STRENGTHENING THE GRID

Effect of High-Temperature Superconducting Power Technologies on Reliability, Power Transfer Capacity, and Energy Use

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Summary

This report evaluates the potential of high-temperature superconducting (HTS) power technologies to address existing problems with the U.S. electric power transmission grid, especially problems with transmission constraints. These constraints that have resulted from the slow growth of transmission systems relative to the growth in demand for power have played a major role in higher electricity prices and reduced reliability in a number of areas across the United States in recent years. Electric power components using superconducting materials have the potential to address these transmission constraints because they have much higher energy density than conventional power equipment, which for transmission means added power-carrying capacity.

Superconducting power equipment requires cooling to sustain operating temperatures hundreds of degrees below ambient temperature. Magnets based on low-temperature superconducting (LTS) materials that require cooling with liquid or gaseous helium have become commercial products for accelerator and magnetic resonance imaging applications. However, the cost of cooling these LTS materials is a substantial barrier to their use in power system components. HTS power equipment, on the other hand, can be cooled with liquid nitrogen which is considerably cheaper than liquid or gaseous helium, thereby reducing or eliminating this cost barrier.

Projects are underway throughout the world to demonstrate the following superconducting electric power components:

- Low-loss and high-capacity power transmission cables
- Compact, high-efficiency, and low-environmental-impact transformers
- Storage of electricity via persistent currents in a coil (superconducting magnetic energy storage or SMES) or persistent rotation with a magnetic bearing (flywheel energy storage systems or FESS).

The various HTS technologies are at different stages of development: commercial SMES, composed of magnets with LTS wire and HTS current leads, has begun to appear in niche markets. HTS cables have been demonstrated at full scale at distribution voltages and in lengths up to a hundred meters. HTS FESS and transformers are also being demonstrated, but at less than full scale.

Computer simulations described in the body of this report show that HTS transmission cables produce a beneficial redistribution of power flows when substituted for conventional cables or conductors or added to the transmission grid. Increased power flows through the HTS cables can relieve stress on a heavily loaded network, resulting in increased reliability and increased power transfer capacity at the same level of reliability. This capability for downtown Chicago is demonstrated in this report. HTS cables can also provide an alternate transmission path at lower voltage to increase transfer capacity. This is demonstrated for California's Path 15 (the northern portion of the grid link between northern and southern California). The length of the simulated HTS cables is consistent with near-term demonstrations for Chicago, but is much longer than what is possible in the near term for Path 15.

At what cost do HTS cables provide these benefits? Engineering comparisons of HTS and conventional power components described in this report identify the range of parameters, principally component utilization and cooling efficiency, for which HTS power components may use less energy than conventional power components. Lower energy use translates into lower operating cost. These engineering comparisons also identify the range of HTS component (plus cooling system) costs and electricity costs in order for the operating cost reduction to be greater than the higher HTS component acquisition cost.

We draw the following conclusions from the data presented and analysis described in this report:

1. Significant transmission constraints exist in many areas of the United States. These constraints have resulted from increased demand, increased power transfers, and very small increases in transmission capacity over the past several years.
2. These transmission constraints have contributed, in some cases, to decreased reliability and to price differentials between load areas.
3. HTS underground cables provide an attractive retrofit option for urban areas that have existing underground transmission circuits and wish to avoid the expense of new excavation to increase capacity. This situation exists because HTS cables have almost zero resistance, very small capacitance and inductance, and high power capacity compared with conventional cables of the same voltage. Thus, the HTS cables provide changes in power flows that reduce stress in heavily loaded circuits, thereby increasing reliability or power-transfer capacity and relieving transmission constraints.
4. When operated at high utilization, HTS cables provide energy savings benefits compared with conventional cables per unit of power delivered for a

range of HTS cable parameters consistent with existing data and engineering estimates. However, whether or not the concomitant HTS cable operating cost savings are greater than the increase in acquisition cost compared with conventional cables depends on the cost of electricity.

5. HTS cables can provide a parallel transmission path at lower voltage to relieve high-voltage transmission constraints. The implementation of this approach for long-distance transmission circuits will depend on the development of periodic cooling stations and sufficient manufacturing capacity for HTS wire.
6. When operated at high utilization, HTS cables provide energy savings benefits compared with conventional overhead lines per unit of power delivered for a range of HTS cable parameters consistent with existing data and engineering estimates. HTS cables may also provide concomitant life-cycle cost benefits for situations in which the usual cost advantage of overhead transmission lines is mitigated by site-specific concerns such as high land-use demands or right-of-way costs or the expense of obtaining siting approvals or increasing power transfer capacity at higher voltage.
7. Flywheel energy storage systems using HTS magnetic bearings are in the demonstration stage and have the potential to achieve performance characteristics that will make flywheels competitive with batteries in a wide range of electricity storage applications.
8. HTS transformers can provide increased power capacity with the same footprint as conventional transformers and could be sited inside buildings because they eliminate fire hazards associated with oil. If estimated HTS-wire cost reductions from a new manufacturing facility are achieved and the wire meets performance requirements, HTS transformers are projected to be cost competitive with conventional transformers for a range of parameters consistent with existing data and engineering estimates.
9. Superconducting magnetic energy storage systems that use low-temperature superconducting coils and HTS current leads have already found a niche market for distributed reactive power support to prevent grid voltage collapse and for maintaining power quality in manufacturing facilities.

The White House Office of Science and Technology Policy (OSTP) authored a National Action Plan on Superconductivity Research and Development more than a decade ago. Based upon the analysis described in this report, a 2002 action plan for HTS power technologies might include the following recommendations:

- The DOE-led HTS power technologies research and development (R&D) program should continue to emphasize second-generation wire development, with the goal of providing HTS wire meeting commercial cost and performance targets.

- The DOE Superconductivity Partnership Initiative should be expanded, building on the current demonstrations that are providing operating experience, to develop new demonstrations with operational energy or power transfer benefits. These new demonstrations should include HTS cable demonstrations at longer lengths and transmission voltages and demonstrations of HTS transformers and FESS at a scale consistent with utility substation and end-user facility needs.
- The HTS R&D program should increase emphasis on and support for the development of cryocoolers with multi-kilowatt capacity that can be mass produced. These cryocoolers should have an efficiency rating greater than today's range of 14-20 percent of the highest possible (Carnot) efficiency at HTS-power-component operating temperatures.
- The HTS R&D program should increase the emphasis on and support for the development of standards for HTS-power-component installation and operation and increase the emphasis on and support for training of industrial staff who will operate and maintain these installations.