



SUPERCONDUCTING CABLE SYSTEMS

 Nexans

INTRODUCTION

An aging and inadequate power grid is widely seen as one of the greatest obstacles to the restructuring of power markets in the United States, Europe and elsewhere. Utilities face several converging pressures: steady load growth, unplanned additions of new generation capacity, rising reliability requirements, sharp price volatility resulting from new competitive forces and stringent barriers to siting

new facilities, particularly extra high voltage equipment.

Proposals for conventional grid expansion are facing persistent challenges, just as it is becoming apparent that industry reform cannot succeed without renewed grid investment, new transmission, and distribution capacity. Consequently, new technologies that can increase the electrical capacity and flexibility

of this vital network attract increased attention.

One of the technologies with the greatest promise to address these concerns is the high capacity underground High-Temperature Superconductor (HTS) cable. HTS cables are capable of serving very large power requirements at medium and high voltage ratings.

SUPERCONDUCTIVITY

In 1911 the Dutch physicist Heike Kamerlingh Onnes (1853–1926) discovered that the resistance of mercury, cooled with liquid helium, falls to zero for temperatures at 4.15K or below. He called this effect, which he found also in other metals, superconductivity.

In superconducting materials, the superconducting state exists as long as temperature T , current I , and magnetic field B are below their critical values T_c , I_c and B_c .

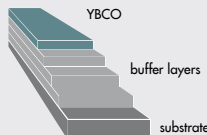
Since 1911, plenty of superconducting materials have been

discovered. In 1986 Johannes Georg Bednorz and Karl Alexander Müller discovered the first ceramic superconductor ($\text{La}_{1.85}\text{Ba}_{0.15}\text{CuO}_4$) with a critical temperature of 35 K. Ceramic superconducting materials, which can be cooled with the less expensive and commonly available liquid nitrogen instead of the expensive liquid helium, were found in 1987.

HTS cables use tapes or wires made of superconducting materials as current carrying elements. $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ (BSCCO) with a critical temperature of 110K and $\text{YBa}_2\text{Cu}_3\text{O}_7$ (YBCO) with a critical

temperature of 92K are commercially available superconductors used in HTS cables.

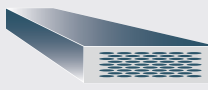
In 2001 the superconducting material magnesium diboride (MgB_2) was found with a critical temperature of 39K. For superconducting cables operated at lower temperatures MgB_2 is used alternatively. MgB_2 is commercially available; its good performance/costs ratio makes it very attractive for high current applications.



YBCO

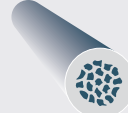
YBCO: $\text{YBa}_2\text{Cu}_3\text{O}_7$ (Y-123)

- coated conductor with multilayer structure
- current densities approaching 100 A/mm^2 at 77 K in tape lengths of hundreds of meters
- current densities and available tape length rapidly improving
- inherently better price/performance ratio than BSCCO
- number of buffer layers and materials depend on manufacturer



BSCCO: $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ (Bi-2223)

- multifilamentary structure in silver matrix
- available in km length
- conductor current densities of 100 A/mm^2 and above commonly available at 77K



MgB_2

- multifilamentary structure in matrix
- available in km length
- current densities of 1000 A/mm^2 available at 20K

HTS CABLE ARCHITECTURES

In superconducting power cables layer(s) of HTS tapes, which transmit power, are stranded around a (hollow) former. The HTS tapes are surrounded by high voltage insulating material, commonly referred to as dielectric. Furthermore, a cryostat insulates the whole cable core against ambient temperature. The HTS tapes are usually cooled with liquid nitrogen, which is pumped through the cable cryostat. Consequently, the dielectric itself is also immersed in liquid nitrogen. Therefore this cable is generally called a cold dielectric cable.

HVAC POWER CABLE

In a HVAC cable design the inner layers of HTS tapes transmit power while the outer layers are grounded. In the outer layers, currents equal in magnitude but opposite in phase to the inner layers are induced. These induced currents completely eliminate the electromagnetic fields of the inner layers.

This is one of the key benefits of the cold dielectric design. The fact that the electromagnetic field is contained inside the superconducting screen also reduces the cable inductance significantly, another important benefit of the cable.

CONCENTRIC MVAC CABLE

For medium voltage applications, superconducting concentric cables offer the most compact design with the best utilization of HTS tapes.

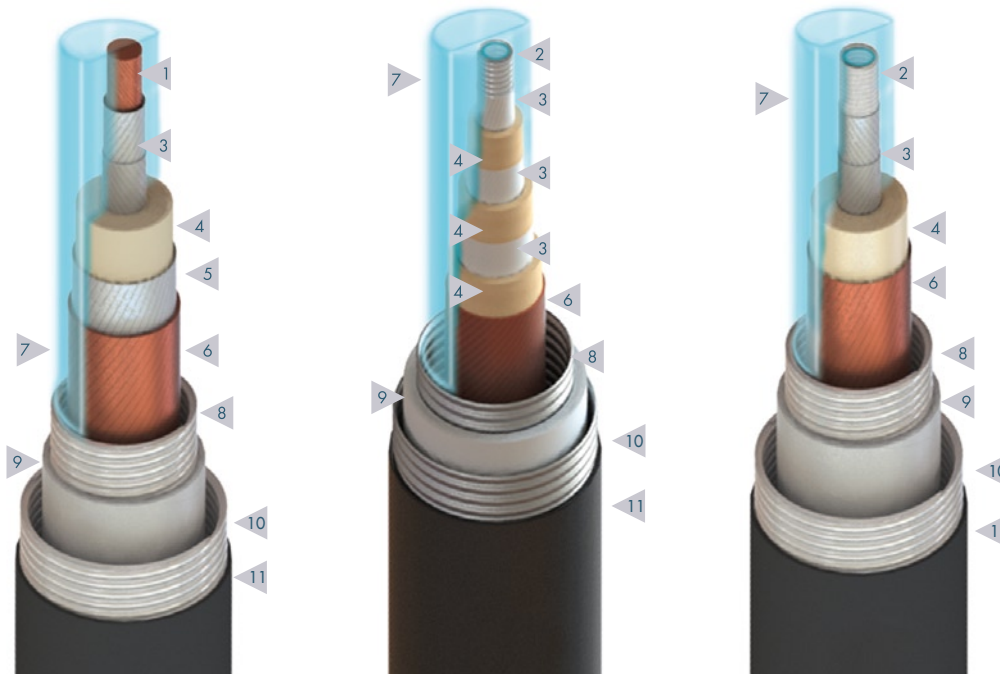
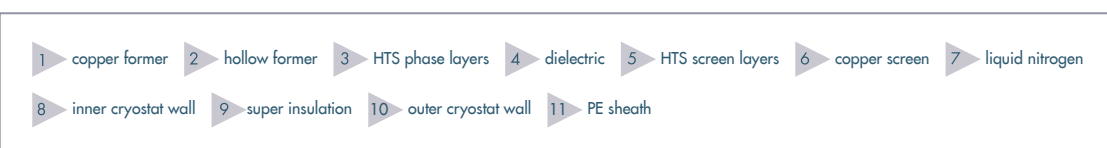
All three phases and a screen, each separated through dielectrics, are stranded around a hollow former. The former can be used as a return channel for liquid nitrogen.

Compact HTS cables with concentric design are able to transmit huge amounts of power in areas of high population density. Using the medium voltage level allows a network architecture, where transformation substations can be placed outside urban areas. Due to their special design, concentric cables, like HVAC power cables, exhibit no external magnetic fields.

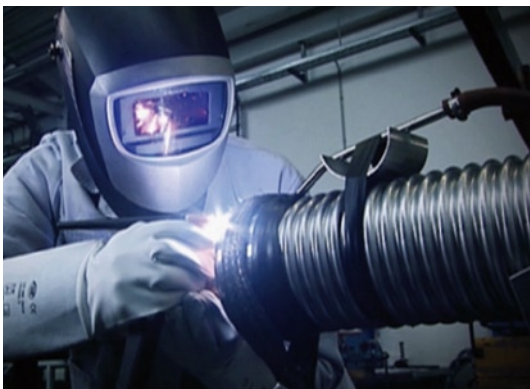
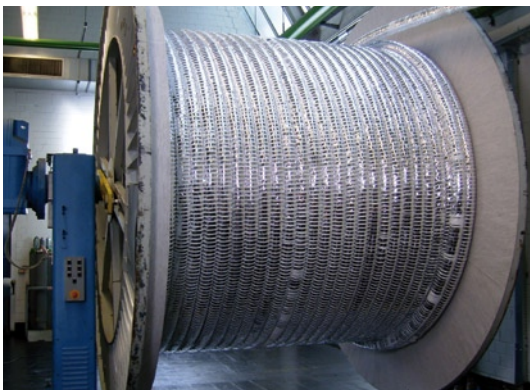
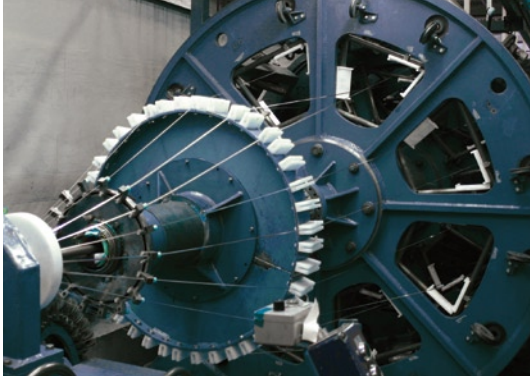
HVDC POWER CABLE

The design of superconducting HVDC power cables is very similar to the design of superconducting HVAC power cables. The inner HTS layers are separated through the dielectric from a screen, consisting of copper wires only.

Bipolar HVDC cable systems enable the transport of huge amounts of bulk power. With voltage levels up to ± 320 kV a transmission power of 4.5 GW and even more is easily attainable. In addition, the absence of charging currents prevents a limitation of the cable length.



CABLE MANUFACTURING



Nexans uses its extensive experience in high voltage cables and accessories to manufacture superconducting cables using existing industrial processes. With the same flexibility to meet customer demands for conventional cables, we have adapted existing stranding machines to comply with technical demands of the superconducting material.

In cold dielectric cables employing PolyPropylene Laminated Paper (PPLP), the lapped dielectric is designed to fulfil the demands on dry bending properties as well as high voltage insulation once impregnated with liquid nitrogen. Like superconducting tapes the dielectric is stranded on conventional machines.

For superconducting cables Nexans is able to produce the cryogenic envelope around the cable core utilizing the UNIWEMA® technology. With more than 30 years of experience in cryostat design and manufacturing a long term high quality vacuum can be ensured to prevent thermal losses.

SUPERCONDUCTING CABLE SYSTEMS



Besides the cable in the cryostat itself, a superconducting cable system consists of terminations, joints and a cooling system.

HTS CABLE TERMINATIONS

The HTS cable terminations as part of the superconducting cable system provide the interface between the cable and the rest of the grid. The superconducting cable termination

- manages the thermal gradient from cryogenic to ambient temperature
- provides electrical field control across the interconnection
- connects the superconducting cable to the cooling system
- compensates the thermal shrinkage of the cable during cool down

HTS CABLE JOINT

The HTS cable joint

- connects several lengths of HTS cables
- allows the mass flow of the coolant
- provides an electrical and mechanical connection of the cable ends

COOLING SYSTEM

The cooling system

- cools down the HTS cable core
- compensates the thermal losses
- enables a mass flow of helium gas or liquid nitrogen

BENEFITS OF SUPERCONDUCTING CABLES



LOWER VOLTAGES

Because of the higher capacity of Very Low Impedance cables (VLI) – approximately three to five times higher ampacity than conventional cables – utilities may employ lower voltage equipment, avoiding both the electrical (I^2R) losses, typical of high current operation, and the capital costs of step up and step down transformers. High current VLI cables at 115 kV or even 69 kV may solve problems that would ordinarily require a 230 kV or 345 kV conventional solution.

EASIER INSTALLATION

HTS cables are actively cooled and thermally independent of the surrounding environment.

LIFE EXTENSION AND IMPROVED ASSET UTILIZATION

Over time, thermal overload leads to an aging and degrading of the cable insulation. By drawing flow away from overtaxed cables and lines, strategic insertions of VLI cable can “take the heat off” urban power delivery networks.

REDUCED ELECTRICAL LOSSES

In optimized designs, lower net energy losses occur in VLI cables than in either conventional lines and cables or unshielded HTS cables with a single conductor per

phase, offering a transmission path with high electrical efficiency. As VLI circuits tend to attract power flow, they will naturally operate at a high capacity factor, reducing the losses on other circuits and further magnifying their efficiency advantage.

INDIRECT AND NON-MONETARY SAVINGS

In addition to these investment cost savings, VLI cables may entail other advantages. For example, the time to install may be shortened because of reduced siting obstacles associated with compact underground installations and less burdensome siting requirements for lower voltage facilities. VLI cables might be routed through existing, retired underground gas, oil or water pipes, through existing (active or inactive) electrical conduit, along highway or railway rights-of-way, or through other existing corridors.

REDUCED REGIONAL CONGESTION COSTS

Finally, and perhaps most significantly, the ability to complete grid upgrade projects more quickly will translate into the earlier elimination or relaxation of grid bottlenecks. Solving physical bottleneck problems will sharply reduce the grid congestion costs that, in today’s

unsettled, imperfectly competitive marketplace, can impose huge penalties on consumers and the economy at large.

UNDERGROUND INSTALLATION

The underground installation of VLI cables eliminates the visual impact of overhead lines.

ENVIRONMENT-FRIENDLY DIELECTRIC

Liquid nitrogen as coolant is inexpensive, abundant and environmentally harmless.

ELIMINATION OF ELECTROMAGNETIC FIELDS

The coaxial design of VLI cold dielectric cables completely suppresses electromagnetic fields.

Nexans tests superconducting power cable systems and their accessories in their one of a kind test field in Hannover, Germany. Combining state-of-the-art high voltage and cryogenic equipment, the test field is suitable for superconducting power cables and other superconducting high voltage applications like fault current limiters.

A 30m x 12m x 9m screened cabin provides ample space to install and test superconducting power cables and their accessories. The cable system is connected to a cooling system outside the cabin.

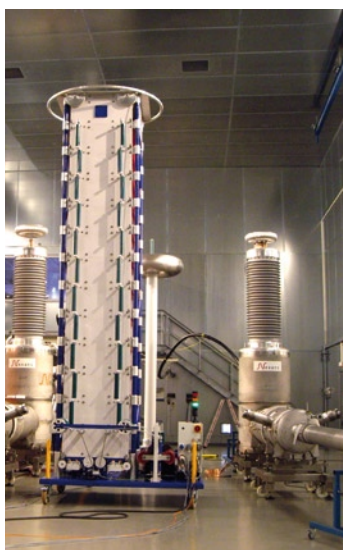
Liquid nitrogen is circulated through the cable loop and a heat exchanger, which allows adjustment of the liquid nitrogen temperature over a wide range. In combination with variable flow rates, the complete spectrum of operating conditions of superconducting power cables can be evaluated and verified.

Gaseous nitrogen is used to cool down and warm up test objects. An automated temperature control system can provide a constant temperature gradient during cool down and warm up.

All relevant test data is recorded by a computer based measurement system that records temperatures, pressures, voltages, and currents during cooling down and the tests.

Making use of a high voltage transformer, the cable dielectric is evaluated by measuring partial discharges, loss angle and cable capacitances.

Test field in Hannover, Germany



Cooling system



Test Equipment Data	
AC voltage	350 kV, 700 kVA
DC voltage	650 kV
Impulse voltage	1.200 kV, 60 kJ
AC current	4 kA
DC current	10 kA

Cooling System Data	
Temperature	65 to 80 K
Mass flow	100 to 2250 g/s
Pressure	up to 15 bars

Services:

- high voltage tests
- high current tests
- network simulations
- feasibility studies



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