NLH 2013 Amended General Rate Application
Information - 40
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NEWFOUNDLAND AND LABRADOR HYDRO

Root Cause Investigation of System Disturbances
On January 4 and 5, 2014
Sunnyside Transformer T1 Fire,
Western Avalon Transformer T5 Tap Changer Failure,
Sunnyside Terminal Station Restoration Failure, and
Holyrood Breaker B1L17 Failure

March 2014

newfoundland labrador hydro
a nalcor energy company

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EXECUTIVE SUMMARY

TapRooT® is a highly structured investigative process designed to focus on the identification of causal factors and specific problems of clearly specified events. By its nature, the purpose of the TapRooT® analysis is to determine the root cause and identify corrective actions directly related to the problem being investigated. In the course of an investigation, TapRoot® often identifies additional areas for consideration that are not directly related to the cause of the problem. TapRoot® is recognized as industry best practices for investigative processes.

Newfoundland and Labrador Hydro (Hydro) has completed a comprehensive review of the events surrounding the supply disruptions on the Island Interconnected System during January 2-8, 2014. The review included investigation of the rotating outages that occurred between January 2-8, 2014[1] and the transmission/terminal station equipment failures that occurred on January 4 and 5, 2014. The focus for this report documents the root cause investigation into four incidents that contributed to the outages, which occurred on January 4 and 5, 2014. These incidents are the Sunnyside Transformer T1 Fire, Western Avalon Transformer T5 Tap Changer Failure, Sunnyside Terminal Station Restoration Failure, and Holyrood Breaker B1L17 Failure. The purpose of this investigation is to identify recommendations and corrective actions that will reduce the likelihood of a reoccurrence of these incidents, based on root causes or most probable root causes where a clear specific root cause was not attainable.

This portion of the review is prepared by an internal team of Nalcor Energy employees. This report utilizes data collected from field inspections of the four incidents by the investigation team, analysis performed by Nalcor staff, equipment inspections by original equipment manufacturers (OEM) such as ABB, Reinhausen and CG Global; external analysis of protection systems performance by Henville Consulting Inc.; and external validation of the TapRooT® process by consultant Brian Tink.

[1] Rotating outages occurred on January 2, 3, 5 and 8, 2014.

On January 4, 2014 an internal fault occurred on Sunnyside T1 transformer, which due to a breaker failing to open, resulted in a fire on the transformer and wide-spread customer outages. The fault on Sunnyside T1 in combination with other factors such as cold weather conditions, power system loading, equipment failures, and protection modifications contributed to the Sunnyside Bus Restoration Failures and Holyrood Breaker B1L17 Breaker Failure. While the cause has not yet been determined on Western Avalon T5 Transformer, there appears to be a connection between this transformer's tap changer failure, and the system disturbance caused by Sunnyside T1 failure.

The key findings of the TapRooT® investigation with recommendations and corrective actions are presented in this report.

- TA1: Conduct a formal risk/reward review on expanding the current program for the installation of on line continuous gas monitor on generator step up (GSU) transformers to include other transformers installed on the Hydro System.
- TA2: When system conditions allow, conduct an in-depth analysis of the DC system for Breaker B1L03 to determine if any high-impedance paths exist which may affect its operation.
- TA3: Consider conducting a formal risk/reward review of system design to determine whether 230kV transformers require their own 230kV breaker in all terminal stations, as this would reduce complexity and increase reliability.
- TA4: Consider conducting a formal risk/reward review of the 230kV breaker failure protection philosophy for transformers at stations that currently do not have breaker fail protection.
- TA5: Consider implementing transformer protection initiation of breaker fail protection at all stations that have breaker fail protection.
- TA6: Conduct an analysis of the Island Interconnected System to determine if a transient overvoltage, due to system harmonics, was a cause of the Western Avalon T5 Failure.

TA7: Review application of lockout protection on all transformers to ensure that the proper isolation of the transformer automatically blocks the initiation of 138kV breaker failure protection on the associated breakers.

TA8: Consider having additional resources (P&C technologists and engineers) available on site to support the restoration of power in emergency situations.

TA9: Review breaker failure protection applications of all transformer protection designs at stations using the same breaker failure relay (Schweitzer Engineering Laboratories type SEL-501). This review would determine whether the breaker failure protection re-trip function (if applied in the SEL-501) is being used in a similar non-conventional application to that at Sunnyside. If it is, modify the scheme to prevent undesirable or unexpected response from the non-conventional application.

TA10: Revise work method SWM-000318 to include:

- Correct procedure to seal the breaker air receiver tanks to prevent moisture ingress while the interrupters are removed; and
- Visual inspection of the breaker air receiver tanks prior to the reinstallation of the interrupters.

TA11: Conduct a risk/reward review of the current practice for the application of the Room Temperature Vulcanizing (RTV) coating with consideration given to the following alternatives which would reduce the amount of time the interrupters are removed from the main receiver tank:

- Materials that can be applied without having to disassemble the breaker;
- Installing spare interrupters that have the RTV coating applied; and
- Applying RTV in a nearer controlled environment (Holyrood has some facilities).

TA12: Conduct a review of the Transmission and Rural Operations (TRO) Central Annual Work Plan to identify opportunities for improvement as it relates to the prioritization and timely execution of work. The review should include, but not be limited to, factors affecting the priority and execution of work, such as the availability of resources (staff, tools and equipment) to effectively execute the annual work plan.

1 INTRODUCTION

This focus area report is part of an internal report on the Hydro power disruptions on January 4 and 5, 2014. The main report references this focus area with respect to root causes and corrective actions around four incidents. These incidents are the Sunnyside Transformer T1 Fire, Western Avalon Transformer T5 Tap Changer Failure, Sunnyside Terminal Station Restoration Failure and Holyrood Breaker B1L17 Failure.

Hydro employs several processes for the systematic investigation of the fixable root causes of quality, safety, production, or maintenance problems. For complex events, the TapRooT® System combines both inductive and deductive techniques for investigations, which can be used both reactively – to create corrective actions that prevent a recurrence – or proactively – to improve performance.

TapRooT® is a highly structured investigative process designed to focus on the identification of causal factors and specific problems of clearly specified events. By its nature, the purpose of the TapRooT® analysis is to determine the root cause and identify corrective actions directly related to the problem being investigated. In the course of an investigation, TapRoot® often identifies additional areas for consideration that are not directly related to the cause of the problem. TapRoot® is recognized as industry best practices for investigative processes.

From an investigation and TapRooT® analysis, the system disturbances of January 4 and 5, 2014, can be attributed to a combination of cold weather, power system loading, equipment failures, and protection modifications.

At 09:05 on January 4, 2014 a fault occurred on Sunnyside T1 transformer, which was the initiating event. Subsequent events were the failure of Western Avalon T5 Transformer Tap Changer, Sunnyside Bus Restoration Failure and Holyrood Breaker B1L17 failing, all of which are interrelated incidents which contributed to causing power outages primarily to the Avalon

Peninsula. Figure 1 below is a pictorial representation of the four incidents and their interdependencies.

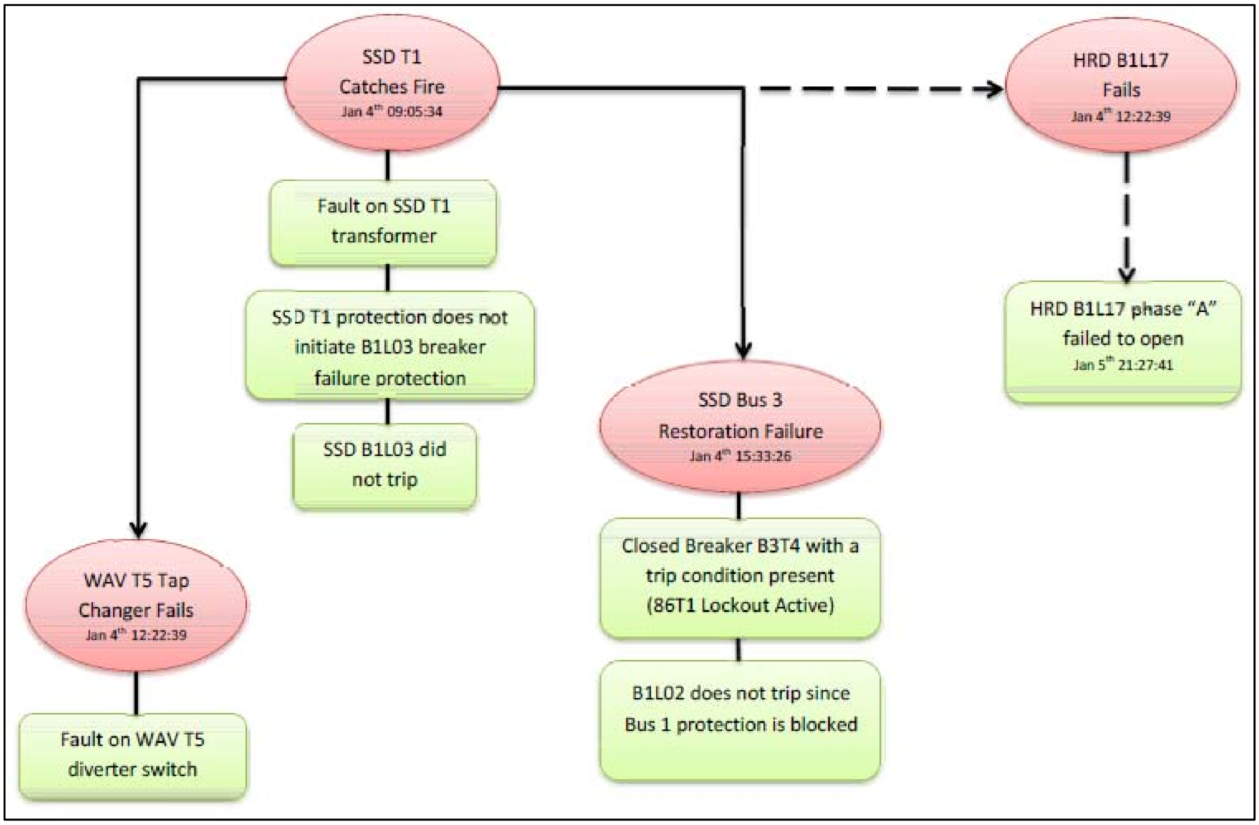

Figure 1 – Incident Interdependences

An internal fault occurred on Sunnyside T1 transformer and if everything operated as the design intended, it would have been taken offline and isolated from the grid for further investigation with a short localized disruption of power. However, breaker B1L03 failed to operate correctly, which caused the fault to remain longer and led to the T1 transformer fire, as well as triggering further system disturbances.

While the investigation has not been completed on Western Avalon T5 Transformer, there appears to be a connection between this transformer's tap changer failure and the system disturbance caused by Sunnyside T1 failure.

In response to the disturbance caused by Sunnyside T1 and breaker B1L03 failure, all three Holyrood generating units tripped offline. An analysis of the fault traces have shown that breaker B1L17, which is one of two breakers connecting generating Unit G1 at Holyrood to the grid, failed at this time.

During the restoration effort of Sunnyside Station, there were difficulties in isolating T1 Transformer, which led to further delays in getting power restored to customers.

Subsequent sections of this report provide a more detailed analysis of the full sequence of events; determining the causal factors, root causes, and provides corrective actions.

2 REVIEW PROCESS

Events within the Hydro system which result in widespread customer outages and/or significant equipment damage are subject to a comprehensive review and investigation. Hydro utilizes its *Standard for Root Cause and Repeat Failure Analysis* (a TapRooT® Investigation) for these comprehensive investigations. As such, the management team selected the four events of January 4 and 5, 2014 to be investigated utilizing the TapRooT® process due to the impact on customers and substantial damage to equipment.

To carry out the investigation it was deemed essential to assemble a qualified team to assist with performing a thorough analysis of the events. The team follows a standard process for conducting root cause investigations. The team utilized both internal and external resources in determining the root causes of the incidents. The team membership had a previous working knowledge of the TapRooT® process itself, as well the support of a TapRooT® Process Matter Expert to help guide the investigation from an external perspective. Independent utility industry experts, with an in-depth knowledge of the operations of power systems, including experience with power system disturbances, were involved in the overall investigation. Subject matter experts were utilized to help with system and data analysis, as well as review protection system operation and design. OEMs and their field-service technicians assisted with equipment design reviews, as well as disassembly, and forensic field investigations. All external members of the team provided independent reports, which supplement this investigation.

2.1 Team Composition

The team composition consisted of Hydro resources, process experts, subject matter experts and OEM technical experts.

2.2 Hydro Resources

Dave Hicks, Manager of Electrical Engineering for Project Execution and Technical Services (PETS), with 24 years experience with Hydro, mostly with high voltage terminal station equipment specification and design. Dave has past experience with Terminals Station Review Committee and is current chair of Transformers and Switchyard Technical Council.

Perry Taylor, Senior Electrical Engineer, with more than 13 years experience covering system analysis, high voltage equipment specification and design review, as well as experience with operation and maintenance of high voltage switchyard of Churchill Falls and the underground power house. Perry is a member of the Transformers and Switchyard Technical Council; a former member of the TapRooT® Technical Council; has been trained in TapRooT® process and has conducted multiple TapRooT® investigations of equipment failures throughout Nalcor Energy.

Blaine Piercey, Senior Electrical/Mechanical Supervisor of Terminal Stations Maintenance crews for TRO Central with more than 29 years experience with Hydro working primarily with terminal station equipment operations and maintenance, including high voltage transformers, circuit breaker overhauls, and air support systems.

Brad Eddy, Electrical Equipment Engineer, with more than five years experience dealing primarily with Hydro's power transformers refurbishment and replacement programs. Brad has been trained in TapRooT® process and has conducted multiple TapRooT® investigations of equipment failures throughout Nalcor Energy.

2.3 Process Experts

Brian Tink, TapRooT® Process Matter Expert and former member of Ontario Power Generation, with 30 years working with both generation and transmission assets.

2.4 Subject Matter Experts

Brian Scott of AMEC, subject matter expert with more than 30 years experience with operation and maintenance with New Brunswick Power's system including power system analysis and power system disturbances events. He was director of reliability and operations for New Brunswick Power.

Blair Seckington of AMEC, subject matter expert with more than 30 years experience with operation and maintenance of power systems including power system disturbances, with Ontario Power Generation. He was a condition assessment and reliability expert with Ontario Power Generation.

Charlie Henville, of Henville Consulting Inc., a Senior Protection and Control Design Review Engineer and former BC Hydro protection and control engineer with more than 44 years of professional engineering experience.

2.5 OEM Technical Experts

ABB: Mustaf Lahloub, transformer field service engineer and forensics expert.
ABB: Scott Morris, field service technician for air blast circuit.
CG Power: Chris Sarrasin, field service technician for power transformers.
Reinhaussen: Markus Zwicknagel, field service technician for tap changers.

2.6 Process Followed

The processes followed by the team are shown in Figure 2 – Process Flow Diagram.

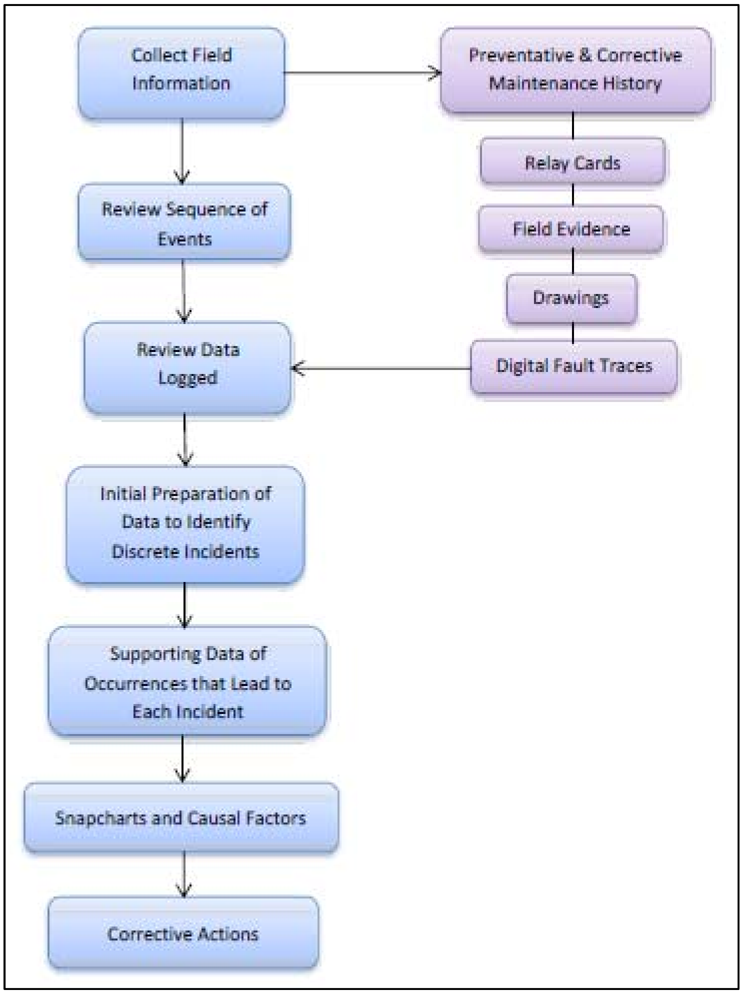

Figure 2 - Process Flow Diagram

In addition to the work performed by external consultants and OEMs, the internal team made an extensive effort, with the help of numerous colleagues throughout the system, to collect all the vital information relevant to the events of January 4 and 5, 2014. Such information included sequence of events records, fault traces, drawings, preventative maintenance and corrective maintenance records, as well as discussions with participants in the incidents. All relevant information was shared with external consultants and OEMs to aid their detailed analysis of failed equipment. Using the collected information, as part of the TapRooT® process, a timeline of events leading up to the incident was created on a SnapCharT®. Conditions to support these events were added to the SnapCharT® and causal factors were identified. These causal factors were then analyzed to identify root causes for the incident. Recommended corrective actions were then developed based on the root causes.

2.7 Schedule

While the root cause investigation officially started on January 7, 2014, with the establishment of the scope of the investigation and assembling the team, internal members of the team were at the various sites on January 5, 2014 to help ensure the preservation of evidence. Site visits to the Sunnyside, Western Avalon and Holyrood Terminal Stations were completed by various members of the investigation team throughout the subsequent investigation.

Brian Tink was consulted and visited the site for the first time on January 13, 2014 to help facilitate the TapRooT® process.

Consultation began immediately with ABB (OEM for Sunnyside T1) on performing an internal inspection to help determine the cause for the failure of Sunnyside T1, as well to begin the design review. A design review was done of Sunnyside T1 and sister units Sunnyside T4, Stony Brook T1 and T2. Mustafa Lahloub began his investigation into the failure and was onsite in Sunnyside immediately following the incident. He performed an internal inspection on January 21, 2014 as soon as the oil test results were complete and the transformer had been drained of its oil. A preliminary report of their findings has been submitted for review, which provides a detailed synopsis of the cause of failure. Their report supplements this report and is attached in Appendix 7 – External Reports.

ABB (OEM for Holyrood breaker B1L17) was consulted, and on January 16, 2014 Scott Morris, a field service representative, came to site to inspect Holyrood breaker B1L17. Mr. Morris also came back to Holyrood on January 27 to oversee the rebuild of breaker B1L17. On February 3, 2014 he travelled to Bishop's Falls to oversee the teardown inspection of the components removed from breaker B1L03 at Sunnyside. Mr. Morris provided two separate reports of his findings, one for each investigation. Both reports supplement this report.

Knowing the incidents of January 4 and 5, 2014 would have a significant impact on the overall power system, and for which the fault recorders would have captured essential data, Charlie Henville was immediately engaged to help with the analysis of this data and to conduct a review of the performance and design of the protection systems. This would help with early identification of any issues that may have contributed to the incidents. Mr. Henville's report supplements this report.

On January 11, 2014, a field service representative from Reinhausen (tap changer OEM for Western Avalon T5 tap changer) came to Western Avalon to inspect the diverter switch, associated with the tap changer. While this investigation is not complete, Reinhausen has provided a preliminary report of their findings. On February 21, 2014, Markus Zwicknagel from Reinhausen and Chris Sarrasin from CG Global (OEM for Western Avalon T5 transformer) were on site to conduct an internal inspection of the Western Avalon transformer T5 tap changer and transformer, to access damage and provide a report as to the cause of the failure.

The team has since met with representatives of the Liberty Consulting Group (Liberty) as part of the Public Utilities Board (PUB) review, during which they reviewed our process and the investigation. While the root cause has been clearly determined for some incidents, there are still some unknowns, due in part to insufficient information to complete a thorough analysis. Further comments from Liberty will be explored and will contribute to the final analysis.

In total, the team has been engaged in the process almost full-time, apart from a few exceptions and competing priorities, for a total of eight weeks.

3 BACKGROUND

The TapRooT® root cause analysis method was utilized by the team for the root cause analysis of the above incidents. Hydro has a Root Cause and Repeat Failure Analysis (RCRFA) Technical Council whose mandate is to ensure that major system disturbances and/or equipment failures are thoroughly investigated by an appropriate team to identify root causes and corrective actions. The RCRFA Technical Council has a Standard for Root Cause and Repeat Failure Analysis, and this standard was followed for this investigation.

The TapRooT® method involves the following general steps:

1. Identification of the incident(s);
2. Information collection (documented on a SnapCharT®);
3. Identification of immediate causes (causal factors in TapRooT® terminology);
4. Identification of all root causes associated with each causal factor; and
5. Creation of corrective actions for each root cause.

Provided that the investigation obtains sufficient information, each causal factor results in one or more root causes, and each root cause results in one or more corrective actions. The purpose of the corrective actions is to prevent the incident from reoccurring.

4 SEQUENCE OF EVENTS: RELEVANT TIME FRAME OF EQUIPMENT FAILURE INCIDENTS

4.1 Incident 1: Sunnyside Transformer T1 Catches Fire

At 09:05:34 on January 4, 2014, a fault occurred on the Sunnyside T1 transformer. The T1 protection operated correctly and initiated a trip to five breakers to clear the fault. Only four of the five circuit breakers tripped within 186 milliseconds to clear the fault. The breaker B1L03 failed to open and the fault remained on Sunnyside T1 transformer. Since the fault was not cleared quickly, it resulted in additional damage and the subsequent fire of the Sunnyside T1 transformer. The fault lasted for two seconds until line protection on TL203 operated and cleared the fault. This resulted in a widespread (187,500 customers) power interruption across the system. Figure 3 below, is a portion of the single line diagram of the Sunnyside Terminal Station showing the equipment involved in the incident. The complete single line for Sunnyside Terminal Station is attached in Appendix 2 – Drawings.

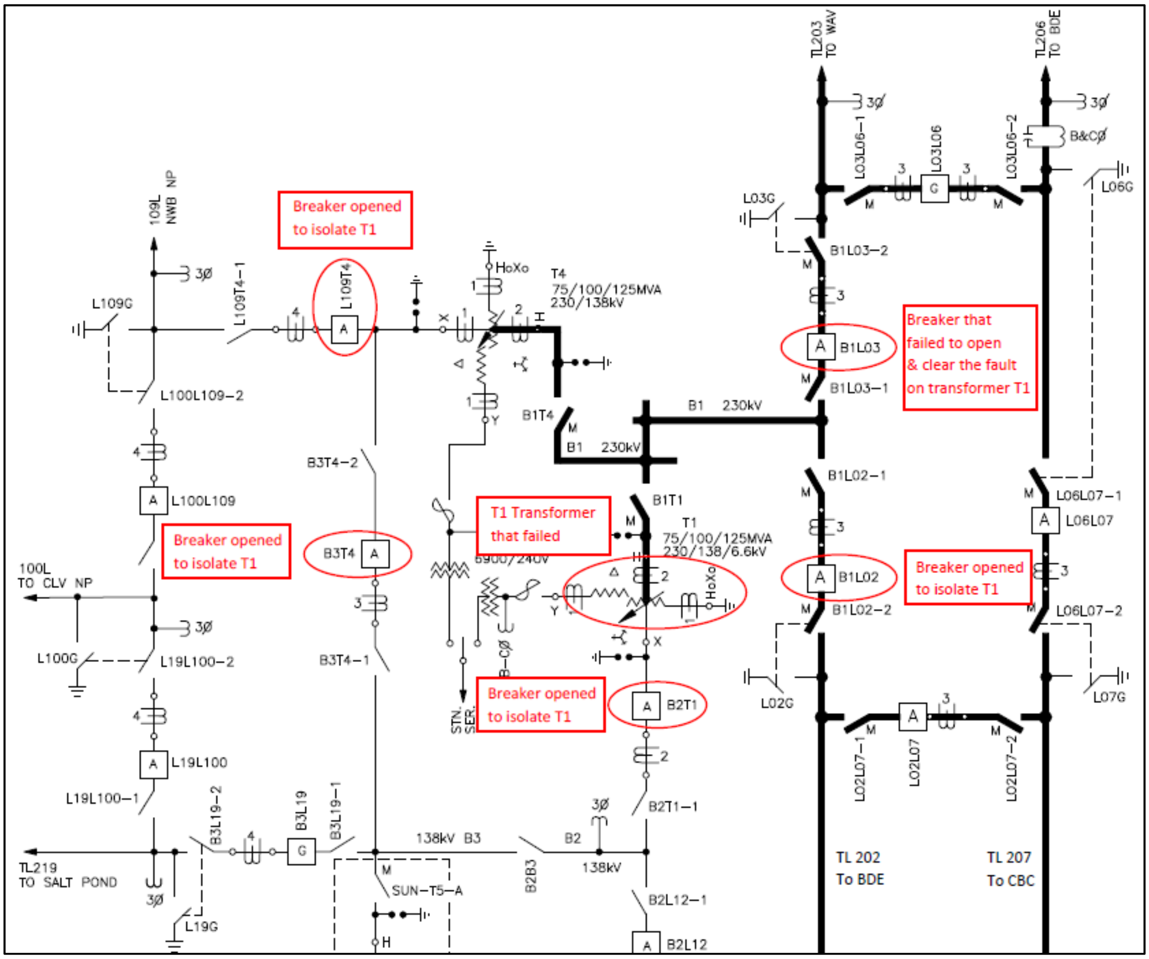

Figure 3 – Sunnyside Terminal Station at 09:05:34

4.2 Incident 2: Western Avalon Transformer T5 Tap Changer Failure

At 12:22:39 on January 4, 2014, Western Avalon T5 tap changer failure resulted in a fault on the transformer. The T5 transformer protection operated correctly and initiated a trip of one breaker and one load break switch, both of which operated correctly and cleared the fault. This incident resulted in an extended outage for some customers, as the T5 Transformer trip had to be investigated before restoration of the station. Figure 4 below is a portion of the single line for the Western Avalon Terminal Station showing the equipment involved in the incident. The complete single line for Western Avalon Terminal Station is attached in Appendix 2 – Drawings.

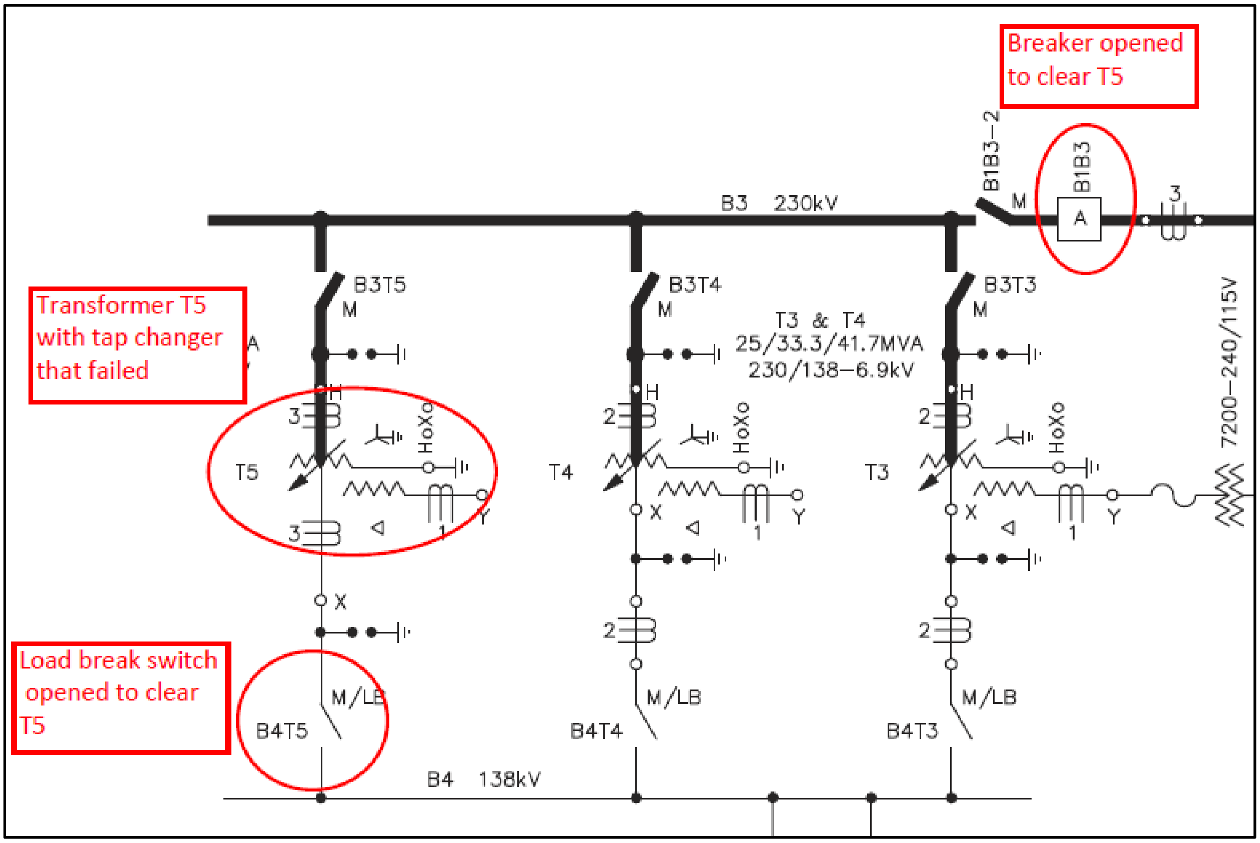

Figure 4 – Western Avalon Terminal Station at 12:22:39

4.3 Incident 3: Sunnyside Terminal Station Restoration Failure

At 12:58:30 on January 4, 2014, an unsuccessful attempt was made to restore power to customers. Temporary protection modifications were made following that unsuccessful attempt to isolate the suspected area of damage due to the fire. At 15:33:26, a second attempt was made to restore power to customers supplied from the Sunnyside Terminal Station. These temporary modifications had an adverse effect on the protection and resulted in a power interruption (165,000 customers) across the system. The details of this event are complex and involve inherent design issues that are further explained in the "Protection Systems Impacts on 4 January 2014 Supply Disruptions - External Protection Review" by Mr. Henville. Figure 5 below is a portion of the single line of the Sunnyside Terminal Station showing the equipment involved in the incident. The complete single line drawing for Sunnyside Terminal Station is attached in Appendix 2 – Drawings.

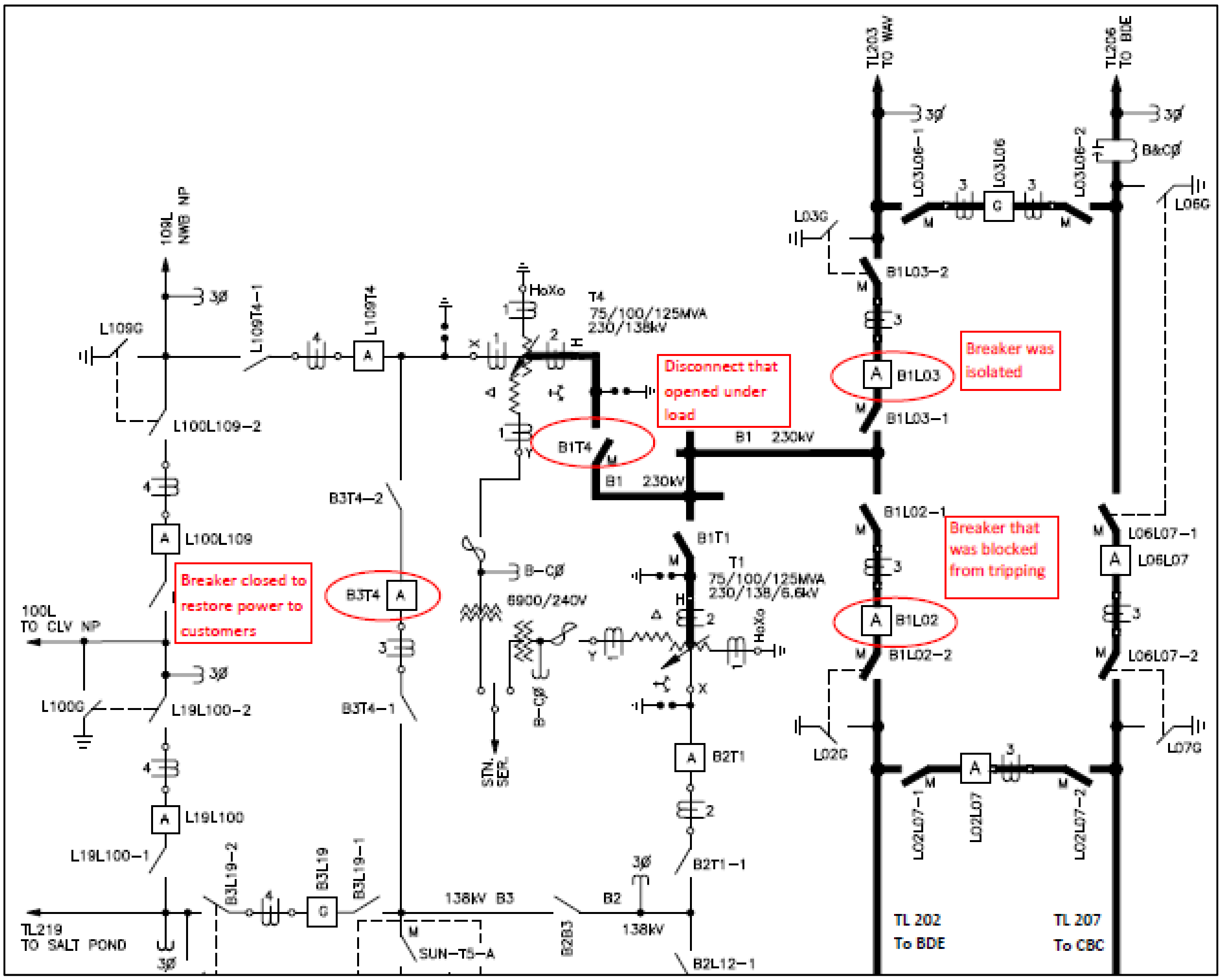

Figure 5 – Sunnyside Terminal Station

4.4 Incident 4: Holyrood Breaker B1L17 failure

At 21:27:34 on January 5, 2014, the Holyrood Terminal Station 230kV disconnect B1T1 was closed in preparation to bring Holyrood Generating Unit G1 online. Closing B1T1 disconnect caused a significant system imbalance, as one phase of breaker B1L17 had failed to open despite breaker indications showing it as being open on all three phases. The protection for TL217 and Bus B1 operated correctly to clear the imbalance. However, as a result of the neutral overcurrent on the system that resulted from one phase of B1L17 failing to open and the heavy loading on the transmission system at the time, a widespread (110,000) customer interruption was initiated by this event. Figure 6 below is a portion of the single line for Holyrood Terminal Station showing the equipment involved in the incident. The complete single line for Sunnyside Terminal Station is attached in Appendix 2 – Drawings.

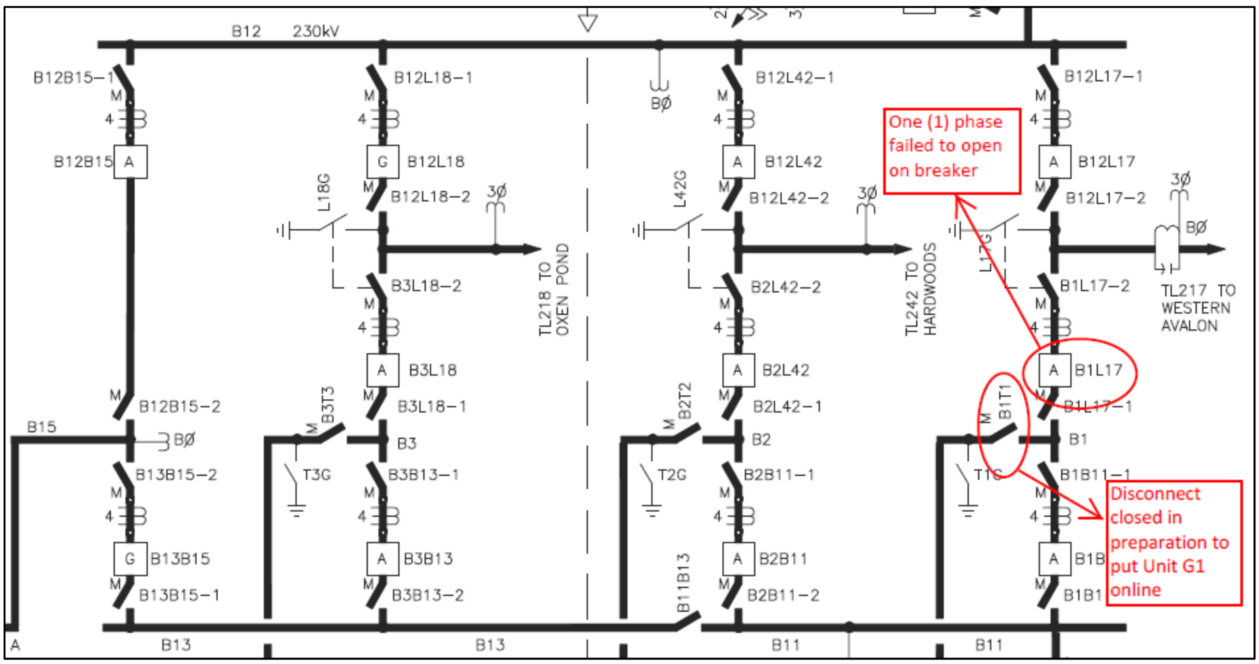

Figure 6 – Holyrood Terminal Station at 21:27:39

5 KEY FINDINGS AND RECOMMENDATIONS

As stated earlier in this report, the TapRooT® method was utilized by the investigation team for the root cause analysis of the four incidents that occurred on January 4 and 5, 2014.

The analysis of the four incidents resulted in a total of eight immediate causes (causal factors in TapRooT® terminology), eight root causes, and 12 recommendations. Below is the breakdown by incident:

- Sunnyside T1 Fire: three causal factors, two root causes and five recommendations;
- Western Avalon T5 Tap Changer Failure: one causal factor, zero root causes and one recommendation (Investigation not complete);
- Sunnyside Terminal Station Restoration Failure: two causal factors, three root causes and three recommendations; and
- Holyrood Breaker B1L17 Failure: one causal factor, three root causes and three recommendations.

5.1 Incident 1: Sunnyside Transformer T1 Catches Fire

Sunnyside T1 transformer failed due to a bushing failure that initiated inside the transformer. As a result of breaker B1L03 failing to open and no 230kV breaker failure protection associated with T1 transformer fault, the fault was present for an extended period of time and consequently, a fire developed. Figure 7 below is the SnapCharT® of the incident which shows the sequence of events and associated information.

Causal Factor #1: Fault on Transformer T1

The presence of combustible gases in transformer oil is an indication of activity inside the transformer and sudden changes can indicate a problem with the transformer. Early detection of changes in these gases can prevent a catastrophic transformer failure.

Hydro currently performs annual independent laboratory analysis of transformer oil, and plans on installing continuous online gas monitors on existing GSU transformers. In addition, all new transformers being purchased have continuous online gas monitors. Sunnyside T1 had a gas relay, which detects both gas accumulation and gas pressure, but does not have a continuous online gas monitor. Continuous online gas monitors were not available at the time Sunnyside T1 was installed in 1978.

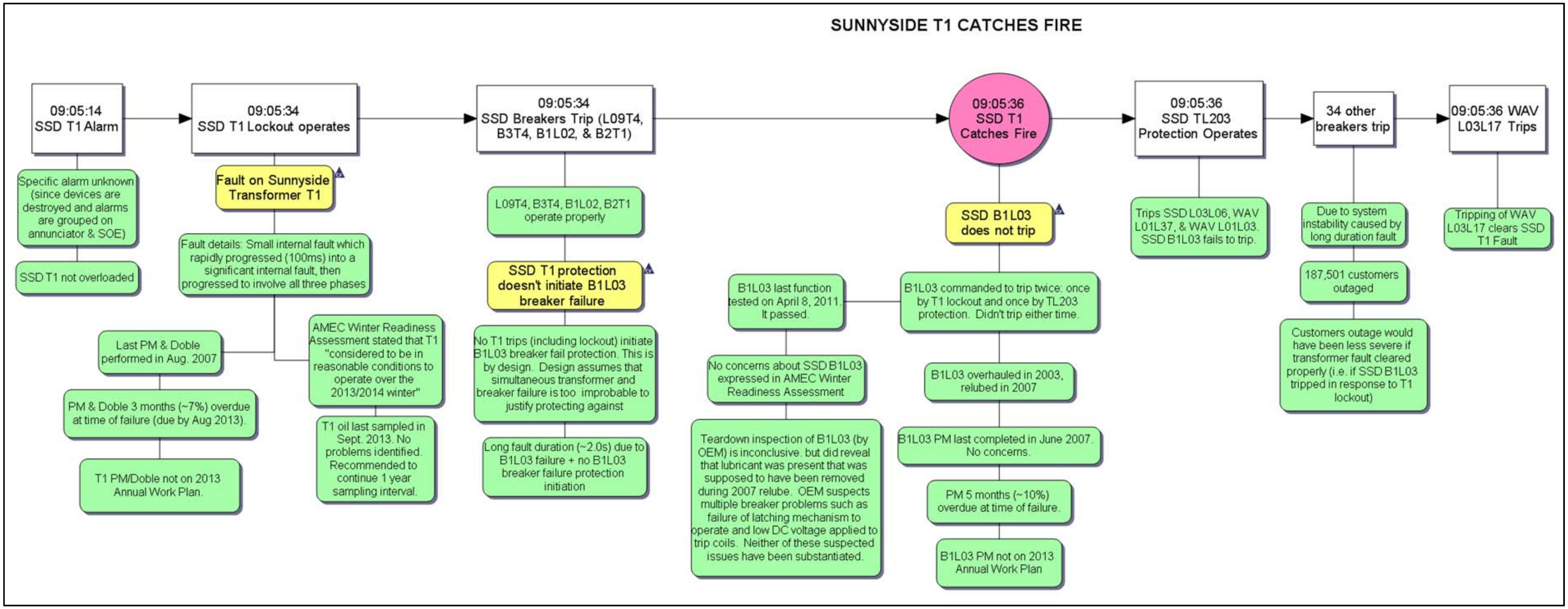

Figure 7 – Sunnyside Transformer T1 Fire SnapCharT®

Root Cause #1: Errors Not Detectable

Errors Not Detectable is a TapRooT® term, which means a problem goes undetected. In this case, it refers to the fact that the generation of combustible gases in the transformer was occurring without being detected by the transformer's gas relay, or any other transformer protection.

Corrective Action #1

Recommendation #	Recommendation
TA1	Conduct a formal risk/reward review on expanding the current program for the installation of online continuous gas monitor on GSU transformers to include other transformers installed on the Hydro system.

Causal Factor #2: SSD B1L03 Does Not Trip

Based on the report by ABB of the inspection of B1L03 the findings are not conclusive and points to issues such as possible high-impedance connections in control circuits, low voltage on DC system, some corrosion of components, low temperatures and/or dirty linkages. In consultation with Hydro's experienced staff and the findings of the ABB report, further testing is required to determine the immediate cause for the B1L03 failure. Breaker B1L03 was overhauled and function tested before it was returned to service. No issues were noted during the standard tests conducted.

Recommendation #	Recommendation
TA2	When system conditions allow, conduct an in-depth analysis of the DC system for breaker B1L03 to determine if any high-impedance paths exist which may affect its operation.

Causal Factor #3: Sunnyside T1 Protection Does Not Initiate B1L03 Breaker Failure Protection

By design, the protection for Sunnyside T1 transformer does not initiate breaker failure protection of the 230kV breakers that protect the transformer. This is also true for Sunnyside T4 transformer. The fault that occurred on T1 on the morning of January 4, 2014 would have cleared faster if the T1 protection initiated breaker B1L03's failure protection and may have cleared it fast enough to prevent the system collapse and transformer from catching fire. The decision not to have this protection initiated was made decades ago during the design of the station. The probability of simultaneous failure of both a transformer and a breaker was considered too low justify this protection.

Root Cause #2: Problem Not Anticipated

During the design of the Sunnyside Terminal Station, the simultaneous failure of a transformer and a 230kV breaker was considered to be too low of a risk to protect against.

Recommendation #	Recommendation
TA3	Consider conducting a formal risk/reward review of system design to determine whether 230kV transformers require their own 230kV breaker in all terminal stations, as this would reduce complexity and increase reliability.
TA4	Consider conducting a formal risk/reward review of the 230kV breaker failure protection philosophy for transformers at stations that currently do not have breaker fail protection.
TA5	Consider implementing transformer protection initiation of breaker fail protection at all stations that have breaker fail protection.

5.2 Incident 2: Western Avalon Transformer T5 Tap Changer Failure

A preliminary analysis of a phase-to-phase fault across the diverter switch of Western Avalon T5 tap changer, suggests a breakdown of insulating materials and/or abnormally high system voltage. Further analysis is required to determine the cause of the fault. Internal inspection of the transformer suggests that it has sustained no damage other than to the tap changer, but further testing is required. Figure 8 below is the SnapCharT® of the incident which shows the sequence of events and associated information.

Causal Factor #4: Fault on Western Avalon T5 Diverter Switch

To date, the root cause for the diverter switch failure has not been determined. From the equipment inspection and subsequent report provided by Reinhausen's field representative, it is their assessment that the failure of the diverter switch was due to a system overvoltage or break down of the insulating oil for the diverter switch. Due to the failure of the hard drive at the Western Avalon Terminal Station, just prior to the incident on January 4, 2014 digital fault traces are not available to determine if a system over-voltage was present. To determine if a system over-voltage or disturbance was the cause of the tap changer failure, further investigation is required.

Recommendation #	Recommendation
TA6	Conduct an analysis of the Island Interconnected System to determine if a transient overvoltage due to system harmonics is a cause of the Western Avalon T5 Failure.

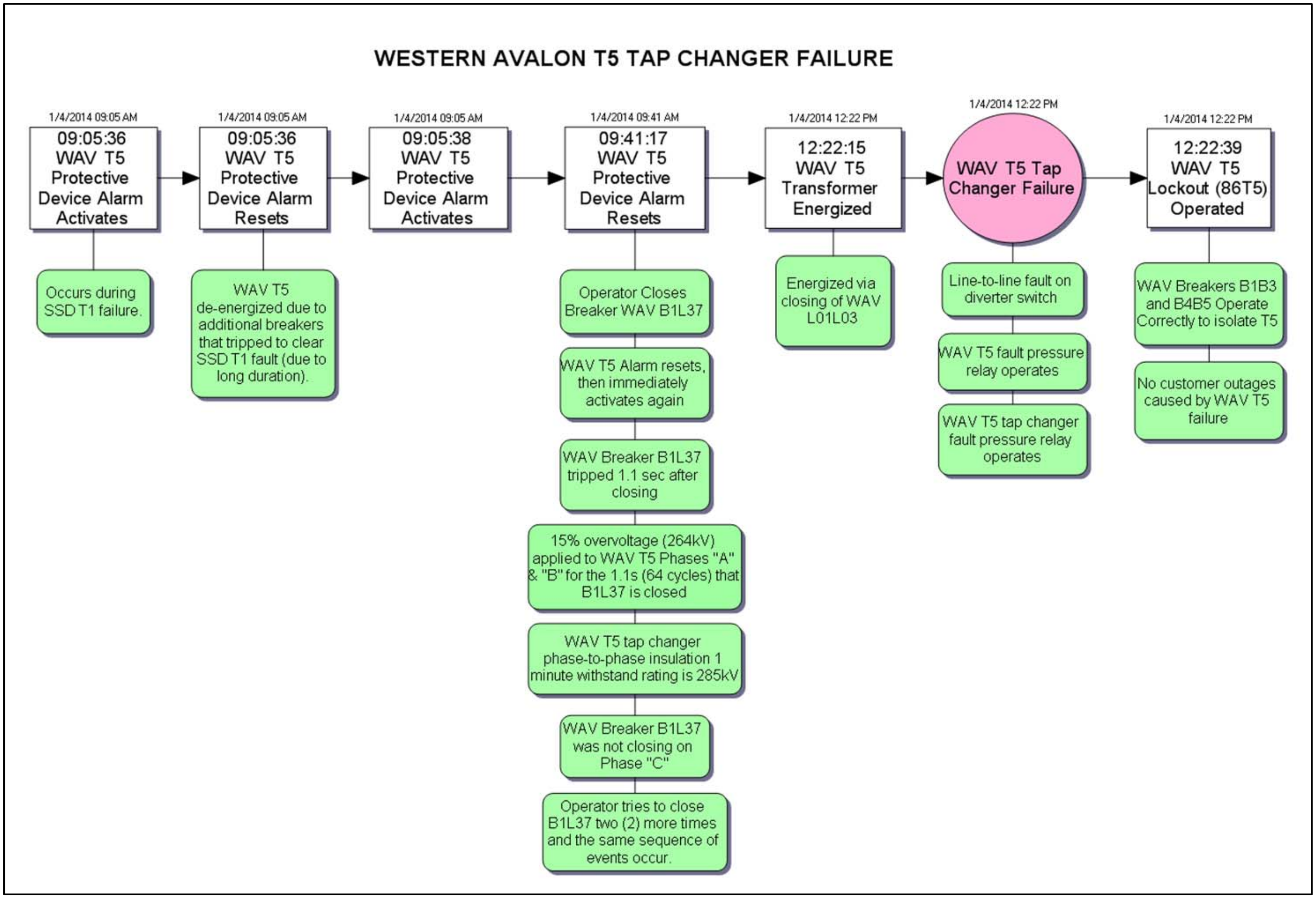

Figure 8 – Western Avalon T5 Tap Changer Failure SnapCharT®

5.3 Incident 3: Sunnyside Terminal Station Restoration Failure

The Sunnyside Terminal Station restoration failure occurred as a result of unnecessary initiation of the breaker failure protection after the fault on T1 had been isolated. The restoration was further impeded by non-conventional application of the B3T4 breaker failure protection and modifications that occurred during the transformer fire event, which protection modification had an adverse effect on the Sunnyside Bus 1 protection. Figure 9 below is the SnapCharT® of the incident which shows the sequence of events and associated information.

Causal Factor #5: Breaker B3T4 Closed with Trip Condition Present

By design, the initiation of B3T4 breaker failure protection was not removed after the isolation of the Sunnyside T1 transformer. When the crews isolated the T1 transformer via the 230kV B1T1 disconnect and 138kV B2T1-1 disconnect, the control circuitry should have automatically blocked the trip commands to any equipment associated with the tripping zone of transformer T1, such as breaker B3T4. However, this is not how the protection scheme is designed and as a result, when B3T4 was closed, its breaker failure protection was initiated and resulted in an extended outage to customers.

Root Cause #3: Problem Not Anticipated

The design of the Sunnyside Terminal Station protection scheme is such that isolation of the T1 transformer would not block the initiation of B3T4 breaker failure.

Recommendation #	Recommendation
TA7	Review application of lockout protection on all transformers to ensure that the proper isolation of the transformer automatically blocks the initiation of 138kV breaker failure protection on the associated breakers.

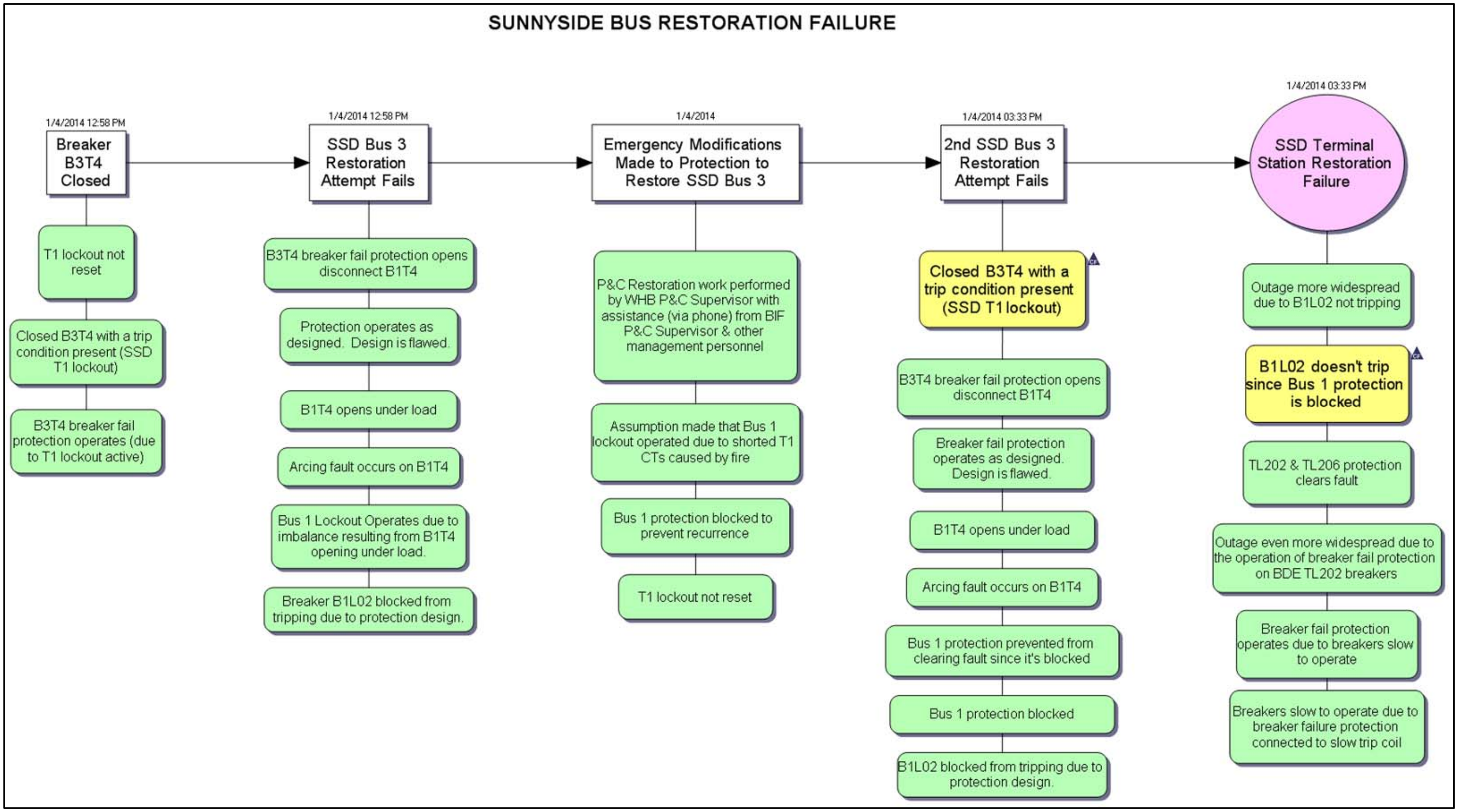

Figure 9 – Sunnyside Terminal Station Restoration Failure SnapCharT®

Causal Factor #6: Sunnyside Breaker B1L02 Does Not Trip Since Bus 1 Protection is Blocked

After the first attempt at 12:58 to restore power to customers supplied from the Sunnyside Terminal Station was unsuccessful, staff reviewed the targets from the protection. They determined that the differential protection operated and initiated the Bus 1 lockout 86B1. In consultation with the Energy Control Center (ECC), it was assumed that the Bus differential protection operated from the Current Transformer (CT) wires on transformer T1, which were likely shorted as a result of the fire. The P&C technician at the site was the supervisor and in consultation with others, emergency modifications were made to the protection to isolate the CT wiring. These emergency modifications had an unforeseeable and undesirable effect on the protection and contributed to a widespread outage at 15:33, when the breaker B3T4 was closed in a second attempt to restore power to customers.

Root Cause #4: Knowledge Based Decision Required

Knowledge Based Decision Required is a TapRooT® term which means that personnel with sufficient knowledge of the work are required to make the decision (or assist with it). In the case of the Sunnyside Terminal Station restoration, the P&C supervisor on site at the time of the fire was relatively unfamiliar with the protection wiring configuration.

Recommendation #	Recommendation
TA8	Consider having additional resources (P&C technologists and engineers) available on site to support the restoration of power in emergency situations.

By design, the non-conventional application of the re-trip function on B3T4 breaker failure protection prevented 230kV breaker B1L02 from opening, when an arcing fault occurred on 230kV disconnect B1T4. When breaker B3T4 was closed, the breaker failure protection was initiated and resulted in the 230kV disconnect B1T4 being opened. Since the re-trip function for breaker B3T4 prevents the tripping of 230kV breaker B1L02, the 230kV disconnect was opening under load and eventually flashed over and resulted in an arcing fault on the B1T4 disconnect.

Additionally, modifications made to Bus 1 protection prevent the breaker B1L02 from opening and clearing the arcing fault. The combination of these two conditions lead to line protection for TL202 and TL206 having to operate to clear the fault and resulted in widespread outages to customers.

Root Cause #5: Problem Not Anticipated

The Sunnyside Terminal Station protection scheme was not designed at the time utilizing conventional applications of the re-trip function with respect to breaker failure applications.

Recommendation #	Recommendation
TA9	Review breaker failure protection applications of all transformer protection designs at stations using the same breaker failure relay (Schweitzer Engineering Laboratories type SEL-501). This review would determine whether the breaker failure protection re-trip function (if applied in the SEL-501) is being used in a similar non-conventional application to that at Sunnyside. If it is, modify the scheme to prevent undesirable or unexpected response from the non-conventional application.

5.4 Incident 4: Holyrood Breaker B1L17 failure

At 21:27 on January 5, 2014 while attempting to connect Holyrood Generating Unit G1 to the grid, the Holyrood 230kV disconnect B1T1 was closed and a fault occurred on the system. It was subsequently determined that breaker B1L17 had previously failed during a trip operation and the failure allowed one of its phases to remain closed while the other two were open. There were no issues with Holyrood Generating Unit G1 that caused this incident. Figure 10 below is the SnapCharT® of the incident which shows the sequence of events and associated information.

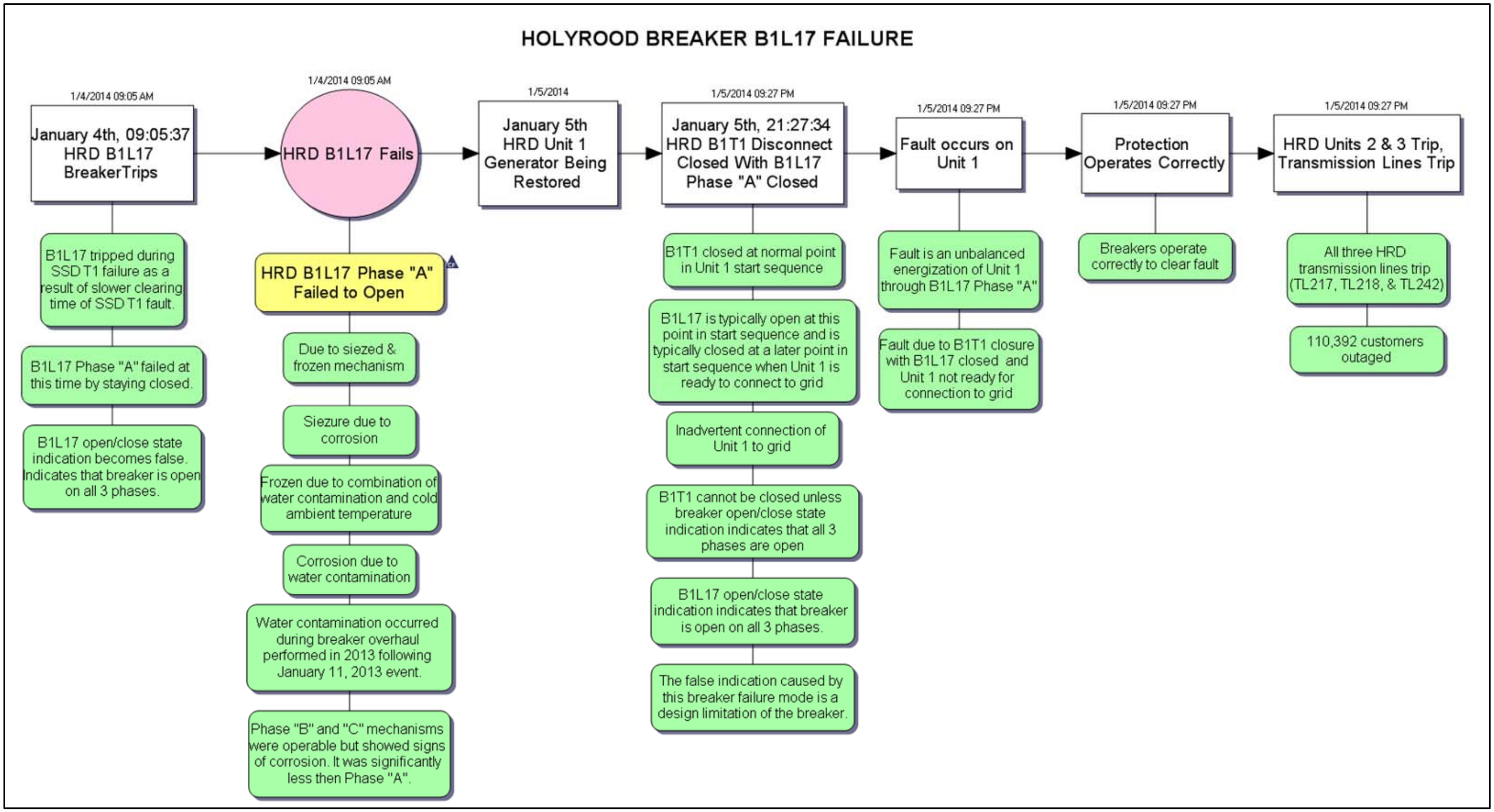

Figure 10 – Holyrood Breaker B1L17 Failure SnapCharT®

Causal Factor #7: Holyrood Breaker B1L17 Phase "A" Failed to Open

Based on an inspection conducted by Hydro maintenance personnel, supported by an expert from the OEM ABB, it was determined that moisture in the main receiver tank for the phase "A" on breaker B1L17 at Holyrood was the immediate cause of its failure to operate correctly on January 5, 2014. Moisture in the main receiver tank lead to corrosion of the main control rod drive on phase "A". This combination of moisture and cold temperatures on January 4, 2014 resulted in the control rod on phase "A" seizing/freezing and failing to open.

In early 2013 breaker B1L17 had work performed on it. This work consisted of the application of RTV coating to its porcelain insulators to reduce the probability of flashover. This work was in response to the flashover that occurred on this breaker on January 11, 2013. The work involved removing the breaker interrupters to apply the RTV coating and protecting the breaker air receiver tanks from environmental contamination while the interrupters are off. For this job, the interrupters were planned to be removed for two weeks, but were actually removed for six weeks due to a reprioritization of work at that time. This increased the exposure time of the breaker without adequate coverage which is the most probable cause of how water got into the receiver tanks of all three phases.

Root Cause #6: Situation Not Covered

The work method SWM-000318 entitled Interrupter Head (Air Blast Circuit Breaker) – Replace, does not contain instructions on how to prevent moisture contamination of the breaker air receiver tanks while the interrupters are removed.

Recommendation #	Recommendation
TA10	Revise work method SWM-000318 to include: i) Correct procedure to seal the breaker air receiver tanks to prevent moisture ingress while the interrupters are removed; and ii) Visual inspection of the breaker air receiver tanks prior to the reinstallation of the interrupters.

Root Cause #7: Work Package Needs Improvement

The current approach to applying the RTV coating is to apply it to the existing interrupters at the Whitbourne maintenance shop. This requires the interrupters and supporting insulator columns being removed from the main receiver tank for the duration of the RTV application, which takes two weeks.

Recommendation #	Recommendation
TA11	Conduct a risk/reward review of the current practice for the application of the RTV coating with consideration given to the following alternatives which would reduce the amount of time the interrupters are removed from the main receiver tank: i) Materials that can be applied without having to disassemble the breaker; ii) Installing spare interrupters that have the RTV coating applied; and iii) Applying RTV in a nearer controlled environment (Holyrood has some facilities).

Root Cause #8: Scheduling Needs Improvement

As a result of maintenance personnel being rescheduled to perform other high-priority work, the reinstallation of the breaker B1L17 interrupters was deferred for four weeks.

Recommendation #	Recommendation
TA12	Conduct a review of the TRO Central Annual Work Plan to identify opportunities for improvement as it relates to the prioritization and timely execution of work. The review should include, but not be limited to, factors affecting the priority and execution of work, such as the availability of resources (staff, tools and equipment), to effectively execute the annual work plan.