High voltage (HV) and extra high voltage (EHV) cable systems are fundamental components of electric power transmission networks. Two basically different insulation technologies are characterising the practical implementation, i.e. the traditional fluid filled lapped paper insulation and the dry extruded synthetic insulation.

Paper insulated cables with mass or oil impregnation are still representing the majority of installed HV and EHV underground and submarine cable systems, though in some countries extruded cables have already exceeded the paper insulated ones. After decades of highly satisfactory service performance their basic designs must be considered mature and not many efforts are spent for further developments any more.

Extruded cables for all voltage levels of AC and partly also for DC are increasingly dominating new installations. There is significant service experience with AC XLPE land cable systems up to 170 and 225 kV, but less with the higher rated voltages up to 500 kV.

Though numerous extruded cables have demonstrated in service for many years their excellent technical and functional level, further developments and improvements are still going on. The reasons are predominantly economical and ecological rather than technical.

Submarine cables, previously preferably paper insulated, are increasingly equipped, too, with synthetic insulation for both AC and DC. The trend goes towards higher transmission voltages and capacities, longer shipping lengths and better performance, i.e. higher availability through improved laying and protection methods.

New transmission media like Gas Insulated Lines (GIL) and High Temperature Superconducting Cables (HTS) could be options for future bulk power transmission. However, their actual commercial application is still minimal.

Working fields of SC B1

The CIGRE Study Committee on Power Cables has accompanied the worldwide cable evolution for almost 80 years. The first committee was founded in 1927 under the designation SC 2. In 1967 it continued as SC 21 and eventually became SC B1 in 2002 as one of the five (B) study committees dealing with subsystems.

Its field of activity is the development and operation of “all Types of AC and DC insulated Cable Systems for Land and Submarine Power Transmission”.

SC B1’s scope of work covers “Theory, design, manufacture, testing, installation, application, operation, maintenance and diagnostic techniques of (high voltage) power cables”.

It is one of the SC’s primary ambitions to effectively participate in and contribute to the progress of worldwide cable systems technologies. SC B1 strives to be an appreciated and recognised forum for international experts and engineers for the exchange of information and knowledge and to add value to these inputs by synthesizing them in high quality documents for the benefit of the international cable community.

Through many years SC B1(21) has produced a comprehensive library of sophisticated technical documents, preferably Technical Brochures (TB) *, which are addressing all sections of a cable system’s life. The figure shows the four major phases of a cable’s life design, con-

*) Lists can be found on www.cigre.org or on www.cigre-b1.org
struction, operation and removal with the allocation of some recent major SC B1 outputs and running activities, respectively.

In previous years, the emphasis of work was mainly on technical aspects of single cables and components, preferably relevant for manufacturers.

Following CIGRE’s new orientation towards enhanced satisfaction of needs of target groups and stakeholders, SC B1 extended its focus from formerly preferably technical competence to other engineering fields, i.e. economical, environmental and social aspects, too.

From the figure it is obvious that the majority of work lies now on complete cable systems and their performance, addressing the topical interests of cable systems owners, operators and users. The following chapters will describe the trends and evolutions of the different phases and will explain the respective SC B1 contributions, either available (TBs, ELECTRA papers) or under consideration.

**Design**

The design phase is the first part of a cable’s life cycle. Here the customer’s requirements (transmittable load) and the network configuration (voltage levels, connecting points, short circuit conditions etc.) have to be translated by the design engineer into adequate system’s components (i.e. cables and accessories), accurate ratings at different load regimes and eventually into an optimal overall engineering for the complete underground transmission systems.

**Construction, Installation**
- TB 194
- TB 210
- WGB 1.B1.08
- JWG B3/B1.09
- WGB 1.B2.22

**Design**
- Cable & Accessories design
  - TB 89
  - TB 177
  - TB 218
  - TB 229
  - WGB 1.B1.25

**Rating, Ampacity**
- TB 5
- TB 104
- TB 27.2
- ELECTRA 174
- ELECTRA 212
- WGB 1.B1.23

**Construction**

**Testing**
- ELECTRA 151
- ELECTRA 218
- TB 219
- TB 303
- WGB 1.B1.24
- TF B1.27

**Operation**
- Operation, Maintenance, Reliability
  - TB 182
  - TB 211
  - TB 279
  - WGB 1.B1.21

**Removal**

**Running working bodies**

In a lot of investigations have been done by SC B1(21) in the past on the design of cables and accessories and published in various documents:

- **TB 89 and TB 177**: Accessories for extruded HV cables
- **TB 218**: Gas Insulated Lines
- **TB 229**: High Temperature Superconducting Cables

**Cable & Accessories Design**

Economical and ecological aspects have become in recent years the main drivers for development activities at cable systems components. In practice these requests shall be tackled with smaller, lighter and longer shipping lengths and fewer and easy to install joints, made of environmentally friendly materials. Improved cleanliness and homogeneity and advanced processing of materials are preconditions for the reduction of insulation wall thickness of cables. However, smaller dimensions inevitably result in higher electrical stresses in both, cables and accessories. Pre-fabricated and pre-tested accessories shall help to cope with these requirements. Of course, the adequacy of such measures must be controlled by stringent Quality Management Systems and validated by appropriate test procedures for safeguarding the expected service reliability (see chapter 5).
At present SC B1 activities in this field are limited to an issue, which needs an update in the context of less costly and environmentally friendly cable designs.

WG 21.14 published in 1992 "Guidelines for tests on high voltage cables with extruded insulation and laminated protective coverings". Numerous improvements on such coverings appeared since then and it was considered that an update should be appropriate. WG B1.25 reviews Advanced Designs of laminated metallic coverings. Results are expected in 2009.

Rating and Ampacity

The rating and ampacity, i.e. the capability of a cable system to transmit electric power, is determined by the admissible temperature of the cable conductor and of the insulation, the internal and external losses and the heat dissipation through the thermal environment around the cable. Though the basic configuration seems to be simple, the accurate calculation is difficult due to a large number of influencing parameters, many of which are often not well known. To avoid potential thermal problems, design engineers often used to base their calculations on assumptions on the safe side. Consequently, most cables were over-dimensionalized and never reached their thermal limits in service, which generally was accepted in the past.

However, nowadays when effective utilization of assets becomes more and more essential, accurate calculation procedures are appreciated.

SC B1(21) has been traditionally busy in this field and produced a number of reports and guidelines:

- TB 5: Current ratings of cables for cyclic and emergency loads
- TB 272: Large Conductors and Composite Screens

Calculation methods for Magnetic fields in HV cable systems with and without ferromagnetic components were published in ELECTRA 174 and in TB 104.

These documents, however, did not include the EMF’s influence on the current de-rating.

WG B1.23 studies the Impact of EMF on Current Ratings and on Cable Systems. The study shall concentrate on the reduction of both the ampacity due to losses and the EMF due to shielding in cables installed in ferromagnetic pipes. Without evocating what could be the right EMF level over the cable system a practical recommendation shall be published in 2009.

System Design

Customer’s requirements and the intrinsic configuration of the network are the basic conditions for all engineering considerations for a new cable line. Not only technical but also economical, environmental and social aspects must be taken into account for the adequate layout of a new cable system. Special attention is required from the design engineer when cables are inserted into networks, which are characterized by overhead lines. Different impedances, earth fault currents, protection schemes, loading characteristics, necessity of shunt compensation etc. need to be carefully considered.

SC B1 recently published three fundamental documents which are addressing the most important system design aspects and shall guide the cable engineer to an optimal technical design with least investment cost, reduced losses and best performance of the new cable link:

- TB 250: Technical and environmental Issues regarding the Integration of a new HV Underground Cable System in the Network
- TB 268: Transients affecting long Cables
- TB 283: Special Bonding of HV Cable Systems

As an amendment to TB 283 an expert team TF B1.26 is still studying Earth Potential Rises in specially bonded Screen Systems. Results are expected in 2007.

Overhead transmission lines are popular with utilities because they are relatively less expensive than cables, but generally unpopular with the public, who often demand undergrounding.

For updating an earlier
TB 110: Comparison of HV Overhead Lines and Underground Cables

WG B1.07 is considering Statistics on Underground Cables in Transmission Networks. With reference to significant underground cable projects realised in the period 1996-2006 the technical reasons why undergrounding was selected shall be identified as well as the factors which must be taken into account in order to make a balanced choice between the two technologies. Results are expected in 2007.

Better and longer utilization of existing assets are nowadays of prime interest for cable systems owners and operators. The difficulties to obtain planning permission for new transmission lines and economical constraints favour efforts for Upgrading and Uprating of Underground Cable Systems, which is presently studied by WG B1.11. Results are expected in 2007.
Construction and installation

Environmental and social aspects are common for all new cable installations.

Traditional techniques for construction of cable routes and for laying and installation of cable systems are often associated, besides high cost and long duration, with considerable social and environmental impacts. To mitigate these impacts innovative construction techniques have been developed, which for instance avoid open trenches and direct burial by trench-less methods such as mechanical laying, horizontal drillings, multipurpose tunnels etc. Less above ground activities help to reduce disturbances on traffic and public, thus increasing the acceptability of a new cable system.

A comprehensive investigation on this issue has been published in TB 194: Construction, Laying and Installation for extruded and self contained fluid filled Cable Systems

Present considerations of WG B1.08 are concentrated on the special case of Cable Systems in multipurpose or shared Structures (tunnels, bridges), which are becoming more and more attractive with regard to construction cost, right of way etc.

In addition a JWG B3/B1.09 studies the Application of long high capacity Gas Insulated Lines in shared Structures. This JWG is focussed on the specific technical aspects of GIL, i.e. their mechanical and thermal design, laying, installation, testing and gas handling. Results are expected in 2007.

The issue of jointing quality is of crucial importance for the system's reliability. As accessories are prepared on site under much more unfavourable conditions than cables during their production in the factory, means to reduce the higher risk of failure need to be carefully considered. Design aspects were studied in TB 210: Interfaces between HV extruded cables and accessories.

Performance issues are addressed by WG B1.22 Cable Accessories Workmanship. Results are expected in 2008.

Testing

Test procedures and requirements for new and installed cable systems are of crucial importance and of highest common interest for suppliers and purchasers. For SC B1 it has always been a central field of activity to prepare, often on request of IEC, test recommendations, which then were implemented in respective IEC specifications. In this context IEC and SC B1 traditionally maintain a very close and effective liaison.

A typical example were recommendations published by WG 21.03 in 1993 in ELECTRA 151 on electrical type, routine, sample and prequalification tests for extruded cables 150 < U ≤ 400 kV, which became basic test procedures in the first edition of IEC 62067(2001). More or less every newly developed EHV cable system with XLPE insulation was qualified and approved by these test specifications before delivery to the customer.

After several years of highly satisfactory practical application the question was raised whether or not the full set of long-term prequalification tests need to be repeated when limited changes are brought to pre-qualified cable systems. With the goal to come quickly and economically to the market with innovative solutions WG B1.06 developed a reduced test called “Extension of Qualification” to control, without jeopardizing the reliability, changes in already pre-qualified cable systems. These recommendations were published in TB 303: Revision of Qualification Procedures for extruded HVAC Underground Cable Systems.

They will be considered by IEC TC 20/WG 16 in future revisions of respective IEC cable test specifications.

Other recent examples of SC B1 test recommendations were:

- TB 219: Testing of DC Extruded Cable Systems for Power Transmissions up to 250 kV.
- Technical Report: Recommendations for Tests of Power Transmission DC Cables up to 800 kV, published in ELECTRA 218

Present work by WG B1.24 relates to Test Procedures for HV Transition Joints, i.e. among others between existing paper insulated and newly installed extruded cables. To date, there are no appropriate test specifications. Results are expected in 2009.

After introduction of AC instead of DC tests for commissioning of extruded land cable systems the question was raised how to test long extruded submarine cables. TF B1.27 presently considers Test Recommendations for XLPE AC Submarine Cables from 170 kV to 500 kV. Results are expected in 2010.
Operation

Availability, reliability and optimal utilisation of an existing cable line is of prime interest for the system operator. After successful commissioning state of the art cable systems generally promise trouble-free service performance for very long time, typically in the range of thirty to forty years. However, such outstanding lifetime can only be expected when the system is consistently safeguarded from detrimental external impact, e.g. overheating, mechanical damage, chemical aggression or water ingress.

Supporting means for safe operational management and efficient utilisation of existing assets are structured maintenance, monitoring of crucial system data and diagnostics of potential weak points. Based on such information the operator shall be able to estimate the system’s condition, its probable availability and reliability and even its remaining life (see chapter 7). Eventually he can draw conclusions whether or not investments for refurbishment or replacement should be considered.

Reliability, Maintenance

Comprehensive information on reliability and service experience is considered essential to the cable industry as a whole as a reflection of the actual situation throughout the cable world. The last CIGRE service experience statistics for land and submarine cables and accessories date back to the early nineties. Since then, significant quantities of cables and accessories have been installed and the associated technologies have evolved and matured. New surveys would seem appropriate. WG B1.10 is preparing an Update of Service Experience of HV Cable Systems. Results are expected in 2007.

Different kinds of maintenance are practiced today by cable system owners with the objective to keep the system’s operational availability as high as possible.

Guidelines for structured maintenance, tailored to different types of cable/accessory were described in - TB 279: Maintenance of HV AC Underground Cables and Accessories

Compared to corrective maintenance (only after a failure) and periodic preventive maintenance in regular time intervals, condition based maintenance that tries to avoid failures by assessing the condition of components or systems, seems to become an interesting option. All there are addressed, but without recommending a specific policy.

Third Party Damages on Underground and Submarine Cables are a very serious problem in terms of systems availability and cost. WG B1.21 is developing guidance to all parties involved (cable owners, other utilities, contractors, authorities) to avoid or at least mitigate such damages. Results are expected in 2008.

Monitoring, Diagnostics

Monitoring and diagnostics are indispensable information sources for condition assessment and thus for optimal utilization of cable systems.

The application of discrete or distributed thermal monitoring devices is a means for safely operating a cable link within its admissible thermal limits. Based on real time data about thermal bottle necks (hot spots) or on the complete thermal profile along a cable route sophisticated dynamic cable rating systems are able to provide information on admissible loads, thus allowing maximization of transmission capabilities including overloads. The issue was published in - TB 247: Optimization of power transmission capability of underground cable systems using thermal monitoring

The challenge with diagnostics of life cable systems is the acquisition of accurate data and their subsequent interpretation with regard to practical conclusions. Whereas small samples of materials (oil, mass) for diagnostic purposes can be extracted without impact to the system from fluid filled paper insulated cables or accessories, sampling is not possible for dry extruded cables. A report Diagnostic methods for HV paper cables and accessories was published in ELECTRA 176.

For extruded cables diagnostic procedures must be absolutely non destructive. One option could be Partial Discharge (PD) testing on site, which was addressed in - TB 182: PD detection in installed HV extruded cable systems.

Practical application of this method, however, is still limited.

Further investigations such as water-tree detection in XLPE insulation of installed cables are still running in cooperation with SC D1 "Materials and new Technologies".

Removal end of life

The decision whether or not to remove and replace an existing cable line is not easy to make. It normally includes significant disturbances in the network and huge
cost for recovering and scrapping the old cable and for investment of a new cable system.

Therefore Remaining Life Estimation of existing HV AC Underground Lines is an important topic, which is of high concern for utilities. It is clear that it won’t be possible to exactly say how long a cable system has still to live, but to convert the growing risk of failure or excessive cost of maintenance (repairs) into an estimation of the remaining useful life will be an important step ahead. WG B1.09 is considering this issue and will give guidelines for a practical strategy for remaining life estimation in 2007.

Résumé and Outlook

HV and EHV underground and submarine cable systems are reliable and well established components of electric power transmission networks. The main drivers for further improvements and ongoing developments are requirements from the changing operating environment. These are increasingly economical, ecological and social rather than technical.

SC B1’s work keeps focused on the topical needs of its stakeholders. At present almost 140 cable experts from all over the world are endeavouring to successfully complete the running working activities within the agreed time frames. Any further information on their actual progress will be available on SC B1’s website www.cigre-b1.org.