High-voltage XLPERFORMANCE cable technology

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Deregulation of the electricity supply markets and growing environmental awareness are creating exciting new markets for power transmission solutions based on extruded cable technology. At the same time, improvements on all fronts are extending the use of XLPE (cross-linked polyethylene) insulated cable systems up to 500 kV. Today's cable system applications are often competitive with overhead lines, while new manufacturing methods are enabling submarine cables with integrated optical fibers and flexible joints to be supplied in longer lengths than ever before. Further development of extruded insulation systems is also contributing to the success of ABB's innovative HVDC Light™ concept.

High-voltage cable systems rated 220 kV and above have become part of the very backbone of modern-day power transmission infrastructure. This importance carries with it, however, a special responsibility on the part of the suppliers to ensure that the systems exhibit the highest reliability and, because of the high electrical stresses at such voltage levels, that the cables and accessories are properly coordinated.

Deregulation – changing the rules

In today's deregulated electricity markets, the rules that used to govern generation, transmission and distribution have changed for both the power utilities and the suppliers. Suddenly, it is the customer who is in the spotlight. Accordingly, the market has to listen more to public opinion, and there is a strong possibility that this will include a call for a less 'visible' T&D infrastructure.

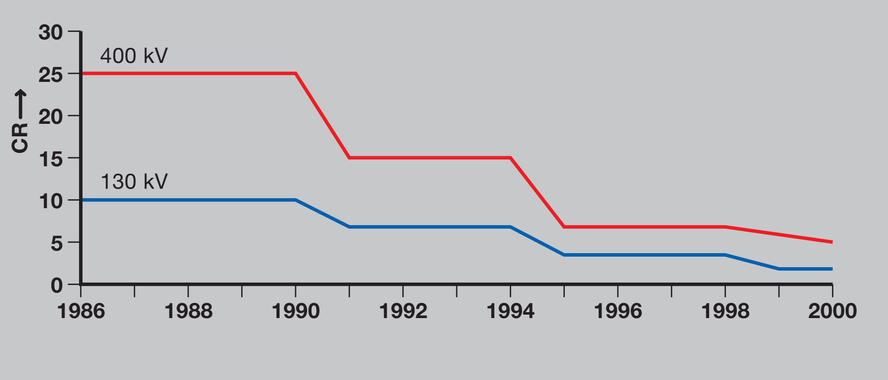
All the actors in this new market have to reduce their costs and at the same time guarantee high reliability for the transmission and distribution systems. A likely scenario is that new cable interconnections will be built and operational margins will be utilized more fully in order to get maximum technical and economic benefit from the electrical network.

Extruded cable systems have a major part to play in this new, competitive environment, especially when it comes to replacing overhead lines with underground cables. XLPE cable systems costs have decreased during the last decade and are likely to fall even further. At the same time, XLPE cable performance has increased enormously. The new message is therefore that XLPE cable systems are able to compete with overhead lines, technically, environmentally and commercially. This is particularly true in the voltage range of 12–170 kV 1.

Extruded insulation – performance and improvements

The well-established trend toward a smaller insulation thickness will continue, resulting in a leaner cable with many advantages, among them longer dispatch lengths, fewer joints, easier

1	Comparison of cost ratio (CR) for XLPE cable systems and overhead transmission lines



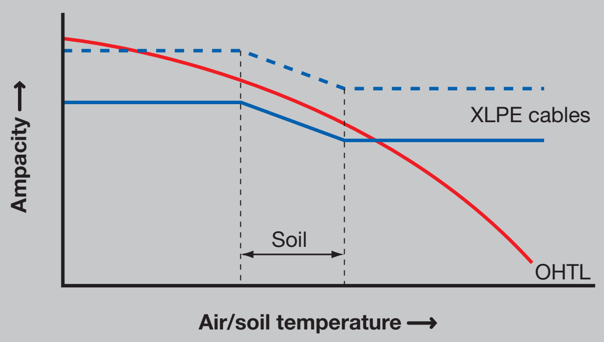
installation, and reduced thermal contraction/expansion of the insulating material. Experience accumulated during EHV XLPE cable system development, improvements made in materials and processes, and the excellent service record of XLPE, have reduced the thickness of cable insulation to 12–15 mm for 132-kV cable systems. This places the XLPE cable systems versus overhead line transmission scenario in a new light, where the cable solution often can be an attractive alternative.

Underground cables versus overhead lines

There are, of course, many operational, security, environmental, reliability and economic parameters that distinguish XLPE cable systems from overhead lines [1]. For modern XLPE cable systems, the reduced cost ratio and environmental and reliability benefits are the most obvious and important considerations. Due to their larger cross-sectional areas, cables usually exhibit fewer losses per MVA than comparable overhead lines. A summary of the benefits of XLPE cable systems is given in the table on page 52.

The ratings of the overhead lines are sometimes dictated by high winter loads, which include a lot of electrical heating equipment. During hot summer days the overhead line carries some 50% less electricity than in winter, making them less attractive if load profiles have to be smoothed out in the future. In areas where there are many air-conditioning units, for example, the benefits of XLPE underground cables make them a genuine alternative 2.

2	Rating of overhead line (OHTL) versus underground XLPE cable. The dashed line indicates that higher powers could be transmitted if the daily load cycle profile is taken into account.



Underground transmission lines also have a better overload capacity for periods of time shorter than 90 minutes due to the high thermal mass of the surrounding soil.

Qualification of 400–500 kV cable systems

The IEC emphasizes the importance of reliability and coordination of the cables and accessories by recommending that the performance of the *total system*, consisting of cable, joints and terminations, be demonstrated. The comprehensive test program, including a 'prequalification' test, is described in detail in IEC 62067.

ABB qualified as a supplier of cable systems for the 400-kV voltage level in 1995.

Quality, materials and manufacturing

Only certified suppliers are contracted to deliver essential materials. All ABB manufacturing sites for HV cables and accessories are ISO 9001 and 14001 certified. The XLPE cable core is produced on a dry curing manufacturing line. The cable insulation system, including the conducting layers, is extruded in a single process using a triplex extrusion cross head located, together with the three extruders for the insulating and conducting materials, in a clean-room 3.

Cable design

4 shows a 400-kV XLPE cable. The cable's copper conductor, which has a cross-sectional area of 2500 mm², is divided into five segments to reduce skin effect losses. ABB uses segmented (Milliken) conductors made of stranded wires for cross-sections greater than 1000 mm². For cross-sections smaller than 1000 mm², the conductors are highly compacted to obtain a rounder, smoother surface.

The metallic screen consists of copper wires on a bedding of crepe paper to reduce the mechanical and thermal impact transferred to the insulation. The number of wires and the total cross-section depend on the short-circuit requirements of the network. Longitudinal water tightness is achieved by filling the gaps between the screen wires with swelling powder.

External protection against mechanical impact and corrosion is provided by a tough, extruded, laminated sheath made from HDPE (high-density polyethylene). A bonded metal foil on the inside of the sheath stops water from diffusing into the cable.

The resulting lean, low-weight cable has several advantages: a greater length of cable can be wound onto any given drum; high eddy-current losses in the cable sheath are avoided; the current-carrying capacity is optimized.

Possible oversheath options are:
- An extruded conductive layer for outer sheath measurements
- An extruded flame-retardant layer for extra safety in hazardous environments

Another option the cable design offers is space-resolved temperature monitoring with optical fibers. The fibers are contained in a stainless-steel tube, approximately the same size as a screen wire, which is integrated in the cable screen. Monitoring the temperature in this way enables the cable load to be optimized.

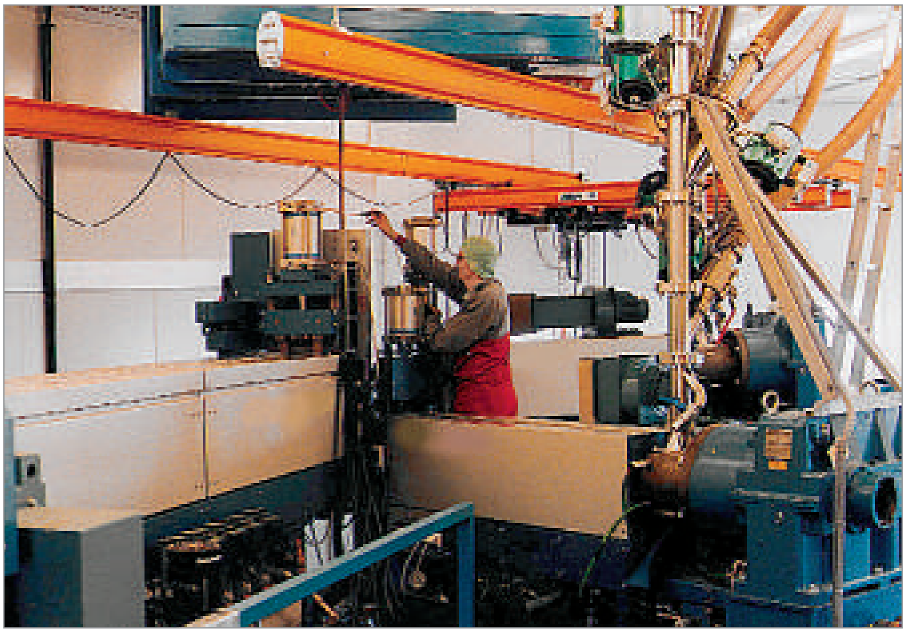
Cable accessories

In the early 1990s ABB developed prefabricated joints for HV and EHV cables which are totally dry, ie with neither gaseous nor liquid materials, and maintenance-free. The main electrical parts can therefore be pre-tested in the factory, speeding up on-site installation and reducing the attendant risks. The joints have integrated sheath insulation in order to comply with the CIGRE recommendation contained in Electra 128, which requires them to withstand impulse voltages of 125 kV between the two joint sections and 63 kV to earth. This permits cross-bonding of the cable screen, which reduces the induced screen currents and losses in the AC cable system. The complete cable system with joint, outdoor terminations and GIS terminations, fulfills the requirements of IEC 62067 in every respect.

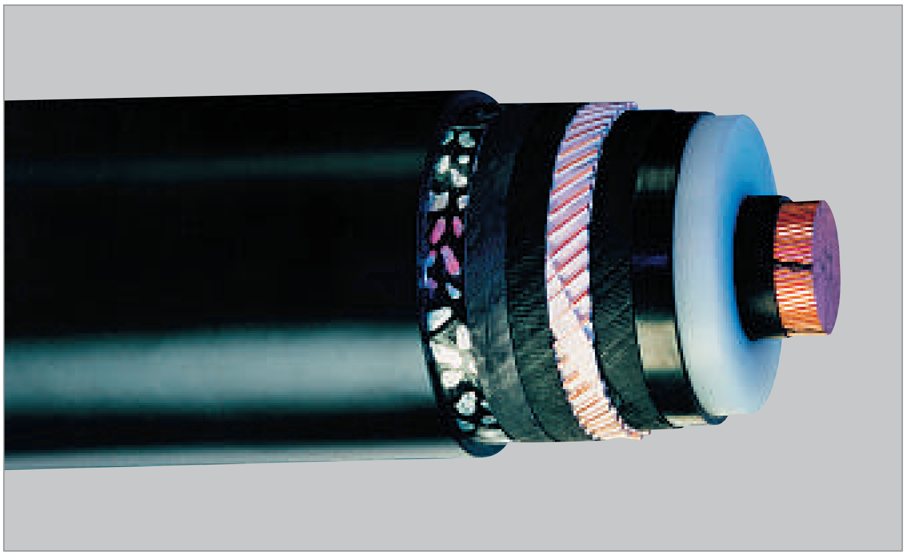
Testing of 220–500 kV cable systems

In the case of medium-voltage cables it is usual to think in terms of components. Even if these come from different suppliers, they can be joined together

3 Vertical extrusion of XLPE cable insulation



4 400-kV XLPE cable. The copper conductor is divided into five segments to reduce skin effect losses.



and the system as a whole will still work. This is why limits are given for the electrical stresses in the construction requirements in IEC 60502.

HV and EHV cables and accessories, on the other hand, are designed as systems. No construction requirements exist for cables for these voltage levels, just the test requirements in IEC 60840 and IEC 62067.

400-kV XLPE cable projects

In 1996 ABB received an order from the public utility Bewag (now Vattenfall Europe) to supply and install a 400-kV XLPE cable system in a 6.3-km long underground tunnel in the center of Berlin. The ventilated tunnel is situated 25 to 35 meters below ground and has a diameter of 3 meters 5. The cable system, with a 1600 mm² segmented copper conductor, has a transmission capacity of 1100 MVA and forms part of a diagonal transmission link between the transmission grids west and east of the capital.

The cable is installed with the three phases arranged vertically, one above the other, on specially designed cable saddle supports 7.2 meters apart, with a short circuit-proof spacer in the middle of each span. The cable route was divided into nine sections, each approximately 730 meters long. GIS terminations were installed at the two substations and the new ABB joint was used to interconnect the cable lengths. The laid cable consists of three main cross-bonded sections, with three minor sections within each main section. The cable circuit went into service in December 1998.

> Greater lengths of low-weight XLPE cable can be wound onto any given drum, while high eddy-current losses in the sheath are avoided.

The Bewag utility subsequently awarded a second 400-kV XLPE cable contract to ABB, this time for a 5.4-km long system, again in an underground tunnel. This cable circuit completes the diagonal link between the transmission grids west and east of Berlin, and was handed over to the customer in July 2000.

Further 345–400 kV cable projects awarded to ABB include orders for 200-km XLPE cables, accessories and installation. Commissioning of these projects is scheduled to take place during 2003–2004.

New submarine cable projects

In 1998 ABB was awarded the Channel Islands Electricity Grid Project, which reinforces the power supply from France to Jersey and, for the first time, connects Guernsey to the European mainland grid. The submarine part

5 400-kV cable system in a 6.3 km underground tunnel running through Berlin's city center

of this project was completed in July 2000.

The main components delivered for the project were:
- Submarine cables between France and Jersey and between Jersey and Guernsey (approx 70 km)
- Underground cables on Jersey and Guernsey
- GIS substations
- New transformers and reactors

The two submarine cables are of the same basic design, ie three-core, separate lead-sheathed, and with triple-extruded XLPE insulation. Each has a fiber optic cable with 24 fibers integrated in it for system communication and inter-tripping. The cables have double wire armor (ie, an inner layer of tensile armor and an outer, so-called rock armor) to protect them from damage that could be caused by tidal currents and fishing.

The cables have a diameter of approximately 250 mm and weigh about 85 kg/m in air.

Both cables were delivered by the factory in their full lengths 6.

Because of the risks posed by fishing activities, the cables between Jersey and Guernsey and the fiber optic cables between Jersey and France were jetted into the seabed for extra protection.

Another submarine cable project is the Ma Wan and Kap Shui Mun Cable, which crosses a channel in Hong Kong. Due to the heavy traffic in this channel, it was decided to forgo conventional installation of the 132-kV and 11-kV systems, which would probably have disturbed shipping even if modern techniques were used. The problem was solved by drilling under the seabed and installing ducts through which the cables were pulled. This has the extra advantage of allowing upgrades to be carried out in the future.

Separate control systems were installed to monitor operation of the cable link, which was completed in 2003.

6	Storage of submarine cable prior to laying

A new submarine cable project has recently been awarded to ABB by Aramco. The cable, which is 53 km long, is rated 110 kV with 3 × 500 mm^2 copper conductors. It will be commissioned in 2004.

HVDC Light™

HVDC Light™, which was launched in 1997, is another ABB innovation in the T&D field that incorporates advanced HV cable technology. High Voltage Direct Current (HVDC) cables are employed for bulk power transportation over long distances, mainly underwater.

Traditional cable technology is based on paper insulation systems impregnated with highly viscous oil. While these cables have many technical advantages, the manufacturing process is slow and the end-product is mechanically sensitive. The industry had therefore been looking for a long time for an extruded HVDC cable of the kind used in AC systems.

With HVDC Light [2], ABB has introduced to the market an extruded cable system, together with new transistor-based converters, that makes HVDC

Environment	Grid security	Economy	Operation
No visual impact	Not affected by wind, snow, ice, fog, etc	Low maintenance	High availability, few faults
Low/no electromagnetic fields	Nothing can be stolen	Minimum investment for lake/river crossings	Usually low losses/MVA
High level of personnel safety, low risk of flashover in air		Land use minimized	High short-time overload capacity
Good working conditions		Value of land/buildings unaffected	

Benefits of underground transmission lines

transmission competitive even at low power ratings. The first commercial system, a link rated at 50 MW, was installed on the Swedish Island of Gotland, where it transmits power from a wind power plant to the town of Visby [3].

Other major projects that have been completed are:

- The Directlink, rated 180 MW at 80 kV, which transfers power between the states of New South Wales and Queensland in Australia.
- The Murraylink, rated 200 MW at 150 kV, built to transfer power between Victoria and South Australia [4].
- The Cross Sound Cable, rated 330 MW at 150 kV, which transfers power between New England and Long Island.

The latest HVDC Light project, to supply power to an offshore platform in the North Sea (Troll A), is due to be commissioned in 2004. (See article starting on page 53.)

Applications for HVDC Light include:

- Feeding of isolated loads (eg, offshore platforms)
- Asynchronous AC grid connection
- Transmission of power from small generation units (eg, wind power plants)
- DC grids with multiple connection points
- Network reliability enhancement through voltage stability and black starts

Tomorrow's electrical infrastructure – here now

Extruded cable systems are available as total solutions, with a 'cradle to grave' supplier commitment. Such systems are turnkey offerings in the commercial as well as the technical sense. They may start with the permit application, continue with the removal of the overhead lines and the supply and installation of the cable system, and end with the environmentally friendly disposal of the old equipment.

Complete cable system applications can also be seen as intelligent combinations of monitoring equipment, converters, load-sharing devices, series and/or shunt compensation devices. Financing, too, can be arranged; here, leasing and a new type of availability guarantee could resolve several commercial uncertainties.

Together, these 'thumbnail' sketches of the future add up to a new customer-value-based market. Extruded insulated cable system applications are destined to play a key role in this evolving market by meeting not only the transmission and distribution network requirements of today but also those of tomorrow.

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