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November 16, 2001

2CAN110108

U. S. Nuclear Regulatory Commission
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Subject: Arkansas Nuclear One - Unit 2
Docket No. 50-368
License No. NPF-6
Response to Request for Additional Information Concerning Deferral of a Main Transformer Cooling Modification Associated with the ANO-2 Power Uprate License Application

Gentlemen:

In a letter dated October 30, 2001 (2CAN100113), Entergy Operations, Inc. informed the Nuclear Regulatory Commission staff that a planned modification to install additional main transformer cooling due to a planned power uprate would be deferred. The commitment to install the cooling was made in the license application dated December 19, 2000 (2CAN120001), to increase the authorized power level for Arkansas Nuclear One, Unit 2 (ANO-2). After reviewing the October 30, 2001 letter, the staff submitted the following request for additional information on November 8, 2001:

"In your October 30, 2001, supplemental letter you stated you no longer plan to install additional main transformer cooling for power uprate. Your letter states that the main transformers are more than capable of operating at uprated conditions due to extra capacity designed into these transformers (i.e., these transformers are capable of operating at greater than 100% of their ratings). Please provide the supporting documentation or justification (such as calculations, letter from the manufacturer, etc)."

Following the power uprate, the loading on the ANO-2 main power transformers will be above the 100% nameplate rating which is 1000.5 MVA (forced oil and air [FOA] @ 65°C average winding temperature rise above maximum ambient temperature of 40°C and maximum 24 hour average ambient temperature of 30°C). To address the acceptability of these main transformers at elevated loadings, ANO funded a study by the transformer design engineer who was employed by the original vendor, (General Electric) at the time the ANO-2 main transformers were designed and constructed, circa 1974. Although the engineer is no longer employed by General Electric, since his resignation he has been used extensively by Entergy as a transformer engineering consultant.

Attached is a section of the engineering report developed by the consultant engineer, which documents the capability of these transformers to withstand loads of 107% of their rating without additional cooling and 113% of their rating with additional cooling (see page 8 of the report) during hot summertime conditions. The appendices to this report, which consist of approximately 50 pages of supporting documentation (e.g., predominantly computer printouts), were not included at this time but can be provided if needed.

During the hot summertime conditions, the load is expected to be approximately 101-103% of the main transformers' existing 1000.5 MVA rating. During the cool months of the year, when there are no appreciable cooling tower/condenser efficiency losses from hot ambient conditions, the load on the main transformers could reach 105-109% of the 1000.5 MVA transformer rating. The potential 109% loading during the cool wintertime months will be acceptable without additional cooling since the ambient temperatures at these times are well under the rated 24-hour average temperature of 30°C. Per Institute of Electrical and Electronics Engineers (IEEE) Standard C57.91-1995 Table 4, the loading on FOA transformers can be increased by 0.75% for every degree Centigrade the average ambient temperature is lowered from the rated 30°C. During the cooler times of the year, when the main transformers could be operated at 105-109% of their rating, the average ambient temperatures will be less than 20°C. An average ambient temperature of 20°C results in an allowable loading of at least another 7.5% above the 107% allowed in the attached engineering report. Consequently, the proposed 105% - 109% loading, which will only occur during the cooler months of the year, will be acceptable.

The existing transformer coolers continue to perform acceptably at this time. These coolers have kept the transformer well below their rated temperatures.

This submittal contains no regulatory commitments.

I declare under penalty of perjury that the foregoing is true and correct. Executed on November 16, 2001.

Very truly yours,

Glenn R. Ashley

Glenn R. Ashley
Manager, Licensing

GRA/dwb
Attachment

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Attachment to 2CAN110108

Evaluation of Main Transformers

Serial Numbers H-409949, 950 and 951

for

Entergy

Arkansas Nuclear One- Unit 2

J.D. MacDonald, P.E.
Engineering Consultant
10-15-96

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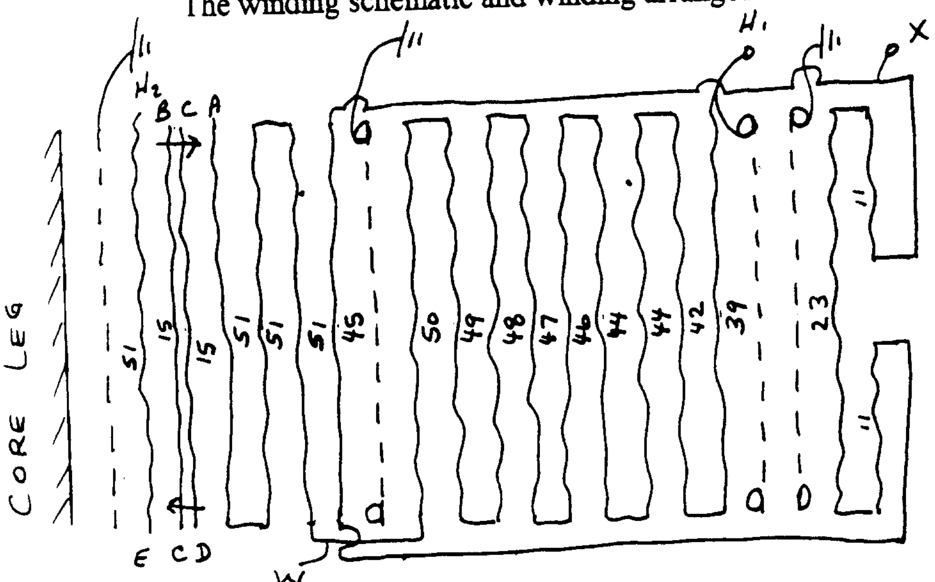
Introduction- This report involves the (3) generator step-up transformers that are installed at Arkansas Nuclear One- Unit #2. They were built by the General Electric Company in Pittsfield, Massachusetts in 1974. The purpose of the evaluation was to determine if these transformers can withstand the short-circuit forces that they can see and to determine the amount of increased load they can carry and still meet ANSI Standard temperature limits. The temperature calculations were made for two conditions, 1-with only the existing cooling equipment and 2-with one additional cooler. The serial numbers for the three units involved are H-409949, '950 and '951 and were built under GE's Production order P.O.-7260135. The one line rating is shown below:

(3) FOA - S - 60 - 333.5 MVA(65C) - 500 kV GRY - 21.7 kV

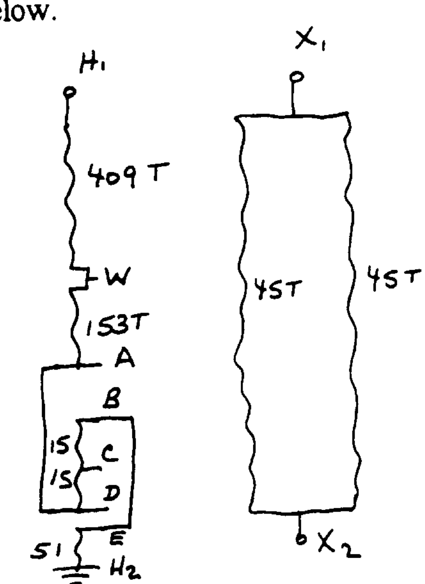
These transformers are of the MK-III design and as such have dyna-comp clamping with dashpots. They are built on a three-legged core with all the windings on the center leg. The LV winding has two windings which are connected in parallel. The inner LV winding is a triple Hobart helical winding which uses hard copper conductor and the outer LV winding is a layer winding with epoxy bonded CTC(continuously transposed conductor). The HV winding is interleaved about the inner LV winding and uses the layer winding construction. The inner HV and the HV taps use epoxy bonded, hard CTC while the outer HV uses soft CTC except for layer #9 which has hard CTC.

The de-energized taps are the buck-boost type with 25 class I thyrites connected across each tap.

The winding schematic and winding arrangement are shown below.



Winding Arrangement



Winding Schematic

Methodology- The short-circuit stresses within the transformer windings were calculated using the Anderson finite element program. The design records were purchases from ABB, Alamo, TN so that these calculations could be made. The calculated stresses were then compared to generally accepted design values.

The up-rating calculations are based on information given in the Certified Test Report for the temperature test at the factory. The oil rises and winding gradients were extrapolated from these values using the exponents given in ANSI C57-12.90-1993. To determine present efficiency of the FOA coolers, the top oil temperature while in service on 7/1/96 was compared to the value measured at the factory.

Short-Circuit Analysis- A three-phase fault was applied to the LV terminals with an infinite bus on the HV terminals. The HV system impedance of 12330 MVA or 8.11% on a 333.5 MVA(one phase) base was used in determining the fault current magnitude. A peak asymmetrical factor of 1.80 was used in the calculations. This value was determined from Table 13 of IEEE Standard C57.12.00-1993.

The winding forces were calculated separately for the axial and radial directions and the winding stresses determined for each force component. This procedure is commonly used by transformer manufacturers because there is little interaction between the axial and radial failure modes. For the radial direction, the inward and outward hoop stresses were calculated. For the axial direction, the conductor tipping stresses and the end ring pressures were determined. For each case the suggested withstand stress is given. The axial misalignment between the LV and the HV windings was taken as 0.5% of the window height or 0.620 inches. This allowance accounts for the manufacturing tolerances in the height of the coils as compared to the design values. The allowance was incorporated into the calculations by elongating the LV winding by 0.620 inches. The calculations were made for the maximum, the rated and the minimum voltage on the HV winding. In the Tables that follow, the voltages are for the normal value at each connection instead of the actual value. The reactance values used to calculate the magnitude of the fault current are shown below. A check on the modeling of the design can be done by comparing the tested versus the calculated values.

H-X Impedance at 333.5 MVA

Voltage Connection (kV)	Calculated Value (%)	Tested Value(%) '949	'950	'951
537.5-21.7	10.79	11.10	*	*
500.0-21.7	11.54	11.84	11.25	11.64
487.5-21.7	11.89	12.21	*	*

* = not measured.

The short-circuit forces are the highest on the maximum tap as the transformer has the minimum impedance on this connection. Consequently, this will be the only tap considered. The conductor stresses from the Anderson program must be modified to take into account the use of the system impedance by the factor shown below.

$$(10.79/(10.79+8.11)) = 0.33$$

In addition the LV stresses must be corrected for the correct current since the Anderson program was run with the LV windings connected in series. For the radial stresses this correction for the inner LV winding is

$$13060/15369=0.85$$

Where 13060 is the amperes in this winding when connected in parallel and 15369 is the amperes used in the Anderson program.

For the LV outer, the correction is

$$2309/15369=0.15$$

Note: The current does not divide equally between the two LV windings because of unequal impedances to the HV winding.

Where 2309 is the amperes in the LV outer winding when connected in parallel with the LV inner winding.

The Table below summarizes the radial forces for the worst case in each winding.

Radial Stresses
537.5-21.7 kV connection

Layer	Anderson (psi)	Corrected (psi)	Allowable (psi)
5(HVi)	-14594	-4816	-20000
6(LVi)	-7812	-2191	-10000
7(HVo)	28916	9542	15000
15(HVo)	-13023	-4298	-7500
16(LVo)	131453	16760	40000

The allowable radial stress for the inward direction, minus sign, was taken from generally accepted industry practices and from my own personal experience. The allowable stress for the outward direction was taken as the yield strength of the copper conductor for tensile loads.

The next phenomenon considered was conductor tipping. Tipping of the conductor is caused by the axial forces on the winding conductor forcing them to tilt into the horizontal position. The calculated values are shown in the table below for the worst layer in each winding.

Conductor Tipping
537.5kV-21.7 kV connection

Layer	Calculated stress	Allowable Stress
1(HVi)	463 psi	12000 psi
6(LVi)	967	953
10(HVo)	597	1403
17(LVo)	124	12000

The calculated and allowable stresses were determined by following the theory for conductor tipping as outlined by M. Waters in his book, The Short-Circuit Strength of Power Transformers, published by MacDonald and Co., London, England 1966 and by using generally accepted industry practice.

The pressure on the layer winding end ring at the point of contact between the end insulation spacer and the end ring was determined for the worst case in each winding. For the helical winding, the pressure on the radial spacers was calculated instead of on the end ring. The allowable stress was taken as the pressboard manufacturer's recommended psi loading for the axial direction. The table below shows the calculated and allowable end ring pressures.

End Ring Pressure
537.5kV-21.7 kV connection

Layer	Calculated Stress	Allowable Stress
1(HVi)	501 psi	2500 psi
6(LVi)	3795	12000(radial spacer)
12(HVo)	603	2500
17(LVo)	108	2500

The computer output sheets for all three tap positions are included in Appendix B.

Thermal Analysis- These transformers did not receive a temperature test(heat run) of their own. Instead, the data from a thermally duplicate unit was used to calibrate the calculations for this design. This is a generally accepted practice. The thermal duplicate has to be a similar design and nearly the same MVA rating. The IEEE Standards Committee is working on a definition of a thermal duplicate so that all manufacturers use the same criteria. The thermal duplicate in this case was s/n H-409912. The Table on the next page shows the temperature information from the CTR(certified test report).

Temperature Rises(333.5 MVA)
487.5kV-21.7kV

Item	Rise
HV winding(average)	46.5 C
LV winding(average)	45.5
Top oil	41.5

The difference between top and bottom oil for this design is about 4 degrees C. So the average oil(also called effective oil) is 39.5 C. The average winding rise minus the effective oil, E.O., gives the average winding rise over adjacent oil. This is called the winding gradient. The Table shows the gradients from the CTR and those from the design engineer's calculations.

Winding Gradients

Winding	Calculated	Certified Test Report
LV	10 C	6.5 C
HV	12	7.5

The data for the gradients looks suspiciously low. To be on the safe side the calculated values were used to calculate the additional load that this transformer can carry with and without one additional cooler.

(P54 & P55)

The exponent on the winding gradient for FOA units from ANSI C57.12.90-1993 is $m = 1.0$. The exponent on the oil rise is also $n = 1.0$ for FOA units. The average losses for the three units as taken from the CTR are shown below. The losses were taken for the 500kV-21.7kV connection since they were the only ones measured. It is likely that the transformers will be operated closer to the 500kV tap than the 487.5 kV tap anyway.

Average Losses(333.5 MVA)
500.0kV-21.7kV

Item	s/n '949	s/n '950	s/n '951	Average
Load loss	759.6 kW	708.6 kW	725.3 kW	731.2 kW
No-load loss	177.6	159.6	161.0	166.1
Total loss	937.6	868.4	886.3	897.3

The pu load can now be calculated that gives an average HV winding rise, which is the hottest winding, of 62.5 C by the following equation keeping 2.5 C margin(see Appendix C for the derivation of this equation).

$$39.5(I^2 X\ 731.2 + 166.1)/897.3 + 12.0I^2 = 62.5$$

Which gives,

$$I = 1.12 \text{ pu or } 375.5 \text{ MVA}$$

The rises at 1.12 pu load are shown below.

Temperature Rises

Item	Rise
Effective oil	47.4 C
HV gradient	15.1
HV/ambient	62.5
LV gradient	12.5
LV/ambient	59.9
Top oil	64.5

The other criteria that must be meet is the winding hottest spot temperature which is 80 C over ambient for a 65 C machine. The design engineer used a 30 C rise over oil for the winding hot which is at the top of the inner LV winding. The pu load that gives an 80 C hot spot can be calculated using the same equation as for the average winding rise.

$$41.5(I^2 X\ 731.2 + 166.1)/897.3 + 30I^2 = 80$$

Which gives,

$$I = 1.07 \text{ pu or } 356.8 \text{ MVA}$$

The oil temperature would be effected in a linear fashion by adding a fifth cooler, see Appendix D for a typical cooler heat dissipation curve. At 1.0 pu load the effective oil temperature would be,

$$39.5\ (4/5) = 31.6 \text{ C}$$

Since the loading on the transformer is limited by the hot spot temperature, only that calculation needs to repeated.

$$33.6(I^2 X\ 731.2 + 166.1)/897.3 + 30I^2 = 80$$

Or,

$$I = 1.13 \text{ pu or } 376.8 \text{ MVA}$$

Ancillary Equipment- The bushings and the de-energized tap changer ratings were reviewed to see if they are capable of carrying the 1.13pu load(376.8 MVA). The table below summarizes the bushing current rating and the maximum current at 376.8 MVA.

Bushing	Catalog Number	Current Rating (amperes)	Maximum Current (at 376.8 MVA), amperes

HV line	11B776	2000	1339 on 487.5 tap
HV neutral	7B552	3000	1339
LV	1B863	21,500	17,367

The rating two de-energized tap changers per transformer, buck-boost taps, are shown below.

DETC Location	Catalog Number	Current Rating (amperes)	Maximum Current (at 376.8 MVA), amperes
HV winding	TC6W1500-120	1500	1339 on 487.5 kV tap

Stray Flux- As the load is increased to 1.13 pu the stray flux heating in the metallic components such as the core clamps and tank increase by approximately the square of the current. This increase in heating is offset somewhat by the decrease in oil temperature due to the addition of the fifth cooler. It is unlikely that the transformer will generate the hot metal gasses at the 1.13 pu load with one additional cooler since it did not generate these gasses at 333.5 MVA with the four coolers.

Discussion-This is a MK-III design with dyne-comp clamping system(dash pots). As such, the winding should remain tightly clamped throughout the life of the transformer. The short-circuit forces are well within acceptable limits with the inner LV winding being at the design limit for the conductor tipping mode of failure. The high voltage winding is interleaved about the low voltage winding with approximately 30% of the HV turns in the inner HV winding (depending on tap position). By interleaving, the axial leakage flux magnetic field strength is reduced considerable as compared to that of a non-interleaved design. Since axial flux causes the radial forces, these forces are also reduced considerably.

The design has considerably margin thermally. The additional load capability is limited by the winding hot spot and not the average winding rise. The units can carry 1.07 pu(356.8 MVA) load with the existing cooling package, assuming that the cooling efficiency is the same as when new. By adding one additional cooler, the loading can be increased to 1.13 pu(376.8 MVA) for a winding hot spot rise of 80 C. The efficiency of the present coolers has likely deteriorated somewhat over the years. Their present efficiency needs to be determined and the calculations redone. The estimated cost of one 4-fan cooler installed is approximately $25,000-$50,000.

The MK-III transformers have proven very reliable based on many years of service being built from 1971 to 1988. These transformers should perform in a like manner even if it is decided to increase the load over the maximum nameplate value. The gas-in-oil should be monitored closely if the load is increased to check for stray flux heating.

J.D. MacDonald, P.E.

Engineering Consultant

October 15, 1996