

Superconductor Power Applications

Prototype electrical-power devices that incorporate components made of high-temperature superconducting (high- T_c) materials are now in development. Analysts predict that the technology will have a significant impact on the power industry within a decade, since high- T_c wire, with its low resistance, promises to deliver more power than the copper or aluminum wires currently used. In fact, most companies involved in development efforts believe that superconducting wire will transform the electric-power industry in much the same way that optical fibers transformed telecommunications.

“Electricity is our principal and most flexible means of integrating coal, hydropower, nuclear, and most renewable resources into a usable energy system,” says James G. Daley, program manager of the Department of Energy’s Superconductivity Program for Electrical Power Systems. Electricity accounts for roughly 36% of the total energy used in the United States. In the United States alone, power requirements are expected to double by 2030; growth will be even more dramatic in the newly industrialized countries of Asia and the former Soviet Union. This poses a serious challenge to the ability of electric utilities to meet increasing consumer demands in an environmentally responsible manner.

High- T_c electric power is expected to have a broad impact on both generation—the process of converting primary energy sources into electricity—and transmission and distribution. “When cooled to very low temperatures, superconducting wire conducts electric current with little or no energy loss, enabling it to transmit far more electricity than conventional copper wire of compara-

ble size,” says Chris Strug, director of marketing for American Superconductor Corp. (ASC) in Westborough, Massachusetts. ASC produces and sells prototype high- T_c electromagnetic coils and multistrand conductors for use by the electric-power industry. “Coils created from superconducting wire produce

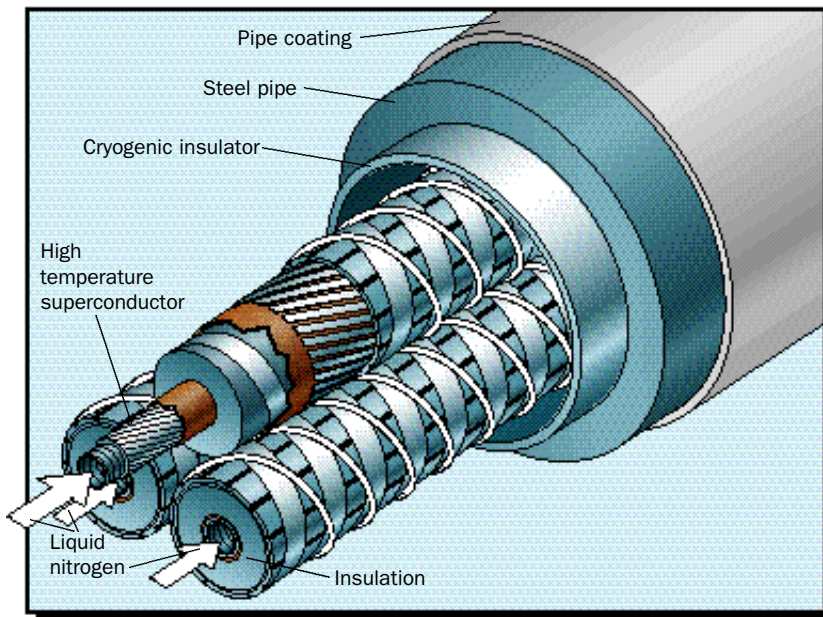
According to Daley, the key requirement for most commercial applications of high- T_c electric-power devices is a flexible, mechanically rugged, and reasonably priced superconducting wire capable of carrying a large current in the presence of a magnetic field. Progress has been made in recent years in

overcoming technological and manufacturing challenges, most notably the achievement of longer lengths of high- T_c wire with adequate performance levels. As a result, several high- T_c electric-power applications are likely to emerge within the next decade, including transmission and distribution cables, transformers, motors and generators, current limiters, and some magnetic-energy-storage devices.

Transmission and distribution cables for the electric-power industry represent an estimated \$3 billion annual market worldwide. Underground high- T_c cables can carry three to five times as much current as

conventional copper cables, says R. L. Hughey of Southwire Co. (Carrollton, GA). This makes the technology extremely attractive to urban planners, who need to retrofit aging infrastructures with increased power capacity, and to suburban engineers, who now find it increasingly difficult to secure clearance for overhead transmission lines. Southwire is collaborating with Oak Ridge National Laboratory (ORNL) and Intermagnetics (Latham, NY) to demonstrate the potential of high- T_c power cables.

Initially, Southwire is developing power cables formed from 100-ft lengths of high- T_c wire that will transmit thousands of amperes of current. Once constructed, the cables will be used to feed Southwire’s headquarters, including corporate offices and two cable plants. The project is expected to be com-



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much stronger magnetic fields, the basis for more compact, more efficient motors, magnets, generators, current limiters, transformers, and energy-storage devices.”

Power applications

Although discovered in 1911, the first generation of low- T_c superconductors only reached the commercial market in the 1970s—mostly for medical MRI systems and for use in electromagnets for commercial laboratories and particle accelerators. However, their stringent cooling requirements and high costs inhibited further commercial development. The discovery of high- T_c materials in 1986 reignited interest in superconducting power applications, largely because their higher operating temperature translates into lower cooling costs.

Carnie Curley Design/American Superconductor

pleted by the fall of 1999. "To truly test the viability of superconductors for power distribution, this cable must be used in a real application, subject to real environmental stresses and real electrical demands," says Hughey. He estimates that the company's power demand equals that of a community of 16,000 people.

ASC is collaborating with Pirelli Cable SpA (Milan, Italy), the world's largest manufacturer of cables for telecommunications and power applications, and Los Alamos National Laboratory (LANL) in a similar project. In 2000, the two companies plan to demonstrate a commercially viable high- T_c cable system, formed from 120-m lengths of wire,

on the Detroit Edison underground transmission network.

Motors and generators are other promising applications, mainly because high- T_c wire can carry much larger electrical currents. The use of high- T_c wire also eliminates energy loss due to electrical resistance, promising significant savings in power costs. ASC is collaborating with Reliance Electric Co., (Cleveland, OH), a subsidiary of Rockwell Automation, in developing 1,000- and 5,000-hp high- T_c motors. The first 1,000-hp prototype will be tested early next year and released commercially in 2001.

Current limiters protect against disturbances in the smooth delivery of electricity, such as power surges resulting from lightning or accidents that cause the utility grid's circuit breakers to shut the system down to protect it from damage. According to ASC's Strug, strategically placed high- T_c current limiters can effectively limit the current spikes circuit breakers must handle. When a large pulse of current comes through the system, the high- T_c coil automatically absorbs the excess energy within milliseconds. No equipment is exposed to damage, which allows utilities to increase loads and provide more reliable service to consumers. Lockheed Martin (San Diego, CA) is collaborating with Southern California Edison, Intermagnetics, and LANL to demonstrate commercially viable high- T_c current limiters.

Transformers lower or raise system voltages in order to transport electricity more efficiently. Because electricity usually passes through at least three transformers before consumer use, an estimated 3% to 6% is lost to transformer inefficiencies. With high- T_c transformers, these losses could be reduced by half, vastly improving energy efficiency, says Sam Mehta of Waukesha Electric Systems in Waukesha, Wisconsin. The devices would also be half their current size and weight, and they would no longer pose a fire hazard because they would not require flammable dielectric cooling oil. Waukesha Electric is working with Intermagnetics, ORNL, and Rochester (NY) Gas and Electric to commercialize prototype megavolt ampere (MV·A) transformers.

ASC pegs the annual market for conventional power transformers with power ratings of more than 30 MV·A at approximately \$3 billion worldwide. The company is collaborating with ABB Power Transmission and Distribution Co. (Zurich, Switzerland), one of the world's largest transformer suppliers, and Electricité de France (Paris, France) on a four-year, \$15 million project to develop efficient superconducting transformers of about 10 MV·A. A prototype will be tested at an Electricité de France substation by the end of 2000—an achievement crucial to the subsequent development of 30-MV·A transformers.

Superconducting magnetic-energy storage (SMES) is another technology that serves to protect modern utility grids from power interruptions that cost U.S. industries as much as \$12 billion annually in equipment failures, manufacturing disruptions, and computer crashes. Developed by ASC and first introduced in 1997, SMES systems use power electronics to sense momentary elec-

tric-power disturbances. They instantly release or absorb energy as needed to restore stability to incoming electric power.

ASC's SMES systems are in use at Tinker Air Force Base in Oklahoma City and at a variety of other sites in the United States and South Africa. In August, Carolina Power and Light agreed to distribute ASC's SMES units to its commercial and industrial customers. The Magnet Business Group of Inter-magnetics recently introduced a new superconducting magnet that is the first to feature high- T_c leads in a commercial SMES system.

In contrast to SMES, flywheel energy-storage devices rely on spinning disks that float on superconducting magnets and store energy in the motion of their rotation. Once charged, such devices will spin almost indefinitely without losing any of their energy to friction. The Boeing Co. and Argonne National Laboratory are collaborating on the development of a prototype flywheel energy-storage system.

Challenges

Many challenges to commercializing high- T_c wire for electric-power applications involve materials issues, says Alex Malozemoff, ASC's chief technical officer. One big obstacle is that all of the high- T_c compounds under consideration are brittle in bulk form. This brittleness makes it difficult to manufacture them into wire, which must be wound in a variety of shapes without loss of the wire's critical current density. In polycrystalline form, most high- T_c compounds demonstrate "weak links" at grain boundaries, which significantly limit current-carrying capacity. Increasing the critical current density of long-length wires is key to commercial electric-power applications.

Researchers at Lucent Technologies, IBM, and Hoechst were among those who pioneered the synthesis of the two most promising high- T_c materials for electric-power applications. Both compounds are members of the barium-strontium-calcium-copper oxide

(BSCCO) family, whose grain-alignment properties are well-suited to the formation of wire. A superconductor known as yttrium-barium-copper oxide (YBCO) has also generated interest, although it has yet to be formed into significant wire lengths. But even these materials require better manufacturing processes.

Lucent holds the patents on the most widely used fabrication method, called oxide powder in tube (OPIT). The precursor powder is synthesized and then packed into a metal tube, called a sheath. The powder is then molded into a wire by deformation processing, which uses dies with tapered holes through which the partially deformed wire is alternatively pushed or pulled. A rolling mill narrows and flattens the squat, cylindrical billet into long lengths of round wire. Several wires are then bundled into another billet and deformed again to achieve flat tapes with multiple filaments that are finer and more

resistant to crack formation. The final step is one or more heat treatments to react the precursor powder to form a high- T_c wire inside the silver sheath. This process has solved the brittleness and weak-link problems and enabled fabrication of a long length of wire.

Another difficulty is that as current flows through a high- T_c material, it generates a magnetic field, which forms vortices of current inside the material that must be pinned. David Bishop and Peter Gammel, both physicists with Lucent, recently developed a new means to achieve strong pinning through their work with a unique class of superconducting materials called nickel borocarbides. These compounds consist of both magnetic materials and superconducting materials that seem to coexist peacefully when their atoms are intermingled. Bishop and Gammel found that it is possible to use the magnetism produced by the material itself to control magnetic vortices.

The ultimate limiting factor is cost: materials for high- T_c wire are expensive, as are the manufacturing and cooling costs. "Regardless of performance gains, wires will not become commercially competitive until the cost of wire is reduced," says Daley. "For the successful development of applications using high- T_c wire, the cost of the wire along with total equipment costs and performance needs to be competitive with existing technologies."

However, Southwire's Hughey remains optimistic that trends are in the right direction, pointing out that high- T_c materials costs are about 50% lower today than 18 months ago. Better production processes are also helping reduce costs. "We have seen no challenge that is insurmountable. Cable companies around the world think that this technology will get there in terms of cost," Hughey says. "It's not an immediate market, but when it does get there, believe me, it's going to be huge." 