

ATTACHMENT 2

Additional Details for Lessons Learned / Suggestions

Post event review determined the direct cause to be:

A small particle of carbon steel, introduced into the generator end winding area.

- The location was under the 76 inch fan baffle ring and just under the outer edge of the silicone rubber pad under the cruciform hold-down assembly.
- The particle rested on the top edge of the top half winding located in frame slot #39, immediately adjacent to the top half winding in slot 38. The #39 top bar is associated with electrical phase X, and the #38 top bar is associated with electrical phase Y.
- The particle was magnetized and oscillated with the 4 pole rotor field. Over time, the 60 Hz oscillation, combined with the magnetic attraction down towards the bar, damaged the end winding laminated insulation material. The particle eventually reached the copper strand. Material then was removed, eventually causing penetration of the strand allowing H2 gas to leak into the bar. This gas migrated with stator water to the hydrogen detrainning tank where the hydrogen was collected and measured.
- A particle of interest showing wear and copper deposits was found and removed from the area of bar damage.

The presence of the particle in the generator internals was a result of either:

- less than effective foreign material exclusion controls for preventing ingress of small particulate material during generator internal work, OR,
- a phenomenon called 'back-of-core burning' where eddy current induced voltages can cause arcing between core plates and key bar supports with potential release of metallic particles.

The root causes of the event are:

1. *Failure to implement Foreign Material Exclusion controls for Main Generator internal work sufficient to prevent contamination by small magnetic particles.*
2. *Potential internal particle generation from arcing between key bars and end- of-core plates.*

Relevant information:

- Previous documentation stated an instance during implementation of a modification to the Generator Core Monitor, where fabrication grinding generated sparks & metallic particles that impacted the gas side of hydrogen coolers stored in an adjacent lay down area.
- Investigation and corrective actions from a previous report of a "Foreign Material [nut] discovered in Main Generator" did not identify contamination by small magnetic particles as an area of concern. Thus, major upgrades to the site foreign material exclusion program and work practices, while generally effective, did not include actions that would prevent small magnetic particle contamination of the main generator.
- Controls that would limit ingress of small magnetic particles should include:
 - Erecting enclosures for removed and exposed components
 - Establishing 'clean areas' with step-off pad controls
 - Performing cleaning and magnetic sweeping of personnel & material prior to entry into the clean area.
- Post maintenance cleaning & inspection activities that could remove small magnetic particles were not specified by procedures, and have not been part of previous maintenance activities:
 - Vacuum cleaning of accessible areas, including use of reaching tools for end winding areas.
 - Magnetic sweeps of accessible areas
 - Analysis of removed materials to determine if contamination by magnetic particles has occurred

- Major outages did not include regular inspection of back-of-core & frame areas [a potential source of particles].
- Boroscopic inspections of back of core areas conducted during a previous forced outage did not identify areas of heating or damage, but were not conclusive due to limited scope and the presence of dust & oil contaminants.

Additional inspections will be required to determine if this mechanism is responsible for particle generation.

Important contributing causes include:

- *Failure to incorporate external operating experience* lessons learned into site program controls.
 - Operating experience from plants that had similar strand failures and back of core issues was not evaluated for impact on the foreign material exclusion program or system / component health plans.
- *Physical characteristics of specific this manufacturers' end windings* increases susceptibility to this type of failure.
 - The 76 inch fan baffle has upstream openings where particulates can enter the end winding area and be trapped atop the winding involutes.
 - The end winding bar insulating laminate is in direct contact with adjacent bars, This prevents material from dropping out of the area to a less critical location.
- *Organizational insensitivity to precursor indications of declining main generator health.*

This has resulted in material condition deficiencies and elevated risks to generation that is undesirable given the economic importance of this high value asset.

Examples include:

- Sequence of events testing to establish baseline hydrogen in-leakage was first recommended in response to a report but the proposed test was repeatedly delayed and finally performed just prior to this incident.
- The scope of generator hydrogen leakage troubleshooting activities was primarily driven by compliance to the outage schedule, rather than condition or risk analyses. This limited leak detection & rework options and resulted in startup with known hydrogen leakage, some from unidentified locations.
- The material condition of temperature instrumentation important to monitoring generator operation and long term health is degraded, evidenced by the number of out-of-service detectors. Rework over several outages has not been effective at restoring all devices to service.
- Generator outage electrical testing did not always meet acceptance criteria. Subsequent justifications for operation were not technically robust and compromised the ability to detect insulation degradation.
- Stator bar integrity pressure and vacuum tests were not performed at recommended intervals.
- Material has been allowed to accumulate in the generator over time. This includes paint chips, Fiberglas, oily residue, and some metallic particulates.

During the course of the investigation, the team noted the following observations that, while not directly contributing to the failure described in this CARD, warrant follow-up actions:

- *OEM & industry recommendations for stator preparation for testing and lay-up have not been historically followed.*

Failure to blow down and vacuum dry the internals can contribute to:

- Failure to identify degrading trends in stator integrity,
- Ineffective leak testing and identification,
- Compromised electrical testing, which degrades the ability to monitor stator insulation health,

- Undesired buildup of internal corrosion products, possibly leading to long term flow and insulation problems,
- *Lack of a detailed Generator Life Cycle Management plan.*

This integrated assessment of the generator and associated systems should be a key component of strategic decision making. Preparation of this document may have identified some of the previously cited technical and organization issues.