BC HYDRO REPORT

Downtown Vancouver
Outage: July 14, 2008

Findings and Recommendations

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1 Executive Summary

On Monday, July 14, 2008, at 8:54 a.m., an underground circuit failed in a manhole in the 500-block of Richards Street in downtown Vancouver. An ensuing fire in the manhole caused additional circuits to fail, leaving approximately 2,000 customers (metered services) without power.

Because of extensive smoke and heat in and around the manhole, BC Hydro crews were unable to begin the restoration process until the Vancouver Fire Department had given the “all clear,” nearly eight hours after the fire broke out. In the interim, BC Hydro mobilized crews and equipment, made plans for the restoration process, and opened and staffed its Corporate Emergency Center to coordinate the restoration effort.

At approximately 4:30 p.m., the Vancouver Fire Department determined that the air quality and temperature had improved sufficiently to allow BC Hydro crews to enter the manhole to conduct a damage assessment. Crews confirmed that a total of 14 circuits were destroyed by the fire.

By approximately 5 p.m., BC Hydro crews initiated the restoration process, which included removing damaged cables, cleaning the manhole, repairing the ducts, pulling in new cable, splicing the cables, testing and energizing the new cable, and re-energizing service to customers.

Working within the confined space of a manhole, crews removed and replaced nearly four kilometres of underground cable.

Power was restored to the first customers by the evening of July 14, and service to approximately half of all affected customers was restored within 24 hours of entry into the manhole. With crews working around the clock, service to approximately 90 per cent of impacted customers was restored within 48 hours, and service to the last customer was restored at approximately 6 p.m. on Thursday, July 17.

The primary objective of this report is to present the findings of an investigation into the root cause of the power outage. This report includes the results of a forensic examination of the destroyed circuits and other components, along with an independent review by a panel of external industry experts.

This report also presents information about BC Hydro's response and restoration to the outage, maintenance and inspection procedures, safety and environmental issues, customer care and compensation, communications, and recommendations for immediate and future action.

BC Hydro has determined that the root cause of the first circuit's failure was an overheated connector which caused melting and thermal decomposition of circuit components and the accumulation of combustible gases. The independent panel concurs that this is the likely cause of the fault (Appendix 1). The ensuing fire was initiated by the power arc on the overheated connector, which caused further decomposition of circuit components and accumulation of combustible gases to the point that excessive heat and flames caused all other circuits to fail in a chain reaction.

According to the forensic evaluation of the damaged circuits conducted by Powertech Labs Inc. there was no evidence of any fire accelerants that may have started the fire, and there was no evidence of overloading on any of the circuits passing through the manhole. (The Powertech report will also be filed with the British Columbia Utilities Commission but separate from this report.)

The next question to answer was what caused the component part to fail, which lead to the circuit's failure. The Powertech report concluded that the root cause of the initial component failure was not likely to be a result of improper assembly. However, the independent panel did not feel that there was enough evidence to support this conclusion: "The Panel feels that the root cause could easily have been either a faulty component or improper assembly."

While circuit failure is not uncommon in underground systems – approximately 20 circuits fail and are repaired every year by BC Hydro – the downtown Vancouver outage was unique because it caused a manhole fire leading to the failure of other circuits.

Underground electrical systems are significantly different from overhead electrical systems. A fault on an overhead distribution line (for example, insulator flashover or branch contact) might not cause damage to the line components. Usually the line can be reenergized in a few seconds, as soon as the hot gases caused by the fault arc have had time to dissipate. In contrast, a fault in an underground system causes damage to the affected insulation. This damage sometimes precludes restoration of service to customers until repairs are made to the circuit, although restoring power by switching customers to a standby circuit is often possible, as it was to some extent with the downtown Vancouver outage. Because of the need to repair insulation to the necessary degree of insulation integrity in an underground system, the repair time for an underground failure can be greater than for an overhead failure. Access considerations (to a manhole, for example) can also increase the repair time for an underground system.

Also, fault energy in an overhead system is dissipated in the surrounding air. Fault energy in an underground system is confined in the manholes and ducts and can result in an explosive dislodgement of manhole covers, creating a worker or public safety issue.

Prior to 2004, BC Hydro conducted routine manhole inspections on an "opportunity" basis, meaning that when a crew was doing specific work in a manhole or in the immediate area a visual inspection was undertaken.

In 2004, BC Hydro initiated a Detailed Condition Assessments (DCA) program. Since the implementation of the DCA program, there have been approximately 20 underground circuit failures per year, a reduction of 50 per cent from the past.

Circuits selected for condition assessment go through a prioritization process based on the importance of the circuit, service conditions, number of faults, age (if known) and expert opinion. The assessment uses a combination of different techniques including visual inspection, electrical testing and metallurgical assessments.

Since the DCA program started in 2004, BC Hydro has completed assessments of circuits in 1,018 manholes.

During a scheduled inspection in January 2008 of the manhole highlighted in this report, BC Hydro discovered a temperature difference of 5.3 °C between the connector in question and its associated cable. This connector was assigned a Level 4 priority, which is BC Hydro's highest priority rating except for situations requiring immediate attention for safety reasons. BC Hydro did not take immediate action to repair this connector, which eventually failed on July 14, 2008.

In its report, the independent panel asked: "Should BC Hydro have taken action to remedy the known problem on this connector?" In response to its own question, the Panel concluded that: "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. The design, operation, inspection, and replacement regime for the BC Hydro feeder cable systems meet or exceed industry norms."

To emphasize the unusual nature of this outage and its cause, the Panel also found it unusual that the failed connector was only three-years-old, when underground components usually have a life of 30 or more years.

Like the multiple outages caused by the winter storms of 2006-07, BC Hydro will take the opportunity to learn from the downtown Vancouver outage and this investigation to make plans to improve service, mitigate risks, and enhance reliability. These improvements will incorporate many of the independent panel's recommendations along with BC Hydro's own initiatives, some of which are already underway.

A summary of all BC Hydro's plans for improvement can be found in Chapter 9 of this report.

2 Background

2.1 Purpose of Report

The purpose of this report is to:

- investigate the nature and root cause of the downtown Vancouver power outage on July 14, 2008; and
- make recommendations to:

  a. mitigate the risks and reduce the damage to BC Hydro's underground electrical distribution system in the event of future incidents;
  b. improve resiliency in the underground system; and
  c. develop system planning criteria and risk mitigation strategies that support the above.

2.2 Scope and Approach

In order to fulfill the purpose of this report, BC Hydro conducted a comprehensive investigation into the downtown Vancouver outage, including a complete forensic evaluation of the damaged circuits by Powertech Labs Inc., and a load testing of the circuits in the manhole.

BC Hydro also engaged three independent external power utility experts to provide a review of BC Hydro's investigation (Chapter 6 and Appendix 1).

This report follows the interim downtown Vancouver outage report BC Hydro filed with the British Columbia Utilities Commission (BCUC) on August 5, 2008 (Appendix 4).

The report is presented in the following structure:

1 Executive Summary

2 Background: Outlining the reason for the report, information on organizations touched on in the report, and description of the downtown Vancouver underground power system.

3 Downtown Vancouver Power Outage: Description of the outage, its impacts, and BC Hydro's repairs, response and restorations.

4 Inspection and Maintenance: Description and history of standard inspection and maintenance procedures for systems and equipment like the ones involved in the incident.

5 Root Cause: Results of Powertech's full and independent forensic analysis of the cables and other components retrieved from incident scene.

6 Independent Panel Review: Background on the three industry experts who reviewed BC Hydro's findings, their scope and approach, their findings, and recommendations.

7 Customer Impact: Information on the impacts on the 2,000 affected customers (meters).

8 Communications: Summary of how information was shared with various groups, including key accounts, public, media, and employees.

9 Plans for Improvement: Actions BC Hydro will take based on the report and recommendations from the independent panel.

The report also has four appendices:

Independent Panel Review by the three external power utility experts engaged to provide a review of BC Hydro's investigation: "BC Hydro's Response to the Underground Cable Fire on July 14, 2008: Fire, Response, Recovery," dated September 15, 2008

BC Hydro Cable Ampacity Program (CYMECAP) Study, August 2008

Various Utilities' Liability/Exemption Clauses

BC Hydro Downtown Vancouver Outage Interim Report to the British Columbia Utilities Commission (BCUC), August 5, 2008

2.3 Organization: Who was Involved

- **BC Hydro, Field Operations:** Field Operations manages BC Hydro's distribution facilities and provides the resources to respond to emergency events affecting all non-generation components of BC Hydro's electric system, including distribution, transmission and telecontrol assets.

- **BC Hydro, Customer Care and Conservation:** Customer Care and Conservation is responsible for all aspects of the customer experience, including managing customer service, building and maintaining relationships with key account customers, and supporting the customer Call Centres, which are staffed by an external service provider (Accenture Business Services for Utilities). Customer Care ensures that agents provide customers with information that is consistent with what is being communicated externally through the media and the BC Hydro website. Key Account Managers provide a direct link to their customers to keep them informed.

- **BC Hydro, Corporate Affairs:** Corporate Affairs is responsible for communications with the public, the media, external organizations, and BC Hydro employees.

- **BC Hydro, Safety, Health and Environment (SHE):** SHE is responsible for governance and oversight of BC Hydro's Security, Dam Safety, Emergency Planning, Corporate Safety and Health, Environment and Sustainability, and Public Safety.

- **BC Hydro, Engineering, Aboriginal Relations and Generation (EARG):** EARG provides engineering and distribution planning standards for planning, design and construction of BC Hydro's distribution system.

  Powertech Labs Inc: Powertech Labs Inc. is a wholly-owned subsidiary of BC Hydro. Powertech offers electrical, chemical, environmental, gas technologies, mechanical, metallurgical, materials, civil and structural engineering expertise to power utilities, as well as to a growing list of other industries (gas transmission and distribution, transportation, and pulp and paper). Powertech has 18 labs and approximately 80 professional engineers, scientists and technologists.

- **BC Transmission Corporation (BCTC):** BCTC is a crown corporation that is responsible for planning, operating and maintaining BC Hydro's transmission system. BCTC is accountable for emergencies associated with transmission lines and substations, as well as for real time operation of the system (generation, transmission, and distribution components).

2.4 Downtown Vancouver Underground System

Power to downtown Vancouver is fed mainly through an underground system. With overhead distribution, there is a practical limit to the number of circuits that can be installed on the same pole line along a corridor from a distribution substation. Normally, no more than two 12 kV overhead circuits are installed on one pole. This limits the amount of power that can be delivered along any single corridor using overhead distribution. With the large load densities of downtown Vancouver, it is necessary to install underground cabling. Downtown Vancouver uses some overhead distribution in lanes and alleys to serve smaller customers.

In the early 1950s, Vancouver installed its first Dual Radial underground system. By the early 1960s, a designated underground policy for the Dual Radial system was developed.

The dual radial system allows connection of large loads in the downtown core directly to underground high voltage circuits. In order to manage an underground system, BC Hydro occasionally needs to be able to take a circuit out of service to conduct repairs and maintenance, or to add new customers. In order to avoid outages to existing customers, a switching scheme is needed to be able to transfer load to an alternate circuit. The dual radial system allows BC Hydro to switch from one circuit to an alternate with no interruption to the customer. Overall, this normally provides a highly reliable solution because power can be restored in minimal time as repairs to a faulty cable are done independently.

The Vancouver downtown underground system consists of approximately 800 manholes with 146 circuits coming out of three substations. The two original substations feeding downtown Vancouver were Murrin and Dal Grauer. These eventually reached full capacity due to the rapid growth of the downtown area. In 1984, Cathedral Square substation came into service to meet the increased load requirements.

3 Downtown Vancouver Power Outage

3.1 Description of Incident

On Monday, July 14, 2008, at 8:54 a.m., an underground circuit failed in a manhole in the 500-block of Richards Street in downtown Vancouver. An ensuing fire in the manhole caused additional circuits to fail, leaving approximately 2,000 customers (metered services) without power. A total of 14 circuits were destroyed by the fire.

3.2 Restoration Response

BC Hydro crews and municipal fire and police personnel promptly responded to the scene of the manhole fire. Because of extensive smoke and heat in and around the manhole, BC Hydro crews were unable to enter the manhole to begin the restoration process until the Vancouver Fire Department (VFD) had given the “all clear” nearly eight hours after the fire broke out. In the interim, BC Hydro was mobilizing crews and equipment, making plans for the restoration process, and had opened and staffed its Corporate Emergency Center to coordinate the restoration effort.

At approximately 4:30 p.m. on July 14, the VFD determined that the air quality and temperature had improved sufficiently to allow BC Hydro crews to enter the manhole to initiate a damage assessment. Crews entered the manhole and confirmed that 14 circuits had been destroyed.

By approximately 5 p.m., BC Hydro crews initiated the restoration process, which included removing damaged cables, cleaning the manhole, repairing the ducts, pulling in new cable, splicing the cables, testing and energizing the new cable, and re-energizing service to customers.

Power was restored to the first customers by the evening of July 14, and service to approximately half of all impacted customers was restored within 24 hours (of entry into the manhole). With crews working around the clock, service to approximately 90 per cent of customers was restored within 48 hours, and service to the last customer was restored at approximately 6 p.m. on Thursday, July 17.

At the peak of the downtown outage, approximately 2,000 customers (metered services) were without power. The following table provides details of the number of affected circuits and the time of restoration. However, power was restored to all customers by the evening of July 17, 2008 using a combination of other non-damaged circuits, some repaired circuits and switching to standby circuits.

Affected Circuit[1]	**Day and Time of Restoration and Outage Duration**[2]	**Number of Customers (Meters) Affected**
A	Wednesday 14:20 53:66 hours	251
B	Wednesday 05:06 44:52 hours	723
C	Wednesday 15:08 54:54 hours	1
D	Wednesday 14:45 53.91 hours	48
E	Wednesday 17:30 56.76 hours	No customers affected – used as part of restoration plan
F	Wednesday 20:00 59:46 hours	551
G	Partial Restoration Wednesday 18:45 57.91 hours Full circuit restoration Sunday 13:00 148:46 hours	No customers affected – used as part of restoration plan
H	Wednesday 21:59 61:05 hours	1
I	Thursday 03:54 67:00 hours	44
J	Thursday 14:50 79:96 hours	4
K	Thursday 17:40 80:86 hours	1
L	Friday 19:56 107:02 hours	259
M	Friday 19:56 107:02 hours	23
N	Friday 23:05 110:51 hours	45

[1] Labeled A to N for the purpose of this report only.

[2] Outage occurred on Monday, July 14, 2008 at 8:54.

3.3 Restoration Process

The following is BC Hydro's priority sequence for restoration of service, which was applied during the downtown Vancouver outage:

- Public safety;
- Generation and transmission facilities (eg. substations) to supply distribution customers;
- Communications facilities for civil authorities;
- Hospitals;
- Critical customers which include police stations, fire stations, ambulance stations, municipal emergency centres;
- Facilities as directed by Municipal, Provincial, and Federal authorities;
- Utility facilities which include gas, sewer, water, telephone, and cellular;
- Emergency reception centres (schools, civil centres); and
- General commercial, industrial and residential customers.

3.4 Repairs undertaken

Working within the confined space of a manhole, BC Hydro crews removed and then replaced nearly four kilometres of underground cable to restore power to all customers.

Specifically, BC Hydro completed the following repairs:

- Removed 3,672 meters of various cable types
- Removed 69 meters of Underground Residential Distribution (URD) cable
- Installed 3,672 meters of Cross Link PolyEthylene (XLPE) 500KCM Copper Feeder
- Installed 69 meters of URD cable
- Installed 20 XLPE-XLPE Straight splices (x3)
- Installed 10 XLPE-Paper Insulated Lead Covered(PILC) Heat Shrink Transition splices (x3)
- Installed 2 XLPE "wye" (1 cable in, 2 cables out) splices. (600amp dead break elbows x18)
- Installed 3 terminations at TP (terminal pole – a pole that is the transition between our overhead system and underground system) pole on URD cable
- Installed 1 straight splice on URD cable (x3)

- Installed new neutral cable in all four directions from the manhole and rebuilt all manhole bonding and grounding
- Rebuilt all racking in the manhole
- Cleaned the five affected manholes with McRae's Environmental Services Ltd.

3.5 BC Hydro Emergency Response

BC Hydro activated its Corporate Emergency Center (CEC) at approximately 11a.m. on July 14. The emergency center remained in activation 24-hours a day until power was restored to all customers and all damaged circuits were repaired. The CEC was de-activated at approximately 4p.m. on Sunday, July 20, 2008.

3.5.1 Notification and Activation

BC Hydro staff with emergency response roles in the BC Hydro Corporate Emergency Centre (CEC) were notified of the incident and reported to the CEC. The Provincial Emergency Program and the City of Vancouver were also notified.

The decision to provide strategic support from the corporate level was based on the following factors:

- the outage potentially impacted critical infrastructure and key customer accounts;
- it impacted multiple BC Hydro business groups; and
- it was considered a high-profile event.

3.5.2 Incident Management

BC Hydro established an emergency response organization at the CEC, which consisted of staff in the Command, Operations, Planning, Finance, and Information Liaison sections. A BCTC representative also worked out of the CEC. At the incident site, there were Operations and Communications personnel. An executive-level policy team provided oversight and policy guidance.

In accordance with BC Hydro's Incident Action Plan, the following priorities were established:

1. ensure public and employee safety;
2. identify impacted critical infrastructure, customer key accounts, and feeder prioritization for a Restoration Plan;
3. facilitate effective and timely communication; and
4. establish the impacts based on the damage assessment and receive situation updates from site.

3.6 Safety and Environment

BC Hydro safety and environmental personnel attended the scene to monitor and address safety and environmental concerns during the outage (air quality, electrical hazards, and interaction with area residents and passersby). The underground fire caused smoke and heat to accumulate in the manhole where the failure occurred. This created an environment that was unfit for BC Hydro crews. Once the fire department assessed that the manhole was safe to enter, BC Hydro began the restoration process.

Fire suppression water was released from the manhole/vault through a drain which is connected to a Metro Vancouver combined stormwater/sanitary sewer that discharges to the Iona Sewage Treatment Plan.

McRae's Environmental Services Ltd., a local firm which provides vacuum and high pressure cleaning units for municipal, storm and sanitary sewer lines, and catch basins, was retained to remove residual water/debris (such as used syringes) from the primary manhole as well as adjacent manholes.

BC Hydro kept Environment Canada apprised of the situation and also liaised with the City of Vancouver's and Metro Vancouver's sewer-use bylaw departments regarding the wash water from the fire fighting.

3.7 Costs

The total cost of restoring power was approximately $525,300. The following table provides a cost breakdown.

Estimated Restoration Costs ($000's)	
Internal Labour	309.6
Materials	176.1
External Contractors	7.2
Environmental	6.2
Security & Traffic Control	13.9
Vehicles	4.8
Operations Centre	7.5
Total Expenditures	**525.3**

4 Inspection and Maintenance

4.1 Background

There are approximately 1,200 underground circuits in BC Hydro's distribution system, which consist of both paper-insulated-lead-covered (PILC) and cross-linked-polyethylene cables (XLPE). Prior to 2004, there had been, on average, 40 underground cable faults per year. The failures generally resulted from manufacturing defects (poor insulation and defective components), substandard materials, degradation due to normal aging, and accelerated aging due to operating and environmental stresses (electrical, thermal, mechanical, and corrosion). Prior to 2004, BC Hydro conducted blanket replacement of cables. Replacement of these cables was based on the fault history of the cable without any prior condition testing. (Many utilities practice blanket replacement based on the number of recorded faults.) Under this program many segments of replaced cable were found to be in good or excellent condition.

4.2 Condition Assessment Process

Prior to 2004, BC Hydro conducted routine manhole inspections on an "opportunity" basis, meaning that when a crew was doing specific work in a manhole or in the immediate area a visual inspection was undertaken.

In 2004, BC Hydro initiated a Detailed Condition Assessments (DCA) program. Since the implementation of DCA, there have been approximately 20 underground circuit failures per year, a reduction of 50 per cent from the past.

Circuits selected for condition assessment now go through a prioritization process based on the importance of the circuit, operating conditions, service history, number of faults, age (if known) and expert opinion. Defective cables or components identified by the DCA are compiled as a work package by BC Hydro's engineering group and sent to BC Hydro's cable department for execution and follow up. This program requires a thorough investigation by Powertech Labs Inc. of the manhole structure, cables and accessories. The assessment uses a combination of different techniques including visual inspection, electrical testing and metallurgical assessments.

Since DCAs started in 2004, BC Hydro has completed assessments of circuits in 1,018 manholes.

BC Hydro's current condition assessment test program relies on an integrated approach that evaluates the condition of all the cable components using a variety of test techniques to identify cable and splice defects to maintain safe and reliable operation of the feeder. The test protocol consists of manhole inspections with the circuits energized and electrical tests on the circuits with the cables de-energized.

Manhole Inspections

Manhole inspections focus on evaluating the condition of all splices and the accessible portions of the cable in the manhole and consist of a visual examination, metallurgical tests, partial discharge, and temperature measurements.

Visual inspection is carried out to check for corrosion, mechanical damage, oil leaks, cracks in the lead sheath, electrical arcing, manhole condition (such as water level and cyclic drying and wetting), and cable installation state such as displacement from the racks.

Partial discharge tests are carried out on the energized cables in the manholes using radio frequency and acoustic partial discharge detectors. Partial discharge is due to localized breakdown of the dielectric insulation of a cable or splice and marks the onset of failure.

Metallurgical tests are carried out to determine the condition of lead sheath of PILC cables and include hardness tests on the lead sheath, fluorescent penetration dye test, and eddy current tests for the detection of cracks in the lead sheath of jacketed cables.

Infrared temperature scans are carried out on the visible portions of cables, splices, and grounding points to check for hot spots.

Typical problems identified during inspections include: electrically leaky cable splices, leaky cable terminations, collapsed splices, and cables displaced off the rack.

Electrical Tests

Condition assessment tests are conducted while the cables are de-energized to detect gross defects such as severe corrosion or breaks in the metallic shield of the cables. In addition, dissipation factor measurements and testing of the leakage current across the cable insulation ensure overall insulation quality.

4.3 Maintenance Programs

BC Hydro's inspection programs are planned and managed by BC Hydro, and inspections are undertaken jointly with Powertech Labs technicians. Powertech Labs complete a detailed condition assessment (DCA) and then review their findings with BC Hydro. These findings include recommendations for maintenance, scheduling of work, resourcing, process efficiencies and lessons learned.

The Detailed Condition Assessment (DCA) of feeder cables is covered through two programs. One is called the Dual Radial (DR) program, which encompasses downtown Vancouver, and the other is the Feeder Condition Assessment (FCA), which covers the rest of the province. The FCA program began as a pilot program in 2004 and since then has evaluated 49 critical circuits (total of 414 manholes) in the Lower Mainland. The Dual Radial program, which began in 2005, has inspected 31 circuits (total of 604 manholes).

5 Root Cause

5.1 Background

BC Hydro conducted a comprehensive investigation into the downtown Vancouver outage, including a complete forensic evaluation of the damaged circuits by Powertech Labs Inc., and a load testing of the circuits in the manhole.

BC Hydro also engaged three independent external power utility experts to provide a full and impartial review of BC Hydro's investigation (Chapter 6 and Appendix 1).

While circuit failure is not uncommon in underground systems – approximately 20 circuits fail and are repaired every year by BC Hydro – the downtown Vancouver outage was unique because it caused a manhole fire leading to the failure of other circuits.

A report prepared in 2005 by Siemens Power Transmission and Distribution for the Commonwealth of Massachusetts on dislodged manhole covers notes that underground electrical systems are significantly different from overhead electrical systems. Overhead electrical systems rely on air as the primary insulating medium. Splices and connections are relatively simple and are in the open air. In contrast, underground electrical systems rely on insulating material along the entire length of the cable to provide the necessary insulation. This insulating material may be either fluid impregnated paper-insulated lead-covered cable (PILC) or cross-linked polyethylene (XLPE). Splices and connections are much more complicated than with overhead construction because of the need to maintain insulation integrity.

The Siemens' report goes on to explain that underground systems are often unforgiving compared to overhead systems. A fault on an overhead distribution line (for example, insulator flashover or branch contact) may not cause damage to the line components. Usually the line can be reenergized in a few seconds, as soon as the hot gases caused by the fault arc have had time to dissipate. In contrast, a fault on an underground system causes significant damage to the affected insulation. This damage sometimes precludes restoration of service to customers until repairs are made to the circuit, although restoring power by switching customers to a standby circuit is often possible, as it was to some extent during the downtown Vancouver outage. Because of the need to repair insulation to the necessary degree of insulation integrity in an underground system, the repair time for an underground failure can be greater than for an overhead failure. Access considerations (to a manhole, for example) can also increase the repair time for an underground system.

The Siemens' report also notes that fault energy in an overhead system is dissipated in the surrounding air, whereas fault energy in an underground system is confined in the manholes and ducts and can result in dislodgement of the manhole covers. In addition, underground systems are also susceptible to energy released in the underground facilities from combustion of gases or oil contained in oil-filled equipment.

5.2 Scope and Approach

BC Hydro contracted Powertech Labs Inc. to conduct a full and independent forensic analysis of the cables and other components retrieved from the manhole, including:

- a critical evaluation of all data provided by BC Hydro;
- a detailed inspection of all the samples removed from the manhole;
- laboratory tests on some of the component materials of the cables and splices; and
- chemical tests on air, soot, and water samples obtained from the affected manhole and adjacent manholes.

In addition to the above analysis, BC Hydro reviewed:

- the load, switching, and protective relay history of the affected circuits over the several week period leading up to the failure;
- photographic documentation for the affected manhole; and
- the physical layout for the duct bank.

BC Hydro's analysis of the affected circuits can be found at Appendix 3.

5.3 Findings

BC Hydro has determined that the root cause of the first circuit's failure was an overheated connector which caused melting and thermal decomposition of circuit components and the accumulation of combustible gases. The ensuing fire was initiated by the power arc on the overheated connector, which caused further decomposition of circuit components and accumulation of combustible gases to the point that excessive heat and flames caused all other circuits to fail in a chain reaction.

The main findings of the Powertech investigation conclude that:

- There was no evidence of any fire accelerants, such as gas leaks, that may have started the fire;
- There was no evidence of any overloading on any of the circuits passing through the manhole;
- Two splices suffered electrical faults; all the other splices suffered thermal damage caused by the fire; and
- All the protective relays were functioning correctly and cleared the faults within the specified limits.

BC Hydro's investigation of the cables in the ductbank also confirms that there was no overloading of any of the cables in the manhole.

The findings of independent review panel are found at Chapter 6 and their complete report at Appendix 1.

6 Independent Panel Review

6.1 Panel composition and biographies

BC Hydro retained independent industry experts (Panel) to review BC Hydro's findings in this investigation. The experts were drawn from various backgrounds to ensure a broad range of experience.

The Panel was comprised of Dr. Richard Brown of Quanta Technology (Raleigh, North Carolina), Dr. John Densley of ArborLec Solutions (Mississauga, ON), and Mr. Ken Hamilton of Manitoba Hydro (Winnipeg, MB).

Dr. Richard Brown, 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 has been on the leadership team of three successful start-up businesses. He 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.

Dr. John Densley, 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 online 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 of electrical trees and interfaces in transmission class cables. He lead several projects investigating electroluminescence and space charge phenomena that occurred during the electrical degradation of extruded insulation systems. He retired from Kinectrics in 2000 and formed ArborLec Solutions Inc. to provide consulting services on electrical insulation systems.

Dr. Densley has published over 100 research papers on insulation systems, and delivered more than 50 technical presentations including seminars, workshops and professional development courses. He is a co-author of a patent on electrical tree suppression in high voltage polymeric insulation.

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.

6.2 Direct Award Justification

Given the two-month timeframe to deliver this report to the BCUC, there was insufficient time available for BC Hydro to proceed with an invited tender and competitive bid process, and therefore a direct award was made to the three expert panelists. The composition and success of this independent expert panel required a balance of specific expertise and talent across a number of highly specialised disciplines. The selection of this panel was done on the basis of "best qualified expert," where qualifications are assured through professional standing and reputation among peers in the industry.

6.3 Scope and Approach

The Panel was asked to consider and respond to the following questions:

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 preventive intervention?

The Panel first visited BC Hydro on September 4, 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 10 and 11. The Panel's activities consisted of presentations, meetings, data collection, and report writing. The Panel's final report was presented to BC Hydro on September 15. Further details of the Panel's activities are found at Appendix 1.

6.4 Panel Findings

The Panel's findings are presented below as responses to the five questions posed by BC Hydro. Panel responses are in italics.

6.4.1 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:

- 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 the manhole. *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 °C, 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 the manhole 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 circuit 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 °C*

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:

- The root cause of the failure of circuit 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 circuit 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 the manhole 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 circuit 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.

6.4.2 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.

6.4.3 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.

6.4.4 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.

6.4.5 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.*

6.5 Panel Conclusions and Recommendations

The Panel concluded that:

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

The Panel offered the following recommendations related to the component failure and the resulting fire. The Panel cautioned that “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.”

- Identify and inspect all components similar to the connector that failed and initiated this event;
- Implement periodic infrared testing of all separable insulated connectors;
- 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; and
- 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.

While outside the scope of the questions posed by BC Hydro, the Panel also added the following recommendations:

> “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 … this is an option that warrants further investigation."
>
> "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."

The Panel's full conclusion and recommendations are found at Appendix 1.

7 Customer Impact

At the peak of the downtown outage, approximately 2,000 customers (metered services) were without power. BC Hydro communicated principally with its customers of record, i.e., the customer that is billed by BC Hydro for the consumption registered on that meter. As is common with any downtown core, the customer attached to a meter could sub-lease part of their building and resell metered electricity to those sub-lessees who are then deemed customers of the BC Hydro customer. Because BC Hydro is not authorized to contact these non-account holders (with respect to service), BC Hydro can only identify the number of meters affected and is not able to report the total number of unmetered electrical services actually affected by the outage.

7.1 Key Accounts

During the restoration process, BC Hydro's Key Account Managers were in contact with their customers to provide regular updates regarding the status of the outage and the estimated time of restoration. This was particularly helpful in the case of some customers communicating their willingness and ability to remain on their own backup systems, which allowed BC Hydro to focus on restoring power to other customers.

BC Hydro relied on account holders to make decisions for their entire property and to provide information directly to affected tenants. A review is underway to confirm customer notification of outages between property management and tenants that aligns and adheres to BC privacy legislation.

Small and Medium Business (SMB) and residential customers obtained outage information through the media, BC Hydro's website, and call center representatives. In 2007, a BC Hydro program was launched to have business customers sign up for proactive notification of outages. Plans are in place to expand this to 1,000 additional businesses in 2008, with full availability planned for 2009-2010.

Some customers complained that BC Hydro's website displayed outdated Estimated Time of Restoration (ETRs) and unclear outage location information. Processes to synchronize outage information are underway, as well as plans to refine location information for potential implementation in 2008-2009.

These improvements are part of BC Hydro's Outage Communication Initiative, which adapted the lessons learned from the winter storms of 2006-07 to both improve the quality and consistency of information provided to customers, and to improve the means of delivering information to customers.

7.2 Call Center

The Call Centre managed outage calls from customers. The highest volume of calls was within the first two days and the daily average of outage calls received during the July 14 – 17 period was 52 per cent higher compared to the year to date (from April 1, 2008) figures.

The greatest impact was on July 15th when 3,128 outage calls came into the Call Centre. Sixty-three per cent (1,976) of the calls were answered in the Interactive Voice Response (IVR). Thirty-five per cent (1,102) of the calls were answered by an agent within 70 seconds. Two per cent (50) of calls were abandoned by the caller.

7.3 Requests for Compensation

BC Hydro appreciates and is fully aware of the importance of its service to the economic activities of its customers and their regions. While BC Hydro makes every effort to provide reliable power, there are many factors beyond its control that may cause power interruptions. BC Hydro cannot guarantee an uninterrupted supply of electricity or that voltage levels will not fluctuate.

In the case of the downtown Vancouver outage, 14 claims for loss have been received to date. All claimants have received a letter from BC Hydro acknowledging their claim, thanking them for their patience, and explaining that the incident is under review.

Customers have claimed for loss of revenue and wages, as well as for spoiled food (both residential and business customers). BC Hydro will respond formally to all claimants via mail as soon as the final review of the incident has been completed.

While BC Hydro sincerely regrets the difficulties caused by power outages, BC Hydro is not liable to pay compensation, as the following excerpt from its Tariff makes explicit:

Terms and Conditions 9.7:

BC Hydro will endeavour to provide a regular and uninterrupted supply of Electricity but it does not guarantee a constant supply of Electricity or the maintenance of unvaried frequency or voltage and shall not be responsible or liable for any loss, injury, damage or expense caused by or resulting from any interruption, termination, failure or defect in the supply of Electricity, whether caused by the negligence of BC Hydro, its servants, agents or otherwise, unless the loss, injury, damage or expense is directly resulting from the wilful misconduct of BC Hydro, its servants, or agents provided, however, that BC Hydro, its servants and agents are not responsible for any loss of profit, loss of revenues or other economic loss even if the loss is directly resulting from the wilful misconduct of BC Hydro, its servants or agents.

7.4 Summary of Liability Clauses

Many other jurisdictions have similar liability clauses to BC Hydro's. BC Hydro surveyed 20 jurisdictions in Canada, the U.S., the U.K. and New Zealand and found that the applicable liability limitation/exemption clauses are found within the utility's tariff terms and conditions or are established by statute or regulation. Appendix 3 summarizes the liability/exemption clauses in the jurisdictions surveyed.

8 Communications

8.1 Key Accounts

During the restoration process, BC Hydro's Key Account Managers were in contact with their customers to provide regular updates regarding the status of the outage and the estimated time of restoration. This was particularly helpful in the case of some customers communicating their willingness and ability to remain on their own backup systems, which allowed BC Hydro to focus on restoring power to other customers.

8.2 Public, Media, Employees

BC Hydro also provided regular outage updates to the public, media, customers and BC Hydro employees via BC Hydro's media spokespeople and senior management, BC Hydro's website, BC Hydro's call centre, news releases, letters to customers, internal employee messaging, and phone messaging.

Given the nature and location of the outage, the incident received major media coverage for three consecutive days. Initially the focus was on what happened, who was involved in the response and what customers were doing to cope. The focus then shifted to getting the perspectives of different stakeholders and experts. More than 50 newspaper articles, and 70 radio and 25 television stories were tracked by BC Hydro's media relations.

Senior BC Hydro officials also provided regular interviews and hosted a technical briefing on the second day of the outage, outlining restoration plans.

On the third day of the outage, BC Hydro's President and CEO hosted a conference call for radio and print reporters and conducted on-camera interviews with the major television news stations. The President and CEO also provided media interviews after power was fully restored to thank customers for their patience. An opinion piece by BC Hydro also appeared in the *Vancouver Sun* on July 25, 2008.

9 Plans for Improvement

The dual radial underground system has provided downtown Vancouver with reliable service for decades. However, the demands on the system have grown significantly and the infrastructure is operating near capacity. The downtown Vancouver outage in July 2008 highlighted the vulnerability in the design of the underground cable system where standby circuits are located in close proximity to running circuits and may not provide appropriate levels of redundancy and contingency.

Currently, there are no distribution standards that limit the number of circuits that are permitted to run through a manhole. A preliminary survey of other Canadian utilities of their system design practices suggests that Vancouver has a higher concentration of running circuits within duct banks compared to its peers.

The downtown outage was a rare event for a system that has historically achieved very high customer reliability performance. However, there are opportunities to mitigate risk of a similar event in advance of significant longer term investment in distribution infrastructure.

The purpose of this report (Section 2.1) was to:

- investigate the nature and root cause of the downtown Vancouver power outage on July 14, 2008; and
- make recommendations to:

  a. mitigate the risks and reduce the damage to BC Hydro's underground electrical distribution system in the event of future incidents;
  b. improve resiliency in the underground system; and
  c. develop system planning criteria and risk mitigation strategies that support the above.

Based on the Powertech investigation and the findings and recommendations made by the independent panel, BC Hydro will review and/or undertake the following plans for improvement.

9.1 Risk Mitigation

Safety:

- The establishment and assignment of a BC Hydro Fire Marshall position is currently underway. The mandate of this position would be to establish the necessary resources and organization to support fire suppression, training, inspection and liaison activities with fire departments, and evaluate opportunities to install fire suppression and deluge systems in the underground distribution system as appropriate to mitigate risk.
- Modify manhole entry procedures to include infrared temperature readings of splice and cable variations to ensure it is safe to enter.
- Ensure BC Hydro "Safety by Design" practices incorporate fire hazard mitigation.
- Define protocols and training of both BC Hydro and Vancouver Fire Department in the appropriate methods of managing electrical fires to enhance both employee and public safety.
- Evaluate use of additional fire retardant barriers (blankets, tape).

9.2 Improving Resiliency

Inspections and Maintenance:

- A BC Hydro initiative is underway to investigate the downtown underground infrastructure to provide recommendations and actions for improvements to critical infrastructure in the downtown core.
- Ensure the criteria for prioritization of repairs is appropriate and that repairs requiring immediate attention are identified clearly.
- Identify and inspect all components similar to the connector that failed and initiated this event.
- Implement periodic infrared testing of all separable insulated connectors.
- 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 BC Hydro's Strategic Asset Management group.
- 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.

- Review the accountabilities, procedures, processes and standards for the preparation, review and finalization of inspection and associated maintenance.
- Evaluate opportunities to leverage technology through the use of RFID (radio frequency identification) tags to track asset inventory and installation records.
- Enhance work management database of components (splices) and component repairs made by BC Hydro and contractor crews. This information would provide system information if defective parts are identified, warranty details for contractor installations and/or training opportunities.

9.3 System Planning

Planning Criteria:

- Following the transformer outage at Cathedral Square in July 2007, BC Hydro and BCTC jointly sponsored a study into the reliability of the system in downtown Vancouver. The scope of the first phase of the project was to review alternatives to reduce restoration time due to equipment failure. The study is currently under review with additional work identified to refine the potential project scope and cost estimates. This study will form the basis of an investment strategy for both transmission and distribution infrastructure in Metro Vancouver.