

RECENT DEVELOPMENT

SUPERCONDUCTIVITY: THE FUTURE OF POWER TRANSMISSION

I. ISSUE

About ten percent of all electric power generated is lost during transmission. Moreover, the limitations of the nation's present utility infrastructure have contributed to prolonged blackouts. However, high-temperature superconductor (HTS) wire may replace existing transmission equipment. This upgrade would increase energy supply and improve the infrastructure, creating a more efficient national power grid. Additionally, this technology would benefit the environmental and transportation sectors. Currently, HTS is an evolving technology with significant recent developments.

II. DESCRIPTION

Normally, electric transmission lines have resistive properties which consume energy as they deliver power.¹ However, in 1986 researchers discovered a ceramic compound that became resistance-free when exposed to temperatures near absolute zero.² Since then, other ceramic materials have been discovered that superconduct at 130 degrees above absolute zero.³ Exposing these materials to liquid nitrogen can cool the materials to this relatively high temperature.⁴ This technique theoretically makes superconductive wires commercially viable.⁵

1. Peter N. Spotts, *Superconductors ready to ramp up for the real world*, CHRISTIAN SCIENCE MONITOR, Dec. 23, 2004, available at <http://www.csmonitor.com/2004/1223/p13s01-stct.html>.

2. *Id.*

3. *Id.*

4. *Id.*

5. *Id.*

A partnership between the Department of Energy's Oak Ridge National Laboratory and American Superconductor (AMSC) is currently developing HTS wire. These superconductors are virtually resistance-free and therefore consume almost no energy.⁶ Additionally, superconducting wire can conduct substantially more current per area than its copper-based counterparts.⁷

Since 1986, AMSC has developed and put to market its first generation (1G) low-cost, high-performance HTS wire.⁸ The company is currently developing its second generation (2G) wire which has a thirty percent increased current capacity over the 1G wire.⁹ The 2G HTS wire performs roughly 200 times better than copper.¹⁰ AMSC's goal is to produce 2G wire at two-to-five times lower cost than 1G wire.¹¹

AMSC employs a relatively new wire architecture which layers 2G elements onto a flexible tape-shaped structure.¹² In commercial applications, this structure is typically 0.4 centimeters (or about 0.16 inches) in width.¹³ A nickel-tungsten alloy substrate lined with sulfur atoms forms the base of the wire.¹⁴ Next, this base is topped with buffer layers which increase the performance of the wire.¹⁵ AMSC then applies the superconducting material yttrium-barium-copper-oxide (YBCO).¹⁶ Finally, AMSC tops the wire with a noble metal layer.¹⁷ The key to 2G's high conductivity is the high interface texture levels between the substrate and the YBCO.¹⁸

AMSC uses a wet chemistry process called metal-organic

6. See generally HTS wire, at <http://www.amsuper.com/products/htsWire/index.cfm>.

7. *Id.*

8. ENERGY OPTIMIZATION NEWS, SIMPLE SUPERCONDUCTORS WITH ORNL METHOD (Aug. 2004) [hereinafter *Superconductors*].

9. Paul Grad, *Creating High-Temperature Superconducting Wire using Nanotech*, ENGINEERING WORLD, June/July 2004, at 39, available at <http://www.amsuper.com/newsEvents/documents/EngineeringWorld--NanotechtoCreate2GWireJune-July2004.pdf> [hereinafter *Nanotech*].

10. *Id.* at 40.

11. *Superconductors*, *supra* note 8.

12. *Nanotech*, *supra* note 9, at 40.

13. *Id.* at 41.

14. *Id.* at 39.

15. *Id.*

16. *Id.* at 40. The YBCO layer has a thickness of about one micron. *Id.* at 41.

17. *Id.* at 39. The term "noble metal" means any metal that is resistant to corrosion or oxidation. Hyperdictionary, available at www.hyperdictionary.com (last visited Feb. 26, 2006).

18. *Id.* at 41.

deposition (MOD) to produce 2G HTS wire.¹⁹ This methodology avoids using expensive vacuum processing.²⁰ Through the MOD method, AMSC hopes to mass-produce 2G HTS using a reel-to-reel system. This method is conceptually similar to an audiocassette where tape passes from one reel to another. Each step in the layering process happens while tape is transferring between reels.²¹ Bob Hawsey, manager of Oak Ridge's superconductivity program, says, "Imagine making electrical wire in the high-speed manner that movie film is produced and you get the idea of the potential of this approach."²² Using MOD technology, AMSC can manufacture large quantities of HTS at a low cost.²³

Commercial applications of superconducting material require 2G HTS to perform at an extremely high current capacity at liquid nitrogen temperatures.²⁴ AMSC has already outperformed the Department of Energy's (DOE) targeted performance milestone for 2G HTS wire.²⁵ This achievement demonstrates that AMSC will eventually produce commercially viable high performance 2G wire using a low-cost method. The AMSC-Oak Ridge team now looks forward to the next phase in 2G HTS development. This phase includes further increasing current capacity and producing longer reel-to-reel wires.²⁶

The Bush-Cheney National Energy Policy continues to stress the importance of increasing overall energy efficiency.²⁷ It defines energy efficiency as "the ability to use less energy to produce the same amount of . . . energy services."²⁸ Specifically, the policy states "we must use technology to reduce demand for energy, repair and maintain our energy infrastructure, and increase energy supply."²⁹ HTS can improve national transmission efficiency in two ways: first, by eliminating line losses and second, by increasing capacity. Jim Daley, team leader for the superconductivity program at the DOE, says "[h]igh temperature

19. *Superconductors*, *supra* note 8.

20. *Id.*

21. *Nanotech*, *supra* note 9, at 40.

22. *Superconductors*, *supra* note 8.

23. *Nanotech*, *supra* note 9, at 41.

24. ALEXIS P. MALOZEMOFF, SECOND GENERATION HTS WIRE: AN ASSESSMENT (Jul. 2004), available at http://www.amsuper.com/documents/2GWhitePaper-July04_002.pdf.

25. *Superconductors*, *supra* note 8.

26. *Id.*

27. NATIONAL ENERGY POLICY: REPORT OF THE NATIONAL ENERGY POLICY DEVELOPMENT GROUP (2001), at 4-1, available at <http://www.whitehouse.gov/energy/National-Energy-Policy.pdf> [hereinafter REPORT].

28. *Id.*

29. *Id.* at 1-1.

superconductivity is the most significant advancement in the field of large-scale electrical equipment in nearly 100 years—it has the potential to truly revolutionize the way the world uses electricity.”³⁰

Transmission grid losses result in the loss of more than ten percent of all power generated.³¹ However, the loss-free characteristic of superconductors allows transmission on HTS wires without consuming energy. Thus, replacing existing transmission lines with HTS will increase the total power available without building new generating plants.

The increased capacity of superconductors allows HTS wires to transmit as much as five times more power than conventional lines.³² The National Energy Policy states that “[o]ne of the greatest energy challenges facing America is the need to use 21st-century technology to improve America’s aging energy infrastructure.”³³ The electric power transmission system has inadequate capacity.³⁴ Transmission “bottlenecks” and increased demand have resulted in prolonged blackouts in recent years.³⁵ This situation has resulted in an increased need for rights-of-way across federal lands for new transmission lines.³⁶ However, new rights-of-way are restricted in the most energy-demanding parts of the country.³⁷ Additionally, powerful state and local entities block transmission expansion projects.³⁸ Replacing existing transmission lines with HTS can avoid these problems by eliminating bottlenecks without the need for new rights-of-way.

Inadequate transmission capacity was one of the causes of price spikes in recent years.³⁹ Additionally, transmission bottlenecks create “load pockets”⁴⁰, which prevent consumers

30. *Superconductors*, *supra* note 8.

31. Dep’t of Energy, *available at* http://electricity.doe.gov/program/electric_rd_supercon.cfm?section=program&level2=supercon (last visited Feb. 26, 2006).

32. *Id.*

33. REPORT, *supra* note 27, at 7-1.

34. *Id.*

35. *Id.* at 7-6.

36. *Id.* at 7-9.

37. *Id.*

38. *See generally* Richard J. Pierce, Jr., *Environmental Regulation, Energy, and Market Entry*, 15 DUKE ENVTL. L. & POL’Y F. 167 (2005) (analyzing the numerous difficulties in realizing a proposed transmission project).

39. *Id.*

40. A “load pocket” is a geographic area that, because of transmission limitations, must have internal generation resources available to ensure reliable service for the area. MARK REEDER, CONDUCT AND IMPACT THRESHOLDS, HOW SHOULD THEY VARY FROM ONE LOAD POCKET TO ANOTHER, *available at* http://www.nyiso.com/public/archive/webdocs/committees/AMP.ICM%20Task%20Force/2001-12-19/pjm_vs_nyiso.pdf.

from purchasing lower cost power.⁴¹ Regional entities estimate this situation costs consumers \$4.8 billion per year.⁴² Thus, implementing HTS transmission can save consumers billions of dollars by reducing congestion costs and local market power.⁴³

In theory, HTS technology can replace existing wiring in any electric device. AMSC has already developed prototype HTS motors, generators, and transformers.⁴⁴ HTS motors match the power output of a conventional counterpart with as little as one-third the size and weight.⁴⁵ Additionally, the motors and generators cost less to operate because of reduced resistive power losses.⁴⁶

The Bush-Cheney National Energy Policy promotes conservation and protection of the environment.⁴⁷ HTS wire's loss-free property effectively increases energy supply without consuming additional resources. Coal energy accounts for about half of U.S. power generation.⁴⁸ Legislative acts and state regulations have required coal-fired power plants to reduce certain types of emissions.⁴⁹ Because transmission line losses reduce to almost zero, implementing a national HTS power line infrastructure will allow coal-fired power plants to supply the same amount of energy while burning less coal. Therefore, an HTS system would protect the environment by reducing pollution.

The transportation sector is responsible for about one-fourth of the total U.S. energy consumption.⁵⁰ Technological advances in this sector play a key role in national energy efficiency.⁵¹ Despite recent technological advances, passenger vehicles continue to average low fuel economies.⁵² The popularity of sport utility vehicles, vans, and pickup trucks largely contributes to this problem.⁵³ The Bush-Cheney National Energy Policy suggests addressing this problem through increasing vehicle efficiency and

41. Pierce, *supra* note 38.

42. *Id.*

43. *Id.*

44. American Superconductor, *at* <http://www.amsuper.com/products/motorsGenerators/index.cfm> (last visited Feb. 26, 2006).

45. *Id.*

46. *Id.*

47. REPORT, *supra* note 27, at 1-1.

48. *Id.* at 1-6.

49. *Id.*

50. *Id.* at 4-9.

51. *Id.*

52. *Id.*

53. *Id.*

increasing transit choices.⁵⁴

The Superconducting Magnetic Levitating Train (maglev) may be part of the solution to increasing energy efficiency in the transit sector. Maglevs use superconducting magnetic coils on the train and guideway to levitate and propel the train.⁵⁵ The high current density of HTS wire makes it an ideal candidate for electromagnetic use.⁵⁶ Japanese maglev trains currently use low-temperature superconductors.⁵⁷ However, Central Japan Railway Company has used HTS in a prototype maglev electromagnetic coil.⁵⁸ This company announced that switching from low-to-high temperature superconducting electromagnets has significant advantages in operating costs.⁵⁹ Implementing HTS maglev trains on American soil could connect cities hundreds of miles apart as well as intra-city destinations. This mode of transportation could relieve congested highways and airports, reducing pollution and conserving energy.

As AMSC optimizes its first-generation HTS production, prices will continue to drop.⁶⁰ However, in normal commercial applications today, the price of copper for equivalent performance is still considerably less expensive.⁶¹ Despite these additional costs, AMSC says the price of 2G wire has the possibility of dropping below the copper level.⁶² In such a case, HTS technology would probably begin to dominate most electrical applications.

III. ASSESSMENT

HTS is a technology, which if implemented, would have uniquely positive effects. Currently, costs are the limiting factor preventing the United States from implementing HTS more widely. If the United States replaced bottleneck sections of the transmission grid with HTS, it could begin to alleviate the inadequate transmission capacity of our infrastructure. After that, the possible applications of this technology seem endless.

54. *Id.*

55. American Superconductor Supply Materials for Japanese Prototype Maglev Train, AtoZofMaterials, May 11, 2004, available at <http://www.amsuper.com/newsEvents/documents/AtoZofMaterials--CJR5-11-2004.pdf>.

56. *Id.*

57. *Id.*

58. *Id.*

59. *Id.*

60. *Nanotech*, *supra* note 9, at 41.

61. *Id.*

62. *Id.*

2006]

SUPERCONDUCTIVITY

257

IV. CONCLUSION

High-temperature superconducting could be the solution to several American energy problems. Replacing the current electric power infrastructure with HTS would result in a cost-effective, energy-efficient, higher capacity transmission system. Additionally, implementing HTS in electric machinery and the transportation sector could lower costs to consumers and reduce pollution. Hopefully, with continued research and development, ubiquitous use of HTS will become a reality.

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