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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 2008 Discussion Group Meeting.

Preferential Subject 1

Technical challenges overcome in newly installed underground and submarine transmission systems.

- Current state-of-the-art in design, testing of AC and DC, submarine and underground cable systems (including High Temperature Superconducting, HTS) and Gas Insulated Lines (GIL),
- Innovations in cable systems installation.

Preferential Subject 2

Current and future methods supporting efficient operation, maintenance and upgrading/replacement decisions of cable systems.

- Maintenance policies,
- Diagnostic methods applied to Cable Systems,
- Remaining Life Assessment Methods.

Preferential Subject 3

Future technical solutions for underground and submarine transmission systems addressing environmental and economical considerations.

- Balancing environmental requirements against economy,
- Electromagnetic Fields (EMF) mitigation, restricted access, installation in tunnels, bridges and along motorways and railways,
- Development trends towards higher voltages and ratings.

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The total number of papers is 22 and distributed with 7 papers on Preferential Subject 1, 4 on Preferential Subject 2 and 11 papers on Preferential Subject 3.

3. Papers for Preferential Subject No. 1

Technical challenges overcome in newly installed underground and submarine transmission systems

- **Current state-of-the-art in design, testing of AC and DC, submarine and underground cable systems (including High Temperature Superconducting, HTS) and Gas Insulated Lines (GIL),**
- **Innovations in cable systems installation.**

Paper B1-101 gives the experimental results from short circuit tests on metallic sheaths, screens and hybrid screens. The tests show that calculated temperature rise according to the non-adiabatic approach in IEC 60949 yields conservative sheath designs. Another important result from the experiments is that a resistive current distribution in hybrid screens gives a good approximation of the real current distribution and thus the temperature rise of the components.
The experiments also show that the temperature limits defined in IEC 61443 are conservative and may be exceeded based on experimental data.

Paper B1-102 presents an approximation to compute the current rating of underground cable installations with multiple cable circuits. The model considers the temperature distribution along the whole cable installation using continuous heat transfer models. This is in contrast to traditional calculations according to IEC or IEEE standards where discrete thermal resistances and shape factors are used to set up the thermal model.
The model presented in this paper has the ability to calculate the temperature of any point of the installation as function of the conductor currents. Comparison with finite element calculations on a 132 kV double circuit shows that that the results from this model yield slightly conservative results, but the temperature distributions are similar.

Paper B1-103 describes a cable project in Argentina which involved crossing of the river Reconquista. The paper describes the alternative solutions that were considered to maintain the current rating at 10m burial depth under the river. The effect of increased spacing between cables, larger conductor cross section, single point bonding and cross bonding of screens were studied. The project finally chose to install a cross bonding section that satisfied the current rating requirement without increasing the conductor cross section.

Paper B1-104 presents the qualification test program for the HVDC interconnection between the Italian main land and the island of Sardinia. The project is one of the world's largest cable projects and very challenging due to the large water depth, the voltage level and the different conductor cross sections/materials along the circuits. The qualification program has been extensive to verify that all cables and accessories designs are fit for purpose under the extreme mechanical stresses. Tests in the laboratory have been followed by sea trials to prove the cable system and the laying equipment. The first pole is scheduled to be completed in 2008.

Paper B1-106 describes a very large 500 kV cable project in central Shanghai where the new cables are installed in a newly built tunnel that will be shared with 220 kV circuits. This very powerful link will consist of 3 circuits capable of transmitting 1000 MW each in steady state conditions and 1500 MW in emergency conditions. The total length of 500 kV 2500mm^2 cables will be approx. 51 km per circuit.

Paper B1-107 gives a summary of the operating experience from the 13,2 kV superconducting cable system installed at AEP Bixby Station. This superconducting triax cable has been in service since August 2006 and the service experience with the system is very good. The cable system has been subjected to network transients without deterioration of the performance and has proven its ability to operate under the relevant, varying ambient conditions.

Paper B1-108 presents type testing of a 22,9 kV 50 MVA HTS cable system in Korea. The cable is designed with all 3- cores inside a single cryogenic envelope. The type test program was based on IEC test standard for oil filled cables with additional tests to confirm the ability of the cable system to withstand the large thermal expansion and contraction of a HTS cable system. The type test was performed on 100m of cable including one joints and terminations.

4. Discussion of Preferential Subject No. 1

Technical challenges overcome in newly installed underground and submarine transmission systems

- **Current state-of-the-art in design, testing of AC and DC, submarine and underground cable systems (including High Temperature Superconducting, HTS) and Gas Insulated Lines (GIL),**
- **Innovations in cable systems installation.**

The papers presented under Preferential Subject No.1 show that there are technical challenges to be overcome both with the cables that are regarded as mature technology and with new technology as represented by HTS cable systems.

The need for transmission of large amounts of energy into large cities creates challenges for the utilities and the cable industry. EHV power cable circuits have to be installed in tunnels which may be shared with other infrastructure and rivers may have to be crossed by using directional drilling and additional thermal challenges.
HTS cable systems are also being developed mainly to upgrade the power capacity of the grid in large cities with limited civil works. However, this technology is still in the development stage. It is interesting to see the different design philosophies that the cable manufacturers have for their systems. There is also a large scatter in the test voltages used for type testing of these systems as there are no recognized international test standards for HTS cable systems. The need for such test recommendations will increase as the HTS technology becomes more mature and available.

The need for interconnections between disconnected grids also gives new challenges for the submarine cable manufacturers. The submarine cable technology has to be further developed to meet depth and transmission capacity requirements. Installation of submarine cable systems at very deep waters also give challenges for the laying equipment and laying methods.

5. Questions from Preferential Subject No.1

Technical challenges overcome in newly installed underground and submarine transmission systems

- **Current state-of-the-art in design, testing of AC and DC, submarine and underground cable systems (including High Temperature Superconducting, HTS) and Gas Insulated Lines (GIL),**
- **Innovations in cable systems installation.**

Question 1:
Most cold dielectric HTS cables are manufactured with a dielectric that needs to be filled with liquid nitrogen before electrical testing can be performed. In the view of longer lengths and industrial production of these cables, how can these cables be routine tested before installation?

Question 2:
Are the limits for the land synthetic cables reached with respect to voltage level, conductor cross section, and electrical stress in the insulation?

Question 3:
How can land cable installation techniques be improved to cut cost of cable links without jeopardizing the reliability?

Question 4:
XLPE insulated AC submarine cables have gradually taken over the market from oil filled submarine cables for voltage levels up to and including 170 kV. The same trend will probably occur for higher voltages in the future. What is the technological status for XLPE insulated submarine cable systems for voltage levels above 170 kV?

6. Papers for Preferential Subject No. 2

Current and future methods supporting efficient operation, maintenance and upgrading/replacement decisions of cable systems

- **Maintenance policies,**
- **Diagnostic methods applied to Cable Systems,**
- **Remaining Life Assessment Methods.**

Paper B1-201 presents results from simulation of overvoltages in power grids. The simulation was performed with the software PSpice which had some limitations in the modelling of cables. The results from the simulations were compared to measurements that were performed on laboratory models.

Paper B1-202 presents results from condition monitoring of medium voltage polymeric cables in India. Loss angle measurements at 0.1 Hz (VLF) were performed on new cables and on field aged cables to assess the sensitivity of the method to detect production deficiencies and the ageing status of cables. Testing on new cables showed that the loss angle at 0.1 Hz was more sensitive to a certain kind of production defect than the loss angle at 50 Hz. The measurements also show that VLF loss angle testing is an effective tool for condition assessment of field aged medium voltage cables of wet design.

Paper B1-203 describes the application of UHF sensors for online detection of PD in cable terminations. The measurements show that a sensitivity of 5 pC is possible with screened sensors and that the measurement system is able to distinguish between internal partial discharges and corona/external noise. The method has been applied in field measurements on cable terminations with good result.

Paper B1-205 presents results from online partial discharge testing on high voltage cable sealing ends. The authors describe the challenges involved with measuring small PD currents in noisy environments and how they have designed a measurement system to discriminate external noise. The paper also presents the results from measurements which demonstrate the ability of the measurement system to distinguish external and internal signals.

7. Discussion of Preferential Subject No. 2

Current and future methods supporting efficient operation, maintenance and upgrading/replacement decisions of cable systems

- **Maintenance policies,**
- **Diagnostic methods applied to Cable Systems,**
- **Remaining Life Assessment Methods.**

The industrialised part of the world depends on a reliable electricity supply and is paralysed in case of extensive power outages. Cable systems are very important parts of the power grid and represents large assets for the utilities. Thus, the utilities need tools to be able to assess the condition of their cable systems to be able to make investment decisions before the systems reach end of life. A Working Group, WG B1-09, has been launched in SC B1 to work on the important subject of remaining life of existing HV AC underground lines.

The challenges on remaining life assessment are different on MV compared to HV/EHV XLPE cable systems. In MV circuits the main challenge is to assess the condition of cables with wet designs while the condition of the accessories is the most important issue for the higher voltages.

8. Questions from Preferential Subject No.2

Current and future methods supporting efficient operation, maintenance and upgrading/replacement decisions of cable systems

- **Maintenance policies,**
- **Diagnostic methods applied to Cable Systems,**
- **Remaining Life Assessment Methods.**

Question 1:
PD measurement in the field on high voltage cable accessories is complicated due to external disturbances and the sensitivity may also depend on the weather conditions at the time of measurement. Taking into account these factors, how can the results from the measurements be correlated with degradation mechanisms in the accessories?

Question 2:
Cables are more and more used. What is the service experience of past and recent cable assets?

9. Papers for Preferential Subject No. 3

Future technical solutions for underground and submarine transmission systems addressing environmental and economical considerations

- **Balancing environmental requirements against economy,**
- **Electromagnetic Fields (EMF) mitigation, restricted access, installation in tunnels, bridges and along motorways and railways,**
- **Development trends towards higher voltages and ratings.**

Paper B1-301 describes the qualification of a 150 kV transition joint between an oil filled cable and a XLPE cable. As there is no test recommendation today for transition joints a qualification program was set up based on IEC 60141-1 for oil filled cable systems, IEC 60840 for XLPE cable systems and national specifications. The transition joint passed most of the program before a cable failure in the oil filled cable occurred.

Paper B1-302 describes the philosophy used by Edenor to plan and execute underground cable installations in densely populated areas. The 132 and 220 kV cables are installed in pipes in order to minimize the necessary length of open trenches and Edenor has chosen cables with lead sheath as their standard design. Edenor will abandon DC testing and introduce AC testing with resonant circuit equipment as after installation test for future cable systems.

Paper B1-303 presents a methodology developed in France to evaluate the compatibility of transition joints between XLPE cables from different cable suppliers and different conductor cross sections. The result of this evaluation may be that the cables can be jointed as is, additional tests need to be performed or the cables cannot be jointed together. A test program is proposed in case further testing is required.

Paper B1-304 presents the development of extruded cable systems for HVDC Light converters. The paper describes the type testing of a cable system for 320 kV.

The authors also presents interesting comparisons between the use of overhead lines and the HVDC Light system and indicates that a cost factor of as low as 2 can be achieved in some cases.

Paper B1-305 describes a new method to shield the cables to limit the magnetic field. The new cable type uses magnetic tapes wrapped around 3-core cables to confine the magnetic field within the cable. Measurements performed on full scale cables confirm the design and the losses generated in the electromagnetic shielding are very low. This design shows interesting properties for circuits with strict restrictions on the external magnetic field.

Paper B1- 306 presents investigations of a 6 core concept to increase the transmission distance for submarine power cables and to reduce the magnetic field of underground cable circuits. The investigations show that the 6-core concept may extend the step out range for MV cables and yield more robust radial power systems. It is also shown that the magnetic field surrounding underground cables can be significantly reduced by using 6 cables arranged in a specific geometry instead of 3 cables.

Paper B1-307 discusses the advantages and disadvantages of replacing traditional cable circuits by HTS cables. The authors believe that future long installations need to be cooled from the ends because of permissions. Focus has to be given to the losses in the cryostat and the losses in the cable to be able to cool with a reasonable pressure drop in the circuit. The authors are investigating the feasibility to install a 6 km long HTS cable link in Amsterdam with end cooling and the results are positive so far.

Paper B1-308 presents the challenges involved when installing HV cables in shared structures and in this case in a railway tunnel. The authors have performed experiments to evaluate the effect of internal cable faults in HVDC cables on the safety and concluded that this is not a problematic issue. However, more work has to be done to evaluate the fire behaviour of the cables inside the tunnels, impact on the cooling system of the tunnel and other safety and operational issues.

Paper B1-309 presents investigations of the environmental impact of different design parameters for cables and the impact of type of installation and grounding.
The calculations were performed with dedicated software developed in France. The calculations show that the losses in the cables contribute significantly to the environmental impact. Thus, single point bonding or cross-bonding, increased conductor cross section and insulated wires in the conductors is preferred from an environmental point of view.

Paper B1-310 discusses a method to define the active and reactive operation area of insulated cables. The charging of the dielectric in long cables results in variation of current along the lengths. In addition the maximum thermal limit of the cables may vary along the length due to external factors such as thermal resistance, temperature, burial depth, etc. The paper presents a method to define the operation area of cables which takes these factors into account.

Paper B1-311 presents the development of an extruded HVDC cable with integrated return conductor. Cables with integrated return conductor have some advantages compared to systems with two separate cables bundled together, one main cable and one return cable. The integrated return conductor makes the cable concentric and easy to install, the magnetic field outside the cable is negligible and it is easier to repair compared to a bundle of two cables.

The author's present calculations which show that the cost efficiency of the integrated return conductor is highest for low to medium power transmission capacity.

10. Discussion of Preferential Subject No. 3

Future technical solutions for underground and submarine transmission systems addressing environmental and economical considerations

- **Balancing environmental requirements against economy,**
- **Electromagnetic Fields (EMF) mitigation, restricted access, installation in tunnels, bridges and along motorways and railways,**
- **Development trends towards higher voltages and ratings.**

Economical considerations have always been important in the design and operation of power systems. However, the focus on environmental aspects is increasing in general especially due to global warming and will probably also become more important when planning new cable links. Paper B1-309 shows some very interesting results on the environmental impact of cable system design and it is interesting to note that the major part of the environmental impact is due to operation of the cable systems and that this may be significantly reduced by using cross bonded systems instead of direct grounding.

Advances in cable technology create new markets for cable links. Paper B1-304 presents the qualification of an extruded HVDC cable system for 320 kV together with voltage source converters. According to the authors this system will improve the competitiveness of HVDC cable systems and that the cost difference between HVDC underground cable systems and overhead lines may become as low as 2. This figure will certainly depend on the route conditions, but development of VSC converters and extruded HVDC cables has made HVDC transmission more attractive for transmission on land.

Two papers present methods to reduce the EMF from power cable links. Paper B1-305 presents results from tests with a magnetic tape wrapped around the cables. This new design may be attractive in densely populated areas and may replace cables in steel pipes. Paper B1-306 presents a comparison of the EMF from underground cable circuits using 3 and 6 cores per circuit. The calculations show that the magnetic field from a cable circuit may be significantly reduced by using 6 cables installed in a special geometry. This may be an attractive alternative to circuits with large conductor cross sections and external magnetic shielding.

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11. Questions from Preferential Subject No.3

Future technical solutions for underground and submarine transmission systems addressing environmental and economical considerations

- **Balancing environmental requirements against economy,**
- **Electromagnetic Fields (EMF) mitigation, restricted access, installation in tunnels, bridges and along motorways and railways,**
- **Development trends towards higher voltages and ratings.**

Question 1:
The electricity sector is particularly in focus for the environmental impact of power generation while the environmental impact from losses in power transmission is less focused in the general debate.
How are the environmental aspects treated during planning of new cable links?

Question 2:
Restrictions in the magnetic field from cable circuits create new challenges for the engineers and several methods have been developed to reduce the field. Finite element methods are often needed to calculate the field and the effect of the different shielding methods.
What is the operational experience with shielding methods for cable circuits and what is the correlation between calculations and measurements? What is the impact on cable rating?

Question 3:
HVDC transmission by voltage source converters has opened new markets for HVDC power cables. Remote islands, oil platforms, etc. may be connected to the land grid and the introduction of extruded HVDC cables has also made land installations more attractive.
How can the extruded underground HVDC cable systems and installation methods be further improved to become even more competitive to overhead lines?

Question 4:
Installation of new cable links in densely populated areas is expensive and time consuming. Big savings can be achieved by installing different kind of infrastructure in the same tunnel, but problems may rise during installation and operation.
What is the service experience from HV cable installations in shared structures?
How are these tunnels protected in case of fire?

Question 5:
Transition joints between XLPE cables and oil filled cables are required for extension of existing links for voltages up to and including 420 kV. No test standards for transition joints exist today, but WG B1-24 is working on a CIGRE recommendation.
Which designs are used today and what is the service experience with these designs?

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