Penrose Substation Fire
05 October 2014

History of Penrose Substation

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Version Control

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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.

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1 Purpose

This report describes the development history of Penrose Substation, with a focus on the assets most affected by the fire in the cable trench on 5 October 2014.

The information in this report is based on a limited search of files, drawings, public reports and newspaper archives. Consequently some of the details and dates may not be completely accurate. Also, it was not practicable to find records, if they exist, of the design decision-making processes that resulted in the present configuration.

2 Early History (1922-1940)

The majority of the land on which the Penrose Substation is constructed was previously owned by the Crown but publicly acquired for the development of water-power in 1922 and 1928 (through the Public Works Act 1908). A substation was established in 1925, supplied by a 50 kV transmission line bringing hydro power from Horahora Power Station on the Waikato River. It appears that Auckland Electric Power Board (AEPB, predecessor to Mercury Energy and Vector) originally took supply at 6.6 kV and later at 22 kV. During the 1920's three 1.25 MW diesel-powered electricity generating sets were installed to meet increasing electricity demand, supplementing AEPB's Kings Wharf Power Station.

Four 110/22 kV transformer banks and 22 kV indoor switchgear were installed at the Penrose site. Several 22 kV cables were installed between Penrose and Kings Wharf (Quay substation) in 1927. In 1929 a 110 kV double circuit steel tower line was constructed to supply the Penrose Substation from the new Arapuni Hydro Power Station.

The AEPB established substations at Remuera and The Drive in 1930, each supplied from Penrose at 22 kV. The Remuera cables were installed on the land owned by AEPB at 29B Gavin Street to exit the Penrose site into Eaglehurst Road. The Drive cables exited through the NZ Herald property into Wilkinson Road.

In 1939, AEPB established the Newmarket Substation, again installing the 22 kV feeders on the land owned by AEPB at 29B Gavin Street.

In 1940 a new double circuit steel tower 110 kV line was constructed from Arapuni to Penrose. This line passed through or near the site of Transpower's Pakuranga Substation which was built in 1968.

The Westfield 22 kV Substation was established in 1942, and supplied by cables from Penrose through McNab Street to the east of the substation site.

3 Post- WWII Development

In 1952, Otahuhu 110 kV Substation was built and connected to the 110 kV line from Arapuni. A new 110 kV line (OTA-PEN B) was constructed between Otahuhu and Penrose, bringing to six the number of 110 kV circuits feeding into Penrose from the south.

In 1954, the first 220 kV line (OTA-WKM A) was constructed to take hydro power from the new Whakamaru Power Station to Auckland city. Initially, three 220/110 kV interconnecting transformers were installed at Otahuhu Substation. Even though the new 220 kV system did not yet extend to Penrose, these developments greatly increased the transmission capacity into the Penrose 110 kV bus and enabled AEPB to take more power from the two Penrose 22 kV switchboards (the second one was installed around 1949 or 1950).

The AEPB established the Glen Innes Substation in 1955, installing 22 kV cables in the strip of land at 29B Gavin Street to exit the site. At this stage there were approximately sixteen 22 kV feeders supplying six substations from Penrose.

There were also two synchronous condensers – a 20 MVAr unit and a 15 MVAr unit – providing voltage support to the 22 kV busbars and feeders.

In 1958, AEPB reinforced the supply to Quay Substation by installing two 110 kV cables from Penrose to support the growth of demand in the CBD. These cable were installed through the main vehicle access route to the substation.

The AEPB established substations at Mt Wellington and Onehunga in 1963. The Onehunga Substation was supplied by 22 kV cables from Penrose through McNab Street to the east of the substation site. The Mt Wellington Substation was supplied by 33 kV cables[1] installed in the strip of land adjacent to the cable trench (owned at the time by AEPB) that provided access to Gavin Street near 64 Gavin Street.

4 Initial 220/33 kV Development (1966)

In 1966, Penrose was upgraded to 220 kV with the construction of a new double circuit transmission line from Otahuhu Substation. The new line was the only 220 kV transmission into Penrose until 2013 when the 220 kV cable circuits from Pakuranga and Hobson St were commissioned.

Also in 1966 about half of the 33 kV outdoor switch-yard that we see today was constructed. It was supplied from two new 50 MVA 220/33 kV transformers (manufactured by CGE - Italy), identified as T8 and T9.

The design decisions made when planning the original 220/33 kV installation set the scene for the future development of the 220 kV and 33 kV systems at Penrose. Some of the key decisions were:

- To supply the 33 kV from a new 220 kV bus rather than from the existing 110 kV system.
- To position the 220 kV switchyard between Gavin Street and the existing 110 kV transmission line structures.

[1] As the 33 kV substation at Penrose had not yet been developed, it is assumed the cables were initially operated at 22 kV and that 33/22/11 kV transformers had been installed at Mt Wellington.

- To position the 220/33 kV transformers and the 33 kV switchgear structure on the opposite side of the 220 kV switch yard from Gavin Street.
- To construct a 220 kV single bus rather than a selectable double bus arrangement[2] (as commonly used at other NZED 220 kV substations, e.g. Otahuhu, Bunnythorpe, Islington, etc).

The layout design would also have been influenced by the existing transmission line corridor containing the existing and new lines from Arapuni and Otahuhu entering the east side of the substation.

It is also important to note that Penrose Substation is constructed on basalt rock, and the substation itself is constrained between State Highway 1 to the west and private properties to the north, south and (in part) east. As a result, access routes for subtransmission cables that supply the distribution load centres are more limited than most other substations.

5 Cable Trench

It appears most likely that the concrete cable trench where the fire occurred was constructed in 1966 as part of the development of the 220 kV and 33 kV switchyards. A file copy of a letter from the General Manager of NZED[3] at the time states that:

a) The Department agrees to meet half the cost of the cable trench across the 220 kV structure;

b) The strip of land adjacent to the cable trench owned by AEPB should be transferred to NZED when the cables are relocated into the cable trench; and

c) All future AEPB cables and services are to be installed in the new trench.

The letter indicates that the Department was seeking to relocate existing AEPB cables (from the AEPB strip of land), presumably to allow better utilisation of the land for the 220 kV substation development. The AEPB land was subsequently acquired by the Crown under the Public Works Act in 1973.

The letter notes that excavation for the trench was already underway in January 1966.

In 1966 and 1967 AEPB established 33 kV substations at McNab Street, St Johns and Orakei. The cables supplying the McNab Substation were installed in ducts crossing SH1 to the east of Penrose. St Johns was initially constructed as a switching station, with the intention that it would supply other substations in the area. The 33 kV cables supplying St Johns were installed in the new cable trench. Orakei Substation was established in 1967, supplied from St Johns.

[2] Double bus may have required more land area than was available between Gavin St and the existing 110 kV yard.
[3] Penrose 220 kV substation: Auckland Electric Power Board Cable Trench, 10 January 1966, File 22/26/1

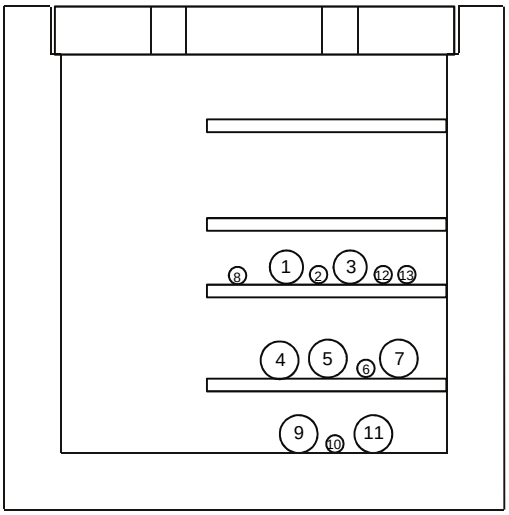
As part of the development of the McNab Substation, three 11 kV cables were installed through the Penrose Substation (in the cable trench) to connect with feeders from the Remuera and Mt Wellington substations to enable load transfer between the AEPB substations.

The Mt Wellington 33 kV cables (that had initially been installed in the AEPB strip of land adjacent to the cable trench) were relocated into the cable trench in 1966.

The Westfield substation was reinforced with additional 22 kV feeders in 1967, with the new cables being installed in the cable trench.

In 1971 AEPB established the St Helliers Substation, which was also supplied from St Johns Substation.

By the end of 1967, there were five 33kV, two 22 kV and three 11 kV cables, plus three pilot cables, in the cable trench, as shown on the following sketch.



6 Penrose 220/110 kV interconnection (1972 & 2010)

In 1972, the first 220/110 kV interconnecting transformer (T10) was installed to provide more supply capacity from the Penrose 110 kV bus. This project had the effect of increasing the operating capacity and/or security of supply onto the Penrose 110 kV bus.

A second interconnecting transformer (T6) was installed and commissioned in 2010. This project became necessary after Vector decided to transfer about 90 MW of CBD load from Mt Roskill Substation to Penrose 33 kV via their Liverpool Substation and the PAK-PEN 110 kV line was soon to be removed, as part of the North Auckland and Northland (NAaN) 220 kV cables project.

7 220/33 kV Capacity Upgrade to 200 MVA (1976)

In 1976, the original 50 MVA transformers were replaced with 200 MVA transformers. This was presumably due to continued growth on the AEPB network, with new substations being established at Te Papapa (1975), Carbine Road (1978) and Rockfield Road (1979), as it is very unusual to replace transformers after only ten years of service. The 33 kV cables supplying the Carbine substation were installed in the cable trench, and the 33 kV cables supplying Te Papapa and Rockfield were both installed in the pedestrian subway under SH1 to the east of Penrose.

The growth in demand also caused AEPB to upgrade the Drive substation to 33 kV, with the new 33 kV cables being installed in 1976 on the same route as the earlier 22kV cables through the NZ Herald property into Wilkinson Road.

A further 11 kV cable was installed through the Penrose Substation (in the cable trench) from McNab Substation to connect with feeders from Mt Wellington Substation to enable additional load transfer between the AEPB substations.

The capacity of the new transformers exceeded the maximum current carrying capacity of available 33 kV circuit breakers, hence the replacement transformers were installed with two 33 kV incoming circuit breakers each. The manufacturing dates of the 33 kV equipment items indicate that the 33 kV switchyard structure was extended towards the motorway. Some additional feeders were installed for AEPB. This upgrade roughly doubled the length of the 33 kV structure and provided a secure (n-1) supply of up to 200 MVA.

8 Replacement of 22 kV Switchboard (1987)

The existing 22 kV Merlin Gerin switchboard was manufactured in 1987. This replaced an old Reyrolle 22 kV switchboard probably manufactured in the 1920's.

9 220/33 kV Capacity Upgrade to 400 MVA (1999)

The 22 kV and 33 kV supply arrangements were satisfactory until the early 1990's when it became apparent that further development of the 33 kV supply at Penrose would soon be necessary. The five existing 110/22 kV supply transformers T1-T5 were nearing end-of-life.

Also, Mercury Energy (renamed from AEPB) wished to replace some 22 kV feeder cables with 33 kV ones. In 1996, Mercury Energy formally requested an increase in 33 kV N-1 capacity from 200 MVA to 400 MVA.

After a detailed engineering investigation, three options were presented to Mercury Energy in September 1997. They were:

Option A: Install a new electrically- independent GXP alongside the existing one (requiring two new 200 MVA transformers). Of the three options, this offered the highest level of supply security and power quality. However it was the most costly option by a substantial margin.

Option B: Install one new 200 MVA transformer which would operate in conjunction with the two existing 200 MVA transformers, T8 & T9 and the existing outdoor 33 kV switchgear. In order to keep the 33 kV bus fault level below 26 kA (as requested by Mercury Energy) it would be necessary to specify the new transformer with an unusually high reactance (more than 35%) and install fault current limiting reactors on the 33 kV sides of T8 and T9. There was concern about 33 kV bus voltage fluctuations during transformer switching and an additional study was undertaken by Transpower to determine the extent of voltage step changes and to specify operating procedures to minimise them.

Option C: Install one new 200 MVA transformer and a new 33 kV indoor switchboard which would normally operate independently of T8 & T9 and the existing outdoor 33 kV switchgear. A normally- open coupling circuit breaker would allow quick restoration of supply to the third 33 kV bus if its single supply transformer tripped for any reason. Being operated independently, i.e. not in parallel with the other two transformers, the measures required for Option B to manage 33 kV bus fault levels and voltage fluctuations would be unnecessary. This was the least costly option and would be upgradeable to Option A later.

All three options were acceptable to Transpower. Mercury Energy chose Option B and signed an investment agreement with Transpower to confirm the project scope and the additional connection charges that would occur.

The key design decisions made were:

- To extend the 220 kV bus one- bay northwards and position the third 220 kV supply transformer T11 to connect to it.
- To position the new 33 kV switchgear building at the northern end of the existing outdoor 33 kV switchyard. Probably this was done to minimise the lengths of 33 kV cables between the new indoor switchboard and T11 and the existing 33 kV outdoor switchyard (the latter cables required to enable parallel operation of T8, T9 and T11).

The position of the 33 kV building was also conveniently close to Vector's existing 33 kV cable trench. This facilitated the relocation of a number of 33 kV feeder cables from the outdoor switchyard to the new indoor switchgear. These cables were installed on above ground cable racks between the cable trench and the 33 kV indoor switchgear terminations.

Vector decommissioned some 22 kV feeders and the remaining ones were migrated to the existing Merlin Gerin switchboard. This enabled the old 1949 vintage switchboard manufactured by Ferguson & Pailin to be decommissioned. As an economical alternative to replacing the 110/22 kV transformers, three 45 MVA 33/22 kV transformers were installed to provide 22 kV supplies from the 33 kV bus.

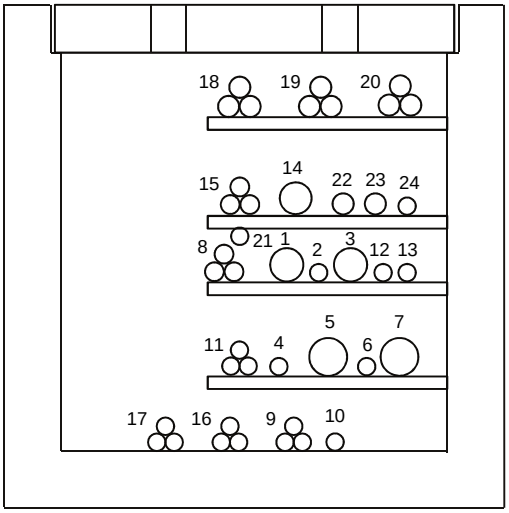
10 Auckland Network Development (Post 2001)

Mercury Energy was able to upgrade the Remuera and Newmarket substations to 33 kV in 1999 and 2000 respectively. Two of the new Newmarket circuits were installed in the new deep tunnel between Penrose and Hobson Street. The rest of the cables were installed in the cable trench.

In 2001 Mercury Energy replaced the 33 kV cables to Mt Wellington substation, with the new cables being installed in the cable trench. Then, in 2008, Vector replaced the 33 kV cables to McNab substation, with two of the new cables being installed in the pedestrian subway under SH1 and the other in existing ducts under SH1.

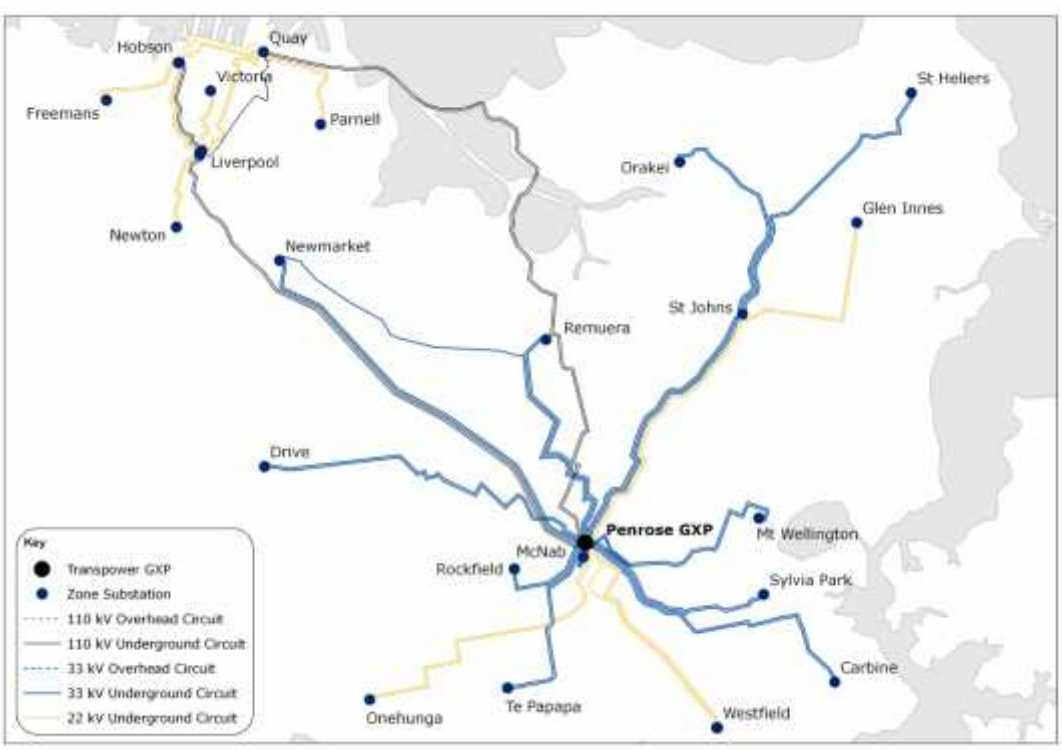
In 2006, Vector established the 33 kV Sylvia Park substation, supplied from Penrose with the cables installed in the cable trench.

At the time of the fire, then, there were twelve 33 kV circuits, two 22 kV circuits and six 11 kV circuits installed in the cable trench, as shown in the following sketch. These cables supplied substations to the east of the Penrose site, primarily from the 33 kV busbars. There were also four 33 kV cables[4] installed on the above ground cable racks to the indoor switchgear that were damaged in the fire even though they were not installed in the cable trench.



The following diagram illustrates the extent of the Auckland region supplied from the Penrose Grid Exit Point. Given the geography of the Auckland isthmus and the historical development of the tranmission system, there are limited opportunities to supply Auckland's eastern suburbs from diverse Grid Exit Points.

[4] One cable to each of The Drive, McNab, Rockfield and Te Papapa substations.



11 Auckland CBD (2001)

In 1995, Mercury Energy committed to a major construction project to reinforce the electricity supply to the CBD. The project included the construction of a deep tunnel between Transpower's Penrose substation and Mercury's Liverpool and Hobson substations. At about the midway point, at Newmarket, an access shaft was constructed to provide normal access to the tunnel and act as an exhaust for the tunnel ventilation.

A 110 kV switchboard was constructed at Liverpool, and connected to Penrose by two 110kV circuits. Two 110 kV circuits connected Liverpool to Hobson, supplying two 110/22 kV transformers. There were also two 110/22 kV transformers at Liverpool. Mercury installed two 33 kV feeders in the tunnel between Penrose and Newmarket, as part of the upgrade to the Newmarket substation noted above.

Two 22 kV cables were also installed between Liverpool and Hobson to form part of a 22kV ring connecting the CBD bulk supply substations to provide additional backup capability.

The project was completed in 2001.

12 Penrose 220 kV Bus Security Upgrade (2001)

About 2001, a project was completed to split the 220 kV bus into three switched sections to reduce the consequences of a busbar fault. This was arranged so that only one 220/33 kV supply transformer and one incoming 220 kV circuit from Otahuhu would be forced out of service if a busbar fault occurred. Previously, a busbar fault would have caused the entire 220 kV switchyard to be automatically switched out of service, causing all 33 kV supply to be lost for a time.

13 220/33 kV T8 Transformer Failure (2009)

An electrical flashover in the on-load tap changer of one of the single phase units comprising T8 led to a complete loss of 33 kV supply from Penrose for about one hour and restricted supply capacity for more than one day. Unfortunately T9 was out of service because one of its single phase units was being overhauled off-site. As T11 did not have the capacity to carry the entire Penrose 33 kV demand at that time of the day, the automatic overload protection tripped it out of service. Full supply capacity was restored the following day by replacing the faulty T8 unit with one of T9's units (which are identical to T8's).

This failure initiated a review that led to the decision to purchase a new 200 MVA 220/33 kV transformer to reduce the reliance on T8 and T9. The new transformer, T7, was commissioned in 2011. It is presently connected to the outdoor 33 kV structure.

14 Grid Upgrade Projects (2014)

After more than twenty years of investigation, negotiation and planning, the security and capacity of transmission into Auckland was re-inforced with the commissioning of a new 220 kV overhead line and cables from Whakamaru to Pakuranga Substation. In a further related project, 220 kV cable circuits were installed from Pakuranga to Penrose and onwards to the new GXPs at Hobson Street and Wairau Road and continuing on to Transpower's Albany substation. This major upgrade to the grid was completed in 2014.

Pakuranga Substation, previously operating at 110 kV, was re-built to operate at 220 kV. An existing transmission line between Otahuhu and Pakuranga substation was upgraded to 220 kV. Together, these projects have strengthened the transmission system into Penrose.

15 220 kV Bus Security Upgrade (2014-2015)

There is work in progress to further increase Penrose 220 kV bus security by joining Bus A and Bus D to form a ring, via a switched bus tie circuit. At present, an outage of Bus B or Bus C will separate Bus A and Bus D, will cause the loss of one OTA-PEN circuit or one PEN 220/110 kV interconnecting transformer and may cause certain 220 kV circuits and interconnecting transformers to experience overloading, thereby requiring load reduction/shedding. To some extent this situation can be managed by scheduling planned outages during low system load periods. However, a forced outage (e.g. a 220 kV bus fault) could occur at any time, causing the above problems if it occurs during peak system loading.

An outage of one of these 220 kV busses will also cause the loss of either PEN 220/33 kV transformer T9 (Bus B) or T11 (Bus C).

The 220 kV ring bus is being implemented using a 220 kV power cable because there is insufficient room for an aerial rigid or strung bus (which would otherwise be used due to its lower cost).

16 Transpower Site Works Near the Cable Trench

At the time of the fire in the cable trench on 5 October 2014, site works for the 220 kV bus tie cable system had recently taken place in the vicinity of the cable trench. Construction of a new concrete trough passing beneath the cable trench was carried out in July and August 2014. At the crossing point, the cable trench is about 1.8 m deep and rests on top of Transpower's new trough.

17 Replacement of Penrose 33 kV Outdoor Switch Yard

For several years, as part of a nationwide equipment renewal programme, Transpower has been planning to replace the outdoor 33 kV switch yard with an indoor switchboard. The two key drivers are:

- To replace the aging 33 kV equipment, some of which is almost 50 years old.
- To implement a Transpower policy to eliminate the safety hazards associated with undertaking equipment maintenance work in outdoor 33 kV switch yards.

Detailed design and primary equipment procurement have been completed. Construction of a new 33 kV switchgear building was scheduled to commence this summer. This has been put on hold while a design review is carried out to consider what changes, if any, should be made as a result of learnings from the recent cable fire.

A.1 Appendix 1: Penrose 220/33 kV Substation Layout