DAVID A. SILVER & ASSOCIATES INC.

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FINAL REPORT

REVIEW AND ANALYSIS OF TVA'S

CABLE SIDEWALL PRESSURE TESTS REPORT

DATED MAY 1986

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NOTICE

REVIEW AND ANALYSIS OF TVA'S CABLE SIDEWALL PRESSURE TESTS REPORT

PURPOSE

The purpose of this report is to provide an independent review of TVA's Cable Sidewall Pressure Tests Report dated May 1986 and advise TVA regarding the adequacy of the report and its conclusions.

RESULTS OF REVIEW AND CONCLUSIONS

The test procedure and instrumentation employed to determine the effects of high sidewall bearing pressure (SWBP) on a select group of electrical cables by pulling the cables in a four horizontal bend conduit set up are considered to be satisfactory and in accordance with the existing state of the art for performing such tests.

Ac dielectric breakdown tests can be considered as a primary criteria for evaluation of cables subjected to a sidewall bearing pressure test. Results of ac dielectric breakdown tests on cable lengths subjected to a sidewall bearing pressure test when compared to values obtained on the identical virgin cables, respectively, can be employed to evaluate the affect of the sidewall bearing pressures to which the cables were subjected. In this regard, the maximum sidewall bearing pressure to which each of the thirty-one cables was subjected while being pulled through a four 90 degree conduit set up by applying moderate to high tensions to the cables is considered to have had minimal to relatively small effect on the dielectric strength of the cables tested.

The results of this test program in conjunction with the results of the Electric Power Research Institute (EPRI) sponsored R&D Project 1519-1 can serve as the basis for consideration of higher permissible sidewall bearing pressures for the same and similar cables than the present limits of 300 pounds/foot for power and control cables and 100 pounds/foot for signal and instrumentation cables.

TEST PROCEDURE AND INSTRUMENTATION

The test procedure and instrumentation employed to determine the effects of high sidewall bearing pressure on a select group of electrical cables by pulling the cables in a four horizontal 90 degree bend conduit set up are considered to be satisfactory. The test procedure and instrumentation are in general agreement with the test procedure and instrumentation utilized in an EPRI sponsored R&D Project 1519-1 entitled 'Maximum Safe Pulling Lengths for Solid Dielectric Insulated Cables'.

REVIEW OF TVA TEST REQUIREMENTS FOR CABLE SIDEWALL BEARING PRESSURE PROJECT, REVISION 3 - MAY 22, 1986

Paragraph 5.0 Procedure

Subparagraph 5.5 states 'Make measurements of the bare copper conductor approximately 1 inch from one end of the conductor for virgin cable and each end for tensioned cable and report the measurements of each conductor to the nearest .001 inch'. The test data in Appendix J lists only one set of copper diameters for each conductor for the tensioned cables. This is of no concern since we would not expect any significant change within 15 to 25 feet of cable. Furthermore, the report clearly states that in many cases the tension applied to the cable pull was very close to the ultimate breaking strength of the conductors and hence reduction in conductor diameters would be expected. This point is mentioned only to bring to your attention an apparent inconsistency between the test requirements and the test data.

Paragraph 6.0 Acceptance Criteria

We do not agree that Paragraph 15, Precision and Accuracy for ASTM D149, provides a basis for judging the extent of change of the tensioned cables compared to the virgin cables by comparison of their respective average breakdown voltages. The statement in paragraph 15.1 that 'the coefficient of variation (standard deviation divided by the mean) may vary from a low of 1 or 2% to as high as 20% or more.' is in our judgement merely an indication of the extent of variation in the dielectric strength measurements that can be anticipated when a number of measurements, probably five, are made on a particular material and electrode system. The next statement in paragraph 15.1 indicates that a narrower distribution of test results can be expected when duplicate tests are made on five specimens from the same sample.

Based on our experience and judgement we would say that a 10% difference in the average dielectric breakdown voltage of the tensioned cable compared to the average breakdown voltage of the virgin cable can be considered as within the normal variation in average dielectric breakdown voltages and within experimental error. When the difference is in the range between 10 to 20% negative and particularly between 15 and 20% negative, there is an indication of change and the test data must be carefully examined and the minimum values must be compared to operating conditions to judge the significance of the change as related to operating conditions.

Another means that can be used for evaluating the significance of a change in average breakdown strengths of tensioned cable compared to virgin cable is the ratio of the difference in average values to the average of their standard deviations. This ratio takes into consideration the variation in the test results of the data comprising the average values in judging the significance of the difference between the average values. The closer that the ratio approaches zero, the less significant is the difference between the average values. Values of the ratio that are less than -1 would necessitate detailed examination of the test data as discussed previously.

DISCUSSION OF CALCULATED VALUES AND TEST RESULTS

Calculation of Sidewall Bearing Pressure

Table 1 presents a listing and comparison of calculated values for sidewall bearing pressure for the thirty-one cables tested. The sidewall bearing pressure values listed in Column 1 are as shown in the TVA report. The sidewall bearing pressure values listed in Column 2 were calculated by us. The reasons for the discrepancies, which are most pronounced for the five single conductor cable pulls, are as follows:

- Column 1 values are based on the bending radius of the outside wall of the conduit. Column 2 SWBP values were calculated using the bending radius of the inside wall of the conduit.

- Column 1 SWBP values for Control Nos. 16 and 17 appear to have been calculated using a bending radius of 0.6671 feet (outside radius of conduit). Column 2 values for these two items were calculated using a conduit bend radius of 0.7311 feet which is the actual bend radius of the conduit (0.7183 feet) plus the thickness of the conduit (0.154 inches).

- Column 1 SWBP values were calculated in most cases using actual average diameters of virgin cables but not in all cases. Column 2 SWBP values are based on the actual average diameters of the virgin cables.

. We agree with the derivation of the formulae for calculating the SWBP for the five single conductor cable pulls. However, it appears in the calculation of Wc that (1) only the vertical component of F_5 has been utilized rather than the resultant vector, (2) summation of weights were used in the denominator of the equation

$$W_c = \frac{F_5 w}{\Sigma W}$$

rather than summation of forces on the pipe, and (3) a minimum threshold value of 0.4 was established for Wc. There appears to be no justification offered for this threshold value either in the report or in the Kommers' paper entitled 'Electric Cable Installations in Raceways' which appears to have been utilized in the TVA report for calculating sidewall bearing pressures. The sidewall bearing pressure values for five single conductor cable pulls in Column 2 were calculated with the corrections noted herein and not observing the minimum threshold value for W_c.

Test Results

Table 2 is a compilation of average dielectric breakdown voltages for virgin and tensioned cables, the percent change in these values and the calculated ratio of the difference in the average dielectric breakdown voltages (KV_{T-V}) divided by the average of the standard deviations. The significance of this ratio was discussed previously. The sidewall bearing pressure values listed are those shown in Column 2 of Table 1.

Based on the previous discussion, the test data for Control Nos. 4, 19 and 28 and other cables exhibiting anomalies in the test data were examined and are discussed herein.

Control No. 4

We believe that the very low dielectric breakdown voltage of 1.5kV in 4T2 was probably caused by a cut in the insulation during stripping of the jacket or mechanical damage during manufacture. It is doubtful that it was caused by sidewall bearing pressure. Excluding the 1.5kV breakdown voltage, the next higher breakdown voltage for the tensioned cable (16.1kV in 4T5) is significantly higher than the lowest breakdown voltage for virgin cable (11.6kV in 4V5). It is considered that this cable did not experience a significant change due to the sidewall bearing pressure.

Control No. 11

This cable exhibited two low breakdown voltages (2.3kV and 5.8kV) on the cable tensioned at 460 pounds (11T6). On removal of the failed areas from the water, the cables broke down at 17.9kV and 20.5kV, respectively. This would lead credence to a position that the conductors were previously damaged during manufacture or when the jackets were stripped from the cables. If in fact the low breakdown voltages were caused by the sidewall bearing pressure at a pulling tension of 460 pounds, it would be reasonable to expect similar and lower breakdown voltages at the succeeding pulls at higher tensions, i.e. higher sidewall bearing pressures. Since this was not the case, it is reasonable to postulate that the low breakdown voltages were not caused by the sidewall bearing pressure.

Control No. 19

The percent difference in average breakdown voltages and the ratio of difference in the averages divided by the average of the standard deviations tend towards the high side of acceptable limits. This is considered to be due to the exceptionally high breakdown voltages for the virgin cables and the two relatively low breakdown voltages for the tensioned cables. In this case, it is desirable to calculate the ratio of the lowest breakdown voltage for the tensioned cable to the highest operating voltage to ground. This ratio calculated to be ~110. In addition, the breakdown stress corresponding to 29.8kV is 500 volts/mil assuming a 60 mil wall thickness of insulation. This is a reasonable breakdown stress for 600 volt rated insulation. Although the breakdown voltages for the tensioned cables are lower than for the virgin cables, this cable subjected to the sidewall bearing test, would be considered to be more than adequate for operation on a 600 volt rated circuit.

Control No. 27

It appears that the breakdown of the virgin cable at 67kV (27V5) was a terminal related failure and therefore should not be included in the analysis.

Control No. 28

For this test, breakdown voltages which occurred at the cable termination were not considered in our analysis. The values of difference in average breakdown voltages consequently change from -9.5% to -6.5%. The ratio of change in average breakdown voltage to average standard deviation changes from -1.37 to -1.07. It is worthy of mention that the 58kV breakdown voltage is an isolated failure of a single cable in five cable pulls performed at essentially the same tension/SWBP. The breakdown voltage of 58kV on tensioned pull 28T6 is of unknown cause and may be associated with a defect in the as manufactured cable.

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TABLE 1
COMPARISON OF CALCULATED SIDEWALL BEARING PRESSURES

Control No.	Sample No.	Cable Description	No. of Cables Pulled	Columns 1 SWBP Lbs/Ft	Columns 2 SWBP Lbs/Ft
1	335	7/C 12	1	1563	1525
2	593	7/C 14	1	1541	1503
3	228	9/C 14	1	1541	1503
4	685	7/C 14	1	1563	1525
5	45	7/C 14	1	1362	1329
6	794	3/C 16+G	1	643	627
7	259	3/C 16+G	1	670	654
8	1168	5/C 16+G	1	937	915
9	323	12/C 16+G	1	1228	1198
10	40	2/C 16	1	447	436
11	131	3PR 16+G	1	1127	1100
12	1067	12/C 16+G	1	1496	1460
13	1173	2/C 16+G	1	770	752
14	1003	1/C 14	5	839	742
15	577	1/C 14	5	602	409
16	632/637	1/C 6	5	2027	1408
17	150	1/C 6	5	1398	1015
18	740	1/C 2	5	1862	1653
19	58	1/C 2	5	1957	1742
20	1114	1/C 2	5	1769	1543
21	1046	1/C 6	5	1408	1127
22	1108	1/C 4	5	1796	1497
23	502	7/C 12	1	1585	1547
24	26	1/C 14	5	864	813
25	440	1/C 14	5	619	555
26	5	1/C 6	5	-	-
27	103	1/C 2/0	3	3104	3007
28	197	1/C 2/0	3	2889	2833
29	5000	Coax RG59B/U	1	373	363
30	5001	2 Coax W/TPs	1	1242	1210
31	5002	7/C 14	1	1697	1656
32	5003	7/C 12	1	1831	1787

Column 1 - TVA report
Column 2 - Calculated values

TABLE 2
SUMMARY OF DIELECTRIC BREAKDOWN VOLTAGES
OF VIRGIN AND TENSIONED CABLES

Control No.	Sample No.	Cable Description	No. of Cables Pulled	Max. Tension Pounds	SWB Lbs/Ft	Average Dielectric Breakdown Voltage: kV - RMS V	kV - RMS T	% Change	KV_{T-V}/σ Avg
1	335	7/C 12	1	700	1525	31.1	31.7	2.1	0.25
2	593	7/C 14	1	690	1503	21.2	19.1	- 9.9	-0.69
3	228	9/C 14	1	690	1503	35.6	32.2	- 9.5	-0.59
4	685	7/C 14	1	700	1525	23.7	20.0	-15.7	-1.06
5	45	7/C 14	1	610	1329	23.8	23.2	- 2.4	-0.22
6	794	3/C 16+G	1	288	627	22.9	21.8	- 4.9	-0.34
7	259	3/C 16+G	1	300	654	17.5	17.5	0.4	0.05
8	1168	5/C 16+G	1	420	915	20.2	19.7	- 2.2	-0.11
9	323	12/C 16+G	1	550	1198	25.6	26.9	5.2	0.33
10	40	2/C 16	1	200	436	13.8	12.5	- 9.6	-0.94
11	131	3PR 16+G	1	505	1100	22.4	20.2	- 9.7	-0.29
12	1067	12/C 16+G	1	670	1460	19.2	19.9	3.9	0.42
13	1173	2/C 16+G	1	345	752	24.6	25.8	4.8	0.45
14	1003	1/C 14	5	550	742	35.5	33.2	- 6.4	-0.73
15	577	1/C 14	5	520	409	34.0	31.8	- 6.5	-0.37
16	632/637	1/C 6	5	3220	1408	35.9	38.2	6.4	0.73
17	150	1/C 6	5	2200	1015	35.9	35.8	- 0.1	-0.02
18	740	1/C 2	5	2620	1653	45.7	44.3	- 3.2	-0.59
19	58	1/C 2	5	2760	1742	45.8	39.2	-14.4	-1.20
20	1114	1/C 2	5	2700	1543	34.4	33.9	- 1.4	-0.12
21	1046	1/C 6	5	2200	1127	36.0	39.2	8.9	1.14
22	1108	1/C 4	5	2780	1497	51.0	49.6	- 2.6	-0.21
23	502	7/C 12	1	710	1547	22.8	22.6	- 0.6	-0.03
24	26	1/C 14	5	805	813	21.7	30.1	39.0	2.61
25	440	1/C 14	5	510	555	41.2	37.5	- 9.1	-0.92
26	5	1/C 6	5	-	-	-	-	-	-
27	103	1/C 2/0	3	6500	3299	93.4	100.0	7.1	0.89
28	197	1/C 2/0	3	6050	3079	100.0	90.5*	- 9.5*	-1.37*
29	5000	Coax RG59B/U	1	132	363	52.0	53.2	2.3	0.12
30	5001	2 Coax	1	440	1210	38.4	38.1	- 0.8	-0.08
		TP's	1	440	1210	20.0	18.8	- 6.0	-0.46
31	5002	7/C 14	1	760	1656	28.7	26.4	- 8.1	-0.58
32	5003	7/C 12	1	820	1787	28.8	32.6	13.1	0.51

V = Virgin cable
T = Tensioned cable

* Excluding terminal failures at less than 90kV, the results are 93.5, -6.5 and -1.07, respectively.