TRANSPOWER

Vector

Penrose Substation Fire

05 October 2014

Investigation Report

Acknowledgement

Transpower and Vector regret the disruption to customers during the 5 October 2014 outage. Everything was done to ensure the network was repaired as quickly as possible, however we do understand and acknowledge the impact the outage had on homes and businesses.

Transpower and Vector acknowledge the dedication and commitment of their employees and service providers, and the NZ Fire Service, in responding to this incident.

This report details findings and recommendations from a joint Transpower and Vector investigation into the fire at Transpower's Penrose Substation.

Both Transpower and Vector have taken the learnings from the investigation to assist in detecting and mitigating similar risks in the future.

Vector Limited is a publicly-listed company that owns and operates the electricity network in Auckland.

Transpower New Zealand Limited is a State Owned Enterprise that owns and operates the New Zealand transmission grid.

Executive Summary

Incident

In the early hours of the morning on Sunday 5 October, New Zealand Fire Service (NZFS) and Transpower personnel were called out to Transpower's Penrose substation. Upon arrival at the substation, they observed thick smoke which was subsequently found to be coming from a fire in a concrete cable trench containing Vector cables and a Transpower lighting cable.

Investigation

Transpower and Vector have conducted a joint investigation into the incident. It covered:

- the cause;
- extent and impact of the outage;
- risk mitigations, and whether these operated according to design; and
- key learnings and recommendations for the future.

The investigation was assisted by an independent international power cable expert, and laboratory testing of cable and joint samples.

Cause

The cause of the fire was the failure of a cable joint in a Vector distribution (11 kV) cable within a concrete cable trench running east-west across the Transpower 220 kV switchyard at Penrose. The joint failed at 23:21 on Saturday 4 October 2014

The cable joint that failed is a common type used in electricity networks internationally.

Extent and Impact of the Outage

The fire spread to all of the cables in the concrete cable trench. This led directly to the loss of electricity supply to 39,043 Vector customers.

To provide safe access for the NZFS personnel to fight the fire, a large part of the Penrose substation had to be de-energised. As a result, a total of 75,339 customers were without power from 03:08 on 5 October 2014. Supply to the Auckland CBD was not affected.

Vector made extensive use of backfeeding within its network to restore supply to affected customers. This limited the number of customers without supply for more than 24 hours to 20,257.

Cable Trench

The large concrete cable trench at Penrose is unusual. There are no directly similar installations at other Transpower substations. Distribution cables are normally buried, but at Penrose the sub-surface material is hard volcanic rock. The trench was constructed in the 1960s to provide an efficient means for a large number of distribution cables to traverse the site, avoiding difficult multiple excavations for individual cable routes. This resulted in multiple cables installed in air. Prior to the 2014 incident, there had been no faults of cables in the trench.

The investigation surveyed network companies in New Zealand, Australia and the United Kingdom, and this confirmed structures such as short tunnels, culverts and trenches are used for installation of cables in locations where burying the cables is not practicable. Within these structures it is common to have multiple cables installed.

Risk Mitigations

Transpower, Vector, and their external experts, had not identified a risk of fire in the cable trench. The investigation did not reveal any records of cable fires from joint failures on Vector's network before the incident. The surveys of network companies confirmed that cable fires from joint failures are very rare. Information on cable fires that have occurred was found to not be publicly available.

In the few cases where cable fire reports have been presented in industry forums overseas, the cause of the fire, remedial measures and lessons learnt are not given in sufficient detail to inform others. A specific review of Penrose site risks carried out by Transpower in 2012 did not identify the cables in the trench as a concern.

The scale of the incident meant emergency response plans were activated, and these operated effectively.

Restoration of Supply to Customers

Transpower and Vector promptly mobilised all necessary resources, and accessed existing spares holdings to complete repairs without delay.

Customers were kept well informed during the outage through regular updates delivered directly across a wide range of channels.

Restoration of full supply to customers took place over three days as temporary cables were installed. As a result:

36,296 (48%) of customers were restored by 18:21 Sunday

54,113 (72%) of customers were restored by 08:00 Monday

73,552 (98%) of customers were restored by 08:00 Tuesday

75,339 (100%) of customers were restored by 14:08 Tuesday

Safety

There were no reported injuries to members of the public, Transpower and Vector staff, their contractors, or emergency services personnel, during the incident and the extensive recovery works. Action by retailers was taken to identify and manage the needs of known medically dependant consumers affected by the outage.

Recommendations for Transpower and Vector

Recommendations are based on learnings from the joint investigation, including from the independent cable expert's report. It is recommended that:

Transpower and Vector jointly:

1. Implement changes at Transpower's Penrose substation as part of the recovery works, including installing replacement cables in two trenches containing segregated ducts for each cable, to effectively eliminate the risk of fire causing multiple cable failures.
2. Transpower and Vector review locations where power cables are installed in open air environments to identify any asset risks and take appropriate actions to mitigate these risks.
3. Review contractual terms and management processes at points of connection to ensure key learnings from the incident are incorporated.

Vector:

1. Review and update its relevant policies, procedures and practices with respect to cables, and cable joints installed in air.
2. Review and update its risk management framework, and risk identification processes, to incorporate key learnings from the incident.
3. Update its standard operating procedures to apply key learnings from the incident.

Transpower:

1. Improve the process for considering customer requests for access and occupation of Transpower land along with the potential risks throughout the lifetime of the assets.
2. Incorporate learnings into asset management practice, design standards and risk management policies.
3. Update standard operating procedures to apply key learnings from the incident.

Implementation of Recommendations

Significant progress has been made on implementing the recommendations set out above. All actions identified to implement the recommendations are underway with a number already completed.

At Penrose, a permanent solution for cables damaged in the fire has been designed and agreed between Vector and Transpower. The replacement cables will be installed in fire segregated ducts along two independent routes across the 220 kV switchyard. This work is being carried out in co-ordination with a project to install a new indoor 33kV switchroom and is scheduled to be completed by June 2016.

Transpower and Vector have each undertaken surveys of their sites to identify situations where failure of cables in air could lead to significant consequences. These surveys have not identified any issues of immediate concern. However, at several sites, interim risk mitigations for cable joints have been implemented as a precautionary measure.

Transpower has developed a process for a comprehensive review of Access and Occupation schedules, to update the records of customer assets on Transpower land, and to evaluate the risks associated with those assets. The documentation updates and risk reviews for the most critical sites are scheduled to be completed within 12-18 months.

Improvements to risk identification and review processes are underway within both organisations, together with enhancements to relevant asset management standards and operating practices.

Table of Contents

1 Introduction

At 02:17 on 5 October 2014, a member of the public rang Emergency Services to report hearing explosions coming from Transpower's Penrose substation. Penrose substation is a large unmanned substation located in the industrial suburb of Penrose, approximately 10 km south-east of the centre of Auckland. When the NZ Fire Service (NZFS) arrived at the substation, they saw thick smoke in the 220 kV switchyard. This was subsequently found to be due to a fire in a cable trench[1] containing Vector cables and a Transpower lighting cable.

Fire damage to the cables in the trench led to feeder trippings that interrupted supply to over 39,000 customers. Transpower then shut down the affected part of the substation to allow NZFS personnel safe access to fight the fire.

As a result, by 03:08 on Sunday 5 October, 75,339 Vector customers supplied from Penrose were without power. Electricity supply was restored to 54,113 (72%) customers within 24 hours and 72,744 customers (97%) within 48 hours. However, the extent of the damage caused by the fire meant that supply to the final customers was only restored in the afternoon of Tuesday 7 October.

Immediately after supply was restored to all customers, Transpower and Vector announced a joint investigation into the Penrose fire and outage, with the investigation to cover:

- The cause of the event on 5 October 2014;
- Extent and impact of the outage;
- Risk mitigations and whether these operated according to design; and
- Key learnings and recommendations for the future.

Transpower and Vector each appointed independent investigators, and jointly engaged Brian Gregory (of Cable Consulting International), a leading international cable expert, to assist with the investigation. Results of this investigation are presented in this report.

In addition, the Minister of Energy and Resources requested the Electricity Authority (EA) to carry out an inquiry. Transpower and Vector have co-operated fully with the EA's investigators. This report has been provided to the EA as an input into their investigation.

A number of reports have been prepared as part of the investigation. These cover areas relevant to the investigation, including customer engagement, asset and risk management, and a history of the development of the Penrose site and surrounding network. Appendix A provides a list of these reports.

[1] The fire occurred in the cable trench that runs east-west across the 220 kV switchyard, references to a cable trench are to this particular trench unless specifically noted otherwise

2 Customers

This section provides an overview of service to customers and the impact of the incident on customers.

A separate background report on Customer Engagement has been prepared and provides further background to this section of the report.

2.1 Service to Customers

Transpower and Vector are responsible for the physical delivery of electricity to customers as shown in Figure 1. Vector's electricity network is used to transport electricity to over 540,000 customers[2] in Auckland via over 18,000km of overhead lines and underground cables.

Figure 1 Electricity System

In recent times, the reliability of the service received by Vector's customers has ranged between 99.97 to 99.98%[3]. This is a near continuous supply of electricity to customer's homes and businesses.

Whilst customers receive a very high level of reliability; Vector does not, and cannot, provide a 100% continuous supply of electricity due to:

- Upstream failures in the electricity system;
- External influences on its network beyond Vector's control (extreme weather, third party damage to the network, i.e. car vs. pole); and
- The failure of equipment on the network

Vector's aim is to provide a high level of reliability at an affordable cost.

The level of reliability experienced by Vector's urban customers is comparable to other major overseas cities, such as Sydney and London.

[2] The number refers to the number of ICPs connected to Vector's network. An ICP (Installation Control Point) is a customer connection to the Vector network. An ICP can be a residential property, a small business or a larger commercial or industrial site. Where the term customer is used in this paper it refers to an ICP.
[3] These include Transpower and Vector outages and are a reflection of the high level of reliability of both networks.

There are certain points in the electricity system, as in all infrastructure networks, where a failure can result in disruption of supply to large numbers of customers. Although such failures are infrequent, they can occur. Since the Penrose incident, significant failures have occurred in London and Washington DC.

On 1 April 2015, an electrical fire in an underground utilities tunnel in Holborn, London, resulted in affected customers being without electricity for up to three days. On 7 April 2015, an explosion and fire at a Maryland power substation resulted in widespread power outages in Washington DC affecting tens of thousands customers intermittently across the city.

2.2 Customers Supplied by Penrose Substation

Penrose substation is the largest of the fourteen connections between the national transmission grid and Vector's electricity network across the Auckland region.

Penrose substation has two separate switchyards (110 kV and 220 kV). Customers in the residential suburbs in the Eastern Bays, Remuera and Epsom, the commercial/retail suburb of Newmarket, and the industrial area through Penrose, Westfield and Mt Wellington are supplied from equipment in the 220 kV switchyard. Customers in the Auckland CBD and neighbouring suburbs are supplied from the 110 kV switchyard via cables installed in Vector's CBD tunnel[4] There are multiple corridors for Vector's supply cables to exit the Penrose substation. A schematic of the Penrose substation is shown in Figure 2.

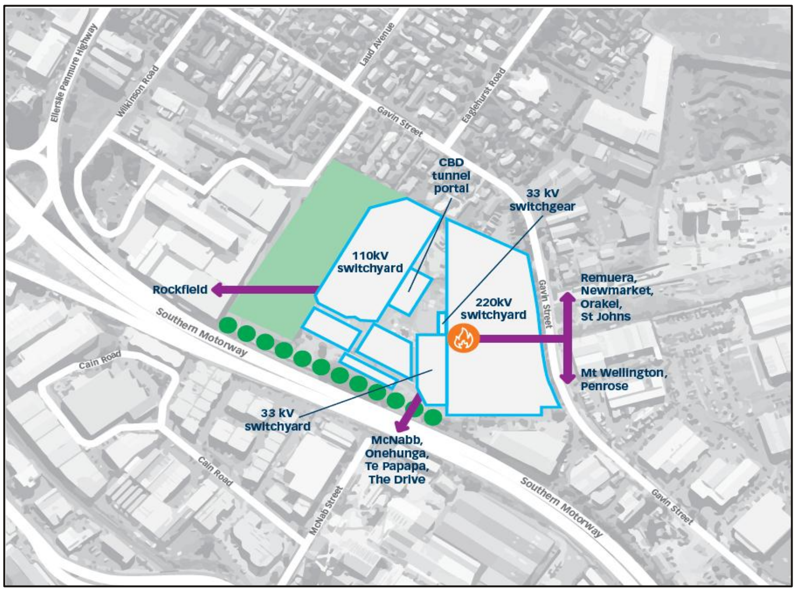


Figure 2 Penrose Substation

[4] This is under normal network configuration. The CBD can also be supplied from other Transpower substations at Mt Roskill and Hobson Street.

2.3 Customer Impact

The fire damaged a number of cables, causing them to trip. Transpower then shut down the 220 kV switchyard to allow NZFS to safely enter the substation and extinguish the fire. As a result, 75,339[5] customers were without power from 03:08 on Sunday, 5 October 2014. Supply to the approximately 36,000 customers in the CBD was not interrupted.

Supply was also interrupted to KiwiRail and Southpark - Transpower's direct-connect customers at Penrose. Figure 3 shows the general area of customers affected by the incident.

Figure 3 General area of customers affected by incident

The mix of Vector's customers affected is summarised below in Table 1 both in terms of customer numbers and total size (load).

Customer Type	Number of Customers	Daily Load (MWh)
Residential	64,146 (85%)	1,200 (31%)
Small business	9,498 (13%)	529 (13%)
Industrial and large commercial	1,695 (2%)	2,214 (56%)

Table 1 Customers Affected by Penrose Fire

[5] Some early media reports stated that up to 85,000 customers were without power.

3 Incident and Restoration

This section covers the incident (including events leading up to the incident), the operational response to the incident, and recovery efforts to restore supply to all customers. Recovery efforts include initial re-livening of the site and repairs to damaged cables. A summary timeline of the incident is shown in Figure 4 and a summary timeline of the response is shown in Figure 5.

This section also describes how the operational response was managed in terms of communication to affected customers, safety, and preventing further damage to equipment after the initial incident.

3.1 Incident

From 02:04 on 5 October 2014, the Transpower remote control system recorded a series of unusual alarms from equipment at Penrose substation. Many of the first alarms were associated with the 220/33 kV supply transformer T11. At 02:09, Transpower's National Grid Operations Centre (NGOC) called out a Transpower Maintainer to go to the substation to investigate the cause of the alarms. T11 subsequently tripped at 02:11 and the Vector Electricity Operations Centre (EOC) was advised.

A member of the public rang Emergency Services at 02:17 on 5 October 2014 to report hearing explosions coming from the Penrose substation.[6] NZFS immediately dispatched appliances in response to the call, and notified NGOC. The fire appliances arrived between 02:26 and 02:28.

The Maintainer met the first response fire appliances at the substation entrance and opened the security gates at 02:41.

The Maintainer reported seeing thick smoke in the vicinity of the 220/33 kV supply transformer T11 when he arrived. This quickly developed into above ground flames, between the adjacent transformers T10 and T11, and the 33 kV indoor switchgear building located in the 220 kV switchyard.

Transpower's site access procedure requires emergency services personnel to be accompanied by an authorised person, because a live, high voltage switchyard is a hazardous environment. Fire fighting in a live switchyard is particularly hazardous.

[6] The loud noise of four circuit breaker trippings between 02:11 and 02:16 was most likely the source of the "explosions" that the resident in Gavin Street heard which caused him to call emergency services.

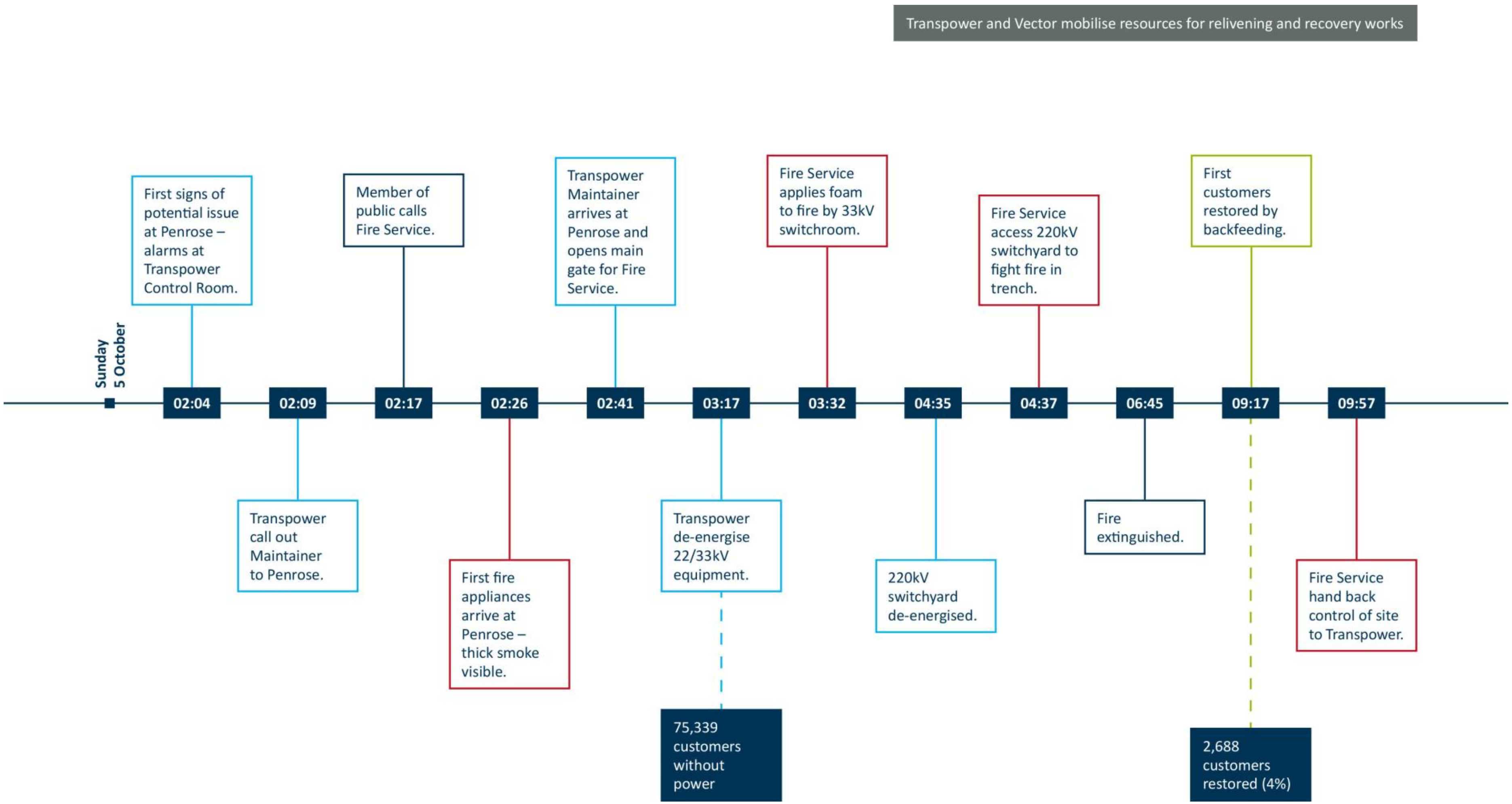


Figure 4 Time Line - Incident

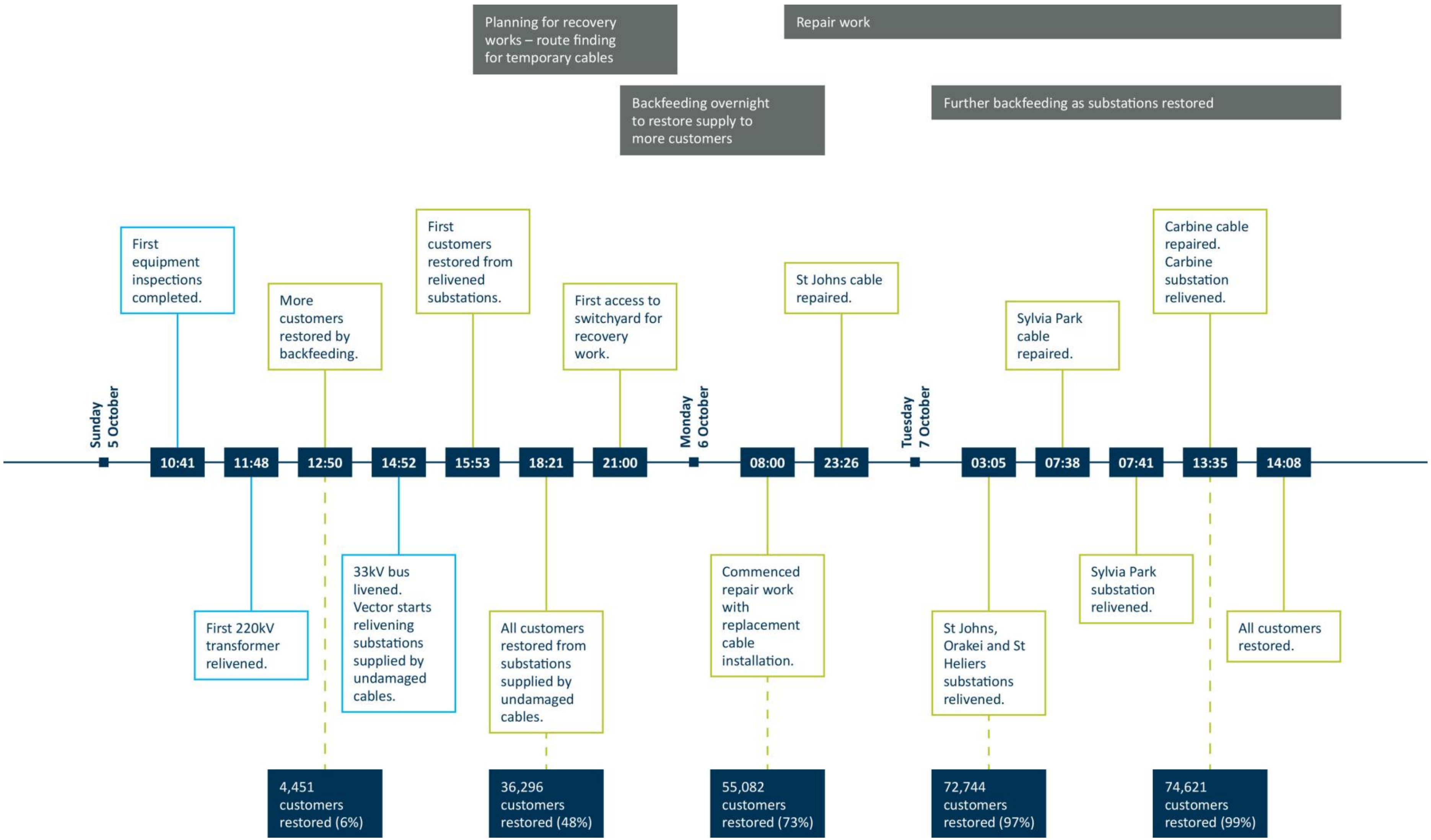


Figure 5 Time Line – Relivening and Repairs

Figure 6 gives an aerial view of the Penrose substation.

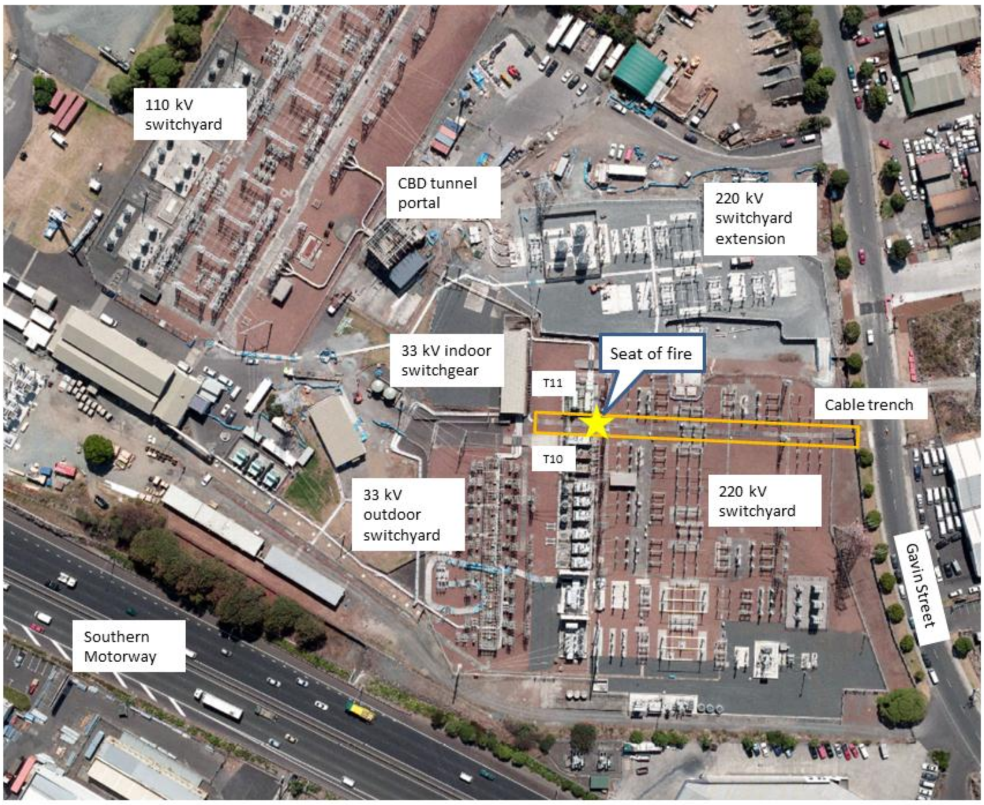


Figure 6 Penrose Site

At 02:50, the Vector EOC was informed by Transpower's NGOC that all 33 kV equipment in the 220 kV switchyard at Penrose substation was being de-energised to enable safe access for NZFS. This required a large number of individual operating actions to safely remove all 33 kV equipment from service.

NZFS was told that the area was safe to enter at 03:22, and firefighting commenced with the application of foam at 03:32. By this stage, flames in the trench had spread from the area between the transformers to near the 33 kV indoor switchgear building, and were threatening the building.

The fire adjacent to the switchgear building was quickly contained, preventing extensive and irreparable damage to the equipment inside. At this point, it became clearer that the Vector cables in the cable trench were on fire and had suffered damage.

The fire continued to spread eastwards along the cable trench towards Gavin Street. Arcing and corona discharging was also occurring in the 220 kV switchyard. Damage from flashovers could have impeded restoration of electricity supply once the fire was extinguished. To avoid equipment damage and to allow NZFS access, the entire 220 kV yard was de-energised.

No further customers were impacted by this decision because the 110 kV supply to the CBD from Penrose remained in service during the incident. Risk to the CBD during this event was mitigated by the availability of alternative Transpower and Vector supplies into this area.

At 04:37, fire fighters entered the 220 kV switchyard. The fire was contained by 06:45. NZFS transferred control of the site back to Transpower at 09:57, and remained on standby for any flare-ups.

A Sequence of Events of the incident is set out at Appendix B.

3.2 Events Leading to the Incident

At 23:21 on Saturday 4 October 2014, there was a feeder fault in a Vector 11 kV feeder (designated Remuera K10) supplied from the Remuera zone substation. The feeder supplied parts of Remuera and Ellerslie in the vicinity of Ladies Mile, Marua Road and Michaels Avenue and is comprised of sections of overhead line and underground cable. It included a section of cable installed in the cable trench at Penrose substation.

The investigation into the Penrose incident subsequently revealed that it was this feeder fault that caused the fire. Further details on the investigation are provided in Section 4.

At the time, the Remuera K10 event was considered by the Vector EOC controller to be a routine feeder fault. Accordingly, the EOC controller notified the faults dispatcher, who called out a faultman to carry out a line patrol and visual inspection to locate the fault. The feeder comprises sections of overhead line and underground cable, and has a history of faults caused by tree branches on the overhead lines.

The faultman started his route patrol from the Remuera substation, following the overhead line towards the end of the feeder as is standard practice. He was in regular contact with the controller during the patrol.

The line patrol suggested the fault was in the overhead section along Michaels Avenue between Marua Road and the Ellerslie Panmure Highway based on information from fault passage indicators. As no physical evidence of the fault had been identified during the line patrol, and given the history of vegetation related faults[7] on the overhead line sections of the feeder, the controller concluded it was a transient fault. The controller therefore manually reclosed the feeder.[8] The feeder was closed at 01:21 on Sunday morning and tripped immediately.

At that stage, a cable riser at the end of the overhead section was considered to be the most likely cause of the fault. The residential load in Celtic Crescent was transferred to the McNab K06 feeder to restore supply to those customers, and the remainder of Remuera K10 feeder was sectionalised, so that the location of

[7] Such as vegetation or tree branches which had hit the lines and fallen to the ground.
[8] In accordance with Vector standard operating procedure at the time.

the fault could be isolated. While this was occurring, the supply to Remuera zone substation was lost, and resources were then diverted to Penrose.

A review of the actions undertaken to locate and isolate the Remuera K10 feeder fault has been completed as part of the investigation. The review concluded that these actions were carried out in accordance with Vector's standard procedures at the time and recommended specific amendments to the procedures in light of the incident.

3.3 Operational Response

This section describes the actions taken by Transpower and Vector in their respective control rooms. It also covers actions from NZFS in fighting and extinguishing the fire and handing control of the substation back to Transpower.

3.3.1 NGOC and EOC Actions

Transpower (NGOC) and Vector (EOC) control rooms both became aware of the incident independently of each other due to alarms from their respective supervisory control and data acquisition (SCADA) systems.

The first contact between them was a phone call from NGOC to EOC at 02:09. At this point, it was considered to be an issue with a Transpower transformer (T11) as a number of alarms had been received relating to its condition. A subsequent phone call from NGOC at 02:23 informed the EOC that a number of assets had tripped, and that the NZFS had received a report of an explosion at Penrose substation.

Both control rooms escalated the incident in accordance with their normal processes. Senior managers travelled to their respective control rooms to oversee incident response, and Transpower and Vector personnel were dispatched to the substation.

At 02:50, Transpower informed Vector that the 33 kV equipment in the 220 kV switchyard would be de-energised to allow safe access for NZFS. This was completed at 03:17. At this point, all supply to the Vector network at 33 kV and 22 kV was disconnected.

During this period, there was uncertainty as to what was on fire and which assets were affected.

A Transpower Manager arrived at Penrose Substation at 03:34 to oversee management of the site, and based himself in the NZFS Command Vehicle. At approximately 03:40, he advised Vector that the fire was in a cable trench containing Vector cables. Once it was confirmed that Vector assets were damaged, a Vector Manager travelled to Penrose substation to liaise with Transpower on site.

While the NZFS was controlling the fire, Transpower and Vector mobilised resources in preparation for relivening and recovery works.

The resources for relivening were in place before NZFS handed control of the site back to Transpower. Vector's operations engineers reviewed plans for backfeeding supply into the affected areas in preparation for restoring supply to customers. Once the extent of damage was confirmed and recovery activities prioritised, these plans were actioned.

3.3.2 NZ Fire Service

NZFS was contacted at 02:17 by a member of the public with a report of explosions. Three fire appliances were initially dispatched from Ellerslie, Remuera and Mt Wellington stations. They arrived between 02:26 and 02:28, and gained access to the substation at 02:41 when the Transpower Maintainer arrived. They were not able to access the affected area of the 220 kV switchyard until power was isolated. The initial assessment was that a fire was occurring on top of the cable trench.

At 02:58 switching commenced to de-energise the live 33 kV equipment and at 03:02 NZFS commenced bringing in foam equipment. All cable failures that directly caused a loss of supply had occurred by 03:05 well before NZFS fire control activities commenced at 03:32.

All live equipment near the west end of the trench was de-energised by 03:17. At 03:22 NZFS was advised it was safe to enter the area adjacent to the 33 kV switchgear building. Foam was then applied to extinguish the fire in this area.

The fire continued to burn in the opposite direction along the trench to the east, in the 220 kV switchyard. The smoke was causing arcing and corona discharge in live 220 kV equipment. NZFS were unable to enter this area until it was de-energised. Following consideration of the impact on supply to the broader Auckland area, the entire 220 kV switchyard was de-energised at 04:37 to allow NZFS to continue fighting the fire along the trench.

Extinguishing the fire in the trench took some time, as difficulties were initially encountered removing the concrete trench covers. High expansion foam had to be used as the cables were on different levels. Two foam generators were required to prevent re-ignition as firefighters moved along the trench. The fire was finally contained at 06:45. At 08:00 NZFS flooded the trench with water to cool the area and prevent flare ups.

Additional fire appliances and other resources had been mobilised during the firefighting. At the peak there were;

- 6 Fire Appliances,
- 1 Command Unit,
- 1 Foam Tender,
- 1 Aerial Appliance, and
- 32 Fire Fighters

Due to the size and complexity of this incident, the NZFS dedicated substantial resources to safely extinguishing the fire.

At 09:57, control of the site was transferred back to Transpower. The NZFS remained on standby to manage any potential flare ups.

3.4 Relivening

Operational co-ordination between Transpower and Vector during relivening and repair works functioned effectively. As it was a Transpower site, once control of the site was handed back to Transpower from NZFS, established site procedures were used, such as site access and permitting for works. Within these existing procedures Transpower and Vector recognised the need to quickly restore customers and took a pragmatic stance without compromising safety or risking damage to assets on site. Co-ordination activities involved Transpower, Vector and their respective contractors and were dealt with during the initial restoration process via regular update and planning meetings on site.

Restoration priorities were established between Transpower and Vector once control of the site was transferred back to Transpower. The initial focus of restoration work concentrated on securing a supply into the Penrose 220 kV bus with sufficient capacity to supply the anticipated loads.

All equipment had to be inspected before it was re-livened, and restoration had to follow a gradual process, to ensure it was carried out safely and no further equipment failures occurred. As a further safety precaution, personnel were cleared from the switchyard before each major item of equipment was energised.

The first equipment inspections were completed at 10:41 allowing step-by-step restoration of the 220 kV supply to commence. The first of the 220/33 kV supply transformers (T7) was energised at 11:48.[9] This was followed by progressive inspection and relivening of the remaining grid equipment in the 220 kV and 33 kV switchyard.

Communications during the restoration phase were affected by degradation of the cell phone service from around 11:00. Restoration was suspended for approximately one hour around 13:47 when the NZ Fire Service had to be called to deal with smouldering timber that had re-ignited. Some equipment that had already been livened had to be de-energised again, to ensure safe access for fire fighters.

In parallel with the Transpower restoration work, Vector was assessing the extent of damage to feeder cables and determining the feeders that could be safely restored.

Livening of the 33 kV bus commenced at 14:52. Vector then started restoring supply to distribution zone substations fed by cables that had not been damaged in the fire. By 18:21, Vector had relivened seven of its zone substations, restoring supply to over 36,000 customers in Epsom, Newmarket, Glen Innes, Penrose and Westfield.

[9] This was a critical milestone, because it restored local service power supply to the substation. The essential controls, protection and monitoring equipment of the entire substation had been operating on battery backup for 8 hours until this point.

Transpower continued restoring the Penrose 33 kV supply transformers to provide additional capacity and improve the security of supply. After smoke residue had been cleaned off equipment, the 220/33 kV transformer T8 was livened at 16:26.

The restoration process was expedited by Transpower operating equipment above normal ratings for short periods. This allowed Vector to restore supply to customers earlier, while Transpower continued inspecting 220 kV equipment.

Throughout Sunday night, Vector's control room carried out extensive reconfiguration of its network to backfeed supply into affected areas. This resulted in a further 18,786 customers being restored overnight on Sunday (nearly half of the customers supplied by the damaged cables in the trench).

Additional Transpower staff were brought to Auckland from other areas to enable 24 hour coverage during the recovery phase. Specialist engineering resources were also deployed to the site to assist with the damage assessment and restoration.

Full restoration of the 220 kV switchyard was the next priority, to provide extra supply security for the CBD from Transpower's Pakuranga substation via Penrose, into the Hobson Street substation. Full supply security to the Penrose Substation was restored at 21.22 on Wednesday 8 October.

3.5 Cable Repairs

The repair works to restore supply to the remaining 20,257 customers were large and complex, and carried out with urgency. All fourteen sub-transmission circuits in the cable trench were damaged beyond repair and needed replacing. The recovery initially focused on repairing five cables, each supplying a different zone substation, to restore supply to customers. The remaining eight cables were then repaired to restore full security.

The recovery effort was affected by significant construction works in progress at the substation prior to the incident, and the additional hazards associated with working on a construction site. There was also a need to co-ordinate site activities and access with Transpower personnel carrying out cleaning of smoke damaged equipment immediately after the fire.

While NZFS was fighting the fire, Vector organised the personnel and resources necessary to carry out the repairs, in anticipation of gaining access to the site. As the cable trench was damaged and could not be used by Vector, alternate temporary routes through the substation had to be agreed for the new cables. These were agreed between Transpower and Vector by Sunday evening. Vector's contractor gained access to the switchyard to commence the cable repairs at 21:00.

Each repair required a damaged section of cable to be cut out and a replacement section of new cable joined. Vector was able to access all necessary materials (cables, joint and accessories) from its strategic spares holdings and from suppliers, to enable repairs to commence as planned.

Crews worked continuously to complete repairs. Working conditions over the initial 24 hours of the repair operation were challenging, with periods of severe rain, high wind and hail during Monday night.

Repairs to the first two cables were completed by early morning on 7 October, and a third cable by 13:35 that day enabling supply to be restored to all customers shortly thereafter. Repairs to all remaining cables were completed by 15 October. The repair effort was a 24-hour operation for the first week before reverting to a daily operation to manage fatigue impact.

Over fifty people were dedicated to working on the recovery effort and over 4,000 man hours were worked without any safety incidents. In total over:

- 8 km of temporary cables was installed;
- 60 joints were made;
- 1,000 cable supports were used;
- 2,000 cable clamps were installed; and
- 5,000 sand bags were used on the site.

3.6 Customer Restoration

Vector's focus was on safely restoring all customers, as quickly as possible.

Restoration of all customers was achieved by relivening customers supplied by undamaged cables, backfeeding to supply customers from adjacent substations, and repairs to damaged cables.

36,296 (48%) of customers restored by 18:21 Sunday

54,113 (72%) of customers restored by 08:00 Monday

73,552 (98%) of customers restored by 08:00 Tuesday

All customers were restored by 14:08 on Tuesday 7 October

Vector's network design enabled extensive use of backfeeding to restore supply to affected customers from adjacent areas that were unaffected. This was carried out in stages starting on the Sunday morning. Over 23,000 customers (nearly one third of those affected) were restored this way, meaning power was restored to them earlier than waiting for repairs to be completed.

Restoration milestones are set out in Table 2.

Date/Time		Description	Customers Restored (cumulative)
Sun 5 Oct	09:57	NZFS return control of site to Transpower	
	12:50	Some customers in Onehunga, Newmarket and Mt Wellington restored via backfeeding	4,451 (6%)
	14:52	Inspections and safety checks completed. 33 kV bus relivened.	
	18:21	Restoration of all substations with undamaged cables	36,296 (48%)
Mon 6 Oct	09:06	Backfeeding to restore supply to customers in St Heliers, Onehunga, Mt Wellington and Remuera	55,082 (73%)
Tue 7 Oct	07:41	Restoration of St Johns, Orakei, St Heliers, and Sylvia Park substations using repaired (new) cables	73,292 (97%)
	14.08	Restoration of supply to all customers[10]	75,339 (100%)

Table 2 Customer Restoration Milestones

3.7 Customer Communications

There was extensive communication during the outage to a wide range of stakeholders, including affected customers, Emergency Services, council and government.

The first customer communication was an update on Transpower's Facebook page at 03:20 on Sunday 5 October. The first media statement was issued at 03:50. In total, eighteen customer updates were provided by Transpower and Vector during the incident, ensuring a steady stream of information was available to customers. Transpower and Vector's communication protocols and plans worked effectively.

Customer updates were delivered via a broad range of communication channels, including Vector's recently developed Smartphone outage application, which enabled rapid and wide dissemination of the latest information.

Vector also provided additional information to retailers to assist them in managing medically dependent customers. Further details on customer communications are provided in the background report on Customer Engagement.

[10] A few customers were on their own generation at this point and required short arranged outages to reconnect to Vector's network.

3.8 Safety

Safety is always the highest priority during incidents, but never more so than when fire is involved and Emergency Services are required to enter electrical substations. Every effort was made to restore supply to customers as quickly as possible without compromising safety.

The fire was contained without threat to nearby businesses and homes. There were no reported injuries or safety incidents affecting members of the public, Transpower and Vector staff, their contractors, or members of Emergency Services during the incident and the extensive recovery works. The site access procedures and operating protocols worked effectively.

During the first week after the fire, short sections of the cable trench were uncovered where the NZFS had gained access to fight the fire. This introduced a potential exposure to personnel from contaminants. The recovery works were carried out well away from this area. The exposure risk was identified early during the site inspection and additional precautions were then taken for personnel working near the cable trench. Personnel that entered the trench wore full cover disposable overalls and P3 respirators. The trench was covered and sealed as the inspection progressed.

Tonkin and Taylor carried out a site inspection and sampling of potential ground contamination, and the results confirmed the additional precautions were appropriate. Paragon Health and Safety also confirmed there were low to very low risks from exposure to contaminants. Results of health testing of workers at the site showed no issues of concern.

Public safety was managed through various mechanisms. When power was first lost, Transpower's NGOC contacted NZ Police at 02:30 to advise them of the incident. Emergency Services were also provided with regular updates of the situation in accordance with standard operating procedures. NZ Police managed traffic at the site and throughout the affected area, as traffic lights were out of service. The NZFS checked local residents were not affected by the fire and smoke.

Communications to the broader public were provided using a range of mechanisms as described in the Customer Communications section 3.7.

3.9 Damage to Equipment

The fire irreparably damaged all the cables in the cable trench, some Vector cables in racks adjacent to the end of the trench, and Transpower control cables that passed across the trench in several places. There was also smoke residue on 220 kV insulators, and scorching to the external cladding of the 33 kV switchgear building.

Protection schemes ensure that electrical equipment is isolated to minimise damage during electrical faults. The protection schemes at Penrose performed as designed with two exceptions[11].

There is a risk when re-livening equipment that undetected damage may lead to faults that cause more significant damage. For some critical assets, the repair times can be months and therefore extensive checks are made to ensure equipment is undamaged before re-livening. As a result of the careful approach taken in restoring supply, there was no additional equipment damage at Penrose substation other than that sustained during the fire.

When reconfiguring the network to restore supply by backfeeding, there was the potential to overload assets and cause damage. The morning and evening peaks caused short-term overloading in the Glen Innes area, which was managed through rolling outages. There were two localised cable faults in this area.

[11] For two of the faults caused by the fire, the main protection did not operate because the fire had damaged communication cables. These faults were cleared by the backup protection, which did not operate exactly as expected. While this did not contribute to the extent of the outage, the operation of the backup protection will be reviewed as part of the current project to replace the outdoor 33 kV switchyard.

4 Investigation

4.1 Methodology and Process

Transpower and Vector commissioned a joint investigation into the incident, appointing independent investigators to determine the cause and identify key learnings for the future.

The joint investigation has focused on the cause of the incident and to assist in this process, Brian Gregory (Cable Consulting International), a cable expert from the United Kingdom, was engaged.

The methodology adopted by the investigation team is described in the flow chart in Figure 7. The investigation intended to identify what happened and, to the extent possible given the damage, why it happened. The historical development of the site, and Transpower and Vector asset management practices provide context. The operational response from Vector, Transpower and NZFS determined customer restoration timeframes. From all these elements lessons can be learned for the future.

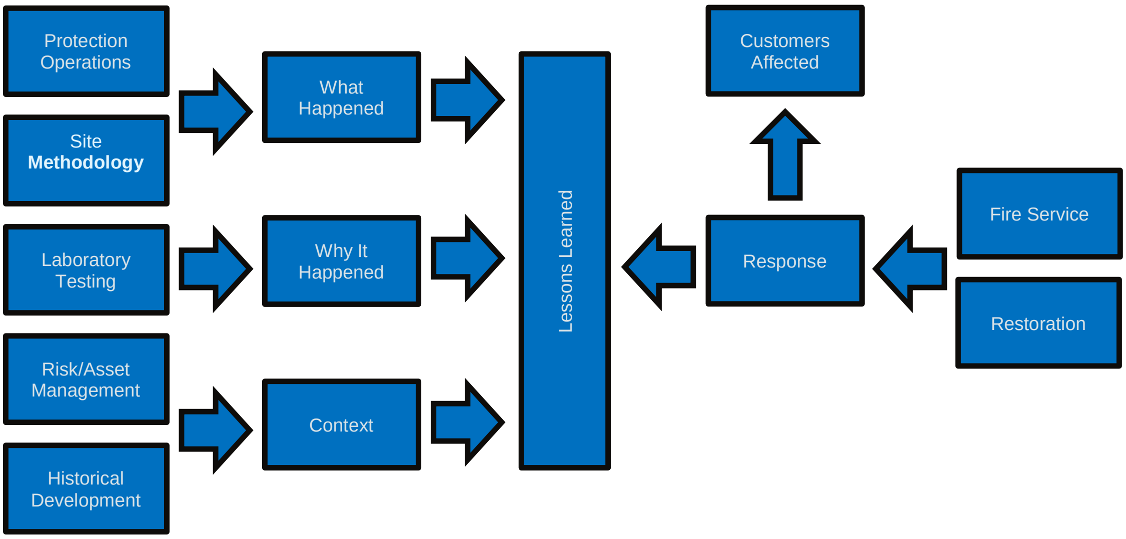


Figure 7 Investigation Methodology

The investigation commenced with an inspection of the damaged cables led by Brian Gregory. The NZFS investigator also participated in the inspection, to give the investigation team the benefit of his extensive experience in determining the seat of a fire.

A summary of the report from the NZFS is included in Section 4.2, with a full copy available on the NZFS website, www.fire.org.nz.

A key input to the investigation has been an analysis of the equipment electrical protection operations that occurred as the fire damaged the energised cables in the cable trench, causing electrical faults. This information has assisted the investigation team to understand the sequence of events and how the fire has developed. The protection analysis is summarised in section 4.3.

The inspection of the cables in the cable trench was carried out in a careful and methodical manner, to ensure all relevant information was identified. Sections of the damaged cables were recovered, with some inspected at the substation. The recovered cable samples were then sent to the Edif ERA Laboratory in Leatherhead, United Kingdom for detailed analysis and inspection. Brian Gregory oversaw this examination, and based on the test results, his own analysis, and inspection, prepared his report which is summarised in section 4.4.

The investigation team has worked co-operatively with the EA on their inquiry. The scope of the EA's inquiry differed from the joint investigation, but it was recognised by Vector and Transpower that information from the investigation, including the cable expert's report, would form an important input into the EA.

Throughout the investigation information and updates were regularly shared with the EA inquiry. Weekly calls were held to discuss progress and deliverables. Specific information, as requested by the EA, and background reports (listed in Appendix A) were supplied from November 2014 onwards. Nine face to face workshops, and a number of additional teleconferences, were also held over the period December 2014 to August 2015. The purpose of these workshops was to provide opportunities for the investigation team to:

- Describe the investigation methodology adopted by the investigation team;
- Explain what happened during the incident and how supply was restored;
- Give advanced information on the findings of the cable expert; and
- Present various background documents relevant to the investigation prepared by the investigation team.

The workshops also allowed the EA to ask specific questions of the investigation team to clarify aspects of the investigation.

The investigation included extensive forensic analysis of sections of cable and individual joints recovered from the cable trench during the inspection which took longer than initially anticipated. This analysis was important to ensure the correct conclusions were drawn on the cause of the fire and the contributory causes of the transition joint failure.

Early drafts of the investigation report, and the cable expert report, were shared with the EA commencing in July.

4.2 NZFS Report

The executive summary from the New Zealand Fire Service report 'Fire Investigation Report – 19 Gavin St, Ellerslie, Auckland' is reproduced below. The report determines the cause of the fire to be accidental. There are no recommendations made within the report.

A fire involving high voltage power cables in a concrete lined trench located at Transpower's Penrose substation had occurred. This caused a major power outage to some areas of Auckland which were supplied with power from the substation. Fire spread also damaged some high voltage cables outside the trench and a small area outside of the switchgear building.

NZFS received a 111 call from a neighbour of the substation at 2:18 a.m. on 5 October 2014.

Fire crews arrived to discover a fire in a section of a cable trench within the switch yard area, however due to the power not being isolated at that stage, firefighting was unable to commence.

The first fire appliance arrived at 2:26 a.m. but it was not until 3:23 a.m. when an initial fire attack occurred in the area of the switchgear building, preventing serious fire damage to the switchgear building.

Following the initial fire attack which extinguished the fire threatening the switchgear building, which was within the switchyard area, fire crews were forced to withdraw. This was due to a concern that power had not been isolated from all areas around the fire. Re-entry to the switchyard area did not occur until 4:37 a.m. when confirmation was received of the power being isolated.

The delay in being able to recommence firefighting did allow fire spread from where the fire originated to along the length of the trench.

While some fire damage occurred to areas outside the cable trench, most fire damage was contained to the cable trench.

An investigation team, including a NZ Fire Service Specialist Fire Investigator, a UK cable expert, Vector and Transpower Engineers as well as private Fire Investigators appointed by insurers was set up. A team approach is internationally recognised as best practice when investigating major fires.

As part of the investigation, fire damaged cables from the area and point of origin, were removed for the cable expert to carry out a closer inspection. Samples of cables not affected by the fire were also removed for inspection.

A number of the cables removed were also taken to the UK for a more in depth investigation by the cable expert.

The Teams origin and cause investigation confirmed the fire originated in the cable trench near the T11 transformer. A transition joint in the Remuera 11 kV feeder cable in this area failed causing an initial release of a large amount of heat, which caused the outer covering of the feeder cable to gradually heat up and ignite. Due to the large number of power cables surrounding this transition joint, once the outer covering had ignited, the fire then gradually spread to the other cables. The concrete lids covering the trench allowed the heat from fire to build up heat within the trench and assisted the fire spread along the trench.

The cause has been classified as accidental due to a failure within a transition joint of the Remuera 11 kV feeder cable

A report from the UK cable expert will be produced covering the cause of the failure.

4.3 Protection Analysis

Protection schemes ensure that electrical equipment is isolated to minimise damage during electrical faults. They monitor current and voltage levels and disconnect equipment if the levels exceed pre-set limits.

Modern protection schemes use microprocessor based electronic devices that provide multifunction capability, with integrated primary and backup protection, fault data recording and remote access for information retrieval. The data obtained from these devices greatly assisted the investigation to identify the sequence of events described in Appendix B.

The faults in the 11 kV cable that started the fire were correctly detected by protection, and circuit breakers opened to clear the faults in the expected time.

As the fire developed, more of the cables in the cable trench were damaged. The cable damage caused electrical faults in the cables, which were detected by the protection schemes. Therefore, the sequence of protection operations informed the order that the cables were damaged and accordingly how the fire developed. This is discussed in more detail in the cable expert report.

4.4 Cable Expert Report

The executive summary from the Cable Consulting International (CCI) report 'Investigation into a Fire in a Cable Trench in Penrose Substation' is reproduced below. This report was commissioned by the joint investigation team to provide an independent assessment of the cause of the incident.

A number of recommendations are made and these have been incorporated into the overall recommendations from the investigation (Section 9).

Transpower and Vector agree with CCI's findings and intend to work with CCI to implement the recommendations made in the report.

On 5th October 2014 a fire was reported at the Penrose Substation. The fire damaged a large number of Vector cables that were installed in a cable trench in the 220 kV switchyard. The damage to the cables resulted in the loss of supply to Auckland's eastern suburbs.

The CCI Author was engaged by Transpower and Vector to investigate the cause of the fire. This report presents the findings of the investigation, and the CCI Author's recommendations for the future installation of cables in similar environments.

The CCI Author has carried out a comprehensive investigation into the cause of the electrical failure and the resulting fire, at both the Penrose Substation and the Edif ERA Laboratory in Leatherhead, Surrey, UK. Further analysis and interpretation of results has been performed at the CCI offices in Underriver, Kent. The CCI Author has been afforded full access to the cables and the cable trench, and background information, as well as the required testing and analysis facilities, to enable this investigation to be undertaken.

The investigation has covered:

- Cause of the fire
    - Examination of the cables in the cable trench
    - Examination of samples of cables retrieved from the cable trench, both at Penrose Substation and at Edif ERA
- Cause of the transition joint failure
    - Detailed examination of the 11 kV PILC (paper insulated lead covered) cable to XLPE (cross-linked polyethylene) cable transition joints
    - Analysis of the electrical stress distribution in the 11 kV PILC to XLPE transition joint
- Assessment of the condition of cables and joints in the cable trench
    - Assessment of the condition of all cables in the cable trench, based on samples of cables retrieved from the Gavin Street end of the cable trench which was least affected by the fire
    - Analysis of the current rating of the cables in the cable trench
- Assessment of the fire development
    - Analysis of the locations of the electrical faults on cables that occurred as a result of the fire
    - Analysis of the energy in the electrical arcs
- Analysis of the fire performance of the cable types installed in the cable trench
- Review of published information related to cable fires and fire performance of cable types

The CCI Author's main conclusions are:

1. The fire was initiated by a power arc in an 11 kV PILC to XLPE transition joint in the Remuera K10 circuit. The energy from the first power arc had the capability to violently burst open the polymeric heat shrink sleeves and copper knitmesh cloth and so admit air into the joint. The arc produced a high temperature that was capable of igniting the flammable joint materials in the presence of air, these being the polymeric sleeves, the PILC cable core insulation (hydrocarbon compound impregnated paper insulation) and the XLPE cable insulation.

2. The fire was accelerated by a second power arc when voltage was reclosed onto the failed joint, and by the subsequent failures of the 33 kV XLPE cables that have wire screens and flammable polyethylene oversheaths. The OF (oil-filled) cables did not contribute until the end when aluminium sheaths ruptured and significantly increased fire severity. Each cable type was flammable and, without means to detect and extinguish the fire, a severe fire was inevitable.

3. The cause of the transition joint failure is the vulnerability of the transition joint design with respect to the electrically stressed insulation in the crutch between the PILC cable cores. This is the position where the power arc occurred. None of the insulation of the failed joint survived the fire and this conclusion is based on the examination of the unfailed transition joint.

4. The older, belted, unscreened, three-core, 11 kV PILC cable type is inherently incompatible in design and material types with the newer screened XLPE single core cable and its materials. In a joint, the transition between the unscreened and screened cable systems occurs in

the crutch of the PILC paper insulated cores and this is the key reason for the generic vulnerability of a transition joint.

5. The contributory causes of the transition joint failure are:

    a. Thermo-mechanical disturbance. The joint was positioned on a curved cable and was not cleated or supported.

    b. Water entry into the paper insulation at the crutch of the PILC cores. The water seals were short in length and on surfaces that allowed variable adhesion.

    c. Drying out of the impregnating compound from within the paper core of the PILC cable inside the joint.

    d. Migration of the void-filling compound to the paper insulating tapes underneath the lead sheath.

    e. Damage to the paper tapes due to the difficulty of effectively inserting high permittivity, void-filling compound.

6. The original 11 kV PILC joints in cast iron shells would not have caused a fire on failure. The conventional PILC joint designs have low electrical design stresses and are mechanically robust. A synergy was seen to exist between the PILC cable and the conventional cast iron joints. During the filling of the joint the hot bituminous insulating compound had mixed with the oil-rosin cable impregnant. It had penetrated long distances along the cable core interstices and paper tape butt gaps, thereby filling and insulating any air voids that are normally formed during jointing.

7. The progression and location of each cable failure had not been influenced by firefighting. All of the cable failure incidents had occurred by 3:04:59, which was before the Fire Service was admitted to the Penrose Switchyard and commenced applying foam at approximately 3:32 am.

8. The fire performance of the three cables types is described:

    a. The polyethylene sheathed, wire screened, 33 kV XLPE insulated cables exhibited the poorest cable fire performance. The polyethylene and XLPE insulation have a high heat release during combustion and thus spread combustion more readily. The cables dripped burning globules and strings of molten polyethylene to spread fire to cables below. The wire screen cable design does not have a metallic sheath or armour, and therefore the cable has limited protection to an external fire.

    b. The OF cables had remarkably good fire performance with only one cable suffering an electrical fault. The corrugated aluminium sheaths were seen to have withstood the fire with less damage than other cable types. Their good fire survivability time is attributed to the high melting points of the extruded aluminium sheaths, high thermal capacity and the exclusion of oxygen from the insulation. The downside of OF cable fire performance is that if the aluminium sheath ruptures the flammable impregnating oil can spread fire to other circuits.

c. The 11 kV PILC cables had the best fire performance. The good fire survivability is attributed to the two robust layers of steel tape armour (high melting point and high thermal capacity), the good high temperature performance of the paper insulation, its low insulation design stress and the exclusion of oxygen from inside the lead sheath. The downside of PILC cable fire performance is that the lead sheath melts at a relatively low temperature compared with aluminium and flammable impregnating compound then drips out, prospectively spreading fire to the cables below.

9. The OF and PILC cables did not contribute to the early development of the fire and its spread to the XLPE cables.

10. A detailed examination of the undamaged XLPE, OF and PILC cables has shown them to all be in good condition. Based on the results of the tests the residual life of the remaining XLPE, OF and PILC cables are predicted by Edif ERA to be 20, 15 and 10 years respectively. Edif ERA noted that some XLPE cables had experienced temperatures above their maximum design operating temperature.

11. The operating temperatures of all the cable circuits and all the types of cables within the cable trench in both the summer and winter seasons has been satisfactory, being below their design temperature limits with sufficient margin to allow for variations in the trench geometry.

12. The temperature calculations show that the reason samples of XLPE cable insulation had experienced temperatures above their design temperature limits was not due to overheating in normal service operation. It is concluded that the cause was heating by hot air from the fire.

13. At the time of the fire, too many cables had been installed in the trench. This did not contribute to the cause of the joint failure, but did contribute to the rate of fire spread. Fire tests have shown that there is a critical mass and critical spacing dimensions at which cable fires accelerate.

14. From a review of publications, while in-air cable installations have been reliable, there has been an appreciable, low incidence of major cable fires. A few of the major cable fire reports and cable system failure reports were found in the public domain. In general i) the cause of a fire, the remedial measures and the lessons learnt are not given in sufficient detail and ii) it is only possible to find information if the incident has received wide publicity.

The CCI Author recommends that:

1. Risk assessments be performed on in-air installations to identify the possibility of electrical failure of the cable lengths and joints.
2. The location of other transition joints installed in air on the network be reviewed.
3. For in-air applications, a technical specification be prepared for transition and straight joints, which includes demonstrated low fire propagation and power arc containment test performances.
4. For new XLPE insulated cable circuits, in significant in-air applications:
    a. Cables be specified with an oversheath having low fire propagation and low smoke zero halogen properties.
    b. Joints of any type be excluded from the in-air installation.
    c. Wire screened XLPE cable circuits be installed with a minimum separation to other cables to be advised by fire test houses and cable manufacturers.
    d. Data and communication cables be installed in a separate fire segregated route.
5. If transition joints installed in air are unavoidable, they be installed within an arc resistant housing.
6. For each significant in-air application:
    a. The rating capacity be calculated and retained on file and be updated as part of the approval process for any new circuit.
    b. The in-service temperature be monitored at regular intervals, and correlated to the calculated cable ratings.
7. Voltage not be reclosed on a failed circuit containing cables in air without taking precautions to manage the risk of fire ignition and propagation.
8. The transition joint design and jointing process be made more consistent with respect to a) the water seals and b) the void-filling compound.
9. Alternative and improved designs of transition joints be assessed.
10. Cable support designs be reviewed for all in-air cable installations.
11. Joint failure statistics be compiled and regularly reviewed.

5 History of Development at Penrose

Penrose substation was established in the 1920s in what was then a rural area on the southern fringe of Auckland. The city has since grown to envelop the site. Penrose is a major supply point for the growing Auckland region. It supplies the largest load of any Transpower urban supply point.

Penrose has been expanded many times since its establishment. The development of the site can be broken into three periods:

- Early history (pre 1966);
- 220 kV Development (1966-1976); and
- Developments since 1976.

A separate background report on the History of Penrose has been prepared and provides further background to this section of the report.

5.1 Early History (pre 1966)

Penrose substation was established in 1925 by the Public Works Department. It was initially connected by a 50 kV transmission line from the south with Auckland Electric Power Board (AEPB, the predecessor to Mercury Energy and Vector) taking supply at 6.6 kV and then at 22 kV.

Penrose was one of a number of substations established to supply power to Auckland. These substations were established on the outskirts of the city at the time. Figure 8 is an aerial photo of the Penrose substation in 1949 showing the substation in open land, with both the southern motorway and Gavin St yet to be constructed. The current site is shown in Figure 6.

Figure 8 Penrose in 1949

Over the period 1930 to 1963, additional transmission lines were built to increase supply into Penrose, and a number of feeders were connected by the AEPB to supply new substations. The timing of these is shown in Figure 9. In 1953, the southern motorway was constructed running past the western boundary of the site, limiting future access and egress routes to/from the site. Around this period, commercial and residential developments had taken place on the northern and eastern boundaries of the site effectively confining the substation footprint.

5.2 220 kV Development (1966 - 1976)

To meet Auckland's continuing growth, Penrose was upgraded to 220 kV in 1966 with the construction of a new double circuit transmission line from Otahuhu Substation. The redevelopment of the substation to establish the new 220 kV and 33 kV switchyards required a significant increase in the footprint of the substation, which was expanded eastwards towards Gavin Street.

The substation expansion necessitated the acquisition of a small strip of land owned by the AEPB adjacent to the original 110 kV substation. This land was used by the AEPB as a corridor for the Mt Wellington subtransmission cables and an overhead line (believed to be an 11 kV feeder linking the Remuera and McNab zone substations). The arrangement for the acquisition of this corridor led to the construction of the cable trench. Further details of the cable trench are provided in Section 5.4.

The timing of developments at the substation related to the 220 kV upgrade, as well as the further development of AEPB substations from Penrose, is outlined in the timeline shown in Figure 9. The 220 kV upgrade provided a large increase in capacity which served to meet Auckland's growth for the next two decades.

5.3 Developments Since 1976

The 22 kV and 33 kV supply arrangements were adequate until the early 1990s when it became apparent that further development of the 33 kV supply from Penrose would soon be necessary.

In 1996, Mercury Energy (Mercury), the successor of AEPB, formally requested an increase in capacity from 200 MVA to 400 MVA. In response, Transpower presented three options. From the available options, Mercury chose to install a new 200 MVA transformer and a 33 kV indoor switchroom. Following the construction of the new switchroom, some of the existing 33 kV feeder cables were transferred from the outdoor switchyard to the new indoor switchboard. These feeders were oil cables – a type of cable construction that was no longer available. Accordingly oil stop joints were constructed in Gavin Street and the cables were joined to sections of new XLPE insulated cables run in the cable trench in place of the original cables to terminate onto the new switchboard.

Shortly afterwards, Vector upgraded the substations at Newmarket and Remuera to 33 kV. This included the installation of new cables from Penrose substation, which were installed in the cable trench to exit the site via Gavin Street.

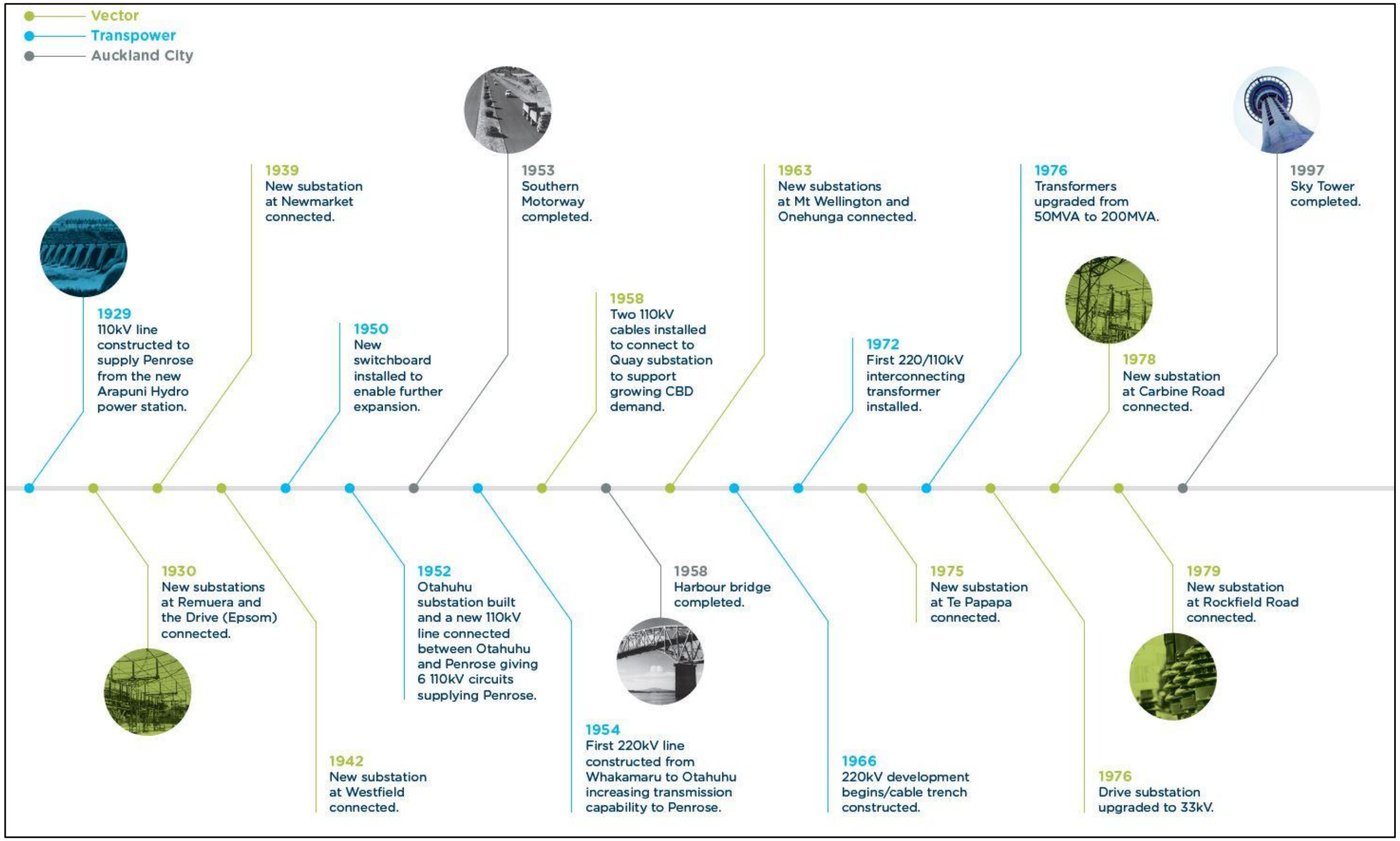


Figure 9 Timeline of Development of the Penrose Substation

The supply to Mt Wellington substation was upgraded in 2001 and McNab substation in 2008. A new substation was established at Sylvia Park as part of the commercial development in 2006.

Between 2001 and 2014, significant network reinforcement work was completed by Transpower and Vector in the Auckland region. Details are provided in section 7.4.2. Many of these projects required work at the Penrose substation but did not result in any changes to cables in the cable trench, other than the relocation of an 11 kV cable. These transmission projects have significantly improved security of supply to the Auckland region and meant the CBD was not impacted at all by the incident.

5.4 Cable Trench

The concrete trench was constructed around 1966 as part of the development of the 220 kV and 33 kV switchyards. Limited details on its design and construction have been located, other than a 1966 internal NZED memo. This indicates the trench was built to relocate AEPB cables to enable ownership of the AEPB land adjacent to the trench to be transferred to NZED. The proposal was for NZED to fund 50% of the trench cost.

The memo also states an intention that all future AEPB cables and services are to be installed in the trench[12]. No evidence as to any final agreement was located.

Penrose is sited upon basalt rock[13] which makes direct burying cables significantly more difficult than in soil. The concrete cable trench was constructed to provide a practical means of conveying a significant number of distribution feeder cables across the switchyard from the station boundary.

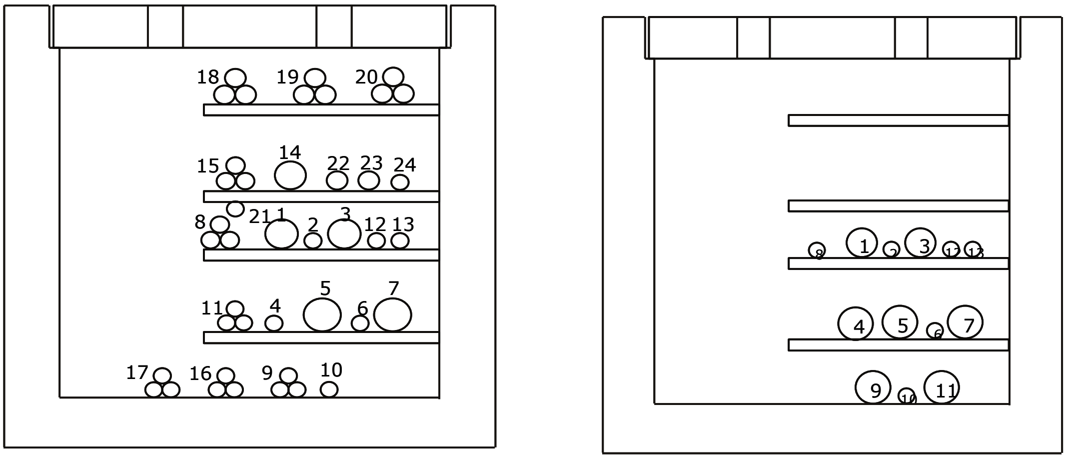
The trench is an open concrete walled structure approximately 1.4m deep, 1.2m wide, and 100m long, covered with heavy concrete lids. The construction of the trench would have required extensive civil work due to the hard rock. The difficult construction conditions encouraged the use of a single trench and influenced its size and design. The trench contains racks on four levels, and was clearly designed to accommodate additional cables to those originally installed.

The concrete trench is owned by Transpower. With the exception of a Transpower lighting cable and some earthing conductors, all other cables, and associated fittings and racks in the trench are owned by Vector.

Upon its completion, a number of existing AEPB cables were relocated to the trench, as well as new cables for substation upgrades and new substations. These included three 11 kV cables used to connect McNab substation with AEPB substations at Remuera and Mt Wellington. These feeders enabled load transfer between zone substations.

[12] All cables to supply Vector zone substations in the eastern suburbs have been installed in the trench. Cables supplying zone substations to the north and west of Penrose use other routes to exit the substation.
[13] Basalt rock is very hard and difficult to excavate. Excavation methods include the use of rock breakers (heavy machinery) and explosives.

By the end of 1967, AEPB had five 33 kV, two 22 kV and three 11 kV cables, plus three pilot cables, in the cable trench, as shown in Figure 10



2015 **1967**

Figure 10 Trench Cross Section

The ground conditions and other site related factors, contributed to the ongoing use of the trench as an egress point from the site. Since its construction, all cables to supply Vector zone substations in the eastern suburbs have been installed in the trench. At the time of the fire, there were twelve 33 kV circuits, two 22 kV circuits and six 11 kV circuits, as well as a Transpower switchyard lighting cable and earthing conductors, and Vector fibre optic cables, in the trench. Details of all cables installed in the trench are in Appendix C.

5.5 Works in Progress at the Time of the Incident

Development work is ongoing at the Penrose substation. At the time of the incident, Transpower was in the process of installing a 220 kV cable to create a 220 kV ring bus to further increase security of supply at Penrose. By July/August 2014, a new concrete trench had been constructed passing beneath the cable trench where the fire occurred.

During the 220 kV switchyard expansion works, vibration monitoring was installed for a short period during rock-breaking work to indicate if there was a potential for damage to adjacent switchyard equipment. Vibration monitoring was carried out from 28 May to 7 June 2014 during rock breaking for the new retaining wall (near where the new 220 kV ring bus cables would penetrate the wall, opposite T11). No significant vibrations were detected.

During the construction of the 220 kV ring bus cable project, temporary props were provided beneath the cable trench carrying the Vector distribution cables. On site investigations after the fire also confirmed that there had been no settlement of the concrete trench due to excavations underneath it.

As part of a nationwide equipment renewal programme, Transpower has planned to replace the Penrose outdoor 33 kV switchyard with an indoor switchboard, in conjunction with Vector. Detailed design and primary equipment procurement has been completed. Construction of a new 33 kV switchgear building was scheduled to commence during summer 2014-15.

6 Access and Occupation Arrangements

Transpower's customers, including Vector, need to connect to the National Grid at Transpower's substations. To do so, some customer assets need to be located at Transpower substations, including the cables necessary to get to the physical point of connection with Transpower assets.

This section covers the arrangements in place for Vector's assets located at Penrose substation.

6.1 Pre 2000

When Transpower came into existence in 1987, there were at least a dozen cables already in the Cable Trench[14] which had been installed by Vector's predecessor (AEPB), including the cable that faulted.

The AEPB was created under the Auckland Electric-power Board Act 1921 (AEPB Act). Under the AEPB Act, the AEPB was given the right to construct electric works as a supply authority licensee.

The electric works installed in the Cable Trench between 1966 and 1 January 1993 were all installed by AEPB as a supply authority licensee and subject to the obligations in the Electricity Supply Regulations in relation to installation, operation and maintenance.

Following the enactment of the Electricity Act 1992, any electric works installed prior to 1 January 1993 were deemed "existing works" and afforded statutory protection. This allowed AEPB's successors, Mercury Energy Limited and then Vector, to continue to have such assets on Transpower's property and to access, maintain (including replace) and operate those assets. Transpower cannot require those assets to be removed or relocated except with Vector's consent.[15]

In 1999, Transpower and Vector entered into a Licence to Occupy (Licence) for a 33 kV indoor switch room project whereby Transpower granted Vector a licence to install new cables at the Penrose substation, and inspect, renew, maintain and operate those cables for a twenty year term (with a right of renewal for a further 20 years). The Licence also shows a cable ladder system, which follows a separate, Transpower-approved route to the west of the 33 kV indoor switchgear building. The Licence did not modify any rights relating to the cables in the Cable Trench other than the specific 33 kV cables which were being re-terminated from the 33 kV outdoor switchyard to the new 33 kV indoor switch room as part of the project.

[14] The Cable Trench is not the only route Vector uses for its cables at Penrose substation. There are other access routes to the North and West, all of which were approved by Transpower (or its predecessors)

[15] Section 35 of the Electricity Act allows a landowner to request that existing works be moved, reconstructed or replaced, but the works owner's consent is still required (not to be unreasonably withheld) and the landowner must meet the cost of the move, reconstruction or replacement.

6.2 Connections Contract

In 2000 Vector entered into a Connections Contract with Transpower. The Connections Contract, together with Vector's existing works rights under the Electricity Act, still govern Vector's access and occupancy at Penrose.

6.2.1 Access and Occupation Schedule

The Connections Contract includes an Access and Occupation Schedule which contains Vector's rights of access to and over Transpower's land at Penrose. The Access and Occupation Schedule grants Vector a licence to occupy and access certain parts of Transpower's Penrose substation in order to install, operate and maintain certain "Facilities" (owned by Vector) for the conveyance of electricity. The Access and Occupation Schedule requires Vector to operate and maintain its Facilities in accordance with "Good Industry Practice". Vector is required to follow Transpower site access procedures to gain access to the site and to carry out work on site.

All of the assets covered by the Licence are listed in the Access and Occupation Schedule. That suggests the intention at the time was to replace the Licence with the Access and Occupation Schedule.

Transpower's view is that when the Connections Contract was entered into the intent was for all existing and future Vector assets at Penrose to be covered by it, to the exclusion of previous agreements.

Vector's view is that the current version of the Connections Contract does not cover all existing Vector assets at Transpower's Penrose substation. Vector agrees that greater certainty is required, and that the Connections Contract should be updated to reflect all existing and future Vector assets.

The list of Facilities at Penrose in the Access and Occupation Schedule is incomplete and inaccurate. Some Facilities are not described correctly[16] and Vector's 11 kV cables installed in the Cable Trench in the 1960s and 1970s (including the cable on which the joint that faulted was installed) are not listed.

Neither Transpower nor Vector has records showing unequivocally that the Access and Occupation Schedule has been updated since the original 2000 version.

6.2.2 New and Relocated Facilities

Transpower's approval is required before Vector can install new Facilities or relocate existing ones to a different Facilities Area.

In deciding whether or not to give its approval, Transpower is concerned with ensuring its own assets and operations are protected, including its development plans and options at the relevant site. Transpower is not concerned with ensuring the customer's assets or operations are protected, or looking into whether the customer's network design is prudent, except to the extent necessary to ensure Transpower does not incur any new material risks. Transpower does not "sign off" generally on all the choices the customer makes about the electrical and physical design of its Facilities. That is the customer's responsibility.

[16] For example, the list refers to three 2 kV feeders (Remuera 1, 2 & 3), which should be referred to as 33 kV feeders, and to one 22 kV feeder (Quay Street 4), which was decommissioned in the 1950's.

Sometimes there will be a conflict between Transpower's interests at a site and a customer's requirement to secure corridors within the site for the installation of its feeders to enable connection to the National Grid. This is most likely to occur at physically constrained sites such as Penrose. In that situation Transpower, as the landowner, is able to protect its interests by refusing permission for the customer's proposal if necessary. It will then be for Transpower and its customer to work together to find a mutually acceptable solution.

Notwithstanding the prescriptive processes in the Connections Contract, it appears the parties have historically used less centralised processes for the approval of the physical location of Vector's cables at Penrose. Transpower's records contain only one formal application from Vector for new connections or changes to the location of its Facilities at Penrose.[17]

Transpower has published documents describing the current process for customers requesting approval to install or modify their assets at Transpower's sites.

6.3 Roles and Responsibilities

Transpower and Vector are each responsible for the performance of their respective networks, and the asset management practices adopted, including risk management, planning, development, operation and maintenance.

Transpower is responsible for the integrity of its sites, but is dependent on connected parties like Vector following good industry practice and processes. In its role as grid owner and owner of the site, Transpower needs to be aware of risks to grid assets that may arise from assets owned by others on its sites. There has been limited centralised awareness within Transpower of the Vector cables in the trench at Penrose.

Vector is responsible for obtaining Transpower approval for new assets or for any changes it proposes at Transpower sites.

[17] From January 2014 (relocation of several 33 kV and fibre optic cables due to Transpower's new 33 kV switchgear building). Transpower's records also contain less formal application correspondence from March 1999 (relocation and new connections for the 33 kV cables covered by the Licence) and 2011 (relocation of McNab K02 11 kV due to Transpower site extension).

7 Asset Management

Asset management is a core activity for Transpower and Vector. Effective asset management helps ensure that electricity is provided safely and reliably at service levels that meet the needs and expectations of customers.

Asset management incorporates consideration and mitigation of risk as part of an optimised decision making approach throughout the asset life cycle. It is not possible or economic to entirely eliminate all risks to network reliability. Effective asset management requires an appropriate balance between performance, cost and risk. Excessive investment in risk mitigation leads to unnecessarily high costs for customers. The management of risk, as it applied to the Penrose substation and the cable trench, is covered in this section.

Transpower and Vector own and manage assets which have long lifespans, fifty years and more. Asset management practices and standards are continually evolving meaning what was constructed historically may differ from current standards. Normal practice is to apply new or current design standards when existing assets are replaced, and to manage any legacy risks through established risk management processes.

7.1 Transpower Asset Management System

A separate report on Asset Management has been prepared by Transpower that provides further background to this section of the report.

Transpower's asset management system has been independently certified against the PAS55:2008 standard. Independent reviews of Transpower's asset management have also been undertaken by the Office of the Auditor General. Further reviews have been undertaken by technical advisers to the Commerce Commission, as part of their review of Transpower's expenditure proposals submitted as part of individual price-quality path regulation. These independent reviews have acknowledged the progress that Transpower has made in improving its asset management approach in recent years.

The following sections focus on transmission asset management planning and feedback processes.

7.1.1 Grid capacity and security

The key risks considered in the long range network planning process are risks to reliability, security, availability and customer service levels. Long range plans for the capacity and security of the transmission network are reviewed annually. The process includes updating forecasts of future demand and generation.

Transpower works with connected parties to prepare these forecasts and the expected performance of the network is then studied under a range of scenarios, to identify risks, investment needs and options. The analysis of risks and investment needs includes a criticality framework, as a proxy for the consequences of failure.

Major new investments in the core grid that are needed to increase capacity or maintain security are subject to one-by-one regulatory approval by the Commerce Commission.

The planning and development of the transmission system in the Auckland region, as outlined in more detail in section 7.1.4, is an example of recent major investments in the grid.

7.1.2 Connection assets

The network planning process also includes review of the capacity and security of Transpower assets at the point where the connection is made to distribution networks.

Investments in new, or upgraded, grid connection assets are subject to specific funding agreements with the relevant connected parties. This means that the connected parties make the risk trade-off between the capability of the connection assets, and the costs of the grid connection service. Based on this trade-off, they can choose connection asset configurations of higher or lower security levels.

Transpower provides the connection assets in accordance with investment agreements, and manages the performance and safety risks associated with those assets.

The network planning process integrates plans for the main grid and for grid connection assets. The outputs from this work are published each year in Transpower's Annual Planning Report.

7.1.3 Replacement and refurbishment

Major transmission assets can have a lifetime of 50 years or more. However, asset related risks can increase over time, to the point where replacement or refurbishment becomes necessary.

An example of replacement and refurbishment work is the nationwide programme for replacement of existing outdoor 33 kV switchyards with indoor equipment to improve safety. The nationwide programme is prioritised taking criticality into account. Most of the outdoor 33 kV switchyards in the Auckland region are being replaced in agreement with Vector, including the remaining outdoor 33 kV switchyard at Penrose.

7.1.4 Substation site planning and development

Asset management planning and development at substation sites incorporates requirements from both the grid planning and equipment replacement perspectives outlined above.

Transpower prepares site strategies for substations to provide strategic direction for the development of the site. The site strategies highlight key issues that must be considered, including future customer requirements. The strategies provide a means of co-ordinating long term investments to achieve efficiencies and improve integration. The current programme of developing and documenting site strategies commenced in June 2012. Site strategy documents have now been published for more than 60 substations.

7.2 Vector Asset Management System

A separate report on Asset Management was prepared by Vector and provides further background to this section of the report. Vector's asset management framework and underlying systems, processes, and practices are mature, well developed, and consistent with a major infrastructure asset manager.

The key document in which Vector's asset management practices are described is Vector's Asset Management Plan (AMP). This is underpinned by other business documents, including standards, policies, procedures, risk schedules and various asset information systems and databases. Vector's AMP is updated annually to outline Vector's asset management policies, responsibilities, targets, investment plans and strategies to deal with the future of the electricity network. The AMP is publicly disclosed, and available on Vector's website.

Vector's asset management practices are regularly reviewed and updated, both internally and externally. External reviews include regulatory reviews, and reviews by Vector's insurers, covering different aspects of the AMP. Vector's Asset Management Plan and network expenditure are regularly reviewed by technical advisors to the Commerce Commission as part of the current regulatory process.

Since 2005 Vector's asset management planning and practices, have been independently reviewed, at least bi-annually, by a number of internationally recognised experts. In recent years Vector has engaged Siemens, Sinclair Knight Merz, and PA Consulting to carry out this work. The scope of these reviews is broad, covering all Vector assets. The use of internationally based experts is, in part, to provide a comparison between practices in other jurisdictions.

These reviews are conducted to provide guidance to Vector's board and management on the appropriateness of Vector's asset management practices. In addition, the reports are also provided to the Auckland Energy Consumer Trust (AECT) in fulfilment of Vector's obligations to its major shareholder to demonstrate good custodianship of the electricity network assets[18].

The reports all generally endorsed Vector's asset management practices. A number of observations were made, all of which were carefully considered by Vector management and the Vector board.

[18] Vector is required under the Deed Requiring Essential Operating Requirements (DREOR) to conduct an independent review of its asset management practices every 2 years and provide this report to the AECT.

7.3 Reviewing Risks

Transpower and Vector each have risk management frameworks designed to identify, assess, monitor and treat risks to acceptable levels taking into account consequence, likelihood, and existing risk controls within the business. Risk controls also include emergency preparedness, and business continuity plans designed to manage the business in the event of a major event and effectively restore business operations.

7.3.1 Transpower Risk Reviews

The Transpower risk management feedback processes of most relevance to the Penrose cable fire are:

- Site Risk Reviews; and
- Studies of High Impact Low Probability (HILP) Events.

7.3.1.1 Site Risk Reviews

Substation risk reviews provide essential feedback for asset management planning and strategy. There are a wide range of processes in place that contribute to the understanding of site risk such as:

- Inspections carried out by maintenance service providers
- Engineering inspections, including post-event reviews
- Studies of high impact, low probability event risks (see next section)
- Specific reviews associated with Site Strategy development
- Development and review of grid risk registers

Risk assessment is often informed by actual incidents. There have been few incidents of failure of customer assets on Transpower land. The Penrose cable fire is the only incident Transpower is aware of that has led to serious consequences.

In 2014, a generic risk was identified of the potential for damage to the grid and safety risks arising from the failure of customer assets on Transpower land. The trigger for the identification of this risk was the failure of a Vector outdoor circuit breaker at a Transpower site. Following this failure, there was a nationwide programme to manage risks with similar circuit breakers.

There had been no other significant problems caused by the failure of customer assets on Transpower land over many years, and the generic risk was therefore not accorded high priority for mitigation, compared with other identified risks.

7.3.1.2 High Impact Low Probability (HILP) events

Understanding and assessing possible HILP events is an important element of Transpower's asset management planning. A methodology for HILP event studies has been developed and published in a peer reviewed paper and presented at an international forum. A HILP study for Penrose was carried out in 2013 as outlined in section 7.5.2.

7.3.2 Vector Risk Management

A separate report on Vector's Risk Management framework was prepared by Vector and provides further background to this section of the report. Vector's aim is to maintain robust risk management practices consistent with the AS/NZ ISO 31000:2009 risk management standard.

Vector's risk management framework is regularly reviewed and updated, both internally and externally. Vector's insurers have carried out independent risk reviews on key risks as part of the insurance process.

Vector's network business unit maintains a key risks profile containing strategic and critical operational risks relevant to its business. Network risks are identified via a number of ways, including:

- Condition assessment of assets through failure trend analysis, physical inspections and testing;
- Reporting of incidents involving harm or potential harm to personnel or the public;
- Equipment failures on the Vector network;
- Information from industry associations, suppliers and manufacturers; and
- Use of external experts.

Vector has identified a number of HILP events. Given the significant consequences of these events, Vector seeks to minimise the impact through a combination of controls to limit the impact of an event and specific contingency plans to restore supply.

The development of network emergency plans are part of Vector's response capability which forms a key part of Vector's risk management framework, particularly for situations where elimination of risks is not feasible. An example is the loss of a zone substation. Vector has individual contingency plans for each of its 107 zone substations.

Vector has not developed contingency plans for the loss of a GXP. It is impractical for Vector to develop these plans as there is insufficient capacity within Vector's network to transfer loads of this magnitude between GXPs. Furthermore, such plans are dependent upon the nature of any specific event, and can vary considerably from event to event.

7.3.3 Fire Risk Mitigation

Fires in electricity substations are very rare events. However, fire can lead to serious damage to equipment, interruption to customers, and safety hazards.

Transpower and Vector use a range of design standards in planning and developing their networks. These ensure assets are designed to appropriately mitigate risks such as fire risk.

There have been major changes in design standards and practices for fire risk mitigation in substations over the past 50 years. Recent designs for substation equipment incorporate increased resilience against common mode failures resulting from fire. In particular, recent designs incorporate greater use of fire-cells and physical segregation. Key elements of current "best practice" substation fire risk mitigation for new installations include:

- Bunded areas around power transformers to contain oil spills;
- Fire walls around power transformers;
- Fire segregation for high voltage power cables;
- Indoor switchboards segregated into multiple fire-rated sections;
- Indoor switchgear built to withstand the effects of internal arc faults;
- Indoor switchgear equipped with high speed protection systems that detects arc faults;
- Highly sensitive smoke detectors installed in control and relay rooms;
- Active fire suppression systems provided for some key locations; and
- Transpower is planning to install hypoxic air fire prevention systems at some critical locations.

It is not practical or economic to apply these latest fire risk mitigation standards immediately to all existing substations. In some cases, it is feasible and economic to retrofit fire protection systems. Examples include the retrofitting of fire walls around existing power transformers, or the provision of external arc flash protection systems for some older indoor switchboard installations.

7.3.4 Contingency Planning and Emergency Preparedness

Electricity networks are exposed to hazards from external events, such as extreme weather, and third party damage. Electricity network equipment itself is generally highly reliable, but occasional failures do occur. All these factors can threaten reliability of supply.

It is not possible to entirely eliminate all risks to network reliability. This means that a prompt and efficient response, after the event, is the most appropriate way of managing certain kinds of incidents or events.

Both Transpower and Vector have extensive arrangements in place to provide 24 hour call out response to faults. The call out fault response is supported by access to a large pool of highly competent industry trades, technician and professional engineering staff. In addition, there are a wide range of other measures in place to ensure a timely and effective response to unexpected events. These include:

- Extensive holdings of spare parts, and complete replacements for some types of equipment;
- Holdings of major strategic spares, such as replacement power transformers and relocatable switchboards and generators; and
- Effective relationships with local suppliers, transport contractors, equipment hire companies and specialist service providers.

In the Penrose incident, despite the unusual nature of the event and the extent of damage caused by the fire, the existing arrangements for contingency planning and emergency response enabled effective response and recovery.

7.4 Auckland Regional Network

The Transpower network in the Auckland region is illustrated geographically in Figure 11.

The Auckland region has some of the highest load densities in the country. Transmission lines supply the Auckland and Northland regions from the south at 220 kV, distributing power at major substations around Auckland and providing through transmission to Northland.

The electricity network supplying Auckland has been upgraded in stages over many years, to meet the growth in the region. Prior to 2014, almost all the electricity used north of the Auckland Harbour Bridge was supplied over one double-circuit line. This put the load at risk from low-probability incidents such as a tower failure, or a fault on one circuit while the other circuit was out for maintenance.

As a result of recent major transmission upgrades, there is now a high capacity 220 kV ring between Otahuhu, Pakuranga and Penrose, and a high capacity 220 kV loop from Otahuhu and Penrose through the Henderson and Albany substations in the North Isthmus. There is also a 110 kV transmission network supporting the 220 kV network.

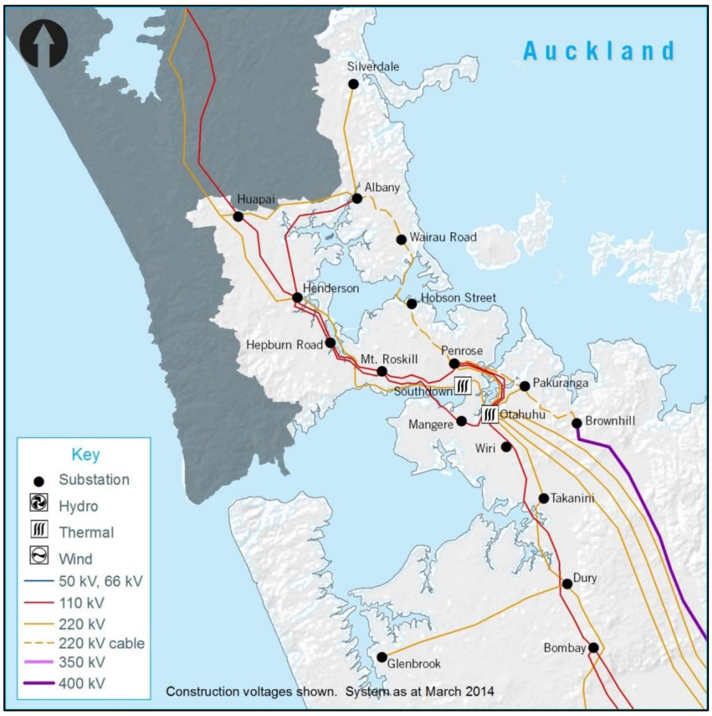


Figure 11 Auckland Region

7.4.1 Regional Outages (Since 1998)

There have been five significant incidents in the 16 years prior to the October 2014 incident at Penrose affecting customers in the Auckland region due to power system failures within and into the region. Each incident has had a different cause, and affected different groups of customers. Details of each incident are given in Table 3.

Date	Incident	Response
Feb 1998	Four Vector 110kV cables supplying Auckland's CBD failed resulting in a loss of supply to for 5 weeks until a temporary supply was established.	Vector improved security into the CBD through a new supply from Mt Roskill in 1999 at a cost of $25 million. In 2001, Vector completed a major project that was already in progress at the time of the incident, involving construction of a 9.2 km tunnel from Transpower's Penrose substation through to Hobson substation. Vector invested over $120 million in the CBD tunnel, cables and substation upgrades.
Jun 2006	A D shackle holding an earth wire broke, resulting in a partial outage of Transpower's Otahuhu substation. South and central Auckland (around half the city) was without power for up to six hours.	In 2009, Transpower completed a $106 million new 220 kV enclosed gas insulated switchgear (GIS) facility at Otahuhu substation separate from the existing 220 kV switchyard. The region's dependence upon Otahuhu was further reduced by connecting the new 220 kV transmission line from Whakamaru into Pakuranga substation in 2012.
Feb 2009	A 33 kV supply transformer failed at the Penrose substation while another transformer was out of service undergoing refurbishment. This resulted in the loss of supply to 74,000 Vector customers.	Following this incident, Transpower installed an additional $5 million transformer at Penrose. Transpower has also established a number of spare transformers that can be used nationwide, in the event of a similar failure.
Oct 2009	A forklift carrying a shipping container accidentally hit a 220 kV circuit running from Otahuhu to Henderson. The other circuit was out of service for maintenance at the time, which meant that the main electricity supply route north was lost. 280,000 customers throughout Northland and north and west Auckland were without power for 3 hours.	In 2014, Transpower completed the North Auckland and Northland (NAaN) project to reinforce supply to West Auckland, the North Shore and Northland, using corridors established by Transpower and Vector, including Vector's CBD tunnel. This development improved security of supply by forming a secure and high capacity transmission ring around central Auckland, and providing an alternative supply route north.
Feb 2011	A fire near Hamilton under one of the 220 kV lines into Auckland resulted in reduced supply capacity into the region with some customers being without power for an hour in Northland, and Vector shutting off all hot water heating.	In 2012, Transpower commissioned a major project that was already under construction at the time of the incident. This project created a new 186 km double circuit transmission line between Whakamaru and Pakuranga meaning there are now five separate 220 kV lines supplying the Auckland region.

Table 3 Significant Events Affecting Auckland Region Supply

There have also been two power system failures external to the Auckland region that affected customers throughout the North Island, including customers in Auckland, for 2 to 3 hours[19]. These outages were part of normal contingency arrangements designed to maintain stability of the electricity system, and were not related to the power supply into or within the Auckland region.

After each incident there have been extensive reviews resulting in a number of recommendations. For example a Ministerial Inquiry was conducted into the loss of supply to Auckland's CBD in 1998. These recommendations have included a number of major projects which have either eliminated or significantly reduced the risk, and severity, of a re-occurrence of similar outages. The projects are described in Section 7.4.2.

7.4.2 Major projects (Since 1998)

Four major projects have been implemented since 1998 to address the future capacity requirements of the Auckland region and mitigate network security risks. In a number of cases projects were modified in response to the significant incidents noted in section 7.4.1. The combined value of these projects was over $1.6 billion.

The projects were:

- In 2001, Vector completed a 9.2 km tunnel from Transpower's Penrose substation into Auckland's CBD to provide improved security into the CBD at a total project cost of over $120 million;
- In 2009, Transpower completed a $106 million new 220 kV gas insulated switchgear (GIS) facility at its Otahuhu substation;
- In 2013, Transpower completed a new 186 km long double circuit transmission line between Whakamaru and Pakuranga. This $894 million project included 220 kV underground cables for the final 11 km into Pakuranga substation. Pakuranga was upgraded from a 110 kV to a 220 kV substation at the same time. This project created a major new transmission route into Auckland, and also reduced the dependence of the Auckland region on the Otahuhu substation; and
- In 2014, Transpower completed the North Auckland and Northland (NAaN) project. 37 km of underground 220 kV cable was commissioned between the Pakuranga, Penrose, and Albany substations, crossing the Auckland harbour bridge. This $424 million project made use of corridors established by Transpower and Vector, including using Vector's CBD tunnel. This development improved security of supply within Auckland by forming a secure and high capacity transmission ring around central Auckland, and reinforced supply to West Auckland, the North Shore, and to Northland. The project includes new grid exit points connecting to Vector's sub-transmission system at Hobson Street in the CBD, and at Wairau Road on the North Shore, with significant associated work by Vector.
- In 2014 Vector spent $73 million upgrading Hobson Street and Wairau Road substations to enable connection of the new transmission link created by the NAaN project.

[19] Some media reports include these outages when looking at power cuts in Auckland.

Details of how each of the above projects has reduced the risk from previous significant incidents are given in Table 3.

In addition to these projects, in the period since 1995, there have been 30 other Transpower projects that have either reinforced supply into the Auckland region, or increased capacity at individual grid exit points in the region.

In the same period Vector has made significant investment in its subtransmission network. This has included normal replacement works and investment to meet Auckland's growth. Whilst this investment has been Auckland wide a number of projects have been carried out in the area supplied from the Transpower Penrose substation. These projects include new supplies to Newmarket, Remuera and Mt Wellington and a new substation to supply Sylvia Park.

Vector regularly invests over $100 million p.a. on its network. In the last six years Vector's investment has been nearly $1 billion.

7.5 Penrose Substation

The history of the development of the Penrose substation is described in Section 5. The Penrose substation is a major supply point for the Auckland region and has the largest load of any Transpower urban grid exit point. It is assigned the highest level in Transpower's criticality framework.

7.5.1 Penrose Substation Site Strategy

A Transpower site strategy was published in June 2012. The strategy development process includes consultation with customers.

The significant projects identified in the Penrose strategy that were in progress at the time of the incident included:

- Extension of the 220 kV bus to become a ring bus. The ring bus will provide improved resilience; and
- Replacement of the existing outdoor 33 kV switchyard with an indoor switchroom, with indoor switchgear separated into fire segregated cells.

7.5.2 Penrose Substation Risk Reviews

A HILP study for Penrose substation was carried out for Transpower in 2013 which included a site review by Marsh. The study confirmed the need to enhance seismic resilience of the critical control buildings, to upgrade building fire protection, and retrofit fire separation barriers for major power transformers. These initiatives are in the process of being implemented. The HILP study did not identify the specific risk of fire in the cable trench carrying distribution cables across the 220 kV switchyard.

7.5.3 Future Development

Vector's Asset Management Plan outlines several near-term and long-term developments affecting customers supplied from the Penrose substation.

In the near-term, the Glenn Innes subtransmission cables are scheduled to be replaced in 2016/17. Currently these are supplied from the Penrose 22 kV bus. A number of options are being considered including replacing the existing cables like-for-like, supplying Glen Innes from St Johns 33 kV bus or by installing cables from Pakuranga GXP.

The Penrose load is significant and is expected to increase further with forecast growth. As part of Vector's long term network development plan two new GXPs have been investigated, one at Southdown and a second at Newmarket. Both of these GXP's will displace load currently supplied via the Penrose 33 kV bus at Penrose. Vector's long-term development plans are dependent upon a number of factors, including whether customer load continues to grow as forecast. Neither of these GXP's are scheduled to be constructed within the plan's 10 year planning horizon.

7.6 Penrose Cable Trench

The construction of the cable trench is covered in Section 5.4. Since its construction the cable trench has been used as the only corridor out of the Penrose substation for 33 kV subtransmission cables supplying zone substations in the eastern suburbs. The cable trench has also been used to enable distribution feeders from McNab[20] substation to supply areas of Remuera and Ellerslie on the eastern side of the motorway.

The area within the substation is considered a controlled environment, where there is negligible risk of third party damage to the cables.

Access to the cable trench is very restricted, with only crawl space available when the covers are in place. Given the hazards of live power cables and the confined space, personnel access is prohibited unless the covers are removed. Therefore inspections of the cable trench and the cables has been limited to occasions when new, or replacement, cables have been installed.

An earlier inspection by Vector in 2001 had identified an 11 kV cast iron PILC cable joint that was leaking bitumen. The maintenance contractor inspected the joint and decided to replace it. The standard repair was carried out, which involved cutting out the faulty joint and installing a short length of new cable with two new joints. By this time XLPE cable was being used on the network, and therefore XLPE cable was installed with two PILC to XLPE transition joints. It was one of these transition joints that failed in October 2014.

Transition joints are used by network companies to enable repairs and extensions to existing PILC cables and joints. The cable joint that failed is a type commonly used in electricity networks in New Zealand and internationally.

[20] McNab substation is located to the west of the motorway.

7.6.1 International Practice

Most cables entering substations are either direct buried or installed in individual ducts. Increasingly, cables supplying inner city substations are installed in deep tunnels, which are designed for full personnel access. There are also smaller, shallow tunnels, or culverts, within some cities, which provide egress for a large number of cables to supply the high density local loads from the inner city substations.

Occasionally, network companies install short tunnels or culverts at other substations, where normal methods of access are difficult or the land is not owned by the utility, but these are not common.

Vector contacted a number of New Zealand network companies to review their practices for structures like the cable trench and found that none had comparable structures. As a result Vector commissioned surveys of network companies in Australia and the United Kingdom to review normal industry practice for the installation of power cables in structures like the cable trench. The surveys identified a wide range of different structures used by network companies, from deep tunnels to shallow troughs. Most of the large tunnels are used solely for transmission cables. Many of the smaller tunnels contain a number of cables comprising a range of different cable types and voltages, including XLPE, PILC and oil filled cables.

Generally, tunnels do not have fire detection or suppression systems. Some network companies have started to paint cables with fire retarding paint, but this is normally only for transmission cables. No smaller structures, like the cable trench, have fire detection, or suppression systems, installed.

In substation buildings, fire detection systems are generally installed to comply with building regulations, but active fire suppression systems are not widely used. Active fire suppression systems are used by network companies with indoor transformers, and at large inner city substations with indoor switchgear.

In congested cities like London, structures like the cable trench are relatively common, often dating back to the 1930s. Sometimes they are larger, and are combined with other utility services, such as gas pipelines or sewer systems. There are also similar structures in Sydney that contain numerous medium voltage cables and often other services such as high pressure gas mains. None of these structures have fire suppression systems.

Historically, network companies had no restriction on the installation of joints in basements or tunnels. Some now avoid joints in close proximity to other cables. If the use of a joint cannot be avoided, they will adopt passive protection measures, such as fire blankets, to protect the cables. No utility had a separate programme to replace or protect existing joints, choosing to carry out fire mitigation measures as part of other works.

7.6.2 Cable Trench Risk Reviews

No specific risk reviews were carried out with respect to the cables in the cable trench. Risk assessments were made for each network project that involved new cables being installed in the trench, but these were focused on the construction and environmental risks pertaining to the specific project. In these projects the trench simply formed a small section of the cable route and the associated construction risks were considered minor.

Project risk reviews were one mechanism for identifying potential risks related to the cables in the cable trench. Had these raised questions relating to the potential consequences of the number of cables within the trench then any subsequent assessment of risks would need to determine potential causes and risks and the likelihood of these events occurring.

7.6.3 Risk Identification Processes

Vector and Transpower's existing risk identification processes use a wide range of sources for identifiying potential risks, ranging from actual events, through to information obtained from specialist reviews, or from interactions with external organisations, including manufacturers, suppliers, industry groups and associations.

(i) Actual Events

Transpower and Vector have no record of fires caused by joint failures prior to this incident. Joint failures are rare[21]. Joint failures causing fires are very rare.

The survey of utility practice showed similar experience overseas. It found that:

- In New Zealand and Australia, three similar joint failures were identified. These failures have occurred over the last ten years with the latest occurring in February 2015. As a result of these failures, the network companies have either made, or, in the latest case, are considering making, changes to their standards related to the installation of joints in air. In all of these incidents the cause was not made public or shared within the industry.
- In the United Kingdom, one utility first became aware of the risk circa. 2006 when an 11 kV joint faulted and caused a fire that damaged several nearby cables. The joint failure occurred in an excavation that had been left open during ongoing works. As a result of this incident, the utility produced the first issue of its standard for the installation of cables and joints in air. In 2012, the utility had a failure of a transition joint in the basement of a zone substation, which again caused a cable fire and damaged several

[21] Based on Vector's actual joint failure rates the expected time between joint failures on an average Vector cable circuit for distribution cables are 1 per 22 years. The expected time for an average subtransmission circuit is 1 per 79 years.

other circuits. The utility updated its standard as a result of this incident. Neither the incidents nor the updated standards were made public or shared within the industry.

In the United Kingdom, there have been a number of "manhole fires", where electrical faults have resulted in explosions under pavements, particularly in London. Many of these appear to be related to link box faults, which have been associated with water ingress and gas leakage into the pits. These are quite different to the Penrose incident.

(ii) External Reviews

Vector undertakes a number of external reviews. Examples include the biennial reviews undertaken by Vector for the AECT, and reviews by insurers. These reviews are carried out by recognised experts, often with experience from other countries. These reviews allow emerging risks not yet experienced by Vector to be highlighted. None of these reviews identified potential risks relating to transition joint failures causing fires. This is again consistent with the surveys of utility practice.

(iii) Industry Organisations

Vector belongs to a number of industry associations, including the UK Energy Networks Association (ENA). The ENA has a database which provides information on equipment defects. Under the direction of the cable expert, a number of searches for information on transition joint failures were carried out. These showed that information in the ENA database on transition joint failures was insufficiently detailed to be of assistance in identifying risks associated with these assets.

(iv) Manufacturers and Suppliers

Procurement and installation of cables is done to network standards. Vector's network standards are regularly updated to incorporate learnings, including feedback from manufacturers and suppliers. Vector has not received any information from manufacturers and suppliers alerting them to the risk of transition joint failures causing fires.

Based on this, the investigation concluded that Vector and Transpower could not have been expected to identify this specific risk. There was no evidence that existing risk management processes were not correctly applied, but it was recognised that there was value in reviewing the current processes for identifying potential HILP events to identify any improvements that could be made.

7.6.4 Cable Trench Fire Risk Mitigations

No network companies were found to have installed fire detection or suppression systems in structures like the cable trench.

It is apparent from the surveys that, where network companies have become aware of the risk of fires from joint faults, they have changed their standards so that, as much as practicable, new joints are not installed in air. If new joints must be installed in air, specific precautions are taken to mitigate the risk of fire. No network companies have initiated a separate programme of retrospectively applying protection measures to existing joints, preferring instead to apply the new standards as part of other works at the substations.

The specific precautions adopted have generally involved painting cables and cable joints with fire retarding paint. Some network companies have specified a type of joint with a fire retardant outer shell, which can be filled with resin.

8 Findings

Cause

1. The cause of the fire was an electrical failure in a cable joint in a Vector distribution (11 kV) feeder cable within a cable trench containing Vector power cables and a Transpower lighting cable, running east-west across the Transpower 220 kV switchyard. The joint failure occurred at 23:21 on Saturday 4 October 2014 resulting initially in the loss of supply to customers in Remuera and Ellerslie.

2. A manual reclose of the distribution feeder, following a line patrol, caused a second fault at 01:21 on Sunday 5 October 2014. The reclose accelerated the fire, but did not affect the scale or duration of the outage.

Investigation

3. The cable joint that failed is a type commonly used in electricity networks in New Zealand, and internationally. These joints are supplied in standard kits by a range of manufacturers.

4. The joint was installed in 2001 as part of a replacement of a PILC cable joint that was leaking bitumen. The replacement involved cutting out the leaking joint, and installing a short length of new XLPE cable, and two new PILC to XLPE transition joints.

5. The failed transition joint was largely destroyed by the fault and the subsequent fire. However, the fault location was clearly identified by the arc erosion on all three copper conductors of the PILC cable.

6. Given the significant damage to the failed transition joint, the second (identical) transition joint was examined to identify any contributory factors to the failure. There was no evidence of an electrical fault on the second transition joint and fire damage was limited to the outer heat shrink layers.

7. The inspections of the two transition joints could not identify any single factor that caused the transition joint failure, but a number of potential contributory factors were identified.

   The investigation found that:

   a. Based on the inspection of the failed transition joint:

      i. The fault occurred in the crutch between the PILC cable cores; and

      ii. The transition joint had been installed on an angle, without cable cleats and joint supports, making it susceptible to moisture ingress at the cable crutch.

b. Based on the inspection of the second (unfailed) transition joint:

   i. The jointer had correctly followed the manufacturer's jointing instructions in making the joint;

   ii. The transition joint is susceptible to moisture ingress at the PILC end of the joint;

   iii. The impregnating compound had dried from the paper insulation, causing the insulating tapes to be thermally degraded;

   iv. Void filling compound had migrated onto the paper insulating tapes in the crutch; and

   v. The paper insulation in the crutch is susceptible to damage when the void filling compound is inserted.

8. The investigation concluded that the cause of the transition joint failure was the vulnerability of the transition joint design with respect to the electrically stressed insulation in the crutch between the PILC cable cores. This is a generic issue faced by all manufacturers when designing transition joints that connect two different cable types.

9. The investigation determined that the fire spread initially to the control cables and XLPE insulated power cables. The oil cables did not contribute to the early development of the fire.

10. The detailed examination of the cables extracted from the cable trench revealed them to be in good condition, with ample remaining life expectancy. An analysis of the cable loading has demonstrated that the cables have been operated within their maximum design operating temperatures with an acceptable margin.

Impact

11. At the time of the fire, the cables in the cable trench supplied 39,043 customers (around 7% of Vector's total customers). Fire damage to the cables in the trench led directly to the loss of supply to those customers.

12. Transpower had to de-energise the area of the Penrose substation where the cable trench is located, to enable safe access for NZ Fire Service to fight the fire. As a result a total of 75,339 Vector customers were without power from 03:08 on Sunday 5 October. Supply from Penrose was also interrupted to Transpower customers KiwiRail and Southpark.

13. Relivening restored supply to 36,296 (48%) customers within 16 hours. Extensive use of backfeeding within Vector's network restored a further 18,786 customers (25%), limiting the number of customers without supply for more than 24 hours to 20,257 (27%). All customers were restored within 59 hours.

Response

14. The incident was a large and complex event that placed extreme demands on Transpower and Vector. The joint response is considered to have been effective because:

    a. There were no reported injuries or safety incidents affecting the public, Transpower and Vector staff, their contractors, or members of Emergency Services;

    b. Relivening and repairs were completed without delay once control of the site was returned to Transpower. Transpower and Vector promptly mobilised all necessary resources, and drew on existing spares holdings to achieve this;

    c. Customers were kept well informed during the outage through regular updates delivered across a wide range of communication channels; and

    d. No other equipment at the substation was damaged during the restoration and recovery efforts.

Risk Mitigations

15. Prior to the fire, Vector, Transpower, and their external experts, had not identified a risk of fire in the cable trench. There had been no cable failures within the cable trench prior to the incident, nor did the investigation find any records of fires caused by joint failures in Transpower and Vector's networks prior to the incident.

16. In 2014, Transpower had identified a generic risk related to customer assets on Transpower land causing damage to grid assets. Transpower had also conducted a HILP study at the Penrose substation in 2013. Neither of these risk review processes specifically identified the risk of fire in the cable trench.

17. Vector commissioned surveys of network companies in Australia and the United Kingdom to review normal industry practice for the installation of cables in structures like the cable trench. The surveys found:

    a. The preferred method for the utilities, as it is for Vector, is to install the cables in the ground, either directly or in ducts;

    b. Network companies occasionally construct short tunnels, culverts or trenches at substations, where normal methods of access are difficult, or the land is not owned by the utility. Multiple cables of various voltage levels, types and ages are installed in such structures;

    c. No fire detection or suppression systems are installed in the smaller structures, like the cable trench;

d. Most larger tunnels do not have fire detection or suppression systems installed;

e. A few network companies have started to paint cables with fire retarding paint, but this is normally only for transmission cables.

Based upon the survey information the investigation concluded the cable trench design, and practices for installing cables in the cable trench, were in line with industry practice.

18. The surveys, and the Cable Expert investigation, found that fires from cable faults are very rare. It was also found that details of any incidents that have occurred globally have not been made public. In the few cases where cable fire reports have been presented in industry forums overseas, the cause of the fire, remedial measures and lessons learnt are not given in sufficient detail to inform others. As a result Vector could not have been expected to have the knowledge to specifically identify this risk.

19. The design and operation of the cable trench is in line with industry practice. The specific risk of a joint failure causing fire in the cable trench was not identified so no controls specific to this risk were in place. Emergency plans were in place to manage outage incidents and these worked effectively.

Other Findings

20. The Cable Expert report concluded too many cables had been installed in the cable trench and this allowed the fire to propagate and sustain itself. Industry standards provide guidelines for testing the fire performance of cables, but do not recommend minimum spacings between cables or the maximum volume of combustible material in a specific installation.

21. The establishment of the cable trench, and its ongoing use as an primary egress point for Vector cables to the east of the substation, was due to a number of factors:

a) The establishment of the 220 kV switchyard in the mid 1960's, led to the design and construction of the cable trench. The cable trench at Penrose is unusual. There are no directly similar installations at other Transpower substations. Upon its construction the cable trench provided an efficient means for a large number of new and existing cables to traverse or exit the site;

b) Significant load growth in Auckland since 1966 required further development of Vector's network which led to further cables being installed over time in the trench; and

c) At Penrose the sub-surface material is hard volcanic rock which made alternative corridors costly and difficult to construct.

It was concluded that the availability of, and ease of access to, the cable trench relative to the perceived cost and difficulty of establishing new (and diverse) routes, encouraged its ongoing use.

22. Recently completed major projects such as the Vector cable tunnel, and the Transpower 220 kV cable network installed as part of the North Auckland and Northland (NAaN) project, meant there was no risk of loss of supply to the Auckland CBD during the incident.

23. The management systems for additions and changes to Vector assets on Transpower land have not been applied consistently by Transpower and Vector. There wasn't a formal process to jointly review the status and condition of customer assets on Transpower land.

9 Learnings and Recommendations

A key focus of the investigation has been to identify and implement learnings from the incident. This section details the review process, the lessons learned, and the key recommendations and actions arising from the investigation.

A number of actions are already underway. Progress to date on implementing the recommendations is outlined in section 10.

Transpower and Vector conducted separate reviews, before sharing lessons learned.

9.1 Vector Review

A series of workshops were held focussing on three key areas:

- Operational Response;
- Asset Management/Risk Management; and
- Customer Management (including communications).

A separate review of the overall management of the incident was conducted with members of Vector's Crisis Management Team (CMT) and Emergency Response Team (ERT). Findings from this review were also included in the final review workshop.

A final review workshop was held, involving senior management, to share the collective learnings from the initial workshops and to identify key learnings from the incident.

The reviews also identified a number of minor business improvement opportunities which have been included in the appropriate business areas for implementation, with many actions already completed.

9.2 Transpower Review

The early stages of the investigation included a review of operational management during the response and recovery phase. Engineering support provided to the recovery team was also reviewed.

The reviews also identified some business improvement opportunities, and these have been allocated to the appropriate business area for scoping and implementation.

9.3 Joint Transpower/Vector Review

Following their own reviews Transpower and Vector shared key learnings, and identified areas where collaboration will be required to implement actions arising from learnings.

Key learnings from the incident are outlined in Section 9.4.

9.4 Key Learnings

Four key learnings were identified:

1. Cable joints installed in air with other cables in close proximity can cause sustained fires when they fail;
2. Risk management processes did not identify very low probability events that had not previously occurred on the network;
3. The nature of the incident identified opportunities for improvement of standard operating procedures; and
4. The asset and risk management processes at the physical interface between Transpower and Vector's networks need to be improved.

These learnings, and recommendations based upon these learnings, are outlined further below. Actions required to implement recommendations are also noted.

The recommendations from the Cable Expert report have been adopted and have been incorporated into the actions outlined in this section. Transpower and Vector intend to work with CCI in implementing these recommendations.

Learning 1 **Cable joints installed in air with other cables in close proximity can cause sustained fires when they fail.**

The permanent replacement of the temporary cables installed as part of the recovery works at Penrose will mitigate the risk of a similar incident occurring at Penrose.

It is recommended that:

Transpower and Vector implement changes at Transpower's Penrose substation as part of the recovery works, including installing replacement cables in two trenches containing segregated ducts for each cable to effectively eliminate the risk of fire causing multiple cable failures.

The actions to implement this recommendation are:

- To design a new permanent solution at the Penrose substation; and
- Construct the solution.

Inspections will be carried out at points of connection between Transpower's grid and Vector's network, other similar sites on the Vector network, and other Transpower sites to identify cable joints in air in critical locations, and assess the potential impact of failure. Actions will then be taken to mitigate any risks identified from the inspections.

It is recommended that:

Transpower and Vector review locations where power cables are installed in open air environments to identify any risks associated with assets at the following locations:

Transpower/Vector points of connection (GXPs)	*[Jointly];*
Vector's network	*[Vector];*
Transpower sites	*[Transpower);*

and take appropriate actions to mitigate these risks.

The actions to implement these recommendations are:

- Inspect all areas on the Vector network where there are multiple cables in open air, including Transpower, and third party substations, assess the consequences of failure, and identify actions to mitigate risks identified from the inspections;
- Inspect all critical Transpower substations to identify cable joints in air, assess the consequences of failure, and identify actions to mitigate risks identified from the inspections;
- Complete all actions identified to mitigate the risks; and
- Vector amend its maintenance schedules to include inspections of all open air cable installations.

The inspections cover existing installations. There is also a need to ensure new (future) installations adequately assess the potential risk, and deploy controls to mitigate the risk of fires from joint failures. New installations may arise from new assets being constructed or from repairs to existing assets.

It is recommended that:

Vector review and update its relevant policies, procedures and practices with respect to cables, and cable joints installed in air.

Transpower incorporate learnings from the Penrose cable fire into asset management practice, including design standards. Include mitigation of risks from failures of cable joints in open air.

The actions to implement these recommendations are:

- Review and amend Vector policies, procedures and practices that deal with cable system design, installation and maintenance; and
- Review and amend Transpower asset management standards that deal with cable system design, installation and maintenance.

Learning 2 Risk management processes did not identify very low probability events that had not previously occurred on the network.

Prior to the incident Transpower and Vector had no recorded instances of joint failures in open air causing a fire. Joint failures causing fires are very rare, and there are comparatively few joints installed in open air. As a result, both Transpower and Vector had no direct previous experience to draw on to assist in identifying this risk. Information from other network companies, manufacturers, or suppliers globally on the failure of joints in open air was not publicly available.

It is recommended that:

Vector review and update its risk management framework, and risk identification processes.

Transpower incorporate learnings from the Penrose cable fire into risk review processes.

The actions to implement these recommendations are:

- Vector review and amend its asset risk management framework;
- Vector amend its procurement processes and contracts to request suppliers to make Vector aware of any significant issues with product failures;
- Vector create a dedicated role within its networks business focused on managing asset risk identification and management processes;
- Vector continue to develop its assessment of asset risk profiles to ensure the criticality of assets is considered;
- Vector review risk identification processes across the Vector group to ensure any learnings from the incident are applied; and
- Transpower review the scope of risk studies, including HILP event studies, to ensure coverage of assets owned by connected parties on Transpower land.

Learning 3 The nature of the incident identified opportunities for improvement of standard operating procedures.

The nature of the incident has highlighted some opportunities for improvement of current procedures.

The Remuera feeder fault review (Section 3.2) identified improvements to Vector's standard operating procedures as they apply to feeders with cable sections installed in air.

The event highlighted the importance of enabling safe access for NZ Fire Service personnel in the event of fire in a substation.

The Electricity Engineers Association's (EEA) Guide to Electrical Network Safety for Emergency Services Personnel[22] provides essential background information to assist emergency services to avoid and control hazards from electrical networks. Building on this industry guide, Transpower currently arranges annual site familiarisation visits to its substations for NZ Fire Service. However, the incident has highlighted the need for Transpower to review its existing arrangements with NZFS.

The learnings from the incident are also relevant to Vector sites and Vector has undertaken to engage with NZFS to review its existing arrangements.

It is recommended that:

Vector update its standard operating procedures to apply key learnings from the incident.

Transpower update its standard operating procedures to apply key learnings from the incident.

The actions to implement this recommendation are:

- Vector update its standard operating procedures for locating faults on feeders with cable sections installed in air;
- Transpower review its communications and existing arrangements with the NZ Fire Service, to identify opportunities for improvement; and
- Vector review its communications and existing arrangements with the NZ Fire Service, to identify opportunities for improvement.

Learning 4 The current asset and risk management processes at the physical interface between Transpower and Vector's networks need to be improved.

The incident has highlighted the opportunity for Transpower and Vector to improve the asset management interface with respect to Vector assets on Transpower property.

More robust management will ensure a greater collective focus on managing the connection interface, including greater awareness of the collective risk posed by all the assets - irrespective of ownership - on any site. As part of this process roles and responsibilities will be further refined.

[22] Third edition issued in May 2015

It is recommended that:

Transpower and Vector review contractual terms and management processes at points of connection to ensure key learnings from the incident are incorporated.

Transpower improve its business process for assessing and approving customer requests for access and occupation of Transpower land.

Transpower establish an on-going process to provide assurance about the status and condition of customer assets on Transpower land and the potential risks to the grid.

The actions to implement the above recommendations are:

- Transpower and Vector review contractual terms and management processes at points of connection;
- Transpower review the business process for assessing and agreeing to customer requests for access and occupation of Transpower land. Ensure that a risk assessment is part of the process; and
- Transpower establish an on-going process to provide assurance about the status and condition of customer assets on Transpower land and the potential risks to the national grid. This process is to focus on critical sites, and to include agreement of risk mitigation plans with customers.

10 Implementation of Recommendations

As at the date of this report all actions identified to implement the recommendations are underway. Significant progress has already been made towards completing these actions.

- At Penrose a permanent solution for cables damaged in the fire has been designed and agreed between Transpower and Vector. The replacement cables will be installed in fire segregated ducts along two independent routes.

  This work will be carried out in conjunction with a separate Transpower project to install a new indoor 33 kV switchroom. The timeframe for completion of this work is June 2016 and is determined by a need to co-ordinate with the indoor switchroom project. Tenders have been let for this work.
- Transpower and Vector have each undertaken surveys of their sites to identify situations where failure of cables in air could lead to significant consequences. These surveys have not identified any issues of immediate concern. However, at several Transpower sites, interim risk mitigations for cable joints have been implemented as a precautionary measure.

  Vector has developed action plans based upon its site surveys and prioritised these. Works on all critical (priority 1) sites have been completed.
- Improvements to risk identification and review processes are underway within both organisations, together with enhancements to relevant asset management standards and operating practices.
- Vector has amended its operating procedures for locating faults on feeders with cable sections installed in air, and has commenced training of staff.
- Transpower has developed a process for a comprehensive review of Access and Occupation schedules to update the records of customer assets on Transpower land, and evaluate the risks associated with those assets. This process has commenced. The documentation updates and risk reviews for the most critical sites are scheduled to be completed within 12-18 months.

Transpower and Vector will track progress on actions through established internal processes.

Transpower

Transpower has an established process called RESOLVE which governs the investigation of significant incidents, and the implementation and tracking of the resulting corrective and preventive actions. The RESOLVE process includes monthly updates on open actions, and the preparation of summary reports on status. This process is administered by the Asset Risk and Investigations Manager.   Requests for closure of actions are independently reviewed and the evidence supporting closure is checked.

The RESOLVE process is led by the National Events Review Group. This group of senior managers meets monthly to review progress on open investigations and the status of open actions. The National Events Review group reports to Transpower executive management.

Vector

Vector will monitor actions through its internal audit function. This function is responsible for ensuring that the corrective actions framework is designed and operating effectively. A transparent process across all of Vector's business units is in place and has been approved by Vector's Board Risk and Assurance Committee.

Any recommendations arising from the Penrose Investigation will be monitored in accordance with this framework and recorded in the group corrective actions register. On a monthly basis the Group Manager Internal Audit and Assurance will follow up with responsible action owners to confirm the status of open corrective actions. This will include confirmation that progress is within expectations and that target dates will be achieved. Any closed actions will be confirmed and where appropriate evidence reviewed to demonstrate successful implementation. In addition to this all completed corrective actions are incorporated into the continuous follow up programme to provide independent assurance that changes to business processes and systems have been embedded.

On a monthly basis the status of the Penrose corrective actions will be communicated to the Executive Risk and Assurance Committee. This reporting will include analysis of open items by priority and ageing, detailed reports on status including updates from responsible action owners and a summary of all closed items during the month. The analysis will then be consolidated into the quarterly internal audit status update to the Board Risk and Assurance Committee.

In addition to this reporting process any overdue actions will be subject to the corrective action escalation procedure. This includes three, six and twelve month escalation triggers to the responsible executive, CEO and Board Risk and Assurance Committee to ensure appropriate governance and focus over the timely implementation of agreed remedial actions.

Glossary

Backfeeding – the process of restoring power to customers affected by a fault where the electricity network is reconfigured to supply electricity from neighbouring areas unaffected by the fault.

Bus (Busbar) – an electricity conductor that is used to connect multiple circuits together within a substation.

Cable joint – electrical equipment used to join two electrical cables together. Where the two cable types are differing technologies the cable joint is referred to as a transition joint.

Cable termination – electrical equipment used to connect a cable to switchgear or other electrical equipment.

Circuit breaker – a switching device, used for connecting and disconnecting electricity supply, including automatic disconnections (or tripping), when network faults occur.

Corona discharge – a visible electrical discharge appearing around the surface of a conductor, such as a transmission line, which is caused by ionisation of the surrounding gas.

Current – the rate at which electrons flow through a circuit, measured in amperes (amps).

De-energise – the process of removing power from electrical equipment.

Distribution network – the network supplied from the sub-transmission network, which is used to distribute electricity to customers. Vector's distribution network operates at voltages of 11 kV and 22 kV.

Fault – a short circuit between one or more phases and ground, or just between phases. It results in high currents that are detected by the power system protection.

Fault Passage Indicators – equipment used on the network to assist in locating faults by providing indication of whether a fault current has passed along the network.

Feeder – an underground cable or overhead line originating from a substation supplying a group of customers.

Grid Exit Point (GXP) – a point of connection between the national grid (Transpower) and local network companies (such as Vector), or large customers.

High Impact Low Probability (HILP) Event – An event that is rare (low probability) but if it occurs can have an extremely high impact, for example a major earthquake causing widespread damage.

Insulator – equipment used to support bus bars and flexible conductors, which is made of a material that does not allow electricity to flow through it.

Isolate – to separate part of the electricity system from the rest of the system to enable safe access or maintenance works to be carried out.

Paper Insulated Lead Covered (PILC) – a type of electricity cable which uses layers of oil impregnated paper as insulation with a lead cover and outer layers of steel tape armouring. PILC cables are no longer manufactured but are still in operation across many electricity networks.

Reclose – the action of closing a circuitbreaker on a circuit which has previously opened due to a fault. A reclose order can be either manually or automatically initiated.

Re-livening – the process of re-engergising electrical equipment that has been de-energised.

SCADA – Supervisory Control and Data Acquisition – a system used by network companies to remotely monitor and control electricity networks.

Self Contained Oil-Filled (OF) – a type of high voltage cable where the paper insulation is impregnated with mineral oil under pressure.

Substation – a part of the electricity system where electricity voltage is transformed from one level to another. Substations can range from large transmission substations, such as Penrose, to zone substations supplying suburbs, to smaller distribution substations.

Switchgear – the combination of electrical disconnect switches, fuses, or circuit breakers used to control, protect and isolate electrical equipment. Within substations switchgear is located on the high and low voltage sides of large power transformers.

Switchroom - a room, or often a self-contained building, containing switchgear.

Switchyard - the restricted access area of a substation where high voltage switching equipment and transformers are located.

Sub-transmission network – the network supplied from the transmission network which supplies power to the distribution network. Vector's sub-transmission network operates at voltages of 22 kV and 33 kV.

Transformer – a device that changes voltage up to a higher voltage or down to a lower voltage. Power transformers are large units used in transmission and sub-transmission networks. Distribution transformers are more widespread and are used within the distribution network to supply power at 400/230 V to customers.

Transmission – the Transpower network which conveys bulk electricity from generating stations to major points of supply, typically operating at voltages of 110 kV and higher.

Tripping – the opening of a circuit breaker due to the operation of protection in response to an electrical fault

XLPE (Cross-linked polyethylene) – the material used as insulation around the conductor in modern electrical cables.

Appendix A – List of Background Reports

The following is a list of background reports prepared that support the investigation.

Customer Engagement Report (Joint Transpower and Vector report)

NZ Fire Service Fire Investigation Report – 19 Gavin St, Ellerslie, Auckland

Cable Consulting International Report - Investigation into a Fire in a Cable Trench at Penrose Substation

History of Penrose Substation (Joint Transpower and Vector report)

Transpower - Asset Management Practices

Vector - Asset Management

Vector – Risk Management

Appendix B – Sequence of Events

The sequence pf events listed below covers the time period from the initial fault (at 23:21 4 October) through to NZFS handing control of Penrose substation back to Transpower (at 09:57 5 October). At this point recovery operations commenced.

Date/time	Description
4/10/2014	
23:21:00	Vector's 11 kV feeder K10 at Remuera substation tripped
5/10/2014	
1:21:00	Vector's 11 kV feeder K10 at Remuera substation tripped after a close order
2:04:29	Sequence of unusual alarms from equipment at Penrose commenced
2:09:00	Transpower NGOC called out the substation maintainer to attend at Penrose
2:10:42	Penrose 220/33 kV transformer T11 tripped
2:11:39	33 kV feeder Remuera No 3tripped
2:12:31	33 kV feeder Newmarket No 3 tripped
2:14:31	11 kV feeder tunnel auxiliary tripped
2:14:47	33 kV feeder Carbine No 2 tripped
2:16:45	33 kV feeder Remuera No 2 tripped
2:17:35	Member of the public called emergency services, to report three explosions at Penrose
2:22:46	33 kV feeder St Johns No 3 tripped
2:22:46	All 22 kV supply from Penrose interrupted by tripping of three 33/22 kV transformers
2:25:00	NZ Fire Service appliances arrived at Penrose substation gate
2:41:00	Substation maintainer arrived at Penrose substation and opened road gate to allow NZFS access
2:44:58	11 kV feeder McNab K02 tripped
2:48:42	33 kV feeder Carbine No 1 tripped
2:48:46	33 kV feeder Mt Wellington No 2 tripped
2:48:54	33 kV feeder Mt Wellington No 1 tripped
2:50:00	Transpower NGOC advises Vector EOC that it will be necessary to de-energise all remaining 33 kV supplies
2:57:13	33 kV feeder Sylvia Park No 2 tripped
2:57:58 to 3:17:12	All remaining in-service 33 kV equipment and supply transformers de-energised
3:04:59	11 kV feeder McNab K19 tripped
3:22	Fire Service advised by Transpower that power is off to switchgear building area

Date/time	Description
3:32	Firefighting commences, with foam applied to cables exiting ground near 33 kV switchgear building
4:26	Transpower Regional Services Manager requests complete shutdown of the 220 kV yard
4:35	220 kV switchyard fully de-energised
4:37	Fire Service advised by Transpower that the 220 kV switchyard is completely de-energised. Now able to apply foam along trench eastwards into 220 kV area.
9:57	Fire Service transfers control of the site back to Transpower
10:41	Penrose 220 kV busbar test livened
11:48	Penrose 220/33 kV transformer T7 returned to service to restore local service power supplies to the substation
11:54	Penrose 220/110 kV transformer T6 returned to service to restore security to 110 kV supplies to CBD
13:47	Restoration suspended for approximately one hour when the NZ Fire Service had to be called to deal with smoke from smouldering timber
14:52	Penrose 33 kV busbar re-energised
15:17	33 kV feeders Newmarket 1 and Newmarket 2 livened
15:23	Penrose T21 and T22 re-energised, to liven 22 kV switchboard
16:46	Penrose 220/33 kV transformer T8 re-energised, to provide security to 33 kV busbar
16:50	33 kV feeders McNab No 1 and 2 livened
17:03 to 17:33	22 kV feeders Glen Innes, Westfield and Onehunga livened
20:47	33 kV feeder SouthPark livened
6/10/2014	
23:26	33 kV feeder St Johns no 3 livened
23:29	220 kV Bus D relivened, together with cable connections to Hobson St
7/10/2014	
07:26	33 kV feeder Sylvia Park 1 livened
12:56	33 kV feeder Carbine No 2 livened
17:57	33 kV feeder Mt Wellington No 2 livened
23:53	33 kV feeder Remuera No 3 livened
8/10/2014	
21:22	Penrose 220 kV Bus B and C restored, bringing Penrose back to full pre-event security levels.

Appendix C – List of Cables in Cable Trench

Trench Position	Circuit	kV	Cable Type
1A	Remuera No3	33	3x1c Al 400 XLPE HDPE
1B	Newmarket No3	33	3x1c Al 400 XLPE HDPE
1C	FO Duct	-	Telecom FO cables
1D	Remuera No2	33	3x1c Al 400 XLPE HDPE
2A	Carbine	-	Pilot 25C 9+16
2B	Not in use	11	3c Al 300 PILC STA
2C	McNab K19	11	3c Al 300 PILC STA
2D	Carbine No1	33	3c Al 300 PICAS O.F PVC
2E	Carbine No2	33	3x1c Cu 630 XLPE HDPE
2F	Tunnel Supplies	11	3c Cu 35 XLPE HDPE
3A	McNab K02	11	3c Cu 0.25 PILC STA
3B	Remuera K10	11	3c Cu 0.25 PILC STA
3C	Westfield No 2	22	3c Cu 0.37 PICAS 0.F PVC
3D	Westfield	-	Pilot 0 + 32C
3E	Westfield No 3	22	3c Cu 0.37 PICAS O.F PVC
3F	St Johns No3	33	3x1c Cu 630 XLPE HDPE
4A	St Johns No1	33	3c Cu 0.45 PICAS O.F PVC
4B	St Johns	-	Pilot 25C 9+16
4C	St Johns No2	33	3c Cu 0.45 PICAS O.F PVC
4D	Mt Wellington K05	11	3c Cu 0.25 PILC STA
4E	Mt Wellington No2	33	3x1c Al 400 XLPE MDPE
5A	Mt Wellington	-	Pilot 25C 9+16
5B	Mt Wellington No1	33	3x1c Al 400 XLPE MDPE
5C	Sylvia Park 1	33	3x1c Al 400 XLPE MDPE
5D	Sylvia Park 2	33	3x1c Al 400 XLPE MDPE