

# Superconductivity for Power Transmission and Distribution Cables

**David Lindsay**  
Director, Ultera  
+1-770-832-4916  
david\_lindsay@southwire.com

**Dag Willén**  
Assist. Director, Ultera  
+45-4348-3998  
d.willen@nkt-research.dk

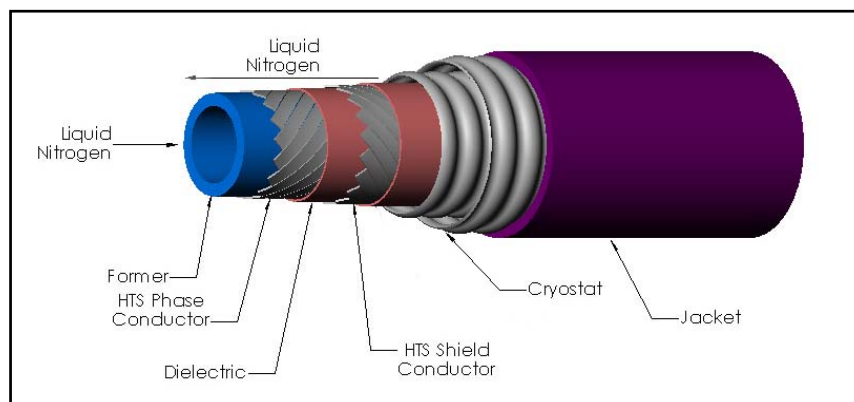
## INTRODUCTION

High temperature superconductivity (HTS) has held the promise of exciting new innovations and advances in power technology for more than a decade. The discovery of HTS materials in 1986 has spurred investment from private companies and government agencies with the goal of transforming the way power is generated, transmitted and used. Companies are developing application technology and devices for power generators, underground transmission cables, transformers, fault-current limiters, motors, and many other applications. HTS wires offer higher performance with reduced electrical losses compared to conventional copper and aluminum wires. Today's HTS wires offer power densities 30 times that of copper. However taking advantage of this increased performance is a significant challenge.

Ultera<sup>TM</sup> is a joint venture between Southwire Company of Carrollton, GA USA and *nkt cables* of Cologne, Germany. This new venture is a marriage of the only two teams to successfully implement HTS cable systems anywhere in the world and provide power to end-users on a daily basis. Ultera is a clear commitment from its parent companies to continue development with the goal of commercialization for this exciting new technology.

## 30-METER DEMONSTRATION PROJECTS

On 6-January 2000 Southwire energized the first superconducting cable system to supply power to a live load. Since that date, the system has been powering the manufacturing complex at the company headquarters in Carrollton, GA. Southwire designed and built three 30-m, single-phase HTS cables rated 12.4 kV, 1,250 Amps. During the three-plus years the system has operated, the cables have provided 100% reliability and service. Southwire used the cold dielectric, co-axial conductor design shown below.

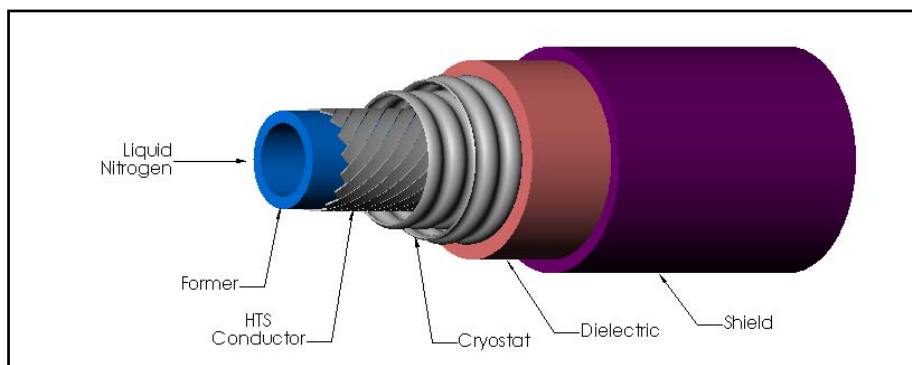


**Figure 1 - Cold Dielectric Superconducting Cable**

The cable is built around a central core that serves as a flow path for the liquid nitrogen (LN) coolant. Superconducting tapes are wrapped around the core and make up the phase conductor, replacing copper or aluminum in conventional cables. The superconducting tapes are then covered with a polymer dielectric tape called Cryoflex™. This is proprietary material developed specifically for HTS cable applications. Cryoflex operates at the temperature of LN, -200°C, and provides the needed electrical insulation. A second layer of HTS tapes is wound on top of the dielectric to form the outer shield conductor. The outer layer of HTS captures all electro-magnetic fields (EMF) emitted from the phase conductor, resulting in a fully shielded cable design. The final cable construction is inserted into a thermal envelope consisting of a double-walled stainless steel pipe. This pipe maintains the -200°C operating temperature.

On 28-May 2001, *nkt cables* energized the first HTS cable system to be installed in a utility substation. The cables were installed in the AMK substation of Copenhagen Energy and provide power to residential and commercial customers of the utility in parts of Copenhagen, Denmark. Like at Southwire, the *nkt cables* system has provided reliable service for the utility since its commission.

The *nkt cables* HTS system consists of three 30-m, single-phase cables rated 36 kV, 2,000 Amps. *nkt cables* designed and built a warm or room-temperature dielectric system. This design differs from the cold dielectric design in the placement of the electrical insulation. Once the phase HTS tapes are wrapped around the central core, the conductor is inserted in the thermally insulating pipe. A conventional XLPE dielectric material is extruded onto the pipe, followed by standard screens and jacket materials.



**Figure 2 - Warm Dielectric Superconducting Cable**

The two cable systems built by Southwire and *nkt cables* consist of several complex components in addition to the conductors. These components include terminations, cooling systems, controls and monitoring systems. Terminations must be designed to transition from a pressurized liquid nitrogen environment to ambient temperatures while carrying rated voltage and current. Cooling systems are designed to maintain a constant operating temperature of approximately -200°C and constant system pressures of approximately 5 bars. Controls and monitoring systems are built to allow fully automated operations 24 hours per day. Each system has been integrated with web servers to allow remote system access by project engineers.



Figure 3 - Southwire (left) and *nkt cables* (middle & right) 30-m demo's

The HTS cables and components have been tested to standard industry qualification requirements for their respective voltage ratings. In both cases, the systems have passed all test requirements including AC withstand, BIL and fault current. While the conductors built by *nkt cables* were installed and operated with multiple bends, the Southwire design has been tested in this configuration in the lab. Both companies have designed and tested splices for connecting multiple lengths of cable to achieve longer lengths.

### **TRIAXIAL CABLE DESIGN**

Ultera is currently working to develop an exciting new conductor design that promises to reduce material cost, reduce cooling requirements, and increase the energy efficiency. A new Triaxial conductor design places all three phase conductors concentric around a common central core. This concept reduces the quantity of HTS wire needed, and reduces the cold surface area, thereby reducing cooling requirements. Electrical field cancellation is achieved by the three concentric phases being 120 electrical degrees apart. A common copper shield is used to carry neutral currents. This new design is a significant step towards reducing system costs and achieving a commercially viable product. The Triax design specifically addresses the two major cost components in a superconducting cable system: HTS wires and refrigeration.

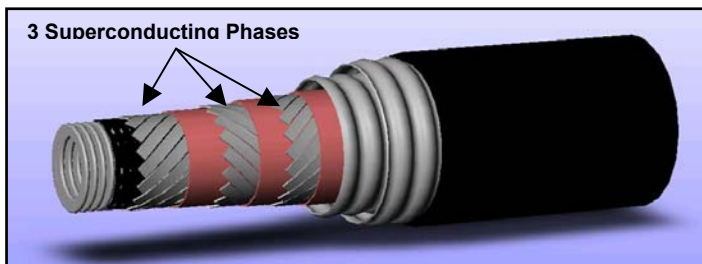
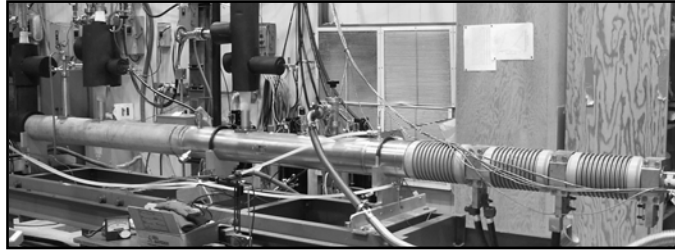


Figure 4 - Triaxial Superconducting Cable

The first full-scale prototype of the Triax design was built and tested at Ultera's development partner Oak Ridge National Lab (ORNL) during the fall of 2002. A picture of the

termination design can be seen in Figure 5. The three concentric phases are connected to copper leads that continue throughout the length of the termination. The three phase connections are shown at the right side of the termination while the neutral bushing is hidden on the back side of the termination body. The triax termination is a slim design in which the body of the termination is no larger in diameter than the cable cryostat.



**Figure 5 - Full scale Triax termination under test at ORNL.**

### **300-METER PROJECT AT AEP**

Ultera's current project is a second U.S. Department of Energy sponsored demonstration in partnership with American Electric Power (AEP) in Columbus, Ohio. The project will showcase the Triax cable design and demonstrate realistic installation parameters. The 300 meter cable run will be installed underground with multiple bends and a splice joining two cable sections together. The circuit is rated 13.2 kV and 3.0 kA<sub>rms</sub> per phase steady state. The fault current requirement is 30 kA. As with the 30 meter installation in Carrollton, GA, the Ultera team will be working with Oak Ridge National Lab for design and development of system components. The system is scheduled to be energized in mid-2005 at the Bixby substation on the AEP system.

Ultera will build on its experiences from its two previous cable projects (Carrollton and Copenhagen) to design, build and implement a reliable, efficient and cost effective cable system. Ultera has over 5 years of day-to-day experience of operation and maintenance of superconducting cable systems. This experience will be used to specify and build reliable cryogenics, controls and interface systems for the cables.

### **APPLICATIONS**

Superconducting cable technology offers benefits to power transmission and distribution including reduced voltage levels, simplification of networks, reduction or elimination of substations, increased power densities, and electricity savings. The ability of HTS cables to carry 3-5 kA<sub>rms</sub> current ratings per phase allow them to handle equivalent power loads at lower voltages. For example, 3.0 kA HTS circuit at 24 kV is approximately equivalent to a 69 kV solid dielectric (XLPE) circuit operating at 1.0 kA. This reduction in voltage level will reduce safety clearances, transformer sizes, simplify and in some cases eliminate permitting complications.

Urban substations, which are today required to step down voltage levels close to the end user, can be relocated to outlying areas of the city. Power that must be brought into these areas at "transmission level" voltages today can be served with "distribution level" HTS circuits. This will allow the downtown substations to be smaller, and thereby saving real estate costs for the utility. New high-density loads such as revitalization and redevelopment projects in urban areas

can be served with lower voltages to eliminate new and often expensive high voltage transformers.

Superconducting cable's ability to move bulk power at lower voltages has potential applications at or near generating facilities as well. In traditional generating facilities, step-up transformers may be moved to locations farther away from the generator by moving the bulk power at the generating voltage. Newer forms of generation such as fuel cells and wind power promise to change the landscape of power generation around the world. HTS cables offer a solution to connect these low-to-mid power level generating facilities to the net at lower voltages. This low-voltage connection simplifies integration of these forms of generation.

Cold dielectric HTS cables offer the benefit of very low impedance when compared to conventional cables. The inductive impedance of cold-dielectric cable is approximately four to six times lower than that of conventional XLPE cables, and eighteen to twenty times lower than an overhead line of the same voltage. The low impedance benefit associated with coaxial or triaxial designs depends upon the thin electrical insulation where shielding currents constrain the magnetic fields to a small volume. The low impedance characteristics of the HTS cable will allow it to essentially 'absorb' high power flows in a network and thereby alleviate bottle-necks at other parts of the system. The full electrical shield achieved by the HTS cable design prevents EMF outside the cable and eliminates some problems associated with siting XLPE cables inside steel ducts, or in close proximity to one another.

## **CONCLUSIONS**

While HTS cables are not a product ready for market in 2003, it is seen as just a few years before this is a reality. Three large-scale demonstration projects on utility transmission and distribution systems are under way in the United States. These include the power systems of American Electric Power (Ultera), Long Island Power Authority (Nexans), and Niagra Mohawk (Sumitomo). Each of these demonstration projects is co-funded by the U.S. Department of Energy and moves HTS cable technology one step closer to commercial applications. Superconducting cables will never reach a 1:1 price point versus overhead or conventional XLPE underground cables. However, when advantages such as lower voltage levels, higher power densities, and retrofitting existing ducts to provide 500% capacity expansion without civil and excavating costs are included in the economic assessment of potential projects, superconducting cables will play an important role in the T&D grid of the future.

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## **ABOUT ULTERA**

Ultera is a joint venture between two of the world's leading wire and cable companies, Southwire Company of Carrollton, Ga. and nkt cables of Denmark. Ultera was created to continue the successful development of high temperature superconducting power cable technology independently initiated by both Southwire and nkt cables. The combined resources of Ultera represent the only two successful HTS cable installations in the world to provide power to residential, commercial and industrial users. Ultera has more than five years of day-to-day operational experience with HTS cable systems providing power to end users in the United States and Denmark. More information is available at <http://www.mysouthwire.com/> and <http://www.nktcables.com/>.