Project Title:	**High-Temperature Superconducting Power Cable**
Organization(s):	**Oak Ridge National Laboratory**
Presenters:	David Lindsay (Southwire Co.), Jonathan Demko (ORNL)
FY 2004 Funding:	$1.7 million (DOE to ORNL)

Project Purpose and FY 2004 Objectives: Southwire Company and ORNL have jointly developed, built, and demonstrated a series of cold-dielectric, high-temperature superconducting (HTS) power cables for this Superconductivity Partnership Initiative (SPI) project. The 30-m cable at Southwire's wire-manufacturing complex in Carrollton, GA, continues to run, accumulating over 26,000 hours at full load to date and running unattended over the last 36 months. This cable is rated at 12.4-kV, 1,250-A, 3-phase, 60-Hz, and 27-MVA. This cold dielectric cable was placed into full service in April 2000 for an extended testing period under actual industrial conditions. In a new cold dielectric cable concept called a tri-axial cable, ORNL has in 2004 worked with Southwire Company to research and improve the overall design and capabilities of the HTS cable system including:

- Design triaxial cable terminations for the 5-m tri-axial, 3-phase, 3,000 A_{rms} cable to be tested at ORNL. This 5-m cable system is a prototype of the 200-m system to be installed at AEP.
- Fabrication and testing of a 1.5-m single-phase cable to evaluate a copper-clad HTS tape architecture, and a 3-m tri-axial cable made with brass-clad HTS tapes to study over-current response and heat transfer characteristics.
- Continued development and testing of cryogenic dielectric material including model cables and terminations. Tested cast and solid dielectric materials for high voltage strength, partial discharge, and thermal shock.
- Developing a cryogenic system specification for the American Electric Power (AEP) project. Estimates of the heat loads, operating pressure, temperature, and flow rate of liquid nitrogen are being prepared.
- Initial design of cable subsystems for a long-length cable installation at Columbus, OH, in partnership with Ultera and AEP.
- Continued research improving cryogenic system performance with industry.

FY 2004 Performance and FY 2005 Plans: The design of the 5-m tri-axial 3000 A_{rms} cable and associated 3-phase terminations is being completed in summer of 2004. The 3-phase cable will be manufactured by Ultera (Southwire) and expected delivery to ORNL is in September 2004. Final assembly of the terminations, initial cooldown, and initial dc/ac testing will take place during the first quarter of FY 2005. The Southwire team participated in a successful SPI Readiness Review in February 2004. The issues identified by the independent review team are being addressed. The issue of cryostat performance and reliability is being worked with vendors.

Plans for FY 2005:

1) Complete electrical testing including high voltage qualification of the 5-m tri-axial, 3-phase, 3,000 A_{rms} cable and terminations at ORNL.
2) Test model cables and terminations to higher ac voltages (up to 69 kV), investigate AC breakdown strength and partial discharge inception and examine scaling to higher BIL levels, and continue development and testing of improved dielectric tapes for use at higher voltages.
3) Complete design of the long length cable demo at AEP Columbus and begin long lead procurements.

FY 2004 Results: Significant progress has been made towards the project objectives during the year:

30-m HTS Cable - In April 2000, the cable was placed into extended service and has logged over 26,000 hours of full power operation since that time. The performance of the superconductor was measured annually since April 2001, most recently in June 2004. There has been no measurable change in the critical current of the superconductor providing further credence to the viability of this promising technology. There have been several cable outages due to the cryogenic system and this experience is being used in specifying technical requirements for the SPI cable project at the AEP Bixby substation.

Cryogenic Dielectric Studies - An aging mechanism of cryogenic cable dielectrics, partial discharge (PD), is being studied using a state-of-the art PD detection system. Several new insulation tape materials have been formulated with the goal of optimizing mechanical and electrical characteristics. Development was conducted on potential materials for the dielectric insulation in the 3-phase terminations that require high breakdown strength and high thermal conductivity at 77 K and 300 K. The development of cast dielectrics for use in cable auxiliaries was stopped due to technical difficulties with material properties and consistency. However significant information was gained on the area and volume effects for scaling solid dielectric materials to large-scale devices at room and liquid nitrogen temperature. A new focus on the use of solid dielectrics for use in these auxiliaries was implemented. For the new termination design, data has been obtained on flashover impulse strength and on partial discharge inception. A revised design using cryogenic-compatible solid dielectrics was implemented.

Tri-axial Cable - The tri-axial cable consists of three concentric superconducting phases made of BSCCO-2223 HTS tapes that are separated by layers of Cryoflex™ cold-dielectric tape, which provides the phase-to-phase electrical insulation. Copper tapes are placed next to the HTS tape for over-current protection. A copper braid is added as the grounding shield. The completed tri-axial cable is enclosed in a flexible cryostat and has circulating liquid nitrogen cooling the outside of the cable. In 2003 ORNL and Southwire started R&D on a compact, 3-phase termination rated for 3 kA_{rms} per phase that will be a full-scale prototype of the cable to be installed at the AEP Bixby substation under the SPI program. Due to issues with cast and filled dielectric materials, a new design approach has been adopted using manufactured pieces in a larger cryostat. This higher capacity cable will include a comprehensive high current test program similar to the one conducted on the 1.3 kA cable, but expanded to include high voltage characterization. The cryogenic skid used for testing 5-m cables at ORNL has been upgraded to handle higher heat loads. This is necessary for testing triaxial cables as the refrigeration load is now for three phases.

Short Sample Cables - A 3-m-long tri-axial HTS cable made using brass-clad BSCCO HTS tape was fabricated and tested to evaluate the ac loss and overcurrent performance. In addition, a 1.5-m single-phase cable was wound with copper-clad HTS tapes. High voltage dielectric tape was applied to evaluate the ac loss, overcurrent and heat transfer characteristics of a simulated triaxial cable. A measurement of the thermal conductivity of Cryoflex dielectric in an open liquid nitrogen bath was also conducted.

Second Generation Conductor Cable - A 1.25-m-long cable was fabricated last year from second generation YBCO coated conductor. The dc performance and ac loss was measured on the second generation conductor cable. Over-current (thermal and E-M force effects) testing of second generation YBCO tapes was conducted. Investigations into the inductance of HTS cables with and without magnetic substrates are being evaluated in short cable sections.

Research Integration: The design, assembly, and operation of the cable test facilities at ORNL and the 30-m demonstration cable at Southwire have been totally integrated efforts drawing upon scientists, engineers, and technicians from Southwire, NKT, ORNL, and private industry. Private consultants, cryogenic equipment manufacturing firms, and superconducting materials suppliers have been used extensively during the project. Major components of the 5-m and 30-m cable systems were procured via competitive subcontracts. Four technical papers were presented at the *Cryogenic Engineering Conference* in September 2003. Four HTS cable technical papers are planned for the *Applied Superconductivity Conference* to be held in October 2004.