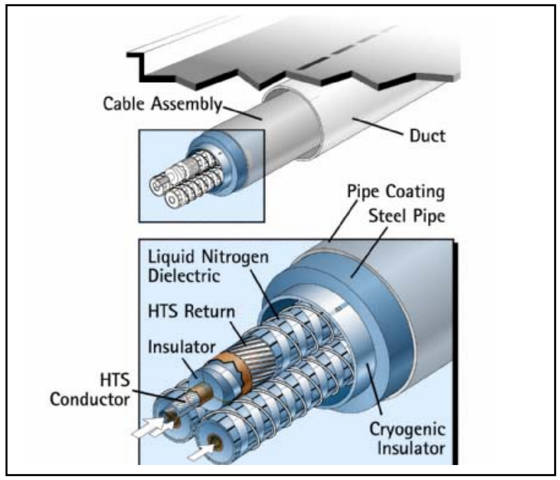
Superconducting Power Technology

Technology Description



Source: American Superconductor

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, etc. 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, may 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 rated at 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 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 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 with Industry (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 underway 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 is 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 is 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 researching motor components with improved performance characteristics.

Current Status

- 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.

Technology History
• In 1911, after technology allowed liquid helium to be produced, Dutch physicist Heike Kammerlingh Onnes found that at 4.2 K, the electrical resistance of mercury decreased to almost zero. This marked the first discovery of superconducting materials. • Until 1986, superconductivity applications were highly limited due to the high cost of cooling to such low temperatures, which resulted in costs higher than the benefits of using the new technology. In 1986, two IBM scientists, J. George Bednorz and Karl Müller achieved superconductivity on lanthanum copper oxides doped with barium or strontium at temperatures as high as 38 K. • In 1987, the compound $Y_1Ba_2Cu_3O_7$ (YBCO) was given considerable attention, as it possessed the highest critical temperature at that time, at 93 K. In the following years, other copper oxide variations were found, such as bismuth lead strontium calcium copper oxide (110 K), and thallium barium calcium copper oxide (125 K). • In 1990, the first (dc) HTS motor was demonstrated. • In 1992, a 1-meter-long HTS cable was demonstrated. • By 1996, a 200-horsepower HTS motor was tested and exceeded its design goals by 60%. A Pirelli Cable team installed a 120m HTS cable in Detroit, Michigan under the DOE Superconductivity Partnership Initiative. Since February 2000, Southwire's 30m prototype cable has been powering three manufacturing plants in Carrollton, Georgia. • HTS transformers have seen increased interest, as Waukesha Electric Systems demonstrated a 1-MVA prototype transformer in 1999. This team is also leading the development of a 5/10-MVA, 26.4-kV/4.2-kV three-phase prototype. • A 750 kW HTS motor was demonstrated by Rockwell Automation. This team is now (in 2006) researching motor components.
Technology Future
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. The Power Delivery Research Initiative, authorized in the 2005 Energy Policy Act, would help enable broad utility involvement in the technology.

Source: National Renewable Energy Laboratory. *U.S. Climate Change Technology Program. Technology Options: For the Near and Long Term.* DOE/PI-0002. November 2003 (draft update, September 2005).

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Market Data

Projected Market for HTS devices (Thousands of Dollars)	Source: *Oak Ridge National Laboratory - High Temperature Superconductivity: The Products and Their Benefits*, 2002 Edition, Total Market Benefits, p 40.								
	2004	**2006**	**2008**	**2010**	**2012**	**2014**	**2016**	**2018**	**2020**
Motors	0	0	27.29	169.24	527.03	1310.49	3103.37	6360.31	11322.83
Transformers	0	3.8	14.22	37.47	90.63	197.73	371.87	605.23	877.71
Generators	0	0	0	4.09	15.56	41.12	101.16	224.26	426.61
Cables	0	0.17	0.59	1.44	2.81	4.86	7.7	11.21	15.17
Total	0	3.97	42.1	212.24	636.03	1554.2	3584.1	7201.01	12642.32

The report assumes electrical generation and equipment market growth averaging 2.5% per year through 2020. This number was chosen based on historic figures (the past fifteen years) and the assumption that electric demand will drive electric supply.

Projected Market for HTS devices (Thousands of Dollars)	Source: *Analysis of Future Prices and Markets for High-Temperature Superconductors,* September 2001, DOE.							
	2011	**2013**	**2015**	**2017**	**2019**	**2021**	**2023**	**2025**
Motors	225	956	4,025	15,399	50,968	108,429	148,770	164,072
Transformers	0	0	243	1,451	9,353	56,081	222,277	390,964
Generators	6,926	24,710	83,634	227,535	445,693	592,904	656,499	675,656
Cables	4,117	14,405	48,335	135,001	318,844	488,783	570,326	586,284
Total	11,270	40,071	136,236	379,386	824,857	1,246,196	1,597,872	1,816,975

Technology Performance

HTS Energy Savings (GWh)	Source: *Oak Ridge National Laboratory – High-Temperature Superconductivity: The Products and Their Benefits*, 2002 Edition, Tables M-2, T-1, G-1, C-2								
	2004	**2006**	**2008**	**2010**	**2012**	**2014**	**2016**	**2018**	**2020**
Motors	0	0	0.4	3	8	21	48	98	172
Transformers	0	0.1	0.2	1	1	3	6	9	14
Generators	0	0	0	0.1	0.2	1	2	3	6
Cables	0	3	18	56	133	270	488	806	1,236
Total	0	4	19	60	143	294	544	916	1,428

HTS Energy Savings (GWh)	Source: *Analysis of Future Prices and Markets for High-Temperature Superconductors,* September 2001, DOE.								
	2009	**2011**	**2013**	**2015**	**2017**	**2019**	**2021**	**2023**	**2025**
Motors	0	0	1	4	15	57	154	300	468
Transformers	0	0	0	0	2	15	94	449	1,194
Generators	2	11	44	171	556	1,417	2,699	4,196	5,785
Cables	1	3	13	55	196	598	1,336	2,289	3,326
Total	3	14	58	231	769	2,086	4,283	7,235	10,774