Superconducting Cables-Some Research Problems*

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1. Introduction

If a superconducting transmission system is ever to find practical application it must be shown to have technical and economic advantages over other methods. Despite the fact that development in this area first started about a decade ago there are a large number of problems, particularly of a practical nature, that have yet to be attacked. Clearly a technical solution must come before a realistic economic assessment can be made, however, based on judgment, a direction for a technical solution can be adopted which it is hoped will lead to satisfactory operation at the lowest cost. Sometimes the choice is not so clear, for example, proposals have been for both rigid¹ and flexible² superconducting systems. Here savings in manufacturing costs are offset against higher installation cost and until more is known about these factors it would appear to be wise, at the national level, to pursue parallel paths.

Important characteristics of transmission networks are already fixed and superconducting cables must be adapted to comply with them. However, the cost of a superconducting cable will be markedly affected by conditions during faults. In any economic optimization of the system it will be necessary to evaluate the design of protective devices and, probably, modify them. In general the load impedance on circuits built with superconducting cables will be lower than that associated with conventional cables. Hence

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it is clear that the voltage-current ratings for other components, such as breakers, will be affected by the decision to incorporate superconducting cables into a transmission system. For illustration the tentative ratings of superconducting transmission systems are shown in Table I. It is quite likely that power ratings at a particular voltage will be doubled or tripled by using two or three cables per phase.

Before describing some problem areas it is worthwhile to list the already apparent advantages of superconducting systems:

- i) The power density is very high, leading to small trenches and lower installation cost, see Table I.
- ii) For similar SIL ratings the system voltage is about one-fifth that of overhead lines. This leads to compact substation design for urban and suburban locations.
- iii) On a weight for weight basis, superconducting cables will carry at least twenty times as much power as a copper/paper cable with the same voltage rating. This means that properly designed flexible cables will be capable of being pulled in long pieces.
- iv) The thermal time constant of a superconducting system will be many hours, thus large diurnal variations of power can be tolerated provided the average dissipation does not exceed the refrigerator capacity.
- v) The system can be designed to operate above or below SIL, thus eliminating the need for reactive compensation and greatly extending the distance over which the cable can be incorporated into a transmission network.

2. Mechanical and Cryogenic Engineering

Helium is the only coolant suitable for superconductors now available. It is a gas with nonlinear properties in the temperature-pressure region of

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interest. For example, large changes in specific heat and Joule-Thomson coefficient occur for small changes in temperature. The design of very long transport systems will thus require further investigation of the fundamental properties of helium. In addition, the mechanism of heat transfer during transient fault conditions is virtually unknown. An experimental program will be needed to determine transient heat transfer coefficients as a knowledge of temperature rise during fault conditions is essential to determine system performance and has an important bearing on the cost of the cable.

The main requirements for the Dewar, or cryostat, are low cost with acceptable heat influx and ease of installation. The main choices are a rigid design, possibly with prepumped vacuum insulation, or a flexible Dewar which can be transported to the site in long pieces. A flexible Dewar would almost certainly require a continuously pumped vacuum. A flexible Dewar designed for power transmission cable application is now commercially available in Europe.*

If niobium is chosen as the superconductor the rather low T_c of this material dictates a cryogenic system with a helium circulating pump. Only a few quite small pumps have been built so far and some development will be necessary. Cables operating above 6.2 K will not require a circulating pump provided the mass flow rate can be adjusted for relatively large differential temperatures in the cable, say 2 K (Ref. 3). It seems likely that the high reliability of screw-type compressors will make them attractive for utility service.

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3. Cable Design

The appropriate superconductor for power transmission applications is still the subject of debate.⁴ Niobium has the advantage of low hysteretic loss and ductility. On the other hand the choice produces a rather inefficient refrigerator design and niobium will not carry faults as super-current. Niobium-tin can operate at a higher temperature, but the losses are rather high and research is in hand to reduce loss and improve the physical properties. Niobium-tin has a high critical current and should permit cables to be designed without losing transmission capability following a fault.

Either type of superconductor may be used in rigid or flexible cable designs. Flexible cables will require a lapped-plastic tape insulation whereas rigid cables will probably use helium, which then serves the dual function of dielectric and coolant. The prognosis for successful operation of plastic tape at operating temperatures of a few degrees above absolute zero appears good.⁵ However, studies of breakdown have shown disparate results.⁶ For example, French work on helium breakdown has produced very low values of breakdown for gaps relevant to cable designs. The design of spacers for use in rigid cables is likely to be difficult. The constraints on plastic for flexible cables are also severe. Not only must the plastic possess the properties associated with "bendability" at room temperature but contraction at the operating temperature must not cause cracking.

Splices in a lapped plastic tape are not likely to pose a severe design problem. Some splices must also be combined with helium transfer joints, at places where the splice is located at the end of a coolant section. In

this case warm helium must be withdrawn from the high-potential center conductor and cold helium reintroduced.

Pothead design for superconducting cables is complicated by the dielectric properties of helium; as the temperature rises the density decreases and the breakdown potential is reduced. In general terms the pothead must accomplish the following:

i) Introduce a temperature gradient from about 6 to 300 K.

ii) Introduce a pressure gradient from the normal coolant pressure of 5 to 10 atmospheres to ambient. In addition the room temperature bushing may contain oil or gas under pressure.

iii) Modify the electric field present in the coaxial cable at the cold end so that a smooth transition is made to an unshielded bushing at the warm end. A connection must be provided for zero sequence currents.

It is likely that potheads will be cooled separately. A method of transferring helium from the high potential bushing to the grounded refrigerator must be devised.

4. Conclusion

Many aspects of a superconducting system are influenced by the transmission network into which it is to be incorporated and vice versa. These "external" problems must be solved by mutual accommodations between cable and network designers. Solutions to external problems will become increasingly important as cables come closer to practical realization in field trials of increasing length and power capacity. In the early stages workers will be concerned with the solutions for "internal" problems, such as good dielectric design, differential contraction, and refrigeration design problems which are least affected by external considerations. Several research efforts are underway in Europe, Russia, Japan, and the U.S.A. which should

produce solutions for most of the internal problems in three or four years. If these solutions are attractive further progress will only be made with the increasing cooperation of the utilities.

TABLE I

Some Tentative Ratings for Superconducting Systems

<u>System Voltage</u> <u>kV</u>	<u>Single Circuit</u> <u>SIL Power</u> <u>MVA</u>	<u>Cable diam</u> <u>cm</u>	<u>Cryostat</u> <u>Overall diam</u> <u>cm</u>
69	221	2.6	20
138	881	4.9	30
230	2450	8.0	35

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