1.3 INFRASTRUCTURE

1.3.1 HIGH-TEMPERATURE SUPERCONDUCTIVITY

Technology Description

America's 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 9% through 2004 – however, only a 3% increase in transmission is planned, and there have been no major new investments in transmission during the past 15 years. Witnessing the regional outages being experienced throughout the country – and those most recently highlighted in the northeast – the inadequacies of the investment in infrastructure investments have, in effect, issued a wake-up call for enhancement of the grid. 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, bearings for flywheels, and 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 the challenges due to delays in electric utility restructuring. Other increased performance benefits include improved stability, reliability, power quality, and deferred generation expansion.

System Concepts

- HTS cables have almost no resistance losses and can transport 3-5 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 local 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. The motors are 50% smaller and lighter than conventional motors, as well.
- HTS generators with more than 100 MVA 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 tapes containing HTS materials operating at 65-77 K, insulated thermally and electrically. A cryogenic refrigerating system maintains the temperature of the cable, extracting heat that manages to leak into the assembly.
- 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 motors, generators, magnetic separators, MRI magnets, 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. Second-generation "coated conductors" have been made in 1-10 m lengths in the laboratory and are to be scaled up in 2002-2004 to 100-m lengths. The 1-m tapes carry approximately 50 amperes of current in nitrogen.
- HTS cables: Under the DOE Superconductivity Partnership Initiative, a team led by Pirelli Cable installed a 120-m cable in the city of Detroit, Michigan. Southwire has installed and tested a 30-m prototype cable that has been powering three manufacturing plants in Carrollton, Georgia, since February 2000.
- HTS transformers: Waukesha Electric Systems, with partial DOE funding, demonstrated a 1-MVA prototype transformer in 1999 and is leading a team developing a 5/10-MVA, 26.4-kV/4.2-kV three-phase prototype.
- HTS motors: Rockwell Automation demonstrated a prototype 750-kW motor in 2000 and is designing a motor with five times the rating.

Current Research, Development, and Demonstration

RD&D Goals

- Performance: Develop HTS wires with 100 times the capacity of conventional copper/aluminum wires. Design and demonstrate a broad portfolio of electric equipment based on HTS: 50% reduction in energy losses compared to conventional equipment, and 50% size of conventional equipment with the same rating. Low-cost, high-performance YBCO coated conductors will be available in 2005 in kilometer lengths.
- Cost: Wire cost of $0.01/ampere-meter. Equipment premium cost payback (efficiency savings) will be achieved in 2-5 years of operation. Equipment total cost payback will be achieved during the operating lifetime. Coated conductor goals: For applications in liquid nitrogen, the wire cost will be less than $50/kA-m; while for applications requiring cooling to temperatures of 20-60 K, the cost will be less than $30/kA-m. By 2010, the cost-performance ratio will have improved by at least a factor of four.

RD&D Challenges

- The manufacture of promising HTS materials in long lengths at low cost remains a key program challenge.
- Materials for cryogenic insulation and standardized, high-efficiency refrigerators (approaching 30% of Carnot efficiency) 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 electric wires and is a key activity for the labs and their industry partners.

RD&D Activities

- DOE funding is used for three key program activities: the Accelerated Coated Conductor Initiative, 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^{TM}) 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 13,000 hours of trouble-free operation in Carrollton, Georgia (Southwire Company). The 30-m cable system has been operating unattended since June 2001.
- During the summer of 2001, Detroit Edison installed a 120-m HTS cable system in an urban substation that serves 14,000 customers.
- Rockwell Automation demonstrated a prototype 1000-HP synchronous motor that exceeded design specifications by 60%, and is now designing a 5000-HP motor.

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. 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 have begun, but the Superconductivity Partnership Initiative could be expanded.