Independent Panel Review

BC Hydro's Response to the Underground Cable Fire on July 14th 2008: Fire, Response, and Recovery

FINAL REPORT

Prepared for: **BC Hydro**

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1 Introduction

The authors of this report were retained by BC Hydro to form an expert panel (Panel) to review BC Hydro's investigation into circumstances surrounding and immediately following the July 14th 2008 fire in a manhole in downtown Vancouver.

The activities requested of the Panel by BC Hydro included the following:

1. Perform a reconnaissance of the site and the post incident investigation activities.
2. Attend meetings and presentations covering the full scope of BC Hydro's operational activities with respect to protection against loss of primary feeders through fire and other heat related failures.
3. Independently prepare a report for BC Hydro's Chief Safety, Health and Environment Officer on the findings of the reconnaissance and meetings using established industry practices as the comparison benchmark.

BC Hydro requested that the following five questions be addressed in the report prepared by the Panel:

1. Is the Panel satisfied that the investigation into the failure that caused the fire and explosion has been thorough and adequately confirmatory in its findings?
2. In the experience of the Panel, was there anything unusual about the circumstances that led up to the fire and explosion?
3. Are the design, operation, inspection, maintenance, and replacement regimes for these cables and their constituent parts consistent with industry norms?
4. In general, how commonly do cables and their component parts exhibit this particular failure mode and what is the proportion of failure effects that involve destructive fires and/or explosions?
5. Is the Panel aware of any predictive models and/or direct diagnostic techniques that would provide a reliable means of predicting the initiation of cable failure modes and facilitate timely preventative intervention?

The remainder of this report is organized as follows. Section 2 describes the event with a high level timeline. Section 3 describes the data gathering activities of the Panel. Section 4 presents the Panel's response to the five questions posed by BC Hydro. Section 5 concludes the report and offers additional general thoughts of the Panel.

2 Description of Event

On Monday, July 14, 2008, at 8:54 a.m., a 12-kV circuit failed in a manhole (MH2445) in the 500-block of Richards Street in downtown Vancouver. This circuit has a designation of CSQ12F215. An ensuing underground fire caused 13 additional circuits to fail, representing approximately 2,000 metered services. All of the 14 circuits in the affected manhole were destroyed by the fire. Eleven of these circuits operated at 12 kV and three of these circuits operated at 4 kV.

At 9:03am, approximately 9 minutes after the initial circuit trip, BC Hydro initiated a trouble order which led to the dispatch of a BC Hydro trouble technician at approximately 9:05am.

At 9:08am, approximately 14 minutes after the initial circuit trip, the Vancouver Fire Department arrived on the scene and secured the area. At this time, smoke was coming out of the manhole, indicating a fire. The Vancouver Fire Department took no action to suppress the fire at this time and waited for a BC Hydro representative to arrive.

Sometime between 9:08am and 9:30am, an explosion occurred in the manhole.

About 9:30am, the BC Hydro trouble technician arrives at the manhole location.

At 9:49am, almost an hour after the initial circuit trip, a second circuit trips. Between this time and 10:32am, an additional 10 circuits trip, for a total of 12 tripped circuits.

At 10:42am, BC Hydro manually de-energized the remaining 2 circuits in the manhole.

Until 4:23pm, the Vancouver Fire Department determines that temperatures and air quality in the manhole are not safe. During this time, BC Hydro prepares for the restoration effort by gathering materials, tools, and workers.

At 4:23pm, the Vancouver Fire Department determines that the temperatures and air quality in the manhole are safe to allow BC Hydro crews to begin repair work in the manhole.

Between 4:23pm and 5:00pm, BC Hydro crews conduct a damage assessment of the manhole.

At 5:00pm, BC Hydro crews begin repair and restoration efforts. Fifty per cent of customers are restored within 24 hours of this time, 90% of customers are restored within 48 hours, and all customers are restored within 73 hours. The last customer was restored on July 17th at 5:40pm.

3 Investigation

The Panel first visited BC Hydro on September 4th 2008. This visit consisted primarily of manhole inspections and a site visit to the labs at Powertech. The Panel returned to BC Hydro on September 10th and 11th 2008. September 10th consisted primarily of presentations, meetings, and data collection. This report was generated by the Panel on September 11th. The primary activities by the panel on these dates include the following:

- Reviewed the sequence of events with BC Hydro Engineering and Operations personnel.
- Visited the manhole in question and inspected the repairs. We also had the opportunity to inspect a manhole in the same area to view typical pre-event conditions layouts and materials.
- Visit Powertech Labs and reviewed the interim report with Dr. Kal Abdolall and inspected the remains retrieved from the manhole.
- Discuss BC Hydro's Asset Management Regime with Murray Keith.
- Reviewed BC Hydro's failure statistics and trends in failure reduction with David Chai.
- Reviewed BC Hydro's typical design for a downtown Vancouver feeder.
- Reviewed the typical material and applications for the underground infrastructure with Fred Dennert.
- Reviewed BC Hydro's maintenance regime and the results of the Detailed Condition Assessment project with Dexter Tarampi.
- Gary Walls presented the data detailing the historic loading of that circuit and Cyme Cable Ampacity Program (CAP) studies identifying operating temperature of the cables and components in MH 2445.
- Wayne Martell detailed the operational response to the incident and the subsequent repair efforts.
- Interview with Don Delecourt regarding fire suppression technology and protocols.
- Danielle Melchior reviewed the conclusions of the BC Hydro investigation into this incident.

BC Hydro has been very cooperative and has facilitated our investigation in all aspects. They have responded fully to all data and interview requests, and have not in any way attempted to influence the independence or objectivity of the Panel.

4 Findings

The findings are presented as responses to the five questions posed by BC Hydro to the Panel. Sections 4.1 through 4.5 correspond to these five questions. Each question is repeated, followed by the response by the Panel to the question.

4.1 *Is the Panel satisfied that the investigation into the failure that caused the fire and explosion has been thorough and adequately confirmatory in its findings?*

Yes, the Panel is satisfied that the investigation into the failure that caused the fire has been thorough, and adequately confirmatory in its findings.

When restoration began, BC Hydro crews removed all of the damaged equipment from the manhole, which was later shipped to Powertech for analysis. When removing this damaged equipment, the BC Hydro crews did not label items with respect to associated ducts and circuits. Therefore, Powertech needed to infer the identification of many of the examined components.

While this increased the complexity of the Powertech work, the overall conclusions would have been the same had this information been available. This is because Powertech was in this manhole in January 2008 and had taken photographs that could be referenced to (1) the damaged components and (2) pictures taken of the manhole just prior to repairs.

The main findings of the Powertech report are in the bulleted list below. Panel comments are provided in italics after each main finding:

- All the protective relays were functioning correctly and cleared the faults within the specified limits. *The Panel concurs.*

- There was no evidence of any fire accelerants, such as gas leaks or gasoline spills that may have started the fire. *The Panel concurs.*

- There was no evidence of any overloading on any of the circuits passing through MH2445. *This conclusion is based on DSC (differential scanning calorimetry) measurements. Two samples did not show a maximum temperature. This could have resulted from the insulation experiencing temperatures above 110 ºC, making the test for these two samples inconclusive. However, peak demand readings and cable ampacity calculations support the conclusion that these circuits are not overloaded.*

- Only two splices have suffered electrical faults (CSQ12F215 and an unidentified splice), all the other splices have suffered thermal damage caused by the fire (i.e. not by heat generated by current overload). *The Panel concurs. However, 12 of the 14 circuits in MH2445 experienced faults during this event. Evidence of 2 of these faults survived the fire, and these both occurred at splices.*

- One of the 600A load break elbow connectors of the Y splice of CSQ12F215 suffered a thermal failure causing melting of the Cu-Al weld joint resulting in the separation of the copper lug from aluminum sleeve of the connector. This type of connector is made of a copper lug that is friction welded to an aluminum sleeve. The temperature of the connector exceeded the melting point of the Al-Cu friction welded junction between the copper lug and the aluminum sleeve, which caused the copper lug to separate from the aluminum sleeve. *The Panel believes that this is the likely failure mode. This conclusion is supported by the January 2008 inspection of the manhole that identified this component as being 5.3 ºC hotter than the attached conductor. This temperature differential is indicative of a connection with higher-than-normal contact resistance.*

The main conclusions of the Powertech report are listed in the bulleted list below. Panel comments are provided in italics after each main conclusion:

- The root cause of the failure of CSQ12F215 was due to an overheating connector on the 600A load break elbows of the Y splice on one of the phases. This probably occurred over a period of several hours, which caused the melting and thermal decomposition of the polymer components of the Y splice and the accumulation of combustible gases. *The Panel concurs that this is the likely cause of the fault that occurred on CSQ12F215.*

- The fire was initiated by the power arc on the overheating connectors of the Y splice on CSQ12F215 which caused the polymer components to catch on fire resulting in further decomposition of the material and accumulation of combustible gases. *The Panel feels that the specific cause of the fire cannot be known with certainty. However, it is likely that the electrical arcing occurring between the separated connections (at the failed friction weld) started the fire, resulting in extensive thermal damage that ultimately resulted in the fault that tripped the circuit.*

- Fire progressed to the remaining circuits by one of the connectors that caught on fire, separated and fell on the bottom splice at the west wall of MH2445 causing it to catch on fire. The heat generated caused the melting of the lead sheath of UC7F147 (circuit 12F211) just above, causing the Novoid X in that splice to fall on the lower splice providing more fuel to the fire. The flames progressed to the cables on the upper racks causing them to catch on fire resulting in the tripping of CSQ12F124, and the production of more decomposition products and volatiles. The fire progressed to the remaining cables and splices, generating more decomposition products and volatiles until the concentration of the gases in the manhole reached the explosive limit, causing the explosion. *The Panel feels that this general sequence of events is likely, but notes that the explosion occurred well before the tripping of circuit CSQ12F124. Evidence from an amateur video (shot by German-speaking tourists from their hotel room) on the CBC website shows that the manhole cover was in place before the explosion and was displaced by this event.*

In its discussion, the Powertech report concludes that the root cause of the initial component failure is not likely to be a result of improper assembly. The Panel does not feel that there is enough evidence to support this conclusion. The Panel feels that the root cause could easily have been either a faulty component or improper assembly.

4.2 *In the experience of the Panel, was there anything unusual about the circumstances that led up to the fire and explosion?*

The panel feels that nothing was unusual about the circumstances that led up to the fire and explosion. As noted above, evidence supports the claim that these circuits were not overloaded. The application of components and materials is consistent with standard utility practices.

Utilities typically run underground distribution equipment such as cables, splices, separable connectors, and terminations to failure. Therefore, utilities must be prepared to respond to underground equipment failures should they occur. BC Hydro is fully prepared, like most utilities, to respond to typical underground distribution equipment failures.

Although there was nothing unusual about the situation leading up to the failure, there were several unusual aspects of the overall event. First, the component that failed was only three years old. Since most underground components are expected to last at least 30 years, it is somewhat unusual, but not rare, that this particular component failed. Second, the failure of component ignited a fire. Again, this is somewhat unusual but is not rare.

4.3 *Are the design, operation, inspection, maintenance, and replacement regimes for these cables and their constituent parts consistent with industry norms?*

The design, operation, and maintenance regimes for these cables and their constituent parts are consistent with industry norms. The BC Hydro inspection and replacement regimes exceed industry norms. This is demonstrated by its Detailed Condition Assessment program (DCA) that has been in place for the last four years and is still evolving. This program has cut the number of feeder cable failures experienced by BC Hydro in half. There are many utilities that do not have any condition assessment program for underground distribution cables and components.

There is a lot of industry activity related to the condition assessment and management of distribution cable and components. This activity is driven by aging equipment, the resulting increase in failure rates, and the impact of more failures on customer reliability and utility operations. Therefore, the industry norms of 2008 may be substantially different in future years.

4.4 *In general, how commonly do cables and their component parts exhibit this particular failure mode and what is the proportion of failure effects that involve destructive fires and/or explosions?*

The initial component failure was caused by a thermal runaway, leading to a separation at a friction weld at a connecting lug. This component was a 15-kV 600 amp separable connector, and this type of failure mode is uncommon for this class of connector. Underground component failures leading to destructive fires and/or explosions are also uncommon for 15-kV cable accessories.

There are no industry statistics that allow specific probabilities or proportions to be computed.

4.5 *Is the Panel aware of any predictive models and/or direct diagnostic techniques that would provide a reliable means of predicting the initiation of cable failure modes and facilitate timely preventative intervention?*

Predictive models for underground component failure rates focus on average failure rates of populations and are not suitable for predicting the failure of specific components.

The most effective diagnostic techniques include: infrared, leakage current, dissipation factor, dielectric spectroscopy, partial discharge (both on-line and off-line), time domain reflectometry, and insulation hardness. In their DCA program, BC Hydro is using all of these except dielectric spectroscopy and dissipation factor. Since BC Hydro uses leakage current tests, performing dissipation factor tests and dielectric spectroscopy are not necessary since they would result in the same information.

With all of these diagnostic techniques, the interpretation of the data to predict remaining life and probability of failure is very difficult. The industry continues to make advances and refinements to data interpretation. BC Hydro is a leader in this area as demonstrated by its DCA program.

5 Conclusion and Recommendations

The scope of the Panel's investigation, as indicated by the questions posed by BC Hydro, consists of the component failure and the resulting fire. Therefore, an initial discussion will focus on this narrow aspect of the event.

In January 2008, BC Hydro discovered a temperature difference of 5.3 ºC between a connector and its associated cable. This connector was assigned a Level 4 priority, which is the highest priority except for situations requiring immediate attention for safety reasons. No action was taken on this connector and it failed on July 14th 2008, causing a fire, and ultimately leading to a major outage in downtown Vancouver.

Should BC Hydro have taken action to remedy the known problem on this connector? Without the benefit of hindsight, it is the opinion of the Panel that the BC Hydro response was prudent. At the time of this report, the DCA program had identified 247 Level 4 situations since its inception. Until this connector failure, none of these Level 4 situations had resulted in a component failure. Therefore, it was reasonable for BC Hydro to address this problem through normal prioritization and scheduling processes.

With regards to the component failure and the resulting fire, the Panel concludes the following:

Conclusions

1. BC Hydro could not have been expected to prevent the connector failure that initiated the event of July 14th 2008.
2. BC Hydro could not have been expected to prevent the connector failure from initiating a fire.
3. The design, operation, inspection, and replacement regime for the BC Hydro feeder cable systems meet or exceed industry norms.

An explosion occurred after the fire had been burning for a while. The fire continued after the explosion. There is no evidence that this explosion caused any additional damage that would not have occurred from a fire alone. After the explosion, it was over twenty minutes before the next circuit tripped. A snapshot of the short explosion looks dramatic, but was a very small factor in this event (apart from safety issues).

The Panel offers these recommendations related to the component failure and the resulting fire. These recommendations have not been evaluated from a safety, financial, or operational perspective, and are to be considered a starting point for BC Hydro to consider further.

Recommendations

1. Identify and inspect all components similar to the connector that failed and initiated this event.
2. Implement periodic infrared testing of all separable insulated connectors.
3. During regular manhole entry, measure the temperature differences between connectors and their associated cables. These readings should be recorded in a database that is accessible to the Strategic Asset Management group.
4. Evaluate and revise the criteria used in the DCA program to categorize situations as Level 1 through Level 4 and those situations requiring immediate attention for safety reasons. This could include greater resolution (i.e., more Levels) and/or more precise criteria for situations requiring immediate attention.

At this point, the Panel has stated its opinion that both the initiating fault and the resulting fire were understandable and that BC Hydro could not have been expected to prevent either. However, these events led to an extensive manhole fire and the loss of a substantial portion of downtown Vancouver for an extended period of time. Although beyond the scope of the questions posed by BC Hydro, the Panel feels that is appropriate to provide some thoughts on these issues.

The damage caused by this event was extensive. Given the extent of the damage, the number of circuits involved, and the fact that repairs needed to occur in the confined space of a manhole, the repair and restoration effort by BC Hydro crews was exemplary. The repair required the replacement of about 4 km of cable and 36 splices and terminations. Given this amount of work, the restoration and repair time for this event were exceptional.

The initial fire started in a single component. The fire eventually spread throughout the manhole. There were opportunities to reduce the likelihood of the fire spreading in this manner. The major opportunities are (1) prevent the fire from spreading, and (2) extinguish the fire.

The typical method used to prevent a fire from spreading is to protect cables with fire resistant tape. Although it would not be typical to wrap separable connectors with this material, it would reduce the likelihood that a fire on a component would spread to protected cables and splices. Essentially the protective tape denies the fire additional fuel to propagate and grow. BC Hydro, like many utilities, used to use asbestos fire resistant tape in this manner, but has removed most of this tape for health and safety reasons. Recently, several non-asbestos options have become available. There are some operational disadvantages to doing this, such as the masking of acoustical partial discharge signatures, but this is an option that warrants further investigation.

Once the BC Hydro trouble technician arrived on the scene, there was only a single circuit out of service. About 20 minutes elapsed before the remaining circuits started to trip with most tripping after about 45 minutes. If BC Hydro and the Vancouver Fire Department had prior established processes and training in place, the circuits in the affected manhole could have been de-energized and the fire extinguished probably before the second circuit tripped. More aggressive policies might even allow the Vancouver Fire Department to act before the arrival of a BC Hydro representative, potentially without de-energizing the manhole. The area of manhole fire suppression represents an important opportunity for BC Hydro to pursue.

6 Panel Biographies

Richard Brown, PhD, P. Eng

Dr. Brown is Vice President of Operations for Quanta Technology and also serves as an Executive Advisor. His areas of expertise are power system reliability, performance improvement, and asset management. He has published more than 80 technical papers in these areas, is author of the book *Electric Power Distribution Reliability*, and has provided consulting services to most major utilities in the United States and many around the world. Dr. Brown is an IEEE Fellow, vice-chair of the IEEE Planning and Implementation Committee, and a registered professional engineer. Dr. Brown has a BSEE, MSEE, and PhD from the University of Washington, Seattle, and an MBA from the University of North Carolina, Chapel Hill. Over his 18 year career, Dr. Brown has worked (chronologically) at Jacobs Engineering, ABB, KEMA, and Quanta.

John Densley, PhD, P. Eng

In 1991, Dr. Densley joined the Electrical Power Systems Group of the Ontario Hydro Research Division, which later became Ontario Power Technologies and then Kinectrics. There he continued his research into aging and diagnostic techniques to assess the condition of electrical insulation systems in power equipment such as cables, transformers and switchgear. The work led to the development of instruments to make on-line measurements of power factor and also an active bridge to measure dielectric properties at low frequency; he was also responsible for a program to measure the partial discharge pulse characteristics in cables. He lead several projects investigating electrical degradation phenomena in extruded insulation systems. He retired from Kinectrics in 2000 and formed Arborlec Solutions Inc. to provide consulting services on electrical insulation systems. John has published over 100 research papers on insulation systems, and delivered more than 50 technical presentations including seminars, workshops and professional development courses.

Mr. Ken Hamilton, P. Eng

Mr. Ken Hamilton is an Underground Standards Design Engineer for Manitoba Hydro. His areas of expertise are on Underground Distribution Systems and National Standards as they apply to the design and construction of Utility Distribution Systems. He has been involved in all aspects of the design and installation of underground distribution systems as well as secondary grid network systems. He also has experience in the design and installation of transmission cables. Mr. Hamilton has been on various Technical Sub committees for the Canadian Standards Association (CSA) and he has also been the Project Monitor for multiple Canadian Electricity Association (CEA) projects.

7 Reference Material

BC Hydro furnished members of the Panel with the following documents to support their investigation:

Documents Related to the Event
1. Chronology of events – Sequence diagram
2. Damage State – cables and vault
3. Photographic Evidence from Cable Crews
4. Manhole 2445 CYMECAP Study
5. Loading Data Spreadsheet
6. Weather Reports for 1 week leading up to event
7. Powertech Report – including Manhole 2445 – Analysis of Protection Operations Report
8. BCUC Interim Report – submitted Aug 5 2008-09-11

Documents Related to Circuitry Design, Cable Design, Construction, Maintenance, Operation, Repair, and Inspection

9. BC Hydro Distribution Standards – Underground electrical 1996 – with updates
10. Underground cable design and manufacture details (cables in duct where fire occurred):
11. MH2445 Feeder Cable one lines
12. DIAGRAM – LANE SOUTH OF Pender St at Richards St. & Seymour St.
13. Maintenance and testing reports for 2000, 2003, 2006, 2007, 2008

Documents Related to Asset Management Regime and Underground Distribution Assets

14. Appendix V from 2007/08 RRA – Asset Management Practices for Distribution Wires Assets
15. Distribution Maintenance 10 Year Business Plan (Fall 2007)
16. Appendix S from 2009/10 RRA (Glossary and Abbreviations)
17. Distribution Maintenance F2008 A Year in Review – May 2008
18. BCTC SLA overview for control centre operations
19. Training of first responders & repair procedures: Work Procedure for Entering Distribution Manholes / Vaults
20. Training of first responders & repair procedures: Underground Electrical Spaces (cable/transformer vaults) Inspection, Switching or Tagging
21. Training of first responders & repair procedures: OSH Standard 303 Confined Spaces
22. Training of first responders & repair procedures: Electrical Training for Firefighters Course Information
23. Audits of underground cable operation and maintenance: Feb 8, 2000 "Power Delivery Asset Maintenance" Internal Audit Report
24. Audits of underground cable operation and maintenance: January 31, 2001 Audit Follow-up

Miscellaneous Documents
25. Manhole Cable survey – BC Hydro comparison with other Utilities
26. Summary Report on distribution Service Performance (Apr 1 07 – Mar 31 08)

Presentations

27. Asset Management – presented by Distribution Maintenance Manager, Specialist engineer
28. CSQMH2445 – presented by Distribution Engineer Lead
29. Underground Cable Design and History – presented by Distribution Engineering Manager – Equipment and Standards
30. Historic Maintenance and Inspection procedures – presented by Special Engineer
31. Incident Restoration Response – Distribution Regional Operations Manager