Why Forensic Analysis is a Critical Step in Motor Repair - Case Study - Part 1

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Forensic Analysis of Multiple Medium Voltage 3MW Self-Excited Generators Following Field Testing

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***Abstract*—Multiple medium voltage 3MW self-excited generators failed at startup following field testing. Initially it was reported that only insulation resistance and polarization index testing was performed. However, forensic evidence showed tunneling in the insulation system that could only come from high energy testing. In this paper we will discuss the steps in performing forensic investigations of electric machinery failure using Root-Cause-Failure-Analysis (RCFA) practices commonly applied in reliability engineering and the tests performed to provide evidence of the causes and hypotheses. The ability to determine the depth of an analysis based upon information provided will also be discussed.**

Keywords-Root Cause; Failure Analysis; Generator Failure; Insulation Failure; High Voltage Testing

I. INTRODUCTION

Immediately following in-service insulation testing two 3MW, self-excited, 4160 Vac generators failed. One of the two had been cleaned, dipped and baked within a 18 months of the failure. It was determined that an RCFA (Root Cause Failure Analysis) would be recommended.

The approach selected was PROACT® (PReserve, Order, Analyze, Communicate, and Track) in order to ensure a robust RCFA. As with most analysis, human input is fallable requiring the investigators to focus on the evidence and eliminate as many potential causes as possible.

The standard used for the analysis was the IEEE Std. 1415-2006, "IEEE Guide for Induction Machine Testing and Failure Analysis"[1], while teardown of the machine was performed to IEEE Std. 1068-2009, "IEEE Standard for the Repair and Rewinding of AC Electric Motors in the Petroleum, Chemical, and Process Industries"[2]. Data gathered utilizing both standards was used in determining root causes as well as providing guidance for corrective action.

The first machine failed immediately on startup while the second machine failed several months following testing. Limited operating and environmental data was provided and the associated third party testing company was not forthcoming with information. Both machines had just under 20 years continuous service life with complete overhaul service performed every five years.

II. THE PROCESS

There are primary steps to the RCFA process. The first step is to preserve whatever data is possible. This data includes: parts; documentation; elements of time and space; people; and paradigms. In the case of this study, the events and times leading to each failure, repair history and the generators were available.

The next step in the process is to put together a team to analyze and provide input. The team consisted of a facilitator, machine owner, and technicians involved in the dismantling and evaluation of the generator. Additional indirect team members consisted of industry experts who were contacted as required. The team is held together by a charter which was simply to identify the root causes of the generator failures.

The analysis, which is the focus of this paper, involves a series of cause and effect relationships. The data collected in the preserve portion of the process is utilized as the ultimate proof as to what did or did not occur. This portion of the study utilizes a logic tree that follows each hypothesis to a positive or negative conclusion. Root causes originate from flawed systems including: latent, organizational, human, and physical.

The next steps involve communication of findings and tracking the results of corrections to the root causes. While we discuss the findings in this paper, it is beyond the scope for the tracking portion of the process.

III. THE FIRST GENERATOR

The first generator was unable to start following maintenance testing. Initially it was discovered that the machine had an insulation to ground fault with the protective circuit preventing generation from occurring. The first three potential issues investigated were potentially a surge arrestor failure, lead insulation failure or winding failure.

A. Surge Arrestor Failure Analysis

Even though it was determined less likely that a surge or lightning strike caused the failure, the surge arrestors and lightning arrestors were tested. Both were rated for 5 kV and the surge arrestor was also rated for 2.5 MFD. Both were tested with a DC high potential tester until voltage would no longer pass and current increased on the instrument, which indicates the actual rating. In this case, both passed voltage at just over 5kV which passed them. The surge arrestor capacitance was tested with a Fluke® Model 189 multimeter and each phase indicated a range of 2.4 to 2.5 MFD. The surge arrestors and lightning arrestors were found not to be an issue and no further investigation along this direction was required.

The surge arrestor and lightning arrestor analysis also reduced the chance that an outside surge or lightning strike would have caused the insulation to ground failure. Data on whether or not these components were disconnected during testing was not available to the team.

B. Lead Insulation Failure

The location of the ground started with the separation of the surge arrestors and lightning arrestors from the circuit. The next step was to then break the neutral connection and use an insulation resistance tester to determine which phase was involved. It was determined that the fault was located in phase A as the test results were greater than 11 GigOhms on B and C and was identified as a direct short to ground on A phase.

The leads related to phase A were disconnected and distanced from any components connected to ground. As each component was separated the insulation resistance was re-tested and the ground was not cleared.

C. Winding Fault to Ground

There were several possibilities related to root cause associated with a grounded system. These included:

- Pinhole short: caused by high impulse, lightning strikes, high voltage testing.
- Aging/brittle insulation: an aged insulation system either because of general age or accelerated aging due to overloading, overheating, or other cause (Reference Figure 1).
- Contamination/foreign object: an object impacting winding.
- A turn short causing ground when it burns through the insulation system.

The first step in evaluating these hypotheses was to perform an AC high potential test until smoke was visible. This would identify the location of the fault. In this case, the applied voltage was relatively low. The suspect coil was marked and removed using a mechanical method in order to keep the insulation system intact for investigation.

A visual inspection of the windings and removal of the coil indicated that the winding had aged. A review of past insulation resistance testing indicated that the insulation resistance had gradually been increasing from year to year. This would indicate that the insulation had been gradually aging over time.

The exact point of fault on the removed coil indicated that the failure occurred towards the top of the slot. The location was identified and the coil unwrapped. Using a microscope,

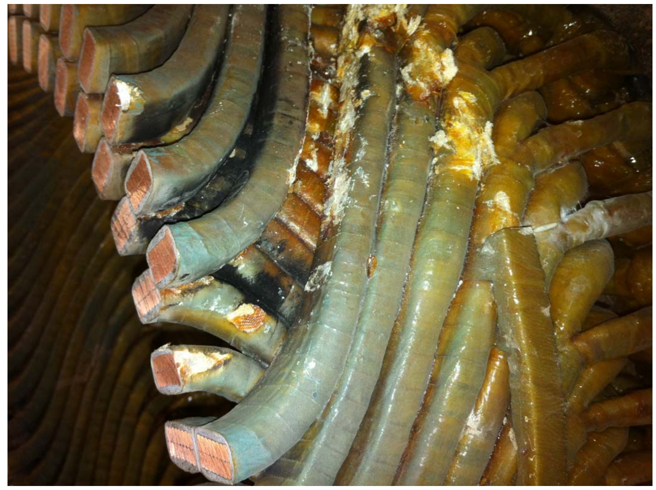

Figure 1. Aged Insulation System

tracking was found around the failure point. However, the conductors themselves were intact.

It was also determined that the humidity levels were high on the day of testing and the winding temperature was below the dewpoint. The protective devices were checked to ensure that the generator had not been operating grounded prior to shutdown for testing.

D. Conclusions for the First Generator

It was determined that the winding had been aged and the insulation was brittle. The maintenance tests were performed during a period of high humidity. Although the third party testing company denied performing high voltage testing it appears that may have been one of the conditions that led to the failure based upon tracking evidence.

IV. Second Generator Failure

During rewind repair of the first generator the second generator failed at the same location during operation a few months folowing field testing. The insulation was found as Figure 2. The initial review identified a similar history as the first generator, so testing and RCFA was also performed.

Figure 2. Failure Point and Surrounding Coils 2nd Generator

The team determined that the initial step would be to follow the same fault tree as with the first generator. The results were similar other than the point of fault where the conductors had vaporized as it had failed under load. It was evaluated as a latent fault.

V. Recommendations and Conclusions

There were several conclusions that came from the investigation:

- Proper tracking of insulation resistance readings is recommended such that increasing test results with temperature correction actually indicates aging insulation.
- Polarization Index (PI) trending would also be recommended including monitoring the PI curve [3].
- Ensure high voltage testing is not performed on the machines when the winding temperature is below the dew point.
- Replace aged insulation as opposed to dipping and baking using epoxy varnish. While this step increases the maintenance costs, the higher cost is associated with unplanned outages. A trade-off would have be be determined in relation to reliability versus maintenance costs.

The overall conclusion was that a combination of aged insulation, humidity and high voltage testing damaged the insulation systems of these generators causing one to immediately fail and the second to have a latent fault that shorted to ground during operation. The primary concern has been that there is a large fleet of generators of about the same age in the field requiring a review of testing history and operating environment.

References

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