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A FEASIBILITY STUDY ON A SUPERCONDUCTING POWER TRANSFORMER

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ABSTRACT

The promising applications of AC superconductivity. Studies on the applications in electrical power apparatuses are being carried out, in which superconducting power transformers are expected to be one of the most important applications in electric power systems. In this paper, we present a feasibility study on a superconducting transformer. Superconducting transformers are superconducting transformers (SCT) can be one of the most compared with conventional transformers in terms of economics. Analysis of the 1000 MVA superconducting transformer shows that the efficiency should be 99,86 %. Based upon a cost of energy 2000 $/kW, our analysis shows a 30 % improvement in the transformer life-cycle costs when superconductivity is used.

1. INTRODUCTION

Nowadays studies on electric power systems have been going on. In these studies, superconducting power transformers are considered to be the most important application area. Superconductors have two properties that beaf the potential for significant improvements in the generation, transmission and use of electric power: A very high current carrying capacity at almost vanishing losses and a resistivity that increases steeply in the transtion from the superconducting to the normal-conducting state. In materials available today, these properties can be technicallly utilised at temperatures below approximately 100 K (- 173 °C). However few studies have been done on superconducting transformer.

2. CONDITIONS FOR DESIGN OF SUPERCONDUCTING TRANSFORMER

Conditions considered in designing an SCT as follows. The transformer is a three-phase unit of core,form configuration, 500/22 kV, 1000 MVA.

A. Conductor

The rectangular copper conductor will be replaced by superconductors. These will consists of superconducting material (Nb, NbTi, or Nb_3Sn) in conjuction with a stabilizer (copper/aluminum/bronze) supported possibly on a steel substarate. The conductor cross section may be tape-like, rectangular or circular, and possibly hollow. The conventional technology relied heavily on conductor configuration and shape, to control electric field stress, and to distribute and support the short-circuit mechanical stresses.

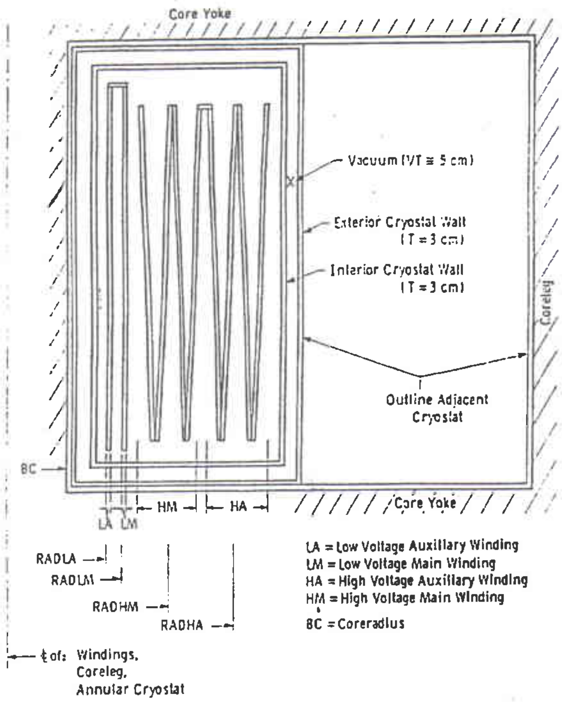

Fig. 1. Conceptual model of superconducting transformer (core-form-three phase)

B. Conductor Model

The choise of conductor model was guided by the following considerations:

a) To forestall major increases in transformer manufacturing cost, extremely complex shapes requiring great shaping accuracy and complex assemblies should be avoided.

b) To avoid flux concentrations and simultaneous induction of high density shielding currents in diamagnetic materials, the design should allow flux to penetrate the windings and conductor, particulary near the winding extremities.

c) Hysteresis losses in the superconductor will be unavoidable but can be minimized. The design should also minimize eddy current losses, to permit higher flux density operation in the leakage flux volume.

C. Current Limiting

Current limiting potential derives from the nonlinear properties of superconductors in that they may exist in two states-superconducting and normal. The transition from the low impedance superconducting state to the high impedance normal state can be controlled to occur during predetermined current overload conditions, at which time the current switches to auxiliary windings with a higher percent impedance that the normal load winding , limiting the overload current. The ability to limit short circuit has a pronounced beneficial effect on transformer structural requirements, circuit breaker requirement, generator design,and possibly other equipment.

D. Insulation

An epoxy/plastic-helium insulation system must be developed similar to the presently used paper-oil system. The development of the paper/oil system for the conventional transformer, over many years and still going on, must be repeated and duplicated for the helium/epoxy-plastics system. The difficulties and efforts required to achieve the objectives should not be minimized or underestimated.

E. Bushing

The bushings must also provide the thermal transition between ambient outside the transformer tank and the superconducting temperatures of the windings. Experience with terminations into cryogenic vessels has been gained in conjuction with superconducting cable programs. It is quite likely that the bushing, in addition to a thermal transition, must also provide a pressure transition.

F. Containment

The windings must be maintained at liquid helium temperatures. This requires a vacuum jacketed annular containment vessel (helium cryostat). The iron core must remain at ambient temperature. The cryostat must be constructed of nonconducting material to avoid the effect of a shorted secondary turn. The most acceptable state of helium from the viewpoint of reliable insulation strength,appears to be the supercritical state requiring pressures on the order of 6 atmospheres. The cryogenic vessel therefore must also be a pressure vessel meeting rigid safety and strength requirements. The possibility of using the electrically insulating dewar walls, together with the thermallly-insulating vacuum jackets, as integral elements of the high-voltage insulation must be explored.

3. FEASIBILITY STUDY

From the feasibility study of the SCT, the total loss of the SCT is about 20-25 % of that of a conventional transformer. SCT can be installed to power system with less problems as a receiving end transformer.
The structure of transformers is relatively simple, and their installation environment can be arranged properly. The SCT can be one of the most promising applications of AC superconductivity. However, for the realization of the SCT, further technical studies on following problems should be carried out.

- Reduction of AC Loss

At present,The best record for the AC loss is 5x 10^4 watt/m^3 at 1 T. Reduction of this value will bring the direct effect on the refrigeration power requirement.

- Development of Heavy Current Wire

It is essential to develop a heavy current wire with an operating current from several hundreds to several thousands amperes. Some technical improvements would be necessary to keep the coupling loss small in spite of the increase of the wire thickness.

- Stabilization of Wire

The AC superconducting wires developed so far have current carrying capacity of the order of 1000 A. The effective cooling surface per loss has to be made large enough. However, the cooling requirement will increase more and more with the increase of wire thickness for practical applications. The establishment of the cooling technology would be necessary.

- Design Endurable for Electromagnetic Force

When the superconducting wire is used in electric machines and devices, we have to into consideration the sustaining vibration in a normal operation and the huge electromagnetic force in a fault condition. Some mechanical reinforcement which does not increase the eddy current loss is necessary.

- Introduction of High Voltage Technology

The high voltage up to 1000 kV is needed for UHV transformers. The insulation problems at liquid helium temperature and those of supercritical helium have to be studied.

4. CRITERIA FOR COMPARISON

Table 1 contains a listing of the elements of cost for both types of transformer that have been evaluated.

Table 1. Costs Elements of Economic Feasibility Study

	Applicability Conventional	Superconducting
1. Initial Costs ($/ kVA)		
Materials		
Copper	x	-
Iron	x	x
Superconductor	-	x
Insulation	x	x
Oil	x	
Auxiliary Equipment		
Cryostat	-	x
Plants		
a. Refrigeration Plant	-	x
Remove Cold End: - AC Losses - Dewar Losses - Dielectric Losses - Lead Losses		
b. Generation Plant	x	x
Supply: Iron Losses Copper Stray Losses Refr. Plant Input Power		
2. Operating Costs ($ / kVA)		
Present Worth of Costs to Operate Generation Plant:		
To Supply Refrigeration Plant	-	x
To Supply Core losses (+Stray)	x	x
To Supply Copper Losses	x	-
Life Cycle Cost	Total	Total

A listing of the relative values of the various cost elements for a 1000 MVA transformer is shown on Table 2. A number of points should be noted. Material costs are a small fraction of the total. Thus future cost variations of the superconducting material will not significantly affect the comparison. Also the refrigeration plant costs are not large, about 30 % of the savings. It is therefore possible to consider improving system reliability by redundancy in the refrigeration plant, while maintaining significant cost benefits. The bulk of the costs and therefore of the difference between the two transformers, is associated with the losses through the energy related costs.

Table 2.Relative Cost Comparison

Superconducting and Conventional Transformer

(1000 MVA = 12 % Impedance)

	Parameter Values	Base Reference
Superconducting Wire	$/kg	68.038
Energy	$/kwhr	0.02
Generation	$/kW	800
Discount Rate	%	10.0
Rating	(MVA)	1000

Relative Cost
(% of Total Conventional)

	Superconducting	Conventional
Conventional Materials	3.0	5.7
S.conducting Material	4.1	-
Refrigeration Plant	14.7	-
Cost of Losses	48.4	94.8
Total Life Cycle Cost	**70.2**	**100.0**

5. CONCLUSIONS

Superconducting transformers are compared with conventional transformers in terms of economics. Superconducting transformers above certain ratings are economically feasible because their life-cycle cost is less than for conventional transformers. This advantage derives from increased efficiency. This conductor design and winding configuration result in an efficiency of the superconducting transformer of 99.86 %. The major advantage of the SCT is reduced size and weight. Based upon a cost of energy of 2000 $/kW our analysis shows a 30 % improvement in the transformer life-cycle costs when superconductivity is used. Superconducting transformers are preferably used in locations with high loading of the network. More compact and lightweight components of SCT simplify transportation..

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