DISSECTION, CONDITION ASSESSMENT AND ANALYSIS OF STATOR WINDINGS TAKEN FROM FAILED IN SERVICE UNITS

CEATI Project T082700-0356

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About This Project

- Awarded in 2009
- Expected 10 dissections in the first year, 15 dissections total and to be finished in 2010 ☺
- On average, one dissection per year
- 10 dissections done
- Previous update in October 2006
- Final Report submitted

Outline of this update

- Project purpose
- Windings investigated
- Methodology
- Findings:
  - Dissections
  - Correlation with diagnostic tests
- Conclusions
- Present status
- Acknowledgements

Objectives

- Determine root cause of hydrogenerator stator winding insulation failures
- Determine insulation condition - (whether a failed sample or simply an aged specimen)
- Determine any “common” failure mechanisms
- Use information gained to enhance understanding of winding life as a function of design, materials, age and service, and assess the best diagnostic tests

Methodology

- Collection of background/operating data including available test results
- Thorough visual inspection
- Suite of electrical tests
- Dissection of samples
- Root cause analysis for failed samples
- Report on each winding
- Final report looking for common issues and findings

Methodology

- Collection of background/operating data including available test results:

-A questionnaire sent to each utility, asking for design, operating, test and failure details

-We tried to determine whether the condition of insulation was predictable from on-line and off-line tests performed before coil removal

Methodology

- Thorough visual inspection

-inspected for surface damages, resulting from coil removal, insulation abrasion, surface PD etc.

-where a failed sample was submitted the failure site would be inspected

-"Tap" test performed on multiple points, to locate delaminated areas

- If bars from line and neutral sides were supplied we compared effects of electrical and thermal aging

Methodology

- Suite of electrical tests

-Surface contact resistance

-IR/PI per IEEE 43 or IEC 60034-27-4

-Capacitance, DF per IEEE 286 or IEC 60034-27-3

-PDIV, PDEV per IEEE 1434, IEEE 56

-DC HI POT per IEEE 95

-AC breakdown

Methodology

- Dissection of samples

-the main purpose of this project

-three or more samples cut from coil: slot part based on "tap" test, slot exit area and first bend area

-one sample from failure point following AC breakdown

-the samples were 10-15 cm (4-6") long

-axial cut through insulation

-insulation layers peeled one by one

-on multiturn coils turn insulation inspected

Methodology

View of 3 samples, both sides.

Methodology

- Root cause analysis for failed samples

Report on each winding:

- USBR - Flatiron Pump GS - G1
- TACOMA POWER - Mossyrock GS - G52
- FORTUM - Langa Mittan - Unit 2
- FORTUM - Langa Lossen - Unit 1
- ESB - Turlough Hill Pump GS - MG-4
- AVISTA Corp. - Noxon Rapids GS - Unit 4
- CHELAN COUNTY – Rocky Reach G11
- GRANT COUNTY – Wanapum G6
- USACE – John Day U3
- SEATTLE City Light-Diablo U32

Coils/Bars Received

- 10 windings from 9 utilities
- Four failed in service-only one failed bar
- 34 coils/bars were dissected
- 13 out of 34 samples were mechanically damaged
- In some cases spare and neutral coils/bars were supplied
- Operating hours from 5000 to 425,000 h
- Starts from 600 to 25,000 (pumped storage generators)

Coils/Bars Received

- 10 windings manufactured by 6 OEMs
- Two described as base load, six peaking, two mixed
- Winding temperatures mainly well below 100 C, some reached short term 133 C
- Utilities supplied diagnostic test data from the windings:

5 had some sort of DC hi pot, 6 machines had IR/PI; 7 had on-line PD (out of 9 that had PD sensors);

- Four machines did not have data on IR/PI
- Three machines had wedge tightness test done
- Most of the test results were many years old

Winding Characteristics

No.	Unit	Year Made	Year Dissected	Ratings	Hours	Starts
1	Seattle City Light Diablo Unit 32	1962	2018	100 MVA 13.8 kV	425k	600
2	Tacoma Power Mossy Rock Unit 52	1968	2010	167 MVA 13.8 kV	190k	15,000
3	Fortum Langa Mittan Unit 2	1973	2010	100 MVA 18 kV	93k	5800
4	Fortum Langa Lossen Unit 1	1973	2010	68 MVA 18 kV	138k	4900
5	ESB Turlough Hill MG1	1974	2011	87.5 MVA 10.5 kV	175k	25,000
6	USBR Flatiron Unit 1	1983	2010	47.8 MVA 13.8 kV	103k	3900
7	Grant County Wanapum Unit 6	1989	2016	109 MVA 13.8 kV	192k	1500
8	USACE John Day Unit 3	1990	2016	163 MVA 13.8 kV	54k	2400
9	Chelan County Rocky Reach Unit 11	2002	2015	132 MVA 15 kV	59k	6100
10	Avista Noxon Rapids Unit 4	2007	2013	126.5 MVA 14.4 kV	5k	?

Tests Before Coil/Bar Dissections

- 8 of 10 windings showed some to significant delamination (tap test)
- Only 1 winding had bars with significant abrasion and surface PD (Machine 5), one other had early signs (Machine 4)
- All the coils/bars had an insulation resistance that was much higher than required for new windings
- PD ranged from 0 on Machine 10, to 500 mV (Machine 5). The rest were in between

Machine 5 – only bar with significant abrasion and surface PD

Eroded surface, PD attack. Rough surface typical of all samples.

Surface PD site

This is the machine with 25,000 starts

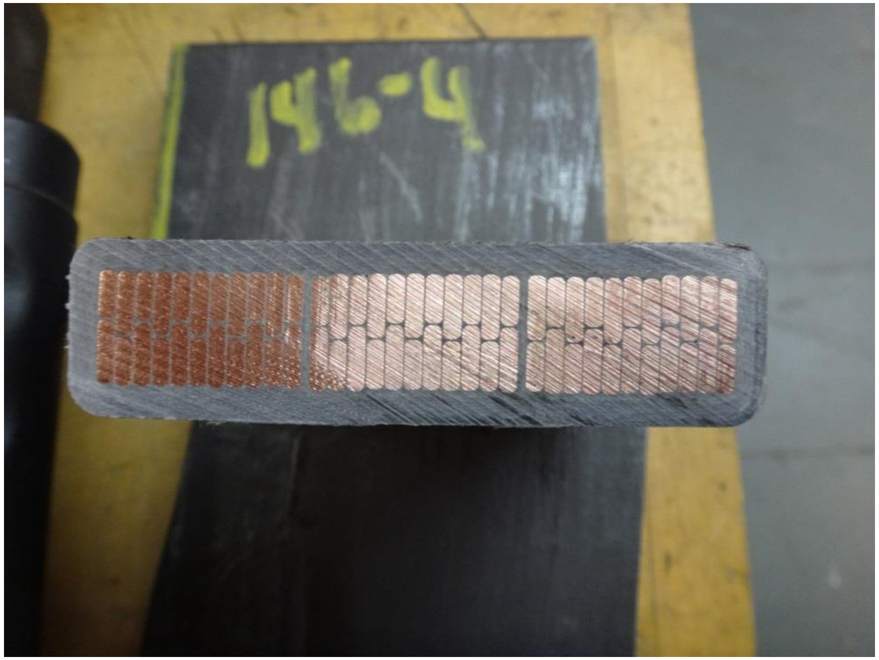
Machine 1 - the most deteriorated

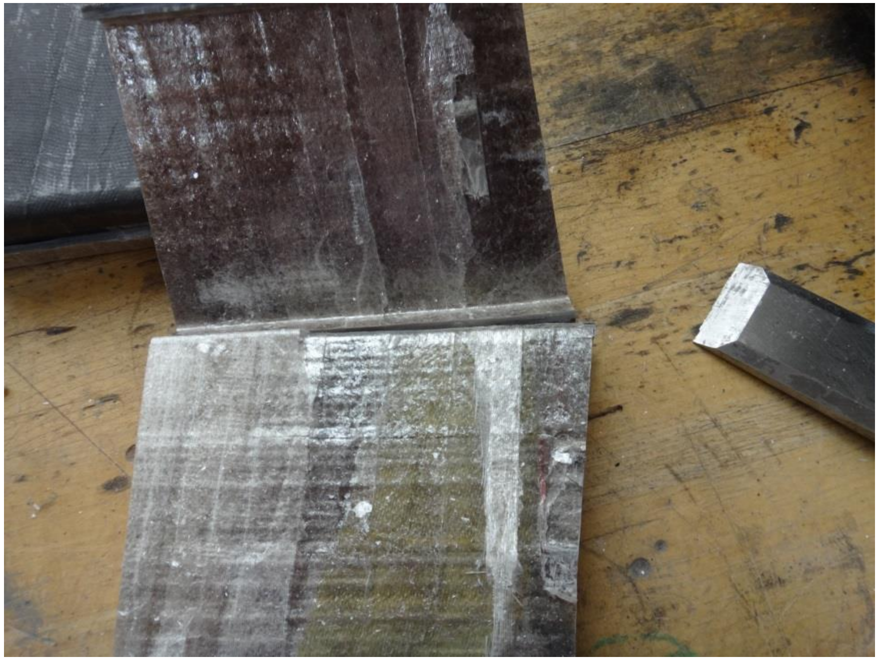
Severe overheating and PD, groundwall delaminated at end of life

This is the oldest machine -1962, 425,000 hours

Machine 10 – showed no deterioration

Coil insulation well consolidated and difficult to separate. Good adhesion to turn insulation.





This is the newest machine - 5,000 hours only.

Machine 10 – failed after 5000 hrs.

Location right at core end and right at point where bulges may have caused insulation mechanical stress resulting in cracking of groundwall?

Correlation of PD and Tap Test with Dissections

No.	PDEV (kV)	Tap Test	Dissection
1	-	mainly hollow	groundwall tapes poorly bonded together. Turn insulation destroyed by severe PD, burning. Minor PD attack on semicon. Conductors fell apart. At end of useful life
2	4	some hollow areas	groundwall reasonably well bonded. Moderate bonding to conductor stack. No PD attack
3	2.5	a few hollow areas	groundwall well bonded. Moderate bond to stack. Minor PD
4	3.5	mainly hollow	groundwall well bonded. Poor bond to conductor stack. No PD. Some overheating at stack. Minor PD attack on semicon
5	1.5	50% hollow areas	groundwall moderately well bonded. Poor bond to conductor stack. considerable burning and PD attack at the stack. Moderate PD attack/burning on semicon
6	5.5	mainly hollow	groundwall moderately well bonded. Poor bond to turn insulation conductor stack. considerable burning and PD attack at the stack. Conductors fell apart. At the end of its useful life
7	4.5	solid	groundwall well bonded. Moderate bond to the conductor stack. Minor PD attack at the stack
8	5.7	not relevant (CRTV coating)	groundwall well bonded. Moderate bond to the conductor stack. Some overheating at the stack
9	5.2	some hollow areas	groundwall moderately well bonded. Poor bond to conductor stack. PD attack and burning at stack
10	6.3	solid	groundwall well bonded. excellent bond to conductor stack. No sign of PD or burning anywhere

Failure Processes (IEEE 56)

- thermal deterioration
- thermal (load) cycling
- internal water leaks (direct water-cooled stators only)
- poor impregnation
- loose coils/bars in the slot
- semicon coating deterioration
- vibration sparking
- stress control interface deterioration
- electrical tracking due to contamination
- voltage surges
- chemical attack
- abrasive particle attack
- magnetic termites
- endwinding vibration

Overview of Dissections

- Surprisingly, only one showed significant signs of abrasion due to looseness in the slot. This was an important failure mechanism for windings made in the 1970s. Perhaps better slot support designs plus pro-active maintenance reduced the probability of this aging process.
- The semicon and grading coatings were mainly in good condition. This was a serious problem for many machines in the 1970s and is occurring again in machines made in the 2000s-most likely result of higher design stress

Overview of Dissections

- Delamination normally caused by thermal aging and/or load cycling
- Most of the winding temperatures are too low to cause thermal aging in epoxy mica (9 of 10 windings)
- Minor thermal aging and load cycles could lead to minor delamination and heat from PD accelerated delamination

Overview of Dissections

- 1981 IEEE survey and 2009 Cigre survey suggest that coil abrasion in the slot and surface PD are just as common as thermal/thermal cycling aging
- Yet only one winding had significant surface problems, compared to 8 with delamination
- Perhaps utilities selected windings where the state of aging was not apparent in visual inspection-since the purpose of the Report is dissection…

Comparing Diagnostic Tests and Dissections

- The tap test seems to be the best indicator of the insulation delamination problem
- PD tests were moderately well-correlated with both surface condition and delamination issues
- Very high Corona probe reading from Machine 6 correlates well with insulation degradation
- Insulation Resistance not correlated to actual insulation condition
- None of the spare/neutral bars showed signs of PD

Summary of Findings

- This report section contains:

-Any off-line or on-line test results supplied by the plant

- Observation of the general condition of the bars
- Results of the electrical tests we did
- Findings from the dissections

Conclusions

1. Most common cause of insulation deterioration in the 10 windings was delamination due to thermal aging/thermal cycling compounded by PD attack
2. It was surprising only 1 winding suffered from abrasion/surface PD, contrary to published surveys
3. The tap test was the best predictor of winding insulation delamination in the 10 windings
4. To aid in predicting maintenance needs, utilities could do better in making sure diagnostic tests are done and the results are available from a database

Project Status

- Coils/bars from 10 windings tested and dissection and reports on each issued in the past 10 years
- No more dissections will be done under current project
- Draft final report prepared and submitted for comments