Penrose Substation Fire
05 October 2014

Summary of Protection Operations

CONFIDENTIAL AND DRAFT

This is a working document and it is a draft only. The content of this document is subject to further investigation and information and does not reflect the final view of Transpower New Zealand Limited or Vector Limited and can not be relied upon in any way.

Document Disclaimer

Any conclusions reached in this document are based on the information currently available to Transpower New Zealand Limited ("Transpower") and Vector Limited ("Vector") and may change as further information becomes available.

Version History

Version	Issued to	Description	Date
1.0	Electricity Authority	Working draft	22/05/2015

Preface

This report was prepared as a supporting document for the joint Transpower/Vector investigation into the fire that occurred in a cable trench at Transpower's Penrose substation on Sunday 5 October 2014. There are a number of cable trenches and above ground cable racks at the Penrose Substation. The fire occurred in the cable trench that runs east-west across the 220 kV switchyard, and all references to a cable trench in this document are to this particular trench unless specifically noted otherwise.

EXECUTIVE SUMMARY

On 4 October at 23:21, a fault occurred in the Vector network in an 11 kV feeder supplied from Remuera zone substation. A reclose was attempted at 01:21 on 5 October.

From 02:04, there was a series of unusual alarms and equipment trippings at Transpower's Penrose substation. At around 02:17, a member of the public called the fire service to report explosions at Penrose substation. A fire was subsequently located in the cable trench.

Between 02:11 and 02:57 there were multiple trippings of 33 kV feeders from Penrose. At 02:22, all three 33 kV/22 kV transformers tripped, removing all supply to the Penrose 22 kV system.

An analysis of protection operations has been undertaken, commencing with the Remuera 11 kV feeder tripping.
The performance of protection for two particular events should be reviewed to see if practicable improvements can be made to the protection design and settings:

1. At 02:14, a line to ground fault on the Penrose-Carbine Number 2 feeder was not cleared immediately. The Penrose 33 kV circuit breaker 1712 opened, but the Carbine 11 kV circuit breaker K20 remained closed and continued to energise the feeder from the Carbine end for 42 seconds until a fault occurred that the Carbine end backup protection could detect.
2. At 02:22, backup protection on the three Penrose 33 kV/22 kV transformers tripped at the same time as backup protection on the St Johns 3 feeder tripped for a fault on the St Johns 3 feeder (being a loss of discrimination between backup protections).

For each of the above events, the fire had damaged the pilot cables, which caused a failure of the communications signalling link and prevented the main differential protection from operating.

The issues identified above are not considered to be material to the original fault or to the equipment damage and loss of supply that occurred as a result of the fire in the cable trench.

The analysis shows that all protections performed as designed and set, within the constraints arising from the damage to the pilot cables.

CONTENTS

1. INTRODUCTION

At around 02:17 on Sunday 4 October 2014, a member of the public called the fire service to report explosions at Penrose substation. A fire was subsequently located in the cable trench.

Prior to the fire being reported, there were two protection operations related to an 11 kV feeder supplied from Vector's Remuera (REMU) substation. Part of this feeder is formed by an 11 kV cable located in the cable trench at Transpower's Penrose (PEN) substation that allows the feeder to be supplied from Vector's McNab (MNAB) substation for backstopping purposes. The feeder is normally open at the MNAB circuit breaker.

On Saturday 4th October 2014 at 23:21, protection at the Vector REMU substation on K10 tripped Vector circuit breaker (CB) K10 to clear an 11 kV fault.

Following a line patrol and investigation, Vector manually re-closed REMU CB K10 on Sunday 5th October 2014 at 01:21 and protection on K10 at REMU immediately tripped CB K10 to clear an 11 kV fault.

The cable trench located at PEN substation includes a number of Vector 33 kV, 22 kV and 11 kV high voltage cables and protection pilot cables, and also some Transpower switchyard lighting cables and Transpower earth grid conductor. The fire that broke out in this trench caused severe damage to these cables.

From 02:04, the Transpower SCADA system reported many unusual alarms from various items of primary equipment at Penrose. Transpower control and protection cables for several bays of outdoor substation equipment cross over the cable trench. These cables suffered fire damage in the area where they cross over the trench. At the same time, the Vector SCADA system reported unusual alarms related to the Carbine 33 kV oil circuits. The control cable for these alarms was also in the cable trench.

At 02:07, the Vector SCADA system reported that the main differential protection for Carbine 33kV feeder No. 2 was blocked. The Carbine pilot cable (which carries the differential protection communications signal) was damaged by the fire.

At 02:10 PEN transformer T11 220 kV and 33 kV CBs tripped. Later checks on T11 showed no primary circuit fault. The control cables that carry these protection trips were damaged by the fire.

Power system faults occurred in several of the 33 kV feeders as the fire developed, leading to a series of protection trips:

- At 02:11 PEN 1812 protection tripped Vector 33 kV feeder 3 to Remuera substation.
- At 02:12 PEN 1612 protection tripped Vector 33 kV feeder 3 to Newmarket substation.
- At 02:14 PEN 1712 protection tripped Vector 33 kV feeder 2 to Carbine substation.
- At 02:16 PEN 1432 protection tripped Vector 33 kV feeder 2 to Remuera substation.
- At 02:22 PEN 1752 protection tripped Vector 33 kV feeder 3 to St Johns substation.
- At the same time that St Johns 3 tripped the three PEN 33 kV/22 kV transformers T21, T22, T23 tripped due to a loss of discrimination with the St Johns 3 backup protection. This removed supply to the PEN 22 kV system.
- At 02:48 PEN 1462 protection tripped Vector 33 kV feeder 1 to Carbine substation.
- At 02:48 PEN 1832 protection tripped Vector 33 kV feeder 2 to Mt Wellington substation.
- At 02:48 PEN 1532 protection tripped Vector 33 kV feeder 1 to Mt Wellington substation.
- At 02:57 PEN 1472 protection tripped Vector 33 kV feeder 2 to Sylvia Park substation.

All 33 kV supply from the site was disconnected by operator action between 02:57 and 03:17, to allow safe entry for the NZ Fire Service, as follows:

- Between 02:57 and 03:06 operators opened the remaining PEN 33 kV feeders.
- At 03:07 operators opened the 110 kV and 220 kV circuit breakers on PEN transformer T10.
- Between 03:07 and 03:12 operators opened the 33 kV circuit breakers on PEN transformers T9, T7, and T5.
- Between 03:16 and 03:17 operators opened the 220 kV circuit breakers on PEN transformers T5, T7, T8, and T9.

At 04:28 the 220 kV bus coupler PEN 798 tripped. The control cables that carry these protection trips were damaged by the fire.

Further switching occurred between 04:30 and 04:33 to open 110 kV and 220 kV circuit breakers on PEN transformer T6, and the 220 kV line circuit breakers PEN 862 and PEN 852 to clear the PEN 220 kV bus to allow the NZ Fire Service access to the 220kV switchyard.

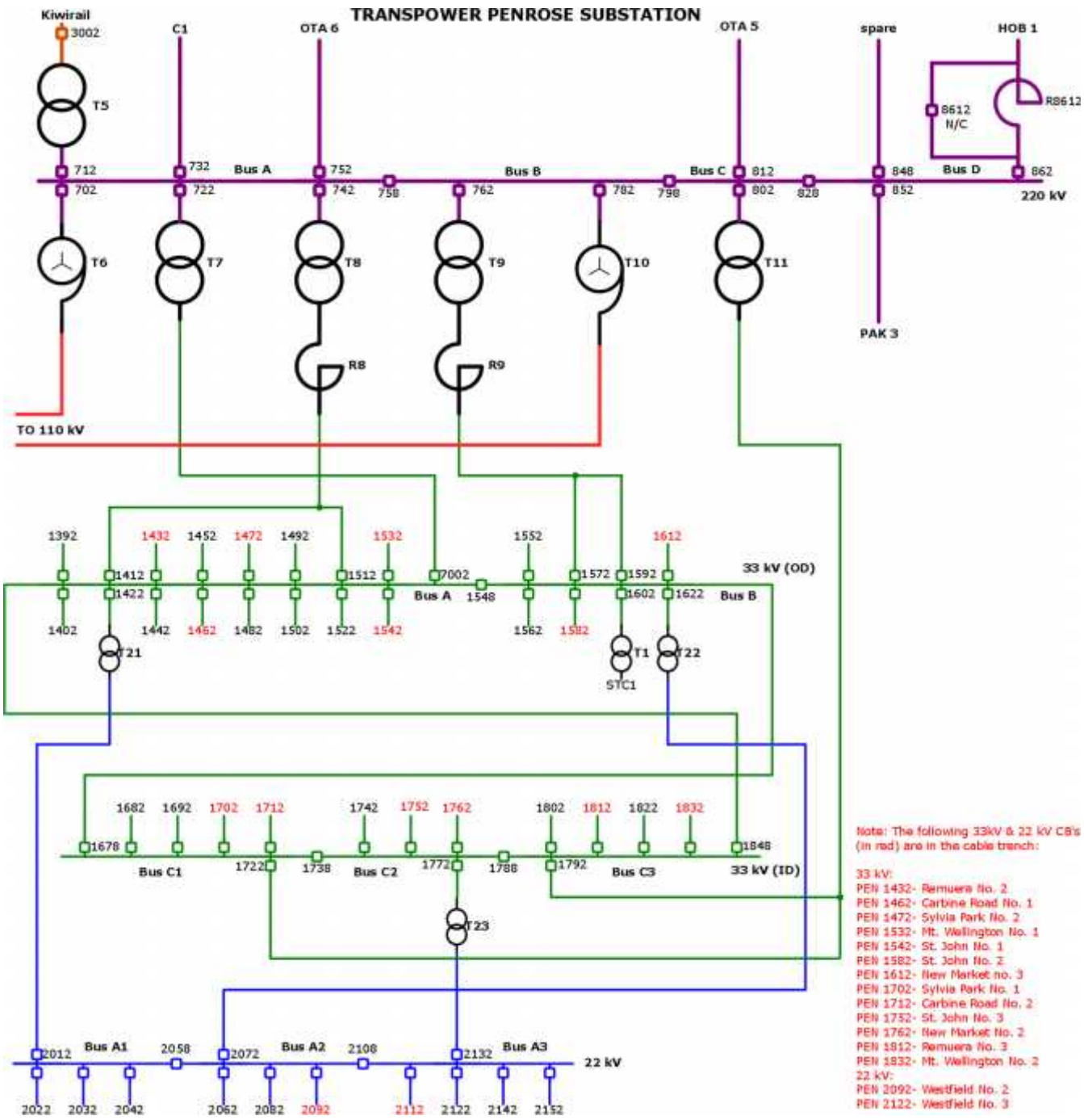
This report outlines the main Vector and Transpower protection operations associated with this event, and presents the findings from a detailed analysis of protection system performance.

2. SYSTEM CONFIGURATION

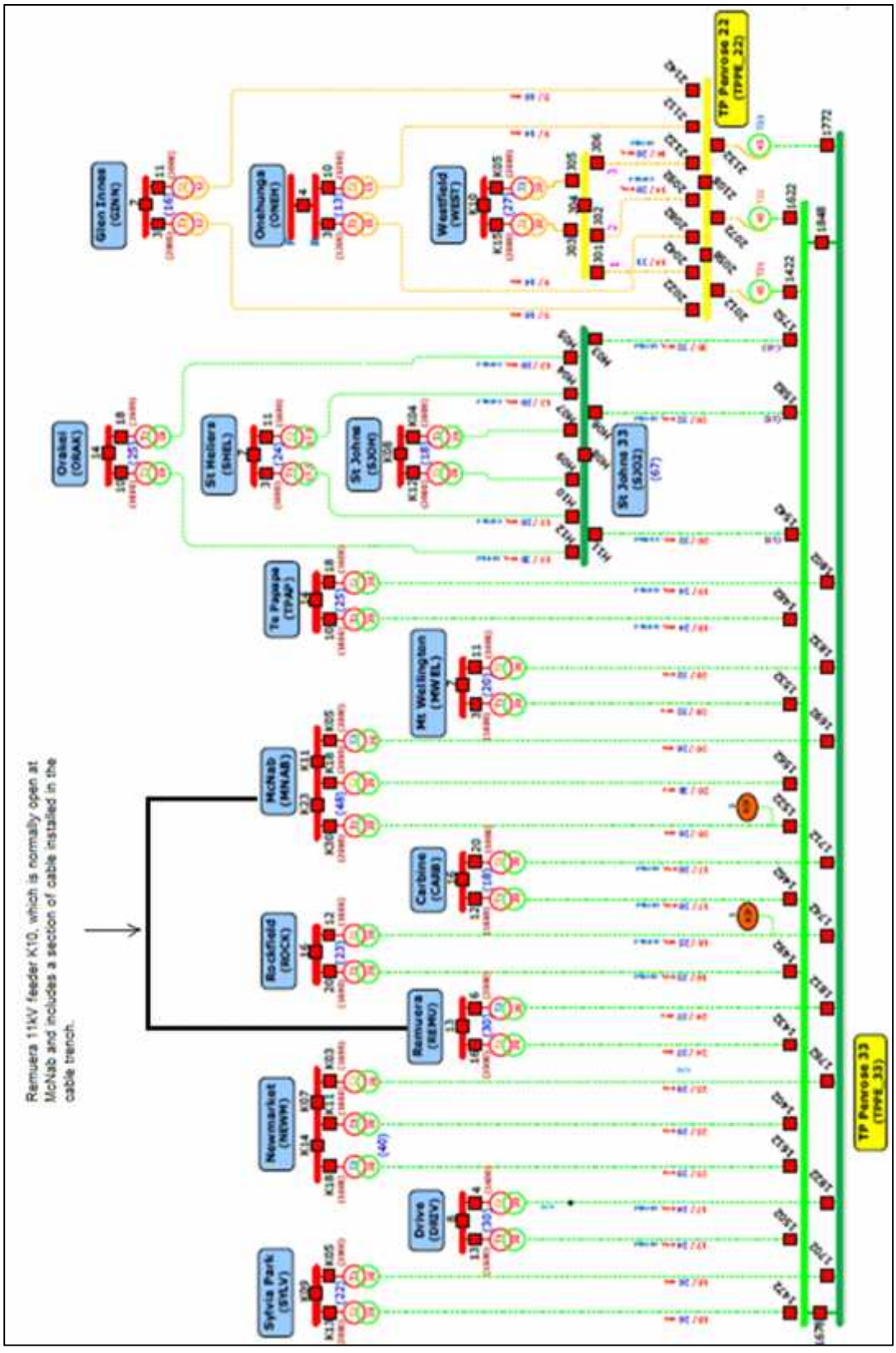
PEN was operating in a normal configuration at 220 kV with PEN 220/33 kV transformers T7, T9 and T11 supplying the PEN 33 kV bus, PEN 220/110 kV transformers T6 and T10 supplying the 110 kV bus, PEN 33/22 kV transformers T21, T22 and T23 supplying the PEN 22 kV bus and PEN 220/25 kV T5 supplying the railways traction load.

PEN 220/33 kV transformer T8 was on "hot" standby with 220 kV CB closed and 33 kV CBs open.

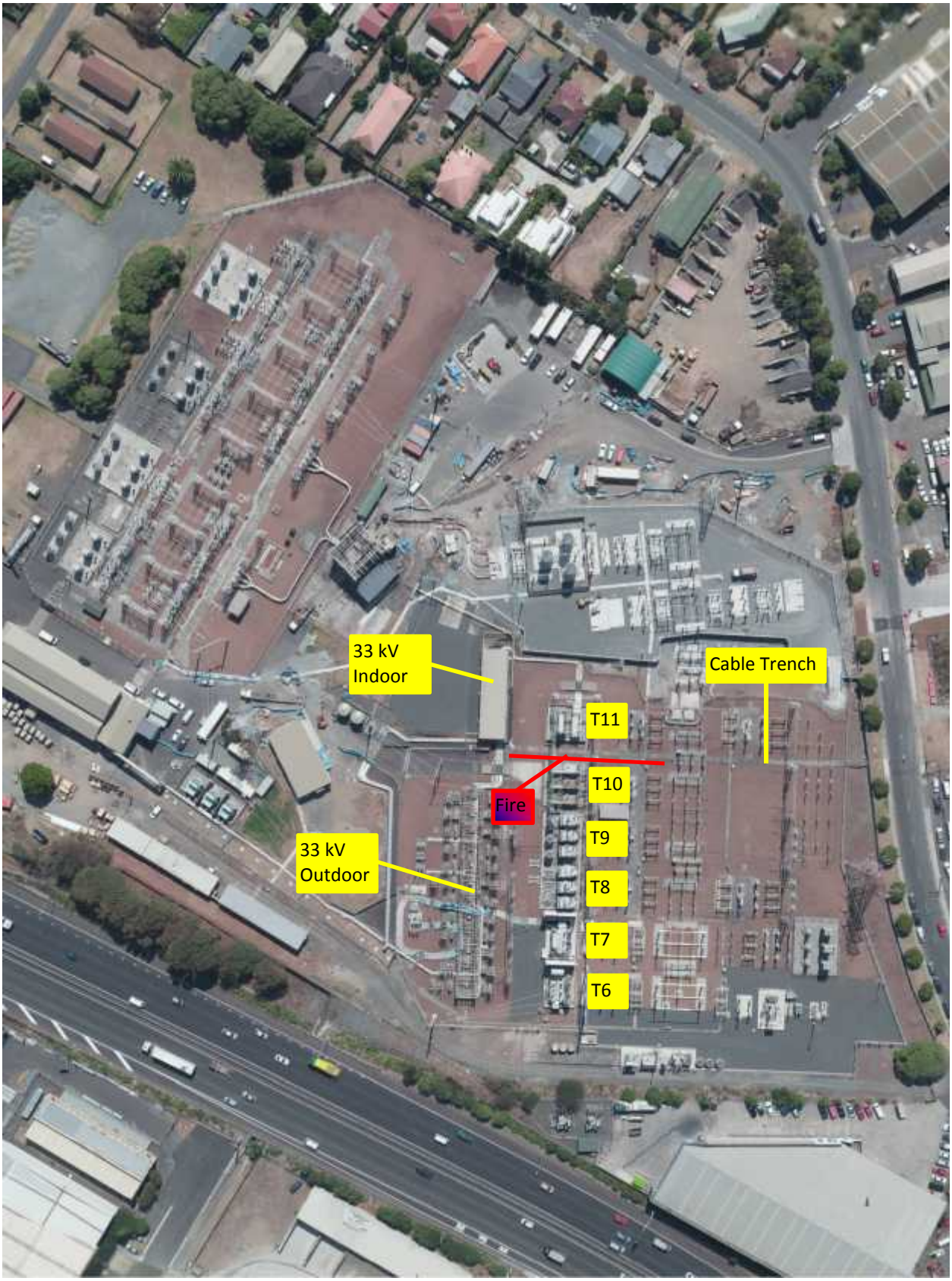
2.1 Transpower Penrose Substation Single Line Diagram



2.2 Vector 33/22 kV Single Line Diagram



2.3 Site Layout Aerial Photograph



3. SUMMARY OF EVENTS

This section presents a table giving a summary of the main operations that are relevant to this analysis.

3.1 Notes on Summary table

It was observed that time stamping of events sourced from the Vector SCADA system differed by approximately 16 seconds from Transpower SCADA time stamps for the same event.[1]

The timing of event information that was sourced from the Vector SCADA system has been adjusted in the table below to align with "Transpower" time to offer a common time base.

NGOC means the Transpower National Grid Operating Centre.

3.2 Summary Table

Time	**4th October 2014**
23:21:30	The Remuera 11 kV feeder K10 faults between red and blue phases and evolves into a three phase fault after 0.053 seconds. The feeder protection clears the fault in 0.561 seconds. The protection operation is considered correct.
Time	**5th October 2014**
01:20:49	The Remuera 11 kV feeder K10 faults between all three phases and clears the fault in 0.550 seconds, after being manually reclosed. The protection operation is considered correct.
02:04:06	Carbine 33 kV feeder No. 2 Oil Cable Pressure Circuit 2A alarm operated. Thought to be due to fire damage to the control cables.
02:04:29	PEN T11 Low Oil Level alarm operated. Thought to be due to fire damage to the control cables.
02:07:12	Carbine 33 kV feeder No. 2 main differential protection blocked, due to a communications signalling link failure, making the main protection inoperable. Thought to be due to fire damage to the protection pilot cables.
02:10:42	PEN T11 CBs all trip due to buchholtz indication with no primary system fault detected. Thought to be due to fire damage to control cables shorting out the Buchholz trip circuit.
02:11:39	The Remuera 33 kV feeder No. 3 faults between blue phase and ground and trips from the main differential protection in 0.215 seconds. The protection tripped the Penrose circuit breaker 1812 and the Remuera circuit breaker K06 to clear the fault. The protection operation is considered correct.
02:12:30	The Newmarket 33 kV feeder No. 3 faults between yellow phase and ground and trips from the main differential protection in 0.131 seconds. The protection tripped the Penrose circuit breaker 1612 and the Newmarket circuit breaker K18 to clear the fault. The protection operation is considered correct.
02:14:31	The 11 kV supply to the tunnel auxiliaries was lost when a drop out fuse on a pole in Gavin Street operated. The 11 kV cable is connected to the McNab 11 kV feeder K02.
02:14:47	The Carbine 33 kV feeder No. 2 faults between red phase and ground and trips from the backup (instantaneous overcurrent) protection in 0.364 seconds. The main feeder differential protection did not operate as the pilot cable had been damaged by the fire at 02:07:12. The Carbine 11 kV circuit breaker K20 did not trip immediately, as the directional overcurrent backup protection could not detect the single phase to earth fault. The fault evolves into a phase to phase fault after 42 seconds, at which time Carbine 11 kV circuit breaker K20 trips on directional overcurrent to clear the fault. While the backup protection operated correctly, the design of the backup protection and the security of the communications signalling link will be reviewed.
02:16:44	The Remuera 33 kV feeder No. 2 faults between red phase and ground and trips from the main translay protection in 0.175 seconds. The protection tripped Penrose circuit breaker 1432 and Remuera circuit breaker K16 to clear the fault. The protection operation is considered correct.

[1] There is currently a 16 second offset between Co-ordinated Universal Time (UTC), and GPS time. UTC is periodically adjusted with the addition of leap seconds, but GPS time – first established in 1980 - has not been adjusted with leap seconds, leading to a 16 second difference. The Transpower SCADA time stamping system is aligned with UTC, but the time stamping on most Vector SCADA sequence of event indications is aligned with GPS time.

02:21:29	St John 33 kV feeder No. 2 main differential protection blocked, due to a communications signalling link failure, making the main protection inoperable. Thought to be due to fire damage to the protection pilot cables.
02:22:45	The St John 33 kV feeder No. 3 faults between blue phase and ground and evolves to a red and blue phase to ground fault after 0.063 seconds. The backup protection clears the fault in 1.040 seconds, with the Transpower inverse time overcurrent protection tripping Penrose circuit breaker 1752 and the Vector directional overcurrent protection tripping St John circuit breaker H03. The feeder differential protection did not operate as the pilot cable had been damaged by the fire at 02:21:29. Given the damage to the pilot cable, the protection operation is considered correct. The protection on Penrose transformers T21, T22, and T23 detect this fault and incorrectly trip due to the transformer backup protection not discriminating with the St John 33 kV feeder backup protection.
02:44:57	The McNab 11 kV feeder K02 faults between all three phases and trips from the feeder protection trips in 0.262 seconds. The protection operation is considered correct.
02:48:41	The Carbine 33 kV feeder No. 1 faults between red and yellow phases and ground, and trips from backup protection, clearing the fault in 0.412 seconds. The Transpower instantaneous overcurrent protection tripped Penrose circuit breaker 1462 to clear the fault. The feeder differential protection did not operate as the pilot cable had been damaged by the fire at 02:09:16. As the Carbine No. 2 feeder had tripped earlier, there was no back feed into the Carbine No. 1 feeder fault and therefore no operation of the directional overcurrent protection at Carbine. Given the damage to the pilot cable, the protection operation is considered correct.
02:48:46	The Mt. Wellington 33 kV feeder No. 2 faults between red phase and ground and trips from the main protection clearing the fault in 0.196 seconds. The feeder translay protection tripped Penrose circuit breaker 1832 and Mt. Wellington circuit breaker K11 to clear the fault. The protection operation is considered correct.
02:48:54	The Mt. Wellington 33 kV feeder No. 1 trips from operation of the main protection after receiving an intertrip signal. The traces show balanced load current before the trip with no fault current, and therefore the intertrip signal is assumed to be due to fire damage to the pilot cable. The main protection tripped Penrose circuit breaker 1532 and Mt. Wellington circuit breaker K03. Given the damage to the pilot cable, the protection operation is considered correct.
02:57:12	The Sylvia Park 33 kV feeder No. 2 faults between blue phase and ground and trips from the main protection clearing the fault in 0.093 seconds. The feeder differential protection tripped the Penrose circuit breaker 1472 and the Sylvia Park circuit breaker K13 to clear the fault. The protection operation is considered correct.
03:05:00	The McNab 11 kV CB K19 feeder faults between all three phases and trips from the feeder protection clearing the fault in 0.358 seconds. The protection operation is considered correct.
04:28	PEN 798 220 kV bus coupler tripped with no primary system fault detected.

4. PROTECTION RELAY PERFORMANCE

A detailed report has been prepared that provides a full analysis of the protection system performance.

The performance of protection for two particular events should be reviewed to see if practicable improvements can be made to the protection design and settings:

1. At 02:14, a line to ground fault on the Penrose-Carbine Number 2 feeder was not cleared immediately. The Penrose 33 kV circuit breaker 1712 opened but the Carbine 11 kV circuit breaker K20 remained closed and continued to energise the feeder from the Carbine end for 42 seconds until a fault occurred that the Carbine end backup protection could detect.
2. At 02:22, backup protection on the three Penrose 33 kV/22 kV transformers tripped at the same time as backup protection on the St Johns 3 feeder tripped for a fault on the St Johns 3 feeder (being a loss of discrimination between backup protections).

For each of the above events, the fire had damaged the pilot cables, which caused a failure of the communications signalling link and prevented the main differential protection from operating.

The issues identified above are not considered to be material to the original fault or to the equipment damage and loss of supply that occurred as a result of the fire in the cable trench.

The main findings of the analysis are that the protection systems performed as designed and set, within the constraint arising from the damage to the pilot cables.