GR-83-2

GRAND COULEE G-19 INSULATION INVESTIGATION

March 1983
Engineering and Research Center

U.S. Department of the Interior
Bureau of Reclamation
Division of Research
Power and Instrumentation Branch

LIBRARY
JAN 4 2002
Bureau of Reclamation
Reclamation Service Center

7-2090 (4-81)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. GR-83-2	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Grand Coulee G-19 Insulation Investigation		5. REPORT DATE March 1983
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) B. Milano, R. L. Becker, R. C. Arbour, H. W. Dugan		8. PERFORMING ORGANIZATION REPORT NO. GR-83-2
9. PERFORMING ORGANIZATION NAME AND ADDRESS Bureau of Reclamation, Engineering and Research Center, Denver, Colorado 80225		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Same		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
Microfiche or hard copy available at the E&R Center, Denver, Colorado

ed. REC(WFA)

16. ABSTRACT
A discussion of the Grand Coulee G-19 stator insulation field test investigation and analysis is presented. The investigation and analysis centers around slot discharge, grading, paint girth burning, and high corona probe meter readings.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS-- /high voltage/direct current/*rotating machines/stators/insulation/electric current/test equipment/tests/*electrical insulation tests/generators/leakage current/dialectrics

b. IDENTIFIERS-- /slot discharge/grading paint/corona

c. COSATI Field/Group 09C COWRR: 0901 SRIM:

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (THIS REPORT) UNCLASSIFIED	21. NO. OF PAGES 7
	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. PRICE

GR-83-2

GRAND COULEE G-19
INSULATION INVESTIGATION

by

B. Milano,

R. C. Arbour,

R. L. Becker,

H. W. Dugan

Power and Instrumentation Branch

Division of Research

Engineering and Research Center

Denver, Colorado

March 1983

SI METRIC

UNITED STATES DEPARTMENT OF THE INTERIOR • BUREAU OF RECLAMATION

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

Concepts presented are of the authors only and are not necessarily official views of the U.S. Government.

CONTENTS

	Page
Introduction	1
Summary and Conclusions	2
Test Results and Analysis	3
Slot Discharge Tests	3
Corona Probe Tests	4
Ramped d-c Tests	4
Grading Paint Repairs	5

INTRODUCTION

Several years ago an inspection of the winding installed in unit G-19 at the Grand Coulee Third Powerplant revealed that the stator coils had become loose and were vibrating radially within the slots. This vibration had caused extensive wear of the coil insulation and the semiconductive shielding paint system. This wear was in the form of a stepladder pattern. The predominant damage occurred to the rear surface of the coil in the bottom of the slot. The coil side had wear which was restricted mainly to the semiconductive shielding paint system. Due to power committments and other factors, temporary rewedging repairs were performed to help stabilize the coil vibration until permanent repairs could be made.

These permanent repairs included replacing coils that were considered questionable due to serious insulation damage, and rewedging the entire winding. Attempts were made to repair the semiconductive paint shielding system by applying new semiconductive paint to the coils that were still in the winding. This repair method proved ineffective when several of these recoated coils were removed for other reasons. It was discovered that the newly applied paint covered less than 25 percent of the damaged shield areas. Possibly the removal of the wedges, cleaning, and the rewedging operations contributed to further deterioration of the semiconductive shielding, and grading paint systems. Only a minor effort was made to repair the semiconductive coil coating by selectively injecting semiconductive paint into the air ducts adjacent to those coils that had marginally worn insulation. These repairs were made approximately two years prior to this investigation. Some areas of the G-19 winding have undergone two rewedging operations which also could have contributed to the semiconductive paint system damage.

Recently the project personnel removed the rotor to repair the turbine and inspect the stator, and based on what they saw, decided to make some grading paint repairs. There were grading paint burn rings on several coils. The bars were still very tightly wedged at this time; however, about 16 slots had somewhat high corona probe readings. The high corona probe readings, high ozone concentrations during operation, and the grading paint burning problem prompted project personnel to request assistance from the Engineering and Research Center to evaluate the conditions of the insulation system.

SUMMARY AND CONCLUSIONS

The most important fact regarding the future of this winding pertains to the potential of the slot discharges to erode the insulation system. It is too early to tell now, but before making a final evaluation, we will perform additional slot discharge investigations on G-19, G-20, and G-21, and obtain more data from the accelerated life test which will be continued.

The Bureau standard a-c withstand tests should be conducted yearly. This test would provide a considerable amount of short term insurance at relatively low cost. However as always, demand, scheduling, operating procedures, and individual project concerns must be considered when evaluating the worth of a yearly a-c withstand test. One important consideration is the difference between an inservice failure and a test-related failure, with respect to both iron damage and outage time. A unit failure during a test, if the test is scheduled and performed during a low demand period, may have much less impact than an inservice failure during a peak load period.

Three concerns relating to this insulation system are the grading paint girth burning, the two coils with the high corona probe readings, and the slot discharges. The grading paint girth burning is the least troublesome problem to deal with at this time. Repairs have already been made. Future visual inspections can quickly determine the extent of additional or recurring girth burning. The burning usually progresses at a very slow rate, and repairs can be scheduled and easily performed (with respect to other repairs). If future repairs are again necessary, a grading paint should be applied, which has substantially lower resistivity. Several sample specimens should be tested in the laboratory to determine the effects of a lower resistivity grading paint.

TEST RESULTS AND ANALYSIS

When we arrived at Grand Coulee, the Contractor had just finished removing the wedges from three slots that had high corona probe readings (slots 8, 9, and 10). They reinjected these slots with semiconductive paint in an effort to reduce the high corona probe readings, but this work did not result in lower probe readings. A lights-out test (winding energized at 7.5 kV a-c) revealed extensive glow-like discharges throughout most of the winding, both in the end turns and in the core area. One large area of the core had been completely rewound several years ago using new

and refurbished coils and had been wedged effectively to eliminate movement. This area was quite dark compared to the rest of the winding. The semiconductive shielding paint system in this area had not experienced the radial vibration imposed on those coils originally installed in the unit. Because of that, the semiconductive coating in this area had little or no wear damage; therefore, the glowing slot discharges from this portion of the winding was not evident here. Intermittent discharges of a higher energy level were observed at several points in the winding. Numerous grading paint areas either had glow rings or tracking, across their lengths. We were informed that subsequent grading paint repairs the week before had greatly reduced the observed glow and tracking in the end turn area.

The discharges we observed in the core slot area occurred wherever the semiconductive shielding paint had been destroyed. That is to say, discharges occurred wherever the paint had worn or flaked off. Attempts to repair the semiconductive shield by means of injecting additional semiconductive paint into the area of observed discharges simply moved the discharges to the new boundary established between the new semiconductive paint and the bare coil insulation surface.

After observing the lights-out test, we concluded that what was occurring in the winding could be referred to as mild slot discharge. The entire coil or major portion thereof was not discharging to ground, but only the very small area of the coil that lacked the semiconductive shield was actually discharging to ground. It may be these discharges that are producing the high ozone levels during normal operation.

Slot Discharge Tests

We connected the slot discharge test equipment to the winding by means of group jumper type capacitive couplers, and made slot discharge measurements with the unit energized at 7.5 kV a-c rms. Readings on the order of 200 mV (millivolts) were obtained. For comparison we performed similar slot discharge measurements on unit G-10 and obtained readings on the order of only 20 mV. Readings between 50 and 150 mV (depending on the pickup system design and quality) have been considered to be the alarm level.

A lights-out test on G-10 and G-13 was also performed for comparison purposes. Both units had the rotors removed in preparation for rewinding; therefore, it was quite easy for us to perform

these comparison type tests. During the lights-out test on G-10, only two spots (discounting the large area surrounding the failure) were discharging to ground. One discharge occurred on a resistive temperature detector lead, and the other on the side of a coil where a nick had been made in the semiconductive paint shield. On G-13, several discharge areas were observed on the end turns, but these were all due to the high amounts of contamination that existed in the unit due to the failure and resulting fire. In both units, no discharges were found in the slot areas.

Corona Probe Tests

The corona probe readings of the two suspect coils in G-19 dropped significantly and leveled off to a steady state value approximately 4 hours after initial energization. However, the readings of the suspect coils were still higher than what we consider good, and significantly higher than the rest of the winding even after 4 hours of applied voltage.

A review of the corona probe test data indicated there were not 16 slots to be concerned with, but only two (slots 16 and 108). Most of the other slots that had high readings were the result of cross coupling of the electrical activity into adjacent slots and electrically adjacent coils. After making this information known to the repair Contractor, they realized that the wrong wedges had been removed in the attempt to reduce the corona readings by injecting semiconductive paint into the slots. Therefore they removed additional wedges (slot 16) and injected semiconductive paint, in a final effort to reduce the high corona probe readings. The injection of semiconductive paint did not reduce the corona probe readings. This tends to indicate that the problem is internal to the coil rather than in the slot. Both of these coils operate near the line end of the string. In addition, the coil in slot 16 has been half-coil spliced.

Ramped d-c Tests

Ramped d-c tests performed on the grading paint seemed to indicate that the voltage-current characteristics were somewhat lower than expected (higher resistance for a given voltage). The resistivity of this paint is high, and is similar to other paint with which the Bureau has had trouble. Apparently these higher-resistance paints do not adequately grade the end turn voltage. This results in overheating, and in corona-related damage near to or at the semiconductive paint boundaries. The problem does not seem to exist with the lower resistivity paints, which grades the end

turn voltage over a greater distance, thereby reducing the voltage gradient and heat buildup. This prevents both overheating, and ionization-related damage. A resistance which is too low can also present a problem in the coil end turn areas, where the grading paint will have acted as an extension of the semiconductive paint, and all the voltage grading will have taken place at the grading paint insulation boundary. Also to be considered is the very poor adhesion quality of the semiconductive grading paint to the coil insulation surface, which may be complicating the girth burning and slot discharge problems. If this is the case, thermal cycling and vibration may greatly aggravate the problem.

Grading Paint Repairs

At the time of our investigation, repairs to the girth burns consisted of cleaning the areas, reestablishing the semiconductive coating at the junction of the coil and core, and applying a second full-length, or in some instances a third full-length coat of grading paint. Many coils already had the second coat applied during the major repair several years ago, the effect of which was not exactly known. Hopefully the additional paint will not only reestablish the grading paint circuit, but also act in parallel with the original coating(s) to reduce the overall grading paint resistivity. This may help to eliminate girth burning from recurring. However, the effects of the protective coating between the two layers of grading paint and the burned grading paint gap at the semiconductive-grading paint boundary may inhibit the two coatings from acting in parallel. The combined resistance of the two coatings may still not be sufficiently low enough to eliminate the girth burning. The girth burning and associated ionization can also be considered a form of discharging and is probably contributing in some degree to the excessive ozone and slot discharge readings obtained earlier.

It should also be pointed out that field conditions for the application of grading paint are somewhat less than ideal. The Contractor had problems applying an even and complete coat of grading paint. In many instances, the paint dripped and could not be applied to all surfaces of the repair area because of adjacent coil interference. The d-c ramp test results of the grading paint indicated vastly different resistance characteristics from coil to coil. This is probably the result of inadequate paint mixing and nonuniform application.

The two coils with the high corona probe readings constitute a more difficult problem. As a result of this investigation, we believe the problem to be internal to the coils. Any discharges that were occurring in the slots should have been eliminated or reduced when these coils and slots were reinjected with semiconductive paint. Because one of these coils had a half-coil splice, and both coils were located near the line end of the winding, further support our concern and contention that the problem is internal. The corona probe measurements indicate a marginal condition. The present corona probe levels have flagged these two coils as possible sources of trouble. These two coils should probably be periodically tested with the corona probe meter to check the rate of deterioration, if any. Any increase in probe readings over the next several years can be considered as an alarm condition. It would be advantageous to also back up the corona probe checkups with an a-c high-potential withstand test at 85 percent of the factory acceptance test level of twice rated plus 1000 volts (that is: 26.3 kV a-c rms). For the first three years, the corona probe and withstand test should be done yearly. If any significant increases in the corona probe readings are found, consideration should be given to replacing that coil.

The slot discharges involve the most difficult questions to be answered. At the time of this investigation, we informed project personnel that we had only an approximate idea of what the background (or normal) level of acceptable slot discharge was and that a comparison type of measurement between G-19, G-20, and G-21 (sister units) would be most informative since benchmark data on G-19 were not available. We also stated that even if G-19 had considerably higher discharge levels than G-20 and G-21, we could not tell if the discharges occurring would be of sufficiently high energy levels to erode the insulation. At the time, we proposed a laboratory accelerated life test on a sample of the G-19 insulation, which is now in progress. The test has been set up to simulate several realistic field conditions (including worst case) as accurately as possible. The test voltage is 7.5 kV a-c rms. Normal line-to-neutral voltage is 8.66 kV. The test has been accelerated by increasing the frequency from 60 to 600 Hz. Initially, the semiconductive paint started to either erode or oxidize, thereby increasing the area where there was no semiconductive paint. Shortly thereafter the surface of the insulation, where there was no semiconductive shielding paint, started to erode. The surface looked as though it had been etched. Numerous channels had developed perpendicular to the ground electrode used to represent a stator iron boundary. Next, the center of the unshielded area started to darken and took on a medium gray color. During this time, the etched-like indentations had continued to grow in depth, length, and

number. Although the testing is ongoing and still in the early stages, it appears that these low-density discharges are capable of eroding the insulation. One question that remains to be answered is, "Will the etching process stop when mica is encountered?" The major task will be in properly applying the various laboratory accelerated life test results. A preliminary report dealing with the details of the simulation and the initial results will be written in the near future.

JAN 4 2002
Bureau of Reclamation
Reclamation Service Center

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-922, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.