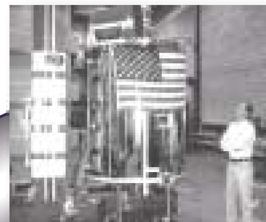
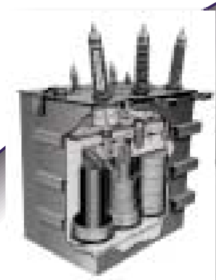
Selected

High-Temperature Superconducting Electric Power Products

Prototypes are outperforming design goals





full-scale utility applications are moving onto the power system and …

Modernizing the Existing Electricity Infrastructure

Superconductivity Program for Electric Systems • Office of Power Delivery • U.S. Department of Energy

January 2000

High Temperature Superconducting Power Products Capture the Attention of Utility Engineers and Planners

Soon superconductors could be so common that we will drop the "super" and refer to them simply as conductors

(Courtesy of American Superconductor Corp.)

Flexible HTS conductors promise reduced operating costs and many other benefits when incorporated into electric power devices. They can change the way power is managed and consumed.

Contents

Critical Role of Wire

The application of superconductors to electric power systems has been pursued for more than 30 years. This persistence is starting to pay off and utilities that once politely acknowledged the long-term potential of superconducting applications are now paying close attention to several prototype devices that are being tested or are nearing testing on utility systems. What has prompted this interest is the development of electric wires that become superconducting when cooled to the affordable operating-temperature realm of liquid nitrogen as well as the development of coils, magnets, conductors, and machines and power components made with these wires. Superconducting wires have as much as 100 times the current carrying capacity as ordinary conductors.

A Real Need

The timing is right for superconducting solutions to emerging business problems. Power generation and transmission equipment is aging and must be replaced. Environmental considerations are increasing. Utilities are changing the way they evaluate capital investments. Deregulation is intensifying competition. Superconducting power products will help the industry meet these challenges by reducing operating costs, enhancing flexibility and reliability, and maximizing the capability of our existing infrastructure. This ultimately could be reflected in lower electricity rates for customers.

Utility Uses

The following pages present technical profiles and specifications for four high-temperature superconducting (HTS) power products that are in the demonstration phase and are likely to gain a foothold in the marketplace. They are: transformers; current controllers; transmission cables; and large motors. These prototypes are providing the technical data and valuable operating experience base needed to accelerate the acceptance of superconducting technologies and to open up vast global markets.

Modernizing the Infrastructure

The general acceptance of superconducting power equipment by the electric utilities and other end-users will ultimately be based on the respective system performance, efficiency, reliability and maintenance, operational lifetime, and installed cost compared to conventional technologies. High-temperature superconductivity can fundamentally reshape the technology of electricity delivery based on the results of full-scale demonstrations in key applications, including transformers, current controllers, cables, and motors.

U.S. Program

The U.S. Department of Energy (DOE) supports national energy, economic, environmental and educational interests by providing leadership in developing HTS electric power devices and facilitating their adoption by the utility industry and private sector. (See the text box for the program goals.) The HTS prototype demonstrations described here are cost-shared through the DOE Superconductivity Program's Superconductivity Partnership Initiative (SPI).

Department of Energy Superconductivity Program Goals

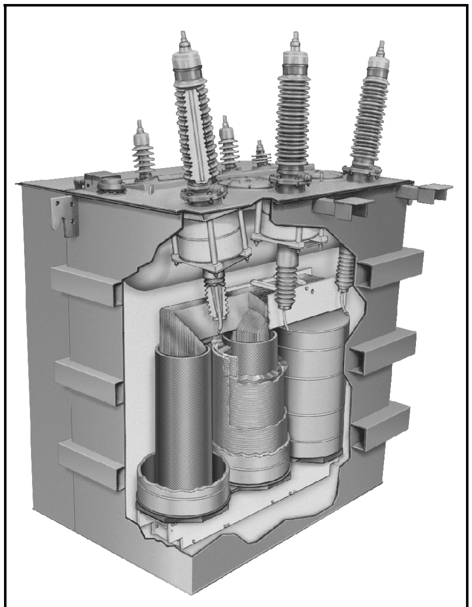
♦ **PERFORMANCE**
- Develop HTS wires with 100 times capacity of conventional copper/aluminum wires
- Design broad portfolio of electric equipment based on HTS
  - 50% size of conventional units with same rating
  - 50% reduction in energy losses compared to conventional equipment

♦ **COST**
- Wire cost $0.01/ampere-meter
- Equipment premium cost payback (efficiency savings) in 2-5 years of operation
- Equipment total cost payback during operating life

TRANSFORMING TRANSFORMERS

Use of HTS windings will turn power transformers into compact, environmentally friendly and highly efficient performers that will help deliver high quality power cost effectively.

HTS transformers use windings made of superconducting tape instead of conventional copper or aluminum. The HTS tapes become superconducting at about 120 K and below. The tapes are usually cooled to liquid nitrogen temperatures (77 K, or -196ºC) or lower to achieve best performance. At these temperatures the superconducting tapes allow current to be transported with nearly zero resistance. However, HTS transformers must still cope with eddy and ac losses in the windings that require refrigeration power. These losses are small compared to losses due to resistive heating in conventional transformer windings. HTS transformers offer the possibility of operating with low losses and at 10 to 30 times greater current density than conventional transformers. The windings are electrically insulated with dielectric materials which are designed to meet ANSI standard dielectric tests for system voltages and the associated basic impulse insulation test levels.


(Courtesy of Waukesha Electric Systems)

System Advantages

HTS transformers have potential advantages over conventional transformers in the following areas: about 30% reduction in total losses, about 45% lower weight, and about 20% reduction in total cost of ownership. These advantages are based on a 100 MVA transformer with HTS wire providing a critical current density of 10 kA/cm^2 and AC losses of 0.25 mW/A-m in a parallel field of 0.1 tesla. Additional benefits include: unprecedented fault current limiting functionality which is expected to protect and reduce the cost of utility system components, and reduced operating impedance which will improve network voltage regulation. In addition to greater efficiency than conventional transformers, HTS transformers eliminate oil cooling, thus reducing fire and environmental hazards associated with oil-based systems. These benefits enable HTS transformers to have higher power densities so they can be sited in high-density urban areas and inside buildings.

Greater Effective Capacity

Utility engineers envision the benefits of HTS transformers and how they could solve substation problems. Ronald C. Johnson, substations engineer at Rochester Gas & Electric Corp. states, “HTS transformers are attractive . . . because they are much smaller, have greatly extended overload capability and don’t have fire and environmental problems associated with insulating oil.” Robert H. Jones, senior engineer at RG&E adds, “Our typical substation is designed with two transformers. If one transformer fails, the other is sized to carry the load of both during the emergency. An HTS transformer can carry up to 200 percent of nameplate rating indefinitely without loss of transformer life. This means we can buy transformers of lower rating to do the same job or pack up to four times the capacity onto the same footprint area. HTS is a breakthrough technology that promises to bring sweeping changes to transformers.”

Low Impedance–High Returns

Conventional transformers are designed with large impedances (typically 10%-16%). This can affect the voltage regulation and reactive power demand in the system. HTS transformers can be designed to have an impedance of about 25% of a conventional transformer. Without fault-current limiters, this lower impedance will allow an HTS transformer to operate through a fault current of 10-20 times rated current. Examples of financial benefits due to the enhancements provided to power system performance and operation are shown in Table 1.

Table 1. Examples of Potential Financial Benefits.
(The numbers provided are typical industry averages)

HTS Transformer Characteristic	Financial Benefits
Current Limiting Capacity	
• Use conventional breaker instead of high current SF6 breaker	$25,000 each
• Replace EHV breaker with circuit switcher	$25,000 each
• Use load break switches instead of breakers	$ 6,000 each
• Elimination of current limiting reactors	$20,000 each
Reduced Impedance(*): Impact on Power System	
• Reduced need for Load Tap Changer units (voltage regulation)	$75,000 per LTC
• Reduced system VAR requirements (Static VAR Compensation)	$50,000 per MVAR
• Reduction in capacitor banks (reduced reactive power losses)	$13,000 per 10 MVA
Reduced Transformer Impedance (*): Impact on Generation	
• Reduced VAR requirements freed up for system, at $50/kVAR	$2.5 million
Additional available generator capacity from improved operation: **25 MW**	
1. Avoided capital cost, at $300/MW for gas turbine generator	$7.5 million
2. Additional revenue, at $0.04/kWh, **50%** capacity factor	$4.4 million (annual)

(*) Assumed: HTS transformer impedance is 25% of that of conventional transformer

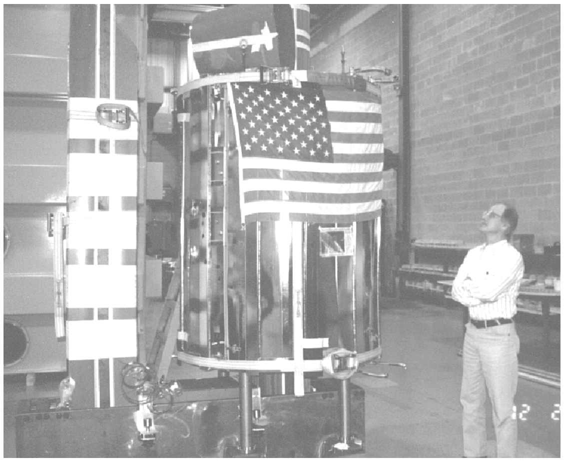
Demonstrating Performance

In March 1997, ABB installed a three-phase 630 kVA, 18.7 kV/420 V HTS transformer at an electric utility in Geneva, Switzerland. This unit was successfully serviced and tested for one year and was decommissioned. Phase I of a project, currently being funded by the DOE and an ABB-led team, focuses on power system studies, quantification of HTS transformer benefits to the owner, and demonstration/characterization of the intrinsic current limiting capability of novel HTS conductors. This phase is expected to be completed by March 2000. If the results of these market and system benefit studies in Phase I are favorable and so warrant, this project will proceed to the next phase, which will include specification and design development of HTS transformers. The project will eventually aim to field-test a 10 MVA, 69 kV/13 kV, HTS transformer at a U.S. utility.

Table 2. 1-MVA Experimental HTS Transformer Core and Coil Assembly Design

Parameter	Specification
Root mean square voltage and current	13.8/6.9 kV, 72.5/145 Amps
Cold mass weight	~ 590 kg (1,300 lb)
Vacuum tank volume	21,600 liters
Vacuum tank dimensions (hxwxd)	3.79 m x 2.78 m x 2.05 m
Vacuum tank weight	8,774 kg (19,300 lb)
Liquid nitrogen tank capacity	300 liters
Weight of liquid nitrogen tank and shield	364 kg (800 lb)
Cryocooler rating (Cryomech GB-37)	30 W at 25 K
Core weight	8,000 kg (17,600 lb)

DOE is also co-funding another project that will result in the installation of a 5/10 MVA, 26.4/ 4.16 kV, HTS transformer at a manufacturing plant in Wisconsin. The transformer will supply electricity to Waukesha Electric System's transformer manufacturing plant. A 1 MVA single-phase transformer has been demonstrated by Waukesha Electric Systems. The 1 MVA transformer is a test bed with a core cross-section of a 30-MVA transformer with a 138 kV/13.8 kV rating. The HTS winding can be operated at 25-77 K and the core is at near room temperature. Table 2 shows the specifications of the 1-MVA experimental HTS transformer core and coil assembly. The test transformer is shown in the photograph.



1-MVA demonstration transformer
(Courtesy of Waukesha Electric Systems)

Partners

ABB Power T&D Company, Inc. Team:
American Superconductor Corp., Air Products and Chemicals, American Electric Power, Southern California Edison, Los Alamos National Laboratory.

Waukesha Electric Systems Team:
Intermagnetics General Corp., Rochester Gas & Electric, Oak Ridge National Laboratory, Rensselaer Polytechnic Institute

SURGE PROTECTION FOR POWER GRIDS

HTS current controllers will provide utilities with surge protection within their local power distribution systems. They will prove to be economical and efficient fault-current limiters.

Old Problem

Every lightning strike, short circuit and power fluctuation is a potential catastrophe for power companies and their customers. These common events cause fault currents, which are sudden, momentary surges of excess energy or current that can damage and destroy expensive transmission and distribution equipment–and cut off service throughout a utility's grid.

New Solution

Utilities overwhelmingly indicate a critical need for a highly efficient current limiter. Yet few are satisfied with conventional solutions, which include larger, more costly transformers, inefficient current-limiting reactors and single-use fuses. HTS current controllers are far more capable than conventional solutions in several critical ways. They are reusable, require minimal maintenance, and do not need replacement after being activated. Most importantly, they also allow utilities to increase line power capacity and make more effective use of the grid.

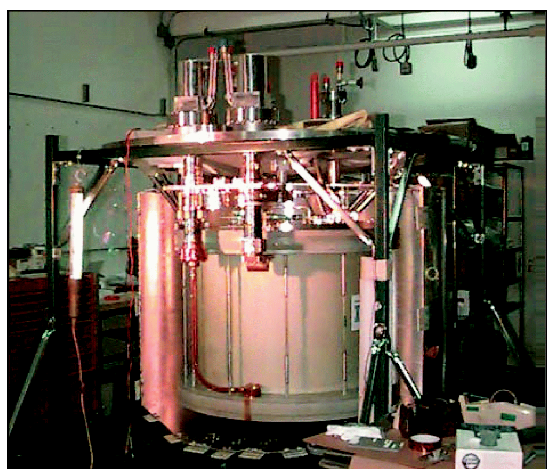
Andrew Power of the UK's National Grid Company believes, "The most exciting application of superconductors is in fault current limiters. HTS fault current limiters will provide the T&D industry with a solution that is impossible with conventional technology."

Superconductors are natural fault current limiters because of their ability to change rapidly from a superconducting, zero impedance state to a normal high impedance state in a fault situation.

In this way, an HTS current controller can detect a power surge and redirect it to an HTS coil that can safely absorb the surge without tripping the circuit breakers. This device limits the impact of a fault current, ensuring uninterrupted power supply to the grid's customers, and protecting utility equipment. HTS fault current limiters are compatible with existing protection devices. Their maximum allowable current is adjustable, which means greater system flexibility and they can defer the need for transmission and distribution system upgrades.

Prototype Exceeds Design Goals

The DOE is funding a project that will develop a 15 kV, 45 kA (asymmetric) pre-commercial current controller. In the first phase of this project the prototype surpassed most of its design goals. The 15 kV prototype device was built and actually rated at 17 kV, 45 kA, and 765 MVA. It operated at 40 K and experienced a peak magnetic field in normal operation of 0.3 Tesla (T) and peak magnetic field in fault conditions of 1.4 T. While the coil's normal operating current is 2,000 A dc, it is able to handle 9,000 A rms during the fault condition.



The cryomagnetic subsystem contains the world's largest HTS coil. (General Atomics)

In an early project test, the prototype 2.4 kV current controller successfully reduced a 3.03 kA fault current, performing 37% above specifications. The specifications also called for the current controller to be able to handle 2 faults of 400 ms each, spaced 15 seconds apart. The prototype limited these fault currents within an interval of less than one second. The current controller also worked as a fast half-cycle circuit breaker. The 2.4 kV current controller was successfully tested in September 1995 at a Southern California Edison substation. The 15 kV controller was shipped to Southern California Edison in 1999. The photograph shows the controller being transported to the Center substation on a 40-foot trailer. Tables 3, 4, and 5 show the specifications of the fault current controller.

During high voltage tests, a flash to ground in an auxiliary piece of equipment rendered one phase inoperable and single-phase testing continued on the controller. During these tests, the prototype achieved fault reduction and a sub-cycle fast breaker operation at 12.47 kV and 10 kA. Testing has been terminated though the HTS coils are still fully operable. Proposed work includes the study and repair of the prototype and modifications to the cryogenic system to improve its reliability.

Partners

General Atomics, Southern California Edison Intermagnetics General Corporation, Los Alamos National Laboratory, California Energy Commission, EPRI.

The superconducting current controller was delivered to the Southern California Edison Center Substation for testing. (General Atomics)

Table 3. 15 kV Fault Current Limiter Device Design

Parameter	Specification
Maximum operating voltage	17 kV rms
Normal operating current	1,200 Amps rms
Maximum interceptable current	45 kA (asm)
Breakdown insulation level	110 kV
Maximum ambient temperature	323 K
Designed fault reduction	80%
Fast breaker operation	8 ms
Multiple fault limiting	Two faults, 1s each 15 s apart

Table 4. 15 kV Fault Current Limiter Coil Characteristics

Parameter	Specification
Configuration	1.0 m OD/0.75 m height solenoid
Operating temperature	40 K
Inductance	5 mH
Nominal operating current	2,037 Adc
Maximum fault current	9,000 A rms
Maximum terminal voltage	20 kV (rated)
Maximum radial field	0.37 T normal operation 1.4 T fault condition

Table 5. 15 kV Fault Current Limiter Subsystem Characteristics

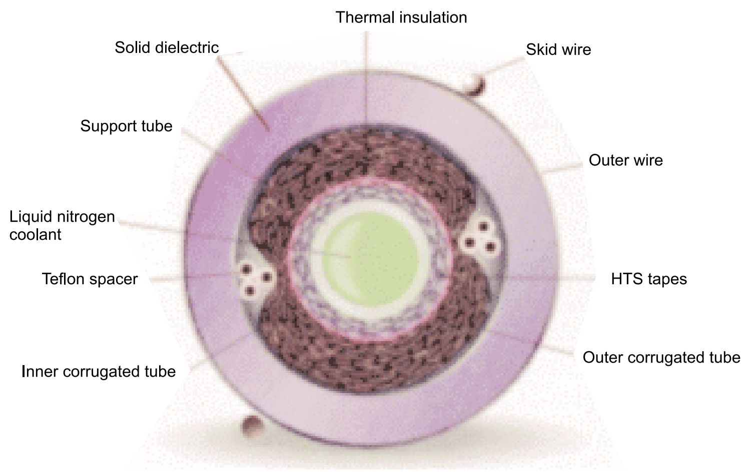
Parameter	Specification
Power electronics	96 5.2 kV, 3 kA thyristors
	144 heat sinks
	300 gallons/minute oil cooled heat exchanger
Cryogenics	9 cryocoolers
	Vacuum insulated
Control subsystem	Self diagnosis
	Autonomous operation
Interface with utilities	NEMA enclosure
	Trailer mounted

HIGH-CAPACITY TRANSMISSION CABLES

HTS cables cooled to 77 K are being demonstrated and will soon be carrying at least 3 to 5 times more than conventional cables through the existing underground city pipes. This offers strategic benefits to utilities and a cost-effective means for repowering the existing electricity delivery infrastructure.

New Possibilities

Network designers have traditionally increased voltage to transmit more power efficiently. For a given capacity line, higher voltage results in lower current and lower ohmic (I^2R) heating losses. That has entailed large investments in high-voltage transformers and related equipment, as well as large electric losses. HTS cables may make it possible to lay out grids in innovative ways to position generators closer to customers, without having to step voltage up and down as frequently as is done today. The economic savings would be formidable.



Warm-Dielectric Cable Design

EPRI

Growing with the Grid

Presently about one-quarter of the 2,200 miles underground transmission cables in the U.S. have been in place beyond their rated lifetimes. HTS cables can meet increasing power demands in urban areas via retrofit applications using existing cable conduits and can eliminate the need to acquire new rights-of-way. Presently, two to three underground copper cables are needed to achieve the capacity of one overhead transmission line and installation costs are 20 to 30 times higher.

In HTS power transmission cables, conventional conductor wire of copper or aluminum is replaced by HTS wire, enabling the cable to carry greater amounts of current with lower resistive losses. Successful application of HTS conductors to transmission cables would allow the use of underground HTS cables for the replacement of overhead lines. Significant environmental benefits are obtained from the use of liquid nitrogen coolant rather than oil.

Two basic HTS cable designs are emerging as possible candidates for power transmission.

Warm-Dielectric Design

One design by Pirelli uses a "room temperature dielectric" material, in which the dielectric (electrical insulation) is outside the thermal insulation and is not exposed to liquid nitrogen temperatures. This simplifies the design considerably since conventional dielectrics can be used. The overall assembly consists of a flexible, hollow core wrapped with several layers of HTS tape, followed by thermal and electrical insulation. Pressurized liquid nitrogen flows through the core to cool the HTS tape. The cable assembly is then jacketed in the conventional manner and completed with skid wire to provide physical protection during cable installation and use.

In 1996, a successful 50-m cable, carrying 3,300 A dc, at 1 μV/cm dc, and 77 K, was demonstrated. In 1998, a 50-m cable prototype was successfully tested at 115 kV, including terminal connections and a splice. This cable was operated at 69 kV and carried 3,300 A dc at 74 K and can carry up to 2000 A ac.

Detroit Edison Project

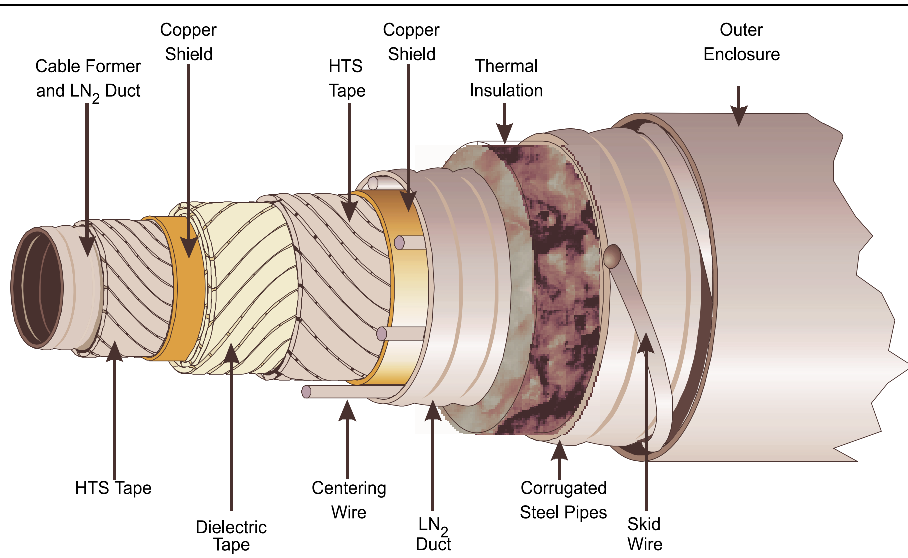
The DOE and Pirelli are co-funding a project to develop and manufacture a 120-m, 24 kV, three phase HTS cable prototype and test it using conventional, industry-accepted techniques. Three such cables will be installed in Detroit Edison's Frisbie substation by 2001. The cables can carry 2,400 A ac at temperatures of 77 K (-196°C). Cooling is done by liquid nitrogen circulating in a hollow core. This is three times the current carrying capacity of a comparable copper cable. The cables will be installed in 4-inch (10-cm) diameter ducts. The HTS cable will replace three conventional circuits in the substation. This real application will use only 110 kg of superconducting wire to conduct as much power as the 8,200 kg of copper wire it replaces.

Energy Secretary Bill Richardson said the project would open "the gateway to the electricity superhighway of the future." Robert Buckler, president and COO of DTE Energy Distribution said, "Having the capability to triple the current-carrying capacity of existing conducts will allow us to avoid digging up and disrupting the infrastructure." As urban areas are revitalized, these cables will be able to bring in the extra power and also increase system reliability. Competitive retail markets will place greater power transfer demands on regional and urban networks.

Bill Carter, Detroit Edison's director of transmission and subtransmission planning remarked, "We will be one of the first utilities to get O&M experience with liquid nitrogen-cooled HTS power technology–something we believe will be of significant value as HTS cable and other power products enter the commercial market." Adds Buckler, "This demonstration project will encompass most of what we expect to encounter in the future if we decide to pursue a major HTS retrofit strategy. Our people are excited at the prospect of learning how to do their work using the new, cutting-edge superconducting technology."

Cold-Dielectric Design

In another design variation, Southwire Company is developing a "cryogenic dielectric" design which exposes the cable's electrical insulation to liquid nitrogen temperatures. This design offers the added benefit of the dielectric acting as a shield to the HTS tapes, which lowers ac losses and eliminates the external electromagnetic field.



Cold-Dielectric Cable Design

In this design, a central former is concentrically surrounded with HTS tape, electrical insulation, and another layer of HTS tape. The entire assembly is then insulated and jacketed to protect it from thermal and physical damage. The cable is cooled by passing liquid nitrogen through the hollow central former along the length of the cable, which is then returned, through gaps in an outer layer of the cable assembly.

Southwire SPI Project

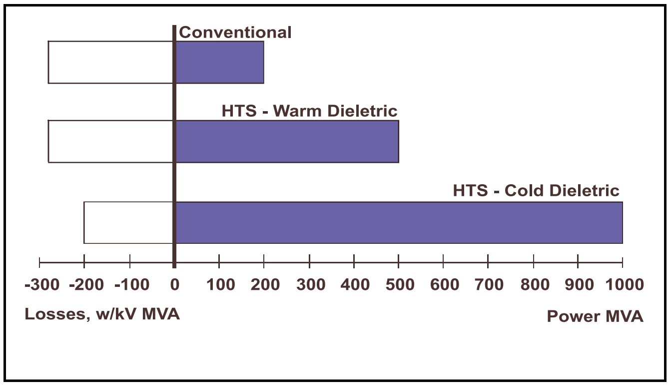
The Southwire project resulted in a 30-m, three phase, 12.5 kV, 1.25 kA, power cable installed in Carrollton, Georgia. The cable powers two manufacturing plants and a corporate headquarters. Southwire Company had previously tested a 5-meter, single phase HTS cable successfully. This demonstration cable is capable of carrying 1,400 Amps, which exceeds the design goal and has demonstrated stable operation at design parameters (7.2 kV ac and 1,250 Amps). The tests on this first 5-m cable provided a number of valuable insights, including the following:

- Measurements of dc critical have been made from 72 - 82 K
- AC losses are on the order of 1 watt/m at operating temperature
- The cable can maintain its integrity at up to 2.5 times the operating voltage (18 kV) ac and at ac currents of up to 1,400 Amps.
- The cable has been operated at the design parameters of 7.2 kV and 1,250 Amps ac for over 72 hours.

The three phase, 30-m cable powers Southwire's own corporate headquarters and manufacturing facility. R.L. Hughey, Southwire project manager said, "The HTS cable will be used under real-world conditions, including varying loads. The load is estimated to be equivalent to that required for the city of Carrollton [about 18,000 people]." He added, "The Southwire cable is the world's first industrial field test of an HTS power delivery system. We're developing a cable which utility companies will use to distribute energy to homes and businesses that will be capable of handling the power demands of the new millennium and beyond."

Cable Performance

The figure below shows that for the same pipe size and voltage (115 kV in pipe 8 inches (20.3 cm) in outer diameter), HTS cable performance surpasses that for conventional cable. Using room-temperature or cryogenic dielectric, they promise to respectively double or quadruple power at equal or lower (two-thirds) losses.



Partners

Pirelli Cables & Systems Team:
American Superconductor Corp., Lotepro, Detroit Edison, Los Alamos National Laboratory, EPRI.

Southwire Company Team:
Intermagnetics General Corp, EURUS Technologies, Georgia Transmission Company, Southern Company, Southern California Edison, Argonne National Laboratory, Oak Ridge National Laboratory.

UNLEASHING HTS HORSEPOWER

Big outputs come in small packages due to revolutionary electric motors that use HTS technology to maximize performance while reducing size, weight and energy costs.

Electric motors run the industrialized world. They also run huge power bills–$55 billion a year in the U.S. alone. Industrial motors of more than 1,000 hp consume about 20% of all electric power generated in the U.S. As industry looks for ways to cut expenses, one of the most promising solutions lies in the HTS motors.

Immediate Savings

Industrial electric motors consume 70% of the electricity used in a typical manufacturing operation, so increased efficiency yields immediate savings in power costs. Each one percent in efficiency improvement provided by HTS motors would result in an estimated savings (across all motors of over 1,000 hp) of more than $300 million per year in the U.S. Over the lifetime of the HTS motor, the savings in power costs would exceed its capital cost. Reduced size and weight additionally cut costs associated with shipping, manufacturing, installing, and maintaining motors. More efficient operation also conserves non-renewable resources and generates fewer pollutants and greenhouse gases.

Basic Design

HTS motors can replace large motors (> 1,000 hp) for pump and fan drives in utility and industrial markets. The HTS motor being developed by Reliance Electric, a division of the Rockwell Automation Company is a cryogenically cooled, ultra-efficient synchronous motor with HTS field windings. The adjustable speed drive (ASD) used to power the motor will be a conventional rectifier/inverter system as used with present AC induction motor products, modified to operate with a synchronous motor. The HTS field winding will operate in the 25 - 40 K temperature range at a DC magnetic field of up to 4 Tesla. The field coils will be cooled by a commercially available cryocooler system that feeds cooled helium gas to and receives warmed helium gas from the rotor. Much of Reliance Electric's work today is geared to accommodate progress on the HTS materials front. David Driscoll, superconducting motors manager said, "All the engineering we're doing today to get a motor at 1,000 hp at 33 K will only help us in the future, when we have wire that will actually be performing [at high field] at 77 K."

The HTS motor components are shown schematically on the next page. In planned commercial models, the magnitude of the magnetic field is approximately twice that of a conventional motor. The HTS motor has an air core (i.e. nonmagnetic) construction so that the air gap field can be increased without the core loss and saturation problems inherent in a laminated iron stator and rotor core. The copper armature winding lies just outside the air gap.

Under steady state operation, the rotor spins in sync with the rotating field created by the three-phase armature currents and the superconducting field winding experiences only DC magnetic fields. Under load or source transients, however, the rotor will move with respect to the armature-created rotating field, and it will experience AC fields. The AC fields are shielded from the HTS field winding by warm and cold AC flux shields located between the HTS coils and the stator winding.

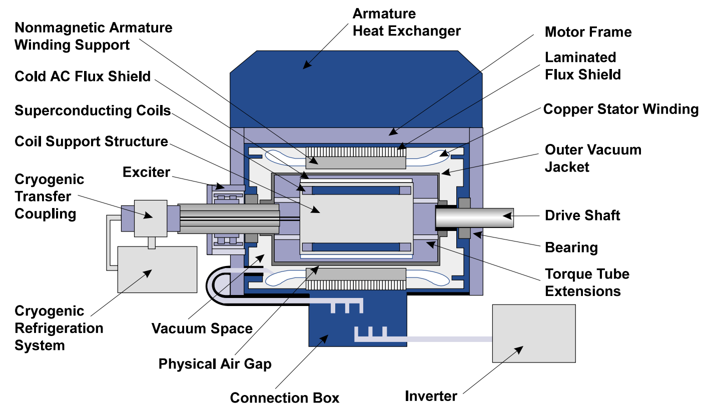
Inside the warm outer AC flux shield will be a thermal insulation space (vacuum) that will surround the rotor cryostat. The cold AC flux shield is on the inside surface of this vacuum space and is a high-conductivity shell near the operating temperature of the superconducting coils. The superconducting field coils are located within the inner shield on a non-magnetic support structure.

Benefits

HTS motors may increase machine efficiency beyond 98%, reducing losses by as much as 50% compared to conventional motors. HTS motors are smaller in size occupying approximately half the volume and may have lower life cycle costs.

Motor Surpasses Design Goals

The DOE is co-funding a project that will build and test a 1,000 hp HTS motor in 2000 and a 5,000 hp HTS motor by 2002. In March 1996, a 200-hp motor was demonstrated which exceeded specifications by 60%. This was the first air-core synchronous motor with rotating superconducting field coils cooled by helium gas. The 1,000-hp motor has been built and is being tested. The performance of the HTS coil did not degrade under the mechanical stresses associated with rotational force. "This first of a kind HTS motor will undergo extensive testing and evaluation in our laboratory," stated Paul T. Gorski, Vice President of Engineering at Rockwell Automation Power Systems group. "At the conclusion of these laboratory tests, we plan to place this motor in an industrial beta site while we manufacture the 5,000 horsepower motor which is being targeted as the commercial entry point for this product."



HTS Motor: Design Features (Reliance Electric)

Table 6 shows the HTS motor specifications for the 1,000 and 5,000 hp motors.

Partners

Rockwell Automation/Reliance Electric, American Superconductor Corp., Air Products and Chemicals, Centerior Energy, Sandia National Laboratory, EPRI.

Table 6. HTS Motor Specifications
Coil Assembly Design

Parameter	Value for 1,000 hp Motor	Value for 5,000 hp Motor
Output power (hp)/(kW)	1,000/746	5,000/3,730
Shaft speed (rpm)	1,800	1,800
Output torque (ft-lb)/(N-m)	2,918/3,956	14,589/19,780
Number of poles	4	4
Armature voltage (V)	4,160	4,160
Power factor	1.0	1.0
Predicted efficiency (% wo/ref)	97.9	98.8
Predicted efficiency (% w/ref)	97.1	98.6
Operating field current (Amps)	126	152
Operating field temperature (K)	33	33
Current density, J_c (kA/cm^2)	13.5	13.5
Maximum field magnetic flux (T)	1.5	1.85
kA-turns/pole	172	327
Rotor outer diameter (in)/(cm)	15.8/40.1	24/60.7
Armature outer diameter (in)/(cm)	27/68.6	38/96.5
Armature length (in)/(cm)	48/121.9	50/127

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