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FOUNDATIONS

for

SUPERCONDUCTIVITY

ANALYSIS

Prepared By

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Introduction and Purpose:

The accurate prediction of future events relies on consistent analysis, using applicable methodology, based on a series of facts and credible assumptions from which the calculations proceed. Numerous firms and organizations are now involved with performing a variety of Superconductivity analyses, and it is felt by the author that few of these efforts begin with the same set of facts and assumptions. Although differences in approach and methodology can lead to healthy and useful debate, differences in beginning assumptions brings the level of debate back to a point prior to the analysis, and this is less than helpful.

Over the past six years, Bob Lawrence & Associates, Inc. has been working under contract to the Oak Ridge National Laboratory (ORNL) to track the projected markets for products which are envisioned to evolve based on superconducting technologies. Concurrent with this effort has been an ongoing analysis of the eventual benefits which will result from commercialization of superconducting technologies. This effort has produced a wealth of knowledge which is continuously drawn upon for requested analyses. The information is based on over 50 references, utility surveys, ongoing tracking of trade publications, and continuing input from Superconductivity Partnership Initiative participants. In addition, the database of facts and assumptions has been thoroughly scrutinized by electric industry experts at the Oak Ridge National Laboratory.

Since the publication of the Products and Benefits 2000 report, our firm has carried out additional analysis by looking at other market parameters of interest. To do this analysis, further research was accomplished to develop an even greater array of facts and assumptions than was previously published in the Products and Benefits 2000 report.

The purpose of this present report is to assemble all of the Facts and Assumptions that our firm has developed, to date, and to present them in a way which allows the most consistent analysis possible of this very important, evolving technology. Furthermore, we welcome all comments or questions regarding this material.

Electric Industry Market Growth:

In prior reports, BL&A has projected, for the next 20 years, an average annual growth in demand and generation of 2.5%, based on historical numbers. This has been the average annual growth rate in generation since 1986. From 1986 until the present time, electric generation has had average increases of 2.5% per year. Inexplicably, during the mid and late 1990's, the EIA steadfastly predicted average future growth of 1.4% per year, a difference of 44% less than the historical average. Since 1995, Bob Lawrence & Associates, Inc. (BL&A) has been predicting annual growth of 2.5%, based on historical precedent and other factors. In projecting future growth, BL&A ascribes to the following rationale:

a) There is no reason to believe that economic growth over the next 20 years will be a different average than the past 15 years (since 1986);

b) The effects of user efficiency increases vs. needed generation increases over the past 15 years have set a pattern which shouldn't differ greatly between now and 2020;

c) The economic growth which is occurring is largely based on electricity-using computers and manufactured items which incorporate electricity-using computers;

d) The pace of technology improvements in computer based and computer related technologies is such that a pattern of expansion of computer integrated technologies, electricity using, is seen in more and more aspects of human life;

e) Electric utility restructuring is leading to greater I^2R electrical efficiency losses in the grid as more amperage is being put through longer portions of the grid. Long distance wheeling will exacerbate this problem.

For these reasons, BL&A believes that it is realistic and intellectually correct to continue with the projection of an average 2.5% annual generation growth for the next 20 years. However, present experience, based on market disruptions and the negative effects of deregulation, now leads our company to project a more conservative average of 2.2%, which is still above the consistently low EIA projection of 1.8-2.0%. In Table 1 is a projection of Electrical Industry Capability, Net Generation, and Total End Use from 1999 (hard data) through 2020.

<u>Dates of Market Entry and 50% Capture</u>:

The earliest equipment to achieve commercialization is predicted to be fault current limiters, predicted for market entry in the 2003-2004 time period; however, the first market entry will probably happen in Japan or Europe before the United States. Transformers and cable are projected for entry in 2005 followed by electric motors in 2006. The final market entry will be by generators, predicted for commercialization in 2011.

A key point in the analysis is the point at which the equipment will capture 50% of the potential market. The results predicted are found in Table 2.

Table 1: Net Generation, Total End Use, and Projected Capability Figures for the Years 1999 Through 2020. Baseline 1999 Data From EIA Report. Based on Ten Year's Data and Projections, 2.2% Escalator Employed.

Year	Net Generation (BKwhr)	Total End Use (BKwhr)	Capability (MW)
1999	3,691	3,312	785,990
2000	3,772	3,385	803,282
2001	3,855	3,459	820,954
2002	3,940	3,535	839,015
2003	4,027	3,613	857,473
2004	4,115	3,693	876,338
2005	4,206	3,774	895,617
2006	4,298	3,857	915,321
2007	4,393	3,942	935,458
2008	4,490	4,029	956,038
2009	4,588	4,117	977,071
2010	4,689	4,208	998,566
2011	4,792	4,300	1,020,535
2012	4,898	4,395	1,042,986
2013	5,006	4,492	1,065,932
2014	5,116	4,590	1,089,383
2015	5,228	4,691	1,113,349
2016	5,343	4,795	1,137,843
2017	5,461	4,900	1,162,875
2018	5,581	5,008	1,188,459
2019	5,704	5,118	1,214,605
2020	5,829	5,231	1,241,326

Table 2: Year of 50% market penetration.

Equipment:	Motors	Transformers	Generators	Underground cable
This year sales: 50% of Market	2016	2015	2021	2013

General Facts and Assumptions:

The following list of Facts and Assumptions is taken from the Products and Benefits 2000 report:

1. Assumption: (Cases 1 and 2) EIA projects an average 0.9% drop in electric price, per year from 1998 through 2020.
2. Assumption: HTS-based transformers, cables, motors, generators, and fault

current limiters will all enter the marketplace with first commercial items in the next 5-10 year time period. This is the projected time period by virtually all authors of articles reviewed for this report. The question then becomes what is the relative shape of the S-curve adoption period of the technology; i.e., how fast does the technology penetrate?

3. Fact: Total electricity delivered to ultimate customers is total generation less 10.6% lost in the transmission and distribution process. Recent data indicates that the grid may be becoming less efficient. Recent figures show a difference of 10.13% in 1997 and 11.05% in 1998.

4. Fact: In 1997, total sales of electricity to ultimate customers was 3,140 billion kWh. In 1998, this rose to 3,240 BkWh and 3312 BkWh in 1999. Total sales revenue was $215 billion in 1997 and $218 billion in 1998, and dropped back to $215 billion in 1999. Amount generated in 1998 was 3,620 billion kWh, which at an average value of 6.75 cents per kWh had a retail value of $244 billion.

5. Fact: Nonutility generation capacity was 12.6% the size of utility generation capacity at the end of 1998. This amounted to 98,085 MW counting only the total installed capacity of nonutility power producers with an installed capacity of 1 MW or more.

6. Fact: Total installed "capability" (slightly different from capacity) in 1998 was 686,692 utility MW plus 98,085 nonutility MW for a total of 784,777 MW. In 1999, nonutility capacity rose to 167,357 MW.

7. Assumption: From 1999 through 2020, net generation will average annual increases of 2.2% .

8. Fact: From 1992 through 1998, annual increases in generating capacity averaged 0.5%. Clearly, capacity increases are not matching needed generation increases. Therefore, it is assumed that, added capacity will average 2.5% per year in the time period of introduction of HTS devices.

9. Fact: On a 1-to-1 substitution basis, HTS devices will save ½ of the present energy losses in cables, electric motors, generators, and transformers. Comparing same cross sections of the engineered applications of HTS material to copper or aluminum materials indicates that in the HTS application the material can carry up to 100 times more current at virtually no resistance in the same cross section. However, HTS devices, of necessity, have only about 10% HTS material in the engineered cross section and require refrigeration (a parasitic loss). The calculated result generally falls into the range of 50% for savings of presently lost (wasted) energy.

10. Fact: All generated electricity goes through nominally 4 stages of transformers between the generator and the final point of use. For each 1 MVA of generating

capacity, there are 3 to 4 MVA of transformer in place. For the purpose of analysis, an even 3 transformers is used as the assumption. When loading levels on the transformers are considered, about 50% of all transformer MVA is found in the transmission system, and 50% in the distribution system.

11. Assumption: One-half of all U.S. power transformer sales will be in the class of 30 MVA, 138-kV/13.8-kV transformer rating for the next two decades.

12. Fact: Power transformers are 99.3 to 99.7% efficient for the 30 MVA, 138-kV/13.8-kV class. However, they are purchased with excess capacity to meet maximum power and temperature limits. Therefore, they operate well below design level for the majority of the operating period and typical evaluation programs force the design to produce the maximum efficiency at or near the expected average loading point. Indeed the full load efficiency is generally well below maximum efficiency. Power transformers are responsible for 25% of all transmission/distribution losses, or $2 billion annually.

13. Assumption: HTS underground cable savings can reach 125,000 kWh per mile per year, or based on 6.89 cents per kWh, a monetary savings of $8612.5 per mile per year. This is equivalent to saving ½ the presently lost power in underground cables.

14. Fact: 64% of all electrical power passes through electric motors, with ½ of this passing through large motors.

15. Fact: Today's electric motor efficiency numbers are estimated to be 96% for General Electric's best to 92% for the average installed large motor. Reliance Electric estimates that today's “average practice” motor (100 hp and up) is 95.9% efficient, compared to their estimate of 98.1% efficiency for an HTS motor equivalent. Therefore, it is assumed that any substitution of an HTS motor for a presently in-place motor would achieve a savings of 50% of presently wasted energy, considering the necessary cryogenic cooling inherent in the system.

16. Assumption: Generator losses are, similarly, expected to be cut by 50% when present systems are replaced by HTS technology systems.

17. Fact: Operating large electric motors (early HTS candidates) use 30% of all electricity generated in the U.S. This is the equivalent of $65.4 billion in retail sales of 1998 generated electricity delivered at the point of end use. According to a Reliance Electric study, the large industrial electric motor market is $300 million per year.

18. Fact: GE produces 10-20 generator replacement rotors per year and 120-150 generators per year in sizes 25-1650 MVA. GE assumes that HTS near-term potential is (worldwide) 100 units per year plus unit upgrades, and 30-40 rotors per year.

19. Assumption: The annual growth rate in the cable market for HTS cable will be 3.4% per year.

20. Assumption: A cable demonstration project of at least 3-5 years will be required to achieve market acceptance.

21. Assumption: HTS cable with life-cycle costs equal to conventional cable and with twice the ampacity would capture 56% of the underground transmission market 10 years after the first commercial sale.

22. Fact: In 1995, there were 3580 miles of underground transmission cable in the U.S. The market in that year for U.S. sales was 158 miles of which 18 miles were replacement sales and 140 miles were new installations.

23. Fact: In any given year, 12% of the total population of all motors in the 5-500-hp class fail. Of these, ½ are rewound and ½ are replaced. The replacement rate on large (>1000 hp) motors is uncertain but, for the purpose of this analysis, the same failure/rewind/replacement rates are assumed since no better assumptions seem to be available.

Kiloamp-Meter Requirements by Product:

Our thanks goes out to the program managers within the Superconductivity Partnership Initiative (SPI) who donated their time and effort to provide us with the following information regarding required kilo-amp meters of superconducting wire per product described:

Electric Motors: To reach numbers for the coated conductor (tape) requirements for electric motors, David Driscoll of Rockwell Automation was contacted. Mr. Driscoll is the program manager for Rockwell's HTS motor development program. Examining present HTS motor designs, a 5000 horsepower motor will utilize 5000kA-meters of tape. Similarly, a 1000hp motor will utilize 1000kA-m of tape. It is noted that tape requirements scale relatively linearly with horsepower.

Transformers: Sam Mehta and Mike Walker at Waukesha Electric Systems report that a 100MVA transformer, under present design, would require 10,000 kA-m of tape, and this requirement is linearly scalable within the power levels of interest.

Generators: HTS coated conductor tape requirements for generators are assumed to have the same kA-m per megawatt ratio as electric motors.

Cable: For the purpose of this study, both Southwire and Pirelli were contacted (R. L. Hughey and David Lindsey at Southwire, Nathan Kelley at Pirelli), and four cable geometries/specifications were examined. They were:

Southwire:
1680A, 3 phase cable (requires 12.6km of wire at Ic=30A per 100ft of cable)
3120A, 3 phase cable (requires 23.1km of wire at Ic=30A per 100 ft of cable)

Pirelli:
Pirelli warm dielectric (retrofit) cable at 2000A, 3 phase: 450kA-m per 100ft
Pirelli cold dielectric, coaxial cable at 2600A, 3 phase: 900kA-m per 100ft

Fault Current Limiters: Conversations with Eddie Leung, formerly of General Atomics, indicate that a 15kV, 45kA (asymmetric) FCL (rated 17kV, 45kA, or 765MVA) requires 1000 kA-m of tape (or wire) for each phase, or 3000 kA-m for each machine. This is virtually the same as the requirement for a 30MVA transformer.

Wire Pricing per Kiloamp-Meter:

There is a continuing conversation regarding the required market entry price of HTS wire in order to assure competitive product pricing. The projected, needed wire cost ranges, in various conversations and discussions, from $10 per KA-m up to $300 per KA-m.. In conversations with present cable and wire manufacturers, the comparable price of copper wire, today, is $23 per KA-m.

Conclusion:

As electric utility superconducting products become closer and closer to a market reality, it becomes more and more important that analysis be carried out consistently, with underlying data and assumptions which are as accurate as possible. It is the intent of this report to provide as much of that underlying data as possible from research and analyses which have been carried out over the past six years. All comments and discussions regarding this information are welcomed, and updated data will be greatly appreciated.