# NEWFOUNDLAND AND LABRADOR HYDRO

## Transmission Availability

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Prepared/Authored by: Brian Scott

Brian Scott
Electrical Engineering Specialist
AMEC Americas Limited

newfoundland labrador hydro
a nalcor energy company

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## EXECUTIVE SUMMARY

Newfoundland and Labrador Hydro (Hydro) is undertaking an internal review of the various aspects of the events and potential contributors to the supply disruptions on the Island Interconnected system during January 2014. The internal review will consider eight sub-sections:

1. Load Forecasting
2. Generation/Reserve Planning
3. Generation Availability
4. Transmission Availability
5. Asset Management Strategy and Practices
6. Coordination and Communication With Customers
7. Emergency Response and Restoration
8. Technology and Communications Infrastructure

The result will be an overall "Summary Report on Supply Disruptions – January 2-8, 2014" which is intended to summarize the results of Hydro's internal review of supply disruptions on the Island Interconnected system during January 2014. Each sub-section will have a supporting report such as this one. The summary document and supporting sub-section reports will be incorporated into the data available to inform those involved in the reviews completed by the Board of Commissioners of Public Utilities (PUB) and the Government of Newfoundland.

This sub-section of the report, "Transmission Availability", provides a chronological summary of the key events involved in the supply disruptions as they unfolded over the two days of January 4th – 5th, 2014. It includes a review of the performance of the transmission network and its operation. It also includes a description of the internal Hydro process used to investigate the outages. This is one of three reports relating to the transmission system. The others are Protection System Impacts and Root Cause Analysis.

The review of the transmission system and the events of those two days consisted of reviewing the specific information related to the events and assessing the performance against the historical performance of Hydro's transmission system and industry practices. The review of specific information included reviewing the sequence of events logs, diagrams, documents and procedures, interviewing technical and operations staff, and participating with the Hydro

internal review team on the root cause analysis.

Hydro's performance of the bulk transmission system has historically compared very favourably with the national average as reported by the Canadian Electrical Association (CEA). Between 2004 and 2012, the latest year for published results, and based on a 5-year rolling average Hydro considerably outperformed comparable utilities represented in the CEA average for both 230 kV transformers and circuit breakers. For 230 kV transmission lines Hydro posted results that were more variable with some results above and others below the CEA averages.

Although not mandated to follow standards as required elsewhere in the interconnected North American electricity system, Hydro generally follows industry practices in the planning, design, construction and operation of the transmission system.

Hydro utilized a rigorous and formal "TapRoot" root cause analysis process led by an external facilitator to conduct an internal investigation of the event. The investigative team was composed of internal Hydro resources from operations and maintenance and external consultants in generation, asset management, protection and control and transmission that had been dedicated to this effort. Expertise throughout the Hydro organization was made available as required to assist in the effort. External OEM suppliers were consulted and participated in the investigation of equipment failures. All of the equipment investigation has not yet been completed.

The "TapRoot" analysis identified 4 key incidents for which the root cause should be determined. Those four incidents were:

1. Sunnyside transformer T1 fire (9:05 Jan. 4, 2014)
2. Western Avalon transformer T5 tap changer failure (12:22 Jan. 4, 2014)
3. Sunnyside bus 3 restoration failure (15:33 Jan. 4, 2014)
4. Holyrood unit #1 breaker B1L17 failure (21:27 Jan. 5, 2014)

The initial incident started with a fault in T1 transformer at Sunnyside terminal station that was quickly detected by the protection system. However, one of the five breakers failed to open

resulting in a delay in clearing the fault. The event rapidly escalated leading to an islanding of the electrical network and a blackout on the Avalon and Burin Peninsulas. The entire outage would have been limited to the failure of the Sunnyside transformer and Burin Peninsula and local area if the breaker had operated properly and the fault had been cleared quickly. The delayed clearing may have contributed to the severity of the transformer damage since the initial fault was detected very quickly. The failed breaker and the delayed clearing led to a configuration at Sunnyside that was more complex and involved additional equipment. When attempts were made later in the day to restore station service and pick up load at Sunnyside some equipment did not operate correctly leading to a loss of supply from Bay d'Espoir and a second blackout of the Avalon Peninsula. The slow clearing also caused power swings leading to separation of the transmission system east of the Sunnyside terminal. Holyrood generating station immediately tripped off when it could not supply the load and one of the unit breakers failed. The failure of the breaker at Holyrood was not discovered until the unit was being brought back on-line the next day and it caused significant additional power interruptions.

A major factor in this outage event was the performance of 230 kV circuit breakers. At least three failed to operate properly during the key incidents investigated.

The results of the root cause analysis process are dealt with in a separate report. That report will provide an identification of the underlying causes for each of the incidents and the actions that can be taken to eliminate or mitigate future occurrences.

Some key messages can be taken from a review of the events.

- Equipment failures, particularly 230 kV air blast circuit breakers (ACB) and their associated air systems, contributed significantly to the extent of the outages and to delays in restoration. Three similar type air blast circuit breakers built between 1966 and 1973 have been associated with the incidents described in this report and failed to operate properly during the 2-day event. The failure modes are different for each so the failures cannot be traced to a single cause factor. However, a thorough review is recommended to assess the acceleration and modification of the existing ACB refurbishment/replacement program, particularly the continued use of these breakers in critical areas on the bulk power system.
- Hydro's historical performance of the 230 kV transmission system has been very good

demonstrating performance results in transformers and circuit breakers better than CEA averages. This event is an uncommon occurrence and the performance of the circuit breakers represents a departure from previous experience.

- The design of the transmission network follows industry practices and provides a reliable and robust network. The events that occurred during the January 4 – 5th outages involved multiple events that are not typically designed for. A more extensive review of the event is recommended to capture unexpected outcomes and use these as lessons for future improvements.
- Hydro has processes and facilities in place to deal with events of this nature that are reviewed and tested on a regular basis. These include a restoration plan for loss of supply to the Avalon Peninsula, a back up control centre, and regular staff training. Enhancements should be made to ensure that facilities work as designed, personnel training encompasses similar extreme events and plans for resource allocation are focused on key issues. A more extensive review of the event is recommended to determine what enhancements should be made in addition to on-going continuous improvement initiatives.
- In the face of the overwhelming volume of data that occurs in an event of this nature, some Information was available but not acted upon that could have enabled operations staff to potentially reduce the impact of the outages. "Protection" alarms and "fault traces" need to be reviewed as soon as possible on an on-going basis during such an event. It is recommended that staff be readily available prior to anticipated extreme weather or potential system emergency conditions and be dedicated to this task during events of this nature. Other recommendations relating to protection and alarms include:
    a. Identify the key set of priority alarms that must be available and reviewed by the operator even during events of this magnitude.
    b. Provide additional training as necessary to operators on the importance of alarms.
    c. Implement a program to install modern digital relays that are able to store time-synchronized fault data. An installation plan should be developed to gain/increase visibility of all major equipment such as 230 kV transformers.
- Internal technical staff and external consultants involved in the event review as well as operations staff are knowledgeable, experienced and professional. Hydro should consider how it can best transfer the knowledge and experience gained both during the

event and in the investigation to the rest of the organization.

## 1 INTRODUCTION

Newfoundland and Labrador Hydro are undertaking an internal review of the supply disruptions on the Island Interconnected system for the period January 2-8, 2014. The internal review will focus on a number of areas. The focus for this sub-section report which deals with Transmission Availability is the performance of the transmission system during the Jan 4-5 disturbance events that largely impacted the Avalon Peninsula.

An overall "Summary Report on Supply Disruptions – January 2-8, 2014" will form the basis of the internal Hydro review. This report contains a number of sub-sections, eight in total, covering various aspects of the review. Each sub-section will have a supporting report such as this one. The summary document and supporting sub-section reports will be incorporated into the data available to inform those involved in the reviews completed by the Board of Commissioners of Public Utilities (PUB) and the Government of Newfoundland.

This sub-section of the report, "Transmission Availability", provides a chronological summary of the key events involved in the supply disruptions as they unfolded over the two days of January $4^{th} - 5^{th}$, 2014. It includes a review of the performance of the transmission network and its operation. It also includes a description of the internal Hydro process used to investigate the outages. This is one of three reports relating to the transmission system. The others are Protection System Impacts and Root Cause Analysis.

## 2 REVIEW PROCESS

Hydro established an internal review team to begin an analysis of the events involved in the supply disruptions in January 2014. Field investigations of damaged equipment were initiated and interviews were conducted with operations and maintenance staff. Hydro utilized a formal "TapRoot" root cause analysis process led by an external facilitator to conduct the internal investigation of the event. The investigative team was composed of internal Hydro resources

from operations and maintenance that had been dedicated to this effort. Expertise throughout the Hydro organization was made available as required to assist in the effort. External OEM suppliers were consulted and participated in the investigation of equipment failures. In addition, external consultants participated in the "TapRoot" process and findings.

The "TapRoot" analysis identified 4 key incidents for which the root cause could be determined. Those four incidents were:

1. Sunnyside transformer T1 fire (9:05 Jan. 4, 2014)
2. Western Avalon T5 tap changer failure (12:22 Jan. 4, 2014)
3. Sunnyside bus 3 restoration failure (15:33 Jan. 4, 2014)
4. Holyrood unit #1 breaker B1L17 failure (21:27 Jan. 5,2014)

Each of the 4 key incidents were thoroughly investigated and all relevant documentation such as the design, maintenance practices, history of equipment, and sequence of events for the incident were reviewed. Any issues were noted and followed-up on. The objective of the process was to determine the causal factors and the appropriate short and long term actions.

The external resources who participated in the "TapRoot" analysis were contracted by Hydro to provide a high level review of the approach used, assist in the analysis, bring knowledge of industry practices and focus on specific areas of expertise. Each of the external resources prepared a report on their focus area. A brief description follows:

1. "Protection Systems Impacts on 4 January 2014 Supply Disruptions" by Charles Henville, Henville Consulting, Inc.

   This report focuses on the protection systems' impact on the disturbances and identifies the protection issues from a high level. A detailed analysis was performed for the incidents at Sunnyside, the failed circuit breaker at Holyrood and the tap changer failure at Western Avalon

2. "Asset Management Strategy and Practice" by Blair Seckington, Director Power Consulting, AMEC Americas Ltd.

   This report contains an investigation and assessment of the Hydro asset management strategy and practices. This includes the strategy and standards, maintenance execution, long term asset plans, critical spares strategy and council of experts. It also looks at the

specific maintenance schedule and execution for the equipment that was involved in the Jan 4 – 5th incidents.

3. "Transmission Availability" by Brian Scott, Electrical Engineering Specialist, AMEC Americas Ltd.

   This report, included here, provides an overview of the transmission system performance during the Jan. 4 – 5th incidents and includes a summary of the sequence of events.

The review of the transmission system performance began with an overview of the transmission system - the location and size of generating units, peak and light load conditions, a general discussion of the loading of the transmission system, an identification of the primary constraints on the system and a summary of operating practices. This was followed by a review of both the detailed list and a summary of the sequence of events, system and terminal station diagrams, documents and procedures. Technical and operations personnel were made available to answer questions. For some of the detailed issues protection traces from Digital Fault Recorders were accessed and analysed. Participation with the Hydro internal review team on the root cause analysis took place early on during the review period and was valuable in focusing the analysis on key areas.

## 3 BACKGROUND

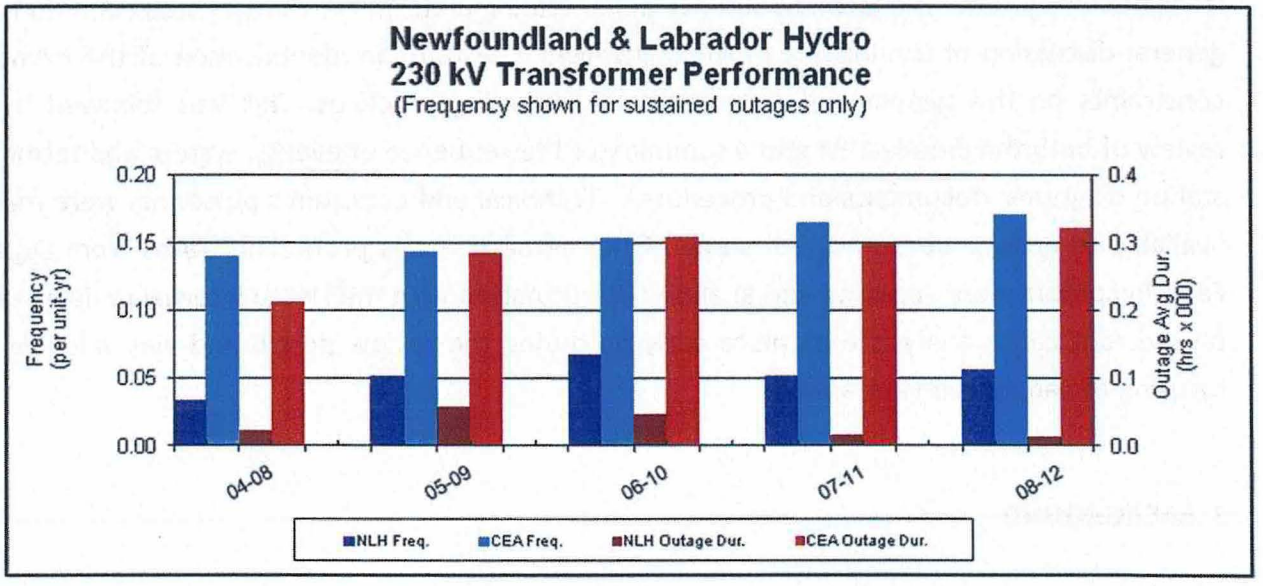
Hydro operates an electrical island that has not been interconnected with the North American electricity grid. As such there is no requirement to adhere to the standards established for the rest of the continent as defined by the North America Electric Reliability Corporation (NERC). Alternately, Hydro must be totally self-sufficient and cannot depend on help from its neighbours when significant supply disruptions occur such as during the events of Jan. 2 - 8, 2014. Hydro has drawn from the experience of others and has planned and constructed its electrical grid largely following the practices including NERC of the electrical industry in North America.

A review of the performance of the transmission system must therefore rely on the established standards and practices of Hydro. Industry practices as well as NERC standards can provide guidance and inform the reasonableness of Hydro's practices.

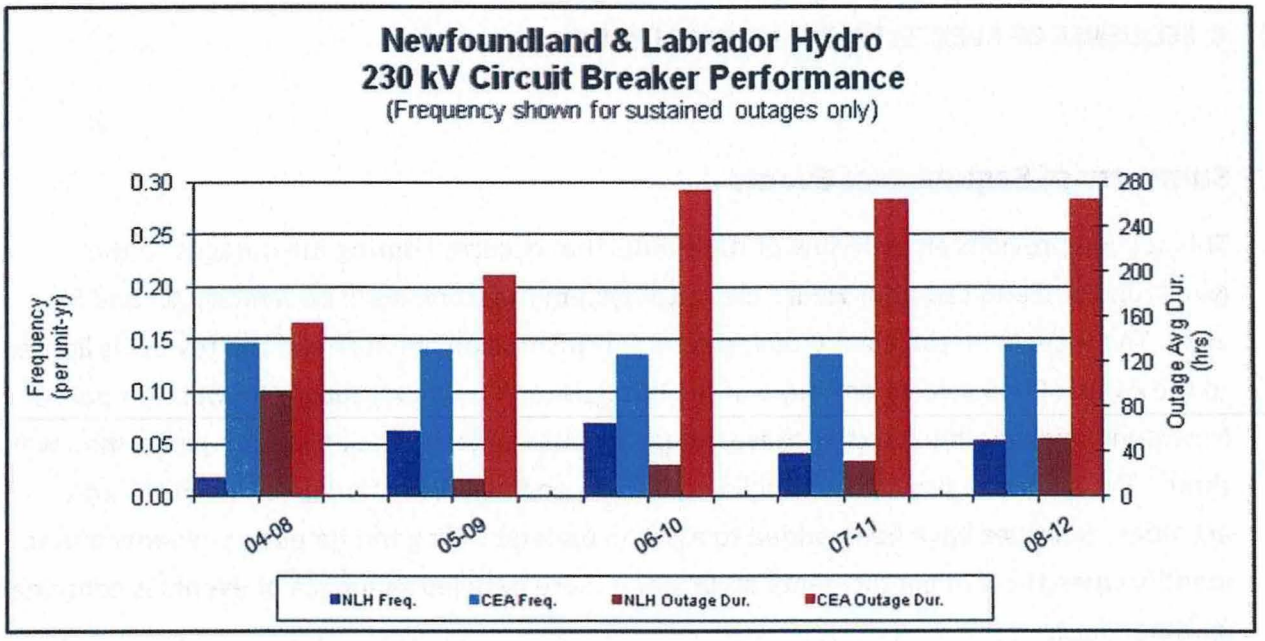
Hydro is a member of CEA and participates in an annual survey of equipment performance.

Hydro compares its results to a rolling 5-year average for similar utilities represented in CEA. Results for 2012, the latest available data published by CEA, demonstrate that the performance for the 230 kV transmission system for Hydro is very good.

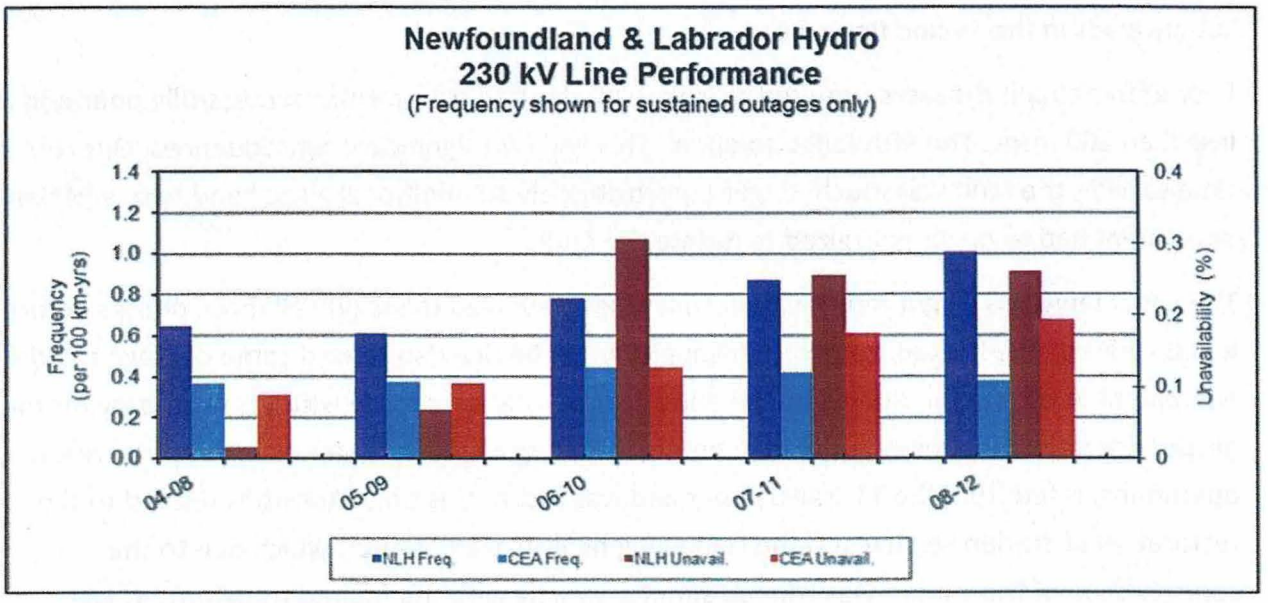
The following graph shows the performance results for 230 kV transformers for the years 2004 – 2012. Each group of bar graphs represents a 5-year period. As can be seen from the graph Hydro (NLH) had significantly fewer outages and the duration of outages was much less than the CEA average.




Hydro (NLH) demonstrated similar performance with 230 kV circuit breakers (see graph below). In this case, Hydro's outage duration for circuit breakers is trending upward but CEA averages show a similar trend and are at a much higher level.




The performance of the Hydro 230 kV transmission system compared to CEA averages is shown in the graph below. Here the frequency or number of outages per 100 km-yrs for Hydro's 230 kV lines is consistently higher. The unavailability of the lines has at times been better than CEA averages but not in the last 3 years of the survey. A review of the details underlying the statistics show that over 80% of Hydro's 230 kV transmission outages in 2012 were due to weather events (45% wind and 37% lightning); an indication that weather variability will have a significant impact on the number and frequency of outages.



# 4 SEQUENCE OF EVENTS: RELEVANT TIME FRAME

## Summary of Sequence of Events

This section provides an overview of the events that occurred during the outages to the Newfoundland and Labrador Hydro electrical system that took place on January 4th and 5th, 2014. The focus is on the 230 kV bulk electrical transmission network and the review is limited to the Avalon Peninsula where most of the outages took place. Although the western part of Newfoundland was impacted by these outage events the transmission system performed well there. The summary provides a timeline of events and highlights the major incidents and activities. Subtitles have been added to assist in understanding the timeline of events and to identify when the 4 major incidents occurred. A more detailed sequence of events is contained in Appendix 1.

### *T1 transformer failure and fire*

On the morning of Saturday, January 4, 2014 at 9:05 am the Newfoundland and Labrador Hydro transmission system experienced a fault on transformer T1 at the Sunnyside terminal station. At the time the 230 kV lines into and out of the station were heavily loaded and the Newfoundland system load was near peak conditions. A total of 554 MW were coming in on the two 230 kV lines from Bay d'Espoir. Of this, 89 MW were flowing through the transformers at Sunnyside to serve area loads and the remaining 445 MW were flowing on two 230 kV lines to supply loads in the Avalon Peninsula.

Four of five circuit breakers required to isolate the faulted transformer successfully operated in less than 200 msec. The fifth failed to open. This had two significant consequences. One, the time to clear the fault was much longer (approximately an additional 2 sec.) and two, additional equipment had to be de-energized to isolate the fault.

The initial fault was a light internal fault that quickly evolved to include all three phases before it was cleared. The faulted transformer caught fire. The fire also caused some damage to other equipment in the station due to smoke and oil spray. Station service which is necessary for the proper operation of equipment in the station, including charging batteries to support critical operations, is fed from the T1 transformer and was lost at this time. Activities related to the restoration of station service and the remaining healthy transformer, which due to the configuration of the station was tripped simultaneously with the faulted transformer, were carried out later in the day.

When the fault was not cleared at Sunnyside, protection circuits at the Western Avalon and Come-by-Chance terminal stations detected the fault. The voltages at these two terminal stations were depressed due to the fault and the power system was beginning to go unstable. As a result, two 230 kV lines were tripped. When the first line between Sunnyside and Western Avalon (TL203) tripped, it cleared the fault. When the second line between Come-by-Chance and Western Avalon (TL237) tripped, it caused a separation of the electrical grid into two islands, Avalon Peninsula and the remainder of Newfoundland. The refinery at Come-by-Chance remained connected to the western island. Although not required to isolate the fault this second line tripped because the fault was seen by the protection for this line, through a combination of low voltage, high current and the power swing. Although it had no impact on this initial event one of the line TL237 circuit breakers that operated to clear the fault indicated a slow clearing time (Western Avalon B1L37). Later during the restoration process this same circuit breaker experienced problems and could not be successfully closed. Post-event analysis has determined that only two of three poles actually closed on this circuit breaker.

***Blackout of the Avalon Peninsula***

Loss of the two 230 kV lines and the separation of the grid resulted in a deficiency of supply for the Avalon Peninsula of nearly 450 MW. This led to an immediate collapse of the system and all three generators at Holyrood with a total generation of about 380 MW tripped off 3 seconds after the initial fault on the transformer. During the tripping of Unit # 1, one of the unit breakers B1L17 failed to open on all three phases. The protection systems at Oxen Pond and Hardwoods terminal station detected the failed breaker operation and circuit breakers at these locations successfully operated to trip transmission lines TL 218 and TL 242. Due to the blackout of the system it was not obvious that the failure had occurred and the problem was not discovered until the time when Unit #1 was being brought back on late the next day.

***Restoration***

Immediately following the blackout the ECC operator performed an overall assessment of the situation to determine the initial cause and the extent of the outage. This included discussions with the Bay d'Espoir plant operator and Newfoundland Power (NP). At this time the operator relied primarily on the mapboard and the SCADA one-line diagrams. Due to the flood of alarms and events of all kinds (1800 alarms and events were received in the first 5 minutes) the operator was limited to performing only a quick review of alarms.

At 9:27 am the ECC operator closed the breaker at Come-by-Chance to re-energize the line to Western Avalon (TL237) and effectively begin the restoration of power to the Avalon Peninsula. Hydro has a System Operating Instruction (Inst. T-032. See Appendix 2) to restore power to the Avalon Peninsula for loss of TL202 and TL206, the two 230 kV lines supplying the peninsula from Bay d'Espoir. This instruction generally was applicable with some key differences; in particular the separation point between the two electrical islands was the two lines on the peninsula side of Sunnyside rather than on the Bay d'Espoir side and the transformer failure T1 at Sunnyside introduced a significant complication. It appears as though the operator used this instruction as a guideline and the step-by-step restoration of lines closely follows the steps contained in the instruction. However, it appears that the operator did not use a group breaker open function prior to restoration as per the instruction. This would have ensured a known starting configuration as well as a controlled configuration for each step in the restoration process..

The restoration instruction outlines a step-by-step procedure for energizing each of the terminal stations beginning with those closest to the supply in Bay d'Espoir. As each station is energized voltages are adjusted. Restoring power to Holyrood terminal station is a priority so that the units can be re-started . Once all stations are connected, the remaining 230 kV lines are closed to complete the grid. The operator needs to co-ordinate with Newfoundland Power to bring on loads in conjunction with the restoration of supply.

This process continued over the next few hours. The procedure could not be followed exactly because the initial conditions were not the same as those in the instruction and at times breakers would not close properly. The operator operated some breakers multiple times without success and then attempted to use alternative ways to get the grid restored. This is not unusual given several factors (the reported history of breakers sometimes failing to close on the first try but being successful later; breaker low air system problems; the vast amount of data that was pouring into ECC; and the stress of wanting to restore power quickly).

The Western Avalon terminal station was particularly difficult to energize with one breaker (B1L37) tripping after each close attempt. There was a problem with the breaker. It was later identified that only two phases closed which caused the breaker to immediately re-open. An investigation was undertaken on Feb. 13, 2014 but the breaker operated properly at that time. Therefore, the underlying cause could not be identified with certainty. The operator eventually went on to energize Hardwoods terminal station first. Then, when the attempt was made to re-energize Holyrood from Hardwoods via line TL242 protection operated and tripped the line immediately. It was tripped because it connected to the failed breaker B1L17 and one phase of the Holyrood unit #1 transformer. The operator proceeded to isolate the entire bus at Holyrood

before retrying. Although this operation was successful, an opportunity to identify breaker B1L17 had failed was missed.

These issues undoubtedly led to some delays in the time needed to restore the 230 kV transmission system on the Avalon Peninsula.

### *Loss of EMS*

Grid power had been lost to Hydro Place during the initial blackout. The EMS continued to operate without any interruptions on the Uninterruptible Power Supply (UPS) fed from the battery. Diesel #1 came on line immediately and the UPS was transferred automatically to the diesel. On the previous day both diesels had shut down due to over temperature alarm when the air intake louvers had closed due to loss of air supply. Diesel #1 was successfully re-started. However Diesel #2 was removed from service due to an undiagnosed synchronization problem and therefore was not available on January 4th. At 10:38 Diesel #1 tripped off on high temperature. The air intake louvers for Diesel #1 had closed causing the temperature to rise. An interim measure had been put in place but the air supply was lost again. An on-call person was in the building and responded quickly by manually opening the louvers and re-starting Diesel #1 at 11:03. Simultaneously with the trip, the UPS again switched to its battery source and continued to run without interruption. At 11:15 the EMS shut down due to loss of battery power. Typically a battery is sized only to provide power for a few minutes allowing time for the diesel to be started manually if required (15 - 30 minutes).

Switching of the UPS between various AC sources is done through the use of transfer switches. When the configuration is in its "normal" mode the transfer is automatic. Once all sources of AC supply were lost as was the case here the system was no longer in a normal mode and switching had to be done manually. Diesel #1 was brought back on-line at 11:03 and the grid power was restored by 11:15. However, the UPS had to be manually transferred to an appropriate AC supply by an employee knowledgeable with the operation of the transfer switch. This on-call person was contacted and brought in to restore the supply. Once the supply for the UPS was restored then the computer system was restarted, the various software systems activated and RTUs were polled to get the latest information at all terminal stations. By 11:46 the EMS was fully operational to perform grid control. A separate report contains the details of the loss of the EMS function.

Hydro has a procedure (see Appendix 3) for the loss of the EMS. The procedure was initiated. A full review of the procedure was not done as part of this external review. However, the ECC operator alerted the operator at Bay d'Espoir and transferred responsibility for frequency

control to the plant and also notified Newfoundland Power of the situation. Hydro considered moving resources to the back-up emergency control centre and activating it but with an understanding of the problem and a restoration of grid power to the building chose to remain at ECC. Hydro operators train annually for the loss of the EMS as well the transfer of operations to the backup control centre.

***Western Avalon T5 tap changer failure***

During the system restoration effort that began around 9:30, one of the first steps taken was to attempt to energize the Western Avalon B1 and B3 busses from Come-by-Chance via line TL237 using breaker B1L37. When this was performed the breaker tripped after 1.2 seconds. During the incident investigation by the external team it was found that only two phases of breaker B1L37 closed. This meant that the transformers connected to the 230 kV bus at Western Avalon, including transformer T5, were energized on two phases only. Although a gas/temperature/oil alarm was generated while the breaker was closed it is not known if the operator actually saw it. This same alarm had also been generated during the initial fault on T1 transformer at Sunnyside. A further 3 unsuccessful attempts were made to close breaker B1L37 that morning. At 12:22 Western Avalon busses B1 and B3 were finally energized when breaker L01L03 was closed connecting the station to Come-by-Chance. The T5 transformer tap changer failed 22 seconds later. There were no records that indicated a problem with the transformer prior to the failure. An Investigation by the tap changer OEM revealed that the failure was caused by a phase to phase flashover inside the tap changer. The investigation is continuing.

***Sunnyside 230 kV Bus Lockout***

At 12:57 after transformer T1 at Sunnyside terminal station had been electrically isolated; the 230 kV side of transformer T4 was energized successfully restoring station service. Approximately 1 ½ minutes later a 138 kV circuit breaker (B3T4) was closed enabling load current to flow through the undamaged transformer T4. The 230 kV bus was immediately tripped by bus differential protection as T4 isolation switch B1T4 opened automatically under load (something it was not designed to do), caused an arc and flashed over. It was noticed that the CT wiring had been damaged by the fire and was therefore considered to be the cause of the incorrect protection trip.

Emergency modifications were made to the wiring of the bus protection and a second attempt was made to energize the 138 kV bus at Sunnyside terminal station at 15:33. The bus protection

did not operate but the T4 isolation switch (B1T4) again opened automatically under load. This caused an arc and a subsequent flashover. The Sunnyside bus protection which should have operated to clear the fault failed to do so because of the emergency modifications and initiated breaker failure protection. The fault lasted for 0.6 seconds. This resulted in the two transmission lines TL 202 and TL206 tripping at the remote end in Bay d'Espoir to clear the fault. Again the supply to the Avalon Peninsula was cut off. The St. John's load that had already been restored following the 9:05 incident was lost for a second time.

The protection operation at Bay d'Espoir caused the outage to be even greater. TL202 breakers were slow to open and breaker failure was activated. This is covered in more detail in the external report on protection.

***Holyrood Unit #1 breaker B1L17 failure***

The transmission system had been restored and by the evening of January 5th most customers had their power back on. During the evening peak there were some load curtailments because generation had not been fully restored. At Holyrood, units #2 and #3 were on-line and total plant generation was approximately 210 MW.

At 21:27 on January 5, 2014 Holyrood unit #1 disconnect switch was closed in preparation for bringing the unit on-line. At the time, it was believed by the operator that the unit was isolated with both unit breakers open. Synchronization would then take place by closing one of the breakers. However, it is now known that breaker B1L17 was failed and one phase of the breaker was still closed. Although there was no fault, the unit transformer was energized through one phase. This caused the voltage to drop to approximately 200 kV and unbalanced currents to flow. Protection operated quickly to remove all supply sources. Transmission lines TL217, TL218 and TL242 were tripped. A lockout signal was generated for all three generating units. The three transformers feeding Newfoundland Power load were tripped and the station service transformers were tripped.

Loss of the two units at Holyrood, created a significant loss of supply once again to the Avalon Peninsula and numerous customer outages. However, there were no additional significant transmission incidents during the restoration that followed.

## 5 KEY FINDINGS AND RECOMMENDATIONS

### Findings

1. One of the key findings in this outage event and a major contributing factor to the extent of the outages and to delays in restoration was the performance of 230 kV circuit breakers. At least three 230 kV air blast circuit breakers (ACB) failed to operate properly during the key incidents investigated. The probability of this happening is very low given that the failure modes are different for each. Specifically, the breakers were:

    a. Breaker B1L03 failed to open at Sunnyside during T1 transformer failure. The breaker was closed manually later in the day. Type: Brown Boveri air blast DCVF Built 1966

    b. Breaker B1L17 at Holyrood opened on only 2 phases when unit #1 tripped following the T1 incident. The problem was found and the breaker has subsequently been repaired under the supervision of ABB. This breaker is scheduled to be replaced as part of the program to upgrade breakers to meet fault level/interrupting capacity requirements. Type: Brown Boveri air blast DLF Built 1973

    c. Breaker B1L37 at Western Avalon closed on only 2 phases and after 1.2 seconds re-opened during Jan 5 – 6 outage events (on 7 occasions). This certainly led to delays in restoration. A number of the close operations occurred prior to the transformer T5 tap changer failure and the closure would have energized the all the 230/138 kV transformers at Western Avalon including transformer T5. It is unclear what if any contribution this would have had on the failure of the transformer. A work permit was issued for Hydro maintenance personnel to investigate B1L37 on Feb. 13th. The breaker operated successfully at that time. Type: Brown Boveri air blast DCVF Built 1968

2. Problems were experienced with other circuit breakers as well:

    a. Breaker B1L17 at Western Avalon experienced a number of difficulties. The operator experienced difficulties operating the breaker and there were issues with the breaker open/close state indication.

    b. Breaker B2L42 at Holyrood showed multiple changes of state between open and close.

3. Hydro's historical performance of the 230 kV transmission system has been very good demonstrating performance results in transformers and circuit breakers better than CEA averages. This event is an uncommon occurrence and the performance of the circuit

breakers represents a departure from previous experience.

4. The design of the transmission network follows industry practices and provides a reliable and robust network. The events that occurred during the January 4 – 5th outages involved multiple events that are not typically designed for.
5. Hydro has processes and facilities in place to deal with events of this nature. These include a restoration plan for loss of supply to the Avalon Peninsula, a back up control centre, and regular staff training.
6. In the face of the overwhelming volume of data that occurs in an event of this nature, some Information was available but not acted upon that could have enabled operations staff to potentially reduce the impact of the outages.
7. Internal technical staff and external consultants involved in the event review as well as operations staff are knowledgeable, experienced and professional.

## Recommendations:

1. A thorough review is recommended to assess the acceleration and modification of the existing ACB refurbishment/replacement program, particularly the continued use of these breakers in critical areas on the bulk power system.
2. A more extensive review of the outage event as it relates to the performance of equipment and use of resources is recommended to capture unexpected outcomes and use these as lessons for future improvements.
3. Enhancements should be made to ensure that processes and facilities that are in place to deal with events of this nature work as designed, personnel training encompasses similar extreme events and plans for resource allocation are focused on key issues. A more extensive review of the event is recommended to determine what enhancements should be made in addition to on-going continuous improvement initiatives.
4. "Protection" alarms and "fault traces" need to be reviewed as soon as possible on an on-going basis during such an event. It is recommended that staff be readily available prior to anticipated extreme weather or potential system emergency conditions and be dedicated to this task during events of this nature.
5. Other recommendations relating to protection and alarms include:
    a. Identify the key set of priority alarms that must be available and reviewed by the operator even during events of this magnitude.

b. Provide additional training as necessary to operators on the importance of alarms.

c. Implement a program to install modern digital relays that are able to store time-synchronized fault data. An installation plan should be developed to gain/increase visibility of all major equipment such as 230 kV transformers.

6. A major event such as this provides very useful information on facilities, equipment and resources, both in terms of what worked well and what needs improvement. Hydro should consider how it can best transfer the knowledge and experience gained both during the event and in the investigation that followed to the entire organization in a deliberate manner.

## 6 RECOMMENDATIONS STATUS

All of the recommendations in this report require an evaluation of the circumstances and development of an implementation plan. They should therefore be completed in the mid to long term timeframe. This section provides some general targets for completion.

Recommendation 1: Assessment and modification of the existing ACB refurbishment / replacement program.

This should be evaluated in two parts. The first would be to assess and modify the program for the upcoming maintenance period. This would be constrained by availability of new equipment, outage plans and other factors. The second would be to evaluate the multi-year plan for the remaining breakers which should coincide with the next budget cycle.

Recommendation 2: A more extensive review of the outage event as it relates to the performance of equipment and use of resources.

All equipment that has been identified as experiencing problems during this event should be investigated and actions incorporated into the scheduled maintenance plans.

A review of the utilization of resources, whether they were adequate and if any training is required, can be done as part of the overall event review.

Recommendation 3: A more extensive review of the event to determine what enhancements should be made to ensure that processes and facilities in place for events of this nature work as designed, personnel training encompasses similar extreme events and plans for resource allocation are focused on key issues.

No action is recommended on this until the investigation is complete. It would be helpful to have a plan in place prior to the next winter season.

Recommendation 4: Protection staff be readily available prior to anticipated extreme weather or potential system emergency conditions and be dedicated to this task during events of this nature.

It is recommended to start action on this recommendation immediately to ensure resources are trained and in place before the next severe weather event occurs.

Recommendation 5: Other recommendations relating to protection and alarms.

Work on the alarm prioritizations can start immediately but it is expected that they will take several months to implement. Operator training on alarms can be done as part of the normal training. A plan for installation of digital relays should be completed prior to the budget cycle.

Recommendation 6: How Hydro can best transfer the knowledge and experience gained both during the event and in the investigation to the rest of the organization.

No action is recommended on this until the investigation is complete.

## APPENDIX 1 DETAILED SEQUENCE OF EVENTS

**Note: This appendix contains a more detailed summary of alarm and events for the outages on January 4th and 5th, 2014. In general, only key alarm/events at the 230 kV level are shown unless more detail is required for clarity purposes. Moreover details are provided only around the timeframes of the actual events and not for the entire period. Time is shown to the nearest minute, second or millisecond.**

**Jan. 04, 2014**

9:05:34.600 Fault detected in transformer T1 at Sunnyside. Lockout 86T1 operates. **Sunnyside T1 failure**

9:05:34.715 138 kV breaker L109T4 at Sunnyside opens (low side of T4 transformer)

9:05:34.753 138 kV breaker B3T4 at Sunnyside opens (low side of T4 transformer)

9:05:34.755 230 kV Breaker B1L02 at Sunnyside opens

9:05:34.786 138 kV breaker B2T1 at Sunnyside opens (low side of T1 transformer). Four of five breakers for T1 Transformer operate. Breaker B1L03 does not open

9:05:35.641 Disconnect switch B1T1 at Sunnyside starts to open. Disconnect switch takes about 5.4 seconds to fully open (9:05:41.036)

When B1L03 does not open and the fault continues to evolve and protection circuits at multiple locations sense the fault after a delay of about 2 seconds and issue a trip signal:

9:05:36.695 TL203 at Sunnyside

9:05:36.704 TL203 at Western Avalon

9:05:36.715 TL237 at Come-by-Chance

The protection operations cause a number of breakers to open:

9:05:36.719 Breaker L03L06 at Sunnyside opens

9:05:36.742 Breaker L01L37 at Western Avalon opens

9:05:36.719 Breaker B1B2 at Come-by-Chance opens. At this point separation between Avalon Peninsula and the rest of the system occurs because TL203 is already open on the Sunnyside end. (See Appendix 4, Figure 1 for trace showing system becoming unstable)

9:05:36.820 Breaker L03L17 at Western Avalon opens which clears the fault on T1 transformer, 2.2 seconds after the fault was initiated.

9:05:36.991 Breaker L01L03 opens at Western Avalon

09:05:36 AC power was lost to the Hydro building

09:05:36 Hydro's EMS switched to battery power

The units at Holyrood cannot supply the load and trip off:

9:05:37.387 Holyrood G1 lockout 86-3/G1

9:05:37.419 Holyrood G2 lockout 86-3/G2

Unit breakers for G1 open:

9:05:37.471 Breaker B1L17 at Holyrood opens. This breaker only opens two phases. C phase remains closed

9:05:37.511 Breaker B1B11 at Holyrood opens. **Holyrood Unit #1 trips**

Unit breakers for G2 open:

9:05:37.517 Breaker B2L42 at Holyrood opens

9:05:37.529 Breaker B2B11 at Holyrood opens. **Holyrood Unit #2 trips**

Unit breakers for G3 open

9:05:37.660 Breaker B3B13 at Holyrood opens

9:05:37.711 Breaker B3L18 at Holyrood opens. **Holyrood Unit #3 trips**

9:06:21.834 Holyrood G3 lockout 86-4/G3. (The lockout indication should occur before the breaker operation so there may have been a delay in indication)

As soon as unit #1 breaker B1L17 at Holyrood opens (2 phases) protection circuits at Hardwoods and Oxen Pond operate to trip the lines feeding Holyrood. This occurs even before

unit #3 has tripped. It appears as though protection also issued a trip to breaker B3L18 at Holyrood. (See Appendix 4, Figure 2 for trace showing neutral current on unit #1 transformer after the unit has tripped)

9:05:37.577 Protection trip initiated for line TL242 Hardwoods

9:05:37:578 Protection trip initiated for line TL218 Oxen Pond

9:05:37.622 Breaker B2L42 at Hardwoods opens

9:05:37.732 Breaker B1L18 at Oxen Pond opens

Breaker B1L37 opens at Western Avalon, then closes and re-opens. The initial opening appears to be a delayed opening to the protection operation initiated at 9:05:36. Operations staff indicated that the close is likely an automatic re-close. The subsequent opening after a delay is consistent with only 2 phases closing as seen later in the morning. A gas/temperature/oil alarm is also seen.

9:05:38.195 Western Avalon T5 gas/temperature/oil alarm

9:05:38.209 Breaker B1L37 at Western Avalon opens

9:05:41.041 Breaker B1L37 at Western Avalon closes

9:05:41.036 Disconnect switch at Sunnyside is fully open providing isolation for the high side of the failed transformer T1

9:05:42.137 Breaker B1L37 at Western Avalon re-opens after 1.2 seconds

09:05:45 Diesel #1 at Hydro Place on-line restoring AC supply

09:05:45 Hydro's EMS switched to diesel supply

09:06:49.649 Disconnect switch B3T3 at Holyrood is opened by plant operator to isolate unit #3

9:09:02 Status of breaker BL42 at Holyrood generating station begins to toggle between open and close, literally dozens of times. The operator would be able to quickly ascertain that the breaker did not actually operate but it would have been difficult to determine the actual state and it would have added confusion to determining the state of the power system.

9:27:44 Operator closes breaker B1B2 at Come-by-Chance to re-energize TL237 to Western Avalon. **Restoration Begins**

9:38:01 Operator opens breaker B1L17 at Western Avalon to prepare to energize bus B1 only.

9:41:00 Operator closes breaker B1L37 at Western Avalon to energize bus B1 from line TL237. Breaker closes but trips again 1.2 seconds later. This is due to only 2 phases closing. Subsequent trip is on phase disagreement (See Appendix 4, Figure 3 for trace showing current in 2 phases only). Since breaker B1B3 is closed (It does not open until the fault on T5 at 12:22) bus B3 is energized which energizes transformer T5. In addition breaker B1L08 is still closed so line TL208 to Voisey's Bay is also energized. A gas/temperature/oil alarm is received for transformer T5 at 9:41:09 during the time when the breaker B1L37 is closed.

9:41:43 Operator opens breaker B1L08 at Western Avalon to isolate TL208 and Voisey's Bay.

9:42:11 Operator attempts to close breaker B1L37 at Western Avalon a second time with the same result as before. Breaker closes but trips after 1.2 seconds and a gas/temperature/oil alarm is received for T5.

9:44:34 Operator opens B1L36 at Hardwoods to prepare to energize Hardwoods terminal station.

9:51:44 Operator closes L01L37 at Western Avalon to energize TL201 and busses B1 and B2 at Hardwoods. No loads have yet been successfully re-energized at Western Avalon. **Hardwoods is restored**

10:14:43 Operator attempts to close B2L42 at Hardwoods to energize line TL242 to Holyrood. This energizes bus B12 at Holyrood. However, since the failed breaker B1L17 at Holyrood has not been isolated (failed state of breaker has not been discovered) and the unit disconnect is still closed, then one phase of unit #1 step-up transformer would be energized. Protection circuits for TL242 operated at both Holyrood and Hardwoods. (See Appendix 4, Figure 4. This contains a trace of the unbalanced current flow as seen from Western Avalon via line TL237) At Holyrood breaker B12L42 tripped open and after 2 minutes an event was generated indicating that the breaker B2L42 failed to close. The protection system operated correctly and the unit transformer was energized through a single phase for about 4 cycles. The unbalanced current flow was probably not high enough to cause significant damage to the generator. About this time breaker B1L17 at Holyrood indicates several open/close operations (4).

10:15:51 Operator opens breaker B13B15 at Holyrood

10:15:56 Operator opens breaker B12B15 at Holyrood

10:16:03 Operator opens breaker B7T5 at Holyrood – low side breaker of transformer T5 connected to 230 kV bus B11

10:16:17 Operator opens breaker B12T10 at Holyrood – high side breaker of transformer T10 connected to 230 kV bus B12. The only 230 kV breakers that remain closed are B12L17 and B12L18.

10:22:31 Operator attempts to close B2L42 at Hardwoods a second time. This time the breaker closes successfully because breaker B12L42 at Holyrood is now open. Transmission line TL242 is re-energized.

10:23:15 Operator opens breaker B12L17 at Holyrood.

10:23:19 Operator opens breaker B12L18 at Holyrood. All 230 kV breakers are now open at Holyrood.

10:23:31 Operator closes breaker B12L42 at Holyrood which energizes bus 12 at Holyrood. **Bus B12 at Holyrood is restored.**

10:24:39 Operator closes breaker B12T10 at Holyrood which energizes the 25 MVA transformer T10 enabling the restoration of station service to the plant. The low side breaker B6T10 is closed about 1 minute later.

10:25:31.281 Disconnect switch B1T1 at Holyrood is opened by plant operator isolating unit #1 and avoiding for the time being any further system issues with unit breaker B1L17.

10:25:50.635 Disconnect switch B2T2 at Holyrood is opened by plant operator to isolate unit #2

10:38:44 Diesel #1 at Hydro Place tripped offline due to high temperature. Air intake louvers had closed due to heavy ice build-up

10:38:44 Hydro's EMS switched to battery power

10:41:13 operator closes breaker B1L36 at Hardwoods to energize line TL236 to Oxen Pond and the Oxen Pond B1 bus. **Oxen Pond is restored.**

10:57:15 Breaker B1L03 at Sunnyside, the one that failed to open during the transformer fault, opens.

11:02 Hydro's EMS shutdown due to loss of UPS Battery Power

11:03 Diesel #1 on-line - UPS does not automatically switch to diesel supply (manual switching required)

11:00 -11:15 AC power is restored to Hydro Place by Newfoundland Power. As noted above, UPS does not automatically switch to AC supply (manual switching required)

11:46:50 Hydro's EMS grid control functions are restored to ECC.

12:00:31 Disconnect switch B2L12-1 at Sunnyside is opened by field personnel, a low-side isolation point for transformer T1. Status is manually set.

12:00:38 Disconnect B2B3 at Sunnyside is opened by field personnel. Status is manually set. This isolates the low side of transformer T1.

12:13:03 Operator attempts to close breaker B1L37 at Western Avalon. Similar to previous attempts the breaker closes but trips after 1.2 seconds and a gas/temperature/oil alarm is received for T5.

12:15:16 Operator attempts to close breaker B1L37 at Western Avalon. This time the breaker fails to close and after 2 minutes an event was generated indicating the status.

12:15:57 In the meantime, operator closes breaker B1L17 at Western Avalon. Since the other end of the line TL217 is open this action has no effect.

12:17:31 After receiving notification that breaker B1L37 at Western Avalon failed to close, the operator attempts another close operation. Again the breaker fails to close and after 2 minutes an event was generated indicating the status.

12:19:47 Operator closes breaker L03L17 at Western Avalon. The breakers for line TL203 had tripped to clear the T1 transformer fault at Sunnyside and were still open. That is, except for the breaker B1L03 at Sunnyside. This breaker had been manually opened at 10:57. Therefore, closing this breaker had no effect.

12:22:07 Operator closes breaker L01L03 at Western Avalon. This energizes busses B1 and B3 at Western Avalon via line TL237 from Come-by-Chance. Due to previous actions, line TL203 to Sunnyside and line TL217 to Holyrood are also energized. Breaker close indication received at 12:22:15.721. The transmission line to Sunnyside appears to be energized prior to opening the

disconnect switches (12:38) to isolate the failed breaker B1L03. Since the status is manually set, this may be just a timing issue and the operator has already been made aware that the breaker has been isolated. **Western Avalon B1 and B3 busses restored**

12:22:39.892 Western Avalon transformer tap changer fails. A phase to phase fault develops. 86T5 lockout protection operates. **Western Avalon T5 tap changer failure**

12:22:39.862 Western Avalon breaker B1B3 opens to clear fault on T5 transformer

12:22:40.486 Western Avalon switch B4T5 opens – low side of transformer T5

12:22:41.294 Western Avalon switch B3T5 opens – high side of transformer T5 to isolate T5 transformer

12:23:12 Operator closes breaker B12L17 at Holyrood enabling power to flow. The other end had been closed at 12:22:07.

12:30:25 Operator closes breaker B1L18 at Oxen Pond energizing line TL218 to Holyrood.

12:30:33 Operator closes breaker B12L18 at Holyrood, the other end of line TL218.

12:38:20 Disconnect switch B1L03-2 at Sunnyside is opened by field personnel. Status is manually set.

12:38:25 Disconnect switch B1L03-1 at Sunnyside is opened by field personnel. Status is manually set. This isolates the breaker B1L03.

12:42:03 Operator closes bus tie breaker B1B3 at Western Avalon. The breaker fails to close and provides indication 2 minutes later at 12:44:04.

12:56:55 Operator initiates close of breaker B1L02 at Sunnyside. At 12:57:07.804 the breaker closes which energizes bus B1 and the healthy transformer T4. Station service is also restored.

12:58:11 Operator opens 138 kV breaker L19L100 at Sunnyside.

12:58:12.030 138 kV breaker L19L100 at Sunnyside opens

12:58:21 Operator initiates close of 138 kV breaker B3T4 at Sunnyside. At 12:58:23.928 the breaker closes. **First attempt to load T4 at Sunnyside**

12:58:24.281 138 kV breaker B3L19 at Sunnyside opens

12:58:24.356 138 kV breaker B2L12 at Sunnyside opens

12:58:25.807 138 kV disconnect switch B1T4 at Sunnyside begins to open.

12:58:30.392 Bus 1 lockout 86B1 at Sunnyside operates due to fault caused by opening of B1T4 under load.

12:58:30.524 Breaker B1L02 at Sunnyside opens

12:58:30.540 138 kV breaker B3T4 at Sunnyside opens

12:58:35.273 138 kV disconnect switch B1T4 at Sunnyside is fully open

13:04:38 Operator attempts to close disconnect switch B1T4 at Sunnyside. Operation fails and open status indicated about 30 seconds later at 13:05:09

14:09:17 Operator attempts again to close disconnect switch B1T4 at Sunnyside. Operation fails and open status indicated about 30 seconds later at 14:09:48

14:36:16.206 138 kV disconnect switch B1T4 at Sunnyside is closed. Since there is no indication of operator action, it is assumed that the switch was closed locally by field personnel. Beginning at 14:16:57 there had been a number of state changes for this switch between Open and In Transit.

14:40:47 Operator closes breaker L03L06 at Sunnyside.

14:41:14 Operator initiates close of breaker B1L02 at Sunnyside. At 14:41:18.339 the breaker closes which similar to the previous attempt energizes bus B1 and the healthy transformer T4. Station service is also restored.

15:33:23 Operator initiates close of 138 kV breaker B3T4 at Sunnyside. At 15:33:26.498 the breaker closes. **Second attempt to load T4 at Sunnyside**

15:33:28.339 Similar to the previous attempt, 138 kV disconnect switch B1T4 at Sunnyside begins to open.

15:33.32.525 Protection signals 77-TL202 PRI and 77-TL202 SEC sent from Bay d'Espoir.

15:33.32.526 Protection signals 77-TL206 PRI and 77-TL206 SEC sent from Bay d'Espoir.

15:33:32.531 Protection signal 85-TL202 PRI received at Sunnyside. Secondary protection signal for TL 202 also received 15 msec. later.

15:33:32.532 Protection signal 85-TL206 PRI received at Sunnyside. Secondary protection signal for TL 206 also received 12 msec. later.

15:33:32.866 Breaker B11L06 at Bay d'Espoir opens and at 15:33:32.889 breaker L06L34 at Bay d'Espoir opens to trip line TL206

15:33:33.122 Lockout 86B3 at Bay d'Espoir operates

15:33:33.150 Breaker B3B4 at Bay d'Espoir opens

15:33:33.215 Breaker B4B5 at Bay d'Espoir opens. B3B4 and B4B5 will trip line TL202 but were slow in opening. **Loss of supply from Bay d'Espoir to Sunnyside and Avalon peninsula including Come-by-Chance initiating a second blackout**

15:33:33.237 Breaker B5B6 at Bay d'Espoir opens. With B4B5 open this trips TL204

15:33:33.247 Breaker L02L07 at Sunnyside opens

15:33:33.258 Breaker B1L02 at Sunnyside opens

15:33:33.353 Breaker B3T6 at Bay d'Espoir opens. Unit #6 is tripped off-line

15:33:33.416 Breaker B3T5 at Bay d'Espoir opens. Unit #5 is tripped off-line

15:33:37.206 – 15:33:37.986 Status indication that breaker B1L02 at Sunnyside opens/closes multiple times (5 close operations followed each time by an open operation).

15:33:37.206 – 15:33:37.986 Status indication that breaker B1L03 at Sunnyside closes opens/closes multiple times (6 close operations followed each time by an open operation).

15:33:37.214 Breaker L02L07 at Sunnyside closes

15:33:37.214 Breaker L02L07 at Sunnyside opens

15:33:37.214 -15:33:37.833 Disconnect switch B1T1 shows In Transit / Open states (4 times)

15:33:39.416 138 kV disconnect switch B1T4 at Sunnyside is fully open

15:37:58 Operator initiates close of breaker B11L06 at Bay d'Espoir. At 15:38:00.875 the breaker closes to energize line TL206 and start the restoration process. **Restoration begins**

**The restoration process that began at 15:38 is not included.**

21:21:40.348 Disconnect switch B2T2 at Holyrood is closed by plant operator to prepare to bring unit #2 on-line

21:34:07.819 Breaker B2L42 at Holyrood is closed by plant operator to synchronize unit #2. **Holyrood unit #2 on-line**

21:34:42.219 Breaker B2B11 at Holyrood is closed by plant operator

**Jan. 5, 2014**

01:39:28.029 Disconnect switch B3T3 at Holyrood is closed by plant operator to prepare to bring unit #3 on-line

01:40:42.797 Breaker B3L18 at Holyrood is closed by plant operator to synchronize unit #3. **Holyrood unit #3 on-line**

01:41:05.969 Breaker B3B13 at Holyrood is closed by plant operator

08:10:16 Operator closes B1L08 at Western Avalon to energize line TL208 to Voisey's Bay. **Voisey's Bay is restored**

**Holyrood generators trip**

21:27:34.420 Unit #1 disconnect switch B1T1 at Holyrood closes. Since breaker B1L17 has failed the unit transformer is energized. This causes the voltage to drop to approximately 200 kV and

protection to operate for lines TL217, TL218 and TL242.

21:27:41.133 Unit #1 disconnect switch at Holyrood opens.

21:27:41.295 Unit #1 lockout operates 86-2/G1

21:27:41.414 Unit #2 lockout operates 86-3/G2

21:27:41.501 Breaker B2L42 at Holyrood opens. This breaker continues to give multiple open/close state changes

21:27:41.575 Breaker B8L39 at Holyrood opens – low-side breaker for transformers T6, T7 and T8 supplying Newfoundland Power Loads

21:27:41.823 Breaker B13B15 at Holyrood opens –one of two high-side breakers for transformers T6, T7 and T8 supplying Newfoundland Power Loads

21:27:41.843 Breaker B7T5 at Holyrood opens – low side of SS transformer

21:27:41.856 Breaker B12L18 at Holyrood opens

21:27:41.996 Unit #3 lockout operates 86-4/G3

21:27:42.010 Breaker B12L17 at Holyrood opens

22:12:31 Operator attempts to open breaker B12B15. Control failure status given after 16 seconds

## APPENDIX 2 HYDRO RESTORATION PLAN FOR AVALON PENINSULA (INSTRUCTION NO. T-032)

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**SYSTEM OPERATING INSTRUCTION**

| | | | |
|---|---|---|---|
| **STATION:** | Energy Control Centre | **Inst. No.** | T-032 |
| **TITLE:** | Restoration Plan for Loss of TL202 and TL206 | **Page** | 1 **of** 3 |

This plan is devised to assist in the restoration of the power system should TL202 and TL206 trip simultaneously. Newfoundland and Labrador Hydro's Energy Control Centre Shift Supervisor will direct all actions necessary to restore the power system to its normal operating state. Upon loss of both 230 kV transmission lines from Bay d'Espoir to Sunnyside, Hydro's automatic restoration scheme will activate. The goal of the scheme is to restore power to TL207 from either TL202 or TL206. A number of items can be performed while the auto-restoration program is running. If unsuccessful, the program will timeout after 1½ to 2 minutes. Complete the following items in preparation of restoring the system.

***Note*- Maintain Contact with Newfoundland Power throughout this Restoration Procedure.**

| | Newfoundland Hydro (NLH) | Comments |
|---|---|---|
| 1. | Upon loss of TL 202/TL 206 auto-restoration program will execute. | ***Check program status - Come -by-Chance (CBC) display set. (T-023)*** |
| 2. | Restore lines and customer load tripped due to underfrequency load shedding (TL 226, TL 220, GBK L1, St. Alban's, etc.) | ***Reminder: - AGC has tripped to Monitor.*** |
| 3. | Monitor and Control West Coast voltage. | ***Follow Guidelines for West Coast Voltage Control.*** |
| 4. | Request Bay d'Espoir Plant to take local control. | ***Have Bay d'Espoir staff monitor and regulate frequency.*** |
| 5. | Notify North Atlantic Refining Ltd and Vale. | ***NARL – 463-8811 ext.487***<br>***Vale – 758-8778 or 697-1102*** |
| 6. | Notify System On-Call and Corporate Relations. | |
| 7. | Execute Group Breaker openings in OPD, HWD, HRD and WAV. | ****NLH will verify group breakers open completed.***<br>****NP will verify Avalon feeders Open.*** |
| 8. | Check CBC, HWD, OPD Cap Banks Open. | ****Verify all Avalon Capacitor Banks Open.*** |

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**SYSTEM OPERATING INSTRUCTION**

| | | | |
|---|---|---|---|
| **STATION:** | Energy Control Centre | **Inst. No.** | T-032 |
| **TITLE:** | Restoration Plan for Loss of TL202 and TL206 | **Page** | 2 of 3 |

| | Newfoundland Hydro (NLH) | Comments |
|---|---|---|
| 9. | If HRD Unit(s) tripped, Request Holyrood's Control Room to open all unit breakers. | ***ECC will verify Holyrood unit breakers open.*** |
| 10. | Execute SSD Group Breaker opening. | ***Separate 138 kV from 230 kV at Sunnyside and verify group breaker open completed.*** |
| 11. | Restore TL 202 and/or TL 206 (If not already done by auto-restoration). If TL202 and TL206 remain out, consider HRD Blackstart from either Newfoundland Power's Mobile Generation at HRD or HWD TL242 (refer to Instruction T-007 and T-023). | ***TL 202 preferred to avoid energizing TL 203 when restoring SSD 138 kV bus. Adjust SSD LTC's to acceptable voltage levels.*** |
| 12. | Restore TL 207 (If not already done by auto-restoration) and restore TL 237 to WAV. | ***Notify NARL to restore (30 MW).***<br>****May require adjusting all online generating units to achieve acceptable Avalon voltage levels.*** |
| 13. | Restore Sunnyside 138 kV bus. Monitor and Control Voltages.<br>*Note:* ****Use of CBC caps will result in excessive Voltage spikes**** | ***Restore TL212 and TL219. Notify Newfoundland Power to restore Burin and SSD Feeders.***<br>****If required the removal TL219 (SSD-SPO) will help lower the Avalon voltage.*** |
| 14. | Restore second line from Bay d'Espoir to Sunnyside, if possible. | ***Monitor and control voltage to acceptable levels.*** |
| 15. | Restore TL237 at WAV, adjust WAV LTC's to acceptable levels (142 kV) and notify Newfoundland Power to restore WAV Loads. | ***64L, B2T1, B2T2, and 86L loads.*** |
| 16. | Close WAV L01L37 to energize TL201 to HWD via B1L01.<br>Adjust HWD LTC's to acceptable levels (68 kV) and notify Newfoundland Power to restore HWD Loads. | ****Use HWD Cap Banks after LTC's usage exhausted.***<br>****Start Hardwoods GT, if not already started.*** |

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**SYSTEM OPERATING INSTRUCTION**

| | | | |
|---|---|---|---|
| **STATION:** | Energy Control Centre | **Inst. No.** | T-032 |
| **TITLE:** | Restoration Plan for Loss of TL202 and TL206 | **Page** | 3 of 3 |

| | Newfoundland Hydro (NLH) | Comments |
|---|---|---|
| 17. | Close HWD B2L42 to energize TL242 to HRD. *If not completed through Black Start T-007* Close HRD B12L42. | ***HRD station service restored. Notify NP and restore 39L and 38L (If not already completed).*** |
| 18. | Close HRD B12L18 to energize TL218 to OPD. Close OPD B1L18. Adjust OPD LTC's to acceptable levels (68KV) and notify Newfoundland Power to restore OPD Loads. | ****Use OPD Cap Banks after LTC's usage exhausted.*** |
| 19. | When HRD Unit(s) are Online, restore all remaining loads. Use CBC Cap Banks as required. | |
| 20. | Restore all remaining 230kV Transmission Lines, TL203, TL217, & TL236. | ***Monitor and control voltage to acceptable levels.*** |

*Notes:*

- To secure the system after load has been restored, place remaining 230 kV transmission lines in-service and start Paradise River plant. Newfoundland Power will restore the remainder of their system, picking up load in consultation with Hydro (ECC).
- The Wind Farms should not be re-connected to the system until the Holyrood plant is in a stable mode of operation and the load is restored. When connected, the output of the wind farm(s) should be limited to the total pick-up capability of the Holyrood plant in the event that the wind generation is suddenly lost or rejected.
- Under extenuating circumstances (HRD offline for extended period), the Wind Farms could possibly supply load to Newfoundland Power's system and help maximize the available Avalon Generation capacity.

**REVISION HISTORY**

| Version Number | Date | Description of Change |
|---|---|---|
| 0 | 2013-04-11 | Original Issue |

| | |
|---|---|
| **PREPARED: Jason Dean** | **APPROVED:** |

## APPENDIX 3: PROCEDURE FOR LOSS OF EMS FUNCTION

HYDRO
THE POWER OF COMMITMENT

### NEWFOUNDLAND AND LABRADOR HYDRO - OPERATIONS STANDARD INSTRUCTION

| TITLE: | Inst. No. 015 |
|---|---|
| CONTINGENCY PLAN FOR LOSS OF THE ENERGY MANAGEMENT SYSTEM FUNCTION | Rev. No. |
| | Page 1 of 4 |

Introduction

The Energy Management System (EMS) is used by the Energy Control Centre (ECC) to operate the power systems on the Island and in Labrador. If the EMS fails and is unable to function, operation of the power system must be carried out by staffing generation and terminal stations normally operated using the EMS. The details of this plan, which are directed by ECC staff, are included in the Contingency Plan for Loss of EMS Function retained as part of several technical and administrative instructions maintained by ECC. This instruction outlines the responsibilities of operating staff who are required to attend stations, the preparation required, and the frequency for testing the contingency plan.

Preparedness

To ensure that individuals are familiar with the procedures and responsibilities associated with this instruction, this contingency plan will be simulated yearly to measure effectiveness.

Responsibilities

Asset Managers – Generation and Terminal Stations

1. Managers should ensure that personnel are aware of this procedure and the rationale for its creation.

| PREPARED BY: | APPROVED/CHECKED BY: | ISSUED DATE: 2003-07-15 |
|---|---|---|
| C. Kirby | | REV. DATE: |

HYDRO
THE POWER OF COMMITMENT

**NEWFOUNDLAND AND LABRADOR HYDRO - OPERATIONS**
**STANDARD INSTRUCTION**

| **TITLE:** | **Inst. No.** 015 |
|---|---|
| **Contingency Plan For Loss of**<br>**The Energy Management System Function** | **Rev. No.** |
| | **Page** 2 **of** 4 |

Responsibilities (cont'd)

| | | |
|---|---|---|
| Asset Managers – Generation and Terminal Stations | 2. | Managers should ensure that the detailed contingency plan referred to in the introduction, equipment manuals, paper/pencils, functional communications equipment, PPE for switching, and other equipment/materials needed by staff during an EMS outage, to manually monitor and control a station, are available at each station listed in the detailed plan. |
| Regional On-call Supervisors | 1. | When contacted by ECC, supervisors will be required to staff stations with switching personnel, and plant operators where appropriate. ECC will identify the stations or plants that require manual operation. |
| | 2. | When presented with event logs from switching or plant personnel, the logs should be forwarded to the Superintendent of ECC. |
| Hydro Generation On-call Supervisors | 1. | When contacted by ECC, supervisors will dispatch operators to the plants specified by ECC. |
| | 2. | ECC will indicate if personnel are required at flow control structures. |

| **PREPARED BY:** | **APPROVED/CHECKED BY:** | **ISSUED DATE:** 2003-07-15 |
|---|---|---|
| C. Kirby | | **REV. DATE:** |

HYDRO
THE POWER OF COMMITMENT

**NEWFOUNDLAND AND LABRADOR HYDRO - OPERATIONS STANDARD INSTRUCTION**

| TITLE: | Inst. No. 015 |
|---|---|
| CONTINGENCY PLAN FOR LOSS OF THE ENERGY MANAGEMENT SYSTEM FUNCTION | Rev. No. |
| | Page 3 of 4 |

Responsibilities (cont'd.)

| | | |
|---|---|---|
| Hydro Generation On-call Supervisors | 3. | When presented with event logs from plant personnel, the logs should be forwarded to the Superintendent of ECC. |
| Switching Staff and Plant Operators | 1. | When arriving on site contact the Energy Control Centre, identify oneself, location and any unsafe conditions that would require immediate attention. Await instructions from ECC. The priority for communications is Operational Voice, Newfoundland Telephone, then VHF. |
| | 2. | ECC staff will contact station personnel hourly to obtain operating data key to that station, (i.e. generation levels, transmission lines flows, bus voltages, delivery point voltages etc. which ever are appropriate). Station personnel shall maintain an hourly log of information and record the time and nature of any abnormal system event, (i.e. time of alarm/outage and activating device/relay), and contact ECC when such an event occurs. |

| PREPARED BY: | APPROVED/CHECKED BY: | ISSUED DATE: 2003-07-15 |
|---|---|---|
| C. Kirby | | REV. DATE: |

HYDRO
THE POWER OF COMMITMENT

**NEWFOUNDLAND AND LABRADOR HYDRO - OPERATIONS**
**STANDARD INSTRUCTION**

| TITLE: | Inst. No. 015 |
|---|---|
| CONTINGENCY PLAN FOR LOSS OF THE ENERGY MANAGEMENT SYSTEM FUNCTION | Rev. No. |
| | Page 4 of 4 |

Responsibilities (cont'd.)

| | | |
|---|---|---|
| Switching Staff and Plant Operators | 3. | Staff should retain their event logs and present them to the appropriate on-call supervisor. |
| ECC Superintendent | 1. | Shall arrange for an annual simulation of the plan to ensure its effectiveness. |

| PREPARED BY: | APPROVED/CHECKED BY: | ISSUED DATE: 2003-07-15 |
|---|---|---|
| C. Kirby | | REV. DATE: |

## APPENDIX 4: DIGITAL FAULT RECORDER TRACES

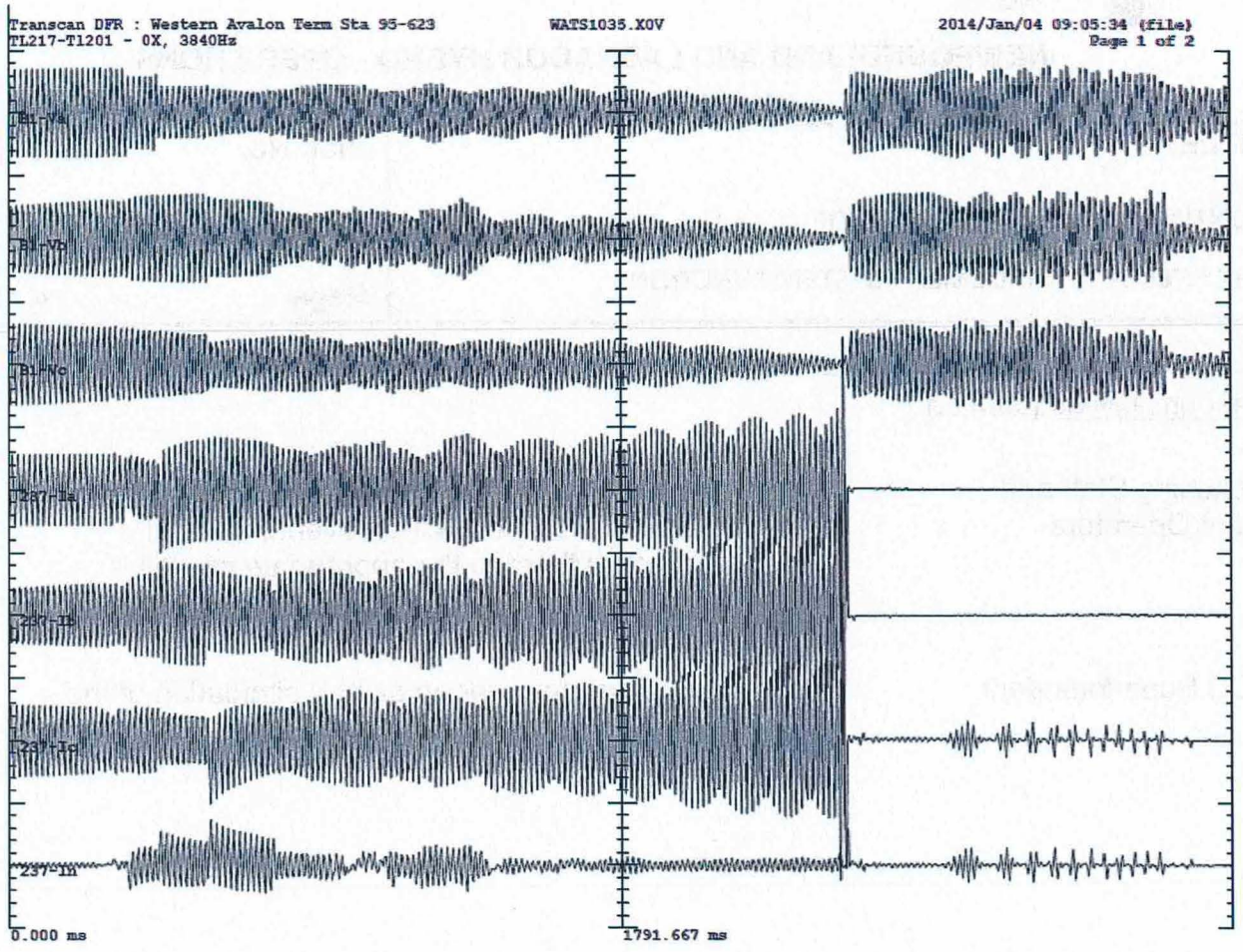


**Figure 1: Loss of Stability of Power System following fault on transformer T1 at Sunnyside**

Traces from Western Avalon station show bus voltages (top 3 traces) rapidly decline and the currents on line TL237 (second set of 3 traces) oscillate and become unstable.

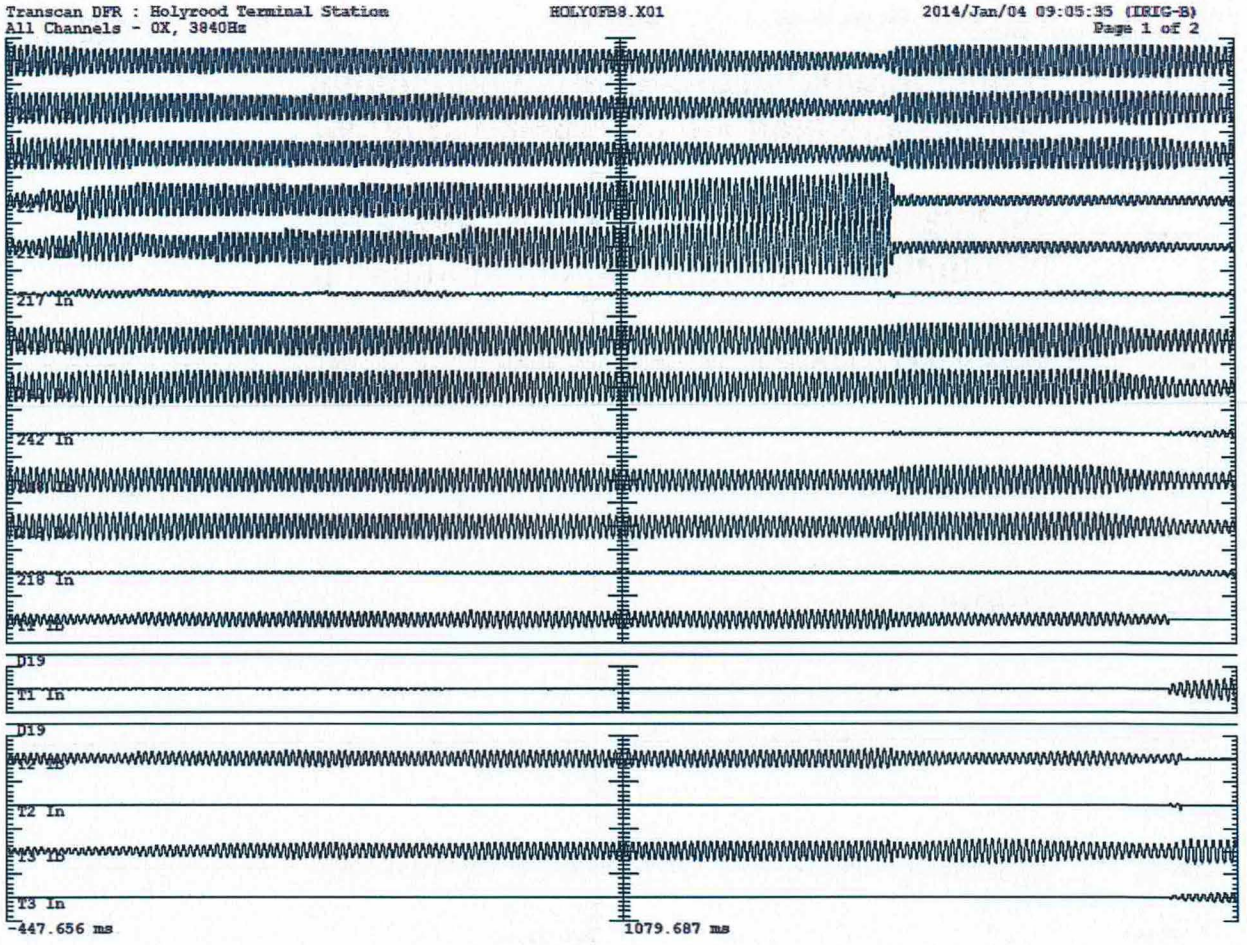


**Figure 2: Holyrood Generator #1 Trip at 9:05:37 Jan. 4, 2014**

Traces from Holyrood generating station show current in B phase and neutral current for each of the three generating unit transformers (bottom 6 traces). Unit #1 shows neutral current increase when the unit trips off while the current in B phase goes to zero. This is as expected because C phase failed to open. Note that when unit #2 trips off both the B phase current and the neutral current goes to zero; unit #3 trips after trace ends as shown above so there is an increase in the B phase current and the neutral current.

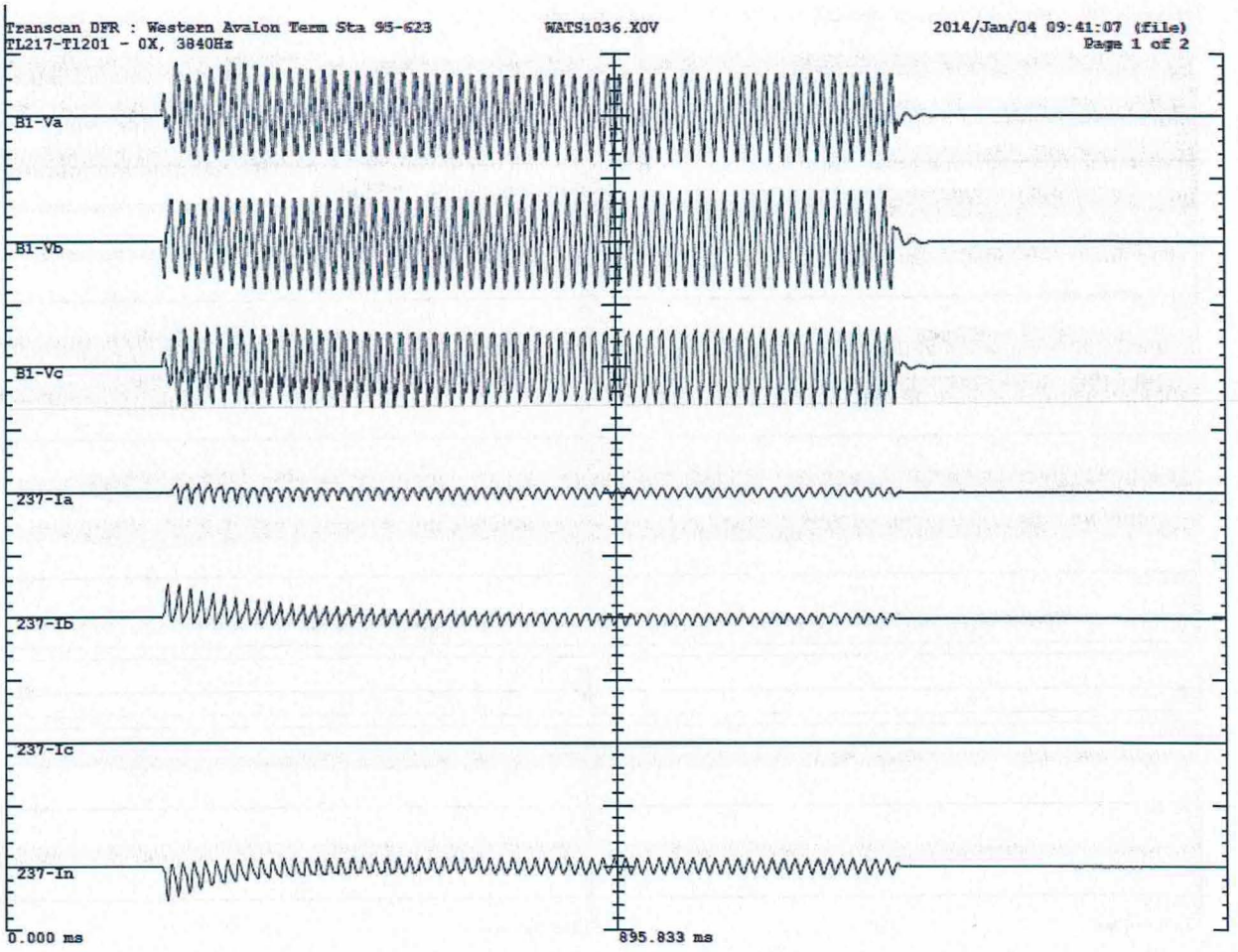


**Figure 3: Circuit Breaker B1L37 at Western Avalon closes on two phases only 9:41 Jan. 4, 2014**

Traces from Western Avalon for TL237 (bottom 4 traces) show current in 2 phases only plus neutral current when breaker B1L37 is closed. Condition lasts for approximately 1.2 seconds.

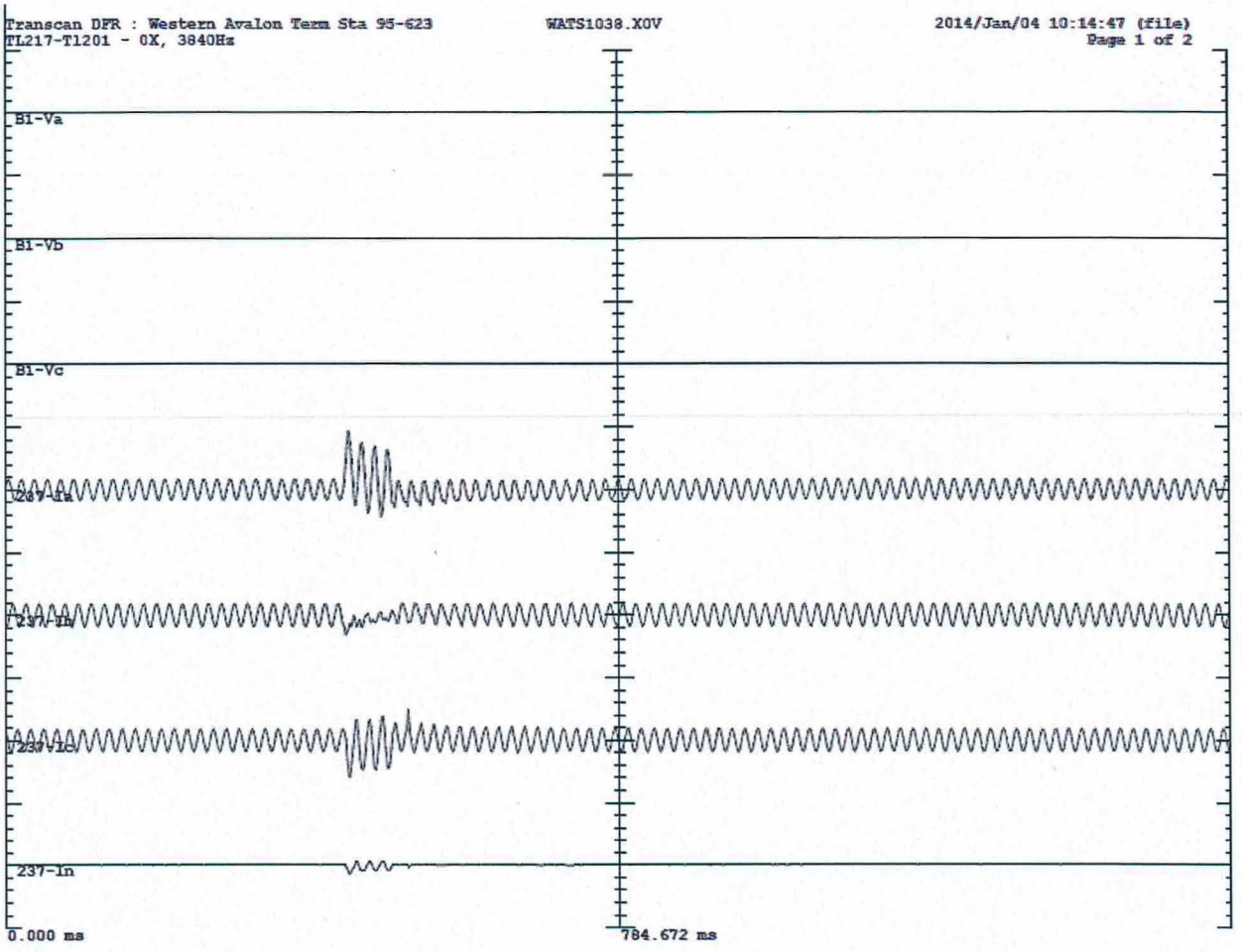


**Figure 4: Holyrood generator transformer T1 is energized 10:14:43 Jan. 4, 2014**

This trace from Western Avalon shows a disturbance that lasts for about 4 cycles when the generating unit #1 transformer at Holyrood is energized because one phase of the breaker B1L37 at Holyrood is still closed.