

**SPECIAL REPORT FOR GROUP B1  
(Insulated Cables)**

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**Special Reporter**

**1. General**

Study Committee B1 is responsible for all aspects regarding land and submarine insulated cable systems.

The scope of work is theory, design, applications, manufacture, installation, testing, operation, maintenance and diagnostic techniques for land and submarine, AC and DC cable systems.

**2. Preferential Subjects**

The Study Committee has selected the following preferential subjects for the 2010 Discussion Group Meeting.

*Preferential Subject 1*

**Technical challenges that have been overcome in newly installed underground and submarine cable systems**

- Current state-of-the-art in the design of AC and DC submarine and underground traditional cable systems
- Current state of the art in cable systems installation techniques.
- Experiences of operation of cable systems

*Preferential Subject 2*

**Key factors in current and foreseen development of cable systems**

- Environmental impact
- Balancing capital costs (including costs for Right of Ways) vs operational costs (including costs for operation and maintenance, social costs, losses, dismantling, etc.)
- Prospects of UHV cable systems

*Preferential Subject 3*

**State-of-the-art and trends for cable system testing**

- Qualification, type testing, routine, sample, after installation testing of cable systems
- Representation of installation and operational stresses in testing of cable systems
- Diagnostic testing of cable systems

The total number of accepted abstracts is 28 which were distributed with 18 papers on Preferential Subject 1, 4 on Preferential Subject 2 and 6 papers on Preferential Subject 3.

One paper on PS 1 has been cancelled.

### 3. Papers for Preferential Subject No. 1

#### Technical challenges that have been overcome in newly installed underground and submarine cable systems

- Current state-of-the-art in the design of AC and DC submarine and underground traditional cable systems
- Current state of the art in cable systems installation techniques.
- Experiences of operation of cable systems

**Paper B1-101** reports on a new approach from Denmark for an optimised way to operate a transmission cable system based on the use of Dynamic Thermal Rating equipment.

DTS (Distributed Temperature Sensing) are more and more used for hot spot detection. Adding to DTS measurements some advanced models and calculations to estimate the conductor temperature enables dynamic rating of the system. This gives many benefits for the system operator but requires knowledge of the dynamic thermal behaviour of the surroundings of the cable. Consequently, a dynamic rating system needs to consider all the thermal parameters of the surroundings of the cables as dynamic ones. Two such dynamic systems have been recently installed in SEAS-NVE's grid. Other systems are planned.

**Paper B1-102** describes new technologies to replace or uprate existing EHV cable lines in Japan where most of underground transmission lines have been installed in ducts and tunnels. From a perspective of cost reduction and difficulty of construction in urban area, it was highly desirable to increase capacity and replace some cables by utilizing the existing ducts and tunnels. To meet these requirements, a 154kV large-sized triplex cable, a 275kV Y-branch joint and a booster pump for water cooling system have been newly developed. The paper presents recent EHV cable projects applying these new technologies which have been successfully completed and which will be used in similar applications in the future.

**Paper B1-103** describes the design, production, testing and installation of a 500 kV cable system including the monitoring equipment at the Sidi Krir Power Station (750 MW) near Alexandria in Egypt and addresses the following aspects: Design, manufacturing, routine testing of the cables, installation of cable system on site.

After a description of the encountered experiences in each of the above-mentioned steps, the paper focuses on the added value generated by the advanced diagnostic monitoring systems (Distributed Temperature Sensing and Partial Discharge Monitoring) of the cable link and the operation of the cable system.

**Paper B1-104** reports on the feasibility study of a submarine link between Malta and Italy and especially on the feasibility of the AC option which would constitute a record-breaking application with transmission of 350-400 MW over 120 km with HVAC double circuit. The double circuit AC option is based on the use of a couple of three-core cables, to be developed in two stages, with a voltage rated either at 132 kV (transmission voltage in Malta) or 220 kV (transmission voltage in Sicily). The studies presented in the paper have focused on:

- steady state operating envelope (maximum active power transfer at thermal limit, reactive power balance) and its optimization by terminal voltage control.
- shunt compensation requirements of the extra-long cable line.
- load flow simulation of the interconnected Maltese and Sicilian networks
- angle and voltage stability

With reference to currently available submarine cables, it is shown that active power transfer over a couple of 132 kV-800 mm<sup>2</sup> cables can reach 350 MW; and up to 470 MW with 220 kV-500 mm<sup>2</sup> cables.

Economic analyses have been carried out in many scenarios to verify import convenience versus local generation, to define optimal rated capacity and to analyse electricity supply optimisation and as well as the expected utilisation rate for the link.

**Paper B1-105** reports on the 200 kV HVDC 400 MW extruded cable Transbay cable project crossing the San Francisco Bay and focuses on the extruded DC submarine cable technology and the installation, as well as commissioning. This project is a milestone in the prospect of extruded HVDC connections.

The innovative submarine HVDC link consists of two cables in bipolar configuration and has the capability to transmit 400 MW over a length of 55 miles (88 km). The two HVDC cables (+/- 200 kV) are laid in bundle and buried at a depth of 6 ft (1.8 m), in a safe corridor separated from any existing AC cables.

The design of the cable for this specific project includes a copper conductor with a cross section of 1100 mm<sup>2</sup>, extruded insulation, lead sheath and armour of steel wires.

**Paper B1-106** reports on the NorNed World's longest power cable (580 km) starting from the feasibility study concluded in 1992 to the final completion and the commissioning leading to the operation stage which started in May 2008. All issues of the project are addressed from pre-engineering to installation and commissioning, operation and repair. A total of 1160km of high voltage cable have been installed, some of it in form of a two core cable and a major part as ordinary single core cable.

Transmission over 580 km is proved to be feasible with rather low losses (4.2 % at full 700 MW load). This project also draws the industry's attention to the need of improved test technology: following successful after installation test NorNed experienced two offshore cable failures and had to mobilise extra vessel spreads in order to get the situation restored.

**Paper B1-107** describes the implementation of a “power from shore” solution on Gjøa platform located approximately 100 km northwest of Bergen, Norway. Two main technical challenges were to be overcome:

- Need of a dynamic HV cable rising 380 m from the sea-bed to the floating platform. This dynamic cable has to withstand the substantial mechanical stresses due to weather conditions and depth. Required fatigue properties are essential. A radial water barrier is also needed to prevent water ingress. A new cable has been designed for this application using copper water barrier.
- Overall length of the cable: about 100 km up to the potential best connection point to the onshore grid. Due to capacitive loading currents, an AC system has a limited maximum length. The cable is designed for  $U_m=123$  kV. The overall AC transmission system is based on voltage regulation at the onshore end where a regulating transformer connected to the 132 kV onshore grid is feeding the cable. The transmission voltage has been optimized to reduce total losses during the lifetime of the system.

**Paper B1-108** describes a range of compact transition joints that can be employed to connect Fluid Filled (FF) cables to extruded cables in the voltage range from 33 kV to 400 kV offering newly developed designs based however on long established components. At 33 kV, the design is based on the main insulation body of a XLPE cable straight joint complemented with a small number of special components. Plug-in technology is used in the 66/150 kV voltage range where both single core and 3 core joints are available with designs incorporating pre-moulded sleeves and epoxy barriers.

At 220/275 kV and 400 kV, the transition joints are based on a combination of traditional FF stop joints with modern dry-type plug-in XLPE cable accessory technology. The range of joints has been subjected to stringent development test programs, before official testing, following the coming recommendations of CIGRE WG B1.24.

**Paper B1-109** details the performance of works on an existing double circuit 132 kV underground cable to restore it to its original power transmission ampacity after repeated breakdowns caused by temperature overheating. The paper explains the measuring method used, the survey performed from measurements, and the outcome analysis that has resulted. Then the paper describes all civil works performed to restore installation reliability. Finally it introduces the approach that has been implemented for cable operation monitoring.

**Paper B1-110** shows the results of a survey performed by a WG created by the Brazilian Study Committee B1 Panel regarding service experience of underground cable systems in the Brazilian energy utilities from 2000 to 2009.

Two groups of questionnaires elaborated for the survey were sent to the Brazilian companies that have high voltage underground cable systems. The participants of the survey totalize four companies located in the most urban Brazilian areas comprising Rio de Janeiro, São Paulo and Belo Horizonte.

The data was summarized and compared in two tables and graphics indicating frequency, duration, unavailability, quantity of faults per year and identification.

**Paper B1-111** presents the sequence of events that followed a bushing failure which occurred on a 525 kV submarine cable termination in British Colombia on April 4, 2008 without any accompanying electrical failure. Due to the operating conditions, some length of cable was contaminated with “humid” air affecting its insulation integrity. This length was estimated to be between 100-150 m from the termination. The paper details the repair options and the associated risks with each option, the cost/benefits of these various options, and the final solution. A novel method was adopted to heat the 9 km long cable in-situ. The paper describes how the “cable insulation dehydration” effect was monitored, how the cable termination was restored, and how the circuit was placed back into service.

**Paper B1-112** assesses the insulation state of existing AC 10 kV XLPE distribution cables in Jiangsu province in China and analyzes the feasibility of a 10 kV grid to be upgraded to 20 kV.

The study is based on the technical principles provided by CIGRE SC B1 documents (B1.09 and B1.11).

Score system is established mainly based on the breakdown voltages of samples coming from existing cables, and also on dielectric loss angle tangent and aging factor. This system is then used to assess and grade the insulation state of existing 10 kV XLPE cables.

By voltage endurance coefficient and breakdown field strength measurement, remaining life expectancies of 10kV cables are checked before they are upgraded to 20 kV. At present, several 10kV power circuits have already been put into test run under 20 kV.

**Paper B1-113** details a practical case study regarding the implementation and the operation of a Cable Monitoring System installed with the goal to increase the ampacity of a 220 kV underground land power cable in order to have a full utilization of the transmission capacity of the Baltic Cable (submarine HVDC link between Sweden and Germany).

Compared to the initial ampacity assessed on conservative assumptions, the ampacity of the cable was optimised by measuring and evaluating the conductor temperature with a cable

monitoring system. An increase of 12 % of the ampacity has been obtained. The calculation of a dynamic ampacity directly in the control centre is considered as a possible next step.

**Paper B1-114** describes the development of a  $\pm 250$  kV DC mass-impregnated (MI) type submarine cable system rated 400 MW to interconnect islands in Korea, and gives the results of type testing. A  $\pm 250$  kV HVDC cable system comprising submarine cable, land cable, flexible joint, transition joint and termination has been developed. In order to check the mechanical and electrical performances, type tests were carried out according to CIGRE recommendations (Electra No. 171 & 189). Result of type tests and additional breakdown test confirmed that the developed cable system was complying with required performances. Moreover, to evaluate long term reliability and stability, the cable and accessories will be subjected to the prequalification (PQ) test.

**Paper B1-115** describes the actions that followed the failure of a submarine cable feeding the Cozumel Island in Mexico that occurred after 13 years of service.

Several tests were necessary to determine the cause of the fault. The initial conditions of the cable were established with the help of a portion of the original cable that was kept as a spare. From these tests, it was concluded that the defect of the cable was due to mechanical efforts (friction and tension), combined with corrosion in the armour depending on the sea water characteristics. The tests were also utilized to specify the characteristics for a new cable.

A new cable was specified and put into operation in December 1999.

Since the commissioning in December 1999, the general parameters of the new 34.5 kV link have been monitored, and show that the specification defined for the new link is appropriate.

**Paper B1-116** compares experimental results and calculated values as per IEC regarding the power losses and the inductance of steel armoured multi-core cables.

The development of three-core submarine XLPE insulated cables for higher voltage levels and larger conductor cross-sections has resulted in physically large cables, having accordingly heavy armour. Then, it is important to review the design criteria for an optimal design.

Current rating calculations are made in accordance with IEC 60287.

For verification purposes, several full-scale measurements on multi-core submarine power cables and power umbilicals have been made. Results confirm that the armour losses obtained in using IEC 60287-1-1 is in fact excessive. It is also stated that sufficient good data have been collected for claiming that the correlation between measurements and “2,5D” Finite Elements Analysis results is very good ( $\pm 5\%$ ) and that it should be possible to modify IEC 60287-1-1.

**Paper B1-117** has been cancelled.

**Paper B1-118** deals with the behaviour of HV cables installed in tunnels under fault conditions. These HV single core cable systems are generally installed in a vertical flexible arrangement, where the cables are supported at intervals of between 5 and 8.5 metres at fixed points, normally by cleats, and allowed to sag in between. This ‘sagging’ allows the cables to take up thermal expansion and contraction in steady state conditions, without the exertion of large thermo-mechanical forces. During load cycles, the thermo-mechanical thrust developed by the cable conductor and sheath in an axial direction, needs to be constrained by the cable cleats without damaging the cable oversheath. Under fault conditions, for instance short circuit faults and lightning strikes, the high fault currents flowing through the cable will result in large lateral electro-mechanical forces between cores, causing cables to shake violently.

The paper outlines the importance of short circuit testing of these cleats, and suggests a test protocol.

#### **4. Discussion of Preferential Subject No. 1**

For long distances, in some ranges of power, and in some cases depending on network parameters, DC is known to be the only solution for HV transmission lines. For underground and submarine cables, extruded and Mass Impregnated cables are now competing at higher and higher voltages and recommendations (prepared by WG B1.32) for testing extruded DC cables above 250 kV will be much welcome for their evaluation and qualification. Several examples are given in 3 papers describing DC cable systems from 88km 200kV= extruded (Transbay in San Francisco) to nearly 600 km 450 kV = MI (NorNed).

On the other hand, it appears that new areas (TB 250 from WG B1.19) are now opened to HV AC transmission over distances around 100 km and for powers ranging from tens to hundreds of MW, for example to supply islands, offshore platforms or vessels. Dynamic cables for high voltage applications become a serious candidate for this kind of electrification and the design of cables has to evolve to take into account the mechanical constraints in dynamic applications while preventing from water ingress. Accurate calculation of the transmission capacity of three-core AC cables is also necessary to optimize their design. As it appears that losses in armour of three-core AC cables can be over-estimated and further work in relevant IEC standards is required for a better rating assessment.

Optimization of the transmission capacity of new and existing cables is the topic of several papers. This can be done by uprating (for example by better assessment of losses in three-core cable as mentioned ), or by upgrading in one of the different ways inventoried by WG B1.11.

One way to optimize the transmission capacity can be found in the daily use of Dynamic Thermal Rating systems as mentioned by WG B1.02 (TB 247 ) and recalled by B1.11

New Dynamic Thermal Rating Systems are coming into operation in different countries.

DTS systems have already proved in the past to be an efficient way to detect hotspots and to make feasible the upgrading of installed cable systems, either by changing the thermal environment of the cable or by using locally cables of better performance. Upgrading part of an existing cable system may require the use of transition equipment. New types of transition joints are now available up to 400 kV, including Y-Branch transition joint at 275 kV. Their performances will be evaluated starting from the recommendations issued by WG B1.24.

New design of cables or cooling systems may be required to retrofit existing structures while increasing performance. High Temperature Superconducting cables may be a solution in some specific cases.

Another way to upgrade an existing system (as mentioned by WG B1.11) is to increase the operating voltage when possible. This must be done on a large scale of an existing grid. This solution is under consideration in a distribution network in China.

Extension of the service life of a system is anyway one of the main challenges for a system operator. In the short term, this starts with proper repair in case of failure as reported on a 550 kV system in Canada. For medium and long term, it can result from a well established maintenance policy as proposed by WG B1.04 (TB 279) and B1.09 (TB 358) and continuous improvement of the design based on the failure cause analysis.

Careful consideration of statistics of failures is recommended to better focus on appropriate measures to improve reliability. Third party damages are reported to be the main cause of failure of underground HV power cables in Brazil. This confirms results of the survey carried out by WG B1.10 (TB 243). The work published by WG B1.21 (TB 398) will probably help in finding solutions for improvement.

Very large transmission capacity can be obtained in cables installed in tunnels. Large cross section High Voltage Cables installed in tunnels is the topic of one paper which outlines the thermo-mechanical and thermo-dynamic forces that the system has to withstand in normal operation, in overload conditions and under fault conditions.

Most of the time, such cables are working in N-1 conditions, and can be unavailable for days or weeks without big problems. But a new type of large cross section cables installed in tunnel is coming, to connect big generators to the grid, for example in nuclear power plants. These cables will work in N configuration and a very high transmission capacity coupled with a very high reliability will be required for them. A completely new approach may be necessary for this kind of systems. This is a new challenge for SC B1.

## **5. Questions from Preferential Subject No.1**

### **Technical challenges that have been overcome in newly installed underground and submarine cable systems**

- Current state-of-the-art in the design of AC and DC submarine and underground traditional cable systems
- Current state of the art in cable systems installation techniques.
- Experiences of operation of cable systems

**Question 1: For some range of power to transmit, it appears that HVAC is a good solution, even for very long cable systems.(100 to 120 km). What are the areas in terms of power/voltage/length which are technically achievable with conventional HVAC cables systems?**

**Question 2: Two papers are describing HVDC submarine links at a voltage below 250 kV. One system is using MI insulation while the other one is extruded. What is the technical state of the art of extruded DC cable systems: Voltages, stresses, temperatures and experiences of operation? What are the trends?**

**Question 3: Some issues regarding global behaviour of large cable systems installed in tunnel has been addressed in one paper, calling for further work on standards. Are there other issues to be covered, especially when a cable system installed in a tunnel is connecting a large generator to the network, for example in nuclear power plants?**

**Question 4: Tests combined to Finite Elements calculations show that current rating calculations according to IEC 60287 for armoured 3core cables can lead to conservative results, potentially resulting in oversized cables. What are the (other) areas to be explored to better optimize the sizing and the cost of submarine and land cable systems?**

**Question 5: What has been learnt to date regarding the installation and operation of High Temperature Superconducting Cable systems (including pilot installations of cables)?**

## 6. Papers for Preferential Subject No. 2

### Key factors in current and foreseen development of cable systems

- Environmental impact
- Balancing capital costs (including costs for Right of Ways) vs operational costs (including costs for operation and maintenance, social costs, losses, dismantling, etc.)
- Prospects of UHV cable systems

**Paper B1-201** presents the impact of a cable system in water during its whole life cycle: Water Eutrophication, Water Depletion, Water Toxicity. The impact of the design of the cable is also evaluated.

The report shows that all major recent design evolutions (paper lapped to XLPE insulation system, lead to aluminium metal screen) have led to a reduction of these impacts. All works that have been carried out by the various SC B1 WGs (ex: insulated wires, special bonding) have resulted in a further decrease on water impact and this is performed at the same time as the decrease of global warming. TF B1.36 has been launched to write the terms of reference of a future working group dealing with life cycle analysis of cable systems.

**Paper B1-202** reports on study and tests performed on fault containment for direct buried HV cables, with the target of exploring new innovative laying methods. These new laying methods would reduce the cost of installation and it is essential to know if they are complying with the most recent requirements regarding safety. As shown in the report, tests prove that they will meet the current requirements regarding mechanical protection, technical performances and third party safety, including fault containment. They can be considered as improvements.

**Paper B1-203** reports on the (more than 30 years) service experience of cables and accessories in Japan. Assuming the performance of XLPE power cable accessories follows a bathtub curve model including initial faults, unexpected faults and degradation faults. Various investigations have been directed toward the cause and prevention of such faults. As a result, the failure rate of cable systems in Japan is lower than in the worldwide statistics.

Failures categorized as the initial faults in the bathtub curve gradually decreased thanks to improvements in the installation procedure, the qualification process for jointing teams and the development of new accessories. The degradation faults are thought to be caused not only by deterioration of the insulation itself, but also by changes in the interface condition between components of the accessories. The aging and deterioration factors are classified into electrical, chemical, and mechanical degradation. The paper finally reports on assessment and technical trends to obtain high reliability XLPE HV cable accessories.

**Paper B1-204** describes how the upgrading of two existing 1200mm<sup>2</sup> copper 400 kV FF cable systems in Vienna, by designing and installing additional forced cooling devices, can reduce costs, limit the environmental impact and the social costs, compared to the installation of a new 2500 mm<sup>2</sup> XLPE cable which would, on the other hand have offered a longer remaining life (40 years instead of 20).

## 7. Discussion of Preferential Subject No. 2

Several papers presented under Preferential Subject 1 have already addressed some items listed under PS 2: losses, upgrading , repairing.

Three papers presented under PS2 are more focused on environmental impact and social costs.

It is shown that the design of a cable may influence the environmental impact of a cable system. It is interesting to learn that all major recent design evolutions (paper lapped to XLPE insulation system, lead to aluminium metal screen, insulated wires ) may have led to a reduction of the impacts on Global Warming and on Water. If SC B1 decides to launch a working group on Life Cycle Analysis, the cable industry will be soon able to evaluate the environmental impact of any future change in design, installation, operation and upgrading of a cable system.

When existing links reach their ampacity saturation and additional loads are expected, a decision must be taken between building a new line or upgrading the existing one following one of the methods already mentioned under PS 1.

WG 21.17 (TB 194) has pointed out that some installation techniques may better favour future upgrading than other ones. On the other hand, some cable designs may be more suitable to given installation techniques.

Everything has to be taken into account for an optimized solution. Consequently, the whole life cycle of the cable system has to be considered to assess the environmental impact of a solution as well as the capital costs versus the operational costs.

In a similar way, future prospects of cable technology have to be taken into account to prepare the upgrading options (increase of voltage, retrofiting, forced cooling, change from AC to DC.....) and assess their technical and environmental impact.

## 8. Questions from Preferential Subject No.2

### Key factors in current and foreseen development of cable systems

- Environmental impact
- Balancing capital costs (including costs for Right of Ways) vs operational costs (including costs for operation and maintenance, social costs, losses, dismantling, etc.)

Prospects of UHV cable systems

**Question 1:** Papers in 2008 and 2010 Sessions indicate how the design of the cable can determine the environmental impact of a cable system during the whole service life of the system. **Are there similar studies made and what are the results?**

**Question 2:** « Events » on HV/EHV underground cables and faults are the main topic of B1 202. **What are the other aspects of a fault in underground lines which have to be taken into account in the design of an underground line? Are these issues well covered by standards and Cigre documents?**

**Question 3:** One paper outlines the upgrading of an existing line as being the optimal solution to reduce the environmental impact of a project, compared with simple replacement. **Are there tools and related criteria to mention to help in decision making regarding both distribution and transmission systems? Are there different experiences in upgrading existing lines?**

**Question 4:** **What are the new considerations between AC and DC transmission solutions in terms of System/Network design and transmitted power versus length taking into account the increasing performances of DC extruded cables (VSC and LCC), the upcoming recommendations from CIGRE for testing DC cable systems, and utilizing state-of-the-art compensation devices for long AC transmissions?**

## **9. Papers for Preferential Subject No. 3**

### **State-of-the-art and trends for cable system testing**

- Qualification, type testing, routine, sample, after installation testing of cable systems
- Representation of installation and operational stresses in testing of cable systems
- Diagnostic testing of cable systems

**Paper B1-301** presents some of the results obtained from the electrical measurements on a 99.7 km, 150kV three-phase AC cable, connecting 215 MW offshore wind farm Horns Rev 2, located in Denmark west coast, to Denmark's 400 kV transmission network.

The measurements were performed at nominal voltage. The cable was energised from the grid side with the receiving end open. A 80 Mvar shunt reactor was installed in the middle of the cable and was energised with the cable.

With the exception of the cable disconnection, the measurements confirmed the theoretical expectations. Further work is necessary to clarify this last point.

**Paper B1-302** points out that traditional methods and test systems for routine and on-site testing of HV and EHV cables according to current standards come to their limit – technically and economically - as the lengths and voltage levels increase. The logistics for the arrangement of tests as well as the testing itself are challenging.

These issues could be solved with a newly developed on-site test system at very low frequency (from 0.1 to 10 Hz) that provides the reliability of established test methods in other voltage ranges and together with a test equipment exhibiting lower weight ( three times less), lower dimensions and power consumption compared to existing systems. As already mentioned, so far test voltages between 0.1 and 10 Hz are not part of the standards for high voltage and it would be necessary to issue a robust framework for tests at these frequencies. The production of the needed standards will however require time, and some preliminary work by CIGRE would be helpful.

**Paper B1-303** describes the collation and data analysis from a wide range of on going utility VLF withstand testing program conducted on medium voltage distribution systems in the US. Currently (in North America) the most commonly employed diagnostic technique for assessing cable systems is a withstand test. These tests use a portable voltage source to apply elevated voltage to the cable system for predetermined time duration. In the past, DC voltage was used for this type of field test since the test units were compact and inexpensive. Later, as utilities began to shift from laminar insulation (PILC) to extruded insulations (PE, HMWPE, XLPE, TRXLPE, and EPR) the use of DC testing has declined due to the fact that DC has

been shown to be damaging for aged PE-based insulations. There was a need for a new testing method. To address this need, voltage sources utilizing AC frequencies in the range of 0.02 to 0.1 Hz were developed (VLF) and a IEEE standard was issued. Since then, thousands of km of cables have been tested and the paper addresses the issues raised by utilities et concludes for example that VLF tests are very practical and that the IEEE standard provides appropriate time and voltage test levels for MV cables.

**Paper B1-304** presents the results of tests carried out on site with variable frequency resonant system for the commissioning of 220 kV – XLPE cables installed in Egypt. To-date more than 10 circuits for a total of 72 km of old and new cable systems have been tested according to IEC (1.7 U<sub>0</sub>/1 hour), since early 2007 and 6 faults during tests (including PD measurement) were reported. This test is considered as useful for assessing the cable system condition. The experiences also show that the test voltage with  $U_0$  for 24 h was not relevant in those cases

**Paper B1-305** reports on the use of Ultra Wide Band PD tests performed on two circuits of 161 kV XLPE cables (2 km length) following repetitive failures which occurred in the first 3 years after commissioning. After two failures of joints, careful inspection of faulted joints and On-Line Ultra Wide Band (UWB) PD test were performed. PD measurements indicated that the circuit had five joints with PD activity. To guarantee reliability of the circuit, one of the joints that presented the largest PD reading was removed from service and the rest of the circuit was left unchanged. Unfortunately almost six months apart, two other joint failures occurred proving that the recorded PD activity using UWB techniques was correct. After the fifth failure occurred almost 3 years ago, the circuits has remained in service.

**Paper B1- 306** presents a new monitoring system method for partial discharge (PD) detection installed in two 220 kV transmission lines in Spain for a total length of 7.7 km of cable with 11 joints and 4 cable ends. High frequency current transformers (HFCT) sensors are placed inside link boxes used for bonding systems and the associated PD measurements electronic devices are placed inside complementary boxes, each one close to each link box. An optical fibre communication network is used to transmit PD recorded raw data and to receive control signals from the control and analysis computer (CAS) which is located in a substation where the cable system is connected. The main performance of the PD monitoring system developed is its capability to distinguish between electric background noise and PD signals. The filtering effectiveness has been proven mathematically and by on site measurements in high electric background interference environment. The developed PD monitoring system is capable of detecting PD activities at around 5 pC in environment of electric background noise around 200 pC.

## 10. Discussion of Preferential Subject No. 3

When the integration of long HV cable systems in the network is shown to be feasible as presented in several papers under PS1, it is highly important to know the electrical characteristics of these systems and to compare computed values with experimental ones.

SC B1 and SC B4 are working closely on these topics and tests mentioned in paper B1.301 offer a high value contribution to this work.

Very Low Frequency after laying testing had been recognized as an interesting way to test HV cables by WG 21.09 in Electra 173. At that time, no equipment was available for HV tests. To-day, this type of test appears to be helpful in distribution voltages, as experienced in

the US and reported in paper B1.303, it is perhaps time to explore this method in the high voltage range.

Under PS1, one paper has pointed out the need of assessing the behaviour of installation equipment of HV cable in tunnels under short-circuit conditions by appropriate tests. Such tests will be costly and their cost will increase the overall cost of the cable systems, but they are adding value to the system.

On the other hand, SC B1 had issued recommendations for preparation of IEC 62067 and more recently WG B1.06 has published TB 303 to introduce the concept of Extension of Qualification and to confirm the ranges of approval of Prequalification Test and Type Test as defined in current IEC 62067. Despite this, it appears that costly tests which are considered as unnecessary in CIGRE recommendations are still requested in some contracts and increase the costs of the cable systems most probably without added value.

PD measurement (TB 182 from WG 21.16, Electra 208 from WG D1.33) and PD monitoring, especially using sensors located at the link boxes in cross-bonded systems, are reported to be a good way to detect PD activity in joints with a sensitivity of 5 pC in environment showing background noise around 200 pC.

Laboratory tests often lead to new concepts of monitoring of HV equipment. Ten years after the work of WG B1.02 on the use of DTS systems (TB 247), it would be interesting to know how field measurements and laboratory tests have opened the way to Dynamic Thermal Rating Systems which would meet the needs of users. Some elements have been given by papers under PS 1.

## **11. Questions from Preferential Subject No.3**

### **State-of-the-art and trends for cable system testing**

- Qualification, type testing, routine, sample, after installation testing of cable systems
- Representation of installation and operational stresses in testing of cable systems
- Diagnostic testing of cable systems

**Question 1: What is the experience collected worldwide with very low frequency testing? Can this testing technique be accepted as field testing for diagnosis purposes, eventually combined with other techniques? In which voltage range?**

**Question 2:** Extension of qualification issues have been addressed by WG B1.06 in Technical Brochure 303. Range of approval of PQ test and Type Tests are well defined. Despite this, many specifications call for Long Term testing in actual installation configuration of a given cable system. **Are there any technical reasons to repeat such tests, when this is not required by IEC and Cigre recommendations, considering their high costs? Is there a need for tests differing from the existing ones?**

**Question 3:** Multiple examples of Cable systems Dynamic Rating have been given. **Are the needs of Utilities regarding the use of DTR collected and expressed? Is there a need to establish recommendations or standards in this area?**

**Question 4:** PD measurement with sensitivity of 5 pC in a background noise of 200 pC is said to be achievable. **Is there any assessment of the time available for repair or replacement before failure, when an accessory shows such a level of partial discharges at operating voltage ?**