Board Order No. P.U. 3(2014)
Investigation and Hearing into Supply Issues and Power Outages on the Island Interconnected System

NEWFOUNDLAND AND LABRADOR HYDRO

Events of January 2013

March 24, 2014

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January 11, 2013 Power System Outage Report

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SUMMARY

A severe winter storm experienced in the eastern region of the province on January 10 and 11, 2013, resulted in island-wide power outages and significant customer impact. The storm was characterized by high winds and heavy snowfall which caused issues in the Holyrood Terminal Station. The period of heaviest snow fall occurred between 06:30 and 09:30 on January 11, 2013.

The power system events began early on the morning of January 11, 2013, at the Holyrood Generating and Terminal Stations, where high winds and heavy, salt contaminated, snow created electrical faults and significant disturbances resulting in the loss of all three generating units and trips and lockouts of the 138 kV and 230 kV busses. This effectively isolated the Holyrood generating and terminal stations from the remainder of the grid. There was a significant customer impact, primarily to customers on the Avalon Peninsula.

This report summarizes the sequence of events that occurred on the power system, the problems experienced, the damage incurred, and identifies remedial actions being taken as a result of follow up investigations.

1 INTRODUCTION

On January 10, 2013 at approximately 16:30, weather in the eastern region of the Island began to deteriorate in snow and blowing snow. These conditions continued, and worsened through the evening hours and overnight, finally changing to freezing rain at about 14:30 on January 11, 2013. The heaviest snow fall occurred between 06:30 and 09:00 on January 11, 2013. The hourly weather data for January 10, 11, and 12, 2013, is contained in Appendix A.

The high, northerly, onshore winds combined with blowing snow caused salt contamination of equipment in the Holyrood Terminal Station which resulted in faults in the station and on adjacent transmission lines. These faults led to a large number of events of differing severity in terms of equipment outages and customer impact.

The number of events and the incidents were quite challenging to analyze and further work is required to fully understand the specific details of some as they were of a significant and abnormal nature, and have not been previously encountered over the years of system operation. To conduct the analysis, information such as sequence of events records, digital fault recorder traces and relay records have been collected and reviewed.

The system map in Figure 1 illustrates the extent of the power system problems experienced on January 11, 2013.

To completely understand the events and failures that occurred on January 11, 2013, follow up investigations were initiated once the power system had been restored. This report summarizes the system events, Hydro's preparation for and response to the events, the results of the investigation and analysis of these events, and the remedial actions being taken to prevent or lessen the impact of such events in the future.

Specifically, discussion of the following is presented:

- Life Safety Review – Holyrood Thermal Generating Station;
- Power System Performance;
- Energy Management System;
- Storm Preparation and Response;
- Holyrood Unit 1 Failure Root Cause Analysis;
- Holyrood Unit 1 Refurbishment; and
- Corporate Emergency Response.

1 **Figure 1: Locations Where Problems Were Encountered**

2 SEQUENCE OF EVENTS

Following is a chronological summary of the power system events of January 11, 2013. System generation prior to the initial event was 1022 MW. All major generation was operating excluding the Stephenville and Hardwoods Gas Turbines.

2.1 January 11, 2013

At 04:13, Unit 3 tripped at the Holyrood Thermal Generating Station. The analysis of this event indicates that it resulted from a single phase fault which occurred somewhere between the high side of the unit transformer and the 230 kV unit breakers. The unit was loaded to 68 MW at the time of the trip. No customer impact was reported as a result of this event.

At 06:42, while Holyrood plant personnel were in the process of restoring Unit 3, there were trips of Units 1 and 2 and transmission line TL 217 at the Western Avalon end. Both units were loaded to 110 MW. Newfoundland Power's 138 kV line, 39L, also tripped at this time. This resulted in a significant customer impact with nearly 250 MW of Newfoundland Power load loss, primarily on the Avalon Peninsula. This was caused by a fault on Unit 1 230 kV breaker B1L17, which was a result of salt contamination.

At 06:48, while all units were off at Holyrood and TL 217 was still open at the Western Avalon end, there was a 138 kV bus lockout and a breaker failure operation associated with the 230 kV breaker B12L17. This resulted in the loss of TL 218 and TL 242. These events effectively de-energized the Holyrood Terminal Station and removed all station service supply to the generating units. There was approximately 240 MW of Newfoundland Power load loss, again primarily on the Avalon Peninsula.

At 07:42, with the Holyrood terminal and generating stations out of service, there was a fault and trip on TL 201, the remaining 230 kV line from Western Avalon to the major load centres in St. John's. Due to protection misoperations on key transmission circuits caused by the significant system over frequency upon the loss of load, there was separation of the eastern

and western areas of the power system. This created widespread power outages in the central and western areas of the province, resulting in the loss of multiple generating stations and transmission lines and the separation of the Deer Lake Power system from the grid. Generating stations at Upper Salmon, Granite Canal, and Cat Arm were out of service at this time.

Restoration efforts started almost immediately but issues were encountered during the western area restoration due to station communications problems at Stony Brook and general switching and equipment issues, all of which resulted in additional abnormal events and equipment trips. The eastern area restoration efforts proceeded as expected but were hampered by storm conditions which delayed personnel gaining access to reset lockouts in the Holyrood Terminal Station.

At 08:51, while Energy Control Centre (ECC) operators were attempting to restore the system within the limits of the generation that was available, TL 201 faulted and tripped again. Approximately 230 MW of customer load was lost during this event. Restoration started again on the eastern system with the re-energization of TL 201. On the west coast, some progress was made through Stony Brook but breaker issues delayed this progress and, at around 09:00, resulted in other abnormal system events.

At 09:07, TL 201 was re-energized and restoration of the St. John's area proceeded again. By 09:30, TL 201 was loaded to approximately 200 MW. By 09:39, restoration was also proceeding in the western area with the Massey Drive Terminal Station re-energization and loading. Restoration of the system continued with conditions returned to normal in the western area by noon with most load busses re-energized and the Deer Lake Power system reconnected. At 10:08, the Granite Canal station was returned to service.

By 13:30, the Holyrood lockouts were reset and at 14:58 the Holyrood 230 kV bus B12 was energized via TL 242. This was followed by restoration of TL 218 and, at 15:08, TL 217 was put in

service, paralleling TL 201 and completing the restoration of the 230 kV transmission system on the Avalon.

At 14:44, the Upper Salmon unit was returned to service following the reset of the unit lockout relay. The Cat Arm units were both back online by 18:53 following resets of the unit lockouts and restoration of the station service supply.

Transformer T1 at Buchans was returned to service at midnight after having locked out earlier in the day. The station was at this time fully restored.

2.2 January 12, 2013

Holyrood Units 2 and 3 were back online at 03:54 and 05:13 on January 12, 2013, respectively. This restored the power system to service across the island.

A detailed sequence of events for the power outage is contained in Appendix B.

3 LIFE SAFETY REVIEW – HOLYROOD PLANT

An investigation team was assembled to investigate the issues encountered at the Holyrood Generating Station during the events of January 11, 2013. Members of this team included representatives of Corporate Health and Safety and the Holyrood Generating Station.

Identifying the key findings and addressing the root cause of life safety concerns that were experienced by the Operators and providing recommended corrective and preventative actions for these issues were part of the investigation team's objective.

The investigation identified the challenges that the Operations department experienced, as noted through their interview statements.

The areas reviewed by the life safety review team were:

- Emergency response technician (ERT) coverage;
- Operator coverage with emergency response training;
- Familiarity of Operations personnel with emergency response equipment;
- Number of hours worked by Operations staff and then operating vehicle by driving home;
- Adequacy of powerhouse emergency lighting;
- Adequacy of powerhouse ventilation;
- Access/Egress from plant;
- Operation of fixed fire suppression system;
- Portable fire extinguishing equipment;
- SWOP not entered or communication of major incident in timely manner; and
- Employee Assistance Program (EAP) response.

There were 14 recommendations made as a result of the Life Safety Review. The majority of these recommendations were generally within the categories of plant emergency response coverage and training, the conditions under which plant staff responded to the event, firefighting equipment operation and major event reporting.

The Life Safety Review Report is contained in Appendix C.

4 POWER SYSTEM PERFORMANCE REVIEW AND ANALYSIS

Upon the restoration of the power system, a review and analysis of the events associated with the power outages across the system was undertaken. This review and analysis of the system events resulted in a number of recommendations for improvements to the system.

The recommendations cover the issues which led to the significant power system events which occurred, generally in the following categories:

- Preventative maintenance procedures and scheduling;
- High voltage breaker replacement, inspection, and repair;
- Function testing and enhancement of protection and control circuitry;
- Digital protective relay firmware and setting changes;
- System stability studies;
- System voltage and frequency studies and control enhancements; and
- Development and enhancement of operating procedures.

The review and analysis of the power system events resulted in 56 recommendations for improvements to the power system in various areas. Specifically, the areas and associated number of recommendations are:

• Transmission and Rural Operations	18
• Thermal Generation	4
• Protection and Control Engineering	20
• Electrical Engineering	2
• Transmission & Distribution Engineering	1
• System Operations and Energy Systems	4
• System Operations and Planning	2
• System Operation, Planning, and P&C Engineering	2
• Hydro Generation	3

4.1 Transmission and Rural Operations

Within the Transmission and Rural Operations (TRO) area, there were many issues with breakers, particularly the 230 kV class. A review of the preventive maintenance program for these breakers has been recommended. The remaining recommendations are related to further inspection and testing of power system equipment and protection and control systems across the power system to ensure proper operation.

4.2 Thermal Generation

The specific recommendations related to thermal generation include a review of data collection and reporting requirements for protection operations and trips. In addition, function testing of specific protection equipment has been recommended.

4.3 Protection and Control Engineering

The recommendations assigned to Protection and Control (P&C) Engineering are, in the majority, related to system protection design, operation and reporting. Protection reviews are recommended on system equipment, transmission lines, and generating station equipment to ensure proper operation. A number of changes to protection are also recommended to prevent nuisance tripping and other issues experienced during the event.

4.4 Electrical Engineering

The recommendations for electrical engineering relate primarily to the specification and installation of new breakers and associated equipment. Specifically, recommendations to increase the insulation creepage distance specified for such equipment to ensure its suitability for operation in contaminated environments such as the Holyrood Terminal Station. Installation of current transformers on both sides of breakers is also recommended to provide for overlapping protection zones.

4.5 Transmission and Distribution Engineering

A review of the standards applied to transmission line jumper length is recommended as a result of the fault and trip on TL 201.

4.6 System Operations and Energy Systems

The recommendations for System Operations and Energy Systems involve the review of existing and preparation of new operating procedures which address how to proceed under some of the conditions experienced during the January 11, 2013, event, such as voltage conditions outside normal limits and incorrect or questionable data being returned from remote locations. Also, further investigation is recommended into the issues with sequence of events (SOE) reporting, and the overvoltage condition which occurred.

4.7 System Operations and Planning

In order to gain a full understanding of the events which occurred, recommendations within the System Operations and Planning area include a detailed load flow and transient stability analysis and a comprehensive review of the sequence of events. The development of guidelines for optimum reactive power dispatch and levels of Avalon loading are also recommended.

4.8 System Operation, Planning, and P&C Engineering

Recommendations include consideration to perform a system voltage study which would simulate normal loading scenarios and abnormal scenarios such as those which occurred on January 11, 2013. From the study, an operation strategy should be developed to assist the ECC operators in maintaining system voltages within acceptable limits. As well, surge and trouble reports should be prepared by System Operations for all disturbances on the power system as they provide valuable information regarding the system equipment and its operation. These reports should be circulated and reviewed by all stakeholders to ensure all necessary investigations and recommended remedial actions are carried out in a timely manner.

4.9 Hydro Generation

With respect to Hydro Generation, recommendations are made for the investigation of lockout operations which occurred at the Cat Arm and Upper Salmon generating stations and the performance issues with the station service supplies at Cat Arm. It is also recommended that, in future, investigations be carried out into all trips of larger generating units to determine the cause and whether the systems operated properly.

The Power System Performance Review and Analysis Report is contained in Appendix D. Detailed descriptions of the report recommendations are contained in Appendix F.

5 ENERGY MANAGEMENT SYSTEM REVIEW

During the power system events on January 11, 2013, communications between the Stony Brook remote terminal unit (RTU) and the Energy Management System (EMS) were lost at 07:45 and were restored by a remote restart of the RTU at 08:55.

The problem with the communications between the ECC and the Stony Brook Terminal Station RTU associated with the system wide power disruptions initially appeared as a RTU lockup. The result was a temporary (two hour) loss of remote control and monitoring of the terminal station until a manual reset to the RTU was performed remotely from the ECC. The result of this loss of monitoring was that some of the SOEs which contained information useful for the power system post analysis were lost.

Upon analysis, the problem was determined to be a buffer overflow problem in the routers used to provide the communications. The communications problem was triggered by an unusually large number of events (99) generated by the system power disruptions. The resolution of the communication problem experienced involves increasing the buffer length from 16 to 64 bytes in the routers which operate at 38,400 bps across the system including routers located at both remote sites and at Hydro Place. This is necessary for all RTU circuits operating at 38,400 bps.

While the failure mechanism and fix now seem obvious, they took a considerable amount of time to determine, as the both the trigger and location of the problem were not clear. In particular, the trigger condition requires all of the following:

- The RTU must be operating at 38,400 bps;
- The buffer length must be 16 bytes (as was the case for all RTUs prior to the implementation of the fix);
- There must be at least 40 events being sent by the RTU (test results have shown that 30 events will not trigger the problem but 40 or over will); and
- The circuit must be on the live SCADA network with traffic loading (the problem could not be replicated with back-to-back routers in the shop).

To resolve the issue with communications resulting from the conditions above, the following remotely located routers have been re-configured over the power system:

- Bay d'Espoir Hydro Plant - Power House 1;
- Bay d'Espoir Hydro Plant - Power House 2;
- Come By Chance Terminal Station;
- Hinds Lake Concentrator;
- Oxen Pond Terminal Station;
- Stony Brook Terminal Station;
- Sunnyside Terminal Station;
- Upper Salmon Concentrator; and
- Upper Salmon Hydro Plant.

The following routers at Hydro Place have also been re-configured:

- ECC1;
- ECC2;
- EMS1; and
- EMS2.

6 STORM PREPARATION AND RESPONSE

6.1 Preparation

In preparation for the forecasted severe winter storm of January 11, 2013, Hydro took the following steps to aid in safe and timely response to system problems:

- All communications between Hydro and Newfoundland Power were tested (VHF, Cell, Satellite, Hotline, & Power fail phone);
- Hydro VHF communications were tested between the ECC and the Holyrood control room and between the ECC and the Bay d'Espoir control room;
- The emergency diesel generators at Hydro Place were tested;
- Hydro alerted Newfoundland Power that it may be seeking assistance for any distribution problems on the Burin Peninsula, if Hydro could not access the area;
- All supervisory personnel in TRO were asked to be on heightened alert for the duration of the storm and be available by cellphone;
- All vehicles at the TRO Eastern office at Whitbourne were fueled up and had pre-use inspections completed to ensure readiness for a quick response;
- Key employees were assigned work vehicles, (mostly four wheel drive and all wheel drive vehicles) and asked to take the vehicles to their home locations, in anticipation that the TCH would be impassible and closed (vehicles were located at Holyrood, St. John's, Bay Roberts, Harbour Grace, and New Harbour);
- The Hardwoods Gas Turbine operator was situated in St. John's and assigned a four wheel drive pickup truck;
- Track vehicles were loaded on trailers at the Whitbourne office ready to be deployed if required;
- At the Holyrood Generating Station, the snow clearing contractor (who clears the site roads) was called to come in early and stay ahead of the storm;
- Operation and security personnel were called in early to relieve the night shift at 16:00 (this was not completely successful as only 2 out of 6 operators were able to gain access to the site); and

- In the lab at Holyrood, polisher regeneration was completed a day early and the units were chemically dosed slightly above normal but below EPRI guidelines, in the event that water treatment staff couldn't make it to site on the morning of January 11, 2013.

6.2 Site Access and Road Conditions

Due to safety and accessibility concerns, Hydro Place and the TRO area office at Whitbourne closed at approximately 06:00 on January 11, 2013.

At just before 07:00 on January 11, 2013, TRO personnel were requested to respond to the Holyrood Terminal Station and to the Hardwoods Gas Turbine. At this time, the storm was in full force, most roads on the Avalon Peninsula were impassable, visibility was near zero, and the RCMP was advising people to stay off the roadways. While some of the major thoroughfares were passable by large four wheel drive vehicles, most secondary roads were impassable. Therefore, while several Hydro employees had work vehicles at home and were ready to respond, they could not leave their residential neighborhoods due to road and weather conditions.

At approximately 07:30, the TRO Stations Supervisor began calling Works, Services and Transportation depots at Whitbourne and Holyrood, as well as several contractors, in an effort to have the road to the Holyrood Generating Station cleared. All of those contacted reported that they would not put employees on the road due to zero visibility conditions. As well, the RCMP at Holyrood was contacted and they advised not to put anyone on the road until conditions improved. At this point, a contractor clearing snow with a backhoe around the Holyrood site was redirected to attempt clearing the 3 km section of access road from the Holyrood Generating Station to the Conception Bay Highway. This section of road was reported to have 1.25 meter drifts in sections.

At approximately 08:00, Corporate Safety and Health contacted EMO to inquire if they could assist in getting personnel into the Holyrood Generating Station. At approximately 09:30, Works, Services and Transportation contacted Hydro indicating that they would do what they could to have the road cleared.

The acting Gas Turbine Operator and an Electrical Maintenance worker were able to report to the Hardwoods Gas Turbine at approximately 08:30 and they remained there well into the evening.

By approximately 11:30, a single lane had been cleared to the Holyrood Generating and terminal stations. Two TRO employees (a P&C technologist and electrical maintenance A) walked to Route 60 at a location near the town of Holyrood and were transported to the Holyrood Generating Station by a Newfoundland Power vehicle which had been able to gain access to Route 60.

At around the same time, a snow clearing contractor from Whitbourne, who was working for Hydro, travelled the Trans Canada Highway (TCH) from Whitbourne to the Salmonier Line and then plowed a single lane down the Salmonier Line from the TCH to Route 60. This allowed a mechanic who resides on the Salmonier line to access Route 60. Hydro employees entered the terminal station at Holyrood at approximately 11:30 and began inspection, troubleshooting, and restoration of affected equipment.

The regular shift change at the Holyrood Generating Station would have normally occurred at 20:00 on January 10, 2013. Attempts were made to get shift operators into the plant early on the evening of January 11, 2013, such that the plant would not be caught without relief at 20:00. This effort was partially successful as only two of the six operators were able to get to the plant. For this reason, operators who were scheduled to go off shift were asked to stay at work, some working as many as 30 hours before being relieved. Some operators who live in the St. John's area obtained a four wheel drive vehicle from Hydro Place in St. John's and arrived at

the plant on the afternoon of January 11, 2013. Otherwise, it was late afternoon on January 11, 2013, when road conditions improved, before Holyrood Generating Station employees could begin returning to work.

Throughout much of January 11, 2013, system problems requiring checkout and troubleshooting were experienced at Hydro facilities throughout central and western Newfoundland. While regular winter driving conditions were experienced in many of these areas, snowmobile travel to the Upper Salmon Generating Station was challenging due to snow drifts as high as 1.25 meters.

6.3 Coordination of Efforts

As with any power system outage or disturbance, the ECC at Hydro Place takes the lead to safely and systematically restore system equipment to service.

At approximately 07:30, a group of TRO operations personnel with access to real time system information at the ECC, gathered at the TRO Central office in Bishop's Falls to offer assistance to field personnel and coordination with the ECC.

At approximately 08:30, the Executive on Call (EOC) issued an alert under the corporate emergency response plan (CERP) which saw a partial mobilization of the CERP team at Hydro Place, to provide overall support and guidance during the storm and associated power outage.

Customer Services personnel were in place to respond to customer calls and to update customers and other stakeholders.

6.4 Communications - Contacting Key Resources

In many cases key resources were contacted, and while willing to do whatever they could do to help, they were unable to leave their neighborhoods due to road conditions. All Hydro vehicles had mobile VHF radios which worked well. There were several reports of employees who had

only cordless phones in their homes which did not function during the power failure. While many key operations personnel in Hydro have cellphones, it became evident that more cellphones would have improved overall communications.

6.5 Safety

While everyone involved in the restoration efforts understood the criticality of getting personnel into the Holyrood generating and terminal stations on the morning of January 11, 2013, Hydro needed to ensure that we were not asking our employees to do anything that was clearly unsafe or making decisions that might put ourselves or someone else in danger. Conditions appear to have been much worse in the areas between Holyrood and Whitbourne than they were in the St. John's metro area. Department of Works, Services, and Transportation personnel, RCMP and contractors were off the road. Despite this, efforts continued to get employees into the Holyrood Terminal Station in as safe a manner as possible.

6.6 Opportunities for Improvement

The primary areas in which there is opportunity for improvement are communications and site accessibility.

6.6.1 Communications

- ***Improved communication between field personnel and the ECC***

  While it is understood that System Operations is extremely busy during such emergency situations, in order to make the best use of response personnel it is critical that field personnel be able to discuss system conditions and equipment priorities with the ECC. During several periods on January 11, 2013, repeated calls to the ECC went unanswered. One operator or shift supervisor assigned to communicate with field personnel would have been an improvement.

- ***Ability to contact key employees when required***

  Many employees reported that that they did not possess hard wired telephones and that the batteries in their cordless phones had run down. As a result, it was difficult to

contact them. As well, several key employees did not have cell phones. As a follow up, it is recommended that managers ensure that key employees have cell phones and agree to carry them as required.

- ***Updating of social media***

Given the widespread use of social media by customers, it would be beneficial to have one Customer Services Representative dedicated to managing and updating social media updates.

- ***Availability of information for media updates***

Corporate Communications found it necessary to contact multiple sources for information pertaining to outages and system conditions. One operations liaison responsible for providing necessary information to Corporate Communications would have been an improvement.

- ***Improved communication between field personnel and the Bay d'Espoir and Holyrood Plants***

In some incidents, it was difficult for field personnel to contact necessary technical resources in the generating stations. One technical resource identified as a liaison for field personnel would have been an improvement.

- ***Communication with Newfoundland Power and Industrial Customers***

There was a general feeling that Hydro could have provided more prompt updates to these customers.

6.6.2 Site Accessibility

Transportation and accessibility to Hydro facilities proved to be a major problem during the storm. Some potential areas of improvement include:

- ***Increased planning to ensure that key facilities are staffed during storm events***

Given the unpredictable nature of the storm, it would have been possible and beneficial to arrange for extra personnel to staff the Holyrood Generating Station (possibly extra operating, instrumentation, electrical and emergency response personnel).

- ***Access road clearing during storms***

During the early morning of January 11, 2013, Hydro had notification that the Department of Works, Services and Transportation, who normally plow the access road to the Holyrood Generation Station, did not have plows on the road. At approximately 07:30, upon realizing that plowing by the Department of Works, Services and Transportation would be delayed, a contractor plowing the site at Holyrood was redirected to concentrate on the access road, such that when conditions improved employees could gain access to the site. In hindsight, had the contractor begun working on the access road sooner, overall system restoration on the east coast may have been realized sooner.

- ***Use of larger and more capable response vehicles.***

All of the available four wheel drive and all wheel drive vehicles at the Eastern Area office at Whitbourne were assigned to employees to take home for the duration of the storm, to allow for quicker response. However, due to the amount of snowfall and drifting (1.25 meters in some areas), employees simply could not leave their residential neighborhoods. Under the conditions on January 11, 2013, large four or six wheel drive vehicles may have allowed Hydro to pick up employees and bring them to the required locations earlier.

6.6.3 Other Opportunities for Improvement

- ***Use of Mobile Generators***

Due to the complete power outage at the Buchans Terminal Station, station service power was not available to operate compressors and other critical services. TRO Central personnel rented a portable diesel generator which was used to power the station to aid in restoration efforts. Portable diesel generators located at key terminal stations, could greatly improve Hydro's response in the event of complete station outages.

- ***Timely retrieval and analysis of fault data and related fault information***

In order to properly troubleshoot and identify the type and location of faults on the electrical system, fault information must be retrieved from remote devices and

analyzed. At present, this information is retrieved by Project Execution and Technical Services personnel. During such storm conditions, these employees should be on call and available to respond at all times.

7 HOLYROOD UNIT 1 FAILURE ROOT CAUSE ANLAYSIS

On January 11, 2013, severe weather conditions, high winds and heavy, wet snow were experienced on the Avalon Peninsula. At 06:42, Holyrood Units 1 and 2 tripped in response to an electrical fault in the Holyrood switchyard, caused by wet snow buildup and salt contamination. Unit 1 experienced higher than normal vibration as it coasted down, with fires occurring at bearing locations along the unit's rotational shaft. The fires were extinguished and, once the unit was secured, an investigation was initiated by Hydro staff and Alstom Power.

Once the initial assessment was complete, the unit was disassembled to allow a more detailed inspection of unit components, for condition assessment purposes. This inspection revealed damage to all five bearings along the turbine-generator shaft, as well as damage to the shaft journal areas at the bearing locations. Other unit components were damaged as well.

A root cause analysis into the failure of Unit 1 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.

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, applicable third party consultants and contractors, and other operating units within Nalcor Energy.

The Unit 1 Failure Root Cause Analysis report is contained in Appendix E.

8 HOLYROOD UNIT 1 REFURBISHMENT

The refurbishment plan for Holyrood Unit 1 was determined by completing two phases of disassembly and inspection. The phase 1 inspection was primarily a visual inspection after removal of the covers. This inspection began on January 18, 2013, and was completed on January 28, 2013, with a recommendation to proceed to a full assessment through disassembly of the unit.

The Phase 1 inspection revealed the following:

- Bearings T1 through T5 all damaged (wiped);
- Oil deflectors T1 through T5 inner and outer damaged (wiped);
- Thrust bearing damaged (wiped);
- Journals T1 through T3 damaged;
- Journals T4 and T5 in good condition;
- Hydrogen seals TE and CE had slight damage;
- Hydrogen seal casings TE and CE in good condition;
- Hydrogen seal casings gas side oil seal TE and CE damaged;
- No damage to fan blades;
- Speed probes and 60 tooth wheel damaged;
- Vibration probes T1 through T3 damaged; and
- Melted babbitt throughout the bearing pedestals and oil system.

The phase 2 inspection began on March 1, 2013, and was completed on March 16, 2013. The result of the phase 2 inspection was a refurbishment plan to return the unit to service. The steam turbine was disassembled and a complete visual and NDE inspection was performed on the upper and lower diaphragms and turbine rotor. This included the mechanical inspection of the turbine rotor and the generator rotor. Testing was also performed on the generator rotor and stator.

Phase 3 of the project included repairs of the various components to restore them to acceptable running condition. Where original parts could not be reused, replacement parts were fabricated.

The phase 3 repairs included:

- Rotor bucket cover repairs;
- Rotor journal repair;
- HP/LP/IP rotor machining;
- Bearing repair;
- Packing and spill strip repair;
- Laser alignment;
- Lube oil flush;
- Lube oil pump repair;
- Generator reassembly;
- Turbine reassembly; and
- Unit commissioning and balancing.

Final balancing of the unit was completed and the unit was subsequently released for service on October 10, 2013.

9 CORPORATE EMERGENCY RESPONSE PLAN REVIEW

A review of the Corporate Emergency Response Plan performance was included in the Life Safety Review conducted into the events of January 11, 2013.

On January 11, 2013, at approximately 08:00, the Manager of Safety and Health received a call from the Holyrood Thermal Generating Station Emergency Response Coordinator (ERC) reporting an incident involving a fire on Unit 1. It was reported that the fire had been extinguished and the unit was no longer on line. On site employees donned self-contained breathing apparatus (SCBAs) in order to respond to the incident. It was also reported that Unit 2 and 3 had also tripped and there was a developing issue in the switchyard, however the ERC was not sure of the nature. The ERC was unaware if the EOC had been alerted of the developing situation. The Manager of Safety and Health advised he would contact the EOC and get direction on next steps, if any were warranted.

At 08:30, the EOC was contacted and advised of the incident at Holyrood. The EOC advised that the CEO and the Vice President Regulated Operations were aware of the incident and the resulting problems with power generation. Through discussions, the EOC and Manager of Safety and Health thought it prudent to issue a CERP 811 (standby) Alert with a pending partial mobilization. The Manager of Safety and Health contacted the ECC and advised that an 811 Alert be issued. Shortly thereafter, the situation at Holyrood was complicated with loss of generation at Upper Salmon and Granite Canal. At this stage, it was agreed to issue another CERP 811 Alert identifying a partial mobilization of the CERP team at Hydro Place. A concern identified was the potential difficulty of getting CERP team members into the Corporate Emergency Operations Centre (CEOC) at Hydro Place as well as operational and technical staff into the Holyrood plant. The Manager of Safety and Health contacted the Emergency Measures Organization (EMO) to inquire if they could provide assistance on getting the employees into the CEOC and thermal plant. The EMO on-call representative advised the EMO does not provide this service and the only thing they could possibly assist with was to help us contact the

Department of Works, Services and Transportation and request assistance in clearing the access road leading to the thermal plant.

At approximately 09:30, the Manager of Safety and Health received a call from a Department of Works, Services and Transportation representative stating they would investigate what they could do, particularly redirecting a snow plow to clear the access road to the plant. There was no further contact with the Department of Works, Services and Transportation.

At 10:00 the CEOC was "live" with CERP members representing Supply Chain Management, Communications and Safety and Health, the Deputy Incident Commander, and the Operations Liaison. All team members began carrying out their respective role related duties as outlined in the Corporate Emergency Response Plan**.** Regularly scheduled conference calls were held with the full CERP team approximately every hour.

The Supply Chain Management and Safety and Health representatives supported the Deputy Incident Commander as requested and assisted by picking up additional technical support (P&C Engineer) using a company four wheel drive vehicle, and transporting them to Hydro Place. At approximately 15:00, the Supply Chain Management and Safety and Health representatives were no longer required and were relieved of their roles in the CEOC.

The CERP process worked well and there was good communication and mobilization of the partial team in a timely fashion.

Recommendations were made related to the CERP performance for the improvement of communications and the assignment of four wheel drive vehicles to assist with mobilization of CERP members in severe weather conditions.

10 CONCLUSION

The winter storm which occurred in the eastern region of the province over January 10 and 11, 2013 caused wide spread outages to the power system and damage to equipment. The first event occurred at 04:13 on January 11, 2013, and the power system was restored to service across the island at 05:13 on January 12, 2013.

While Hydro personnel were prepared for the storm and possible problems on the power system, the weather and road conditions made it challenging to access Hydro sites to respond to problems being experienced.

Once the power system was restored, follow up investigations were initiated to fully understand the events and failures that occurred on January 11, 2013. These detailed investigations and analyses have resulted in numerous recommendations for improvement in a number of areas. Remedial action plans have been developed to ensure that the recommendations are studied and appropriate improvements implemented.