DIAGNOSING HIGH-POTENTIAL TEST FAILURES
IN LARGE WATER-COOLED HYDROGENERATORS

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Abstract - This paper describes the effort of the Bureau of Reclamation to:

1. Determine the reason for an increasing failure rate when performing routine stator winding maintenance a-c high-potential tests
2. Develop a measurement system to determine which stator bars are in imminent danger of failure
3. Develop a repair program to alleviate the failure problem.

Introduction

The Bureau of Reclamation owns and operates three 700-MW, 15-kV hydrogenerators having water-cooled stator windings at the Grand Coulee power complex on the Columbia River in the state of Washington. Units 22, 23, and 24 have 486 slots with 6 parallel circuits per phase of 27 coils each. The groundwall insulation is composed of epoxy binder and mica mat tapes. Alternating strips of conductive and nonconductive RTV (room temperature vulcanizing) material are molded to the sides of the coils to create an interference fit that secures the coils in the stator slots. The water cooling system uses deionized distilled water and operates at 60 pounds per square inch. Five coils are connected in series in each loop of the cooling system.

Recently, routine maintenance a-c high-potential tests of 21 kV rms resulted in a steadily increasing number of stator winding groundwall insulation failures. Almost all the failures occurred in the end turn area 1-1/2 to 3 inches out of the stator iron, both above and below the stator core. Water in the groundwall insulation was suspected as the probable cause because these machines have a history of water leaks in the cooling water system interconnecting fittings. Dissection of a failed coil within 1 week of failure revealed free water in the groundwall insulation in the area of the fault. The presence of water caused extensive delamination of the taped layers and softening of the epoxy binder. Insulation on the bar samples could be easily unwrapped. The insulating tapes were found to be extremely soft and pliable. Previous coil failures had gone unexplained because failed specimen samples were stored for weeks before examination. During that time, the very low concentrations of water responsible for the failure evaporated.

Initial Failures

During routine maintenance a-c high-potential tests on unit 23 in March 1988, two stator bars sustained groundwall failures in the end turn area near the semiconductive slot paint. The high-potential test was 21 kV rms line-to-ground to be maintained for 1 minute. The faulted bars were replaced and the unit returned to service after passing a reduced a-c high-potential test of 15 kV rms for 1 minute. Since the unit operates at 15 kV rms line-to-line, it was believed that a successful test

at 15 kV rms line-to-ground gave some assurance of insulation integrity and reduced the risk of another groundwall insulation failure. At that time, the failure mechanism was still unknown.

In July 1988, unit 22 was scheduled for an annual warranty inspection of the stator winding and core. This unit is identical in construction to unit 23. Due to the groundwall failures on unit 23, the test voltage to be applied to each phase of unit 22 was reduced to 19 kV rms line-to-ground. The results of these tests on July 26, 1988, were as follows:

1. Phase A - The bar in the front of slot 97 failed below the stator iron at 11.2 kV rms as the voltage was being raised.
2. Phase B - The bar in the front of slot 315 failed below the stator iron at a sustained voltage of 18.6 kV rms after 26 seconds.
3. Phase C - The bar in the front of slot 106 failed above the stator iron at 14.3 kV rms as the voltage was being raised.

All of these failures occurred 1-1/2 to 2-1/2 inches from the end of the stator core iron in the straight portion of the bars (see figure 1). Close physical inspection of the failed bars in the stator slots revealed no prior physical damage or other obvious reasons for the failures.

Figure 1 - Simplified view of a stator winding end turn

Dissection of previous failure areas (in 1987) had revealed tape delaminations near the conductor. It was observed that the mica mat tapes easily unrolled and were quite flexible. Fully cured tape systems normally do not exhibit these characteristics. The generator manufacturer's analysis had indicated normal curing of the tape. Although the insulation appeared free of moisture, the general consensus of Reclamation engineers was that the tapes had been wet and that moisture had destroyed the epoxy binder between tapes. However, no leaks in the water-carrying strands of these bars could be located.

Prior to July 26, 1988, all failed coils had been carefully removed from the machine and shipped to the generator manufacturer for dissection and analysis. This process required time, and usually 1 to 2 months elapsed between failure and dissection. No moisture was ever found in these examinations. Reclamation engineers were becoming increasingly suspicious that the moisture was escaping from the insulation during the time that elapsed between failure and dissection. Therefore, an immediate dissection would be performed on the July 1988 failures to determine if water was causing the failures. Arrangements were made for Reclamation research and design engineers to travel to the project to participate in the investigation on July 28, 1988. The failed stator bar in the front of slot 106 was removed on that date and prepared for dissection.

Investigation of the failed bar from slot 106 began on Friday, July 29, in the afternoon. The failure was located on the leading side of the bar about 2 inches above the point where the top of the stator iron had intersected the bar (see figure 1). The failure area was easily identified by the hole in the groundwall. The bar was sectioned using a power hacksaw, with the first cut 2 inches below the failure at the approximate location of the intersection of the top of the stator iron. There was no evidence of moisture in this cut. The next cut was made 2 inches above the failure, which yielded a specimen 4 inches long with the fault in the middle. There was visual evidence of moisture in the groundwall insulation in this cut. Discoloration (darkness) of the groundwall insulation on three sides of the strand bundle was apparent. The discoloration disappeared in a few minutes after being exposed to air. The moisture evaporated, leaving no visual indication of its former presence. The groundwall insulation was pried from the strand bundle in the specimen through two cuts made along the edges of the bar. The groundwall separated very easily and was damp to the touch on the inside. Free water did not appear, except when the insulation was squeezed or compressed. The insulation tapes separated easily and were quite flexible as had been discovered in previous dissections. The fault path went straight through the insulation. There was no tracking along the laminar planes of the insulating tapes.

Two additional cuts were made closer to the connection end. Moisture was evident at each cut, with greater amounts at the cut nearest the connection end. Water ran from the insulation during the cutting at this location. The water had travelled approximately 24 inches inside the groundwall insulation.

Numerous cooling water leaks have occurred in the cast copper connection fittings of these generators, particularly in unit 22. Improved quality control during construction reduced but did not eliminate leaks in units 23 and 24. Each end of each bar has a water header. The cast copper connection fittings

used to connect the water headers to form coils and groups of coils consist of 90° elbows and associated couplings (see figure 1). The leaks occur under the 3/8- to 1/2-inch-thick epoxy encapsulation encasing the cast copper connection fittings. The epoxy encapsulations, called "blister packs," are made by injection of epoxy into a mold. The mold extends about 1-1/2 inches over the groundwall insulation of the bar, ensuring a quality seal to the insulation. The blister pack on this particular bar in slot 106 had been replaced in November 1986, August 1987, and February 1988, and was in need of replacement again. The moisture source was never located, as is the problem with many of the leaks in these units. The leakage through the porous cast copper may be only a few drops per day, or in some instances per year, but when the moisture is sealed in, it is forced under pressure by the cooling water system into the groundwall insulation between tape layers. Evidently, when the moisture between tape layers moves into the area of a groundplane, such as is present with the semi-conductive slot paint, the bar is in imminent danger of failure should sufficient voltage be present on the strand bundle.

Subsequent dissection of the other two July 26 bar failures in the presence of the generator manufacturer's representatives on August 3, 1988, yielded the same results. Moisture had migrated from leaks at the connectors through the layers of the groundwall insulation to the area of the stator groundplane, resulting in insufficient insulation strength and subsequent failure during the a-c high potential test.

Development of Stator Bar Insulation Capacitance Testing

After laboratory dissection of the bar removed from slot 106, capacitance measurements were made with a hand-held Data Precision Model 938 capacitance meter. A crude capacitor was constructed with a 4-inch band of aluminum foil wrapped around the coil. The foil and the copper strand bundles of the coil formed the capacitor plates with a dielectric medium consisting of the coil insulation. Measurements were made of dry and wet bar samples of end turn areas of bars. A typical dry bar reading was about 4.0 picofarads and a typical wet bar reading was about 8.0 picofarads. This 2-to-1 ratio of capacitance between virtually identical segments of insulation was due to the difference in dielectric constants caused by the moisture in one of the samples. The dielectric constant of dry mica versus distilled water is 6-to-80. Therefore, a small amount of water in the insulation makes a relatively large difference in capacitance.

Further experimentation led to the development of a metallic clip that slipped over the edge of the end turn portion of the bars. The clip consisted of parallel 2-inch by 2-3/8-inch aluminum plates separated by a 1-1/4-inch block of PVC (polyvinyl chloride). Capacitance was measured between the parallel plates. Insertion of a section of dry stator bar into the clip resulted in a capacitance reading of 4.0 picofarads. Insertion of the wet section of the bar from slot 106 resulted in a capacitance reading of 7.5 picofarads, even though the sample appeared to be dry. These readings were made with the clip mounted directly on the capacitance meter. Very short leads were used to connect the clip to the meter terminals.

A second clip was developed that would fit over the blister packs. The parallel aluminum plates were 1-1/16 by 3-1/4-inches, spaced 3-1/8 inches apart by a PVC block. This clip was also mounted directly to another capacitance meter with very short leads.

These capacitance meters have a feature that allows interlead capacitance to be nulled so the meters indicate the capacitance of only the test specimen. This feature worked well with short leads; however, the meter could not be nulled when 3-foot leads were used between the clip and the meter. Use of longer leads became necessary when measuring the capacitance of the stator bars in the machine due to physical limitations in the end turn areas.

Only limited experimental development of this test could be accomplished in the Denver Office laboratory. A complete survey of unit 22 was performed during the week of August 8, 1988. The capacitance of each bar and each blister pack on each end of the stator core was measured with the Data Precision capacitance meters with the test procedure developed in the Denver laboratory. A total of 3,888 measurements were made. The readings for the bars had 26.5 picofarads of interlead capacitance that could not be nulled but was subsequently subtracted from each reading.

Although the bar readings from unit 22 were relatively small (averaging 4.0 to 5.0 picofarads), some readings were detectably higher (6.0 to 10.9 picofarads). These high-reading bars were suspected of having moisture in the groundwall insulation. Two bars were selected for removal to verify that the capacitance readings were a valid indication of moisture in the groundwall insulation. The bar in the front of slot 65 (having a capacitance of 9.1 picofarads) at the turbine end, and the bar in the front of slot 391 (having a capacitance of 10.9 picofarads) at the turbine end were selected for removal. These bars also had a history of leaks and blister pack replacements. Physical inspection at the time of the survey indicated probable moisture problems. Tapping on the surface of the insulation produced dull, soft sounds in the areas where the high readings occurred. Tapping other areas produced sharp ringing sounds. A slight degree of softness could be detected when the insulation that sounded dull and soft was squeezed.

The results of the unit 22 survey were sent to the generator manufacturer on August 12, 1988. The manufacturer was also notified that the bars in the front of slots 65 and 391 were to be removed to confirm the accuracy of the capacitance measurements. On August 16, 1988, the generator manufacturer notified Project personnel they wished to participate in the investigation of the two bars being removed and that they were bringing specialized instrumentation to further develop the capacitance evaluation process. On August 17, 1988, the two bars were removed from the generator and extensive onsite testing began using several types of capacitance meters and various electrode configurations in an effort to optimize the measurement procedure.

Refinement of Stator Bar Insulation Capacitance Measurements

The original electrode configuration used onsite measured the capacitance of the stator bar between two parallel plates. This placed the insulation on either side of the bar in series between the plates, thus effectively decreasing the total capacitance measurement. The refined measurement system used the strand bundle in the center of the bar as one electrode and measured the capacitance to two plates on either side of the coil. This placed the insulation on either side of the bar in parallel, effectively increasing the total capacitance measurement. The plates were mounted in the jaws of a spring-type clip similar to

those used on battery jumper cables. Measurement consistency was greatly improved after the electrodes were lined with soft, semiconducting material. Clamping onto the sides of the stator bar excludes air from the measurement and sets the position of the electrodes when the capacitance measurement is made. Proper shielding must be used with this system inside the generator because adjacent bars also act as electrodes. Without shielding, the readings will include capacitance from the clamp electrodes to those adjacent bars, thus reducing the sensitivity of the measurements.

The manufacturer used three different instruments when making the measurements:

1. Doric C-meter, Model 132A
2. Wayne-Kerr capacitance-dissipation factor multiple-frequency bridge
3. Micro Tech programmable multiple-frequency bridge

The Doric C-meter is a hand-held, battery-powered, auto-ranging device that is portable and easy to operate.

The Wayne-Kerr instrument is a laboratory-type, multiple-frequency bridge that is easy to operate but not very portable. The lowest operating frequency is 100 hertz. The instrument also determines the dissipation factor of the test specimen.

The Micro Tech instrument is a laboratory-type, programmable, multiple-frequency capacitance bridge. It is more difficult to operate than the Wayne-Kerr and is not very portable. Any test frequency can be selected down to 0.1 hertz.

Each measuring system has its advantages and all appear to make adequate measurements. The Doric C-meter is ideal for making a quick maintenance-type check of the stator winding. If a suspicious reading occurs, a more sophisticated instrument can be used to obtain a more definitive measurement.

The Wayne-Kerr bridge determines dissipation factor, which later tests have shown to be almost as useful as capacitance in indicating moisture in the groundwall insulation. High dissipation factor is also an indication of delaminated groundwall insulation.

The Micro Tech bridge allows the test frequency to be selected down to 0.1 hertz. Tests have shown that the ratio of capacitance between dry and wet groundwall insulation increases with decreasing frequency; i.e., at 100 hertz the difference between wet and dry insulation is a factor of 2, at 1 hertz the factor is 3, and at 0.1 hertz the factor is almost 4.

Extensive experimentation with different electrodes led to the selection of the system that uses the center conductor of the coil as one electrode and 1-inch-wide plates on either side of the coil as the other electrode. The plates are shielded with guard electrodes to prevent the meter from measuring additional stray capacitance from adjacent coils.

Manufacturer's Survey of Unit 22

The generator manufacturer used the guarded electrode system in conjunction with the Wayne-Kerr bridge operating at 100 hertz to conduct a survey of

unit 22 with the bulk of the winding in place in the stator. Average capacitance and dissipation factor readings were 23.05 picofarads and 5.29 percent, respectively. The highest capacitance and dissipation factor readings were 73.4 picofarads and 25.5 percent, respectively. The system was relatively easy to use and provided excellent repeatability. All of the bars on each end of the winding were measured. The blister packs were not measured.

Expanded Tests of Selected Bars

The next objective was to determine the significance of the range in readings from unit 22 in terms of water content in the insulation and danger of electrical failure. A set of 30 top stator bars was selected for an extensive series of tests in an attempt to correlate these readings to other standard evaluation-type tests. Different values of measured capacitance and dissipation factor were used in the test bar selection process to determine which readings indicate that the groundwall of the bar has sufficient moisture to place the bar in imminent danger of failure. Some of the bars had lower than average capacitance (less than 23 picofarads) with relatively high dissipation factor (greater than 5.0 percent). Several of these were included in the expanded tests to determine the significance of this abnormality. Capacitance values for the selected bars ranged from a low of 16.1 picofarads to a high of 73.4 picofarads. Dissipation factors ranged from a low of 3.0 percent to a high of 18.5 percent.

The expanded testing included:

- new capacitance and dissipation factor measurements
- Doble power factor measurements at 3, 6, and 9 kV
- a d-c ramp test to 15 kV
- an a-c high-potential withstand test of 31 kV rms for 1 minute
- a d-c high-potential withstand test of 52 kV for 1 minute.

This series of tests required that the bars be electrically isolated from the rest of the winding. The test voltages were selected by the generator manufacturer and approved by Reclamation. After completion of the electrical tests, the generator manufacturer performed moisture measurements on samples of the bar groundwall insulation taken from the end turn area.

Expanded Test Results

The bars were isolated during the week of September 26-30, 1988, when approximately 3/4-inch was cut out of the jumper connections. Plastic bags were placed over the cut ends to minimize evaporation of water from the insulation. The expanded tests began October 4, 1988, and finished on October 7, 1988. All tests were completed on each bar before moving to the next bar. Capacitance and dissipation factor measurements were conducted on several bars with results virtually identical to those previously obtained, so this portion of the expanded testing was eliminated.

The a-c high-potential withstand tests (refer to table 1) resulted in three insulation failures and five tests where the test set tripped off before 60 seconds because of arcing-type leaders appearing across the grading paint portion of the bar. The d-c

high-potential withstand test resulted in one bar insulation failure and indicated that one bar had insulation of very poor quality. On the poor quality insulation test, breakdown did not occur; however, the current was still increasing at the end of 60 seconds when the test was terminated. This bar was considered to have failed the test because it probably would have incurred a breakdown given sufficient time at 52 kV d.c. All the failures occurred on the end of the bar having the high capacitance reading and occurred 2 to 3 inches out of the stator iron.

Significant correlation was found between high capacitance and dissipation factor and the high-potential test failures. Moisture content also correlated quite well with the high capacitance and dissipation factor readings. However, as is normally the case with this type of testing, there are exceptions, and a general statement such as "all bar segment capacitance readings over 40.0 picofarads will fail" cannot be made. One bar having a capacitance of 36.0 picofarads and a dissipation factor of 12.0 percent failed the test, while four bars with both higher capacitance and dissipation factor withstood the test voltage. High capacitance and dissipation factor appear to be an excellent indicator of water in the insulation, but until water penetrates to the ground-plane established by the semiconductive paint, the bar will probably pass a high-potential withstand test. Unfortunately, due to interbar ties for mechanical security, it is impossible to measure the capacitance and dissipation factor of the bar immediately above the grading paint.

To take both high capacitance and high dissipation factor into account, the generator manufacturer recommended the creation of an empirical number (C+DF) by addition of the capacitance (C in picofarads) and the dissipation factor (DF in percent). It was observed that all the bars that failed the expanded series of tests had a number C+DF greater than 48. Similarly, all the bars that were found to be in either "very bad" or "quite bad" condition, on the basis of total bar electrical tests or water content, had a C+DF number greater than 38.5. One exception to these statements was bar 340 that had a combined number of 52.4 and passed all of the electrical tests. Unfortunately, no moisture measurement was made on this bar.

The most sensitive test for detecting bars close to failure appears to be the Doble power factor test. Normal power factor for the subject bars at 9 kV was found to range from 1.0 to 2.0 percent. For three bars that failed, the power factor was in the 12- to 14-percent range. All bars having power factors over 6.0 percent failed. Bar 169, having the questionable d-c high-potential withstand test results, is considered to have failed the test and was included in the above group of bars having high power factor. The main disadvantage to Doble power factor testing is that the bar must be electrically and therefore mechanically isolated from the rest of the winding.

The remaining 28 bars in unit 22 with high C+DF numbers (greater than 38.5) were given the expanded tests in November 1988. If the Doble power factor at 9 kV rms was less than 3.0 percent, the bars were given a 25-kV rms a-c proof test for 1 minute. Bars having Doble power factors in excess of 3.0 percent were given a 31-kV rms a-c proof test for 1 minute and a 52-kV d-c proof test for 1 minute. This series of tests resulted in two a-c high-potential withstand test failures, four d-c high-potential withstand test failures, and one that did not fail but had questionable test results.

Expanded Tests for Units 23 and 24

Capacitance and dissipation factor surveys were conducted on units 23 and 24 using the same measurement system as was used on unit 22. Unit 23 had 10 bars with C+DF numbers greater than 38.5. In unit 24, thirty-six bars were found having C+DF numbers greater than 38.5. The expanded series of tests were conducted on 16 isolated bars in unit 24 using the same selection criteria as the second set of extended tests on unit 22. The bar in the top of slot 33 failed the a-c high-potential withstand test as the test voltage reached 31 kV rms. The Doble power factor on this bar was 6.36 percent. The maximum power factor on the remaining 15 bars was 3.81 percent; all these bars successfully passed the expanded tests. See table 2 for data.

Three of the ten bars in unit 23, which had C+DF numbers greater than 38.5, were selected for isolation and expanded testing. None of the bars had Doble power factors in excess of 3.0 percent and all passed the 25-kV a-c high-potential withstand test. However, the bar in slot 318 was replaced because the C+DF number was 72.2.

Statistical Analysis

Statistical analysis was done by both Reclamation and the generator manufacturer using the data gathered by the generator manufacturer on units 22 and 23. The average capacitance of the bars of the two generators is practically identical with those of unit 22 at 23.05 picofarads and unit 23 at 23.12 picofarads. Unit 22 has a standard deviation of 5.29, compared with 3.15 for unit 23. The standard deviation in capacitance for unit 22 is 68 percent higher than the standard deviation in capacitance for unit 23. The analysis revealed a major difference in dissipation factor (DF) between the two units. The average DF for unit 22 was 51 percent higher than the average DF for unit 23 (5.37 and 3.56 percent, respectively). The standard deviation of the DF for unit 22 was 94 percent higher than the standard deviation of the DF for unit 23 (2.321 and 1.197 percent, respectively). When plotted together as shown in figure 2, these differences are emphasized, showing that unit 22 contains a much greater number of bars with wet groundwall insulation than unit 23.

Figure 2 - Overlay of dissipation factor for units 22 and 23

Recommended Repair Procedures

All concerned generally agreed that achievement of a zero cooling water leakage condition in the existing windings would be practically impossible. Replacement of the cast copper connections that are known to leak with forged copper fittings would alleviate some of the problem; however, replacement of the water boxes on each end of the bar would require an excessive amount of heat that would damage the groundwall insulation system, thereby requiring the bars to be reinsulated. The existing blister packs need to be removed to prevent water from being forced into the layers of groundwall insulation. In response to this dilemma, the generator manufacturer has proposed a different type insulation system for the copper end connectors. The new insulation system allows water to vent to the atmosphere should a leak occur (see figure 3). This system also provides a high level of insulation between adjacent end connectors to prevent end turn flashovers.

One of the main objectives of this investigation was to develop short-term repair procedures to allow units 23 and 24 to return to commercial service for 6 to 12 months with some degree of certainty that they would not suffer an online failure. All suspect stator bars were isolated and subjected to the expanded test series. All failed bars were replaced. All bars having C+DF numbers in excess of 38.5 were pressure tested with helium gas at 200 pounds per square inch (blister packs removed) to check for leaks. All defective connections were replaced or repaired. Groundwall insulation was sealed at water boxes by removing a narrow band of insulation adjacent to the box and applying Loctite 290 Weld Porosity Sealant to the strand interstices. Then, the new type of insulation system was applied to the copper connections. The new system uses self-amalgamating silicone rubber tape with a porous substrate that allows leakage water to vent to the atmosphere (see figure 3). Bar capacitance and dissipation factor will be monitored every 3 months and evaluated accordingly.

Figure 3 - New insulation system for copper end connectors

The long-term repair procedures embody basically the same requirements as the short-term fix, but also require the replacement of all blister packs and cast copper fittings. The repair procedures also include replacing the Teflon cooling hoses with a silicone rubber system and installing an enhanced leak monitoring system on the coolant head tank. Bar capacitance and dissipation factor will be monitored annually.

Replacement of the bars in generators already having water in the groundwall insulation is being contemplated. We realize that these bars will never again have the same groundwall insulation strength as dry bars since the insulation in the wet areas is now permanently delaminated. However, experience gained with the operation of units 23 and 24 should indicate whether the water in the groundwall insulation will continue to migrate toward the groundplane and cause further problems in the event that entry of additional water into the insulation has been halted. Then again, the water in the groundwall insulation may cause other problems unforeseen at this time. The decision on the replacement of these bars is being delayed until some operating experience has been reviewed.

Evaluation of Stator Bar Insulation Capacitance Measurement System

The present measurement system is very effective in determining if moisture is present in the end turn portion of the stator bar. The system is relatively easy to use and the measurements are repeatable. Measurements are quantitative in that the higher capacitance and dissipation factor readings indicate more water in the insulation. Capacitance measurements are not accurate in predicting groundwall failure unless the measurement can be made adjacent to the grading paint on the bar. In the case of units 22, 23, and 24 at Grand Coulee, this is not possible due to the interbar mechanical bracing.

Table 1. - Unit 22 expanded winding bar test data.
First series: 10/4 through 10/7/88

Slot No.	Capacitance (PF)	Dissipation Factor (%)	C+DF	9-kV Power Factor (%)	A-C Hi-pot. (kV)	D-C Hi-pot. (kV)
F3	31.6	8.2	39.8	3.27	31	52
F9	56.5	18.3	74.8	5.13	31	52
F34	25.0	8.0	33.0	1.57	31	52
F38	24.0	8.0	32.0	1.55	31	52
F48	28.0	8.0	36.0	1.02	GPL	52
F61	21.0	7.0	28.0	.89	31	52
F148	40.0	12.0	52.0	1.50	31	52
*F169	32.0	9.0	41.0	2.03	31	52 Ques.
F170	30.0	4.0	34.0	1.04	31	52
F189	29.0	3.0	32.0	1.47	31	52
*F193	36.0	12.0	48.0	14.29	31	52 9 s
F223	21.0	7.0	28.0	1.08	31	52
F227	37.0	14.0	51.0	1.44	31	52
F291	20.0	7.0	27.0	1.08	31	52
F306	23.0	6.0	29.0	1.97	31	52
F327	15.0	6.0	21.0	1.07	31	52
F337	31.0	11.0	42.0	4.97	GPL	52
F340	41.0	11.0	52.0	4.17	31	52
F341	22.0	6.0	28.0	1.35	31	52
*F349	48.0	16.0	64.0	7.54	31 29 s	
F362	24.0	9.0	33.0	1.64	31	52
F368	17.0	8.0	25.0	1.04	31	52
F412	26.0	10.0	36.0	1.38	31	52
*F418	73.0	17.0	90.0	13.1	26	
F443	23.0	8.0	31.0	1.36	31	52
F449	27.0	12.0	39.0	.91	GPL	
F451	43.0	14.0	57.0	2.28	GPL	52
F453	21.0	8.0	29.0	1.03	GPL	52
F464	33.0	12.0	45.0	.93	31	52
*F484	52.0	19.0	71.0	14.79	6	

Second series: 11/21/88

Slot No.	Capacitance (PF)	Dissipation Factor (%)	C+DF	9-kV Power Factor (%)	A-C Hi-pot. (kV)	D-C Hi-pot. (kV)
B64	24.5	18.0	42.5	1.56	25	
*B81	52.4	17.6	70.0	4.49	25	35
F140	60.7	20.5	81.2	3.84	25	52
F143	33.3	22.1	55.4	1.04	25	
B148	63.0	20.9	83.9	2.98	25	52
*F151	62.5	17.0	79.5	7.00	25	45
F161	50.9	15.0	65.9	2.82	25	
F164	40.2	10.5	50.7	1.91	25	
F190	25.6	15.6	41.2	1.81	25	
*F259	58.6	18.6	77.2	7.13	31 16 s	
*F265	51.4	14.9	66.3	5.30	31	52 10 s
B268	49.5	14.2	63.7	5.05	25	52
*F272	59.5	17.1	76.6	22.09	15	
B308	26.0	25.5	51.5	1.00	25	
B309	35.3	21.9	57.2	1.17	25	
B330	42.8	12.3	55.1	2.88	25	
B341	42.8	12.3	55.1	1.24	25	
B363	84.1	6.5	90.6	1.43	25	
B375	51.5	16.0	67.5	4.45	25	52
F375	43.0	10.6	53.6	4.77	31	52
F386	64.0	19.0	83.0	1.40	25	
F421	54.0	18.5	72.5	2.49	25	
B421	24.1	16.0	40.1	1.02	25	
*F428	54.7	16.5	71.2	5.65	31	42
B452	56.4	18.0	74.4	1.95	25	
B455	37.5	14.0	51.5	.88	25	
B458	30.4	7.3	37.7	.91	25	
B485	41.6	13.0	54.6	6.06	31	52

*Denotes failures

GPL Denotes grading paint leader

Table 2. - Expanded winding bar test data. 11/4/88
Unit 24

Slot No.	Capaci- tance (PF)	Dissi- pation Factor (%)	C+DF	9-kV Power Factor (%)	A-C Hi-pot. (kV)	D-C Hi-pot. (kV)
B6	39.0	17.5	56.5	2.80	25	
*F33	42.8	13.8	56.6	6.36	30	
B46	37.3	16.8	54.1	1.59	25	
B335	73.9	19.4	93.3	2.11	25	
F377	34.9	18.7	53.6	3.53	31	52
B383	55.4	17.0	72.4	3.81	31	52
F401	30.1	16.0	46.1	1.49	25	
B406	30.3	17.6	47.9	3.42	31	52
F431	27.9	18.3	46.2	3.67	31	52
B434	30.0	20.0	50.0	1.59	25	
B435	32.9	24.9	57.8	3.79	31	52
F465	39.7	21.7	61.4	3.20	31	52
B468	63.9	4.9	68.8	1.07	25	
B469	101.7	16.0	117.7	2.97	31	52
B474	61.0	13.2	74.2	1.34	25	
B476	53.3	16.7	70.0	1.63	25	

Unit 23

Slot No.	Capaci- tance (PF)	Dissi- pation Factor (%)	C+DF	9-kV Power Factor (%)	A-C Hi-pot. (kV)	D-C Hi-pot. (kV)
F108	24.8	22.5	47.3	<3.0	25	
B163	42.5	14.4	56.9	<3.0	25	
F318	57.3	14.9	72.2	<3.0	25	

*Denotes failures