced. This project was very challenging because there was 13 months only to conduct the project planning to commissioning for the construction of the 13.3km-long underground cable system. Several issues were faced over the course of this project; however, the use of partial discharge sensors and DTS systems enabled the appropriate measures to be taken in a timely manner to mitigate the impacts of these issues.

B1-108: This paper presents the tunneling techniques using a newly developed boring machine. It enables the expansion of tunnels by lengths of over 1000 m via continuous drilling at shallow depths. It helps to minimize the environmental impact and save costs in cable system construction compared to the open trench method. Evaluation of current ratings had been conducted by means of finite element method in case of cable laying conditions by this method and open trench method. The calculations showed that current ratings in both cases to be similar. This technology was applied in a part of a real cable project where a section of about 300 m to gather operational experience.

B1-109: This paper describes the grounding design of 400 kV single core cable systems with a conductive outer sheath for tunnel installation. It was confirmed that audible and visible flashover occurs upon the switching operation during commissioning test because the conductive outer sheath of the cable was not grounded during this test. Many types of switching operation tests were carried out on this system to identify the location of the flashover. Induced voltage analyses ware also carried out. The results qualitatively confirmed that each cable supporting metal should be grounded to mitigate the flashover under such systems.

B1-110: This paper reports on the sheath circulating current upon asymmetrical cable installation. Formulae for calculating the sheath loss factors for various asymmetrical cross bonded cable systems were proposed. Furthermore, calculations were conducted for mixed configurations of flat and trefoil cable formations within a minor section of a cable system. The results show a deviation from the calculated screen loss factors based on the IEC approach.

B1-111: Cancelled

B1-112: This paper reports the feasibility study result of the replacement of a 2 km-long, 2-circuit, 220 kV overhead transmission line with insulated cable systems. The options of underground and submarine systems were considered. A feasibility study was conducted, starting with a technical field visit and followed by a route option study, a civil work study grounding system design, preliminary cable design, environmental aspect mitigation measures, economic evaluation, cable reel transportation planning, etc. Based on these studies, the underground option was selected taking into consideration the project budget, the impact on the environment during the construction phase, the cable reel transportation, the conductor size, and the desire for easy access to the system to carry out corrective measures on the system. The underground option is now in the design phase.

B1-113: Cancelled

B1-114: This paper describes grounding systems for 230 kV insulated cable systems. Studies were carried out on both 230 kV OF cable systems and an XLPE cable systems having single point bonding, mid point bonding, both ends bonding, cross bonding non-transposed cables, and cross bonding with transposed cables. Calculations were carried out for each case and, based on these predictions, the merits and drawbacks of each type of system were discussed. Examples of actual 230 kV insulated power cable systems were also evaluated.

B1-115: This paper introduces the safety measures taken against the induced voltage from other cable circuits during construction and maintenance projects in France. Verification methods of the cable system for higher safety are also introduced.

B1-116: This paper describes the practices involved in the recovery process after cable faults in the 400 kV OF submarine cable systems between Spain and Morocco. An accident took place in October 2016 and two cables out of the seven cables were damaged. The fault was located and work was undertaken to prevent oil leakage and to repair the system. Based on these experiences, it is suggested that “Definition of contingency counter-measure plan", "The use of appropriate ROVs" and "Spare parts strategies" are very important.

B1-117: This paper discusses the optimal conditions for switching operations in the 420 kV submarine cable system between Italy and the island of Sicily, which contains both newly installed 420 kV XLPE cables and the existing OF cable. Studies were carried out to characterize the over voltage and in-rush current during the switching operations. Various operation modes were simulated and calculations were carried out using two different software packages for comparison and improved accuracy. Based on the results, it was concluded that both software packages provided equivalent results. Moreover, it was clarified that energization from the Italy side results in lower switching over voltages and point-on-wave controller switching provides safety energization of the system. It is also confirmed the accuracy of the employed models.

B1-118: This paper reports the design approach used for an export cable for an off-shore wind farm.

The method was based on existing standards, such as IEC, and often results in over-sized conductor design because of the fluctuating power output of wind turbines. Thus, the aim of this paper is to provide a rational method for designing the transmission capacity of such cables based on simple wind data. By this method, clients can avoid collecting long-term wind data from a site and tenderers do not have to conduct complex calculations. In the proposed method, the preloading current, which corresponds to the average load, is evaluated over a certain period (for example, three years). Next, the time required to reach the maximum temperature under full load conditions is calculated using a dynamic temperature model. Based on an analysis of 50 cases of calculation, it was concluded that the ampacity can be increased by more than 20 % through the application of this method.

B1-119: This paper describes a project to remove a 420 kV OF submarine cable system installed at Oslo Fjord in 1981. Many studies were carried out to execute this project successfully taking into consideration the environment as well as the restrictions on vessel traffic and fishing in the area. One important aspect was the minimization of the risk for oil leakage and the avoidance of HSE problems. Many numbers of contracts and risk managements were carried out for these purposes. Preparation work was conducted on-shore, at the landfall point, and off-shore. The cable properties were verified to ensure that they could be recycled. On-shore cable disposal work was elaborately planned and executed. Consequently, about 65% of the total project cost was recovered from the income of the recycled materials.

B1-120 This paper describes the submarine cable design, testing, and installation used to provide a power supply to the Martin Linge offshore oil and gas platform. The power supply line to the platform is the longest existing AC transmission line; it was 163 km in length as of 2017. It was designed to minimize the reactive power through the use of an optimized voltage and conductor size. In addition, during cable production, the thickness of the insulation was tightly controlled to suppress increases in capacitance. A dynamic cable system was also developed. It was assumed to have 1.5 million times of bending history due to the waves after over 30 years of operation. To verify its endurance, a bending test of up to 2 million bending cycles was carried out.

B1-121: Cancelled

B1-122: This paper describes the history of the development of HVDC XLPE systems in Korea. The development of a nanoparticle-based material for LCC operation began in 2010. The latest status of the development of a 525 kV system was introduced step-by-step. 80 kV and 250 kV systems were initially developed using the proposed material for LCC operation (maximum 90 °C). A PQ test was conducted on the 320 kV system, which uses commercially available insulation material, for VSC operation (maximum 70 °C). Currently, a 525 kV system for LCC and VSC operations is under development.

B1-123: This paper describes the results of a study of the over voltages under fault conditions in symmetrical monopolar and bipolar VSC type HVDC power system. The simulation results show that, in the symmetrical monopolar system, the over voltage is higher and its waveform has a longer wave front and tail compared to the waveform with the standard switching impulse. There is no evidence yet that longer impulses are not covered by the existing impulse test methods; however, more studies are needed for further clarification.

B1-124: This paper reports on the collaborative work between the TSO and the highway operator on the 320 kV Italy–France HVDC interconnection project. For cable installation in the highway viaducts, the TSO and the highway operator held intensive discussions from the beginning of the project. It was decided that aluminum conductors should be used for lighter cables. Moreover, studies were conducted on the use of a pantograph solution to absorb the thermal expansion and contraction of the cables. These practices are expected to be useful for similar projects in the future.

B1-125: This paper describes the design of an 80 kV DC submarine cable for a power supply to the Johan Sverdrup oil and gas platform. A detailed cable route survey and a study on the method for cable installation were carried out at an early stage of the project. Based on the findings, the cable route was optimized and the cable burial and protection methods were decided in each section. The conductor size and cable structures were selected based on the thermal and mechanical requirements for the cable with a 100 MW transmission capacity, a 200 km route length, and a maximum depth of

600 m. This design process reduced the risk during cable laying drastically and, consequently, greatly reduced the project cost.

B1-126: This paper presents the temperature measurements collected from the NorNed HVDC link over two years and the analysis of this data. The temperatures along the first 5–6 km of cables from the terminal to the submarine section were measured by a DTS monitoring system using optical fibers integrated into the lead sheath of the cables. The measured temperatures were compared to the calculations according to IEC 60287, by using the parameters and assumptions during engineering stage. Analyses were carried out with different laying conditions. The differences between the calculated and measured temperatures were the largest with air- and water-filled micro-tunnels; this was mainly due to the assumptions regarding the thermal properties of the surroundings in the calculations.

B1-127: This paper describes the ± 320 kV VSC HVDC cable system that has been in operation in China since December 2015. Specifically, the project outline, design of cable and accessories, prequalification test, type test, factory test, and after-installation test are explained. The transmission line is 10.7 km long, including 6.2 km that was installed within a tunnel. The maximum delivery length of the cable could be extended to 1341 m by implementing special newly designed drums. The use of long cable lengths helped to reduce the total number of joints to 16. Cables having 1800 mm^2 conductors were designed to remain within the maximum conductor temperature of 70 °C, permitted load current of 1600 A, and rated transmission of 1 GW. A prequalification test and a type test were carried out according to Cigre TB 496. Additional special tests, including measurements of the semi-conductive screen resistivity at 90°C, insulation space charge etc., were conducted per an agreement between the customer and the manufacturer.

1.2 Discussion of Preferential Subject No. 1

The papers submitted for Preferential Subject No. 1 cover (1) the design, manufacturing, installation, and operation of new cable systems, (2) testing technologies, (3) HSE and related issues, and (4) lessons learnt from new projects. More than half of the papers submitted this year are related to these topics within PS1, which clearly indicates the higher amount of activity being conducted in the insulated power cable industry.

From the topics relating to the technologies for new projects and the lessons learnt from each project, a variety of new points were raised: First, new design schemes of export cables for wind farms that have rational and larger ampacity designs, including feedback in the form of temperature measurements on submarine cables, have been discussed. In addition, branch joints have been developed to facilitate easier installation of inter-array cables of wind farms. Moreover, practical studies on the planning of underground and submarine cable projects were carried out, including intensive studies to mitigate the project risk and optimize the system. Experiences and development strategies have been proposed, offering more rational implementation ways for more difficult projects; these include experiences from underground projects carried out in the very crowded cities under very severe restrictions (including time limitations), an HVDC project in the highway mountain tunnels, and an alternative open trench method based on a new drilling technology. These studies imply that the cable system industry is entering into the new fields which have not experienced in the past.

The submitted papers regarding testing technologies have focused on suppressing the over voltage associated with the switching operation and evaluating the system properties under the waveforms, which have not been evaluated in the past. Circuit simulations have been applied to conduct tailor-made evaluations of specific cable systems and to enable more realistic evaluations. The effectiveness of PD measurements for on-site testing has also been reported.

It is remarkable that many papers addressing HSE issues were submitted. These papers largely covered analytical and measurement-based magnetic field evaluations and methods of mitigating the magnetic field, studies of the sheath circuit induced voltage and methods to mitigate the discharge due to the induced voltage, and experiences from a submarine oil-filled cable removal project in which each part of the project was optimized and the risk to the environment was reduced. These papers show a clear trend that the cable system industry is paying much attention to these types of social interests and compliance with respect to these issues.

HVDC cable systems and their development are very hot subjects but are relatively new in the history of cable systems. On the other hand, perspectives on the older and established technologies are also important. There is a report discussing the reduction of the out-of-service-time during repair work on existing systems; this report also considered the risk of the future and near-future availability of current technologies and difficulties in transferring these technologies to the engineers of the next generations. This issue will be particularly realistic and serious for OF cables; thus, it is important to establish long-term strategies to manage these issues.

The expansion of cable systems in future projects will likely involve challenges that have not yet been encountered. Large disasters have been affecting cable systems recently; these are now being studied by WG B1.54. These circumstances are likely to be the driving force behind future technical development.

1.3 Questions from Preferential Subject No. 1

The review of the papers and the discussion implied the following questions for Preferential Subject No. 1 (Recent experiences with underground and submarine AC and DC cable systems):

Question PS1 Q1: HSE issues have various impacts on the life cycles of cable systems, including the design, manufacturing, operation, and recycling stages. What kind of impacts can be expected? What kind of measures should be considered to minimize such impacts? How can we balance the advantages and drawbacks resulting from these measures?

Question PS1 Q2: The applications of HV/EHV AC cable systems are expanding broadly. For these systems, what kinds of issues should be considered important in the repair of faults, maintenance, replacement, and improvement works? Some of those systems were state-of-the-art technology when they were built but are now reaching greater ages. Hence, it can be anticipated that current state-of-the-art technologies might be unavailable after several tens years from now. To plan for such circumstances, are there any actions or strategies that could be conducted at present?

Question PS1 Q3: The applications of insulated cable systems for off-shore platforms, mountainous regions, very long traffic tunnels, etc., are increasing. There were less experiences to install cable systems in such locations. In addition, cable systems have recently been faced with large disturbances such as earthquakes or other natural disasters. What kinds of technologies shall be developed as solutions for these new challenges? What collaborations can be developed with related parties or third parties to realize valuable solutions?

Question PS1 Q4: As the applications of cable systems have been expanded, AC and DC systems have been faced with unique over-voltages that are not addressed in the existing standards. Standardization for specific conditions will encounter conflicting ideas regarding over-voltage testing due to the increasing complexity of the systems. How shall the over-voltage evaluation methods be considered? What types of trade-offs could be considered in these considerations?

Question PS1 Q5: HVDC extruded cable systems are relatively new in the history of cable systems, but their field operating histories are rapidly getting larger. From their field operating experiences, are there any technical recommendations or proposals which will be valuable for the design and operation of HVDC extruded cable systems?

2. Preferential Subject No. 2

The title for PS2 is **Best use of existing underground and submarine AC and DC cable systems**. The subject covers:

- Condition assessment and diagnostic testing of T&D cable systems
- Innovative tools for monitoring cables and accessories
- Upgrading methodologies and related experiences, including AC to DC conversion
- Trends in maintenance strategies, asset management, and remaining life methodologies

This preferential subject attracted 8 contributions.

2.1 Papers for Preferential Subject No. 2

B1-201: This paper describes the development of an on-line PD detection system. The system is configured by HFCT sensors: the main unit as the master and local units as slaves connected by optical fibers. In the local unit, the external noise is eliminated by the Frequency Pulse Shape method. More than 80 % of noise signal reduction was achieved by using 40960 signal data. The Time of Arrival method was introduced to locate the PD point by identifying the arrival time differences of PD pulses. The method was found to be accurate to ± 5 m. Furthermore, an automatic PD pattern diagnosis method was developed. Four typical patterns in the oscilloscope display of the PD signal generated in XLPE cable systems were defined. The similarities between each measured PD signal and those patterns were automatically evaluated. Furthermore, the developed PD detected system has been evaluated in a field test on 345 kV XLPE cable line in South Korea.

B1-202: This paper addresses the self-cleaning incipient faults that sometimes occur before final faults in underground XLPE cable distribution systems. These faults are caused by moisture accumulation in cable joints. It is described the findings regarding the incipient faults identified by power quality monitoring systems (PQMSs) in 22 kV closed ring networks and is described the practical experience in preventing final faults. Specifically, when the PQMS recorded an irregular waveform that could be caused by an incipient fault, partial discharge measurements, and time domain reflectometry (TDR) analysis were used to locate the fault point. Furthermore, by the dissecting the affected joints, it was possible to understand the root cause of this phenomenon.

B1-203: This paper considers a new 380 kV high voltage link that was built in Belgium in 2016–2017. 10 km-long, 380 kV underground extruded cable systems with four circuits were installed in this link. Condition monitoring systems were highly necessary due to the importance of this link to the Belgian grid. It is described the design and installation of the PD monitoring system and the DTS/RTTR monitoring system applied to the cable systems. PD sensors (HFCT) were installed at each of 24 terminations and 132 joints to continuously measure the PD activity. In the commissioning tests of the cable systems, no PD signals were detected by any of the 156 sensors. Moreover, the DTS/RTTR system provides information about the loading conditions of the cables which is useful to the system operator.

B1-204: This paper describes a special on-site taping method to improve the fire resistance performance of existing cables in a substation and the surrounding building in Spain. Until the mid-2000s, intumescent paint was widely used for this purpose. However, the paint layer tended to crack after several years due to thermal cycling of the cable and produce heavy smoke when burned For these reasons, new flame retardant materials have been developed to satisfy the fire retardant performance and low smoke density to meet the requirements specified in IEC 60332-3-23 and IEC 61034, respectively. Thus, Halogen-Free Flame-retardant (HFFR) materials have recently been used for the outer sheath of the HV power cables. In this study, an extruded PE-based tape charged with a ceramifying compound was proposed. It was demonstrated that an external fiberglass tape to pack this PE-based tape can meet these requirements.

B1-205: This paper discusses a strategy to maintain the reliability of the aged oil-filled cable lines. In Japan, 4000 km of aged oil-filled cables still exist. Periodic Dissolved Gas Analysis (DGA) has been conducted on the joints to diagnose; however, some cable faults have occurred still. Thus, Japanese utility companies require improved maintenance technologies; several efforts have been initiated to answer to this need. These approaches include the following: revision of the DGA test result judgment criteria based on hundreds of datasets obtained from dismantling joints and conducting DGA, new pattern analysis techniques, application of support vector machines, tanδ deterioration diagnosis based on the copper compound concentration in insulation oil as measured by Inductively Coupled Plasma method, and PD diagnosis based on the experimental results from PD phenomena under different oil-filled insulation deterioration conditions. Furthermore, in order to prevent fire incidents at earth faults, an Fiber Reinforced Plastic (FRP) trough with an aramid sheet wrapping and circuit separation with an FRP board have been applied to the oil-filled cable lines installed in a tunnel.

B1-206: This paper deals with the design of the export cables for wind farms. While they are generally designed based on the full load at steady-state, most cables are never operated at their design limits due to the intermittent loading and design margins. Thus, estimation of cable temperature can help to optimize export cable systems. This paper describes an analytical approach to estimate the cable temperature based on the wind speed, the wind park power curve, and the thermal model of the cable. The developed one-dimensional model is a thermo-electric equivalent model of the cable to allow fast calculations. Validation studies showed sufficient accuracy of the estimations obtained using this model.

B1-207: This paper describes a methodology for evaluating the third party damage probability (TPDP) to the submarine export cables of offshore wind farms. The main third party threats are posed by vessel anchors (including anchor dragging and emergency anchors) and fishing gear. To develop the methodology, various data (such as vessel navigation records, vessel type and size categories, anchor failure rates, engine failure rates, fishing gear data, etc.) were analyzed. Software was used to evaluate the probability of cable damage in terms of the contact frequency due to these reasons. In addition, a relatively shallow buried cable was evaluated as an example. The results showed that the developed method can be used to assess the TPDP according to changes in the cable conditions.

B1-208: This paper examines a new idea to convert existing AC cable systems to MVDC systems, which is one option for the transmission of renewable power. A computer simulation was carried out to clarify the uncertain field properties of DC insulation systems. Electric field analyses were carried out on a 12/20 kV cable system, including a liquid silicone joint. The calculations revealed that the field distribution in the DC system is inverted compared to that in the AC system. The maximum field shifted from XLPE insulation to liquid silicon insulation above DC 15 kV, but still sufficiently lower than the breakdown strength of liquid silicone. This study was carried out as one of the design process. It is also necessary to consider the long term field operation and the space charge behavior, which will have a significant influence on the DC insulation properties. The development of a PEA method for liquid insulation is ongoing.

2.2 Discussion of Preferential Subject No. 2

The papers submitted for Preferential Subject No.2 are covering various topics relating to best and more effective use of existing cable systems.

To date, improvements of existing monitoring methods have frequently been discussed under this topic. This time, the oil-filled cable degradation phenomenon, which cannot be detected by existing methods (such as tanδ and DGA), was investigated and innovative diagnosis methods were developed based on physical-chemical investigations. We expect an increase in this kind of scientific approach in the future.

A new scheme for preventing earth faults by detecting “self-clearing faults” was developed for distribution networks. Another report demonstrated that the cable temperature can be calculated accurately for a wind farm based on the wind data from the area. These studies seem to be employing more “active” (rather than passive) methods for system monitoring than existing technologies.

Cable systems are generally constructed on large scales, requiring more challenging techniques to implement new functions in existing systems. Two papers were submitted on this topic, describing fire resistance performance upgrade and the conversion of an existing MVAC system to MVDC. The proposed solutions are rational but many issues are yet be considered and verified, because it will be required to arrange and/or change the existing system having long-term field operation histories.

In addition, a method for assessing the risk for third party damage to submarine cables based on the ship traffic information and the cable route was reported. This approach applies new information which is not generally considered in the management of submarine cable systems. This implies that new management schemes should be extended based on a wider range of information.

These papers and discussions shall inform our expectations regarding the future development of diagnostic methods and management strategies for cable systems. Cost-saving investment strategies and diagnostic and monitoring methods based on new parameters and information has rarely been used in this industry in the past, but are anticipated to be of high importance in the coming years.

2.3 Questions from Preferential Subject No. 2

The review of the papers and the associated discussion implied the following questions for Preferential Subject No. 2 (Best use of existing underground and submarine AC and DC cable systems):

Question PS2 Q1: Partial Discharge (PD) measurements are widely applied. How shall PD measurements be employed for improving their effectiveness? How shall the targets of PD measurements and measurement effectiveness be considered? What are the best practices for on-site PD measurement to make continuous and/or regular monitoring and relevant evaluation of results more effective? Are there any ideas regarding diagnosis methods for cable systems to attain more valuable outputs?

Question PS2 Q2: Some papers are reporting the effectiveness of the combined methods and technologies for diagnosis and/or monitoring of the system. What kinds of combined methods have actually been applied on-site? What are the advantages and drawbacks of such combined methods?

Question PS2 Q3: The appropriate timing of cable system replacement will ensure higher reliability for the system. However, replacement works incur higher costs and longer time investments to carry out the replacement work. Thus, replacement project is not easy to carry out. What methods and/or criteria should be considered for the decision of replacement projects? Diagnosis methods are considered effective to monitor the system condition. However, how effective are they and what are their limitations?

Question PS2 Q4: What kinds of active monitoring technologies that use environmental parameters from outside of the cable system (such as wind data, vessel traffic information, etc.) can be developed? For realizing such kinds of new monitoring schemes, what kinds of technical actions should be considered by the cable system engineers and stakeholders? What are the barriers to overcome the barriers hindering their realization?

Question PS2 Q5: Retrofitting can be conducted to provide new functions to existing systems, and it is effective to make the best use of the existing system. What are some examples of this practice and/or experiences from actual projects? What technologies are expected to be developed in the future? Furthermore, retrofitted systems might be used for longer times. Thus, how will the life of the aged systems be affected by the incorporation of new functions?

3. Preferential Subject No. 3

The title for PS3 is **AC and DC underground and submarine cable systems in the network of the future**. The subject covers:

- New functionalities expected from cable systems
- Innovative cables and systems
- Environmental challenges for future cable systems
- Higher voltage levels for AC and DC Cables

This preferential subject attracted 10 contributions.

3.1 Papers for Preferential Subject No. 3

B1-301: The paper reports the performance of HTS cable systems of 1.0 km and 2.5 km in length in Ishikari (Japan) and St. Petersburg (Russia), respectively. In the tests, the cable constructions and layout of a cryostat pipes were studied from the viewpoint of the pressure loss from the liquid nitrogen and the heat input to cable. Based on the results, the feasibility of a long-length HTS transmission cable system was studied. It was concluded that MW-scale power transmission with voltage of 200 kV or below is realistic and that the distance can be extended by incorporating intermediate cooling stations at 20–60 km intervals.

B1-302: This paper evaluates polypropylene (PP) insulated power cables, which allow higher temperature operation than XLPE insulated cables, but are limited in their applications due to their high stiffness and low impact strength, especially at low temperatures. Here novel PP insulated cables were developed using an improved material formed by copolymerization. 22.9 kV PP insulated power cables were manufactured by this method and their thermal, mechanical, electrical, and aging properties were evaluated. The results indicated good performance and, currently, a national project is in progress to develop a 154 kV PP insulated cable system.

B1-303: This paper describes a commercial project of constructing a superconducting cable system in Korea. The 50 MVA, 1 km-long, three-core superconducting AC cable system, including two sets of joints and two sets of outdoor terminations will be installed in a real grid to replace a conventional 154 kV AC cable system. One 10 kW cooling system for primary use and another one for back-up will be applied to maintain stable operating temperature. This project is being realized based on many research and development steps over 20 years. Superconducting cable systems, like that designed in this project, are expected to reduce the need for high voltage substations and transformers in urban areas in the future.

B1-304: This paper reports on the design and testing of a 500 kV XLPE submarine cable with a transmission capacity of 1100 MW. The submarine cable route was 17.7 km in length and had a maximum depth of 50 m. Copper armour was selected based on the cable ampacity calculations, the cable force analysis, and the project requirements. A conductor size of 1800 mm^2 was selected based on the ampacity calculations for different laying modes. Factory joints were developed with ultra-clean materials and improved portable on-site extrusion technology. Type test and prequalification test were carried out according to CIGRE recommendations and IEC standards. The system passed an on-site voltage test conducted for $1.7U_0$ (60 min) by using frequency resonant transformers.

B1-305: This paper describes about the improvement in the existing approach for fault location and repair of submarine power cables. In general, submarine cable repairs are conducted by cutting the cable on the sea floor and raising the cable ends up to a vessel on the sea surface, jointing them to a new section of cable, and returning them to the sea floor; this generally requires a lot of time and incurs a high cost. This paper reports on the development and application of novel techniques for locating faults and for repairing submarine power cables on the seabed. The fault location was carried out using Distributed Temperature Sensing (DTS) or Distributed Vibration Sensing (DVS). The cable repair work was carried out by divers in the sea with a newly developed habitat system which can create a dry environment around the fault point and facilitate repair work inside it. The repair of a return cable in 2014 and the repair of a 24 kV three-core AC submarine cable in 2016 were completed successfully using this method.

B1-306: This paper describes the armour loss in three-core submarine cables. Impedance (resistance) measurements were carried out on two types of three-core cables and the results revealed that the resistance of these cables depends on the type and number of wires. Permeability measurements were carried out on three grades of magnetic wire. The magnetic field dependence of the permeability in the higher-grade wire was found to be small, with the real and imaginary parts of the permeability being 20–30 % of that of the lower-grade wire. Loss factors were calculated based on these measurements and compared with the values based on IEC 60287; the experimentally measured and calculated loss factor for the armour λ_2, was about 10 % of the value based on the IEC standard. Moreover, the loss factor was found to be affected by the pitch and the material of the armour. Thus, it was concluded that the transmission loss or the conductor size could be drastically decreased by appropriate design and the use of better materials.

B1-307: This paper describes the development of HPTE insulated cable systems with a PP based material. HPTE has advantages of not requiring degassing because it does not involve crosslinking, easy material filtering, and full recyclability. This material was applied a 150 kV HV class AC system. For extruded HVDC cable systems, the main concern is the space charge behavior; many countries are trying to mitigate this issue. Non-crosslinked HPTE is expected to contribute to this issue. A DC 320 kV LCC scheme Cigre type test and DC 350 kV sustained polarity reversal test were carried out on the cable and its accessories; the results indicated good performance. Many improvements were established and a full size DC 600 kV VSC scheme type test was conducted at a conductor temperature of 90 °C and it was successfully completed. It is expected that this technology will contribute to high capacity power transmission in the future.

B1-308: This paper describes the prequalification process, organized by German TSOs, for 525 kV extruded HVDC land cable systems, which are in demand for the interconnecting links in Germany. 525 kV systems reduce the power loss and reduce the right of way for cable installation compared to 320 kV systems. German TSOs require prequalification tests that deviate slightly from Cigre TB 496 for cable systems. PQ tests of five test loops fabricated by four manufacturers were conducted in 2017 and final testing will be completed by the end of 2018.

B1-309: This paper reports the development of a 640 kV XLPE insulated HVDC cables and their accessories for land applications. They are based on the same technology platform as 525 kV systems. The cable insulation was found to have a sufficiently high resistivity even at the higher electric field level in the PQ and type test conditions. Prefabricated joints incorporating non-linear field grading technology were used as intermediate joints. The termination was developed based on HVDC bushing technology and know-how. It was found that a 640 kV DC cable system can transmit about 20 % more power than a 525 kV system and has the capability to transmit up to 3 GW through one pair of cables.

B1-310: This paper describes the electromagnetic interference in parallel HVDC cable circuits. Mutual induction can cause higher transient over voltage, which necessitates special considerations for the safety of the site workers. The induced voltage at faulting was calculated for the NorNed 450 kV link and the Nordlink 525 kV link, which run partially in parallel, using EMTP-RV. The results indicated that the induced voltage was between 100 V and more than 300 V; however, in case of repair works, an induction voltage of 25 kV could be expected if the wire armour was removed and non-grounded screens were applied under poor burying conditions. This result indicates that the mutual induction between parallel HVDC cable circuits can induce significant voltages, which should be considered in future projects. This work is on-going and there still work to be done to further verify the improved reliability.

3.2 Discussion of Preferential Subject No. 3

The papers submitted for Preferential Subject No.3 are relating to superconducting cables, higher voltage HVDC cables, new insulation materials, and issues relating to submarine cables.

Two papers discuss superconducting cable systems. Both have surpassed the basic development stage and pilot studies, and proceeded to commercial projects and feasibility studies of long distance projects.

Two papers described new cables using PP based material as the alternative to XLPE. However, the development of new insulation materials for cable systems is challenging as this application requires long term reliability. These activities will guide the future direction of the development of new insulation materials.

Submarine cable repair under the sea has previously been thought to be quite difficult. However, there is one paper on this topic, which sheds light on the many possibilities in the future in insulated cable technologies.

The appropriate evaluation of armour loss and the corresponding optimal design for submarine cables have been common interests in recent years and scientific calculations have been applied to tackle these problems. This is also the case for the study of electromagnetic interference. These practices facilitate more rational design methods. Hence, further development in this field is highly anticipated.

The challenges associated with higher voltage AC and DC cables are significant over the history of the technical evolution of cable systems. These practices is also typically appearing in HVDC cable system developments, and field applications of 525 kV and 640 kV extruded HVDC cables are within the range of reality. WG B1.62 and WG B1.66 have been launched to study the testing scheme up to DC 800 kV, and these activities shall aid in the realization of higher-and-higher power transmission technologies using insulated cable systems.

Superior performance far surpassing that of the current state-of-the-art technology is highly expected for the network of cable systems in the future. All the submitted papers demonstrate that the necessary works to realize this goal are being intensively carried out. On the other hand, these new technologies have yet to be applied extensively in the field. Thus, it is necessary to establish methodologies to evaluate the long term stability appropriately and in a short time.

3.3 Questions from Preferential Subject No. 3

The review of the papers and the discussion implied the following questions for Preferential Subject No. 3 (AC and DC underground and submarine cable systems in the network of the future):

Question PS3 Q1: High voltage or long distance HTS cable systems are limited still to laboratory testing and feasibility studies. What will be the bottlenecks hindering field applications of such higher voltage or longer distance superconducting cable systems? What are the actual barriers limiting their implementation? Bulk power transmission using fewer cables is one of the "selling points" of HTS cable systems. However, is it really a realistic solution if these systems are associated with losses due to failure?

Question PS3 Q2: There are some papers that describe the commercialization of new insulating materials other than XLPE. What are the technical limitations or issues in the way of their broad applications? What features cannot be evaluated based on the existing standards for such materials? What methods could be used to evaluate their conformity over a 30-to-40-year lifetime during the research and development stage?

Question PS3 Q3: In recent years, the rated voltages of developing HVDC cable systems are getting higher and higher. How high will the voltage be in future DC cable systems? Which will be most widely used for such extra high voltage systems: LCC or VSC? What are the maximum operating temperature of HVDC cables and maximum thermal drop across insulation being experienced? How shall the maximum temperature of HVDC extruded cables be considered? What are the degradation mechanisms of HVDC extruded insulation?

Question PS3 Q4: Steel armour loss evaluation has attracted discussions during recent SC B1 group discussion meeting and WG B1.64 has been established for further discussion. How will the reliability of the calculation results be improved and how should it be standardized? In what areas are more work needed (such as calculation tool development, etc.) ?

Question PS3 Q5: The application of submarine cables is expanding. Innovative methods, such as cable repair and jointing technologies under water, are being developed. For further application of submarine cables, what kinds of technical developments are expected? What are the challenges faced or break-throughs needed for their realization? The field application of wet design cable is also increasing. What rated voltage can we expect and what are the limitations of their application?

IMPORTANT NOTE

It is expected that above questions relevant to the three Preferential Subjects will attract a number of prepared contributions. The timing of the B1 session usually allows a **maximum of 45 prepared contributions**. Contributors are invited to comply with Cigre rules i.e.:

1. **To send their contributions by two weeks prior to the session, latest by Friday 17th of August**. Contributions shall be prepared using the templates that can be downloaded from the Cigre website, which are also posted on Cigre B1 website along with the latest information regarding SC B1.
2. **To visit SC B1 Chair, Secretary and Special Reporter to discuss and check the contents of contributions from 8h30 to 11h00 (sharp) and from 14h15 to 16h00 (sharp) on Thursday 30th of August**, the day before the Group Meeting (Meeting room number will be communicated on the notification of the acceptance of your contribution(s)).

The **SC B1 session held on Friday 31st of August** will start **at 8h45 in "Salle Bleue"** and the lunch time will be from 12h30 to 14h00 (sharp).

A questionnaire prepared by the Customer Advisory Group of SC B1 will be circulated to better understand the expectations of the Insulated Cables community.