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World Project Now for Superconductor

Save Earth by Superconductor

This year ISTEC has started special features on the current world projects for HTS superconductor and its application.

This month, Dr. A. P. Malozemoff, introduces the US activity.

We hope that our readers of Web21 will be initiated by this article not only for the research work but also for a business plan.

ISTEC
Yutaka Yamada

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U. S. Activity in Superconductor Technology for Power Grid

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Abstract

Projects for enhancing superconductor wire performance and carrying out technology demonstrations of electric power grid equipment continue actively in the U. S., involving a number of wire, cable, motor and transformer manufacturers and utilities, with support from several U. S. government agencies. The U. S. leads the world in supplying commercial second generation high temperature superconductor wire, principally from AMSC and SuperPower, and a number of other entrepreneurial wire development efforts are under way. But U. S. activity in superconductor wire and power grid technology was significantly impacted by the termination of the U. S. Department of Energy's program on superconducting power equipment, which had for almost two decades been the center point of the U. S. effort in this area. Ongoing focus on applications, both government-supported and commercial is still needed, assisting the growing U. S. (and worldwide) industry in bridging to a future flourishing commercial superconductor power equipment market.

Introduction and Overview

This report summarizes the status and future prospects for U. S. activity in superconductor electric power grid technology, building on a recent major report by Wolsky, [1] which provides a thorough review of both companies and specific projects in this area.

The focus here is on power grid technology based on high temperature superconductor (HTS) wire using the cuprate superconductors[2], particularly first generation (1G) $Bi_2Sr_2Ca_2Cu_3O_{10}$ (BSCCO-2223) and second generation (2G) $RE_1Ba_2Cu_3O_7$ (REBCO-123, where RE stands for rare earths and yttrium), and to a small extent on MgB_2 wire , which is being considered for fault current limiter and rotating machine applications. Although all these types of superconductor wires can address magnet applications, like magnetic resonance imaging, high energy physics and high field research magnets, such applications will not be considered here except insofar as they provide an additional market pull for superconductor wire.

Seen as a whole, the U. S. activity in superconductor grid technology leads the world in its scope and level of sophistication. It has the world's two leading suppliers of second generation (2G) high temperature superconductor (HTS) wire, AMSC and SuperPower. The world's most advanced HTS cable installation, the LIPA cable, which has operated since 2008 in the Long Island grid and originally used 1G wire, is now introducing 2G wire in one of its three phases. The world's most advanced HTS rotating machine, a 36 MW ship propulsion motor, was demonstrated by the U. S. Navy's Office of Naval Research (ONR) already in 2008. Major projects are under way to install the world's first fault current limiting cable in the New York City grid and to develop a 5 MW current limiting transformer. These and many other presently active projects are summarized in **Table I**.

AMSC, Boeing, Emerson Electric, General Electric, Southwire, Varian Power Systems and Waukesha Electric Systems are the main U. S.-headquartered industrial participants, along with smaller companies,

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some focused on wire such as Grid Logic, Hyper Tech Research, MetOx, Superconductor Technologies Inc. (STI) and 3G-HTS, and some focused on coils and systems, such as Advanced Magnet Lab, BEW Engineering, Empirical Systems Aerospace, and Tai-Yang. The main participating U. S. utilities are American Electric Power, Con Edison, the Long Island Power Authority (LIPA) and Southern California Edison. Governmental funding support is provided by the U. S. Departments of Defense, Energy and Homeland Security and by NASA. The U. S. activity is further enhanced by relevant R&D in several national laboratories (Argonne, Brookhaven, Los Alamos and Oak Ridge) and in many universities, particularly the Applied Superconductivity Center and Center for Advanced Power Systems at Florida State University, and the Texas Center for Superconductivity at the University of Houston. Superconductor power applications are studied and promoted by the Coalition for Commercial Applications of Superconductivity (CCAS), EPRI's Program 36 on Underground Transmission and the IEEE Working Group on Fault Current Limiter Testing.

Of course it should be recognized that a significant portion of the present U. S. activity is conducted by U. S. companies owned by foreign companies (SuperPower Inc. now owned by Furukawa Electric Co. of Japan and TECO-Westinghouse owned by TECO of Taiwan - Republic of China), by U. S. divisions of foreign companies (ABB of Switzerland), directly by foreign companies (Nexans and Air Liquide of France), or by partially foreign-owned joint ventures (Ultera, a joint venture of Southwire Company of the U. S. and nkt cables of Denmark).

Challenges

Nevertheless, some clouds have arisen in recent years around the future of U. S. superconductor grid technology. One was the termination of the almost two-decade-long U. S. Department of Energy (DOE) program, by its Office of Electricity, on superconductor power equipment, which promoted in an organized way the development of HTS wire and the formation of vertically integrated industrial teams to demonstrate in-grid superconductor power equipment. This program supported the key LIPA, Columbus-Bixby and Albany cable demonstrations (the first still active, Albany long since decommissioned, and Columbus-Bixby project expected to conclude at the end of 2012). It also supported the development of fault current limiter technology, culminating in the successful demonstration of a single phase transmission voltage fault current limiter by Siemens, Nexans and AMSC. One reason for the termination of the program was the sense that the technology was sufficiently established to allow industry to carry forward commercialization without further government support.

While this may be true for superconductor AC cable and fault current limiter technology, it is not true for some other major commercial opportunities such as superconductor generators for wind turbines, transformers and DC cables for long distance power transmission. Furthermore, while HTS and MgB_2 wire have reached performance levels adequate for commercial-scale power equipment demonstrations, further improvement in wire properties and reduction in cost could significantly assist commercialization and could benefit by on-going co-ordinated, government-sponsored research.

Another program supported by the U. S. Air Force Office for Scientific Research (AFOSR), the MURI program on underlying materials science of HTS wire technology, was also terminated several years ago, while a new AFOSR program was started to search for higher temperature - ideally room temperature - superconductors. Similarly at DOE, as their power equipment program terminated, a new Energy Frontier Research Center (EFRC) program was started to search for and characterize new superconductors - the

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Center for Emerging Superconductivity (CES) supported by DOE's Basic Energy Sciences Department. One of the underlying rationales for this new focus on discovery of higher temperature superconductors, both by AFOSR and EFRC-CES, was the idea that truly successful grid application required a room temperature superconductor so as to eliminate refrigeration cost and complexity. This perspective has been challenged by those who believe that present HTS materials are already well on their way to successful commercial grid application. In fact questions have been raised, not only about the difficulty of discovering a room temperature superconductor, but also about the practicality of such a superconductor, even if it could be found, on the general grounds that very short coherence lengths and thermal activation would increase grain boundary barriers and enhance flux creep, thus suppressing critical current.[3] More recently, CES introduced a new effort to understand flux creep and enhance critical current in the cuprates, with particular focus on operating conditions of a wind generator.

Another disappointment has been that the U. S. Navy put on hold superconductor motor development for electric ships, delaying, perhaps indefinitely, the opportunity to test the successfully laboratory-tested 36 MW ship propulsion motor on a ship. Interest persists at a low level in the U. S. Air Force in a high-speed ultra-compact generator for all-electric aircraft.

Finally, perhaps the biggest disappointment has been the lack of any truly commercial U. S. power project to date. Recognizing that the wire price is still quite high and that refrigeration systems are also costly and complex, utilities nevertheless may benefit commercially from the unique benefits of HTS power equipment. For example, superconductor AC cables, such as the LIPA cable, have now been well demonstrated and tested around the world. In urban environments with dense underground infrastructure, these cables offer a way to install compact, higher power underground links, allowing utilities to avoid major costs in digging up city streets and rerouting existing underground infrastructure. Reasons for the delay in taking advantage of this new technology for such applications can be many. The Great Recession and the ensuing weak recovery temporarily slowed growth of power demand and hence the urgency in the need for higher power urban links. The utilities' unfamiliarity with the technology is surely a factor, though in-grid installations such as the LIPA and Bixby cables are beginning to provide demonstrations of feasibility and long-term reliability. Cost tradeoffs are also a significant issue – installation savings must be substantial enough to outweigh the presently higher cost of the HTS cable itself with its refrigeration infrastructure. Similar issues apply to other applications such as rotating machinery and fault current limiters. And the technology for wind generators, transformers or DC cables, as mentioned above, is still insufficiently developed or demonstrated; these applications call for renewed focus.

Projects

Nevertheless, a variety of important programs continue in the U. S., as summarized in **Tables I and II**. On the wire side, both AMSC and SuperPower maintain active in-house and collaborative R&D to support and enhance their commercial wire production, and their sales are steadily growing. For instance, AMSC continues to deliver 2G HTS wire on its 2010 order from LS Cable (Korea) for 3 million meters (delivery spread out over several years), which is the world's largest wire order to date. Hyper Tech Research is delivering MgB_2 wire to a 12 kV fault current limiter project of Rolls Royce and Applied Superconductivity Ltd. in the U. K. Several new wire development and manufacturing efforts are underway at Grid Logic (MgB2), MetOx (2G HTS), STI (2G HTS) and 3G-HTS (round wire with YBCO). Although these latter companies are far behind AMSC and SuperPower in establishing viable 2G HTS production, they claim long-term advantages to their 2G HTS wire processes; time will tell.

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Several U. S. government projects support U. S. companies in wire development (**Table II**). ARPA-E, a relatively new branch of DOE supporting innovative energy technologies, has a series of projects developing enhanced or novel HTS wire. The EFRC-CES program, mentioned earlier, works with AMSC and SuperPower. While these programs are helpful, they can hardly replace the co-ordinated effort sponsored by DOE's superconductor power equipment program, supporting major efforts at Oak Ridge and Los Alamos National Laboratories which have now all but disappeared.

In the area of applications (see **Table I**), perhaps most significant is the Hydra project by AMSC and Con Edison to install a fault current limiting AC cable linking two substations in New York City at the distribution voltage (13.8 kV) level. This project is supported by the Department of Homeland Security with the goal of increasing security for critical assets like New York's financial district by providing alternative energy links to the substation powering a given district. The cable is being fabricated by Ultera and refrigeration system by Air Liquide. Two other projects target DC cable: a Navy project led by the Center for Advanced Power Systems (CAPS) to study and build a prototype DC cable for on-board ship power distribution, and the commercial Tres Amigas project to link the three main asynchronous U. S. power grids with DC cables (in the first stage with conventional technology, only later with HTS).

Another major project is the Fault Current Limiting Superconducting Transformer project led by Waukesha Electric Systems, with SuperPower and Southern California Edison (SCE) as partners. The 28 MVA (69 kV/12.47 kV) system features compactness, fault current limiting and avoidance of oil for enhanced fire safety. It will be tested in the SCE grid. A standalone superconducting resistive fault current limiter is also being developed in an internal program at Varian Power Systems. AMSC and Nexans are teaming to offer distribution level superconductor fault current limiters for the U. S. market.

Wind generator technology is supported by DOE's Energy Efficiency and Renewable Energy (EERE) department in a multi-party program led by Advanced Magnet Lab (AML). GE, including its recently acquired Converteam subsidiary in the U. K., also has ongoing internal interest in superconductor generator technology. Unfortunately no U. S. program is yet applying the most advanced rotating machinery technology, which was demonstrated in the Navy's ONR 36.5 MW ship propulsion motor, to high power wind generators.

A project led by ABB, including Brookhaven National Lab and SuperPower and supported by ARPA-E, is developing a magnetic energy storage system (SMES). The goal is storage of intermittent wind and solar energy, though the presently funded phase of the project is limited to design and a coil demonstration. A frequently cited application of SMES is voltage dip and sag protection to sensitive grid and industrial grid sites, but over a decade ago AMSC had fielded nine in-grid commercial SMES systems (using LTS) for this purpose; these were in fact the world's first commercial superconductor products for the power grid. But AMSC finally terminated this product in favor of a now widely used and lower cost power-electronic solution providing just reactive (out-of-phase) power. One other energy storage project at Boeing, supported by ARPA-E, focuses on flywheel storage using superconducting bearings.

Several other non-grid-focused U. S. government programs provide market pull for superconductor wire: the DOE High Energy Physics program supporting HTS wire development for future particle accelerators, the National Institutes of Health interest in ultra-high field HTS-based NMR, and the National Science Foundation's 32 T HTS-based user magnet for the National High Field Magnet Laboratory.

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Conclusion

In conclusion, over the last two decades, U. S. companies and government have made huge investments developing superconductor wire and power grid equipment in expectation of a major commercial market and need for such superconductor power equipment. The wire is now available and many applications are well demonstrated. The industry is poised to grow. Government support is still very important to help perfect the wire and demonstrate other important applications, helping the industry bridge to the opening of that commercial market.

Table I. Sponsored U. S.-Based Power Systems Projects

Project Sponsor	Application	Title	Technical Targets	Status, Target	Member	Budget, Period	Source
DOE OE	Cable	LIPA HTS Cable I and II	138kV/2.4kA, 600m 3-phase cable system in-grid, Phase I with 3 1G HTS cables, Phase II with 1 2G HTS cable	In operation since 2008, Phase II complete 2012	AMSC(lead),Nexans, Air Liquide, LIPA	$49 M, 2003-2011; $0.2 M, 2012	Wolsky 2012
DHS	Cable	Resilient Electrical Grids (Project Hydra)	13.8 kV/4 kA, 170 m, 3-phase coaxial fault-current-limiting cable to be installed in NYC grid.	25m test completed, full cable being fabricated	AMSC (lead), Con Edison, Ultera, Air Liquide, Altran, ORNL	$29 M, 2007-2014	Wolsky 2012
Tres Amigas LLC	DC Cable	Tres Amigas Super Station	DC power transfer between 3 main U. S. interconnects; first phase not superconducting	Raising funds	Tres Amigas LLC	TBD	Wolsky 2012; http://www.tresamigasllc.com/location.php
DOD ONR	DC Cable	Superconducting DC Cable	Study of helium-cooled DC superconducting cable for warship power; demo of 1 kV 30 m monopole cable	Underway	CAPS, Southwire, NSWC	$5M, 2007-2013	Wolsky 2012
DOE Smart Grid	Trans-former	Fault Current Limiting Superconducting Transformer	28MVA, 3-phase (69kV/12.47kV) with current limiting, 2G HTS wire, Smart Grid commun./control, in-grid test starting by end 2013	Design under develop-ment	Waukesha (lead), SuperPower, SCE, ORNL, TCSUH	$21.5M ($10.7M from DOE), 2010.2.1-2015.1.31	Wolsky 2012, http://www.smartgrid.gov/sites/default/files/waukesha-oe0000244-final.pdf
DOE EERE	Wind gene-rator	Fully Superconducting Direct-Drive Generator for Large Wind Turbines	Performance tests of specific drivetrain components, build and demonstrate a sub-scale system and complete detailed design for 10 MW, using MgB_2 conductor	case study	AML, Emerson Electric, Argonne, Creare, BEW Engineering	Phase I $0.7 M, Phase II $2.5 M, 2012-2014	Wolsky 2012
NASA	Rotating machine	High-Fidelity Sizing Model for Superconducting Rotating Machines	Model for high-power superconducting machines for electrical generators and turbo-electric propulsion fans.	Started	AML, Boeing, Empirical Systems Aerospace	$0.9 M, 2011.6.13-2014	Wolsky 2012
DOE ARPA-E	SMES	Magnetic Energy Storage System	Storage using ultra high field HTS magnets, for storing intermittent wind and solar power, technology demonstration only in first phase	first wire delivered, coil trial begun	ABB (lead), Brookhaven Nat'l Lab, SuperPower	$4.2M, 2010.10.1-2013.9.30	Wolsky 2012, http://arpa-e.energy.gov/?q=arpa-e-projects /magnetic-energy-storage-system
DOE ARPA-E	Flywheel	Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS)	In-grid demonstration of flywheel energy storage system with advanced fiber technology and superconducting bearings	Design complete, assembly underway, June 2012	Boeing Research & Technology	$2.3 M, 2010.10.1-2013.9.30	Wolsky 2012, https://www.uaf.edu/files/acep/BoeingFlywheelOverview_06_20_2012.pdf

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Table II. U. S. Sponsored Wire Projects

Project Sponsor	Application	Title	Technical Targets	Status, Target	Members	Budget, Period	Source
DOE ARPA-E	Wire	Improved Superconducting Wire for Wind Generators	Higher current 2G HTS wire (RABiTS^{TM}-MOD process) with several fold reduction in cost and minimal rare earth, for direct drive wind generators	Started	BNL (lead), AMSC	$1.5 M, 2012.1.1-2013.12.31	http://arpa-e.energy.gov/?q=arpa-e-projects /improved-superconducting-wire-wind-generators
	Wire and Coils	Low-Cost Superconducting Wires for High Power Wind Generators	Engineer nanoscale defects in superconducting film: focus on IBAD-MOCVD REBaCuO films, quadruple current relative to today's wire [3000 A/12mm-width (30K, 2.5T), $36/kAm]	Started	UH(lead), SuperPower, TECO, Tai-Yang, NREL	$3.1 M (phase I, 80% funded), 2012.2.22-2014.12.31	http://arpa-e.energy.gov/?q=arpa-e-projects/low-cost-superconducting-wire-wind-generators
	Wire	Low-Cost High-Temperature Superconducting Wires	Novel wire process using fine superconducting MgB_2 particles in metal matrix	Announced 2012.12.19	Grid Logic	$3.8 M	http://arpa-e.energy.gov/?q=arpa-e-news-item/arpa-e-awards-130-million-66-transformational-energy-technology-projects
DOE BES	New Supercon-ductors and Wire	Center for Emergent Super-conductivity: an Energy Frontier Research Center	Finding new superconducting materials, understanding mechanism of HTS, controlling vortex matter to raise 2G HTS critical current	Ongoing	BNL (lead), ANL, UIUC, LANL, AMSC, SuperPower	$22M (phase I), 2009-2013	http://science.energy.gov/bes/efrc/centers/ces/; Wolsky 2012

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