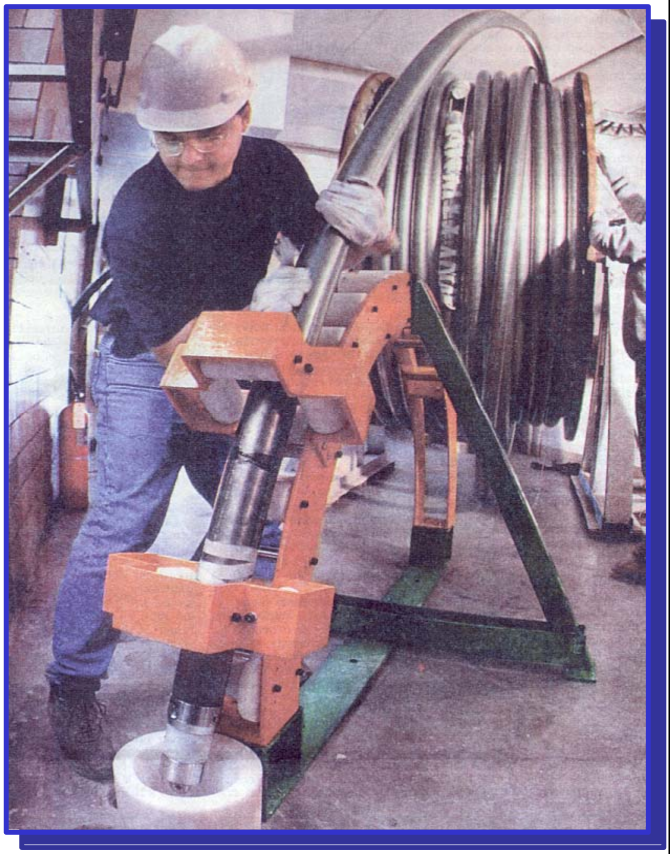
1.3 INFRASTRUCTURE

1.3.1 HIGH-TEMPERATURE SUPERCONDUCTIVITY

Technology Description



The United States' ongoing appetite for clean, reliable, and affordable electricity has increased at a rate that seriously threatens to exceed current capacity. Demand is estimated to increase by an average rate of 1.8% per year for the next 20 years, yet investments in transmission and distribution infrastructure have not kept pace with those in generation. Furthermore, a majority of the new gas-fired generation is not optimally sited where existing transmission assets are located. Witnessing the regional outages being experienced throughout the country – and those most recently highlighted in the northeast blackout of August 2003 – the inadequacies of the investment in infrastructure have, in effect, issued a wake-up call for modernizing and expanding grid capacity. High-temperature superconducting (HTS) wires can carry many more times the amount of electricity of ordinary aluminum or copper wires. HTS materials were first discovered in the mid-1980s and are brittle oxide, or ceramic-like materials, that can carry electricity with virtually no resistance losses. Through years of Federal research in partnership with companies throughout the nation, technology has developed to bond these HTS materials to various metals, providing the flexibility to fashion these ceramics into wires for use in transmission cables and for coils for power transformers, motors, generators, and the like. Superconducting technologies make possible electric power equipment that is half the size of conventional alternatives, with half the energy losses. When HTS equipment becomes pervasive, up to 50% of the energy now lost in transmission and distribution will become available for customer use. HTS also will reduce the impact of power delivery on the environment and is helping create a new high-tech industry to help meet industry challenges due to delays in electric utility restructuring. Other benefits of superconducting electric power systems include improved grid stability, reliability, power quality, and deferred generation expansion. Affordability of capacity expansion is also enhanced, because underground superconducting cables require only 10% of the rights-of-way of conventional overhead transmission; and because HTS cables may be installed in conventional underground ducts without extensive street excavation.

System Concepts

- HTS cables have almost no resistance losses and can transport three-five times as much power as a conventional cable in the same size conduit.
- HTS power transformers have about 30% reduction in total losses, can be 50% smaller and lighter than conventional units, have a total ownership cost that is about 20% lower, are nonflammable, and do not contain oil or any other potential pollutant. In addition, there are electrical performance benefits associated with current limiting capacity and reduced impedance that will yield cost savings to power companies.
- HTS Fault Current Limiters can provide power companies with surge protection within the transmission and distribution system. They are reusable, require minimal maintenance, and do not need replacement after being activated.

- HTS motors with more than 750 kW would save enough energy over their lifetime to pay for the motor. Replacement of all U.S. motors greater than 750-kW with HTS motors would save consumers $2 billion per year in electricity costs. The motors are 50% smaller and lighter than conventional motors, as well.
- HTS generators with more than 100 MVA output will be more energy efficient, compact, and lighter than the conventional generator. The generator has characteristics that may help stabilize the transmission grid.

System Components

- HTS cables consist of large numbers of wires containing HTS materials operating at 65-77 K, insulated thermally and electrically from the environment. A cryogenic refrigerating system maintains the temperature of the cable, at the desired operating temperature, regardless of the load on the cable.
- HTS transformers use the same types of HTS materials as cables, formed into coils and mounted on conventional transformer cores. Electrical insulation is accomplished by means other than conventional oil-and-paper, and typically involves a combination of solid materials, liquid cryogens, and vacuum. HTS transformers may be overloaded for periods of time without loss of transformer life.
- HTS motors, generators, magnetic separators, and current limiters use HTS wires and tapes in a coil form. Rotating cryogenic seals provide cooling for the rotating machines.
- HTS flywheel systems use nearly frictionless bearings made from superconducting "discs," cooled below the transition temperature of the HTS materials.

Technology Status/Applications

- HTS wires: First generation "BSCCO" wires are available today in kilometer lengths at about $200/kA-m. Prototype, pre-commercial, second-generation "coated conductors" have been made in 10-100 m lengths by industry and are to be scaled up in 2006-2008 to 1,000-m lengths. The 100-m tapes carry approximately 100 amperes of current in nitrogen.
- HTS cables: Under the DOE Superconductivity Partnership Initiative (SPI), a team led by Southwire Company has installed and successfully tested a 30-m prototype cable that has been powering three manufacturing plants in Carrollton, Georgia, since February 2000. Three new HTS cable demonstration projects are planned with partial DOE funding from the SPI for 2006. A 600-m cable to be operated at 138-kV will be installed on Long Island, New York; and a 350-m distribution cable will be installed in downtown Albany, New York. A section of the 350-m cable will also be manufactured using second-generation "coated conductors." A 200-m HTS distribution cable carrying 3,000 amperes will be installed at a suburban substation in Columbus, Ohio.
- HTS transformers: Waukesha Electric Systems, with partial DOE funding, demonstrated a 1-MVA single-phase prototype transformer in 1999 and is leading a team developing technology needed for electrical insulation that would be used for a pre-commercial, three-phase prototype transformer.
- HTS motors: Rockwell Automation successfully demonstrated a prototype 750-kW motor in 2000 and is designing a motor with improved performance characteristics.

Current Research, Development, and Demonstration

RD&D Goals

- Performance: HTS wires with 100 times the capacity of conventional copper/aluminum wires. More broadly, the program aims to develop and demonstrate a diverse portfolio of electric equipment based on HTS, such that the equipment can achieve a 50% reduction in energy losses compared to conventional equipment and a 50% size reduction compared to conventional equipment with the same rating. Low-cost, high-performance, second-generation coated conductors are expected to become available in 2008 in kilometer-scale lengths.
- Cost: (a) for the conducting wire, the aim for $0.01/ampere-meter; (b) equipment premium cost payback (efficiency savings) to be achieved in two-five years of operation; and (c) equipment total cost payback to be achieved during the operating lifetime. For coated conductor goals for applications in liquid nitrogen, the wire cost goal is to be less than $50/kA-m; while for applications requiring cooling to temperatures of 20-60 degrees K, the cost goal is to less than $30/kA-m. By 2010, the cost-performance ratio will have improved by at least a factor of 2.

RD&D Challenges

- The manufacture of promising HTS materials in long lengths with minimum defects and low loss, all at low cost, remains a key program challenge.
- Materials for cryogenic insulation and standardized, high-efficiency refrigerators (approaching 30% of Carnot efficiency) are required.
- Improved dielectric materials used to insulate electric power equipment at cryogenic temperatures are required.
- Scale-up of national laboratory discoveries for "coated conductors" requires the use of film industry or semiconductor industry processing expertise and equipment to make kilometer-long electric wires and is a key activity for the labs and their industry partners. Fashioning these long wires into commercially viable forms needed to wind low-loss coils is also a key challenge.

RD&D Activities

- DOE funding is used for three key program activities: Second Generation Wire Research, the Superconductivity Partnership Initiative, and Strategic Research. Performers include national laboratories, industry, academia, and other Federal agencies.

Recent Progress

- The development at the national laboratories of ion-beam assisted deposition and rolling-assisted, biaxially textured substrate (RABiTS™) technologies for producing high-performance HTS film conductors suitable for cables and transformers, and the involvement of four unique industry-led teams to capitalize on it, was a major success story for FY 1997.
- The world's first HTS cable to power industrial plants exceeded 28,000 hours of trouble-free operation in Carrollton, Georgia, (Southwire Company) in early 2005, and is the world's longest-running superconducting cable. The 30-m cable system has been operating unattended since June 2001.
- Short lengths of coated conductors made under stringent laboratory conditions exceeded the DOE goal of 1,000 A/cm width.
- SuperPower verified greater than 80% current limiting performance of proof-of-concept Fault Current Limiter at up to 8,660 volts.
- Rockwell Automation demonstrated a prototype 1000-HP synchronous motor that exceeded design specifications by 60%, and is now designing a motor that would use second-generation coated conductors with enhanced performance-to-cost ratio for the industrial marketplace.

Commercialization and Deployment Activities

- High-temperature superconducting cables and equipment: Commercialization and market introduction requires development of inexpensive wires for transmission and distribution, and end uses such as electric motors. These wires are now under development under a government-industry partnership but are still years from wide-scale use. In addition, there is an international race underway to develop and deploy the new second-generation coated conductors. Numerous companies in Europe, Japan, Korea and China are pursuing the technologies first demonstrated by the national labs. Using high-temperature superconductivity wires to replace existing electric wires and cables may be analogous to the market penetration that occurred when the United States moved from copper wire to fiber optics in communications. Some pre-commercial demonstrations using commercial BSCCO wires are underway, but the Superconductivity Partnerships with Industry and the Second-Generation Wire Initiative could be expanded to include additional U.S. companies.