Superconductivity Transmission Through Superconductor Technology

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Superconductors are still an evolving field of science and technology. While they have been put to some use, their potentially greatest use as electrical conductors has not been fully realized. If superconducting wire in particular can be created to work at high temperatures and can be mass-produced, then reducing greenhouse gases from power plants will be possible. Other uses for superconductors could help prevent blackouts brownouts and ensure that good quality power is distributed consistently.

What is superconductivity?

Superconductivity in some metals, ceramics and, more recently, plastics, allows electrons to travel through these materials with no electrical resistance. This means that these materials can theoretically deliver an electrical current from one place to another without any loss of electrical energy, as nothing is lost due to friction caused by electrical energy turning into heat energy.

The phenomenon of superconductivity requires extremely low temperatures, generally somewhere just above absolute zero (0 degrees Kelvin, -273 degrees Celsius or –459 degrees Fahrenheit). The temperature at which electrical resistance in materials is zero varies depending on the material. This temperature is referred to as critical temperature (T_c), and it is achieved by cooling the materials with either liquid helium (for low temperature superconductors) or liquid nitrogen (for high temperature superconductors). One reason HTS are more attractive for commercial use is because liquid nitrogen is more abundant, cheaper and easier to handle because it has a higher temperature than helium.

Electrical resistance in superconducting metals occurs because of the atomic structure of metals – which can be thought of as metallic nuclei swimming in a "sea" of electrons; negatively-charged electrons are not bound to a particular positively-charged nucleus. In a normal metal, electrons will move quickly and constantly collide, thus creating heat energy (which is why materials are normally at a temperature above absolute zero).

However, in superconducting metals, electrons are greatly slowed down and do not collide into one another. This is why superconducting materials do not lose energy – heat is never created because there are no collisions. In a superconducting metal, an electron moves through two rows of positively-charged atoms, thus pulling the two rows of atoms inward because of their attraction to the electron. The distortion created then causes another electron to follow behind the first. These two electrons pair up and encounter less resistance overall.

Another important aspect of superconductors is the demonstration of the Meissner Effect – which is the expulsion of an interior magnetic field of a material that is in a superconducting state. This then prevents the material from being penetrated by external magnetic fields, and allows for magnetic levitation. This technology has been applied as mag-lev (magnetic levitation) technology that can power high-speed trains. Japan had tested this technology, and in 1999 the MLX01 test vehicle recorded a top speed of 343 miles per hour. In this instance, strong superconducting magnets cause a transport vehicle to float above a track, thereby eliminating resistance and friction, allowing trains to move at higher speeds without wasting energy, by turning electricity into heat electrical energy.

This technology could result in increased efficiency of mass transportation like trains and subways that traditionally run on electricity. The amount of fossil energy burned to power them could be reduced because less electricity is lost due to friction of wheels on tracks during braking and normal travel. However, mag-lev technology is not applied because magnets can create potential biohazards. Radio frequency energy can cause blindness and sterility because it has a heating effect on the body. It is also thought that low levels of electromagnetic energy are thought to affect the body's immune system. There have not been any recent discoveries on how to reduce the risks of electromagnetic energy coming from superconducting magnets so they can still be used for greater efficiency in transportation.

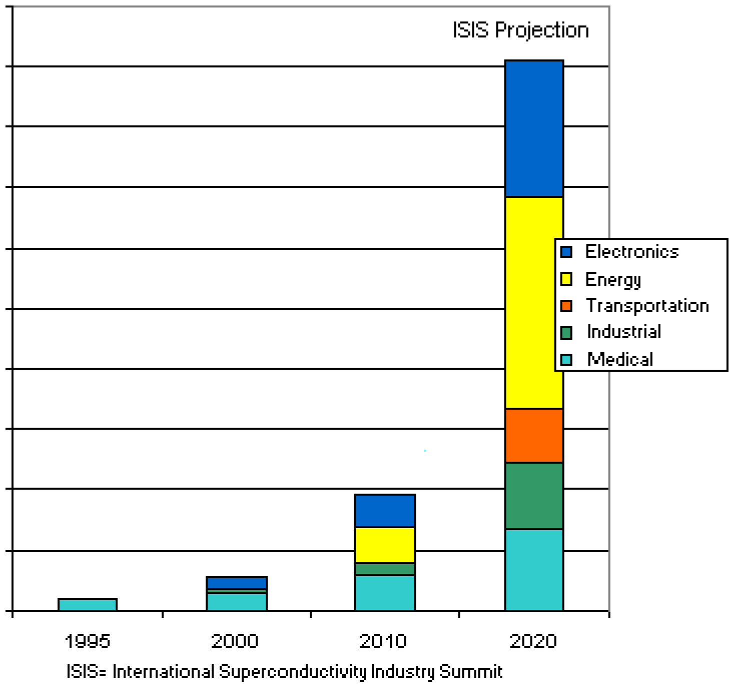
In 1986, high temperature superconductors (HTS) were discovered. These were not metals, but ceramics. Ceramics tend to be hard and brittle, making their applications somewhat limited at this stage of development. While ceramics do not need to be cooled down as much or with liquid helium, they are difficult to form long flexible wires with. Developing HTS wires that can be mass produced in long lengths will be a great advance in the realms of electricity transfer and the superconductor market.

The Superconductor Market

Assuming a linear growth rate, it is estimated that the US superconductor market is expected to grow to nearly $5 billion by the year 2010 and $38 billion by 2020. According to the president of the Houston-based HTS company Metal Oxide Technologies, Inc., the estimated worldwide market is currently $30 billion. The following figure is an estimated breakdown of markets where superconductors are expected to have economic and technological impact. The low-temperature superconductors will mainly be used in medical and industrial applications, and high-temperature superconductors are expected to have major influence in the electronics, energy, and transportation markets.

A Department of Energy analysis says that the domestic market for superconducting wire alone will exceed $600 million annually by the year 2025. However, the Department of Energy reduced the FY-2004 budget for superconductivity research. According to Charles Schumer (D-NY), the DOE cut between $15 and $20 million from the superconductivity program. But the DOE's Office of Electricity and Distribution said the figure stood at $6 to $7 million. According to Pete Domenici (R-NM), the Superconductivity Technology Center at Los Alamos was reduced from $7.6 million to $4.8 million, or a 37% cut in funding.

FIGURE 1: SUPERCONDUCTOR DEMAND GROWTH



Source: Superconductors.org, http://superconductors.org/Uses.htm

A secondary outcome of the high-temperature superconductor industry is the helium and nitrogen markets. Qatar, for example, is soon to be the third largest producer of liquid helium and is currently building a helium plant that will be ready by the end of 2005. Qatar will then provide10% of the world helium supply.

High Temperature Superconductor Research Developments

*Sup*erconducting wires have the potential to eliminate half of the energy transmission losses that currently occur when electricity passes through copper wire. This increase in energy efficiency would therefore lead to a reduction in output required by power plants. This in turn would decrease the amount of greenhouse gases emitted from fossil energy dependent power plants. Additionally, these superconducting wires can carry approximately three and one half times the amount of electricity as copper wire. Physicists in Finland have calculated that the European Union alone could reduce their carbon dioxide emissions between 27 and 53 million tons if high temperature superconductors were used in power plants.[1]

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[1] "**Superconductors could help Europe meet Kyoto target**," http://physicsweb.org/article/news/7/7/20, accessed 31 March 2004.

In response to the August 14^{th} blackout, HTS transmission test lines are being set up in Albany, New York. They plan to put in place BSCCO (barium strontium calcium copper oxide) HTS, which is a powdery, brittle substance that can be formed into long thin tape that wires are eventually made from. The process of creating BSCCO wire is done in very expensive and time-consuming batches. In addition to being difficult to turn into wire, BSCCO superconductors lose their ability to superconduct in the magnetic fields created by an AC current transmission. In terms of production, this type of cable cost $200 to transmit a kiloamp over a distance of one meter when copper wire does the same job for $10 to $25.

SuperPower, a Schenectady, New York superconducting materials company has come up with a second-generation (2G) high-temperature ceramics superconductor that can be made into wire. The new HTS, YBCO (yttrium barium copper oxide), developed by SuperPower is not made in expensive, discrete batches, but instead in a continuous production process that reduces its cost. The process begins with a nickel-alloy strip, one centimeter wide and only tens of microns thick, which is coated with a buffer layer. This buffer layer forms a template for the crystal structure of subsequent layers of YBCO crystals that are grown on top. Finally, a layer of silver is added to protect the YBCO and act as an electrical contact.

The $26 million dollar project in Albany will have both a section of first-generation cable (350 meters long) that will be part of the Niagara Mohawk Power Corporation's grid. The second part of the project will replace 30 meters of the BSCCO cable with YBCO cable. Money for this came from NYSERDA ($6 million) and the DOE's superconductivity research initiative ($13 million). British Industrial Gases will provide the cooling (nitrogen gas) and Sumitomo Electric will provide the cables. The first-generation cable should be carrying electricity by 2005 and the second-generation section should be in place by 2006.

In November of 2003, Sangmoon Park, a research scientist at Brookhaven National Laboratory has developed a safer and more environmentally friendly way to create a sodium cobalt oxyhydrate superconductor. Previously, the only method available to create the superconductor created a great deal of chemical waste. Her method involves using plain water, which is both less toxic and allows for the possible transformation of the material into pliable wire. Water-based superconductors may lead to the creation of materials that are less mechanically restrictive.

As of March 9, 2004, American Superconductor (AMSC) had a major breakthrough in the development and manufacture of 2G HTS cables. They were able to create an electric current carrying capacity in multiple 10-meter lengths of wire equal to or better than 250 amperes/cm of width of the wire. However, for commercial applications, the performance level of 2G HTS wire must be 300 amperes/cm-width at liquid nitrogen temperatures. At this stage AMSC is approaching performance levels required for commercial applications. In addition to high transmission levels, the company's production process is repeatable and uniform and was designed with mass-production in mind.

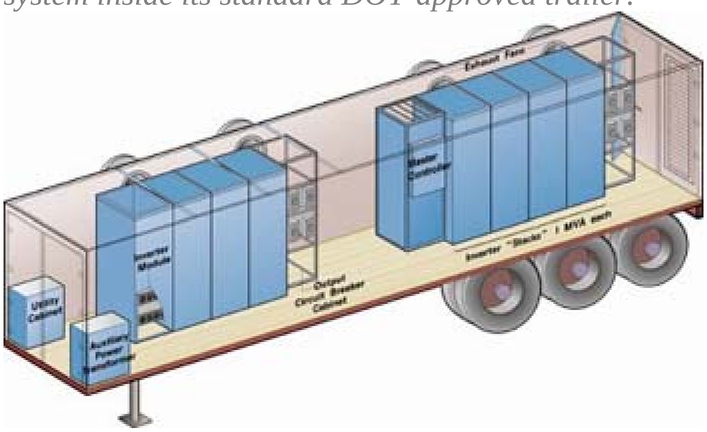
Whether or not superconducting cables can be made economical in a deregulated energy market that has little or no incentive to update energy infrastructure remains to be seen. Thus far, the commercial viability of superconducting cables has not been possible.

Another potential superconductor application for the electricity grid is a device known as the D-VAR (Dynamic Volt-Ampere-Reactive) also created by American Superconductor. This system provides a powerful and cost-effective way to increase the reliability of power transmission grids by instantly injecting reactive power (VARs) into the grid at precise locations where voltage problems occur. These systems can fit on portable tractor-trailers and can be brought to substations in need of more electricity.

Because D-VAR voltage regulation systems are scalable and mobile, they allow for optimizing the grid's energy flow. They allow for only a particular substation to be injected with more electricity as needed, rather than cranking up and winding down the power plant to increase energy flow to a particular area. Because fluctuations in the output of a power plant waste the most energy, this small unit at substations will be more efficient and can therefore reduce greenhouse gas emissions from power plants.

On March 29, 2004, Long Island Power Authority (LIPA) agreed to purchase a D-VAR system to be installed in the East Hampton electrical substation located on the South Fork of Eastern Long Island. The goal is to increase transmission grid reliability and to reduce the costs and environmental impacts associated with operating the grid during times of peak demand. This will be American Superconductor's 22nd D-VAR system installed in North America. LIPA serves 1.1 million customers in Nassau and Suffolk counties and in terms of customers, is the third largest municipal electricity provider in the nation.

Figure 2: The D-VAR System. *A cut-away view of a typical D-VAR dynamic voltage regulation system inside its standard DOT-approved trailer.*



Source: American Superconductor
http://www.amsuper.com/html/products/transmissionGrid/104273030481.html

The D-VAR system also has applications for the wind energy sector. The greatest problem utilities have is the large amount of reactive power consumed by the typical wind farm. This reactive demand can cause a steep drop in voltage. Varying voltage is inefficient for power generation. However, the D-VAR system handles fluctuations in energy supply and demand, and should mitigate voltage irregularities at the point of interconnection between the wind farm and the grid. Potential benefits of installing a D-VAR device at the utility/windfarm interface for the windfarm could be:

- The voltage is regulated continuously within a narrow bandwidth. This keeps the wind farm on-line and avoids the need to trip-off due to either steady-state or transient low or high voltage conditions. It also maximizes KWH output opportunities and increases revenues.

- Step-voltage changes due to local and remote capacitor bank switching are eliminated, preventing excess gearbox torque and premature gearbox failure.
- Capacitor bank switching events are minimized which reduces switch maintenance costs.
- Wind farm revenues are maximized because of the ability to remain on-line.
- Overall interconnection and impact mitigation costs are minimized.

Utilities derive benefits by:

- Eliminating large VAR demands, and their resulting voltage swings caused by uncompensated wind farm operation.
- Mitigating or eliminating the need to install capacitor banks on the transmission system to control voltage.[2]

Another device created by AMSC has also been created with the end goal of increased grid efficiency. The S-MES, or Superconducting Magnetic Energy Storage System, is a device for storing and instantaneously discharging large quantities of power. Some of these systems are already in use for assisting large industrial customers with voltage stability and power quality problems. AMSC has also created the D-SMES, or Distributed-SMES System, which is similar to the SMES but is designed for utilities to improve system-level reliability and transfer capacity. The D-SMES system also reduces the need to put up more power lines. This then leads to greater efficiency in power usage and provides cost-effective power stabilization.

In November of 2003, the Tennessee Valley Authority (TVA) and AMSC revealed the development of another device with high-quality and reliable electricity transmission in mind. The SuperVAR transmission technology will be used by the TVA to prevent future blackouts. The SuperVAR stabilizes grid voltages in order to place less stress on power lines as the demand for power increases and more electricity is transmitted. This may lead to voltage instability, which in turn, may result in power outages.

SuperVAR synchronous condensers are high-temperature superconductor rotating machines, which run in harmony with the power system. They are controlled by a regulator to generate or absorb reactive power, acting as a "shock absorber" when the power system's voltage drops or changes suddenly. Balancing voltage prevents damage to the transmission system and to generating plants. In coordination with Gallatin Department of Electricity, the SuperVAR prototype will be connected to the grid at a substation serving the Hoeganaes Corporation in Gallatin, Tennessee sometime this year.

One very important purpose served by the SuperVAR device is that it eliminates the need for urban areas to utilize their old and polluting Reliability-Must-Run (RMR) generating facilities which are required to operate in order to maintain system reliability and voltage support. Like the D-VAR and S-MES systems, SuperVAR also enables existing transmission

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[2]"Wind Energy," American Superconductors.

assets to be operated at higher capacities thereby minimizing the need to construct new power generating facilities or install additional transmission lines in areas of increasing demand.

Another device for protecting the grid from energy surges is called a matrix fault current limiter and is being developed by Intermagnetics General. The $12.2 million project has been funded in part by the DOE ($6 million) and Electrical Power Research Institute (EPRI) ($600,000). The idea behind the devices is that when a surge pushes the amount of current above a particular energy level, resistance in the superconducting material increases. This increased resistance then turns some of the electrical energy into heat, thereby reducing the power flow. This device will also create a magnetic field as its temperature rises that will also reduce the material's superconducting capability. One reason why this device will be useful for utility companies is because they can push more energy through the grid without fear of overload or power surges. This is especially helpful as it reduces the need to build more power stations to run energy through. The matrix fault current limiter is set to be ready for public utilities to use by 2006.

Superconductor technology could be close to major breakthroughs that would dramatically change the future of electricity transmission. As soon as materials can superconduct at higher temperatures and HTS wire can be mass-produced, their applications will have a great effect on the reduction of greenhouse gases. Because approximately 7% of electricity will no longer be lost as heat during transmission, power plants will not need to burn as much fossil fuel in order to meet consumer energy needs.

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