ELECTRIC POWER RESEARCH INSTITUTE

Superconducting DC Cable for Long Distance Power Transmission

Issue Brief

Figure 1: Installation of a superconducting DC cable (manufactured by Southwire) at an American Electric Power substation. Photo courtesy: Southwire

Underground superconducting direct current (DC) cable systems can provide a level of bulk power transfer that is not feasible with today's conventional technology. It will be an essential component for connecting clean, renewable power generation throughout the nation and for distributing that power with a minimum impact on the environment.

Over the next two decades, environmental and government regulations concerning fossil fuel power generation and greenhouse gas emissions are likely to pose significant challenges to the electric power industry. For example, recent federal legislation requires 20 percent of all electric power generation in the U.S. to come from renewable resources by the year 2020 (many states have already adopted similar measures). Solutions to protect the environment and meet these goals include solar, wind farm, and nuclear power, but these sources are typically located far from urban centers where power demand is greatest. Therefore, the success of non-fossil fuel power generation depends on reliable, cost-effective delivery of bulk power from remote renewable energy sites, such as rural wind farms, as well as nuclear power plants, to the nation's urban load centers from coast to coast. Underground superconducting DC cable systems can provide a level of bulk power transfer that is not feasible with today's conventional technology.

Why use Superconducting DC Cable?

Superconducting DC cable can transfer up to five times the power of conventional cable of similar size in a smaller right-of-way over a longer distance. Due to its zero electrical resistance, and relatively low refrigeration power requirements, high power superconducting DC cabling operates with less than five percent loss of power from the power generator to the delivery point, while conventional overhead lines (AC or DC) can lose 10 percent or more of the power during transmission over very long distances. The efficiencies of superconducting cable deliver more power to more consumers.

The U.S. Department of Energy (DOE) supports the use of superconducting cabling as the basis for the next-generation power delivery system, calling it the best way to build the cleanest, most efficient energy "superhighway" across the U.S. To meet rising electric demand and deliver power from new remote renewable power sources to load centers requires enhanced transmission systems that minimize environmental impact. Underground superconducting DC cable is an essential component in such an enhanced transmission system.

What are the Technical Advantages of Superconducting DC Cables?

Unlike overhead high-voltage alternating current (AC) cable, underground superconducting DC is more efficient over long distances, carries higher power at lower voltages, and is less vulnerable to external damage from storms or intentional human intervention. Underground superconducting DC cable uses voltage source converters instead of the current source converters used by overhead high-voltage DC lines. This enables multiple interconnections, at distribution voltages, to the local AC network from underground DC cables carrying significant power. In high population centers, where excavation for new power transmission lines is problematic, superconducting cables with greater capacity can replace existing lower load lines to meet increased demand. Also, the use of voltage source converters provides an additional means to stabilize the existing grid.

Why DC Instead of AC Power Transmission?

Shortly after the beginning of the 20th century, DC power transmission was replaced by ac in order to achieve efficient transmission of electric power over long distances with available conductors and at safe voltages. However, the advent of solid-state power electronic AC-to-DC conversion equipment has reinvigorated DC application. Today, high-voltage DC power is more desirable for long-range transmission than ac in many ways. For example, DC: uses two wires rather than three, uses a simpler conductor, eliminates capacitive elements to cancel inherent inductive behavior, and can use the earth as one of the current-carrying elements in contingency situations.

How Does Superconducting DC Cable work?

Some pure metals have the proper magnetic and density properties for superconductivity when cooled using liquid helium to near absolute zero (4°K, -269°C)—a costly process. Since their first discovery in 1986, researchers have identified various materials that when cooled to a relatively "high" temperature of ~40–164°K (-233°C to -109°C) achieved superconductivity with cooling materials such as liquid nitrogen—a plentiful and much less costly means of cooling.

For power transmission, superconducting DC cabling is encased in a tube of flowing liquid nitrogen (see Figure 2). Cryogenic refrigerators located periodically along the length of the cable run maintain the proper nitrogen content, pressure, and temperature, assisted by a vacuum shell as a form of insulation from the ambient temperatures of the soil. The refrigerators and vacuum equipment are installed in the same underground vaults that are used for making splices in the initial installation of the cable runs. These vaults also serve as cable maintenance points, allowing crews to cap off and replace sections of damaged cabling.

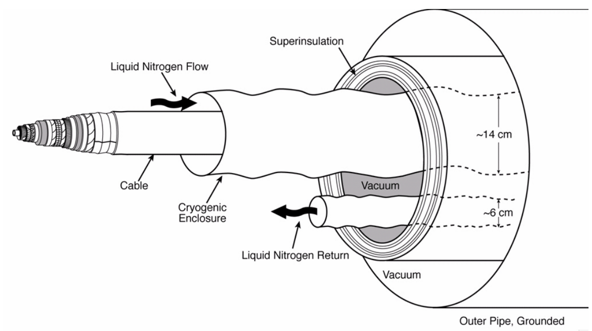

Figure 2: Design concept for a Superconducting DC Cable

What is the State of the Technology Today?

Only AC superconducting cables have been installed in utility applications to date. In July 2006, National Grid installed the first grid-connected high temperature superconducting (HTS) cable in Albany New York. This was a distribution voltage cable. The Long Island Power Authority (LIPA) launched the first transmission voltage HTS cable in April 2008 with a peak capacity of 574 megawatts over a distance of 2000 feet. While the Albany cable was decommissioned after a successful two-year demonstration, LIPA has stated that it intends to operate its cable indefinitely. Other pilot projects are underway in the U.S. in Ohio, and abroad in Europe, China, Korea, and Japan. Research is focused on validating designs, demonstrating reliability, understanding maintenance requirements, and improving integration with existing ac power systems. These AC cables have provided an excellent engineering design and operational experience foundation for the eventual development of a DC cable, which would use most of the same technology.

Cryogenic cooling systems and vacuum pumps, superconductive electric wire and cable, and installation tools are available from a number of manufacturers. These manufacturers are focused on creating lower-cost, more efficient cables and insulation, reducing the quantity of superconducting material needed in cabling, and increasing load capacity, as well as producing lower cost, more reliable, compact, and fault-tolerant refrigeration and vacuum systems.

What is EPRI TI Doing to Advance the Technology?

EPRI's Office of Technology Innovation (TI) has sponsored groundbreaking research into the use of superconducting DC cable systems and has recently published a report that outlines an engineering-based design for building the next-generation power grid using today's technology. The goal is to build a commercial, interregional prototype within about 10 years, though many intermediate steps along the way will be needed to reach this goal. The target capacity for the system is 10 GW, with a nominal current and voltage of about 50 to 100 kA and 100 to 200 kV. The engineering report examines cable design, DC-AC system interfaces, vacuum and cryogenic technologies, end station connections, cable installation and fabrication, and the effects of elevation and siting on long distance cable runs. The report also includes a previously unpublished system study that examines the capital and operating costs of deploying a 1000-mile, 5-GW transmission line. The system study concludes that, if present downward trends in the cost of superconductors continue, superconducting DC cabling would be less expensive than conventional high-voltage ac or DC overhead transmission systems and would have lower line losses. For more information, refer to EPRI report 1020458, published in December 2009. Two companion TI-published reports highlight the practical issues of integrating a long-distance, high-power superconducting DC link into the existing, lower-power ac transmission and distribution systems (see EPRI reports 1020330 and 1020339, published in November 2009 and December 2009, respectively).

What are the Next Steps?

EPRI has identified a number of further engineering research needs for large-scale superconducting DC cable deployment. These next steps include reducing system costs, investigating potential alternates to current vacuum insulation, improving cable design and fabrication, examining new converter technologies, and further optimizing control when integrating with the existing power grid.

What are the Benefits?

If deployed throughout the U.S., underground superconducting DC cable transmission has the potential to fundamentally transform the energy industry. Some of the high-level benefits include:

- High efficiency (less power lost during transmission) means reduced greenhouse gas emissions
- Underground superconducting cables require less space, reducing environmental siting, aesthetic, and right-of-way issues
- The high capacity of superconducting cables can link remote wind farm, solar, and nuclear power plants more effectively to the nation's power grid, increasing the effectiveness of these remote generation sources
- Aside from minimizing the use of unsightly overhead power transmission lines, underground transmission cabling will be safer from storms, vandalism, or potential terrorist threats

What is the Future of Superconducting DC Cable?

Ultimately, superconducting DC cabling could serve as the major backbone for a major upgrade of the country's aging high-voltage transmission network. In 2001, Dr. Chauncey Starr, founder and president emeritus of EPRI, introduced the concept of the SuperGrid. As envisioned, a superconducting DC cable cooled by liquid hydrogen would link underground nuclear power plants that would produce both the electricity and the hydrogen that flowed on the DC cable, with hydrogen serving additional duty as both energy storage medium and end-use fuel. The nitrogen-cooled superconducting DC cable project described in the EPRI report (1020458), while worthwhile in and of itself, would also be a first step toward the SuperGrid. However, much work remains to realize first widespread implement of superconducting DC cable and ultimately the SuperGrid. The timeframe for the full development, application, and acceptance of superconducting DC cable systems would likely be 20–40 years.

References

1. *Program on Technology Innovation: a Superconducting DC Cable.* EPRI, Palo Alto, CA: 2009. 1020458.

2. *Program on Technology Innovation: Study on the Integration of High Temperature Superconducting DC Cables within the Eastern and Western North American Power Grids.* EPRI, Palo Alto, CA: 2009. 1020330.

3. *Program on Technology Innovation: Transient Response of a Superconducting DC Long Length Cable System Using Voltage Source Converters.* EPRI, Palo Alto, CA: 2009. 1020339.

Contact Information

For more information, contact the EPRI Customer Assistance Center at 800.313.3774 (askepri@epri.com).

For further information on Superconducting DC Cable, contact Steve Eckroad at 704.595.2717 (seckroad@epri.com).

1020916 June 2010

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com