Q. Please provide any reports or analyses prepared after completion of a significant unit outage (>2 weeks) in the last five years.

A. Hydro assesses the causes of unplanned generating unit outages and depending on the complexity and significance of the damage will complete a root cause analysis and report. The only significant unplanned unit outage extending beyond two weeks in the past five years with a root cause analysis and formal report completed was the Holyrood Unit 1 failure on January 11, 2013. This report is attached as PUB-NLH-228 Attachment 1.

Hydro is completing root cause analysis and reports on the following recent unplanned generating unit outages: Bay d'Espoir, Unit 6 excitation transformer (February 2014) and Stephenville Gas Turbine End "B" (January 2014).

newfoundland labrador
hydro
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September 30, 2013

Board of Commissioners of Public Utilities
Prince Charles Building
120 Torbay Road, P.O. Box 21040
St. John's, NL
A1A 5B2

ATTENTION: Ms. Cheryl Blundon
Director of Corporate Services & Board Secretary

Dear Ms. Blundon:

Re: An Application by Newfoundland and Labrador Hydro (Hydro) pursuant to Subsection 41(3) of the Act for approval of the Restoration of Unit 1 Turbine and Generator at the Holyrood Thermal Generating Station

Enclosed please find the original and eight copies of Hydro's Holyrood Unit 1 January 11, 2013 Failure Root Cause Analysis final report.

Should you have any questions, please contact the undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

Geoffrey P. Young
Senior Legal Counsel

GPY/jc

cc: Gerard Hayes – Newfoundland Power
Paul Coxworthy – Stewart McKelvey Stirling Scales
Thomas J. O'Reilly, Q.C. – Cox & Palmer
Thomas Johnson – Consumer Advocate
Dean Porter – Poole Althouse

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Newfoundland and Labrador Hydro

Holyrood Unit 1 Failure - January 11, 2013

Root Cause Analysis: Final Report

Prepared By (Lead Investigator): Sean Mullowney
Date: 2013/09/30

Reviewed By: [signature]
Date: 2013/09/30

Approved By: Greg Read for A. Marche
Date: 2013/09/30

Approved By: Terry LeDrew
Date: 2013/09/30

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Table of Contents

1. Summary

On January 11, 2013, severe weather conditions caused an electrical fault in the Holyrood Terminal Station, which caused Holyrood Units 1 and 2 to trip offline. While Unit 2 coasted down normally and without incident, Unit 1 experienced high vibration due to a loss of oil lubrication for approximately three minutes during the coast down. All five journal bearings and other components were later found to be damaged. When lubricating oil was restored after three minutes, it resulted in localized fires at some of the damaged, hot bearing locations. The fires were extinguished by plant personnel. There were no injuries.

Root cause analysis was completed by a team of internal and external personnel with expertise in the equipment function and root cause analysis theory. The TapRooT® root cause analysis techniques were applied for this investigation.

Three causal factors were identified:

1. The established maintenance test procedures did not adequately validate the system function, for the direct current (DC) lubrication oil pump, which serves as a contingency for bearing lubrication when two alternating current (AC) pumps are unavailable.

2. During the incident, the station service system voltage was insufficient to start the second alternating current (AC) lubricating pump, due to the system wide voltage depression experienced after the electrical fault in the Holyrood Terminal Station.

3. The direct current (DC) lubrication oil pump started based upon the loss of both AC pumps, but it did not maintain adequate lubrication to the bearings due to an undetected motor speed issue.

Root causes and corrective actions were determined for each causal factor. Most corrective actions pertain to strengthening internal operating and maintenance procedures and specifications for third party maintenance. Several of the corrective actions have already been implemented and the remainder has been assigned.

Following are the key lessons learned from this incident:

A. The overall system function must be considered when developing and reviewing equipment functional test procedures. In this case, established maintenance test procedures verified that the Holyrood Unit 1 DC Lube Oil Pump was operating but failed to verify that it was providing the system's overall function of delivering sufficient lubricating oil to the bearings. OEM recommended test

procedures may not be adequate for ensuring full functionality of equipment and systems.

B. Technical specifications for third party maintenance contracts must be sufficiently detailed to ensure that equipment performance criteria and suitable maintenance testing and adjustments are clearly and thoroughly specified. In this case, the DC pump maintenance specification did not adequately specify the performance criteria and adjustments, and a pump was returned to service that was not able to perform.

C. Equipment specifications and system design must include fail safe design for both black-out and brown-out conditions. In this case, there was a brown-out condition such that the station service voltage was too low for the South AC Pump to start.

These lessons learned will be shared broadly by the investigation team with Holyrood plant personnel, Hydro's engineering personnel in the Project Execution and Technical Services Division, applicable third party consultants and contractors, and other operating units within Nalcor Energy.

2. Initial Conditions / Initiating Event

On January 11, 2013, severe weather conditions including high winds and heavy, wet snow occurred on the Avalon Peninsula. At 06:42 AM, an electrical fault occurred on C phase of the 230 kV Breaker B1L17 in the terminal station, one of two unit breakers for Holyrood Unit 1 generator. Holyrood Units 1 and 2 tripped offline in response to the electrical fault in the Holyrood Terminal Station. Unit 1 experienced higher than normal vibration levels as it coasted down, with fires at various bearing locations along the unit's rotational shaft.

Protection systems for Holyrood Units 1 and 2 operated, opening the unit breakers for both generators and removing them from operation. Once removed from operation, the unit's control system is designed to coast the rotating unit down to a rest position. Then a turning gear motor is engaged to turn the unit shaft at two revolutions per minute (RPM) to prevent shaft deflection until the unit has fully cooled down (four days in duration).

The removal of the generating units and other transmission system voltage support equipment resulted in a severe depression in system voltage to approximately 80% of normal voltage levels (See Figure 1).

Prior to the failure event two alternating current (AC) lube oil pumps that provide lubrication for the turbine-generator journal bearings were in operation on Unit 1. These pumps are commonly referred to as the North and South AC Pumps. The North AC Pump is powered directly from the generating unit (unit service) and is designed to come offline with the unit. The South AC Pump is powered by the plant station service which is fed from the terminal station.

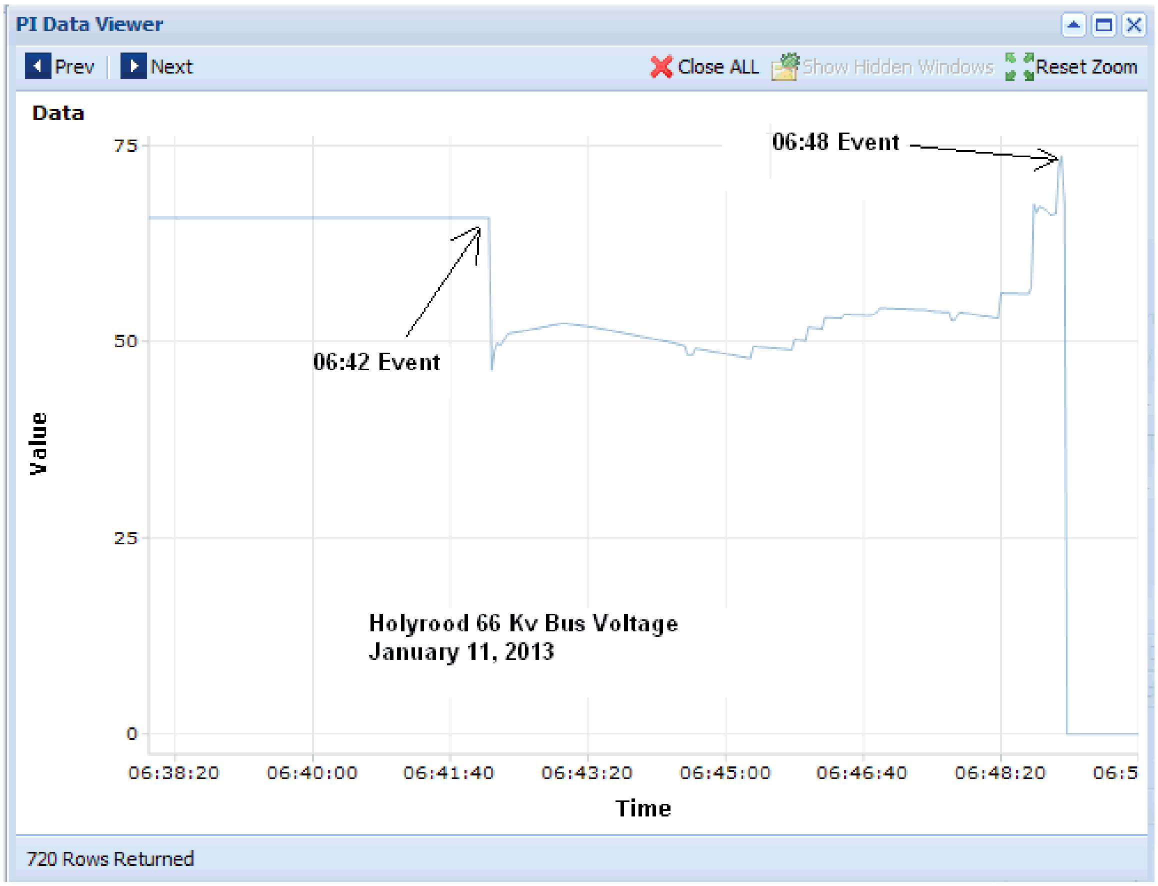


Figure 1: Voltage depression experienced in the Holyrood Terminal Station during January 11, 2013 06:42 fault event

3. Incident Description

Once disconnected from the grid, Unit 2 coasted down without issue, as designed. However, Unit 1 experienced higher than normal vibration levels as it coasted down. The Unit 1 generator bearing vibration levels increased to 217 and 272 microns on the inboard and outboard bearings respectively, prior to failure. Normal vibration levels are in the range of 50-90 microns. A horizontal flame emanated from the inboard bearing.

A fire was also experienced in the generator front standard. The turbine crossover pipes were observed to be shaking during the failure event.

Appendix A contains a report from Alstom Power, outlining the initial observations based on the “as found” condition of Unit 1 following the January 11 event. Following this initial assessment, the unit was disassembled for a more detailed inspection and condition assessment of the individual components. This inspection revealed damage to all five bearings and journals along the turbine-generator shaft. The turbine-generator rotor assembly had moved 3.5 mm horizontally towards the generator. The shims under the generator feet were found to have been dislocated due to the excessive vibration. Other unit components were damaged as well.

Holyrood Units 1 and 2 each have three separate lubricating pumps for supplying oil to the bearings and generator seals. There are two AC pumps and a direct current (DC) pump. The North AC Pump is the primary pump and it draws electrical power directly from the unit’s generator. The South AC Pump is a secondary pump that draws power from the station service, which is fed from the Island Interconnected System via the Holyrood Terminal Station. The DC Pump is a third line of defense for the supply of lubricating oil, and it draws power from dedicated battery banks located in the Holyrood powerhouse.

When Unit 1 was removed from operation in response to the terminal station electrical fault, the North AC Pump consequentially shut down. The South AC Pump tripped offline due to the voltage depression that was experienced during the terminal station electrical fault (See Figure 1). It did not restart with the loss of the North AC Pump, as is expected when the station service supply is available. The DC Pump started in response to the loss of the AC pumps and the resultant drop in lubricating oil pressure. However, it did not deliver sufficient lubricating oil to the generator bearings. The lack of sufficient lubricating oil continued for a period of approximately three minutes and fourteen seconds. With the plant completely shut down, many alarms and process upsets were being reviewed and assessed. Plant personnel manually started the 600 V emergency diesel generator D1, which removed the station service supply from the grid and established supply from the diesel generator. This resulted in the South AC Pump starting, recovering sufficient lubricating oil pressure. (See Figure 2 below for plant Distributed Control System {DCS} trends which illustrate this sequence of events.)

The fires experienced at the Unit 1 turbine-generator bearings were the result of restoration of lubricating oil to the damaged hot bearings and seals, following the three minute and fourteen second period during which the unit rotated without adequate lubrication.

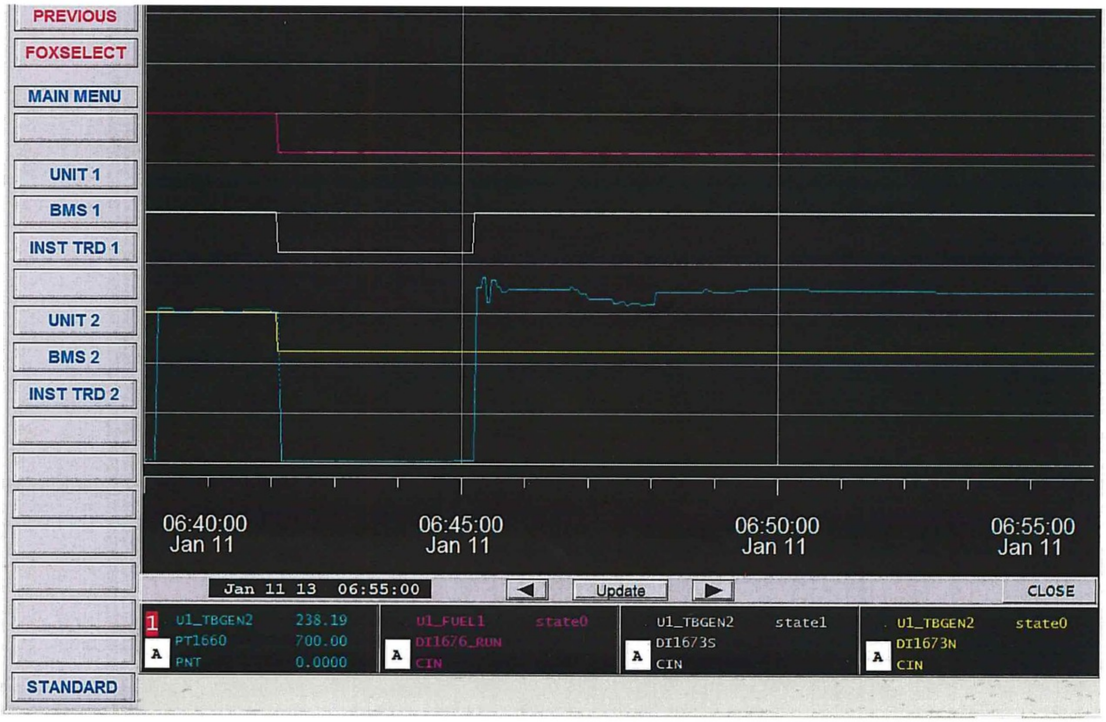


Figure 2: Status of Unit 1 Lube Oil Pumps and Lubricating Pressure during January 11, 2013 event. PT1660 (blue) is lubricating oil pressure at the front standard of the unit. DI1676_RUN (magenta) is the run/stop status of the DC lube oil pump. (The DC pump's run status is triggered by a normally closed contact that opens to indicate run/start. Its running indication is opposite of both AC pumps North and South. i.e. run is indicated after the state change, the portion of the trend that is lower vertically.) DI1673s (white) is the run/stop status of the AC lube oil pump South. DI1673N is the run/stop status of the AC Lube Oil pump North. Upon loss of AC pumps, the lube oil pressure crashes, despite the fact that the DC lube oil pump started. Pressure is restored three minutes and fourteen seconds later after manual start of emergency diesel restores power to AC lube oil pump South.

4. Immediate Corrective Actions

Plant personnel extinguished all fires at the Unit 1 bearing locations and ensured that all issues relating to safety and further equipment damage were mitigated.

5. Root Cause Investigation

A detailed investigation was initiated on January 17, 2013 to determine the underlying root causes of the damage to Unit 1. An investigation team and peer reviewers were identified early and consisted of internal and external personnel with expertise in the equipment function and root cause analysis theory. The TapRooT® root cause analysis techniques were applied for this investigation. This work involved several phases and iterations of information gathering, testing, and analysis of test data to determine the sequence of events, define the causal factors[1], analyze the root causes and develop corrective actions. The investigation is now complete.

6. Causes and Corrective Actions

Three causal factors were identified during the TapRooT® analysis:

1. Inadequate DC Pump Test Procedures;
2. Inadequate System Voltage; and
3. DC Powered Lubricating Pump Not Operating Correctly.

The SnapCharT® in Appendix B provides a visual representation of the sequence of events and illustrates how each causal factor related to the incident. The three causal factors are identified on this SnapCharT® as “CF”.

Following is a description of each causal factor, the root causes and the recommended corrective actions.

<u>Causal Factor #1: Inadequate DC Pump Test Procedures</u>

The investigation revealed that the established maintenance test procedures for the DC Pump did not adequately validate the system function. The established procedures were:

- *Procedure 0324, Turb/Gen Operation – Cold Startup of Unit #1 and #2 from a Major or Minor Overhaul*
  - This procedure is used by plant personnel for unit startup
  - An excerpt as it relates to lubricating pumps is located in Appendix C

- *Turbine and Auxiliaries Weekly Checks*
  - This check sheet is used by plant personnel to test the DC Pump weekly
  - An actual completed check sheet from January 10, 2013 is included in Appendix D.

While both of these tests included verification that the DC Pump is operable, neither test required verification that the DC Pump actually delivered lubricating oil to the

[1] A causal factor is a mistake or equipment failure that, if corrected, could have prevented the incident from occurring or would have significantly mitigated its consequences.

bearings. As a result, an existing capacity issue with the operation of Unit 1 DC Pump, with respect to delivery of lubricating oil to the bearings, was not detected during unit startup and weekly online function tests.

Root Causes

With respect to causal factor #1, the following root causes were identified using the TapRooT® methodology:

1. **Human Performance Difficulty: Human Engineering: Human-Machine Interface, Displays for monitoring Turbine-Generator Lubricating Pressure Needs Improvement.**

2. **Human Performance Difficulty: Management System: Standards Needs Improvement**

Appendix E includes a copy of an excerpt from the General Electric (GE) original equipment manufacturer (OEM) turbine generator manual, provided to Hydro when the units were originally installed and commissioned in 1969. The section titled PUMP TEST AND AUTOMATIC STARTING states:

> *Provisions are made to test the AC and DC motor pumps which are on "stand-by". An orifice and solenoid valve is included with each starting pressure switch and a "run" pressure switch is included for each pump. The "run" pressure switch senses pressure between the pump discharge connection and its isolating discharge check valve. The test is performed by pushing the pump test pushbutton and energizing the test solenoid valve. The solenoid valve is an open-closed design and causes oil to flow from the header to drain through the orifice in the starting pressure switch sensing line. The orifice drops the oil pressure sensed by the starting pressure switch and causes the switch to close and start the motor pump. As soon as the pump is running, its discharge pressure will rise to normal pressure and the "run" pressure switch will close, lighting the "run" signal lamp. Releasing the test push button closes the solenoid valve and the automatic start pressure switch opens. The motor is stopped by turning the motor control SBI switch or equivalent to the "stop" position.*

The components involved in the tests referenced above (test solenoid valve, starting pressure switch, etc.) are located in the Unit 1 lube oil tank on the first floor of the Holyrood plant. The turbine generator assembly is located on the third floor of the plant, 34 vertical feet above the tank. The test as per the GE manual is confirming that the pressure switch will sense a drop of pressure in the starting pressure switch sensing line and accordingly call for the South AC Pump or DC Pump to start, depending on the test being performed. Once started, a "run" signal lamp is illuminated for a given pump.

The *Turbine and Auxiliaries Weekly Checks* check sheet and the *Turb/Gen Operation – Cold Startup of Units 1 and 2 from a Major or Minor Overhaul* procedure, used by plant personnel, addressed these OEM recommendations. The test procedures, as written, were confirming the starting circuitry of the pumps (similarly to the OEM test, to come in to operation based on loss of lube oil pressure in the lube oil tank), but did not include a step to confirm that adequate lubricating oil was being delivered to the bearings on the turbine-generator shaft.

Corrective Actions

1. It is recommended to design and install a new DCS display to indicate status of existing electronic oil pressure transmitters that are installed directly in the front standard of the turbine-generator assembly on the third floor. The weekly online test should be modified to require plant personnel to use this DCS display to monitor the lubrication oil pressure during tests of the South AC Pump and DC Pump, and to log a copy of the pressure trend with the test sheet.

    - **This corrective action is complete!** The DCS display is in service and test procedures have been revised. The test form and a sample DCS screen shot are located in Appendix F.

2. It is recommended to create two new test procedures for testing the South AC Pump and DC Pump on a weekly basis as well as prior to all return to service.

    - **This corrective action is complete!** The following new procedures, located in Appendix G, have been created and added to the plant procedures database:
        - *Procedure #1076, Unit 1 and 2 – AC Standby and DC Turbine Lubricating Oil Test – Weekly;*
        - *Procedure #1077, Unit 1 &2 Turbine AC/DC Lube Oil Pumps Test Procedure -Return to Service*.

<u>Causal Factor #2: Inadequate System Voltage</u>

During the incident, station service system voltage available to the Unit 1 South AC Pump was insufficient to start the pump, due to the system wide voltage depression experienced after the Holyrood Terminal Station fault and resulting loss of system voltage support.

Root Cause

With respect to causal factor #2, the following root cause was identified using the TapRooT® methodology:

Equipment Difficulty: Design: Design Specifications, Problem Not Anticipated

The Unit 1 South AC Pump's starting circuitry is located in Motor Control Center (MCC) E1, which is an essential services MCC. It is backed up by the 600 V emergency diesel generator D1. In a no-voltage or black start condition, under-voltage protective relaying calls for D1 to start and re-energize or re-establish appropriate voltage to the motor loads of MCC E1. On the morning of January 11, 2013, the Holyrood Terminal Station experienced what is referred to as a brown-out, or a severe and sustained voltage depression (See Figure 1). This brown-out condition had a dual effect with respect to MCC E1: (1) the system voltage which is normally supplied was at a level below which the starting coil for the Unit 1 South AC Pump is rated to close; and (2) the voltage level was insufficiently low for the under voltage relays to call for a start of emergency diesel D1.

Corrective Actions

1. It is recommended to install new coils in the motor starters of MCC-E1, with an improved low voltage tolerance compared to the original starter coils.

    - **This corrective action is complete!** New coils, with a 50% improvement in low voltage tolerance, have been procured and installed.

2. It is recommended to examine the present under-voltage scheme that calls for the starting of the emergency diesels that back up the plant essential services MCC's, with consideration of protection from a brown-out as well as a black-out condition.

    - This corrective action has been assigned to Hydro's Protection and Controls Engineering personnel. Design enhancements to prevent a similar occurrence are currently being evaluated.

<u>Causal Factor #3: DC Powered Lubricating Pump Not Operating Properly</u>

The DC Pump started based upon the loss of both the North AC Pump and the South AC Pump, but did not maintain adequate lubrication to the bearings.

Root Causes

With respect to causal factor #3, the following root causes were identified using the TapRooT® methodology:

1. Human Performance Difficulty: Procedures, Situation Not Covered

At an undetermined point in time prior to the failure event (prior to April 2009, as the plant DCS historian data only goes back that far), the adjustable resistor in the field circuit of the DC lube oil pump motor (located in the motor's electrical starter cabinet) was moved, thereby decreasing electrical resistance. In a shunt wound DC motor, decreasing resistance in the field circuit decreases the motor's speed. As found and tested after the January 11, 2013 incident, the motor was rotating at approximately 2800 RPM, as compared to a rated speed of 3500 RPM. The maintenance procedures did not include a check of the DC motor speed. As a result, the slow speed was not detected.

2. Equipment Difficulty: Quality Control Needs Improvement

A problem with the rotational speed of the Unit 1 DC Lube Oil Pump motor was identified during the root cause investigation. The motor was sent to Pennecon Energy for an independent analysis. Pennecon Energy identified and corrected two issues affecting speed: (1) the brush boxes were offset; and (2) the motor neutral plane was improperly adjusted. The technical details of these issues are more fully described in the *Investigation of DC Lubrication System* report located in Appendix H.

The speed issues were a result of maintenance of the DC motor performed by a third party service provider. The Unit 1 DC lube oil pump motor was returned to the plant following third party maintenance and was placed in service with these issues present. The service contract specification did not address the specific required adjustments to ensure motor performance. There is a need for enhanced quality control with respect to the contracting of third party maintenance work for DC motors. The service contract for motor maintenance is presently due for renewal. Specific requirements and expertise in working on DC motors will be a requirement in the new tender package.

Corrective Actions

1. It is recommended to create a new maintenance standard requiring motor speed to be verified after any intervention with the DC lubrication system. If maintenance is performed on any component of the system (pump, DC motor, electrical starter, etc.) by plant staff or by a third party service provider, the motor and pump speed should be verified to be correct, prior to the system being made available and released for service.

    - **This corrective action is complete!** A new maintenance procedure has been created: *MSD176: Rotational Speed Check of 258 V DC Motor Emergency Lube Oil Pump*. The new procedure is located in Appendix I.

2. It is recommended to improve the technical specification for the third party provision of motor maintenance services to include specific requirements for adjustment of DC motors.

- This corrective action has been assigned to Hydro's Electrical Engineering personnel. The improvements to the technical specification will be incorporated into the tender document when the maintenance services are tendered later in 2013.

Unit 1 DC Motor Amperage and System Pressure Cycling Issue

During the course of the investigation, an issue arose with the operation of the DC Pump during testing. The pump motor amperage and oil pressure are expected to be constant when the oil lubrication system is in steady state operation. But, during testing, the motor amperage and oil pressure exhibited a cycling behavior. Following a series of additional testing, it was determined that the cycling behavior related to the test conditions. There is no cycling problem when the pump is in service. Hence, the cycling issue was ruled out as having any relevance to the root cause analysis. The technical description of this testing and analysis in located in Appendix J.

7. Lessons Learned

Following are the key lessons learned from this incident:

1. The overall system function must be considered when developing and reviewing equipment functional test procedures. In this case, established test procedures verified that the Holyrood Unit 1 DC Lube Oil Pump was operating but failed to verify that it was providing the system's overall function of delivering sufficient lubricating oil to the bearings. OEM recommended test procedures may not be adequate for ensuring full functionality of equipment and systems.

2. Technical specifications for third party maintenance contracts must be sufficiently detailed to ensure that equipment performance criteria and suitable testing and adjustments are clearly and thoroughly specified. In this case, the DC pump maintenance specification did not adequately specify the performance criteria and adjustments, and a motor was returned to service that was not able to perform.

3. Equipment specifications and system design must include fail safe design for both black-out and brown-out conditions. In this case, there was a brown-out condition such that the station service voltage was too low for the South AC Pump to start.

These lessons learned will be shared broadly by the investigation team with Holyrood plant personnel, Hydro's engineering personnel in the Project Execution and Technical Services Division, applicable third party consultants and contractors, and other operating units within Nalcor Energy.

8. Investigation Team

- Sean Mullowney, P. Eng. - Lead Investigator / Electrical Investigator
  Electrical Design Engineer
  Project Execution & Technical Services (PETS)
  Newfoundland and Labrador Hydro

- Todd Collins, P. Eng. - Mechanical Investigator
  Mechanical Design Engineer
  Project Execution & Technical Services
  Newfoundland and Labrador Hydro

- Christian Thangasamy, M. Eng., P. Eng. - Plant Investigator / TapRooT® coach
  Plant Mechanical Engineer
  Holyrood Thermal Generating Station
  Newfoundland and Labrador Hydro

- Tobie Comtois - Plant Investigator / IBEW Rep.
  Electrical Maintenance Department
  Holyrood Thermal Generating Station
  Newfoundland and Labrador Hydro

- Greg Read, P. Eng. - Team Lead
  Program Manager
  Project Execution, Regulated
  Newfoundland and Labrador Hydro

- Ken Turnbill - TapRooT® Work Session Facilitator
  System Improvements Inc.

9. Peer Review / Approval

An internal peer review of the root cause analysis has been completed and feedback has been incorporated into the report. An external peer review is pending and any feedback may be incorporated into a final revision of the report. The peer reviewers are:

- Howard Richards, P. Eng.
  Chair, Root Cause Analysis Technical Council
  Newfoundland and Labrador Hydro
  Peer Reviewer - TapRooT® Process

- Herb Sirois
  FM Global
  Peer Reviewer - Technical

- Michel Burbaud
  FM Global
  Peer Reviewer - Independent / Cold Eyes

Final review and approval of this report has been executed by:

- Terry LeDrew, P. Eng.
  Plant Manager, Thermal Generation
  Holyrood Thermal Generating Station
  Newfoundland and Labrador Hydro

- Alberta Marche, P. Eng.
  Manager, Project Execution Regulated
  Newfoundland and Labrador Hydro

APPENDIX A

Alstom Power Holyrood Unit 1
Inspection Report January 15, 2013

Nalcor Holyrood Unit 1 Turbine and Generator Inspection Report January 15, 2013

POWER | ALSTOM

Holyrood Unit 1

Observations as found – January 15, 2013

The following documents the condition of the Unit 1 turbine and generator as found after the unanticipated event of January 11, 2015.

The unit had not been touched since the trip. Powder from the fire extinguisher used to put out a fire on the #1 bearing remained on the turbine.

Vibration Effects

The effects of vibration could be seen in many places around the unit as follows:

- #2 control valve pin had walked loose
- Insulation from cross-over piping expansion joint on floor on both sides of LP hood
- Safety covers had come loose from many flanges
- Dirt had migrated from under gantry tracks towards the turbine on both the left and right sides
- Instrumentation covers had shook loose
- Covers had opened under bushing box
- Loose screw was noted inside doghouse
- Damage to vacuum breaker was noted
- Carbon dust was found on mezzanine level under collectors
- Loose insulation found on top of cross-over pipe

Generator Shims

The shims on the generator base had moved and buckled indicating that they had come loose enough to move during the event. Keys and hold down bolts appeared to be intact. See photos below:

Figure 1 Generator Shim – LHS Turbine End

Figure 2 Generator Shim – RHS Collector End

Oil Deflectors

Outer oil deflector clearance was measured on the #3 and #4 bearings. On both bearings there was no clearance on the bottom. On #3 the upper clearance was 0.180" and on #4 the upper clearance was 0.160". Normal for these bearings would be about 0.005" at the bottom and 0.020" at the top. Oil deflector damage had occurred. Also it appeared that the journals were sitting more than 0.100" low. This could indicate damaged bearings.

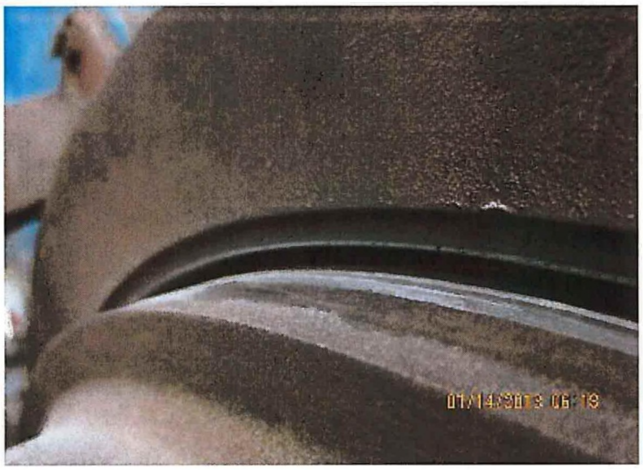


Figure 3 Bearing #4 – upper oil deflector clearance

Figure 4 Bearing #4 – lower oil deflector clearance

B-Phase

The B-phase bus duct on the mezzanine level appeared to have been distressed. On this duct only, the liners at each coupling had migrated out from under the connector rings. See Photos below.

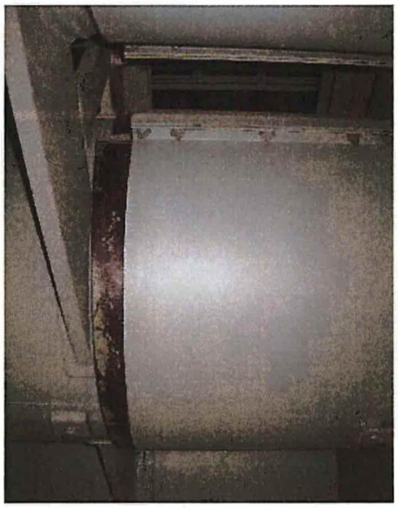


Figure 5 B-PhaseDuct

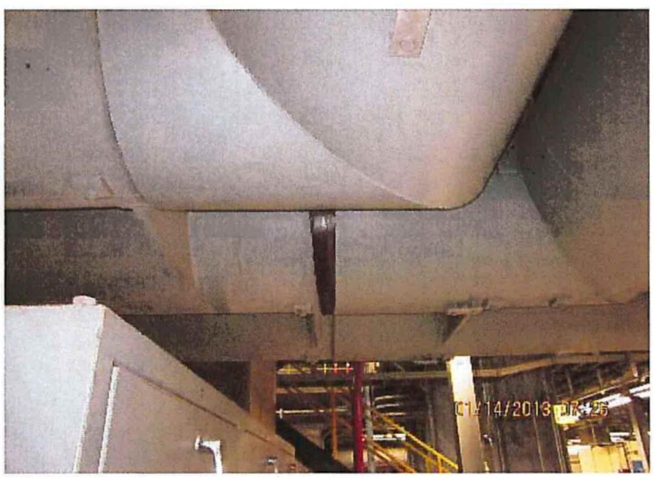


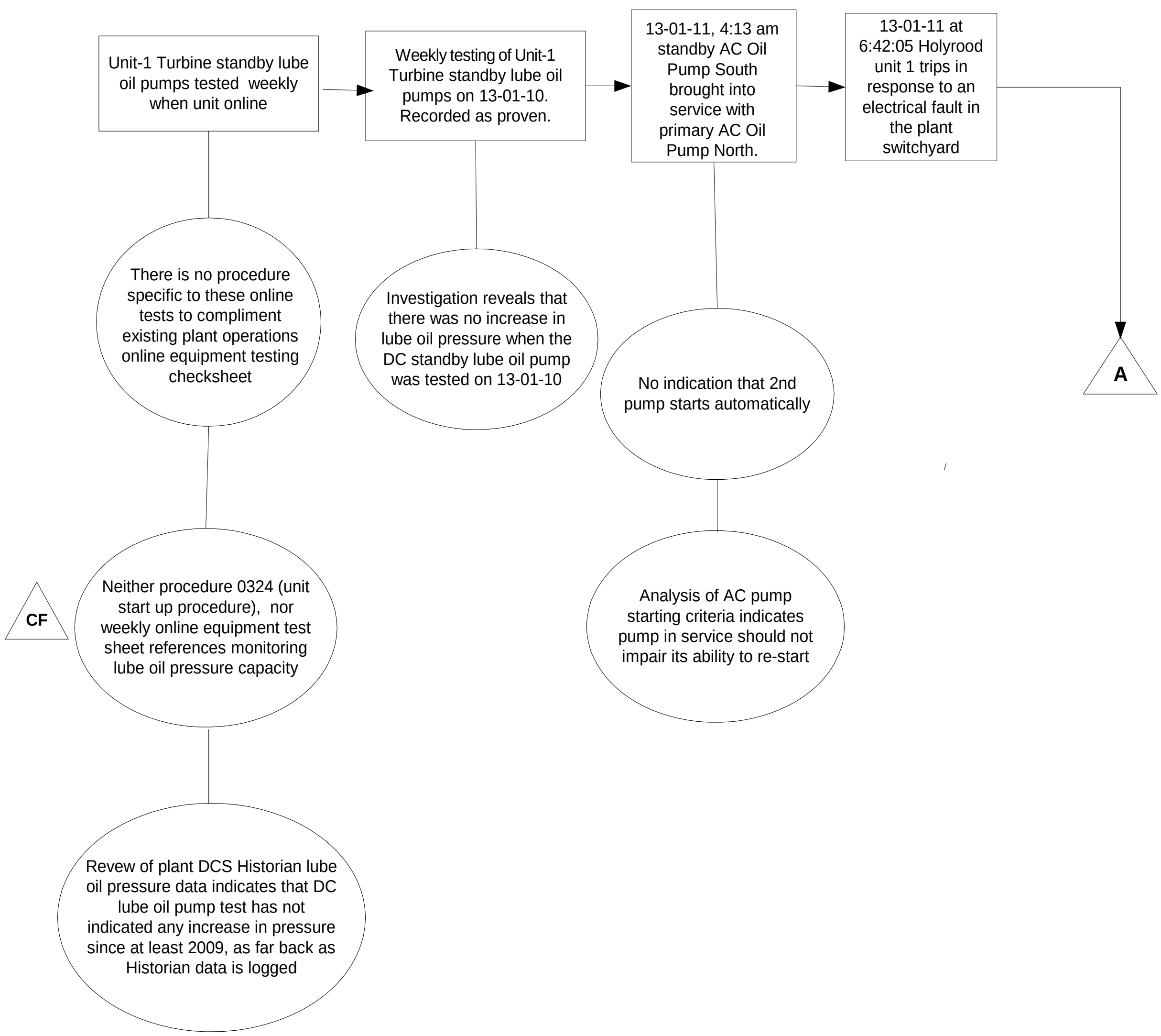
Figure 6 B-Phase Duct

Note: These findings are based on visual inspection only and further more detail investigation may lead to additional findings.

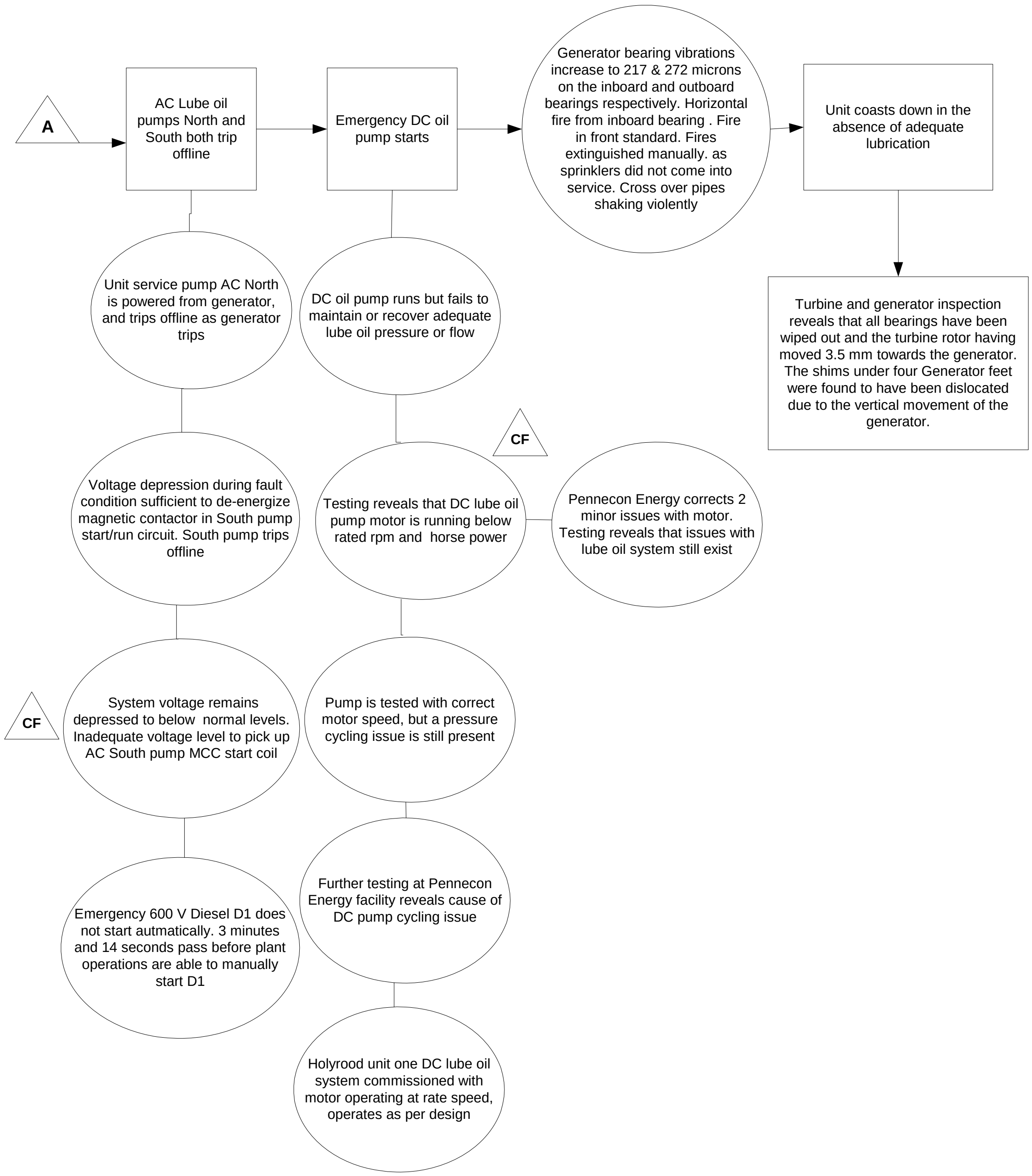
APPENDIX B

Holyrood Unit 1 Failure Analysis SnapCharT®

Holyrood January 11, 2013 U1 Failure Root Cause Analysis Snap Chart



Holyrood January 11, 2013 U1 Failure Root Cause Analysis Snap Chart, Continued



APPENDIX C

Excerpt from Holyrood Unit Startup Procedure #0324

(a) Travelling screens and screen wash pump selector switch placed in AUTO.
(b) Turn OFF C.W. pump motor heater.
(c) Open fully the condenser outfall valves and the partition valves.
(d) Select the C.W. pump discharge valve to 'AUTO'.
(e) When the pump is started and the discharge valve moves to the "cracked" position, select "manual" and slowly open valve keeping watch on condenser for leaks. Place valve selector switch in "AUTO" when valve is fully open.
(f) After two (2) hours the partition valves may be closed.

NOTE: The partition valves are opened and the C.W. discharge lines are flushed after lengthy shut down to avoid plugging condenser tubes with mussels that may have grown in the discharge pipe.

(g) Vent condenser by throttling outfall valve and opening condenser vents until water issues from vents.

3. Turbine Generator cooling system to be placed in service.

(a) Open cooling water (sea water from C. W. System) inlet valve to cooler and vent coolers.

NOTE: The inlet valve to cooler should be left closed until the C. W. system has been flushed and placed in service, to prevent plugging.

(b) T. G. head tank should be at normal level and the level control valve placed in "AUTO" on W.D.P.F. console.
(c) Start T.G. pump with discharge valve closed and slowly pressurize system.
(d) Vent T. G. coolers, Hydrogen coolers, Turbine lube oil tank coolers and Boiler feed pump coolers.

4. Generator

(a) Verify that turbine lube oil reservoir is full and the Bowser has been cleaned.
(b) Pressurize generator casing with air to 15 to 30 kPa.
(c) AC oil pump can now be started and depending on the position of the three-way supply valve (located in the lube oil tank) oil will be supplied to the bearings and generator seals or to generator seals only.
(d) With oil flowing to bearings and seals; perform tests of the oil pumps as follows:

(1) Leave the D.C. oil pump breaker open.
(2) North A.C. oil pump in operation and south in "AUTO".
(3) Stop NORTH pump. Check that south A.A. pump starts automatically.
(4) Place North A.C. oil pump in "AUTO" and stop South A.C. pump. Check that North starts automatically.

(5) Close breaker on D.C. oil pump and place in "AUTO". Stop A.C. oil pumps. Check that D.C. pump starts automatically.
(6) Start one A.C. oil pump and place the other A.C. pump in "AUTO". Shut down D.C. pump and place in "AUTO".

(e) The turbine may be placed on turning gear.

NOTE: It is recommended that the turbine be on turning gear eight (8) hours prior to pre-warming.

(f) Carbon dioxide is now admitted to the generator to purge the air. CO_2 is admitted to the bottom of the generator through the CO_2 distribution pipe and air in the generator is discharged to atmosphere through the Hydrogen feed pipe. The admission of CO_2 is controlled by valve C42 and C45 always maintaining between 15 and 30 kPa generator pressure during purging. CO_2 shall be admitted to the generator until the percentage of CO_2 in the discharge (vent) pipe is in excess of 70%.

(g) Hydrogen may now be admitted through the top of the generator through the hydrogen distribution pipe and the carbon dioxide-air mixture is discharged to atmosphere through the CO_2 feed pipe. The admission of hydrogen (H2) to the generator is controlled with valve H-26, maintaining a generator pressure 15 to 30 kPa. Hydrogen shall be admitted until the gas mixture discharged is in excess of 90%.

(h) The generator can be pressurized to operating pressure of 320 kPa and the seal oil booster system placed in service. As the pressure increases the purity should increase to exceed 95%.

(i) Hydraulic fluid pumping system start-up.
1. Verify turbine in tripped condition.
2. Check hydraulic fluid tank level.
3. Check coolers in service.
4. Open by-pass valve and start hydraulic fluid pump.
5. Close by-pass slowly - pressurizing system.
6. Place 2nd pump in stand-by.

5. Low Pressure Feedwater System

Note: Refer to Procedure #'s POP-003, POP-015, POP-016, POP-032, POP-053, POI-01/02/03 and POI-13

The Deaerator should be filled and steam open to coil allowing the water to heat up. After this is achieved, do not use RFW pump to put water in the boiler.

1. Ensure that there is an adequate water level in both the RFW tanks and in the Hotwell.
2. Ensure Hotwell water is checked by the Lab for chlorides, Condensate Polisher Regeneration chemicals, etc. (Lab) before and after the CW (salt water) system is placed in service as per Procedure POP-015.
3. Ensure Extraction pumps have proper oil levels.
4. Close all known vents and drains on the LP Feed system. Refer to dry lay-up instructions POI-001/002//003 as required.
5. Check the DA rundown and DA recirculation are closed when filling DA.
6. Ensure Extraction Pump Seal Water is in service.
7. Ensure Hotwell make-up and Surplus Stations are in service. Align set point and process of Hotwell Level Control at normal operating level and place in auto.
8. Check the 4kv starter Breakers for proper operating position.
9. Check the discharge valves are opened approximately 10% on both Extraction pumps before starting Extraction pumps.
10. Open suction Valves to both Extraction pumps.
11. Ensure that the Condensate Polisher has been rinsed down. Refer to POP-053 Putting a Condensate Polisher in line.
12. Ensure that the Condensate Polisher plant is at '0%' percent before starting Extraction pump.
13. Ensure that the Low Load Recirc Valve is in the open position.
14. Ensure Extraction Pump Motor Cooling Water is in service (Unit #3 only).
15. Start the Condensate Extraction Pump as per Procedure POP-032.
16. Start hydrazine/ammonia pump if required, and slowly open Deaerator (Fill) Control Valve to fill D.A. if required, **maintaining a slow rate of fill**, while monitoring the Hotwell level at the same time as per Procedure POP-003. Check for leaks and at normal level 70%, the steam coil may be opened partially.
17. Open the Pegging Steam supply to the Deaerator, if hot, prior to adding water.
18. Slowly open the pump discharge valve and allow the system to purge and fill with water.
19. Check system periodically after start up for anything that is not

APPENDIX D

Holyrood Unit Turbine and Auxiliaries Weekly Checks, January 10, 2013

11693 Hyd
199.99 Bearing

File #102.01.35/12
Revision #: 2
Rev. Date: Dec 20, 2012

To be completed weekly every Wednesday when Units are on or in Stand-By mode.

Scope: To ensure Turbine & Generator runs down with oil to the bearings and generator seals. Also ensuring alarms work on Unit 3 bearing oil tank.

TURBINE AND AUXILIARIES WEEKLY CHECKS

Standby AC Oil Pump Test	Unit #1 U.C.B.	✓	Alarms Rec'd (Y) / N
	Unit #2 U.C.B.	✓	Alarms Rec'd (Y) / (N)
	Notes:		
Emergency D.C. Oil Pump Test	Unit #1 U.C.B.	✓	Alarms Rec'd (Y) / N
	Unit #2 U.C.B.	✓	Alarms Rec'd (Y) / N
	Notes:		
Standby Hydraulic Fluid Pump Test	Unit #1 U.C.B.	✓	Alarms Rec'd Y / (N)
	Unit #2 U.C.B.	did not start on test	Alarms Rec'd Y / (N)
	Notes:		
Emergency Seal Oil Pump Test	Unit #1 Skid		Alarms Rec'd Y / N
	Unit #2 Skid		Alarms Rec'd Y / N
	Unit #3 Skid		Alarms Rec'd Y ✓ N
	Notes:		
Oil Tank Level (Low Level -4) **Gauge Hi/Lo Test** (High Level +4)	Unit #3 M.O.T.		Alarms Rec'd Y✓ N
	Notes:		Level Indication
Front Standard Emergency Governor Test (Oil Trip & Lock Out)	Unit #3 F.S.		Alarms Rec'd ~~Y / N~~
	Notes: Not performed due to light integrity issues with unit trips		
Auxiliary Oil Pump (A.O.P.) Test	Unit #3 M.O.T.		Alarms Rec'd Y ✓ N
	Notes:		
Emergency Bearing Oil Pump (DC Flushing) Test	Unit #3 M.O.T.		Alarms Rec'd Y✓ N
	Notes:		
AC Flushing Oil Pump Test	Unit #3 M.O.T.		Alarms Rec'd Y✓ N
	Notes:		

Completed By: Terry Barnable
Date: 13 / 01 / 16 (YY MM DD)

Shift Supervisor: Don Malone
Shift: C

APPENDIX E

Excerpt from General Electric Turbine – Generator Manual

MAIN LUBE OIL TANK AND LUBE SYSTEM
(Motor Pumps)

TANK ASSEMBLY

The lube oil tank is a compact, simple design. Elimination of the turbine shaft-driven centrifugal oil pump also eliminates the booster pump priming system for the shaft pump as well as the need for a 200 psig lube-hydraulic system pressure. The lube system pressure level is now 65 psi and permits the use of much smaller motor pumps than was possible in the past. Three full-capacity motor pumps are standard - two with AC motors, one with a DC motor. The AC motor pumps normally supply lube oil for the turbine generator. Either pump can supply bearing flow and generator shaft seal flow with the other pump as a standby" or back-up pump.
The DC motor pump is an emergency pump and backs up the two AC pumps.

GRAVITY FLOW HEAT EXCHANGERS

Cooling the lube oil is accomplished by finned tube heat exchangers in the tank. The bearing drains return to the lube tank through a single pipe connection.
Three gravity flow, finned tube heat exchanger units are mounted in a series - flow arrangement in a compartment inside the rank. The returning lube oil passes into the compartment through the heat exchangers and through an orifice plate dam back into the main reservoir of oil. The lube oil in the tank will be about 120°F with the coolers arranged this way. The orifice plate dam is used to provide a level of oil in the cooler compartment to submerge the heat exchanger tubes and establish a uniform flow through the tubes. The finned tubes also are very effective in detraining air and foam.
Each heat exchanger unit is designed with a cooling capacity of 50% of the turbine requirements. Any two units will thus provide adequate cooling capacity, with the third unit as spare capacity. The oil side of each cooler unit is oil tight permitting removal of water boxes on the spare cooler for cleaning and inspection of tubes. Normal cooling water temperature is 95°F max.
The oil pumps are vertical, 20 HP motor-driven centrifugal pumps. Each pump has a suction strainer and is isolated from the lube system header by a check valve in its discharge piping. Two of the pumps have AC motors. One AC pump normally supplies the turbine with lube oil. The other AC pump is on standby or back-up service. Each pump has an automatic start pressure switch which senses pressure in the lube system header. The DC motor pump starting pressure switch is set to actuate at a lower pressure than for the two AC pump switches so that the AC motor pumps normally will take care of the turbine lube oil supply and the DC motor pump will automatically start only on an "emergency basis".

VAPOR EXTRACTOR

A motor driven vapor extractor which includes an oil separator is provided on the tank. The extractor is adjusted to maintain a slight vacuum of about 1"
This vacuum prevents oil vapor from passing out through small openings in the tank structure and wetting external areas of the tank. The extractor also scavenges the turbine generator lube and shaft seal drain piping to remove oil vapors, moisture and any hydrogen which might accidentally pass into the seal drain system oil return to the lube tank. The exhaust from the vapor extractor is piped to a vent which discharges outside the building to atmosphere.

OIL PUMPS

All three pumps discharge into a common header in the tank. Oil for the generator shaft seal system is supplied directly from the header to the hydrogen shaft seal oil unit with its own pressure regulators, filters, etc. Oil for the turbine generator bearings passes through a blocking valve which permits shutting off oil to the bearings during bearing inspection, but still permits the motor pump in service to maintain seal oil pressure at the generator shaft seals. Next the lube oil passes through a diaphragm type, pressure regulating valve which maintains bearing lube oil pressure at 25 psig at turbine centerline and then on to the bearings. 170KPa

PUMP TEST AND AUTOMATIC STARTING

Provisions are made to test the AC and DC motor pumps which are on "stand-by". An orifice and solenoid valve are included with each starting pressure switch and a "run" pressure switch is included for each pump. The "run" pressure switch senses pressure between the pump discharge connection and its isolating discharge check valve. The test is performed by pushing the pump test pushbutton and energizing the test solenoid valve. The solenoid valve is an open-closed design and causes oil to flow from the header to drain through the orifice in the starting pressure switch sensing line. The orifice drops the oil pressure sensed by the starting pressure switch and causes the switch to close and start the motor pump. As soon as the pump is running, its discharge pressure will rise to normal pressure and the "run" pressure switch will close, lighting the "run" signal lamp. Releasing the test pushbutton closes the solenoid valve and the automatic start pressure switch opens. The motor is stopped by turning the motor control SBI switch or equivalent to the "stop" position.
This feature is not only provided for all three motors on a panel at the tank, but provisions are made for connections to the customer's own central Control Panel.

The motor control switches for these pumps should be three-position SB-1 or equivalent switches. The three positions are "run", "auto-start" or "stand-by" and "stop". A spring return from "stop" to "auto-start" should be used to automatically return the control switches to the automatic start condition and maintain the AC and DC pumps as back-up pumps. The motor-pump starters should have seal-in contacts in parallel with the automatic start pressure switch contacts to prevent cycling and also to require the operator to manually stop the pump. The motor control switches should have a "pull to lock out" or similar feature in order to minimize the possibility that the motor control would be accidentally left in the "off" condition. An additional precaution against leaving the motor pump in the "off" condition is to have a green light lighted when the motor control switch is in the "auto-start" position. When the motor control switch is in the "locked out" position, the green light would go off.

TANK CONSOLE

A metal console is located on the top of the tank along one side. The console contains the pressure switches for the pumps, the pump test pushbuttons and solenoid valves, the lube oil tank thermometer and oil level gage. All the electrical devices are wired to terminal strips in the console and space has been designated for customer Connection conduits and wire. Some of the accessories included are: a remote pressure transmitter for lube oil pressure; a low bearing oil pressure switch and a thermocouple for lube oil tank temperature.

OIL CONDITIONER

For filtration purposes, an oil conditioner is included in the lube system. The oil conditioner is used to dehydrate, clean, and polish the oil and includes such equipment as: a vapor extractor; a polishing filter; and a transfer and by-pass pump system, driven by CGE 1 H.P. - 460 V - 1800 RPM motors. The type of oil conditioner used is a Bowser Model (823-P).

SGEI 3054

PERIODIC OPERATIONAL TESTS SUMMARY

The following operational tests are in addition to the normal observations given in the "Operating Instructions".

Once a Day

1. Operate the main stop valve, reheat stop valve and intercept valves by sequence testing at operator's control panel.

2. Close the extraction check valves equipped with an air operated test mechanism part way by operating the test levers.

Once a Week

1. Observe closure of the main stop valves, intercept valves and reheat stop valves during sequence testing by watching travel of the valve stems.

2. Test the overspeed governor by means of the pushbutton and indicating lights at the operator's control panel. (Maintain load on the unit during this test).

3. Start the stand-by oil pump and the D.C. emergency oil pump by operating the test arrangement provided. This can be done from the control room or at the main oil tank console.

4. Start the stand-by hydraulic fluid pump by operating the test arrangement provided. This can be done from the control room or at the hydraulic fluid power unit.

Once a Month

1. If the unit has been on the line continuously, close the control valves to check for sticking.

2. If the unit has been on load-limit control continuously, operate for a short period of time on the speed governor load control.

Every 3 - 6 Months

1. If the unit is not to be removed from the line, check operation of the overspeed governor by the test logic. Otherwise check by actual overspeeding. This test will verify the capability of all steam valves to close.

Every 6 to 12 Months

1. Check operation of the overspeed governor by overspeeding the turbine.

2. Test the main stop valve, control valves and intercept valve for tightness.

3. Test operation of the vacuum trip.

4. Test operation of the solenoid trip.

APPENDIX F

Check Sheet with New DCS Display Addition

File #102.01.35/12
Revision #: 3
Rev. Date: Mar 27, 2013

To be completed weekly every Wednesday when Units are on or in Stand-By mode.

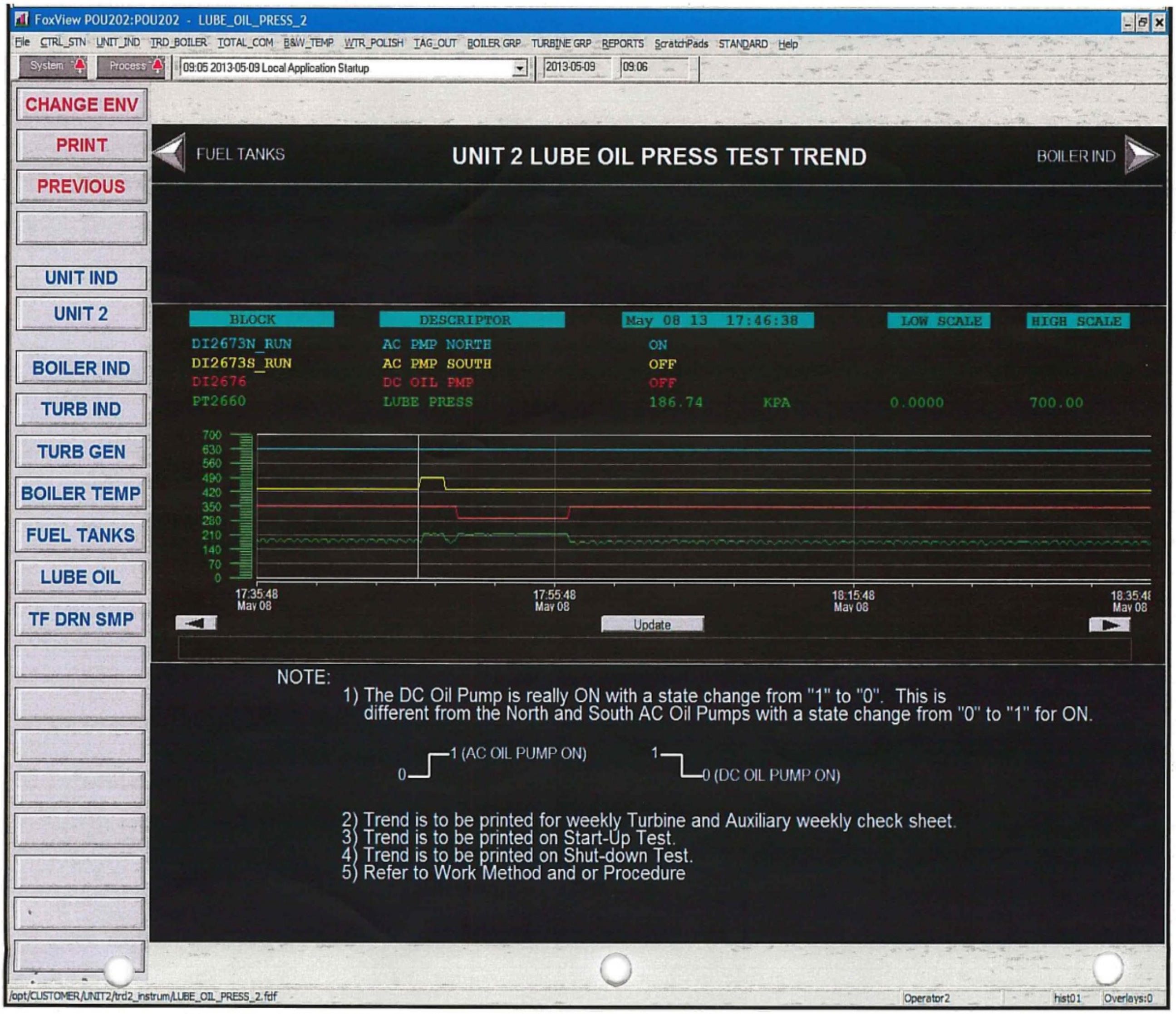
TURBINE AND AUXILIARIES WEEKLY CHECKS				
	Unit 1 & 2			
Standby AC Oil Pump Test	Unit #1 U.C.B.		Alarms Rec'd	Y / N
	Unit #2 U.C.B.	✓	Alarms Rec'd	Y / (N)
	Notes:			
Emergency D.C. Oil Pump Test	Unit #1 U.C.B.		Alarms Rec'd	Y / N
Print permanent trends of lube oil pressure	Unit #2 U.C.B.	✓	Alarms Rec'd	(Y) / N
	Notes:			
Standby Hydraulic Fluid Pump Test	Unit #1 U.C.B.		Alarms Rec'd	Y / N
Two running due to low Pressure	Unit #2 U.C.B.		Alarms Rec'd	Y / N
	Notes:			
Emergency Seal Oil Pump Test	Unit #1 Skid		Alarms Rec'd	Y / N
	Unit #2 Skid		Alarms Rec'd	Y / N
	Unit #3 Skid		Alarms Rec'd	Y / N
	Notes:			
	Unit 3			
Oil Tank Level (Low Level -4)	Unit #3 M.O.T.		Alarms Rec'd	Y / N
Gauge Hi/Lo Test (High Level +4)	**Notes:**		Level Indication ______	
Auxiliary Oil Pump (A.O.P.) Test	Unit #3 M.O.T.		Alarms Rec'd	Y / N
	Notes:			
AC Flushing Oil Pump Test	Unit #3 M.O.T.		Alarms Rec'd	Y / N
	Notes:			
Emergency Bearing Oil Pump (DC Flushing) Test	Unit #3 M.O.T.		Alarms Rec'd	Y / N
Print permanent trends of lube oil pressure	**Notes:**			
Front Standard Emergency Governor Test (Oil Trip & Lock Out)	Unit #3 F.S.		Alarms Rec'd	Y / N
	Notes:			

Completed By: "D" Shift   Shift Supervisor: Glen Kennedy

Date: 13 / 5 / 8 (YY MM DD)   Shift: D

- Unit 3 Shut down.
- Unit 1 Shut down.

H:\Holyrood\Forms\Operations Forms\Turbine&Auxiliaries-Wkly Checks.xls


FoxView POU202:POU202 - LUBE_OIL_PRESS_2
09:05 2013-05-09 Local Application Startup
2013-05-09
09:06
CHANGE ENV
PRINT
PREVIOUS
UNIT IND
UNIT 2
BOILER IND
TURB IND
TURB GEN
BOILER TEMP
FUEL TANKS
LUBE OIL
TF DRN SMP
FUEL TANKS
UNIT 2 LUBE OIL PRESS TEST TREND
BOILER IND
BLOCK
DESCRIPTOR
May 08 13 17:46:38
LOW SCALE
HIGH SCALE
DI2673N_RUN
AC PMP NORTH
ON
DI2673S_RUN
AC PMP SOUTH
OFF
DI2676
DC OIL PMP
OFF
PT2660
LUBE PRESS
186.74
KPA
0.0000
700.00
700
630
560
490
420
350
280
210
140
70
0
17:35:48 May 08
17:55:48 May 08
18:15:48 May 08
Update
NOTE:
1) The DC Oil Pump is really ON with a state change from "1" to "0". This is different from the North and South AC Oil Pumps with a state change from "0" to "1" for ON.
0
1 (AC OIL PUMP ON)
1
0 (DC OIL PUMP ON)
2) Trend is to be printed for weekly Turbine and Auxiliary weekly check sheet.
3) Trend is to be printed on Start-Up Test.
4) Trend is to be printed on Shut-down Test.
5) Refer to Work Method and or Procedure
/opt/CUSTOMER/UNIT2/trd2_instrum/LUBE_OIL_PRESS_2.fdf
Operator2
hist01
Overlays:0

APPENDIX G

Plant Operational Procedural Enhancements

Re: 1077 - POP-162 Unit 1 & 2 Turbine " AC/DC lube oil pumps test procedure -" Return to service ".

Request Title: **POP-162 Unit 1 & 2 Turbine " AC/DC lube oil pumps test procedure-" Return to service".**

Document Control Coordinator : Gerard Cochrane

Beverly Kennedy on Sept 20th, 2013 at 02:04 PM

Request Details

Requester: Beverly Kennedy

Details:

Cancellation Message (if applicable):

Request Change Status : Approved

Solution Definition and Development Information

Procedure No: 1077	Entered By: Beverly Kennedy Date: May 29th, 2013 08:52 AM
Title	**POP-162 Unit 1 & 2 Turbine " AC/DC lube oil pumps test procedure-" Return to service".**

Archive Information

Issue Date:	05/29/2013 May 29th, 2013
Distribution:	Manager - Operations, Manager - Work Execution, Operations
Manual/Group:	Maintenance Standards, Plant Operating Procedures
Revision No:	0
Revision Date:	09/23/2013
Prepared By:	Beverly Kennedy
Controller:	Gerard Cochrane
Reviewers:	Gerard Cochrane, Gerard Cochrane, Evan Cabot, Gerard Cochrane, Chris House, Gerard Cochrane, Evan Cabot, Gerard Cochrane
Approved By:	Terry LeDrew/HO/NLHydro

Procedure Scope

This directive describes the procedure for testing the reliability of the Turbine AC & DC lube oil pumps.

Reference Information

GE TIL 914-2 Back-up lube oil system reliability.

EQUIPMENT : AC & DC lube oil pumps.

Re: 1076 - POP-163 Unit 1, 2 and 3 - Turbine Emergency DC lube oil Test -Weekly

Request Title: POP-163 Unit 1 and 2 - AC Standby and DC Turbine Lubricating Oil Test -Weekly Reviewers are Evan, Chris and Gerard

Document Control Coordinator: Gerard Cochrane

Beverly Kennedy on Sept 26th, 2013 at 01:24 PM

Request Details

Requester: Beverly Kennedy

Details:

Cancellation Message (if applicable):

Request Change Status: New Request

Solution Definition and Development Information

Procedure No: 1076	Entered By: Beverly Kennedy Date: May 29th, 2013 08:48 AM
Title	**POP-163 Unit 1 and 2 - AC Standby and DC Turbine Lubricating Oil Test -Weekly**

Archive Information

Issue Date:	05/29/2013 May 29th, 2013
Distribution:	Operations
Manual/Group:	Plant Operating Procedures
Revision No:	0
Revision Date:	
Prepared By:	Beverly Kennedy
Controller:	Gerard Cochrane
Reviewers:	Evan Cabot, Gerard Cochrane, Chris House
Approved By:	Terry LeDrew/HO/NLHydro

Procedure Scope

This directive describes the procedure for testing the reliability of the AC Standby and DC Turbine Lubricating Oil Pumps on a weekly basis

Reference Information

GE TIL 914-2 Back-up lube oil system reliability.

EQUIPMENT : AC Stand-by and Emergency DC lube oil pump.

Procedure Details

Note 1 Unit Control Board (UCB) - is the Operator designated for a particular Unit situated in the Control Room

Note 2 The UCB Operator will have the permanent trend screen displaying on the DCS that shows the Turbine Lube Oil Pressure vs the AC and DC pump starts

1. Turbine on line
2. Battery Chargers On.
3. Check to ensure the DC lube oil pump is in Auto.
4. Check to ensure that the South AC lube oil pump is in Auto.
5. Check that the North AC lube oil pump is in service
6. Before Function Testing have a Field Operator ready to check AC and DC lube oil pumps to confirm that both pumps start in the field, to record lube oil pressure at the Lube Oil Set and Turbine Front Standard as required in the following steps of this procedure. The Field Operator is to report to the Shift Supervisor any unusual noise originating from the motors or pumps when either the AC and DC pump start or when the pumps are running. The Field Operator will also ensure the oil level in the lube oil tank is at normal operating level before and after testing and report to the Shift Supervisor if it is not.
7. With the North AC oil pump running, Record the Lube Oil Pressure at the front standard and check this pressure against the DCS Lube Oil Pressure reading. Note any differences and record.
8. Push the AC Oil Pump test button from the unit control board. Confirm with the Field Operator that the South Pump is running and record the lube oil pressure at the Lube Oil Set. Then record the lube oil pressure at the Turbine Front Standard. Confirm with the UCB Operator that the red "running" light is ON for the South AC oil pump.
9. The UCB Operator will contact the Field Operator to confirm that the North AC oil pump is running and the lube oil pressure is adequate. If so, the UCB Operator can shut down the South AC Oil Pump and place it in Auto
10. Push the DC Oil Pump test button from the unit control board. Confirm with the Field Operator that the DC Oil Pump is running and record the lube oil pressure at the Lube Oil Set. Then record the pressure at the Turbine Front Standard. Confirm with the UCB Operator that the red "running" light is ON for the DC oil pump.
11. The lube oil pressure at the Turbine Front Standard should increase by a minimum of 35

Kpa, with the DC and North AC oil pump running. If not, report this to the Shift Supervisor.

12. Check the pre and post test data.

13. Return DC lube oil pump to auto.

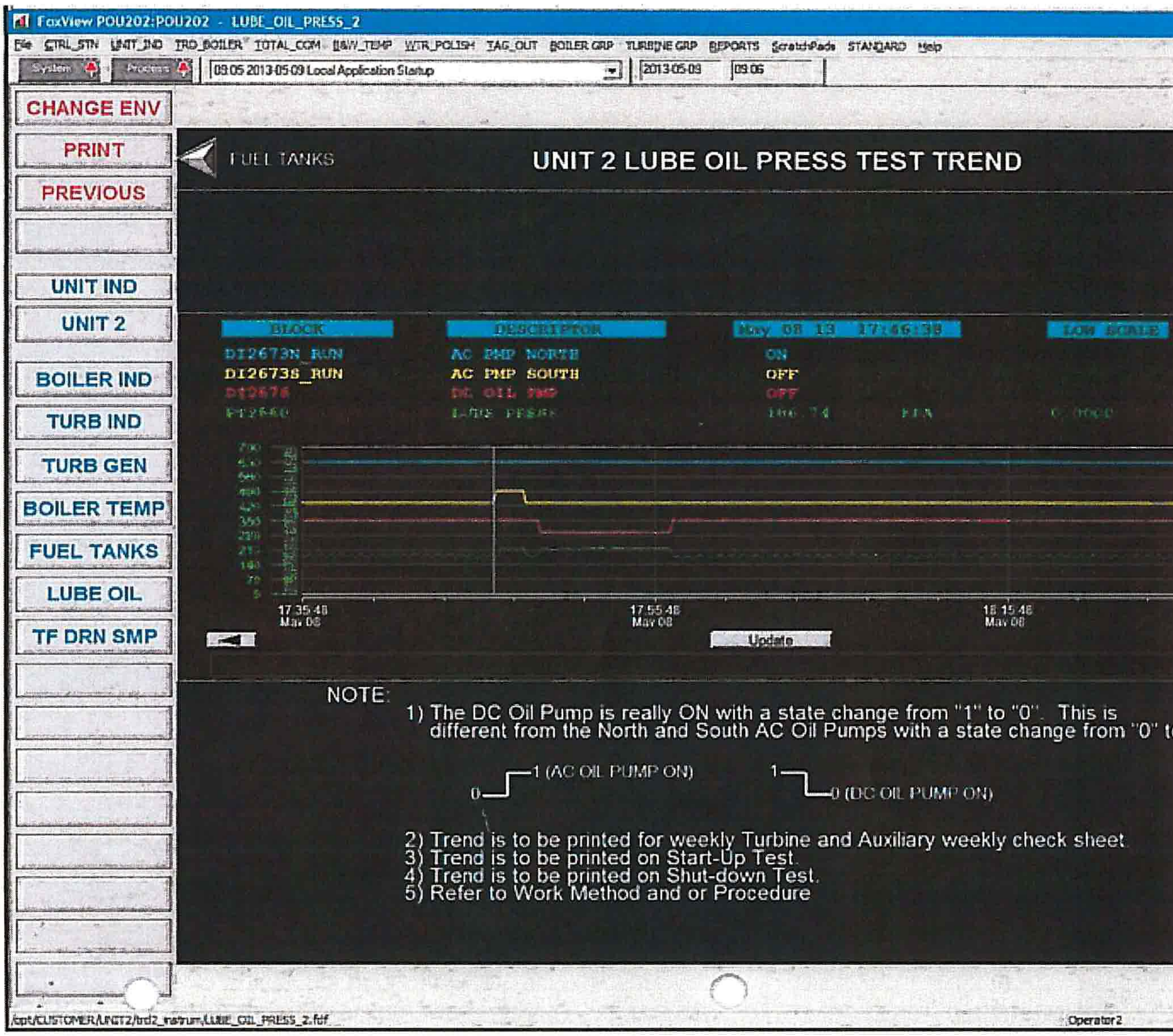
14. Investigate and correct malfunctions.

15. Repeat the test after the issues have been resolved

16. Print the permanent trend showing clearly the Turbine Lube Oil Pressure with the North AC oil pump running, South AC pump and DC pump starts. The trend should show step increases in lube oil pressure with a start of the AC South stand-by pump and with a start of the DC Oil Pump while the North AC oil pump remains in service at all times This sheet shall be submitted to the Manager, Operations. **See sample below.**

17. Record all test information in the unit control board and the shift supervisor's station log books.

SAMPLE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PREVIOUS
UNIT IND
UNIT 2
BOILER IND
TURB IND
TURB GEN
BOILER TEMP
FUEL TANKS
LUBE OIL
TF DRN SMP
FUEL TANKS
UNIT 2 LUBE OIL PRESS TEST TREND
BLOCK
DESCRIPTOR
LOW SCALE
DI2673N_RUN
AC PMP NORTH
ON
DI2673S_RUN
AC PMP SOUTH
OFF
17:35:48
17:55:48
18:15:48
Update
NOTE:
1) The DC Oil Pump is really ON with a state change from "1" to "0". This is different from the North and South AC Oil Pumps with a state change from "0" to
0
1 (AC OIL PUMP ON)
1
0 (DC OIL PUMP ON)
2) Trend is to be printed for weekly Turbine and Auxiliary weekly check sheet.
3) Trend is to be printed on Start-Up Test.
4) Trend is to be printed on Shut-down Test.
5) Refer to Work Method and or Procedure
Operator2

Procedure Details

Unit 1, 2 Turbine AC / DC lube oil pump test procedure- Return to service".

1. Turbine at rest- not on turning gear.

2. Verify that turbine lube oil reservoir is full and full flow filters in service.

3. Verify that the three-way supply oil valve (located in the lube oil tank) is positioned to supply oil to the generator seals and bearings.

4. Pressurize generator casing with air to 15 to 30 kPa.

5. North AC oil pump can now be started.

6. With oil flowing to seals and bearings: perform the following test on both AC oil pumps and DC oil pump as follows:

    (1) Open up the D.C. oil pump breaker and lock out the D.C oil pump pistol grip handle on the unit control board.

    (2) With the North A.C. oil pump in Operation and South AC oil pump in "AUTO".

    a. Record lube oil pressure at front standard.

    b. Record lube oil pump discharge pressure at lube oil tank.

    c. Verify oil flow to all bearings.

    d. Verify "run" red indicating light on UCB for North AC lube oil pump.

    (3) Stop North AC oil pump. Check that South A.C. oil pump starts automatically.

    a. Record lube oil pressure at front standard.

    b. Record lube oil pump discharge pressure at lube oil tank.

    c. Verify oil flow to all bearings.

    d. Verify "run" red indicating light on UCB for South AC lube oil pump.

7. Place North A.C. oil pump in "AUTO" and stop South A.C. oil pump. Place the South AC oil pump pistol grip handle to the full locked-out position. Check that North AC oil pump starts automatically.

8. Close breaker on D.C. oil pump and place in "AUTO". Stop the North A.C. oil pump and place the pistol grip handle to the full lock-out position. Check that D.C. Oil pump starts automatically.

a. Record lube oil pressure at front standard.

b. Record lube oil pump discharge pressure at lube oil tank.

c. Verify oil flow to all bearings.

d. Verify "run" red indicating light on UCB for DC lube oil pump.

Note 1; the minimum lube pressure at the front standard should not be less than 35 kpa on the start of the DC pump.

Note 2: The minimum operating DC lube oil pump pressure at the front standard should not be less than 83 kpa

9. With the battery Chargers in the off position record the following.

   a. The lube oil pressure at the lube oil tank.

   b. The lube oil pressure at the front standard.

   Note: With the assistance from maintenance personnel record the following:

   c. Voltage of armature (VDC)

   d. Current of armature (A)

   e. Voltage of field (VDC)

   f. Current of field (A)

   g. Motor speed (rpm)

10. Run the Emergency DC lube oil pump for minimum 25 minutes and record the following:

   a. The lube oil pressure at the lube oil tank.

   b. The lube oil pressure at the front standard.

   Note: With the assistance from maintenance personnel record the following:

   c. Voltage of armature (VDC)

   d. Current of armature (A)

e. Voltage of field (VDC)

f. Current of field (A)

g. Motor speed (rpm)

11. Check the pre and post data parameters.

a. Put the unit start up on hold if any differences are found between pre test and post test parameters.

b. Investigate and correct malfunctions.

c. Repeat the test after the issues have been resolved.

d. If lube oil pressure at the front standard and lube oil tank are in acceptable operating range continue on with the following procedure steps.

12. Place battery Chargers back in service.

13. Start North A.C. oil pump and place the South A.C. oil pump in "AUTO". Shut down D.C. Oil pump and place in "AUTO".

14. The turbine may be placed on turning gear.

15. Record all test information in the unit control board and the shift supervisor's station log books.

APPENDIX H

Investigation of Unit 1 DC Lubrication System

newfoundland labrador hydro
a nalcor energy company

Newfoundland and Labrador Hydro – a Nalcor Company
Holyrood January 11, 2013 U1 Failure Root Cause Analysis
Investigation of Unit 1 DC lubrication System

Prepared By: Sean Mullowney

Date: June 28/2013

Reviewed By: Greg Reid

Date: July 2, 2013

newfoundland labrador hydro
a nalcor energy company

Approved By: Terry Le[illegible]

Date: June 28/13

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1. Background

The following report summarizes the work that has been completed to date by the Newfoundland and Labrador Hydro (Hydro) Holyrood Unit 1 Failure Root Cause Analysis Team, as it relates to the issue(s) with the Unit 1 DC lubricating pump system.

Much of this investigative work occurred in the area where Alstom Power and Hydro personnel were working to disassemble and repair the unit. This required careful coordination to ensure the safety of all personnel, as testing commenced.

This commitment to safety necessitated certain delays in the investigative testing, to ensure that no personnel were put in harm's way.

2. Investigation Sequence of Events

The following is a chronological timeline of the investigation, as it unfolded in the days after the January 11th event:

- January 17th – January 29th:
  - Root cause analysis team was formed, and collection of data began. Data included plant DCS (Distributed Control System) Historian alarm data, DCS SOE (Sequence of Events) alarm lists, ECC (Energy Control Center) SOE alarm lists, plant turbine-generator protection/control schematics and interviews with plant operations personnel who were working on January 11th;
  - Examination of unit damage was possible during the week of January 21st, as Alstom Power began unit disassembly activities during this week;
  - Data, as well as physical examination of unit components, allowed the team to conclude that, following unit trip at 06:42 on January 11th, the turbine-generator coasted down with the absence of sufficient delivery of lubrication to its bearings;
  - DCS trends confirm loss of both AC lubricating pumps and crash of lube oil pressure following unit trip (see Figure 1 below); and
  - Lubricating oil pressure is re-established three minutes and 14 seconds after unit trip, when manual start of emergency diesel D1 re-establishes power to MCC-E1 (see Casual Factor # 2 in main report).

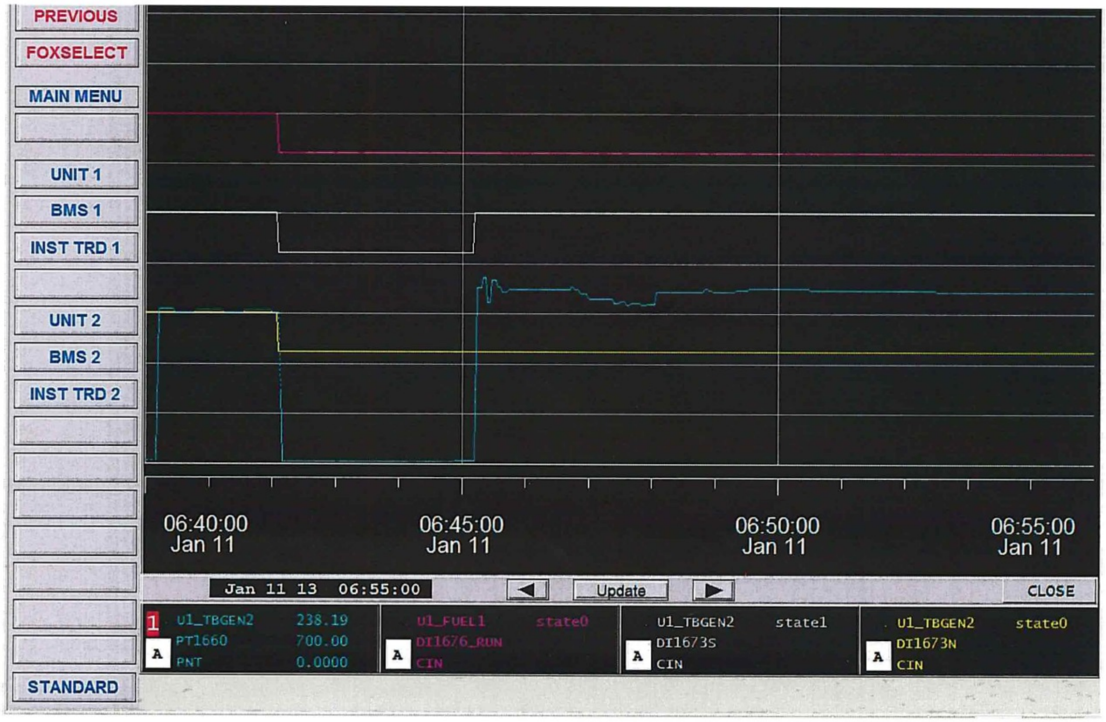

Figure 1: Status of Unit 1 Lube Oil Pumps and Lubricating Pressure during January 11, 2013 event. PT1660 (blue) is lubricating oil pressure at the front standard of the unit. DI1676_RUN (magenta) is the run/stop status of the DC lube oil pump (Note: DC pump's run status is triggered by a normally closed contact that opens to indicate run/start. Its running indication is opposite of both AC pumps North and South {i.e. run is indicated after the state change, the portion of the trend that is lower vertically}). DI1673s (white) is the run/stop status of the AC lube oil pump South. DI1673N is the run/stop status of the AC Lube Oil pump North. Upon loss of AC pumps the lube oil pressure crashes, despite DC lube oil pump starting. Pressure is restored 3 minutes, 14 seconds later after manual start of emergency diesel restores power to AC lube oil pump South.

- February 4th - February 15th:
  - DCS trend data collected, indicates that DC lubricating oil pump starts in response to loss of AC pumps/falling lubricating pressure but does not aid in recovery of pressure (see Figure 1 above);
  - Review of DCS Historian data shows that weekly online DC pump test has not shown a pressure increase back as far as November 2009 (as far back as data for present version of Historian is available);
  - DC starter controls function tested, no component failures found;

- DC lubricating pump motor is decoupled from pump and controls tested (simulation of loss of AC pumps and falling lubricating pressure). Motor starts in response to these triggers (indication that DC motor starter is in working order, supports DCS trend data indication that DC pump started on January 11th);
- DC lubricating pump motor rotation is confirmed to be correct;
- Check valves (valves which allow oil flow in one direction, and seal when pressure is introduced in opposite direction) that are installed in the piping for each lubricating pump (2 AC, 1 DC) are confirmed to be free (i.e. neither stuck open, preventing establishment of oil pressure);
- Piping from each pump to the main lubricating oil header is checked with a boroscope to confirm that there are no blockages in the lines;
- Filters on each pump inlet are checked and confirmed to be free of blockages; and
- DC pump removed from tank, inspected, disassembled, components checked by Alstom Power. No issue(s) found.

- February 27th:

  - Alstom Power has unit disassembly and lubricating system temporary arrangement to a point where test runs of the system with DC and both AC and pumps can commence (i.e. cleaning of lubricating oil tank complete, re-installation of pumps, inspection of oil coolers, temporary jumpers installed around bearing locations, tank refilled with oil).

- Week of March 4th:

  - DC lube oil pump is function tested with temporary lubricating oil piping arrangement to Unit 1 turbine-generator (i.e. generator, turbine rotors, bearing, etc. removed, temporary jumpers installed around bearing locations);
  - Inability to achieve or maintain adequate pressure is noted (see Figure 2 below, a representative test from March 5);
  - Cycling of lubricating pressure and DC motor amperage is noted;
  - Further testing/observation of DC motor starter conducted; and

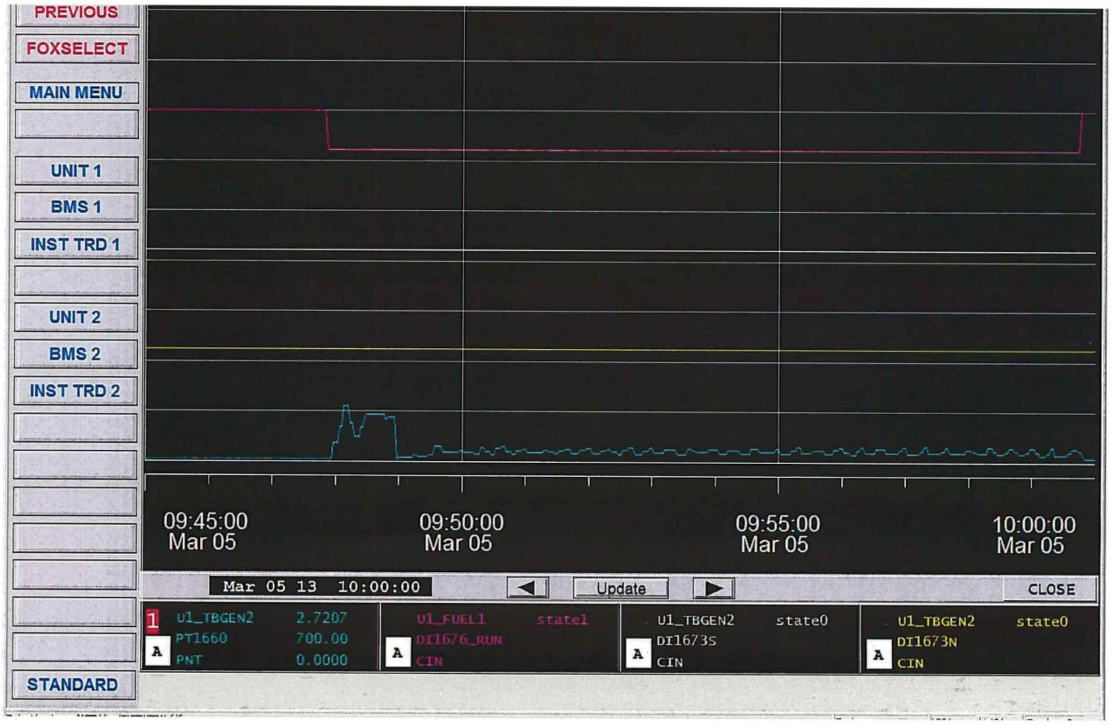

Figure 2: DC lube oil pump test from March 5, 2013. Note the falling magenta line indicates starting of the DC lube oil pump. There is an increase in pressure (blue) for a short time before pressure crashes and cycles

  - Test conducted with the feedback to the control valve in the lubricating oil tank removed, to allow the valve to fully open (removing feedback essentially removes valve control action from system). No change in system operation was noted (see Figure 3 below).

- March 11 to April 5th:

  - Measured rotational speed of DC pump motor. Nameplate rated speed is 3,500 RPM (Revolutions Per Minute), measured speed was 2,840 RPM;
  - Unit 2 DC Lube Oil Pump motor was tested and its speed was measured for comparative purposes, to confirm that Unit 1 speed is abnormal;
  - Consulted with external motor resource (Pennecon Energy);
  - Removed Unit 1 DC motor and sent it to Pennecon Energy test shop for independent analysis (see report in Appendix A);

Figure 3: DC lube oil pump test with tank control valve wide open. Magenta is the start/run status of the DC lube oil pump. White is the lube oil pressure in the tank (expect higher value as there is approximately 42 feet of vertical head between the tank and the turbine-generator). Blue is the pressure in the front standard of the turbine-generator. Note the same cyclic pattern in the pressure trend as in Figure 2.

- Two issues (motor brush boxes slightly off and motor neutral plane adjustment necessary) noted and corrected; and
- Motor speed at no load now acceptable, Pennecon Energy report declares motor operation to be in line with nameplate specification data.

- Week of April 8th:
  - Motor re-coupled to DC Pump and tested;
  - Motor speed measured and found to be improved (3,160 RPM) but still below nameplate rated speed of 3,500 RPM;
  - Motor amperage and system pressure cycling still present;
  - Adjusted variable resistor in field circuit of motor (present in DC starter) and nameplate speed achieved; and
  - Lubrication oil delivery to turbine-generator bearing locations improved, but pressure and motor amperage cycling issue still present.

- Week of April 23rd:

    - Unit 2 taken offline for eight hours for planned maintenance outage;
    - Connected Unit 1 lube oil pump motor to starter for Unit 2 DC lube oil pump and performed functional test;
    - Motor amperage and system pressure cycling still observed;
    - This test eliminated Unit 1 DC pump electrical starter as cause of cycling issues (i.e. independent starter and power supply, cycling issue still present); and
    - Team focus returned to lube oil tank components.

- Week of April 29th:

    - Unit 1 DC lubricating pump removed from tank and coupled to Unit 1 AC North motor and installed in AC North pump well (system has and continues to operate at full pressure when testing either of the AC pumps, pressure cycling issue unique to DC pump/motor assembly);
    - Pressure and motor amperage (AC North motor with this test) cycling issue present on AC North motor/DC pump combination (see Figure 4 below); and
    - As DC pump is common factor with this test it seems to indicate that casual factor for DC lubrication issues is within pump itself.

- Week of May 6th:

    - Flowserve Engineer brought to site to consult with Hydro Root Cause Analysis team. Flowserve is the Original Equipment Manufacturer (OEM) for the Ingersoll Rand Unit 1 DC pump, and contracted pump service provider for the plant (see Flowserve service report, Appendix B);
    - Decision is made to send Unit 1 DC pump to Flowserve laboratory in Ontario for independent function testing; and
    - DC pump is uncoupled and preparations are made to ship it and an AC pump motor (AC as the test facility does not have the means to run a DC motor of this size).

- Week of May 13th:

    - Informed by Flowserve that, due to previous bookings at their test facility June 5th is earliest they can perform testing on Unit 1 DC pump.

- Week of June 3rd:
  - Flowserve performs testing on Unit 1 DC pump in their laboratory (with water, in the absence of lubricating oil) and informs Hydro that they are unable to replicate the cycling issue that has been experienced with the testing performed on the modified lubrication system for Unit 1 at the Holyrood plant; and

Figure 4: Test of DC Pump when coupled to AC South motor. Note that a test of AC pump South (white) provides normal and stable lube oil pressure (blue). When the AC North motor (yellow) is ran while coupled to the DC pump a similar cyclic pattern is exhibited as when DC motor and pump are ran together.

  - Holyrood plant manager makes contact with Unit 1 OEM to request they provide assistance to tap root team, with a view of reviewing the entire lubrication system from a system design stand point.

- Week of June 10th:
  - GE informs Hydro that a proposal for technical assistance is being prepared.

APPENDIX I

Plant Maintenance Procedural Enhancements

Re 1080 - MSTD-176 Rotational and speed check of 258 Volt DC motor for emergency lube oil pumps

Request Title: **MSTD - 176 Rotational and speed check of 258 Volt DC motor for emergency lube oil pumps. Wayne the procedure was created and needs to be reviewed.**

Document Control Coordinator : Wayne Rice

Beverly Kennedy on Sept 9th, 2013 at 02:31 PM

Request Details

Requester: Beverly Kennedy

Details:

Cancellation Message (if applicable):

Request Change Status : Approved

Solution Definition and Development Information

Procedure No: 1080 Entered By: Beverly Kennedy Date: Sept 9th, 2013 10:46 AM

Title	**MSTD-176 Rotational and Speed Check of 258 Volt DC Motor for Emergency Lube Oil Pumps**

Archive Information

Issue Date:	09/09/2013 Sept 9th, 2013
Distribution:	Electrical Maintenance 'A', Electrical Maintenance Supervisor, Manager - Work Execution
Manual/Group:	Maintenance Standards
Revision No:	0
Revision Date:	09/25/2013
Prepared By:	Beverly Kennedy
Controller:	Wayne Rice
Reviewers:	Wayne Rice, Wayne Rice
Approved By:	Terry LeDrew/HO/NLHydro

Procedure Scope

To ensure that all 258V motors for emergency lube oil pumps are electrically connected for proper rotation and speed, and meet required operating parameters before being coupled.

Note that this procedure pertains to preventive or corrective maintenance interventions by the Electrical Department.

Beyond any maintenance interventions, it is the responsibility of the Operations Department to perform functional checks of plant DC emergency lube oil pumps and associated systems prior to placing a main generating unit in service. While Electrical Maintenance A personnel may assist with these functional checks if requested by the Shift Supervisor, the tests are prescribed and championed by Operations and contained in the applicable Operations procedure.

This Maintenance Standard is not intended to supplant or cover any of the work performed during these functional checks.

Reference Information

Procedure Details

- Any 258 Volt DC motor disconnected with the intent of being eventually reconnected at that same specific location will have its supply and motor leads identified with two(2) color bands (per lead) as follow:

Polarity	Supply	motor
A	Red/white	Red/white
B	Black/Blue	Black/Blue

Note that because many DC equipment leads are often colored, identification of tape bands vs lead color may sometime be difficult, Blue and Black shall be deemed equivalent, so will Red and White.

- Any 258 VDC motor returned from repairs "off-site" or being placed in service for the first time (e.g. new, refurbished, or in-stock replacement) will have the following tests completed and documented before being coupled:

1. 250 VDC Megger and Bridge (micro-ohm) test of Field and Armature;

2. Rotation checked; if the rotation observed is the reverse of that indicated on the nameplate, the polarity (or phasing) of the field must be reversed with respect to that of the armature. Once the wiring changes are completed, repeat the testing to confirm proper rotation. Mark leads to match the new established phasing, as per the table above.

3. Run for ten (10) minutes to verify operation and confirm steady operating speed as per OEM nameplate. Accurate speed measurement can be taken by synchronizing a calibrated strobe light to the cooling fan blades of the DC motor. If the speed of rotation is found to be inadequate, adjust the field rheostat located in the motor starter until the desired speed is attained. All pertinent information and readings, including field and armature data (E and I), will be logged on the PM check sheet or, in the case of a corrective maintenance intervention, recorded on the completed work order and

communicated by email to the Manager - Work Execution, the Manager - LTAP, the Manager - Operations, the Short Term Work Planning & Scheduling (STWPS) Supervisor and the SPA Responsible for the Emergency Lube Oil System;

4. Vibration and bearing temperature test if any sign of abnormal condition is suspected.

- Any 258 VDC motor disconnected but not removed from site will not require any of the specific tests outlined in 2) to 4), provided the electrician in control of the work or the supervisor can verify that the lead markings have not been altered.

APPENDIX J

Unit 1 Lubrication DC Motor Amperage and System Pressure Cycling Issue

<u>Unit 1 Lubrication DC Motor Amperage and System Pressure Cycling Issue</u>

Following resolution of the issues affecting motor speed, subsequent test runs of the Unit 1 DC Lube Oil System for Holyrood Unit 1 revealed a motor amperage and oil pressure cycling issue. The technical details of this issue are more completely described in the **Investigation of DC Lubrication System** report located in Appendix G.

The report in Appendix G summarizes the testing that was performed to determine the cause of this cycling issue, up to the point of the submission of the draft root cause analysis report on July 2, 2013.

Further investigation was undertaken during the summer months to gain a full understanding of the cause of this motor amperage and system pressure cycling issue.

The Unit 1 lube oil tank has a capacity of 2514 gallons. With a total vertical height of 57 inches, an inch of oil depth in the tank correlates to approximately 44.1 gallons. The DC lube oil pump has an impeller diameter of 6-7/8", while the AC pump's impeller is 7-3/16" in diameter. During the testing completed on the AC and DC oil pumps this past winter and spring, the oil level in the tank was 28 inches, which correlates to a volume of 1235 gallons. At 28 inches, the DC pump has a suction head (i.e. the elevation difference between the oil level and the center line of the pump suction) of 9.25 inches, as the pump impeller center line is 18.75 inches from the bottom of the tank.

To allow pump testing while the bearings were disassembled, temporary piping arrangements were made to allow a closed loop system. As testing progressed with the DC lube oil pump installed in the Unit 1 lube oil tank with the temporary lubrication system piping arrangement, it consistently pumped at a pressure of 160 kilopascals (kPa) for approximately 50 seconds prior to any cycling issues. After 50 seconds, the discharge pressure temporarily decayed to approximately 145 kPa, and then decayed further and began to cycle at pressures between 96 kPa and 90 kPa.

In an effort to determine the root cause of the pressure cycling issues experienced during these tests, the Unit 1 DC lube oil pump and motor were removed and installed in a testing tank at Pennecon Energy's facility. (Pennecon Energy possesses an appropriate DC test set to power the motor.) During this testing, the discharge line for the pump was routed back into the tank in order to recirculate oil and maintain a consistent tank level. The pump's DC motor was set up to run at the rated speed of 3500 RPM, such that the pump was pumping 210 gallons per minute (GPM) of lube oil, at a pressure of 160 kPa. The pump and motor performed as designed, with no cycling issues.

A second pump was also installed in the tank for the purpose of draining the oil level in a controlled manner. At approximately four inches of oil above the DC pump centerline, it began to exhibit the same cycling behavior as the DC oil pump did during the testing at the plant.

During the testing at the plant, the pump discharged oil at 160 kPa for 50 seconds before losing suction and exhibiting the cycling behavior. The rate of oil flow for the DC pump is 210 GPM. The system capacity for the Unit 1 lubrication piping system is 200 gallons. An oil volume of 210 gallons is equivalent to 4.5 inches of height in the lube oil tank. Hence the pump suction head after 50 seconds was 4.75 inches. The pump still had approximately 0.75 inch of head above the required Net Positive Suction Head[2] (NPSH) of 4 inches. Therefore it regained its pressure to 145 kPa momentarily before losing suction at a tank level of 4 inches.

From this testing it was concluded that the cycling was a result of not meeting the pump NPSH requirements due to the temporary piping arrangement and oil level in the tank during the testing. The temporary piping arrangement was required to accommodate bearing repair work that was being carried out. Temporary bypass arrangements were used, consisting of pans that were open to the atmosphere (as opposed to intact piping with the assembled unit), with drains that connected into the system's lubrication piping. Once the system capacity was reached (200 gallons) with the temporary piping modification in place, the oil was not returning back to the lubrication tank quickly enough to maintain a suction head of greater than 4 inches. As soon as the suction head fell below 4 inches, the pump would lose suction and the cycling behavior would commence.

Due to the larger impeller diameter the AC lube oil pump delivers 275 GPM at a pressure of 160 kPa, without restrictions. At a system capacity of 200 gallons the pump would fill up the system in 43.5 seconds and still have a suction head of 4.75 inches. The required NPSH for the AC lube oil pump is 3 inches. Hence it would continue to pump without cycling because the suction head would not reach the 3 inch level required for it to lose suction. As a result, the AC pump would operate properly during testing.

While the Unit 1 DC lube oil pump and motor were undergoing the testing described above at the Pennecon Energy facility, the Holyrood Unit 2 DC pump and motor (identical system design as Unit 1) was removed from service and installed in Unit 1 position. Following reassembly of Unit 1, the DC motor speed was verified and the DC lubrication system operated as designed.

[2] The Net Positive Suction Head is the head (elevation difference) value at a specific point (e.g. the inlet of a pump) required to keep the fluid from cavitating.

After the Unit 1 pump and motor testing was completed at the Pennecon Energy testing facility, it was returned to the Holyrood plant and was installed in Unit 2. With motor speed verified, it operated as designed as well.

This testing verified that the causal factor that contributed to the January 11, 2013 Unit 1 failure at Holyrood, with respect to the DC lubrication system, was low motor speed, as described above.