OAK RIDGE NATIONAL LABORATORY REVIEW

More Power To The GRID

Working with industry, ORNL is testing advanced conductors and developing superconducting cables to improve the efficiency of the U.S. electric grid.

On August 16, 2004, a year and two days after the largest power blackout in U.S. history, 3M announced the first commercial sale of an advanced conductor for overhead power lines. This conductor, if put into widespread use, could greatly reduce the probability of blackouts while carrying at least double the electrical current. Xcel Energy will give 3M's ceramic-core conductor its first commercial application in 2005 when the conductor is installed on a 10-mile transmission line in Minnesota.

John Stovall, Roger Kisner, and Tom Rizy, researchers in the Cooling, Heating & Power Group in ORNL's Engineering Science and Technology Division, are excited about this sale. For two years, they have field-tested the high-temperature 3M conductor, the core of which consists of ceramic Nextel™ fibers enveloped in an aluminum-zirconium matrix.

Recently, the tests have been conducted at the Powerline Conductor Accelerated Testing (PCAT) facility, part of the National Transmission Technology Research Center. NTTRC, jointly supported by the Department of Energy and Tennessee Valley Authority, was established at ORNL to evaluate conductors and high-voltage power electronics in response to DOE's National Transmission Grid Study, issued in May 2002. In that document DOE named advanced conductors as a key enabling technology for upgrading the national electricity transmission system.

Transmission Tests

Tests at the NTTRC demonstrated that the 3M composite conductor can carry 1.5 to 3 times the current of conventional steel-core, power-line cables at the same voltage. The tests also showed that the conductor and its accessories can withstand extreme heat. Tests in other U.S. locales indicated that the 3M conductor holds up better when subjected to high winds, vibrations, salt corrosion, and extreme cold than do the heavier lines, 20 to 50 years old, that are threaded through transmission corridors nationwide. These advantages make the new conductor ideal for seacoast installations. The results have been good news for 3M, which invented the conductor to eliminate transmission bottlenecks that contribute to brownouts and blackouts.


3M ceramic core conductor.

One major transmission problem has been power-line sag. When hot weather generates demand for more electricity for air conditioning, power lines heat up, stretch, and sag. If an overloaded line sags into a tree, the current can be discharged to the ground, causing a short circuit and sometimes triggering a major power outage. Sag was a cause of the two major U.S. blackouts in 1996 and 2003.

"We found that the 3M conductor's sag at a rated operating temperature of 210°C will be the same as that of a standard steel line at the rated operating temperature of 100°C," Stovall says. "Effectively, the 3M conductor has less sag at the temperature allowed for operation of conventional power lines.

Utilities may be reluctant to install 3M conductors because they cost more than steel-core lines. "But if a utility wants to move twice as much electrical current between point A and point B," Stovall says, "replacing a steel-core line with a high-temperature 3M conductor is cheaper and easier than acquiring a new right-of-way in a transmission corridor and installing a second set of transmission towers for an additional conventional line."

Superconductivity and Transmission

The power grid of the future will likely include devices made from high-temperature superconducting (HTS) wires based on a technology developed jointly by ORNL and industry. Within the next two years American Superconductor Corporation plans to commercialize an HTS wire based on ORNL's RABITS™ (rolling assisted, biaxially textured substrates) technology, which was licensed in 2000 to the Massachusetts-based company. The wire will be used to make cables that can help electric utilities deliver more power with greater voltage control and current density. Thus, RABITS™ will help utilities meet increasing demands without building additional transmission towers or installing new underground rights-of-way under crowded city streets.


Superconducting cable.

Ten years ago, ORNL developers of RABITS™ demonstrated that crystallographic texture could be introduced into metal by rolling and annealing the metal into a thin tape, and that the texture can be transferred to a superconductive oxide coating through buffer layers deposited on the metal substrate. The buffer layers also block unwanted coating-substrate chemical reactions. The resulting orientation of crystals in the superconductive oxide, such as yttrium-barium-copper oxide (YBCO), allows the coated tape to conduct large electrical currents without resistance at liquid nitrogen temperature (77K).

American Superconductor is currently making a higher-performance, longer-length, RABiTS-based, nickel-tungsten substrate coated with very thin buffer layers. The company produces wide ribbons of material that will be slit into 100-meter-long, 4-millimeter-wide wires.

Today American Superconductor's first-generation, or 1G, HTS wires are commercial. Second-generation (2G) wires are expected to be a formed-fit replacement for 1G wires in the next few years. Researchers predict a decreased need for silver in the manufacturing process will make the 2G wire less expensive. Also, 2G wire will work better than 1G wire in the presence of a strong magnetic field in a motor, generator, or transformer.

In 2000 ORNL signed a cooperative research and development agreement (CRADA) with American Superconductor to develop the 2G wire using RABiTS technology, according to Bob Hawsey, manager of ORNL's Superconductivity Program. "We had a major achievement in 2004 in collaboration with American Superconductor," Hawsey says. "We developed a wet-chemistry method, called metal organic decomposition (MOD), for deposition of all layers on the nickel-tungsten alloy."

ORNL's Parans Paranthaman and University of Tennessee research professor Srivatson (Watson) Sathyamurthy, who developed MOD technology for the deposition of buffer layers, are working with American Superconductor to produce a 2G wire completely by wet chemistry processing. "A superconducting wire could be made like movie film, in which a plastic substrate is run through a series of chemical baths to place layers on the film," Hawsey says. "Currently, these layers are deposited on an ORNL substrate in a vacuum chamber, similar to the way semiconductors are made."

ORNL researchers produced a nickel-tungsten substrate on which they deposited a lanthanum zirconate buffer layer. ORNL sent the coated tape to American Superconductor, which deposited a cerium dioxide buffer layer on the tape plus a YBCO layer, using the company's proprietary process. The resulting wire carried 140 amperes of current in liquid nitrogen. By comparison, a copper wire containing much more material carries only 12 amps.

ORNL researchers continue to make progress in developing alternative approaches to growing YBCO on RABiTS substrates. For example, ORNL's Hans Christen and colleagues demonstrated in 2004 the viability of Neocera's pulsed- electron deposition system by achieving >1.5 million amperes/cm2 on RABiTS samples. ORNL's Ron Feenstra and his collaborators showed that electron beam evaporation could be used to deposit YBCO on RABiTS and that short samples could carry about 400 amps of current, a 30% increase in current from 2003.

ORNL's largest and longest-running applied superconductivity project, which involves Southwire Company, is geared to developing and demonstrating superconducting cable technology. Southwire's 30-meter HTS cable with ORNL-designed terminations is operating five years after being energized in February 2000. ORNL and Southwire are making progress toward a 2006 demonstration of a 200-meter cable using 2G wire in Columbus, Ohio.

Control room at a nuclear power plant on the aging U.S. electric grid.—*Courtesy Tennessee Valley Authority*

As utilities prepare to handle higher amounts of electric power in the future, they must upgrade their substations by replacing aging circuit breakers, which protect utility equipment from damage by shutting down the flow of electricity if, say, a tree falls across a transmission line and causes a short. Utilities could save money in the future by installing superconducting fault-current limiters instead of new, larger circuit breakers.

"We initiated a new CRADA with SuperPower on the development of fault-current-limiting technology that will operate at transmission level voltages of 138 kilovolts," Hawsey notes. "This technology would be a valuable new addition to electric utilities' toolkits for managing high fault currents as utilities upgrade substation capacity."

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