ONTARIO HYDRO
RESEARCH DIVISION REPORT

To Mr. F.J. Simpson
Director of Research

NEUTRALIZING TRANSFORMERS

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Suggested modification of specifications is seen as one way of reducing the high cost of neutralizing transformers. This move could also encourage other manufacturers to enter this field. A sample design for a neutralizing transformer meeting a modified specification is presented.

INTRODUCTION

Ontario Hydro is one of the larger Canadian users of neutralizing transformers. Due to the high cost of this equipment, a study to determine the cause of the high cost was initiated. As a consequence, presented in this report are suggestions on modifications of Ontario Hydro specifications for neutralizing transformers which are designed to improve the performance yet reduce the cost of the product. A sample design of a neutralizing transformer that is expected to meet the modified specifications is also presented.

THE SPECIFICATION

The present specification (C-4087-77) appears to be written around a commercially available product. This makes it difficult for other manufacturers to enter and compete in this field. It is reasoned that the specification should specify only the performance and not the design of this equipment.

It has been known for some time that the performance of neutralizing transformers is greatly affected by the transient component of the ground potential rise. The specification should therefore recognize and specify this.

The suggested modifications to the specifications include:

(1) Remove the requirement for the transformer to be oil filled. For the voltage involved here, oil filling is not necessary and the manufacturer can be left to decide on the insulation system.

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(2) Remove the requirement for using No 22 AWG telephone-type cable for the secondary winding. This constrains the design of the manufacturer. The designer may wish to use a different gauge of wire to obtain certain desirable characteristics from his transformer.

(3) Increase the flux capability of the transformer. The presently specified value of 3.75 V·s/kV is adequate only under steady state conditions. This value should be increased at least by a factor of two to improve the transient performance of the transformer.

(4) Specify residual flux. The specification should call for the residual flux to be less than 10% of saturation flux. Values higher than this have a detrimental effect on the performance of the transformer under transient ground potential rise conditions.

(5) Remove the requirement of withstanding 150% of rated voltage continuously. This requirement needlessly increases the voltage rating of the transformer. Since the transformer is seldom if ever subjected to rated voltage in service, the above requirement is questionable. Increasing the flux capability of the transformer appears to be sufficient.

(6) Reduce the requirement for the dielectric test voltage between the primary and the secondary windings. Since the function of the neutralizing transformer is to maintain only a small voltage difference between the primary and the secondaries, the test voltage requirement could be easily reduced to rated voltage plus 1 kV, from the present value of 2 times rated voltage plus 1 kV.

NEUTRALIZING TRANSFORMER DESIGN

Outlined below is a design for a 25 pair, 4.5-kV neutralizing transformer. Modified specifications are assumed including 7.5 V·s/kV flux capability as well as 10% residual flux.

Winding Considerations

To meet the transmission requirements of neutralizing transformers, the use of multipair telephone cable for the secondary winding is indicated. In addition to the non-shielded cables, these cables are also available with ALPETH or PAP sheathing. In addition to providing shielding, the aluminum sheath can serve as the primary conductor for the transformer.

The PAP sheathed cable appears to be especially well suited for this application since it features a dc dielectric strength of 20 kV between the cable conductors and the sheath. Other important characteristics for this cable are:

a) Dielectric strength between conductors:

19 AWG	-	10 kV (dc)
12 AWG	-	8 kV
24 AWG	-	5 kV

b) Sheath resistance:

19 AWG, 25 pair	3.3 Ω/km
22 AWG, 25 pair	4.6 Ω/km
24 AWG, 25 pair	4.6 Ω/km

c) Outer diameter:

19 AWG, 25 pair	21 mm
22 AWG, 25 pair	16 mm
24 AWG, 25 pair	14 mm

d) Bending diameter: 12 times cable diameter.

Core Considerations

A core using standard grain-oriented electrical-grade silicon steel (M5 or M6)* laminations is indicated. Since there is a requirement for low remanence, the core should be stacked into an E-I configuration. A spacer of proper thickness can be inserted between the E and I sections on assembly to provide the required remanence control.

Design

It is proposed that the cable sheath be used as the primary winding of the transformer. Try using the No 22 AWG, 25-pair, PAP cable for the transformer winding with an inner diameter of 300 mm. Using a core shape as shown in Figure 1, we obtain a core area of 0.055 m^2.

Assuming a saturation flux density of 1.8 T, 27 V at 60 Hz can be induced in each turn.

To meet the 33.5 V·s capability (4.5 x 7.5), the transformer winding requires 340 turns. To accommodate the 340 turns of the 16 mm PAP cable, a window area of 0.08 m^2 is required. Figure 1 also shows the proposed core and window dimensions.

Based on dimensions in Figure 1, the cable length and winding resistances can be calculated:

Cable Length	=	500 m (1650 ft)
Loop Resistance	=	56 Ω
Primary Resistance	=	2.3 Ω

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* Magnetic data in Figure 3 has been obtained from Allegheny Ludlum Steel Corp Data Book.

Also based on dimensions in Figure 1 and magnetic characteristics for the iron, shown in Figure 3, an excitation curve can be calculated. The excitation curves in Figure 2 have been calculated for a closed core and for a core with two 0.1 mm gaps.

Since the transformer uses a polyethylene insulated cable, intended for direct burial, there is no need to immerse the transformer in oil. What is required is a suitable protective coating over the core assembly to prevent the iron from rusting. There are several makes of varnishes on the market suitable for this application.

After assembly of the core and windings, it is desirable to house them in a suitable weatherproof housing with the required connection terminals.

PERFORMANCE

Based on the calculated excitation curves, and assuming an external resistance of 35 Ω for the primary circuit the remanent voltage can be calculated. The table below gives remanent voltages for both the gapped and ungapped transformers.

Steady State Voltage (kV)	Remanent Voltage (V)	
	No Gap	2x0.1 mm gaps
0.5	0.9	4
1.0	1.4	8
2.0	2.4	15
4.0	3.6	28
8.0	16.0	64
9.0	150.0	150

DISCUSSION

The design of the neutralizing transformers presented in this report has not been optimized in any way. No doubt the transformer can be optimized for lowest weight and physical size, or for lowest loop resistance and insertion loss.

The designed 4.5-kV transformer can be compared to a 9-kV commercial unit because it does have the flux capability of a 9-kV unit. The cable used in its construction will readily pass the modified dielectric test requirements of either the 4.5- or 9.0-kV class transformer.

The transformer with the two 0.1 mm gaps is superior to the non-gapped unit, in spite of the somewhat larger remanent voltages listed in the above table. Its superiority lies in its low remanence (<10%), and its ability to handle net dc residual current without polarizing the core.

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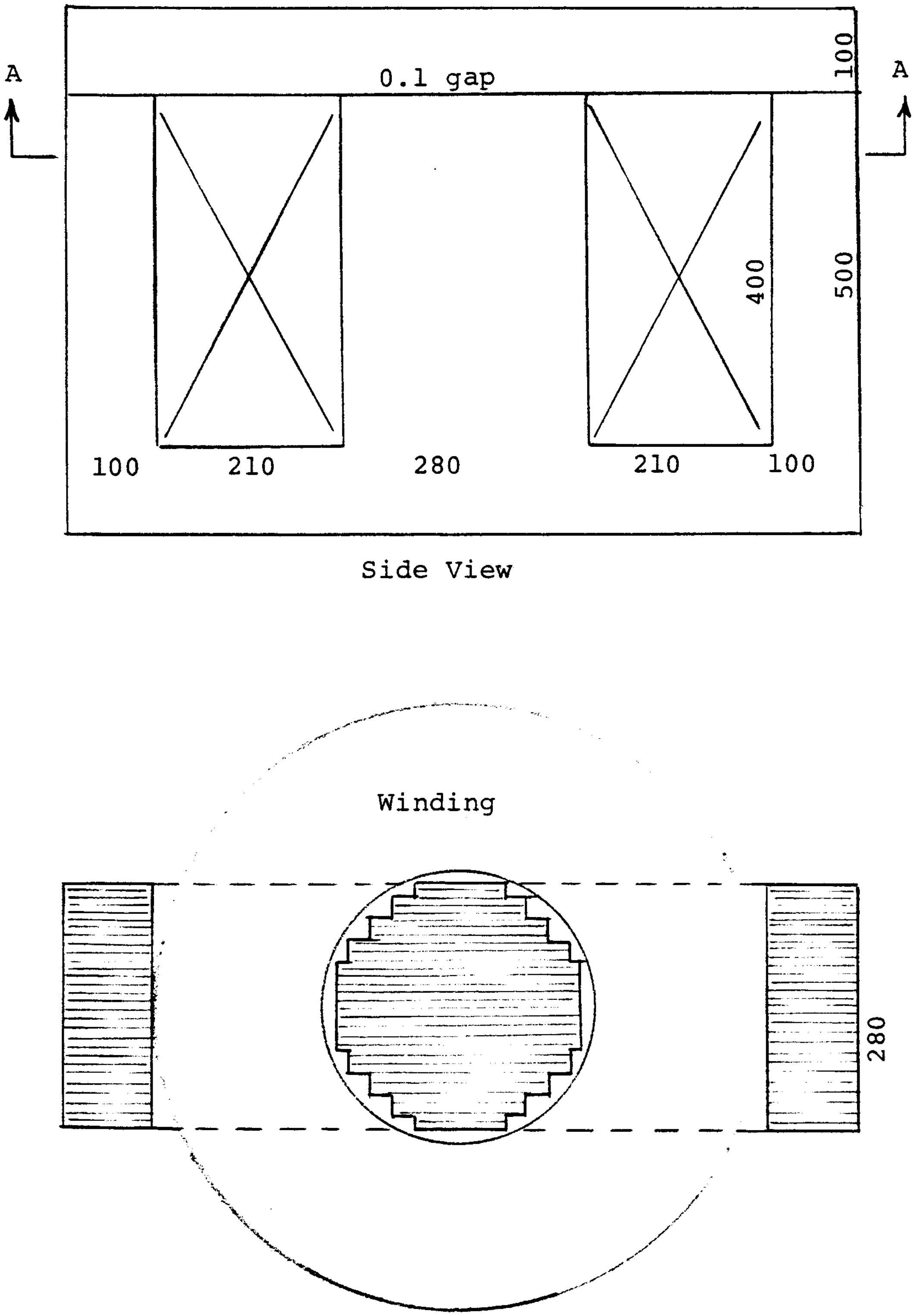

Figure 1

DIMENSIONING FOR NEUTRALIZING TRANSFORMER
(Dimensions in mm)

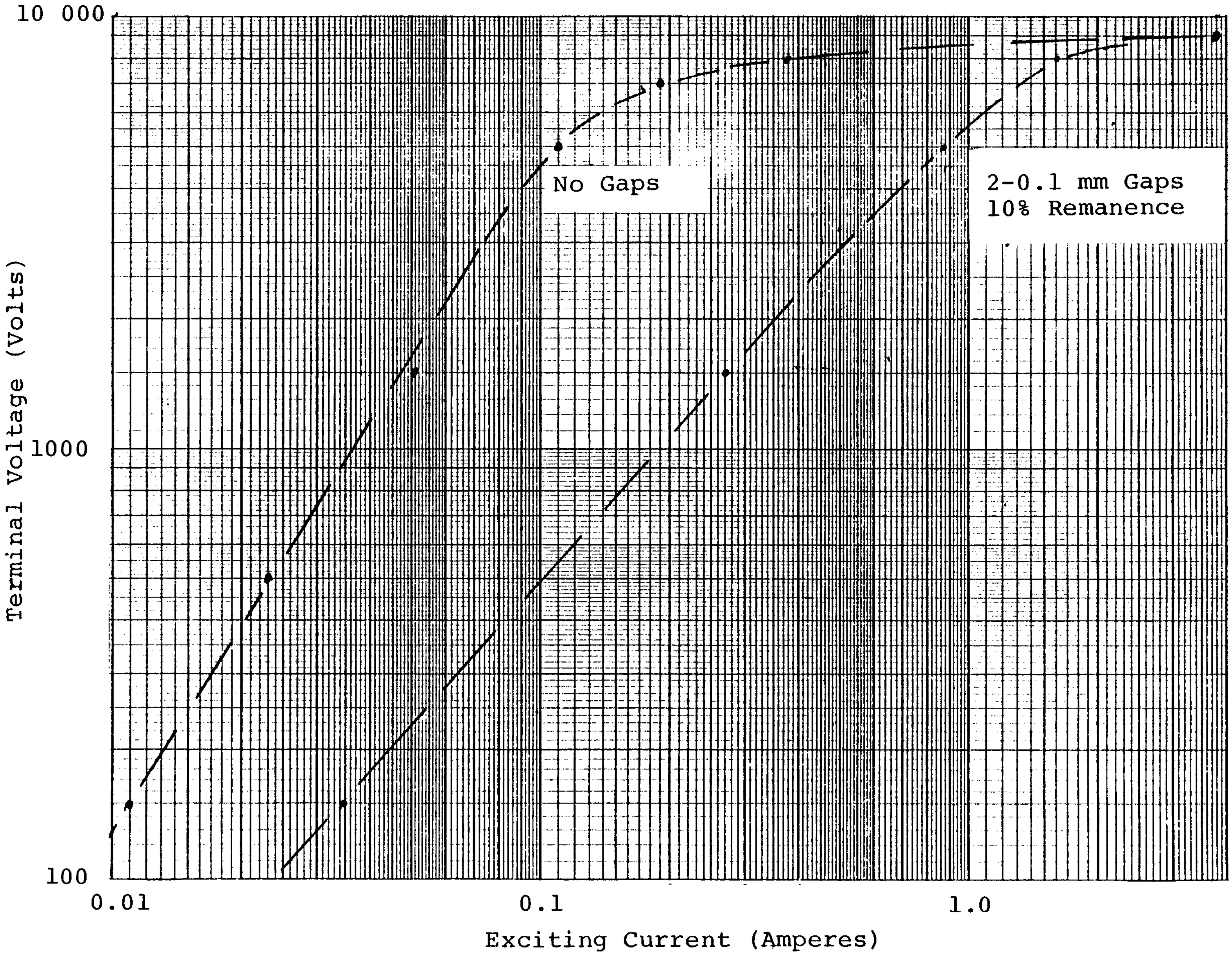

Figure 2

EXCITATION CHARACTERISTICS FOR NEUTRALIZING TRANSFORMER

Figure 3

Magnetization Curves

.014" Silectron and Silectcor 66 (AISI M-6)