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| **Organization:** | **Oak Ridge National Laboratory** |
| **Project Title:** | **High-Temperature Superconducting Power Cable** |
| **Presenters:** | David Lindsay (Southwire Company), Jonathan Demko (ORNL) |
| **FY 2005 Funding:** | $1400 K (DOE to ORNL) |

**Project Purpose and FY 2005 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 29,000 hours at full load to date and running unattended over the last 48 months. This cable is rated at 12.4-kV, 1,250-A, 3-phase, 60-Hz, and 27-MVA. The cable was placed into full service in April 2000 for an extended testing period under industrial conditions. In FY 2005, ORNL has worked with Southwire to research and improve the overall design and capabilities of the HTS cable system including:

- Design and fabrication by industry of triaxial cable terminations for the 5-m triaxial, 3-phase, 3,000 $A_{rms}$ cable that was assembled and tested at ORNL.
- Continued development and testing of cryogenic dielectric material including model cables and terminations. Tested solid dielectric materials for high voltage ac withstand and impulse strength, partial discharge, and thermal shock.
- Developed 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 developed based on the latest experimental data from the 5-m cable test. Supported system failure modes analysis.
- Finalize the 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 2005 Performance and FY 2006 Plans:**

The design of the 5-m triaxial 3000 $A_{rms}$ cable and associated 3-phase terminations was completed in the fall of 2004. The 3-phase cable was manufactured by Ultera, a joint venture between Southwire Company and *nkt cables*. The termination parts were manufactured by machine shops in Tennessee, Georgia, and Ohio. Assembly of the cable and terminations was completed in April. Purging of the cable, cooldown and testing began immediately after the assembly was complete.

Qualification tests were successfully completed with the cable straight. Low voltage testing included dc voltage-current (VI) characterization, operation at 3 kA dc, 2.5 kA ac and 3 kA ac. Additional testing of the cable to validate the high voltage insulation design began in May. Testing was conducted with the cable straight and bent 90 degrees. The tests included a hold at rated voltage of 7.6 kV, ac withstand testing up to 34 kV - 39 kV, and basic insulation level (BIL) impulse tests at +/-110 kV. The dc VI characteristics were measured in the bent configuration as well as a second application of over-current testing to simulate a fault. The Southwire team participated in a HAZOP Review at Praxair (SPI team member) facility in January and a successful SPI Readiness Review in June. The issues identified by the independent review team are being addressed.

Demonstration pull tests of cryostats and cables for the AEP demonstration were conducted by Ultera during March and June 2005. The issue of cryostat performance and reliability is being worked with vendors. Testing of the stranding line was conducted to prepare for the winding of the 5-m triax and ultimately the 200-m AEP project cable.

Plans for FY 2006 include:
1) Complete evaluation of the electrical testing and cryogenic operation of the 5-m triaxial, 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 detailed design of the long length cable demo at AEP Columbus and continue component procurements.
4) Assist with cable and termination assembly at Bixby substation.
5) Assist with start-up and check-out procedures at Bixby substation.

**FY 2005 Results:** Significant progress has been made toward the project objectives during the year.

*30-m HTS Cable*. In April 2000, the cable was placed into extended service and has logged over 29,000 hours of full power operation since that time. The performance of the superconductor was measured again in June 2005. There has been no measurable change in the critical current of the superconductor. There have been several cable outages due to the cryogenic system and this experience is being used in specifying technical requirements for the SPI project with AEP. During 2005, the system experienced a line-to-ground fault and direct lightning strike to the HTS switchyard – both with no damage to the HTS cables as demonstrated by the critical current measurements taken in June 2005.

*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. 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 materials. However significant information was gained on the 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 have been obtained on flashover impulse strength and on partial discharge inception. A revised design using cryogenic-compatible solid dielectrics was implemented. High voltage testing was conducted on half-scale and full-scale terminations.

*Triaxial Cable.* The triaxial 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 is then added as the grounding shield on the outside of the cable structure. The completed triaxial 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. The current design approach uses manufactured dielectric pieces in the cryostat. This higher capacity cable underwent a comprehensive high current test program as well as high voltage characterization.

**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 cables*, 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 HTS cable technical papers were presented at the Applied Superconductivity Conference in October 2004. One abstract was submitted to the Cryogenic Engineering Conference in September 2005.