Generator Report on
Virginia Electric Power Company
North Anna Unit #1
Transformer Incident of December 5, 1982

By:

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A. Introduction

On December 5, 1982, with unit 1 operating at 30 percent power its Phase B main transformer apparently experienced a fault between the high voltage lead and the low voltage winding. As a result, the 22 kV system was apparently exposed to voltage considerably above the 22 kV level. Consequently, damage occurred to the generator and other elements of the 22 kV system. This report will focus on the generator portion of the 22 kV system.

The first section of this report will summarize the generator field inspection which was made by Westinghouse personnel at the site following the reported generator damage.

The second section of the report summarizes the system analysis which was made to attempt to correlate the evidence of the physical damage to the equipment and the limited data available from a fault recorder made of the 500 kV system quantities. Since there were no fault recorder records made at the 22 kV level at the time of the event, we can only hypothesize events and attempt to correlate them to subsequent damage.

The summary will review the various generator exposures to higher than 22 kV as a result of various transformer incidents and to offer possible explanations of why the generator winding system of unit #1 was damaged this time and why unit #2 did not experience an instantaneous insulation failure as a result of previous transformer incidents.

B. Generator Field Inspection Report

I. PURPOSE

The purpose of the trip was to inspect the generator following a transformer incident.

II. PRESENT

The following representatives of Westinghouse were present during this inspection:

Mr. C. Patrick, Richmond Power Generation Service Division
Mr. L. Karp, Richmond Power Generation Service Division
Mr. P. Yaffee, Richmond Power Generation Service Division
Mr. P. Dorsey, Richmond Power Generation Service Division
Mr. R. Ward, Orlando Program Management Department

III. GENERAL

1. This unit is a hydrogen inner-cooled turbine generator with the following nameplate rating:

   - KVA, 1,088,600
   - Stator volts, 22,000 volts
   - Stator amps, 28,568
   - Power factor, .9
   - Three phase, 60 cycles, 1800 RPM
   - Rotor amps, 7336
   - Exciter volts, 570
   - Temperature rise at 75 psig hydrogen with 46° C Maximum cold gas will not exceed: Stator, 64° C - rotor, 64°C
   - Maximum operational hydrogen pressure = 75 psig
   - Serial 1F76P785
   - Instruction Book - 20804

2. This unit was placed in commercial operation on June 6, 1978. Stator is wound with Thermalastic insulated coils. The unit is operated as a base loaded machine. This is the fifth inspection performed by Westinghouse personnel. The first inspection occurred in March of 1977

when the unit was motorized while on turning gear prior to the actual first in service date. A crawl through inspection was made and no damage was observed. All tests were satisfactory. Second inspection occurred on November 6, 1979. This was the warranty inspection and all tests were satisfactory and no work was performed. A crawl through inspection was made on March 2, 1982. The inspection was satisfactory and no tests were made. A crawl through inspection was made on October 12, 1982. The inspection was satisfactory and no tests were made. However, a loose backup plate at the neutral was removed. This backup plate was used for welding the neutral bus conductor together.

3. As a result of the December 5, 1982, incident, the generator was completely dismantled. The rotor was removed. The coolers and cooler baffles were not removed.

IV. INSPECTION

A. Stator

Conditions observed in the inspection of the stator winding were as follows:

1. General appearance of the winding was fair except for the area between 7:00 and 11:00 facing the exciter end and the T-1, T-4 phase belt areas on both ends. There was heavy carbonization from 7:00-11:00 facing the exciter end.

2. There was no movement of the slot wedges and/or filler strips under the wedges. There were no loose wedges.

3. End winding spacers, support blocks, brackets, supporting studs and twine lashings were tight and in good condition except for the areas noted above. Parallel ring clamping assemblies were tight. Bottom support rings were fitted tightly on the bottom coils. Connection taping was firm and appeared to be in good condition except for bottom coil No. 9. Gas openings and vent tubes were intact and appeared to be in good condition. There was some copper splatter at the opposite end of the cross connections from coil bottom No. 9.

4. There was no evidence of corona attack on the end portions of the winding.

5. Examination of the winding was made for evidence of tape separation. No tape separations were observed.

6. Stator iron and the exciter end shield were splattered with copper and coated with carbon. There was no physical evidence of hot spots or significant mechanical damage on the turbine end.

7. The main lead bushings were removed and packed and could not be inspected.

8. The air gap baffle was in good condition.

9. The neutral lead enclosure had been repaired and the damage to it could not be determined.

B. Rotor

The rotor was not inspected.

C. Brushless Exciter

The brushless exciter was completely dismantled by PGSD personnel for testing and cleaning. All components appeared to be in good condition.

V. DETAILS OF DAMAGED AREA

1. The stator coils and parallel rings, frame and end shield were completely carbonized between 7:00 and 11:00 as viewed from the exciter end.

2. Tube damage was noted on bottom coils 9, 10 and 11. This damage occurred from the spewed copper at the damaged area.

3. The parallel ring clamping assembly at 9:30 was carbonized and splattered with copper. However, there did not appear to be electrical arcing paths across the surfaces to ground.

4. The end shield was carbonized and splattered with copper and one building bolt at 9:30 may have been involved in a ground arc to it.

5. There were broken diamond spacer ties on the exciter end between top coils 6-7, 17-18, 27-28, 38 & 39 and the turbine end between top coils 26-27 and 6-7.

VI. DISCUSSION

As a result of the main transformer incident on this unit, a high voltage was probably impressed on the stator winding. The stator neutral grounding conductor vaporized and the neutral grounding transformer was damaged. The current apparently continued flowing to ground through the vaporized copper and neutral lead enclosure. The end of the neutral lead enclosure was completely vaporized as the current flowed through the neutral lead enclosure to the ground cables connected to the enclosure. This current continued until the cables pulled out of the terminals.

During this period, a phase-to-phase fault through the insulation occurred at the parallel rings. Figure 1 shows the fault area prior to the incident and without insulation. Initial breakdown was probably a phase-to-phase fault between the cross-connection and the coil B-9 and the T-2 parallel ring. Shortly thereafter, T-4 parallel ring was involved. Figure 2 shows the area of copper removed as the result of the incident and subsequent arcing.

Other evidence of damage such as broken ties, carbonized windings, end shield, parallel ring clamping assemblies, damaged vent tubes, copper splatter, etc., are believed to be the effect of the incident and not part of the initiating mechanism.

VII. SUMMARY

1. Damage to the stator was sufficient to require the complete removal of all coils, the removal and restack of the end shield and a complete rewind.

2. Because of the time requirements to repair this stator and windings, a decision was made to replace the generator with North Anna Unit #4 which was in storage.

3. It was recommended that the new stator be inspected in one year.

C. Systems Analysis

This section discusses an analysis of the available system information from the December 5, 1982 incident pertaining to the generator and associated equipment. Since there were no fault recorder records made at the 22KV level at the time of the event, an attempt was made to correlate the evidence of the physical damage to the equipment and the limited data available from a fault recorder made of the 500KV system quantities.

Apparently there was a fault between the high voltage lead of the B-Phase transformer and the low voltage winding of that same transformer. There was evidence of a phase-to-phase to ground fault on A- and B-Phases of the isolated phase buswork. The generator neutral grounding transformer was damaged and the lead connecting the generator neutral and the grounding transformer was reported to have melted. There was evidence of severe arcing on the generator neutral lead enclosure and physical separation and arcing of the leads connecting the neutral enclosure and generator frame. There was evidence of sustained arcing inside the generator between the T_2 Terminal (B-Phase) and the middle of one portion of the A-Phase winding and the neutral end of the A-Phase winding.

The fault recorder records made at the 500 kv level indicate high values of current in the A-, B- and C-Phase circuits to the generator step-up transformer bank. Also indicated on those oscillograms are the phase to neutral voltages and zero sequence voltage and currents.

A calculation was made to determine the approximate values of currents and the distribution of the currents between the transmission system and the

generating unit for a single phase to ground fault on the high voltage terminals of the B-Phase transformer with no other event occurring. For purposes of this calculation, the system positive and negative sequence reactances were assumed to be five percent on the generator MVA base and 525 kv base; the zero sequence impedance of the system was assumed to be ten percent on the same MVA and voltage base. The results of this calculation are shown in Figure 3.

A calculation was also made to determine the approximate values of system and generator currents for a double phase to ground fault on the 22 kv system with no grounding impedance on the 22 kv system. That is, the generator neutral grounding transformer was assumed to be shorted out. The results of that calculation are shown on Figure 4. The 500 kv oscillogram was analyzed by VEPCO personnel and determined to be as follows:

Phase A current = 4,740 amperes lagging a reference voltage by 98°.

Phase B current = 14,310 amperes lagging a reference voltage by 192°.

Phase C current = 3,060 amperes lagging a reference voltage by 312°.

Since the A-Phase and C-Phase transformers did not show evidence of electrical damage or loss of integrity, it follows that the currents flowing in the high voltage windings of those transformers must be balanced out by currents flowing in the low voltage windings. It can then be demonstrated that the current flowing in the section of the isolated phase buss between the transformer and the generator breaker in Phase A will be as indicated on Figure 5. Since the B-Phase current indicated on the oscillogram will be divided between at least two paths, it cannot be positively determined what the currents in the B- and C-Phase bus sections were. By comparing the magnitude of the calculated currents shown in Figure 4 with the recorded currents tabulated above, it appears likely that a double line to ground fault, which bypassed the generator grounding transformer, occurred on the 22 kv system immediately following the transformer incident.

Calculation of the fault current distribution for various combinations of postulated simultaneous faults would be exceedingly complex and beyond the scope of this investigation. In the absence of any more recorded data, it is impossible to determine definitely the sequence and the progression of faults in the isolated phase bus and the damage within the generator.

Since the oscillogram indicates very high fault currents were flowing to ground, an effort was made to determine the approximate time it would take to raise the temperature of the conductor between the generator neutral and the grounding transformer to the melting point. We have been informed that the conductor was a 4/0 cable. It was assumed that the conductor was copper with an annealing temperature of 500^{o}C and a melting point of 1,100^{o}C. On the basis of all heat stored, it was determined that the conductor would reach the annealing temperature in approximately three cycles and the melting temperature in approximately 4.6 cycles with 110,000 amperes flowing through it. The calculations indicate that the conductor could have had as much as 170,000 amperes flowing through it. With 160,000 amperes, the time to reach the annealing temperature is 1.6 cycles and the time to reach the 1,100^{o}C is 2.4 cycles.

These calculations suggest that it is possible that the conductor melted even before the 22 kv BBC generator breaker opened and the system was connected to ground only by means of the arcs involved in the faults.

An electrical arc between the low voltage winding of the transformer and the high voltage terminal of the transformer would have the effect of elevating the entire 22 kv system considerably above the normal operating voltage to ground. It would seem that the most likely fault mode would be between any of the phase conductors and ground and/or the flashover of the neutral grounding equipment. Based on these assumptions and the available facts, it is the authors' opinion that a double line to ground fault between A- and B-Phases and flashover of the grounding equipment occurred immediately after the initial transformer fault and that the generator neutral grounding lead disintegrated within a very few cycles.

D. Summary

It appears there were four transformer incidents at VEPCO possibly involving voltage levels above 22 kV when the generator was electrically tied to the transformer and generating power.

One such event appears to have occurred August 22, 1982, on North Anna #2 transformer which apparently involved the high voltage bushing of phase B, corona shield, low voltage winding, and the tank. From records of available oscillograms it appears there were intermittent strikes from the high voltage components to the low voltage winding. Since transformer ground was also involved in this incident maximum elevation of the 22 kV system may not have occurred. In any event, the grounding transformer did flash-over which apparently represented the lowest insulation strength link in the 22 kV insulation system.

Another incident occurred November 29, 1980, on North Anna #2 which was most like the December 5, 1982, event. In this case, the high and low voltage transformer voltage lead coil were involved and apparently elevated the 22 kV system. As a result, potential transformers failed and a three phase fault occurred in the isolated phase bus which apparently isolated the generator from this incident.

On July 3, 1981, the B-phase of the North Anna #2 transformer experienced a high voltage to ground failure which also involved the low voltage winding. Since ground was also involved, the maximum elevation of the 22 kV system may not have occurred. It has also been reported that subsequent ground fault arcing developed in the isolated phase bus.

Thus the transformer incident of December 5, 1982, may have exposed unit #1 generator to the highest magnitude of voltage of any previous incident on either unit #1 or #2 generators or at least no peripheral components such as potential transformers, isolated phase bus ducts, or grounding equipment sacrificed themselves to isolate or protect unit #1 generator from the elevated voltage. Therefore the concept of coordinating the 22 kV insulation system is raised.

Since it is advantageous to preserve the high resistance grounding along with its grounding cable and of course the generator winding, it would be desirable to prevent high voltages from ever reaching the generator terminals. Hence any such insulation coordination plan should consider a system which could provide controlled voltage suppression to ground in the isolated phase bus duct between the transformer and the generator. However, such a system will most likely present the generator with a three phase fault on its terminals. Although undesired, a three phase fault may be more desirable than the rewind of a generator exposed to high voltages. To date, the authors are not aware of any such system which has been designed or in service which has a good probability of not destructively failing itself under the discussed conditions thus imposing a fault on the generator.

In conclusion, it is the authors' opinion that the generator damage was caused by a high voltage initiated from an external source. North Anna #1 generator was replaced with North Anna #4 generator which was in storage and the unit returned to service in March 1983.

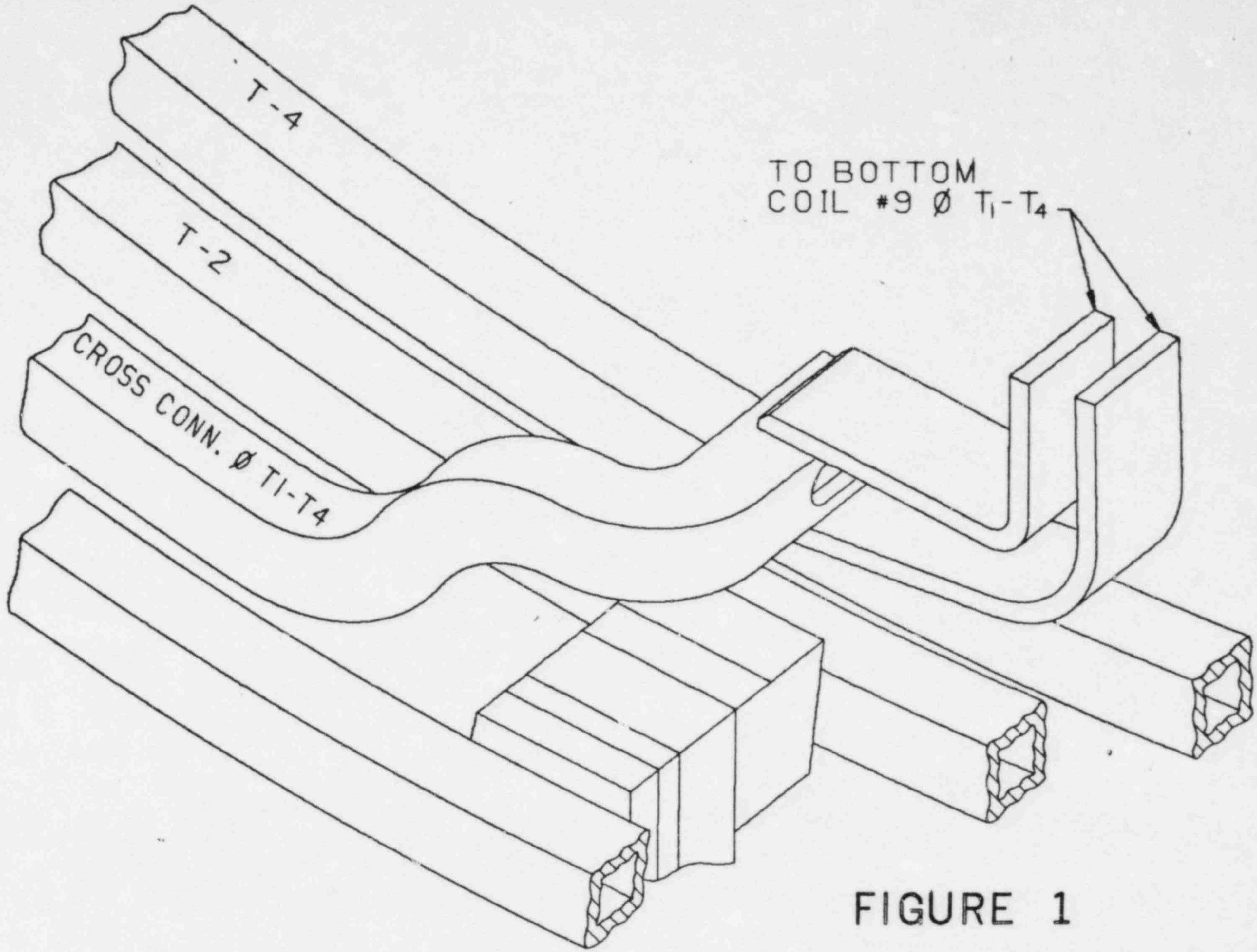


FIGURE 1

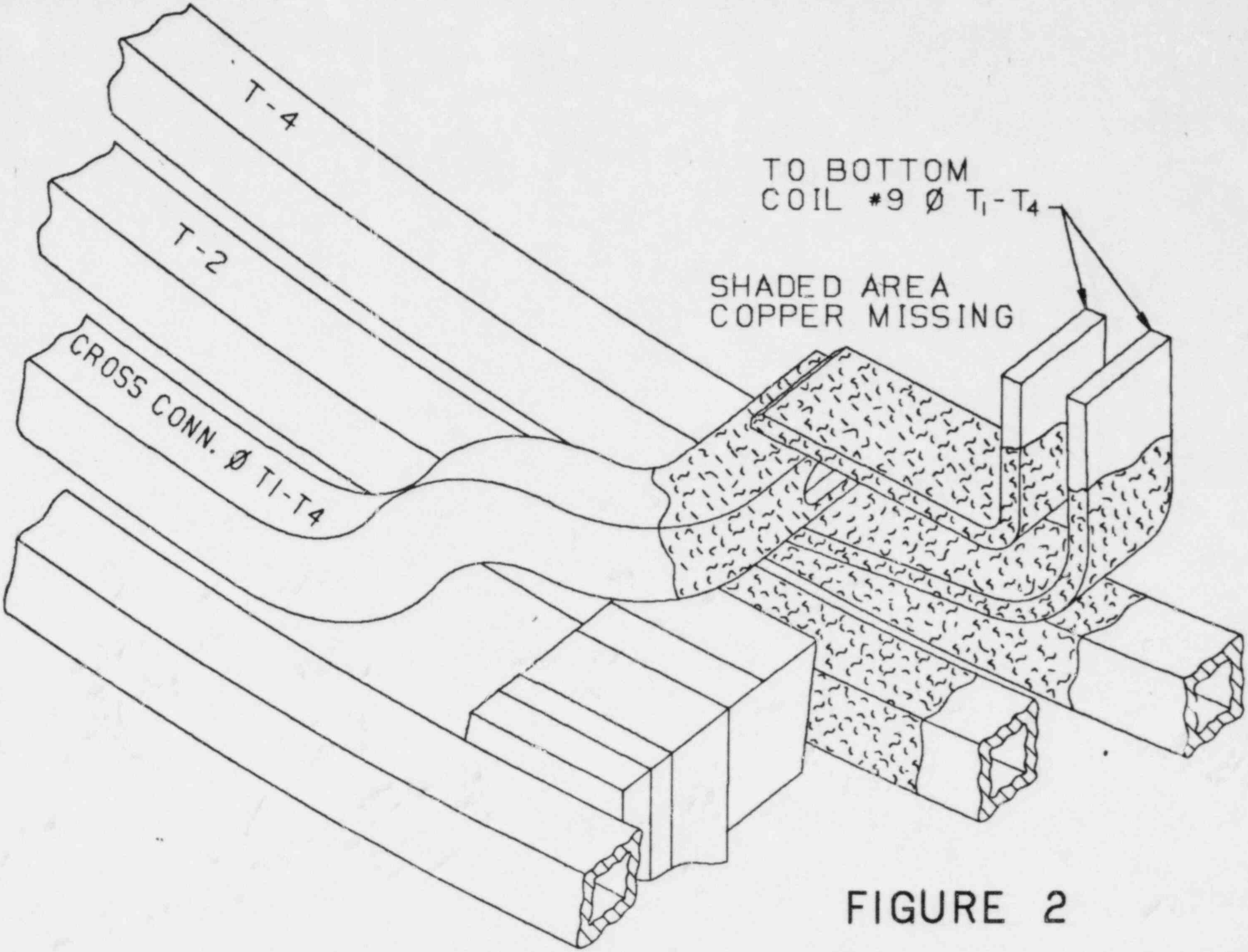


FIGURE 2

PART NAME - S.Z.PARR-RING-FAULT

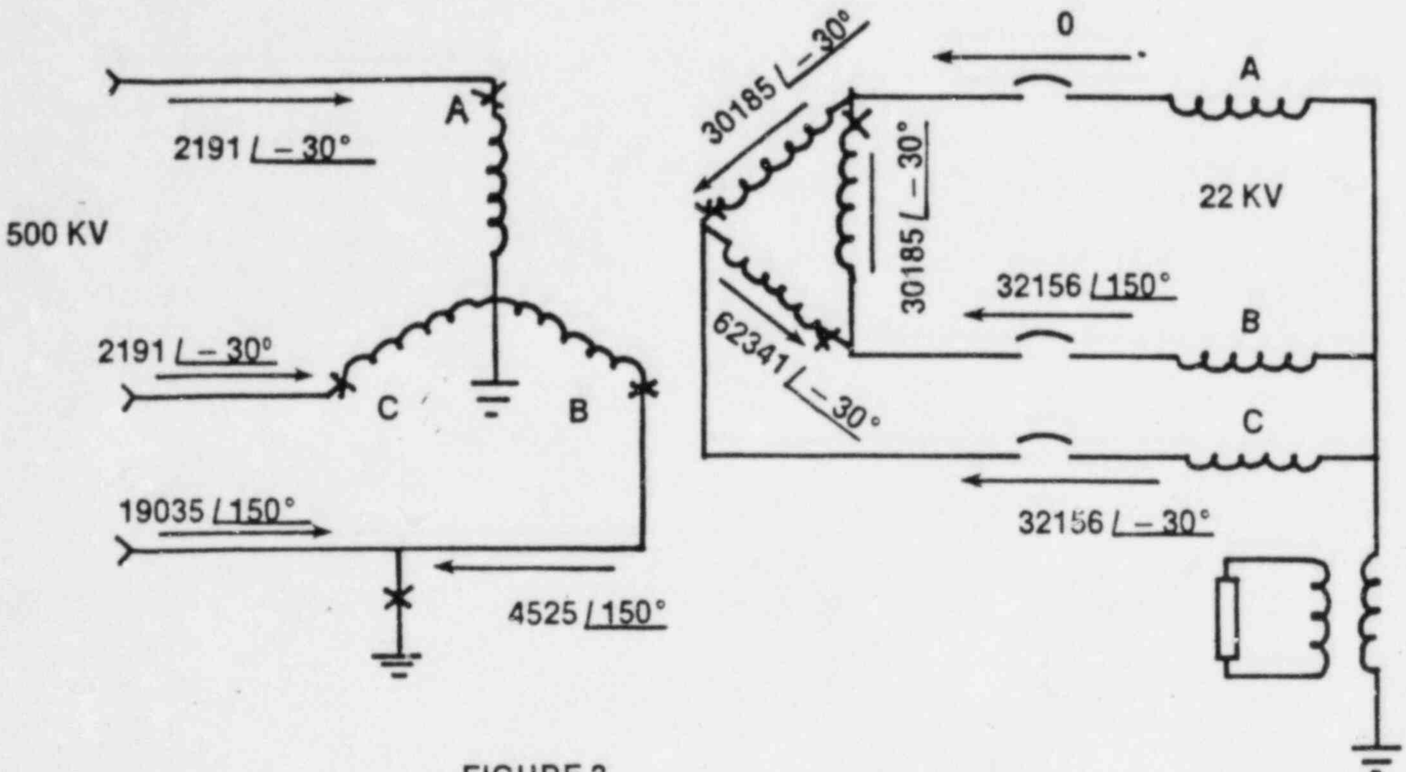


FIGURE 3

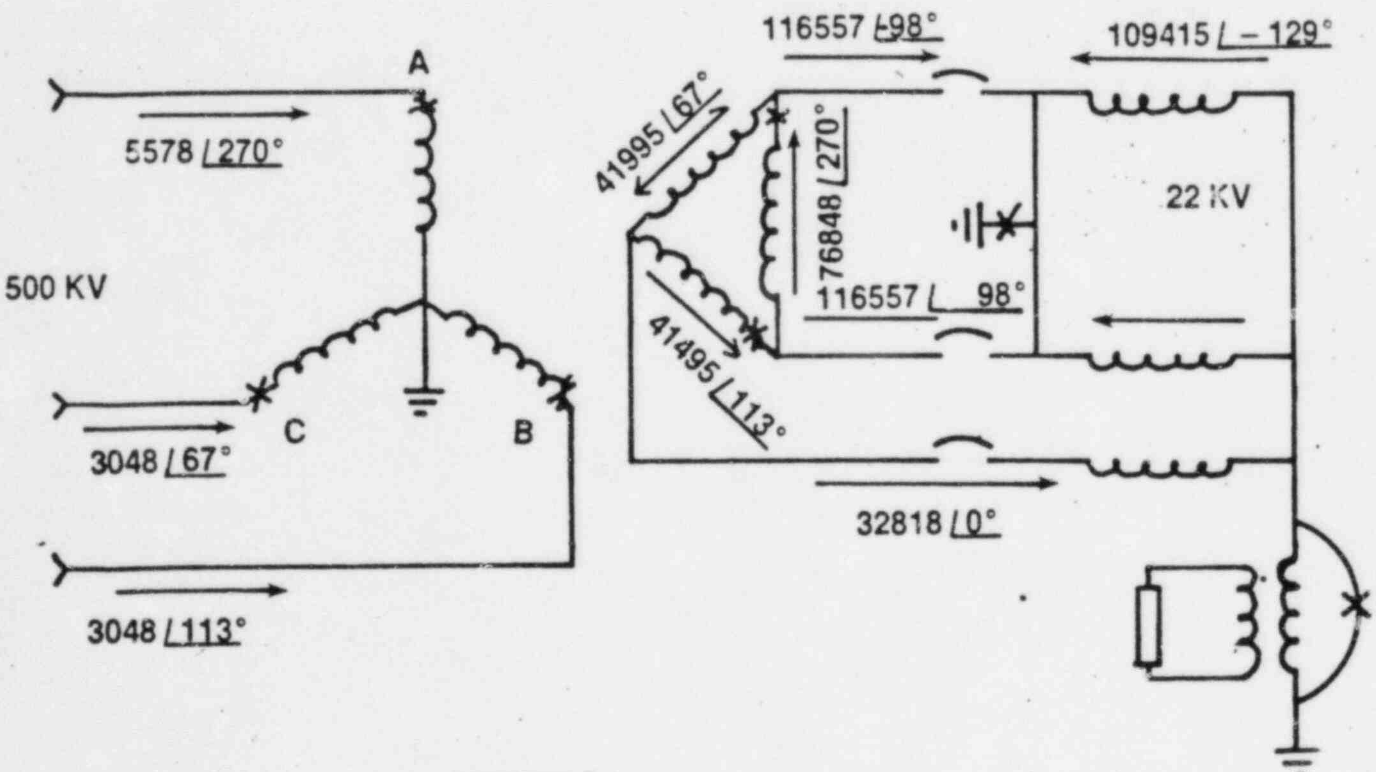
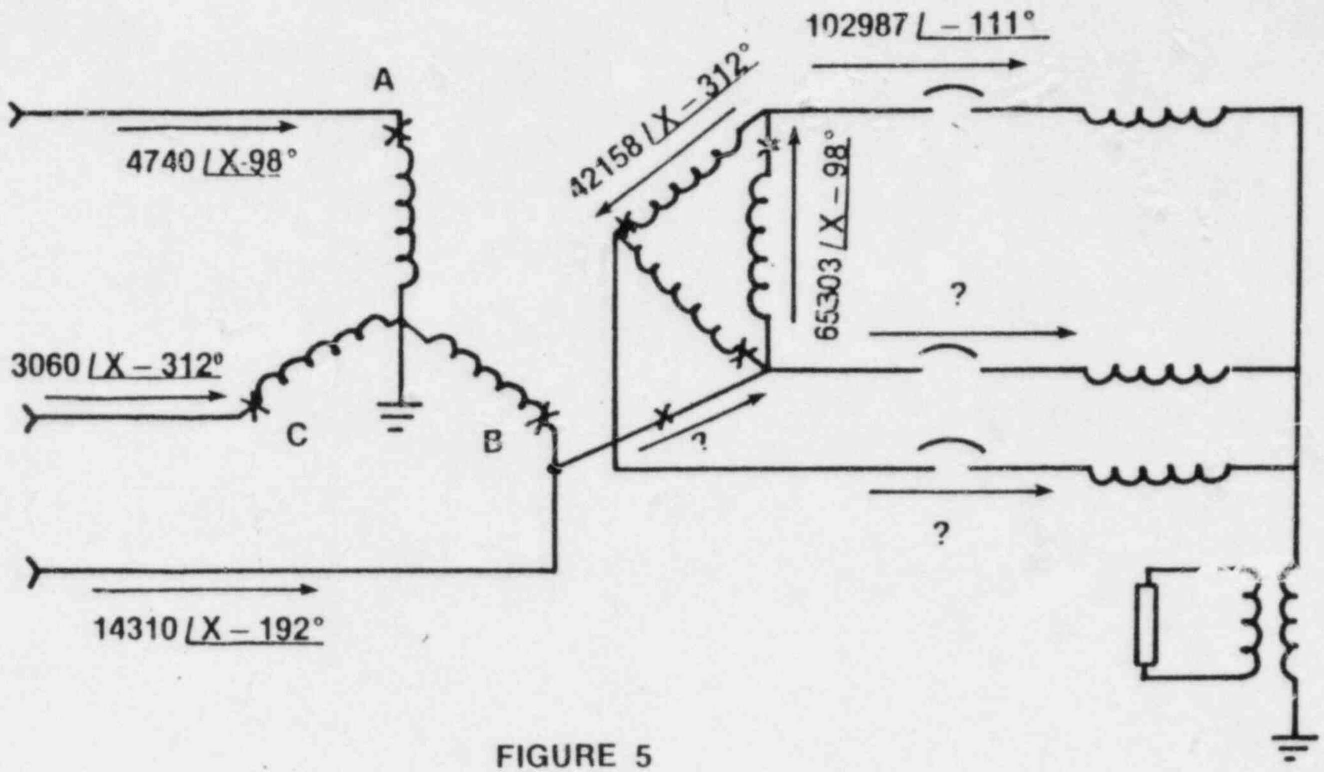


FIGURE 4



A
4740 /X-98°
3060 /X – 312°
C
B
14310 /X – 192°
42158 /X – 312°
65303 /X – 98°
102987 /– 111°
?
?
?

FIGURE 5