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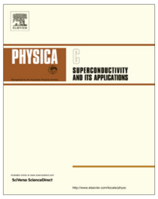

Does the electric power grid need a room temperature superconductor?

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A R T I C L E I N F O

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A B S T R A C T

Superconductivity can revolutionize electric power grids, for example with high power underground cables to open urban power bottlenecks and fault current limiters to solve growing fault currents problems. Technology based on high temperature superconductor (HTS) wire is beginning to meet these critical needs. Wire performance is continually improving. For example, American Superconductor has recently demonstrated long wires with up to 500 A/cm-width at 77 K, almost doubling its previous production performance. But refrigeration, even at 77 K, is a complication, driving interest in discovering room temperature superconductors (RTS). Unfortunately, short coherence lengths and accelerated flux creep will make RTS applications unlikely. Existing HTS technology, in fact, offers a good compromise of relatively high operating temperature but not so high as to incur coherence-length and flux-creep limitations. So – no, power grids do not need RTS; existing HTS wire is proving to be what grids really need.

1. Introduction

The power grids that supply global electricity needs are among the greatest technological achievements of mankind. However, as demand continues to grow, it is becoming increasingly difficult to meet the need by simply replicating existing technology, using conventional copper-based generators, transformers, power transmission and distribution links and switchgear. Particularly in large urban areas, which are increasingly the engines of worldwide economic activity, crowded underground infrastructure is making it more difficult to install additional conventional power cables for increased capacity, creating an urban “power bottleneck”. Furthermore, as urban grids expand, fault currents increase and now in some grids approach rated limits of existing power equipment. In these locations, an effective means of current limiting is urgently needed. Demand for renewable energy is also growing, but sources are often remote from major load centers; so more efficient long-distance power transport is needed. And environmental concerns are increasing, driving demands for more underground circuits and more efficient power equipment that does not use contaminating oil and other potentially noxious or flammable components.

Superconductivity offers solutions to these problems [1]. Lossless supercurrent flow enables high current density wires, which can be used to design and deploy much higher capacity superconductor cables in the same form factor. Lossless current flow also enables highly efficient long distance DC cables. Meanwhile, the rapid transition from zero to high resistance above a superconductor’s critical current opens up a new solution to the problem of limiting fault currents. Environmental concerns are addressed by the increased efficiency of superconductor power equipment and use of environmentally clean coolants like liquid nitrogen instead of oil.

However, the low operating temperature required by low-temperature metallic superconductors (LTS), with superconductor transition temperatures below 23 K has prevented their practical use in the power grid. High temperature superconductors (HTS), based on cuprate compositions such as $YBa_2Cu_3O_7$ (YBCO), with transition temperature above 90 K, have opened the door to practical superconductor power equipment operating in the liquid nitrogen temperature range. Significant progress has been made in developing and producing the wires needed for such power equipment, and also in developing and testing a new generation of such superconductor power equipment [1]. However, interest in further simplifying refrigeration requirements has driven an ongoing interest in finding room temperature superconductors (RTS), which many believe could spark an even greater revolution in electric power equipment.

While RTS at this point are purely hypothetical, existing theory does not rule them out [2]. And certain general properties of superconductivity enable predictions of some RTS material properties, if they were ever discovered. In this article, we explore the potential for RTS materials to have a revolutionary impact on the power grid when compared with existing, proven HTS materials.

2. Progress in HTS wires and applications

Superconductor wire based on HTS cuprates has matured in recent years, and several companies around the world now offer wire

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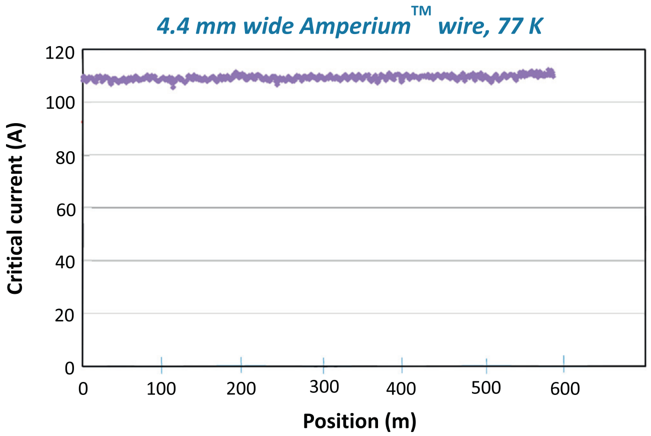

Fig. 1. Critical current (ave. 109 A) at 77 K, measured at 1 m gauge length of 1 m and 1 μV/cm electric field, over 587 m of tape-shaped second generation HTS wire 4.4 mm wide, based on YBCO superconductor (Courtesy of American Superconductor).

commercially [1]. At American Superconductor, for example, highly uniform long-length wire based on YBCO has been achieved in its now well-established production [3]. Fig. 1 shows the remarkably uniform current as a function of position in a 587 m long, 4.4 mm wide tape-shaped wire, with a performance of 272 A/cm-width in the HTS insert at 77 K. The inset in Fig. 2 shows a schematic wire cross section, with the "insert" consisting of a layer of YBCO (in dark[1] blue) deposited epitaxially on a textured Ni–W substrate (indicated in light blue), encased in solder and sandwiched between brass strips. This kind of wire is called second generation HTS wire, in contrast to a multifilamentary technology based on the bismuth-based HTS that are called first generation. Further enhancement of the American Superconductor process has recently enabled wires with up to 500 A/cm-width in the HTS insert at 77 K, as shown in Fig. 2. The solder fillets at the edges are very important in protecting the wire from a failure mode of delamination in the HTS layer, a problem that often arises when an unprotected wire is wound in an epoxy-impregnated coil and then cooled. Finally Fig. 3 shows a further recent advance in American Superconductor's wire technology: a wire with a fully non-magnetic substrate consisting of Ni–9W, as an alternative to the magnetic Ni–5W substrate used up to now in American Superconductor's wire production [3]. The advances shown in Figs. 2 and 3 are being prepared for regular production.

Second generation HTS wire has now been successfully used in a variety of significant demonstrations, such as a 400 m distribution-level cable fabricated by LS Cable of South Korea and installed in 2011 in the Icheon substation of the South Korean national utility KEPCO, [4] and a 66 kV single phase fault current limiter fabricated by Siemens, Nexans and American Superconductor, tested in 2011 at the PowerTech facility in Vancouver, Canada [5]. A cross section of the kind of HTS cable used in the Icheon installation is shown in Fig. 4, with three phases in one jacket and two layers HTS wires wound helically around a flexible former to form the phase conductor.

Such demonstrations, in addition to many others conducted around the world during the last decade, [1] are building a record of reliability and demonstrating the advantages of HTS power technology to a generally highly conservative utility industry. As the wire cost comes down with increasing production capacity and manufacturing experience, the interest in HTS technology to address the grid needs described above is growing, and widespread commercialization looks increasingly likely, in spite of the long gestation period that the technology has gone through since the initial discovery of YBCO in 1987.

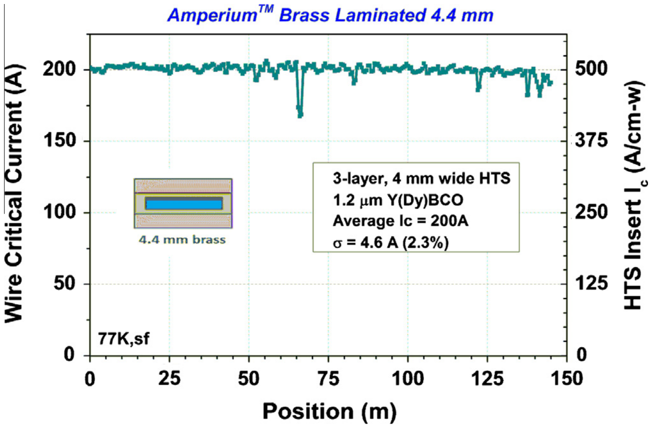

Fig. 2. Critical current at 77 K, measured vs. position at 1 m gauge length and 1 μV/cm, in recent American Superconductor HTS wire with thicker YBCO [3].

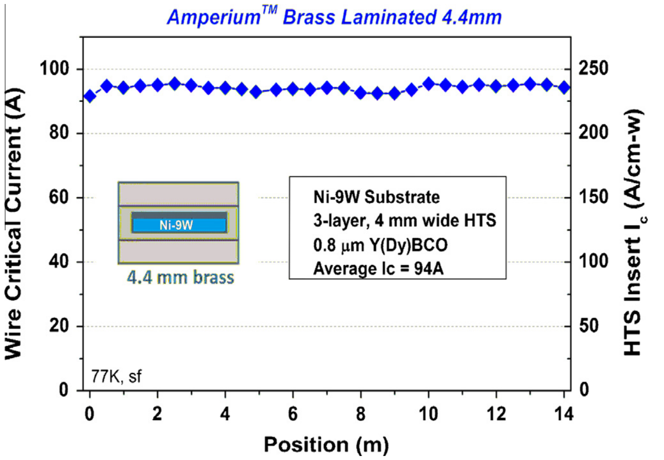

Fig. 3. Critical current at 77 K in an American Superconductor HTS wire based on non-magnetic Ni–9W substrate [3].

3. The refrigeration challenge and drive for a room temperature superconductor

These demonstrations of HTS power equipment generally use liquid nitrogen for cooling, although other applications such as motors and generators typically operate with conduction cooling and closed cycle refrigerators in the temperature range 30–40 K. Reliable refrigeration, even for the liquid nitrogen temperature range, adds cost and complexity to the overall power equipment system. So there is a natural interest in finding a room temperature superconductor (RTS) that would alleviate these concerns and dramatically facilitate the widespread use of superconductor electric power grid technology.

Of course, room temperature superconductors are today purely hypothetical [2], since the highest superconductor temperature attained under normal atmospheric pressure is only 135 K or −138 C. Nevertheless, the theory of superconductivity allows one to make certain predictions about the properties of such superconductors, were they ever to be discovered. And, unfortunately, those predic-

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[1] For interpretation of color in Fig. 2, the reader is referred to the web version of this article.